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INTERIM-NIGHT INTEGRATED GOGGLE HEAD TRACKING SYSTEM (I-NIGHTS) FINAL REPORT, VOLUME I: GROUND TEST SUMMARY

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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Helmet-Mounted displays (HMDs) and Night Vision Goggles (NVGs) are being developed for military aircrews. NVGs use image intensifier tubes to amplify ambient starlight thereby enhancing nighttime operations. HMDs present sensor video (infrared, low light TV, etc.) and critical mission data (flight information, weapon status, threat situation) directly to the crew member's eyes. The information remains within his field-of-view no matter where he turns his head. This permits traditional head-down tasks to be performed in a head-up mode. However, placing HMD/NVG technology on the helmet is not a simple task. Many safety related and human factors issues must be considered.

The United States Air Force's Interim-Night Integrated goggle and Head Tracking System (I-NIGHTS) Program addressed many of the safety and human factors issues while testing three I-NIGHTS Helmet designs. Testing had two primary objectives: a) to quantify system performance; b) to identify and quantify the risks of using HMD/NVGs on military aircraft; and c) investigate human factors related issues. This report summarizes the I-NIGHTS program, testing, and results.

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FOREWORD

This report summarizes the testing and results performed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Office of the United States Air Force.

I-NIGHTS results are documented in two volumes. Volume I discusses the ground testing performed to quantify system characteristics, identify risks and assess safety for flight test. Volume II discusses the results from the flight test phase and subjective crew member comments.

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LIST OF ABBREVIATIONS

ACES	Advanced Concept Ejection Seat
AERPS	Aircrew Eye/Respiratory Protection System
ANSI	American National Standards Institute
ANVIS-6	Aviator's Night Vision System-6
AFTI	Advanced Flight Test Integrator
CG	Center-of-Gravity
CRT	Cathode Ray Tube
deg	Degree
DOD	Dept of Defense
DRI	Dynamic Response Index
DT&E	Development Test and Evaluation
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FOV	Field-of-View
GEC	General Electric Company - Avionics Inc
HMD	Helmet-Mounted Display
HMST	Helmet-Mounted Systems Technology
HUD	Head Up Display
Hz	Hertz
IAW	In Accordance With
IN	Inches
I-NIGHTS	Interim-Night Integrated Goggle & Head Tracking System
I^2 TUBE	Image Intensifier Tubes
KTAS	Knots True Air Speed
LBS	Pounds
LRIP	Low Rate Initial Production
MAJCOM	Major Command
mm	Millimeter
mrad	Milliradian
MTL	Manikin Test Laboratory
NADC	Naval Air Development Center
nm	Nanometer

LIST OF ABBREVIATIONS (Continued)

NVG	Night Vision Goggle
psi	Pounds Per Square Inch
QDC	Quick-Disconnect Connector
RD	Rapid Decompression
RDC	Rapid Development Capability
SACM	Simulated Air Combat Maneuver
SMOTEC	Special Missions Operational Test and Evaluation Center
SOF	Safety-of-Flight
USAF	United States Air Force
VDT	Vertical Deceleration Tower
WT	Weight
3D	Three Dimensional

1. EXECUTIVE SUMMARY

1.1 Introduction

The Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) program was established to develop an ejection-safe aviator's flight helmet. The technical challenge in this program is the incorporation of night vision goggles (NVGs) in the design as a helmet-mounted device (HMD) while maintaining safety-of-flight (SOF) considerations. The purpose of NVGs is to aid the aircrew member flying at night. However, the detailed aspects of NVG/HMD systems have not yet been perfected. Their use during flight is still an emerging field with many technical hurdles to overcome. The SOF considerations go beyond the essential protective qualities of the helmet to include its fit, comfort and stability along with the capacity NOT to cause an injury during ejection. Present NVG/HMD systems cannot be worn during ejection due to the high probability of severe injury.

The Air Force I-NIGHTS program performed extensive ground and flight testing to quantify NVG performance and SOF considerations for three helmet designs.

1.2 Background

The I-NIGHTS began as a cooperative Air Force/Navy joint development program with the Navy designated as lead service. The prime contractor, McDonnell Douglas, subcontracted with General Electric Company (GEC) Avionics, Honeywell, and Kaiser Electronics. Each of the three subcontractors designed and built a prototype helmet system for government testing.

The Navy I-NIGHTS program was granted Rapid Development Capability (RDC) status in 1989 to correct urgent fleet safety shortfalls as well as meet the current operational needs of the

F/A-18 night attack mission requirement. The planned Navy approach was to downselect from three vendors to one after ground and flight tests had been conducted, and then procure 100 units initially as a low rate initial production (LRIP) milestone. The Navy terminated its I-NIGHTS program in December 1990 after realizing the technology was not mature enough for downselection to a production decision.

The Air Force took a different approach to evaluate the three helmet designs. This approach included: a) a risk reduction effort prior to 6.4, full scale development; b) demonstrate the concepts to the various Major Commands (MAJCOMs) through flight tests; and c) develop test methodology to aid future development programs.

I-NIGHTS helmets (Figures 1, 2, and 3) are modular in nature and are designed to more evenly distribute the weight of the optical systems in an attempt to provide a lower ejection risk. I-NIGHTS systems underwent extensive ground tests (Table 1) to assess the risk of ejection and evaluate system performance. In addition to the ground tests, the systems underwent flight evaluations to assess performance under actual mission scenarios. Flight testing was accomplished in MH-53, MH-60, HC-130, and B-52 aircraft (Table 2).

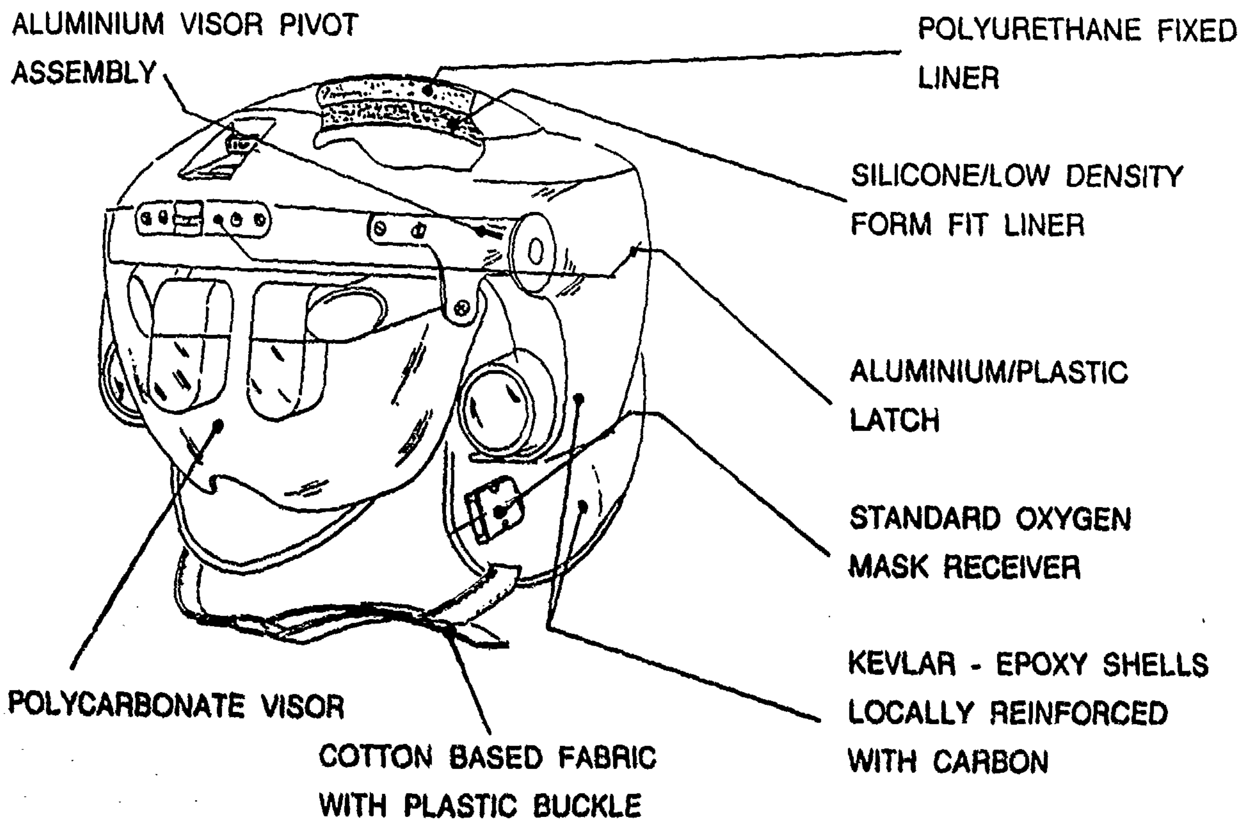

Figure 1. GEC I-NIGHTS System Drawing

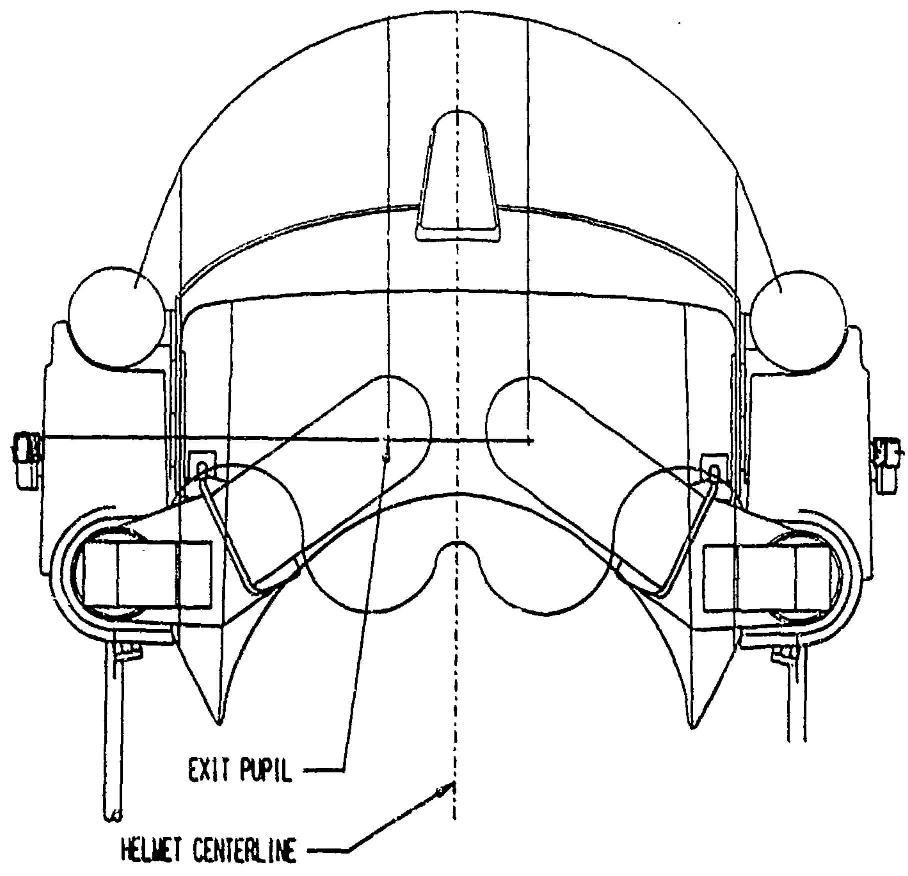

Figure 2. Honeywell I-NIGHTS System Drawing

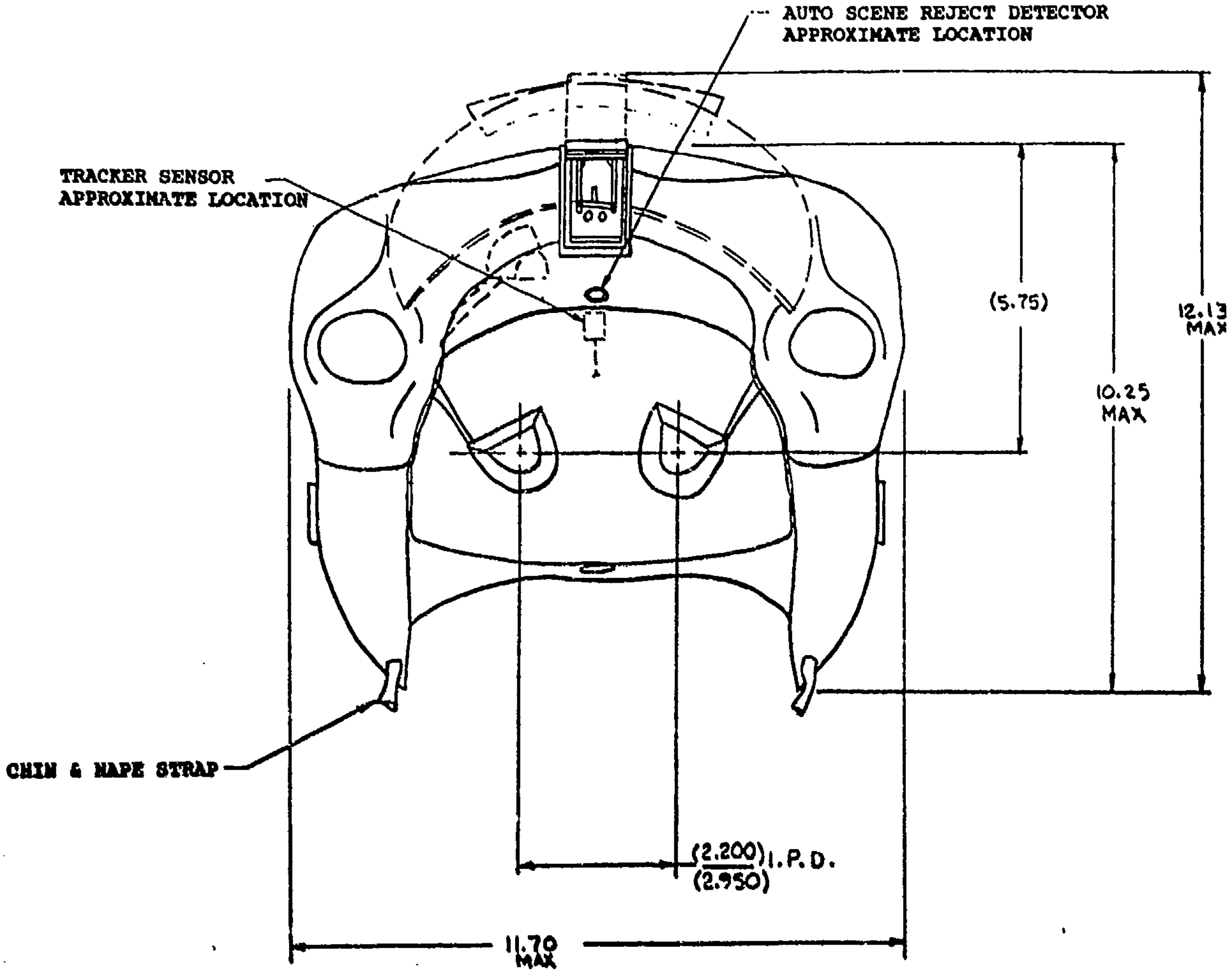

Figure 3. Kaiser I-NIGHTS System Drawing

Table 1. I-NIGHTS Testing

OPTICAL CHARACTERISTICS
- Exit Pupil
- Eye Relief
- Brightness Gain
- Field-of-View
- Luminance Non-Uniformity
- Modulation Contrast
- Magnification
- Image Rotation
- S Distortion
- Optical Axis Misalignment
- Horizontal Resolution
- Vertical Resolution

MASS PROPERTIES
- Weight Measurements
- CG Calculations

FIT ASSESSMENT
- Comfort
- Optical Adjustment
- Stability
- Laser Scan

PERSONAL EQUIPMENT INTEGRATION
- Compatibility With:
  - Aircrew
  - Life Support Equipment
  - DON/DOFF
  - Mission Task Performance
  - Emergency Procedures (Pre/Post Bailout)

AIRCRAFT INTEGRATION
- Emergency Procedures (Egress)
- Electromagnetic Interference
- Physical Restrictions
- Visual Restrictions

ACOUSTICAL PROPERTIES
- Sound Attenuation
- Speech Intelligibility

ALTITUDE CHAMBER
- Aircrew Compatibility
- Rapid Decompression
- Visor Fogging

DYNAMIC SYSTEM PERFORMANCE: CENTRIFUGE
- Comfort
- Image Migration
- Eye Relief

EXPLOSIVE ATMOSPHERE
- High Voltage Connector Arcing

CRASH LANDING: Gx IMPACT
- Head/Neck Loads
- Structural Integrity

EJECTION: Gz VERTICAL DECELERATION TOWER
- Ejection Simulation
- Head/Neck Loads

WINDBLAST
- Pitot Airflow
- Structural Integrity
- Head/Neck Loads

MAN/SEAT SEPARATION
- Seat Separation
- Head/Neck Loads
- Riser Interference
- Eye Relief

PARACHUTE DEPLOYMENT
- Riser Interference
- Head/Neck Loads
- Eye Relief
- Structural Integrity

Table 2. I-NIGHTS Test Schedule

Ground Tests: Mar 90 - Nov 90

Flight Tests:

MH-60	Dec 90 - Jan 91	Hurlburt Field, FL
MH-53	Feb - Mar 91	Hurlburt Field, FL
HC-130	Mar - Apr 91	NAS Moffett Field, CA
B-52	Jul - Aug 91	Ellsworth AFB, SD

All three I-NIGHTS systems function in a similar manner. They incorporate two battery powered, generation III image intensifier tubes (I^2 tubes); two optional cathode ray tubes (CRTs); and a magnetic head tracker. The I^2 tubes are extremely sensitive to light in the region from 0.6 to 0.9 microns (600 nanometers (nm) to 900 nm). This region overlaps the spectral distribution of starlight which peaks at about 0.9 microns. The I^2 tubes amplify ambient starlight and moonlight to enhance night vision capability. The CRTs provide the means to present symbology and/or sensor video data to the crew member. A variety of prisms, lenses, and beam splitters are used to move the intensified image to a combiner in front of each eye.

The head tracker senses the magnetic field around the helmet to provide head position data. This data can be used to slew aircraft sensors in the direction the crew member is looking and/or update the symbology relevant to head position. Due to aircraft avionic integration issues, the CRTs and head tracker could not be flight tested.

1.3 Critical Factors

The critical factors for the I-NIGHTS program evolved from system performance and flight testing concerns. Undertaken as a risk reduction effort, the I-NIGHTS program needed to quantify designed versus as-built system performance. Additionally, safety-of-flight (SOF) concerns had to be addressed prior to entering the flight test phase. Two factors emerged as being critical to the risk reduction effort. These factors are the fit of the helmet on the crew member and the helmet's weight (WT) and center-of-gravity (CG). The following sections discuss these factors.

1.3.1 Fit Assessment

Helmet fit was identified as a critical factor in I-NIGHTS ground and flight testing for several reasons. One reason is that the I-NIGHTS helmets are "exit pupil" systems which provide sensor and/or mission data (HUD symbology) directly to the crew member's eyes. Another reason is helmet size. In its specification, the Navy directed the three helmet vendors to provide a "large" size helmet. The Navy wanted to ensure the helmet would fit all the pilots in it's test program; "one size fits all." This immediately leads to problems. A "small" head in a "large" helmet can provide misleading test results and could result in an injury. The Navy did not provide anthropomorphic data to specify how large was "large." Consequently, each vendor specified it's own parameters for size. Therefore, there is no consistency between size in the three helmet designs.

The "fit" of a helmet-mounted device is critical to the performance of the mission as well as the performance of the system itself. I-NIGHTS testing discovered that fitting a HMD involves more than just getting a head inside the helmet shell. Several factors evolved into a "fit equation." The fit equation consists of: a) comfort; b) optical adjustment; and most importantly c) helmet stability.

Comfort is the most obvious element of the fit. The aircrew member must typically wear the helmet for several hours. The average sortie duration for fighter aircraft during Operation

Desert Storm was approximately four hours with some sorties lasting as long as six hours. If the crew member experiences hot spots, headaches, or just an annoying discomfort, he will be distracted from his mission and his performance will be degraded. In fighter aircraft it is highly impractical to remove the helmet to relieve the pain or to just "take a breather." If the crew member cannot or will not wear the helmet, then the best optics in the world are of no use.

A second factor in the fit equation is optical adjustment. Optical adjustment is the ability of the HMD optics to align correctly by adapting to varying facial features. This is critical since many HMDs are "exit pupil" systems which provide sensor and mission data (HUD symbology) directly to the crew member's eyes. "Exit pupil" means that the human eye must be positioned and maintained within a circular area where the image/data is displayed. A set of binoculars and a telescope are examples of exit pupil systems. When the eye is correctly aligned within the exit pupil the entire image can be seen. As the crew member's eye position begins to move out of the exit pupil the image begins to vignette and will rapidly disappear.

Optical adjustment, with adequate range of movement, must align the optics relative to each eye. However, eyes are often not symmetrical about the centerline of the face. One eye could be slightly deeper, higher, or wider from the facial centerline than the other. The optics must compensate for these differences or at least one eye will have a less than optimum image and a small tolerance for deviations from the exit pupil.

The third factor in the fit equation is the most important - stability. Helmet instability can place the crew member's eyes on the edge or outside the exit pupil, thereby degrading or eliminating the image. This may force the crew member to terminate a maneuver or delay a response while attempting to stabilize the helmet. Either of these will limit mission performance.

Instability is indicated by a rotational slippage or simply a downward movement of the helmet itself. Rotational slippage, relative to the head, can be up/down or left/right. A helmet with a high and slightly forward center-of-gravity (top heavy) will tend to rotate downward during high G maneuvers. A more balanced helmet may slip to the left/right during a quick head turn to "check six." A direct downward movement can be experienced under high G loads as the helmet liner more firmly seats into the helmet or as the liner itself compresses under the load. In some cases, the helmet may not automatically return to its original position as the G load is reduced. This requires the crew member to stop what he is doing, free his hands and physically re-set the helmet. Although the helmet can be extremely comfortable and the optics precisely aligned, if the alignment cannot be maintained, the system may be unusable; most likely at a critical point in the mission.

Fit assessments were completed to determine the stability of fitted subjects for both ground and flight tests. Data to make this determination was gathered via three means: a) a comfort assessment; b) a stability assessment; and c) 3D laser scanner (Reference Appendix C). Each test subject was individually fitted and assessed in the three I-NIGHTS helmets. Each fitting ensured that the helmet set on the head in an optimum position and that the optics were correctly aligned as best as possible (keeping in mind the "one size fits all" philosophy). Considering the data from the two assessments and laser scanning, each subject was judged to have passed or failed. The results are presented in Table 3.

Table 3. Fit Assessment Pass/Fail Results

Vendor System	Subjects Tested	Number Passed	Number Failed
GEC Avionics	36	21	15
Honeywell	33	20	13
Kaiser	36	20	16

1.3.2 Weight/Center-of-Gravity

A second major area of concern was helmet weight/center-of-gravity (WT/CG). HMDs add to the weight supported by the crew member's head and neck during high G maneuvers and emergency situations such as ejection and crash landing. But, how much weight and at what CG can the neck tolerate? At what WT/CG/force combination does a neck strain, injury, or fatality occur? The Army, Navy, and Air Force are developing HMDs for aircrew use despite the fact that "there are currently no established criteria for allowable limits on mass and mass CG location for such [HMDs]..."[1] The three greatest components affecting the risk of injury are the overall weight of the HMD system, the HMD's CG, and the force encountered during ejection.

The weight of the standard USAF helmet (HGU-55/P) is approximately 4.4 pounds including the visor and oxygen mask. Severe injuries such as cervical vertebral fractures have occurred with this helmet, although neck strains and sprains are more common. The weight of the I-NIGHTS helmets (including visor and mask) which were tested ranged from a low of 6.1 pounds in an NVG-only configuration to a high of 8.4 pounds in an NVG + CRT configuration. One might reasonably expect that increasing the weight would also increase the risk of injury. Any HMD display technology naturally adds to the overall weight of the helmet; therefore, it is important to determine a weight related injury threshold.

Some of the increased risk of injury associated with added weight can be offset with proper CG placement. Indeed, proper CG placement is even more important than the weight. The head is physiologically balanced at its CG and logic indicates that coincident head/HMD CG is desirable. However, the optimal solution is not as simple as placing the HMD CG at this same location. Experiences in the centrifuge suggest that a HMD CG slightly aft of the head's CG is helpful during normal operations and high G maneuvers. However, during ejection, the aft CG may subject the crew member to greater risk by placing an injurious or fatal load on the spine.

CG location is a design consideration trade-off. Optical physics or a maximum weight specification may dictate the location of display devices and optics. This will move the HMD CG away from a desired point (assuming that a "desired" point can be identified). Counter balancing can move the CG to a more optimal position but, this commonly used tactic adds to the overall weight supported by the head. Thus, what WT/CG combinations are reasonably acceptable during ejection?

The third component which significantly affects the risk of injury is the force of the ejection. USAF aircraft use several different types of ejection seats. Each seat imposes a different force loading during ejection. A correlation of the risk of injury to the force of ejection is described by the Dynamic Response Index (DRI). The DRI "is a number which is proportional to the peak load in a simple mechanical model (mass, spring, damper) of the human spine during acceleration. The DRI has been related to the probability of thoracolumbar spinal fracture during ejection seat use. The USAF use of the DRI to evaluate ejection seats is embodied in Military Specification: Seat System: Upward Ejection, Aircraft, General Specification for

1072, MIL-S-9479B (USAF)."[2] Figure 4 shows the relationship between DRI and the probability of spinal injury. But, what WT/CG/force combinations are reasonably acceptable during ejection?

The I-NIGHTS program helped establish an interim boundary in the area of head supported weight. Prior to entering the flight test phase, the Air Force had to demonstrate that the I-NIGHTS HMDs were safe-to-fly for a limited duration flight test schedule. Flight test hardware included the ACES II ejection seat used on the F-16 and the Martin-Baker seat used on the B-52. The results of the testing produced interim criteria for future HMDs to follow and are summarized in Table 4. These results suggest the CG must remain in the same area regardless of the seat or helmet weight used. The following recommendations are taken directly from the Interim Head/Neck Criteria Consultation Report:

> "Recommendations: It is recommended that as an interim criteria: total head supported mass be less than 4.5 lbs with a combined helmet/head center-of-gravity located between -0.8 and 0.25 inches along the x-axis, and between 0.5 and 1.5 inches along the z-axis, for safety during the catapult phase of escape using seats with DRI no greater than 18. For helmets weighing less than 4.0 lbs, the helmet/head center-of-gravity limit in the x-axis can be extended forward to 0.5 inches. For seats with DRI not greater than 13, helmets can weigh 5 lbs with the center-of-gravity located between -0.8 and 0.5 inches along the x-axis and between 0.5 and 1.5 inches along the z-axis. It is assumed that mass is distributed such that the center-of-gravity is symmetrical, ±0.15 inches, with respect to the x-z plane. These recommendations relate only to the catapult phase of ejection and not to other phases of the escape sequence. In general, it is recommended

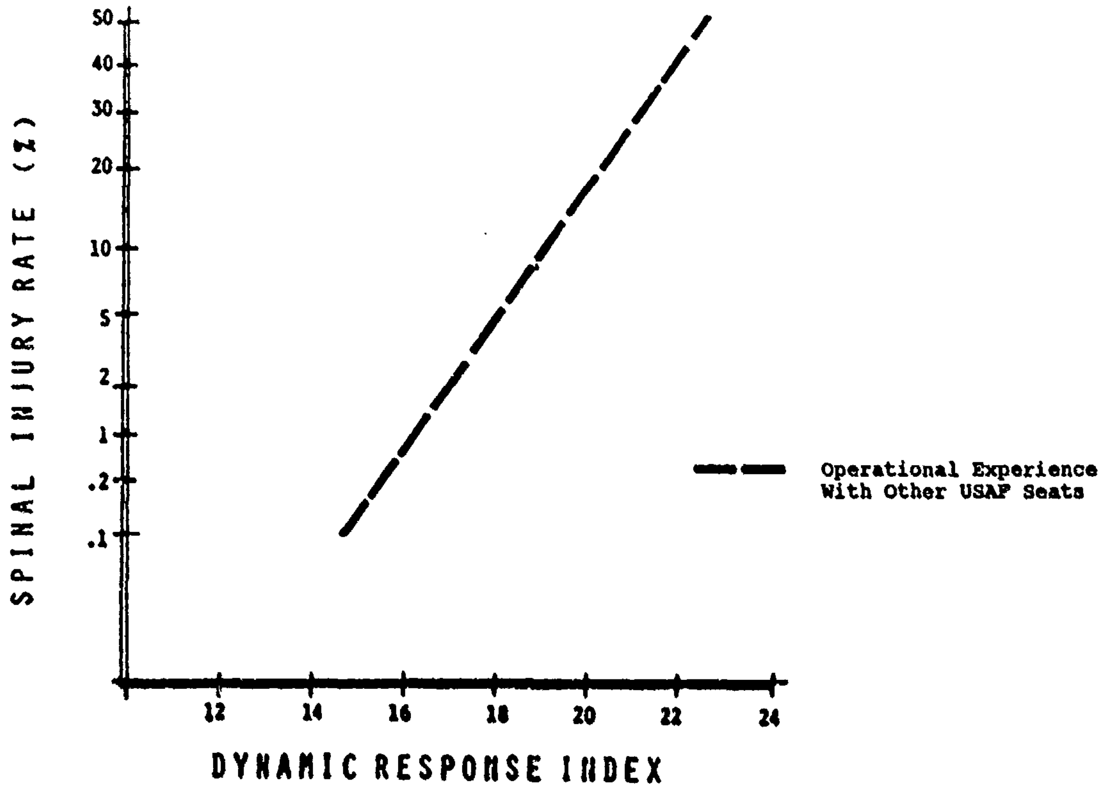

Figure 4. Spinal Injury Rate from Operational Experience Vs Dynamic Response Index

Table 4. Interim Weight/Center-of-Gravity Criteria

EJECTION SEAT	DYNAMIC RESPONSE INDEX (DRI)	MAXIMUM TOTAL HEAD SUPPORTED WEIGHT (LBS)	MAXIMUM NET HEAD GC OFFSET FROM HEAD ANATOMICAL AXIS ORIGIN (IN)		
			X	Y	Z[1]
ACES II	13	5.0	-0.8 to 0.5	±0.15	0.5 to 1.5
B-52	18	4.5	-0.8 to 0.25	±0.15	0.5 to 1.5
B-52	18	<4.0	-0.8 to 0.5	±0.15	0.5 to 1.5

[1]Data could not be collected at CGs below 0.7 on the Z axis

that helmet systems be lighter, 3.5 to 4.0 lbs, in order to enhance overall pilot acceptance under in-flight conditions."[3]

1.4 Ground Testing

The three I-NIGHTS designs underwent extensive ground testing. These tests were conducted to evaluate system performance and to assess the risk of injury during ejection. Table 1 summarizes the objectives for each test. Optical characteristics, mass properties, fit assessment, acoustical properties and centrifuge tests were conducted to quantify system performance. The remaining tests were required to assess SOF concerns prior to testing in operational aircraft. The reader is directed to the test specific sections in this report and to the test plans and reports in the appendices for greater detail.

1.5 Flight Testing

After completion of ground testing, the I-NIGHTS helmets were provided to aircrews for an operational evaluation. The purpose of this evaluation was to collect data from potential users on the utility and capabilities of the various designs. This phase of the evaluation was limited to the NVG portion of the helmet since aircraft avionic integration issues prevented use of the HMD CRTs. The helmets were first provided to HC-130, MH-53, and MH-60 pilots. These aircraft were selected on the basis that they were lower risk (two pilots and non-ejection seat) and that they would provide good human factors data (previous experience with NVGs). Each pilot was scheduled to fly two flights with each helmet. One flight was scheduled for a high illumination night (moonlight greater than 40% of a full moon) and one for a low illumination night (moonlight less than 40% of a full moon). In all cases the crews were experienced with the Aviator's Night Vision Imaging System-6 (ANVIS-6) night vision system. During each flight one pilot and the safety observer used ANVIS-6 while the other pilot used an I-NIGHTS helmet. The evaluations were conducted via questionnaire. Questionnaires were completed before, during, and after each flight.

1.6 Lessons Learned/Recommendations

The major results from the ground and flight evaluations are that helmet fit and WT/CG are a paramount factor to overall system performance. The term "helmet fit" includes comfort, stability, and optics alignment. It is essential that the optics remain in a precise position for the duration of helmet wear. This precise positioning is necessary to ensure that the exit pupil of the optics is aligned with the pupil of the eye. For this evaluation, only two of each helmet were available and the helmet shells were "large." This "one size fits all" approach did not provide helmets that were comfortable or stable for every test subject. Test subjects reported various degrees of slippage and hot spots with each of the helmets. A major design challenge is to provide a helmet that fits tight enough to maintain the optics (combiners) in a precise position while not being so tight as to be uncomfortable.

The second major result is the establishment of interim weight and center-of-gravity criteria as presented in Table 4. It is recommended that future helmet systems weigh less than 4.0 pounds and the CG be close to the head's natural CG. This will reduce the risk of injury during ejection or crash landing and will enhance aircrew acceptance for normal in-flight conditions. However, extensive work is still needed to more clearly define the relationship between WT/CG and the risk of injury. General conclusions for the I-NIGHTS program are presented in Section 5. of this report.

2. PROGRAM DESCRIPTION

The Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) began as a cooperative Air Force/Navy joint development program with the Navy designated as the lead service. The Navy I-NIGHTS program was granted Rapid Development Capability (RDC) status in 1989 to correct urgent fleet safety shortfalls as well as to meet the current operational needs of the F/A-18 night attack mission requirement. The planned Navy approach was to downselect from three vendors to one vendor after ground and flight tests had been conducted, and then procure 100 units initially as a low rate initial production (LRIP) milestone. The Navy terminated its I-NIGHTS program in December 1990 after realizing the technology was not mature enough for downselection to a production decision.

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I-NIGHTS helmets (Figures 1, 2, 3, 5, 6, and 7) are modular in nature and are designed to more evenly distribute the weight of the optical systems in an attempt to provide a lower ejection risk. I-NIGHTS systems underwent extensive ground tests (Table 1) to assess the risk of ejection and evaluate system performance. In addition to the ground tests, the systems underwent flight evaluations to assess performance under actual mission scenarios. Flight testing was accomplished in MH-53, MH-60, HC-130, and B-52 aircraft (Table 2).

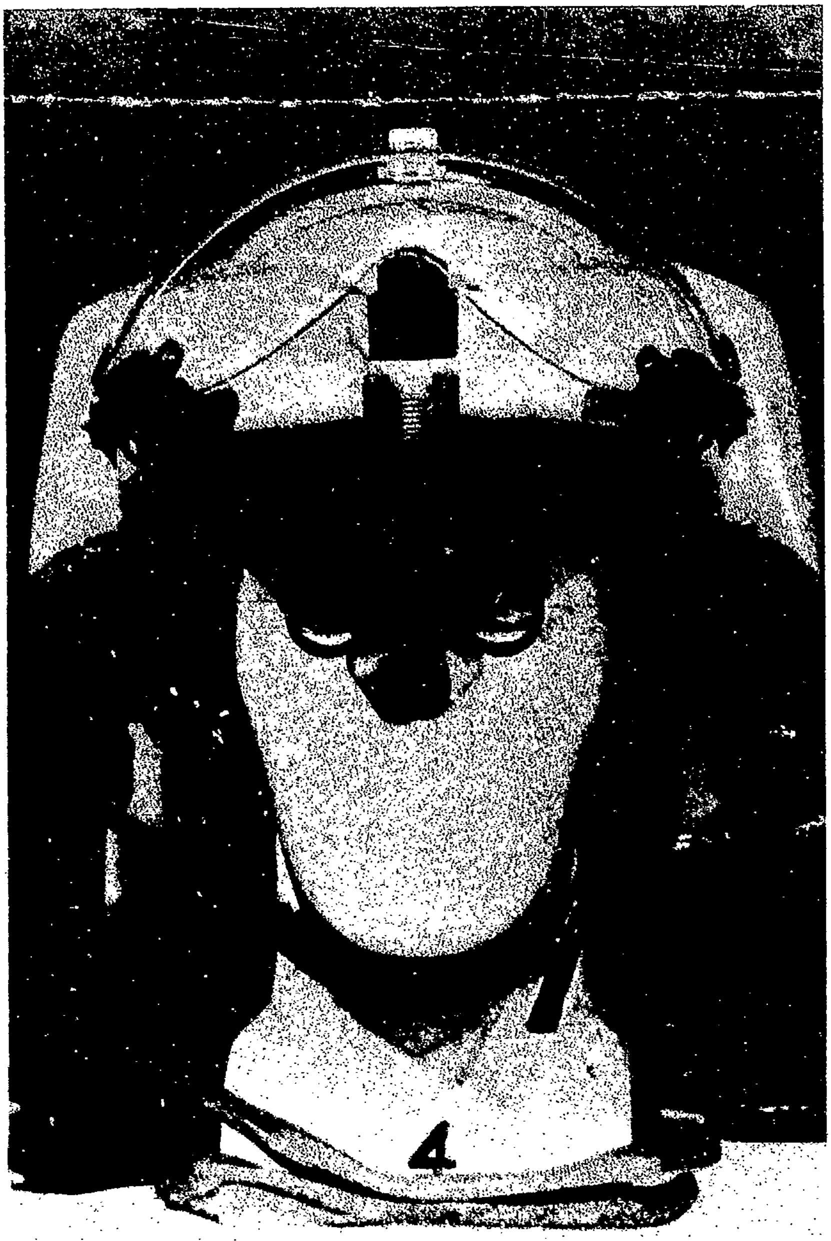


Figure 5. GEC I-NIGHTS Helmet

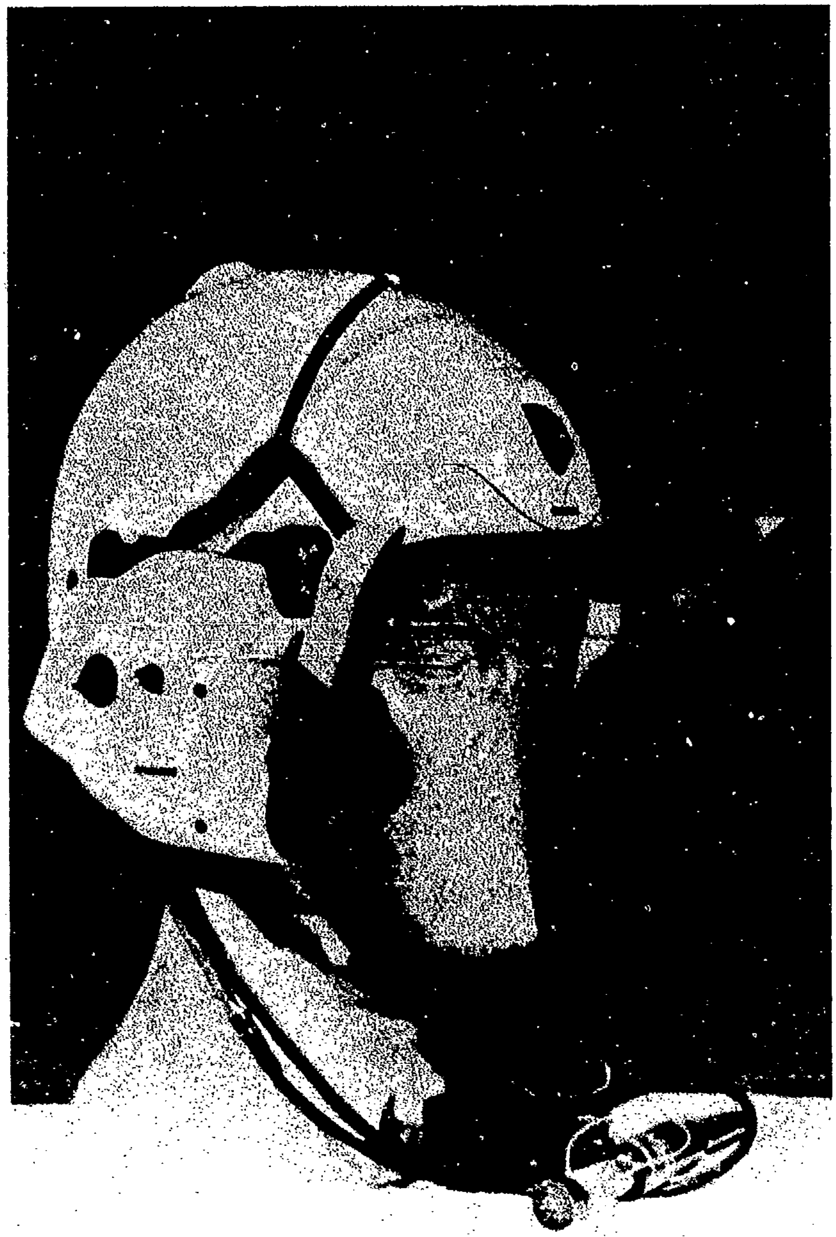


Figure 6. Honeywell I-NIGHTS Helmet

Figure 7. Kaiser I-NIGHTS Helmet

2.1 System Descriptions

The I-NIGHTS helmet systems were designed to aid the aircrew member flying at night. The prime contractor, McDonnell Douglas, subcontracted with General Electric Company (GEC) Avionics, Honeywell, and Kaiser Electronics. All three I-NIGHTS systems function in a similar manner. They incorporate two-battery powered, generation III image intensifier tubes (I^2 tubes); two optional cathode ray tubes (CRTs); and a magnetic head tracker. The I^2 tubes are extremely sensitive to light in the spectromagnetic region from 0.6 to 0.9 microns (600 nm to 900 nm). This region overlaps the spectral distribution of starlight which peaks at about 0.9 microns. The I^2 tubes amplify ambient starlight and moonlight to enhance night vision capability. The CRTs provide the means to present symbology and/or sensor video data to the crew member. The head tracker senses the magnetic field around the helmet to provide head position data. This data can be used to slew aircraft sensors in the direction the crew member is looking and/or update the symbology relevant to head position. Due to aircraft avionic integration issues, the CRTs and head tracker could not be flight tested.

The helmets have the I^2 tubes mounted on both sides of the helmet. A variety of prisms, lenses, and beam splitters are used to move the intensified image to a combiner in front of each eye. The combiner is positioned 10 to 20 mm from each eye, and it combines the intensified image with any visible ambient light superimposed with the visible scene. Each I-NIGHTS helmet employs a unique design to send the image output from the I^2 tube through the combiner to the eye. In two of the systems the combiners are movable and can be "stowed" out of the way when not in use. The third system uses fixed combiners.

The image intensified scene appears as shades of green varying from light green to dark green. The light green represents areas of high ambient light, and the dark green represents areas of low light. The image intensified scene, as viewed through the combiners, has a field-of-view of approximately 35° with a Snellen visual acuity approaching 20/60. By comparison, ANVIS has a field-of-view of 40° and an Snellen acuity of 20/40. The intent of the I-NIGHTS program was not to meet or exceed ANVIS performance standards, but to demonstrate a night vision capability in an "ejection-safe" helmet system.

Two parameters that were heavily emphasized during the I-NIGHTS program were weight (WT) and center-of-gravity (CG). These parameters were focused upon in order to demonstrate the feasibility of an "ejection-safe" helmet system. The I-NIGHTS helmets weigh 6.1 to 8.4 pounds (including visor and MBU-12/P oxygen mask). This is heavy when compared to the Air Force standard helmet and mask (the HGU-55/P, MBU-12/P) at 4.4 pounds. However, results from the aircrew evaluations indicate that aircrews have experienced less neck fatigue with the I-NIGHTS helmets than with the HGU-55/P and ANVIS combination. The lower fatigue rate results from a better distribution of the weight, resulting in an improved CG. The CG of the I-NIGHTS systems is slightly higher and forward compared to the normal CG for the human head.

The helmet systems are individually fitted to each crew member through the use of a removable helmet liner. The liner "form fits" the helmet to the crew member. This process makes the helmet more stable and comfortable. During the flight test phase the crew member obtained the helmet at life support. The liner was inserted and the combiners were adjusted to align in front of each eye. The lights were turned off and the crew member used an eye chart to check the alignment of the combiners along with the focus and visual acuity. Combiner misalignment reduces the field-of-view and can induce eye fatigue.

2.2 Test Program Summary

Development Test and Evaluation (DT&E) was conducted independently by the Air Force and the Navy. However, some ground tests and evaluations were coordinated between the two services to maximize joint test requirements and eliminate duplication of effort.

Each service planned independent flight evaluations to assure that each service's flight evaluation fully addressed their unique mission requirements, environmental conditions, and tactical considerations. The results of ground and flight testing were shared between the two services.

2.2.1 Ground Test Summary

The Naval Air Development Center (NADC) coordinated and conducted most of the ground and laboratory performance evaluation for the Navy. The Navy tests focused on ejection risk issues and will be reported separately. The Air Force ground tests were completed prior to safety certification and flight tests. Ground testing was conducted from Mar 90 through Nov 90 and is summarized in Table 1.

2.2.2 Flight Test Summary

Flight Tests were conducted following NVG ground tests and safety certification for each respective aircraft. The following test aircraft were used:

Table 5. Flight Test Schedule

Test A/C	User	Period	Location
MH-60	AFSOC (SMOTEC)	Dec 90 - Jan 91	Hurlburt Fld, FL
MH-53	AFSOC (SMOTEC)	Feb 91 - Mar 91	Hurlburt Fld, FL
HC-130	MAC (AF Reserve)	Mar 91 - Apr 91	Moffett Fld, CA
B-52	SAC (99 SWW)	Jul 91 - Aug 91	Ellsworth AFB, SD

3. GROUND TESTING REVIEW

Original planning for I-NIGHTS ground tests was based upon testing identified for the full scale development of the Aircrew Eye/Respiratory Protection System (AERPS) Program. The AERPS program, managed by the Life Support Program Office, Wright-Patterson AFB, Ohio, had the best available baseline of tests which related to the I-NIGHTS program test needs. A preliminary list of tests was tailored for I-NIGHTS by adding night vision goggle (NVG) optics performance tests and other appropriate ground tests, as required. One of the additional tests added was "fit assessment." It soon became apparent that a "good" versus "poor" fit could greatly affect the outcome of most of the ground tests. The importance of fit cannot be over-emphasized for both ground and flight tests alike.

Some tests were deleted from the preliminary list because I-NIGHTS is a prototype system, risk reduction program, and not a full scale development program. Those tests deleted included the following: static parachute drop, land drag, water drag, and live parachute jumps. Alternative tests with an instrumented manikin were substituted to simulate parachute deployment. The major reasons for deleting the above tests were:

- Limited duration flight test program
- Systems would not be used operationally outside of the scope of the short term test program
- Limited mock-up systems available (2 each) did not provide enough assets for some potentially destructive tests
- Unnecessary risk of injury possible for land drag, water drag, and live parachute jumps

3.1 Ground Test Descriptions

Table 6 provides a summary of the NVG ground tests conducted before the I-NIGHTS flight tests. The corresponding ground test results are summarized in paragraph 3.2.

Table 6. Summary of NVG Ground Tests Conducted

Subject/Test Area	OPR	OPR Location	Test Location
Optical Characteristics	AL/CFHO	WPAFB, OH	WPAFB, OH
Mass Properties	AL/CFBV	WPAFB, OH	WPAFB, OH
Fit Assessment	AL/CFHW	WPAFB, OH	WPAFB, OH Hurlburt Fld, FL
Personal Equipment Integration	AL/CFTS	Brooks AFB, TX	Brooks AFB, TX
Aircraft Integration	3246TW AL/CFTS	Eglin AFB, FL Brooks AFB, TX	Eglin AFB, FL Brooks AFB, TX Hurlburt Fld, FL Eaker AFB, AR NAS Pensacola, FL
Acoustical Properties	AL/CFBA	WPAFB, OH	WPAFB, OH
Altitude Chamber	AL/CFTS	Brooks AFB, TX	Brooks AFB, TX
Dynamic System Performance	AL/CFBS	WPAFB, OH	WPAFB, OH
Explosive Atmosphere	WL/FIGX	WPAFB, OH	Munich, FRG
Crash Landing	AL/CFBE	WPAFB, OH	WPAFB, OH
Ejection	AL/CFBE	WPAFB, OH	WPAFB, OH
Windblast	AL/CFBE	WPAFB, OH	Bohemia, NY
Man/Seat Separation	AL/CFA (HMST)	WPAFB, OH	NAS China Lake, CA
Parachute Deployment	AL/CFA (HMST), 4950TW	WPAFB, OH	WPAFB, OH

(WPAFB: Wright-Patterson Air Force Base, Ohio)

3.1.1 Optical Characteristics Evaluation

The following parameters were evaluated under controlled laboratory conditions:

Exit Pupil Diameter

Eye Relief

Brightness Gain

Field-of-View (FOV)

Luminance Non-Uniformity (Center 80% of FOV)

Modulation Contrast

- @ 5 degrees
- @ 10 degrees

Magnification

Image Rotation

Optical Axis Misalignment

- Horizontal
- Vertical
- Total

"S" Distortion (peak to valley)

Resolution

- Horizontal
- Vertical

CRT Image Quality

- Sinewave Response
- Line Width Measurement
- Line Luminance Test

See Appendix A. These tests were accomplished by Armstrong Laboratory's Visual Display Systems Branch (AL/CFHV), at Wright-Patterson AFB, Ohio.

3.1.2 Mass Properties: Weight/Center-of-Gravity (CG)

The weight/CG tests were conducted to accurately measure the mass properties of the I-NIGHTS NVG helmet systems (Figure 8). The mass properties of all NVG configurations were mathematically combined with representative human head mass properties extracted from a subject data base. All tests were conducted by Armstrong Laboratory's Vulnerability Assessment Branch (AL/CFBV) in the

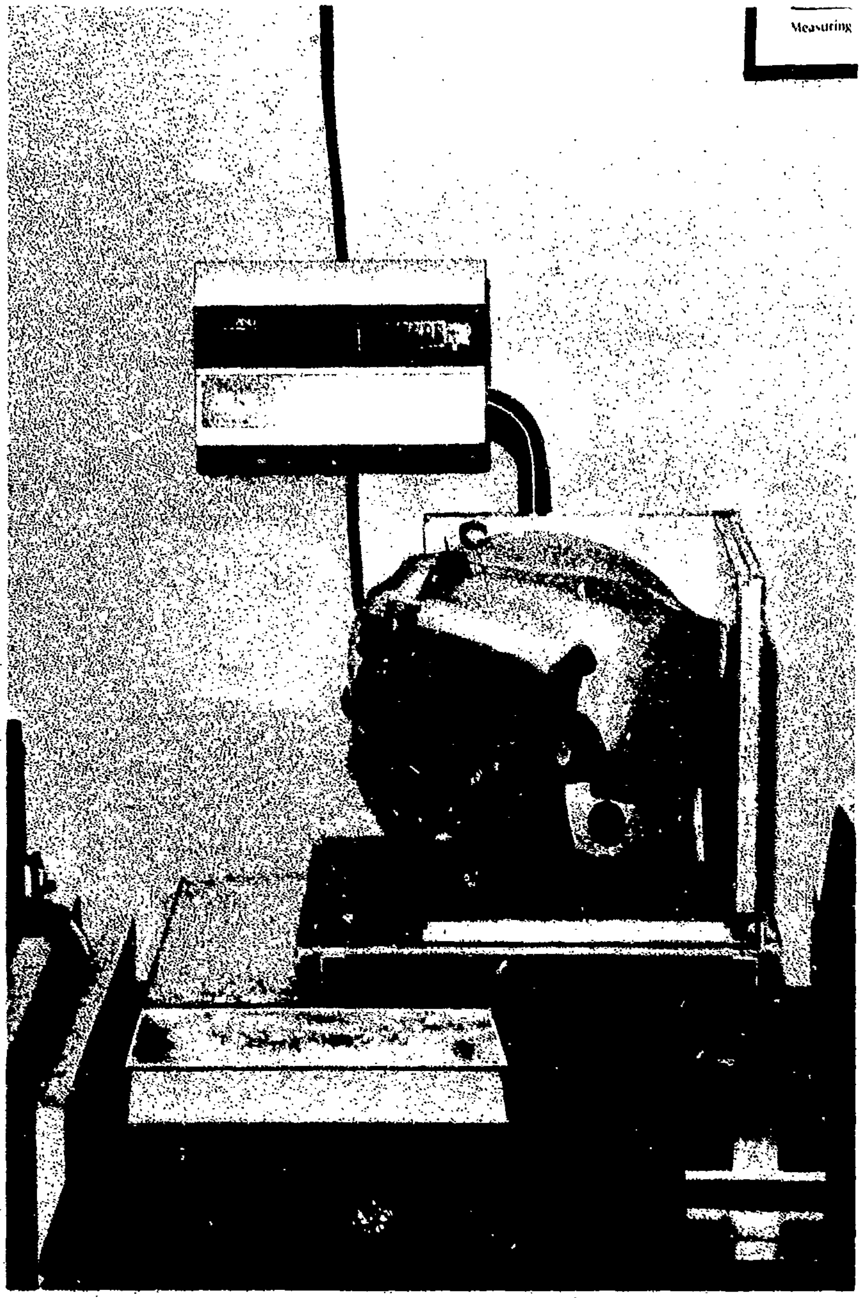


Figure 8. Weighing an I-NIGHTS Helmet

Manikin Testing Laboratory (MTL) located in Building 824, Area B, Wright-Patterson AFB, Ohio. The measurements were made using the Automated Mass Properties Measurement System which consisted of the Space Electronics mass properties instrument, a Hewlett Packard microcomputer, an electronic scale and moment table assembly. All calculations were made with the use of software and associated computers resident to the test agency (AL/CFBV). See Appendix B for test plan.

3.1.3 Fit Assessment

Fit assessments were completed to determine the suitability of fitted subjects for both ground and flight tests. First, ground test subjects were assessed in each of the three I-NIGHTS helmets including: anthropometric measurement of each subject, tabulation of a fit questionnaire and documentation of each subject's fit parameters. The fit was assessed in the following three categories: comfort, optical adjustment, and stability. Prior to the flight test phase, the test pilots were also assessed for fit suitability in the same manner as the ground test subjects. Fit assessments were accomplished by Armstrong Laboratory's Design Technology Branch (AL/CFHD) at Wright-Patterson AFB, Ohio.

The fit assessment consisted of several steps. The first step was to examine the "fitting" procedures for the three I-NIGHTS vendors and determine the acceptance or rejection criteria. It might have been necessary to modify "fitting" procedures such as the helmet liner construction or helmet placement to optimize the helmet fit. Any modifications needed to be made prior to the beginning of actual fit testing. A set of fit testing methods was created and these were verified with a small preliminary test. Some changes were subsequently made to accommodate the particular helmet system.

The second step was to conduct a generic fit study in the laboratory with the intent of defining fit criteria. This portion of the study included: a) head and face measurements by traditional means; b) full head surface laser scanning; c) assessment of comfort; d) assessment of stability using both force and distance measures as well as a questionnaire; and e) the assessment of optics placement.

The third step was to utilize the laboratory fit assessment information to determine, if possible, which head sizes appear to achieve a "good" fit. The purpose of this was to reduce the amount of fit assessment needed for the flight test subjects while at the same time maximizing the amount of information which could be gleaned with a minimal number of subjects during flight testing.

The fourth and final step was to analyze the data and prepare a report documenting the results. Due to the importance of "fit," a separate section (4.0) has been set aside to deal with fit related issues. See Appendix C for test plan.

3.1.4 Personal Equipment Integration

These assessments were conducted to demonstrate that the I-NIGHTS helmets were compatible with the required life support and mission essential equipment. Compatibility was defined as the ability of the personal flight equipment to provide its function as written in the aircraft Technical Order (T.O.), and the ability of the aircrew to accomplish simulated mission tasks. Trained test subjects, representing approximately the 5th, 50th, and 95th percentiles (weight and stature) of the USAF aircrew population were used for these tests. Mission tasks were determined by consultations with rated aircrew members at the test sites. All subjects wore the personal flight equipment required for their specific aircraft and/or mission (MH-53, MH-60, HC-130, B-52).

Data was collected on the following: 1) any adverse interaction between the I-NIGHTS helmet and the test subject, the personal flight equipment, and the aircraft cockpit during simulated normal and emergency situations; 2) reduced mobility (head and body); 3) increased thermal loading; 4) ability to complete don/doffing, ingress/non-emergency egress, and simulated mission tasks (access to emergency and non-emergency controls and displays); 5) comfort; 6) chinstrap and visor operation; 7) visual limitations; and 8) any physical damage to the helmet.

An inversion wheel assessment was made using a replica ACES II seat. Subjects wore the required personal flight equipment and an I-NIGHTS helmet. After strapping in, subjects were tilted side to side to simulate lateral Gs (G_y) and then rotated (inverted) to simulate $-1.0G_z$. Any adverse equipment interaction and helmet discomfort were recorded. This testing was jointly directed by Armstrong Laboratory's Crew Technology Division (AL/CFTS), Brooks AFB, Texas and the Chemical Defense Branch, 3246 Test Wing, Eglin AFB, Florida. See Appendix D for test procedure.

3.1.5 Aircraft Integration

The purpose of these tests was to demonstrate/evaluate each of three I-NIGHTS vendor systems with regard to aircrew survivability during emergency doff, emergency ground egress, and parachute descent after parachute deployment. Data was also collected to assess I-NIGHTS NVG systems for electromagnetic interference/electromagnetic compatibility (EMI/EMC). See Appendix D for more information.

Ground egress tests were performed in the MH-53, MH-60, HC-130, B-52, A-10 and F-16 aircraft. All procedures were performed by three test subjects from the 3246 Test Wing in conjunction with USAF AL/CFTS (Brooks AFB, Texas) personnel. The test locations included: Brooks AFB, Texas; Eglin AFB, Florida; Hurlburt Field, Florida; Pensacola Naval Air Station, Florida; and Eaker AFB, Arkansas.

The test subjects were representative of the 5th, 50th, and 95th percentiles (DOD-Handbook-743 Anthropometry of US Military Personnel). The pass/fail criteria used was that emergency ground egress must be achievable in a reasonable period of time IAW applicable T.O.'s from selected crew stations. The test subjects were trained life support/survival personnel who wore each of the I-NIGHTS systems along with required gear worn during flight. The ground emergency procedures were followed, as defined in the T.O. for each aircraft.

For parachute hanging harness tests, the test subjects donned each I-NIGHTS system along with required life support and flight gear for each aircraft to be flown during the flight tests. Each person was suspended above the ground by the parachute risers and subsequently completed post egress procedures according to T.O. 14D1-2-1, change 13, page 3-25 (Figure 9). A record was made of all post egress procedures which could/could not be accomplished and any changes in procedures were noted.

The purpose of EMI/EMC tests was to determine if any electromagnetic interference was caused by the I-NIGHTS NVG systems. A limited EMI/EMC check with the aircraft avionics systems was conducted. All aircraft avionics systems were sequentially operated while each I-NIGHTS system was operating. A standard aircraft checklist was used to operate the I-NIGHTS systems. If no interference was observed while the I-NIGHTS system was on, then the system passed the EMI/EMC tests.

Figure 9. Life Support Personnel Demonstrating the Hanging Harness Test

3.1.6 Acoustical Properties

The objective of this testing was to measure the hearing protection and voice communication performance of NVG helmets from the three I-NIGHTS manufacturers. The purpose of the test was to: (a) determine if the headsets met the hearing protection requirements of MIL-P-38268C; and (b) quantitatively measure speech intelligibility to estimate the operational performance of the headsets. Testing was accomplished at Wright-Patterson AFB, Ohio, by Armstrong Laboratory's Bioacoustics and Bio-communications Branch (AL/CFBA). See Appendix E for test plan.

3.1.6.1 Sound Attenuation

Hearing protection attenuation was measured in accordance with the specific guidelines established by American National Standards Institute (ANSI) standard S12.6-1984, "Method for the Measurement of Real-Ear Attenuation of Hearing Protectors." The study design of this method was a repeated measures design with each of 10 subjects participating three times in each control condition and test condition for each of nine test signals, and for each of three I-NIGHTS helmets (Figure 10). Data for each of the three I-NIGHTS helmets was tabulated and processed to provide mean and standard deviations of the attenuation for each test signal. The attenuation (amount of hearing protection measured) was defined as the arithmetic difference between the unoccluded (subjects not wearing I-NIGHTS helmet) and occluded (subjects wearing I-NIGHTS helmet) hearing threshold levels.

3.1.6.2 Speech Intelligibility

The speech intelligibility testing employed a balanced, round robin design. Each subject participated as both speaker and listener at four noise levels with each of the three I-NIGHTS

Figure 10. Sound Attenuation

helmets being assessed. Experiment conditions were randomized to minimize any possible order effect. The criterion measured was speech intelligibility as measured by the Modified Rhyme Test (MRT) (ANSI S3.2, 1989).

3.1.7 Altitude Chamber

The altitude chamber tests focused on the following two objectives:

a) Demonstrate compatibility of the I-NIGHTS helmets with current aircrew protective equipment and life support systems.

b) Demonstrate compatibility of the I-NIGHTS helmets with the aircrew member, cockpit, required life support equipment, and mission essential tasks associated with each crew station.

These tests were conducted by the Crew Technology Division, Crew Systems Branch (AL/CFTS) at Brooks AFB, Texas. See Appendix D for test procedure.

3.1.7.1 Rapid Decompression Evaluation

Unmanned rapid decompressions (RDs) were conducted in a hyperbaric chamber to verify the structural integrity of the helmet shell and optical components. The helmets were mounted on a brass manikin head. Each helmet received two exposures from a simulated altitude of 8,000 to 25,000 feet (5.45 psi differential) in approximately one second. Following each RD, the liner was removed and the helmet shell, optics, and liner were examined for physical damage.

3.1.7.2 Visor Fogging

A lens/visor fogging evaluation was conducted by AL/CFTS. Two temperature conditions were assessed: 32° Fahrenheit at 80% relative humidity, and 75° Fahrenheit at 80% relative humidity. Subjects entered the chamber from ambient temperature and humidity conditions. An assessment of air blown over the lens/visor was made and a time for fogging to occur and clear was noted.

3.1.8 Dynamic System Performance: Centrifuge

The centrifuge tests were conducted to evaluate how the I-NIGHTS systems operate under sustained acceleration. The tests were devised to determine if the I-NIGHTS systems provided usable visual information at typical acceleration levels. The pilot's ability to judge his orientation while the NVG was operating was also evaluated. This testing was also conducted with the oxygen mask removed to emulate helicopter and HC-130 scenarios (Figure 11). This configuration provided less helmet stability than experienced during tests where an oxygen mask was worn under the same G-forces.

Figure 11. Centrifuge Cab

The centrifuge tests primarily consisted of two gradual onset profiles and a Simulated Air Combat Maneuver (SACM). The two gradual onset runs tests from $+1G_z$ to $+4G_z$, and from $+1G_z$ to $+8G_z$, were performed to measure migration of the intensified image. Image migration results from helmet slippage and is measured by the difference between where the test subject is looking (straight ahead, center) and where the helmet is pointing (degrees off center). The SACM presented various peak Gs experienced during an air combat maneuver. At some point, the test subject was directed to "check the six o'clock position" and look left and right. Two additional centrifuge tests were conducted to simulate $\pm 1.5G_y$ profiles (left and right), and one $-1G_z$ profile. These three profiles were used to emulate side-to-side and foot-to-head forces sometimes found in helicopters mission profiles.

This testing was accomplished in the centrifuge located at Wright-Patterson AFB, Ohio, by Armstrong Laboratory's Combined Stress Branch (AL/CFBS). See Appendix F for test procedure.

3.1.9 Explosive Atmosphere

The objective of this testing was to verify the safety of the high voltage, quick-disconnect connector (QDC) in the presence of a potentially explosive atmosphere. The QDC must safely function and disconnect at all altitudes. Therefore, tests were conducted from sea level to 50,000 ft at 10,000 ft intervals. The QDC was placed inside a vacuumed test cell and connected to a high voltage power supply. The temperature and pressure were allowed to stabilize prior to introducing the fuel-air mixture. After three minutes, the QDC was pulled apart to see if the fuel-air mixture would ignite.

This testing was sponsored by Wright Laboratory's Advanced Flight Test Integrator (AFTI) Office (WL/FIGX). Tests were actually conducted in Munich, Germany. See Appendix G for nominal test information.

3.1.10 Crash Landing Evaluation: G_x Impact Sled Test

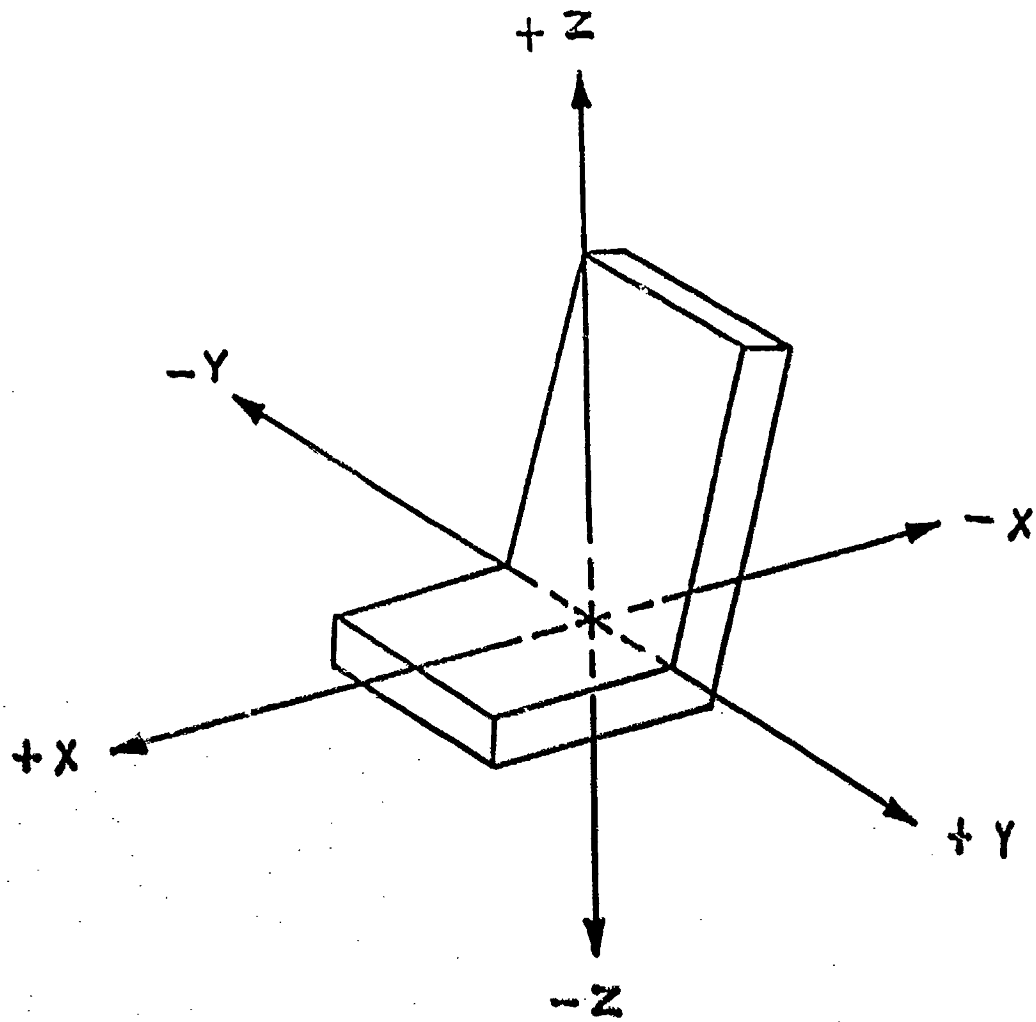
The objective of this test was to measure head accelerations and neck forces for the baseline HGU-55/P helmet and to compare the results with the I-NIGHTS helmets. The test was designed to meet the objectives by subjecting an anthropomorphic manikin fitted with a test helmet to a high-energy acceleration pulse. The HGU-55/P helmet was considered the baseline system, and a comparison was made with three I-NIGHTS helmets (GEC, Honeywell, Kaiser).

Initial testing began at +20Gs in the G_x direction. The +20G profile was a simulation of a worst case acceleration encountered during an emergency helicopter landing. However, due to the destruction of two I-NIGHTS systems at the +20G impact level, the test organization recommended reducing testing to a +15G profile. (See Table 7.) The +15G profile provided a simulation of a 50th percentile fixed wing emergency landing, and a 50th to 95th percentile helicopter emergency landing. The test matrix below provides an overview of the G_x Impact Test Program.

Table 7. G_x Impact Test Matrix

TEST CELL	ACCELERATION LEVEL	HELMET	# TESTS
A1	+15G	HGU-55/P	3
B1	+15G	I-NIGHTS GEC	3
C1	+15G	I-NIGHTS Honeywell	3
D1	+15G	I-NIGHTS Kaiser	3

The coordinate system used for the G_x impact sled tests and other tests described in this section is shown in Figure 12.



* The seat/man origin will be at the center of the line intersecting the planes of the seat back and seat pan.

Figure 12. Coordinate System

This testing was accomplished in the Horizontal Impulse Accelerator at Wright-Patterson AFB, Ohio, by Armstrong Laboratory's Biomechanical Protection Branch (AL/CFBE). See Appendix H for test plan.

3.1.11 Ejection: G_z Vertical Deceleration Tower

The Vertical Deceleration Tower (VDT) is used to simulate the force pulse experienced by a crew member ejecting from an aircraft. The force pulse can be varied in magnitude, rise time, and duration to evaluate various ejection situations. VDT testing included both human subjects and manikins. Humans were tested up to $+10G_z$ while manikins were tested from $+6G_z$ to $+20G_z$. The manikins were instrumented with accelerometers and measured head/neck forces in the X, Y and Z axis.

VDT testing was accomplished at Wright-Patterson AFB, Ohio, by Armstrong Laboratory's Biomechanical Protection Branch (AL/CFBE). See Appendix I for test plan.

3.1.12 Windblast

Windblast testing had three primary objectives:

a) Verify the structural integrity of the three I-NIGHTS helmet systems;

b) Measure the head/neck loads;

c) Verify the compatibility with the ACES II seat mounted pitot tubes.

An instrumented manikin was fitted with each of the three I-NIGHTS helmets. While wearing one of the helmets, the manikin was strapped into an ACES II ejection seat and subjected to windblasts simulating ejections at 375, 450, 550, and 600 knots. For each speed, the seat pitch angle was set at 17° and 34° to simulate ejections from F-15 and F-16 aircraft. The testing was conducted at Dayton T. Brown facilities located in Bohemia, New York by Armstrong Laboratory's Biomechanical Protection Branch (AL/CFBE). See Appendix J for test plan.

3.1.13 Man/Seat Separation

The purpose of this test was to confirm that a crew member wearing an I-NIGHTS helmet could safely separate from the seat should an ejection occur. Tests were designed to study the interactions between the I-NIGHTS helmets and the deploying parachute riser assemblies. Test objectives included measuring the head/neck loading, verifying eye relief, and safe seat separation. Testing was accomplished at Naval Air Station, China Lake, California, by Armstrong Laboratory's Helmet-Mounted Systems Technology Office (AL/CFA (HMST)). See Appendix K for test plan.

3.1.14 Parachute Deployment

The objective of this testing was to evaluate riser interference with the I-NIGHTS helmets while simulating a B-52 parachute deployment sequence. The B-52 sequence was selected since the extreme riser loads represent the worst case scenario. Additional objectives include measurement of the head/neck loads experienced by an instrumented manikin and the evaluation of eye relief.

The testing consisted of fitting the manikin with an I-NIGHTS helmet and a parachute harness/riser assembly. The manikin was raised in the air via a crane and then allowed to fall. After falling a predetermined distance, the parachute risers (which were still attached to the crane) deployed subjecting the manikin to the proper forces experienced in a B-52 ejection. Inertial accelerometers in the manikin measured the forces and the event was recorded on high speed film. Each helmet was tested with the manikin in a vertical and a horizontal body position. Each body position drop was repeated three times to obtain nominal average measurement values. Testing was accomplished at the 4950 Test Wing facilities at Wright-Patterson AFB, Ohio, by Armstrong Laboratory's Helmet-Mounted Systems Technology Office (AL/CFA (HMST)). See Appendix L for test plan.

3.2 Ground Test Results & Discussions

The following sections provide a summary of the test results for each ground test.

3.2.1 Optical Characteristics Evaluation

The information in Tables 8 through 11 provide an average for each applicable parameter along with maximum/minimum measurements and sample sizes for each I-NIGHTS NVG system tested. Table 12 contains ANVIS information and is included to provide optics performance overview for a fielded system as a comparison. Figure 13 depicts a representative equipment setup to measure NVG Field-of-View optical characteristics. See Appendix A for additional test data.

3.2.2 Mass Properties: Weight/Center-of-Gravity (CG)

Inertial properties (weight and CG) are useful reference points in evaluating helmet systems. These parameters are most important in evaluating risk of injury due to ejection and/or crash profiles. Weight and CG each contribute to the risk of injury since they have a bearing on head/neck loads and the forces incurred during crash and/or ejection. However, the extent of injury, injury thresholds, and tolerance levels are not well established. Interim head/neck criterion is currently being developed based upon past studies and laboratory experience, see section 3.2.11.

Table 8. GEC Avionics I-NIGHTS Optical Performance

Parameter	Average	Max	Min	Sample Size
Exit Pupil	9.75mm	10.1mm	9.2mm	14
Eye Relief	20.48mm	24.1mm	17.1mm	14
Brightness Gain at 3.7 * 10-4 ft-L	2480	2849	1956	14
FOV	36.5 deg	38.0 deg	34.2 deg	14
Luminance non-uniformity	+/-40.3%	+/-47.9%	+/-33.5%	12
Modulation Contrast	97.1%	99.3%	95.2%	14
Magnification	0.99	0.94	1.02	14
Image Rotation	N/A	46.9mrad	3.9mrad	14
S Distortion	6.7mrad	10.9mrad	2.3mrad	14
Optical Axes Misalignment (Total)	----	15.1mrad	-1.1mrad	14
Resolution				
Horizontal	20/62	20/77	20/54	14
Vertical	20/59	20/77	20/48	14

Table 9. Honeywell I-NIGHTS Optical Performance

Parameter Size	Average	Max	Min	Sample
Exit Pupil	11.9mm	12.2mm	11.3mm	12
Eye Relief	38.1mm	42.4mm	35.2mm	12
Brightness Gain at 3.7 * 10-4 ft-L	2500	3265	1406	12
FOV	36.4 deg	38.2 deg	35.4 deg	10
Luminance non-uniformity	+/-76.2%	+/-84.4%	+/-59.5%	12
Modulation Contrast	95.8%	97.1%	94.5%	12
Magnification	1.02	1.08	0.99	15
Image Rotation	N/A	50.8mrad	-1.9mrad	15
S Distortion	3.09mrad	4.7mrad	0.65mrad	15
Optical Axes Misalignment (Total)	----	-39.8mrad	-3.2mrad	15
Resolution				
Horizontal	20/85	20/135	20/54	14
Vertical	20/69	20/48	20/96	14

Table 10. Kaiser I-NIGHTS Optical Performance

Parameter Size	Average	Max	Min	Sample
Exit Pupil	11.9mm	12.1mm	11.7mm	12
Eye Relief	20.3mm	21.7mm	19.6mm	12
Brightness Gain at 3.7 * 10-4 ft-L	2077	2760	1643	12
FOV	31.8 deg	32.5 deg	30.6 deg	12
Luminance non-uniformity	+/-29.0%	+/-19.9%	+/-41.0%	12
Modulation Contrast	95.3%	99.5%	91.2%	12
Magnification	1.01	1.03	1.00	12
Image Rotation	N/A	7.4mrad	0.17mrad	12
S Distortion	0.74mrad	1.3mrad	0.41mrad	12
Optical Axes Misalignment (Total)	----	21.6mrad	1.4mrad	12
Resolution				
Horizontal	20/47	20/77	20/34	12
Vertical	20/43	20/77	20/34	12

Table 11. Consolidated Report Optical Performance (Average by Vendor)

Parameter	GEC	Honeywell	Kaiser
Exit Pupil	9.75mm	11.9mm	11.9mm
Eye Relief	20.48mm	38.1mm	20.3mm
Brightness Gain at 3.7 * 10-4 ft-L	2480	2500	2077
FOV	36.5 deg	36.4 deg	31.8 deg
Luminance non-uniformity	+/-40.3%	+/-76.2%	+/-29.0%
Modulation Contrast	97.1%	95.8%	95.3%
Magnification	0.99	1.02	1.01
Image Rotation	N/A	N/A	N/A
S Distortion	6.7mrad	3.09mrad	0.74mrad
Optical Axes Misalignment (Total)	----	----	----
Resolution			
Horizontal	20/62	20/85	20/47
Vertical	20/59	20/69	20/43

Table 12. ANVIS NVS #0698 Optical Performance

	Right	Left	Spec
Exit Pupil Diameter	N/A	N/A	N/A
Eye Relief (Questionable)	26.6mm	27.6mm	15.0mm
Brightness Gain (@ 3.7E-04 ft-L)	2559	2707	not < 2000
Field of View	40 deg	40 deg	40 deg (+1, -2)
Luminance Non-Uniformity (Center 80% of FOV)	-----------Not Measured-----------		
Modulation Contrast			
@ 5 deg	0.963%	0.964%	
@ 10 deg	0.976%	0.978%	
Magnification	1.00	0.98	1.00 (+/- 5%)
Image Rotation	-19.6mrad	-7.70mrad	
Optical Axis Misalignment			
Horizontal	-----------Not Measured-----------		
Vertical	-----------Not Measured-----------		
Total	-----------Not Measured-----------		
"S" Distortion (peak to valley)	10.2mrad	5.00mrad	not > 1.33mrad
Resolution			
Horizontal	20/48	20/48	not > 20/45
Vertical	20/48	20/48	not > 20/45
Weight of Binocular Without Battery Pack	677g	677g	not > 550g

NOTES:

1. The ANVIS system is a non-pupil forming system and the three I-NIGHTS systems are all pupil-forming systems. Since the ANVIS system is a non-pupil forming system with a 40 deg field of view the measurement of the eye relief may be greater than what may be expected due to underfilling the NVG field of view. For this reason the eye relief is considered questionable.

2. On the performance overview for ANVIS, the heading (SPEC) refers to the minimum optical requirements for the ANVIS system obtained from military specification (MIL-A-49425). These minimums are presented for comparison with the Armstrong Laboratories measurement.

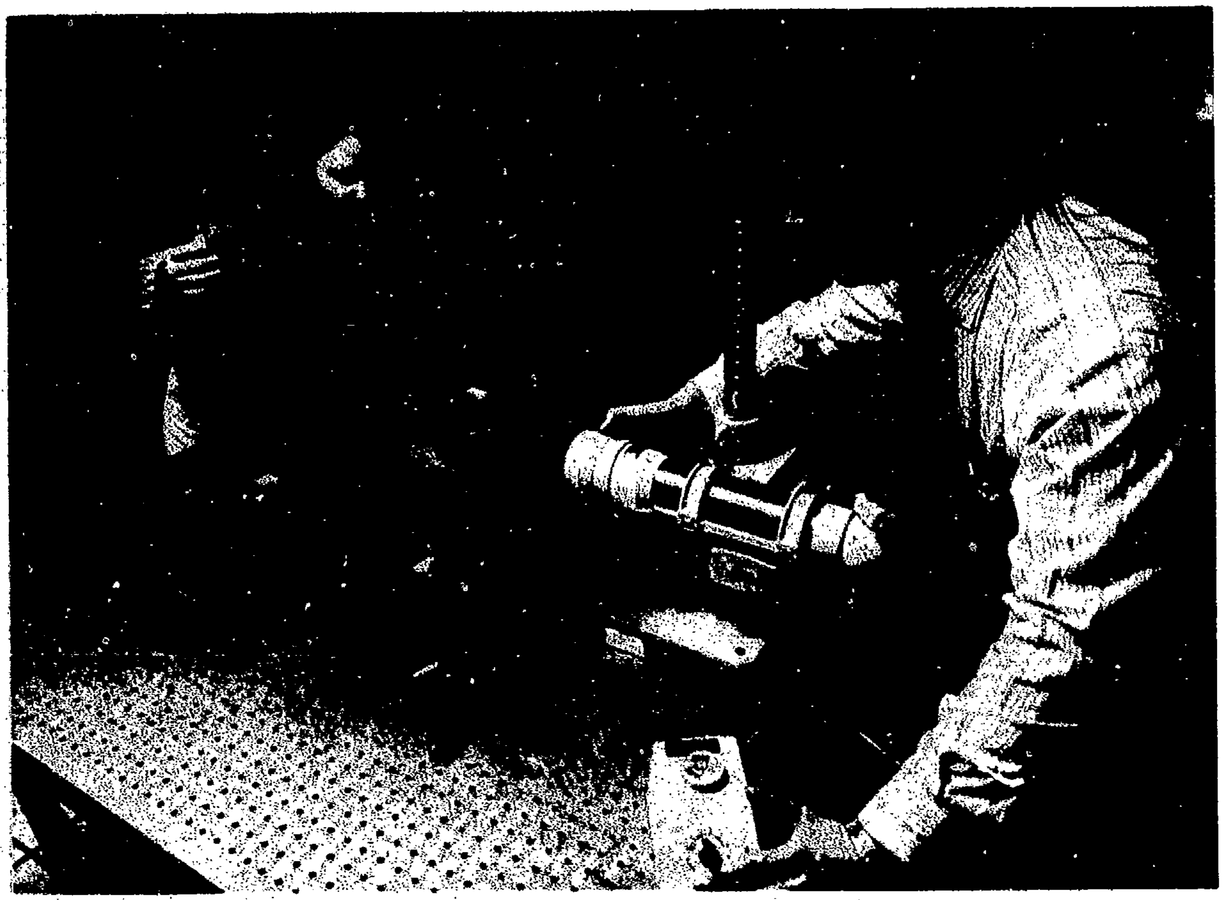


Figure 13. Equipment Set Up to Measure NVG Field-of-View.

Other factors that need to be considered are fit, comfort, fatigue, and stability. The weight and CG data for the I-NIGHTS NVG systems are summarized in Tables 13 and 14. Figure 14 depicts an I-NIGHTS helmet mounted on a manikin head and placed on a motion table to determine the helmet's center-of-gravity. See Appendix B for analysis report.

Table 13. I-NIGHTS (NVG only) Helmet (Accuracy +/- 0.02 LBS) Weight (LBS)

GEC	5.03
Honeywell	5.05
Kaiser	5.16

Table 14. I-NIGHTS (NVG only) Helmet CG (Accuracy 0.13 in) (Inches - Anatomical Coordinates)

	X	Y	Z
GEC	.35	-.03	1.04
Honeywell	.18	.08	.73
Kaiser	.60	-.06	1.46
*ADAM Head	-.32	-.03	1.01

***Baseline manikin head data**

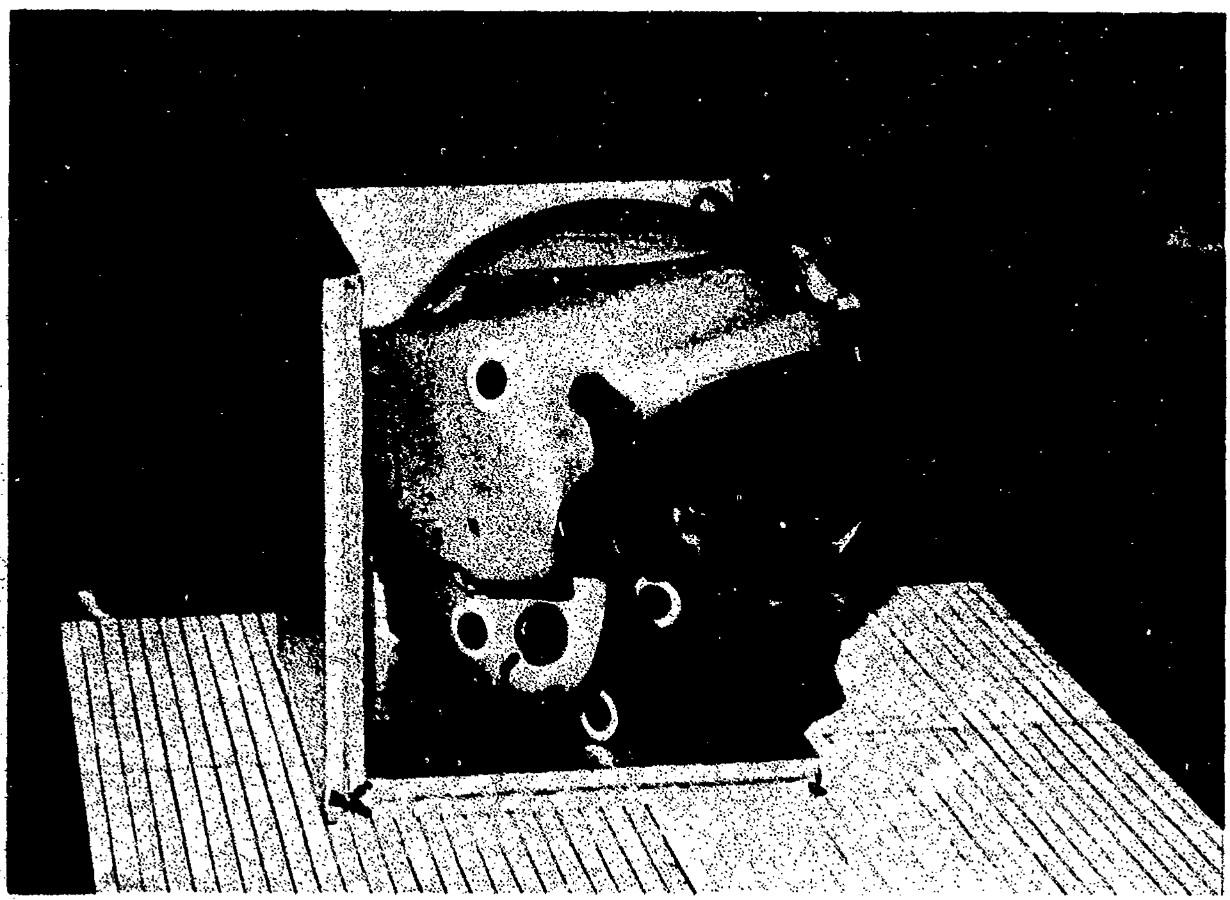


Figure 14. Motion Table to Determine Helmet Center-of-Gravity.

3.2.3 Fit Assessment

Fit assessments were conducted on most of the ground test subjects. The importance of a "good fit" is just as necessary for ground testing as it is for flight testing. For example, ground tests such as centrifuge are most susceptible to invalid results or even injury if a poor helmet fit is obtained. Due to the importance of fit assessment a separate section (4.0) was developed to discuss fit related issues. See Appendix C for test report.

3.2.4 Personal Equipment Integration

Verification tests on the inversion wheel did not reveal any interferences between the helmet and flight equipment or the ejection seat. Maintaining head stability was difficult due to the weight of the helmets and might be very uncomfortable if inverted for a prolonged period. The size of the helmets and the optical components might contact the seat during quick head movements; this is especially true for the Honeywell I-NIGHTS system if the combiners were in the stowed position.

Unaided field-of-view measurement results indicate that peripheral vision from the tested helmets (GEC and Honeywell) is less than that afforded by the HGU-55/P helmet. The mounting locations of the combiner assemblies had a significant impact on the field-of-view, reducing the upward and side peripheral fields by 10°-40° and 10°-35°, respectively.

Problems discovered during the integration tests were related to fit, comfort, and vision. In the four aircraft tested, subjects were able to compensate for reduced field-of-view by looking over, under, or around the combiner assemblies. Aircrew members stated they prefer to look under the combiners to avoid excessive head movement and lessen neck strain and fatigue. The ability to see under the combiners was difficult with the Honeywell I-NIGHTS system due to the location of its combiner assemblies. Additionally, the high CG and weight of the systems caused the helmets to roll forward on some test subjects. The addition of an oxygen mask (when required) reduced helmet slippage.

Other comments included making nape straps on the Kaiser I-NIGHTS helmet better and more functional. Standardized placement of the chin strap releases was also a concern. Routing of the optics cables was identified as a problem as well as placement of the battery packs. Cables and battery packs should be positioned such that they are usable and accessible. However, they should not hinder nor prevent rapid movement. See Appendix D for test results.

3.2.5 Aircraft Integration

Only one problem was detected for egress during ground evaluation: the extra bulk of unused, heavy cabling (for helmet tracker interface) of the I-NIGHTS was found to be unacceptable to crew members participating in the ground evaluations. The systems were re-configured to remove all unnecessary cabling. The re-configuration did not invalidate any other ground test data.

Field-of-View within the cockpit was limited because crew members had to tilt their heads to see the cockpit instruments and controls (Figure 15). The crew members completed instrument cross check by looking above or below the combiners. The GEC I-NIGHTS system combiners restricted upward vision, and the visor mounting brackets affected right/left-side vision. The Honeywell I-NIGHTS system restricted downward vision. In addition, during one test, a 95th percentile crew member's vision was completely obstructed by sunlight hitting the Honeywell I-NIGHTS combiners; the glare from the combiners created a "prism" effect. (The

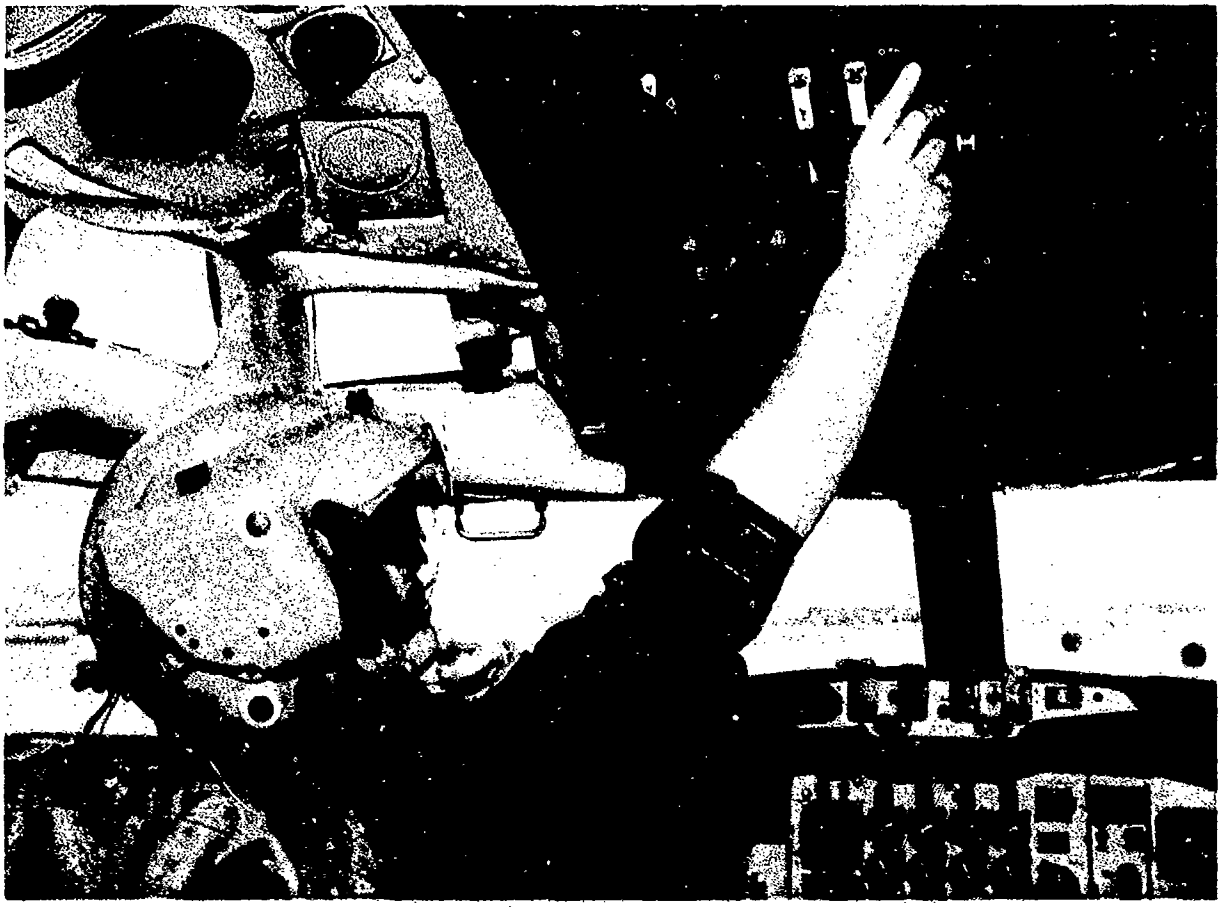


Figure 15. Crew Member Ensuring Unobstructed Field-of-View to all Cockpit Instruments

aircraft was facing directly into the sun.) The Kaiser I-NIGHTS system afforded good visibility for looking above or below the combiners; however, the subjects felt that the visor straps (side buckles) interfered with vision on the right/left sides. Internal interviews with aircrews suggested that they preferred to look under the combiners to avoid excessive head movement.

No EMI interference was found between all of the I-NIGHTS and aircraft systems tested. See Appendix D for test results.

3.2.6 Acoustical Properties

I-NIGHTS helmets from three different manufacturers were evaluated in the laboratory for sound attenuation and speech intelligibility using standardized measurement procedures. The performance data were summarized and presented in tabular and graphic form. General criteria was used to estimate the acceptability of performance in an operational situation. See Appendix E for data report.

3.2.6.1 Sound Attenuation

Sound attenuation measured in this study for the three I-NIGHTS NVG helmets is displayed in Table 15 along with the Military Specification E-83425 values. Military Specification E-83425 sound attenuation values for helmets are contained in the top of Table 15. The attenuation values for the test signals from 500 Hz to 4000 Hz are minimum values. The sum values for the three groups of frequencies are also minimum sum values. Both the individual test signal values and the group sum values must be equalled or exceeded to comply with the specification. All systems failed to meet MIL SPEC in at least one frequency range. Exposure to aircraft noise while wearing the systems could be reduced by wearing earplugs. Another factor that affects sound attenuation is the fit of the earcup. A tight well-centered earcup will enhance the ability to hear across all frequency ranges.

3.2.6.2 Speech Intelligibility

The speech intelligibility scores measured for the I-NIGHTS NVG helmets in various noise environments are presented in tabular

Table 15. Sound Attenuation Results

SOUND ATTENUATION

MIL SPEC FOR HELMETS & I-NIGHT ATTENUATION DATA

	FREQUENCY IN Hz								
	125	250	500	1000	2000	3150	4000	6300	8000
MIL SPEC E-83425			23	32	35	35	35		
	SUM > 23		SUM > 178					SUM > 60	
KAISER	11	9	12	28	38*	44*	44*	41	44
	SUM = 21		SUM = 166					SUM = 85*	
GEC	13	11	9	20	35	42*	41*	46	48
	SUM = 24*		SUM = 147					SUM = 94*	
HONEY-WELL	12	7	9	23	29	40*	41*	42	42
	SUM = 19		SUM = 142					SUM = 86*	

* MEETS MIL SPEC

form (see Table 16). The intelligibility scores are the average percent correct responses for the helmet and noise conditions shown. The scores were adjusted for those correct answers obtained by guessing. All I-NIGHTS helmets compared favorably to the baseline HGU/55-P helmet and are considered to be acceptable for flight test conditions.

3.2.7 Altitude Chamber

Hyperbaric chamber subjects had difficulty performing one-handed and two-handed valsalva[1] with the visors lowered and locked (Figure 16). The large size of Honeywell I-NIGHTS and Kaiser I-NIGHTS visors sit low on the face and cover the valsalva pads on the oxygen mask. Similar complaints were made on the GEC I-NIGHTS visor. However, one subject was able to valsalva by pulling down on the mask. No problems were experienced when the visors were raised. The Honeywell I-NIGHTS combiners are positioned close to the mask and may interfere with the crew member's ability to valsalva regardless of visor position.

3.2.7.1 Rapid Decompression

Rapid decompression exposures did not damage the helmet shells, optical components (external), or liner materials. Additional testing of the optical systems was performed to ensure that the systems were still operational.

3.2.7.2 Visor Fogging

Slight visor fogging was observed in the environmental chamber; especially at the colder temperature. The fogging did not

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[1] Valsalva: The process of equalizing the pressure in the inner ear by holding the mouth and nostrils closed while forcibly exhaling.

Table 16. Speech Intelligibility Results

SPEECH INTELLIGIBILITY
(PERCENT CORRECT RESPONSES)
I-NIGHTS SYSTEM VS 55P

I-NIGHTS SYSTEM / 55P	NOISE LEVELS (dB SPL)			
	0	95	105	115
GEC	98.2	97.2	95.2	89.2
55P	97.75	98.4	96.45	89.95
HONEYWELL	99.4	98	94	82.2
55P	99.25	98.3	96.25	87.4
KAISER	97.2	98	95.8	87.6
55P	98.05	98.15	95.9	87.85

THIS TABLE SHOWS AVERAGE PERCENT OF CORRECT RESPONSES FOR THE HELMET AND NOISE CONDITIONS SHOWN

Figure 16. Altitude Chamber

completely obstruct the subjects' vision and could be easily cleared by maintaining mask seal, or blowing air over the visor by temporarily switching the oxygen regulator to the emergency setting.

3.2.8 Dynamic System Performance: Centrifuge

Testing was conducted to determine if combiners would contact facial features under acceleration conditions. No such incidents occurred. Additional testing was conducted to determine whether contact with the face would occur with common head movements (under +1Gz conditions). Some light contact occurred in the eyebrow and cheek regions with all systems, particularly in the case of tilting the head directly back (90°-120°). None of the contact was reported to be uncomfortable or unacceptable. However, the aircrew members were advised of the potential for contact with facial features.

In situations with dynamic loads, there is potential for migration of the intensified image. This could occur as a result of helmet slippage during extreme head movements, or aircraft accelerations. The need for good helmet stability is essential to improve the aircrew member's ability to maintain exit pupil and to reduce the probability of injury due to contact with the eye or eye socket regions of the face.

Centrifuge results confirmed what was expected due to helmet weight and CG differences between the I-NIGHTS helmets and the baseline helmet (HGU-55/P). The standard helmet exceeded the performance of all three I-NIGHTS helmets in terms of image migration, repositioning of helmet, and downward shift. In terms of image migration, the GEC I-NIGHTS helmet exhibited the poorest performance. The lack of good stability with the Honeywell I-NIGHTS helmet resulted in a helmet shift during the higher "G" conditions especially when testing with the oxygen mask dangling or removed. The Kaiser I-NIGHTS helmet performed the best in terms of image migration and fit. However, there seemed to be an increase in discomfort while wearing the Kaiser I-NIGHTS helmet during acceleration. Wearing an oxygen mask increased helmet stability in all three I-NIGHTS systems. See Appendix F for data and technical paper.

3.2.9 Explosive Atmosphere

No explosions resulted from disengaging the high voltage QDC in the presence of a potentially explosive fuel-air mixture. The QDC was considered to have passed explosive atmosphere testing. However, the physical and operating characteristics of the QDC obtained for I-NIGHTS testing were not desirable. Therefore, HMST program office is funding an in-house research and development effort to produce a suitable QDC.

3.2.10 Crash Landing Evaluation: G_x Impact Sled Tests

The $+15G_x$ impact level was determined to be the most representative of rotary-wing or fixed-wing aircraft crash conditions. All of the I-NIGHTS systems survived three tests at $+15G_x$. Ground tests and preliminary system analysis indicated that there appeared to be no greater risk of injury due to the tension (z axis) loads within the neck than would be estimated for the ANVIS-6. However, there may be increased risk of injury in the forward (x) axis due to shear forces. At the acceleration level used for testing ($15G_x$), the tension forces were less than that estimated to cause neck injury (tearing of ligaments or bone damage). However, the shear forces measured in the manikin neck during testing of two of the I-NIGHTS systems (GEC Avionics and Honeywell, Inc) were greater than those estimated to cause neck injury. Test data on shear forces within the neck associated with ANVIS-6 were not available. However, preliminary analysis indicates that the shear forces measured in the manikin neck with the I-NIGHTS systems may be in excess of those estimated with ANVIS-6. Note also that the ANVIS-6 is designed to break away at accelerations of +5 to +10Gs; although the reliability and consistency of the breakaway system is considered poor. When the risk of injury due to shear forces was weighed against the probability of mishap in the flight test program, the risk was considered "acceptable." The probability of mishap was deemed "remote" for MH-53 and MH-60 aircraft, and "extremely improbable" for HC-130 aircraft based on 10-year class "A" mishap statistics for those aircraft. Note that the mishap statistics address all flying hours, as opposed to addressing only night operations. No testing was accomplished to assess the possibility of facial injury if the acceleration vector were to occur in the +x direction, as would be the case if a helicopter were moving in the aft direction at the time of crash. See Appendix H for preliminary summary.

3.2.11 Ejection: G. Vertical Deceleration Tower

VDT testing (Figure 17) was accomplished to establish interim criteria for helmet weight and CG (Table 17). A helmet-mounted weight study was initiated to further explore the forces on the head/neck due to ejection. This study will produce a family of parametric curves representing x, y, z forces and moments for various helmet weights and CGs. Additional study is required to establish confident injury thresholds. See appendix I for Interim Head/Neck Criteria Consultation Report.

3.2.12 Windblast

Windblast testing produced seven pitot compatibility failures while using the ACES II "fixed" pitot configuration. No failures resulted during tests conducted using the ACES II "deployable" pitot configuration. The conclusion was to conduct all I-NIGHTS F-15/F-16 flight tests while using the deployable pitot configuration.

Maximum head/neck loading was encountered at 600 knots and a seat angle of 34°. However, all three helmet designs exceeded the

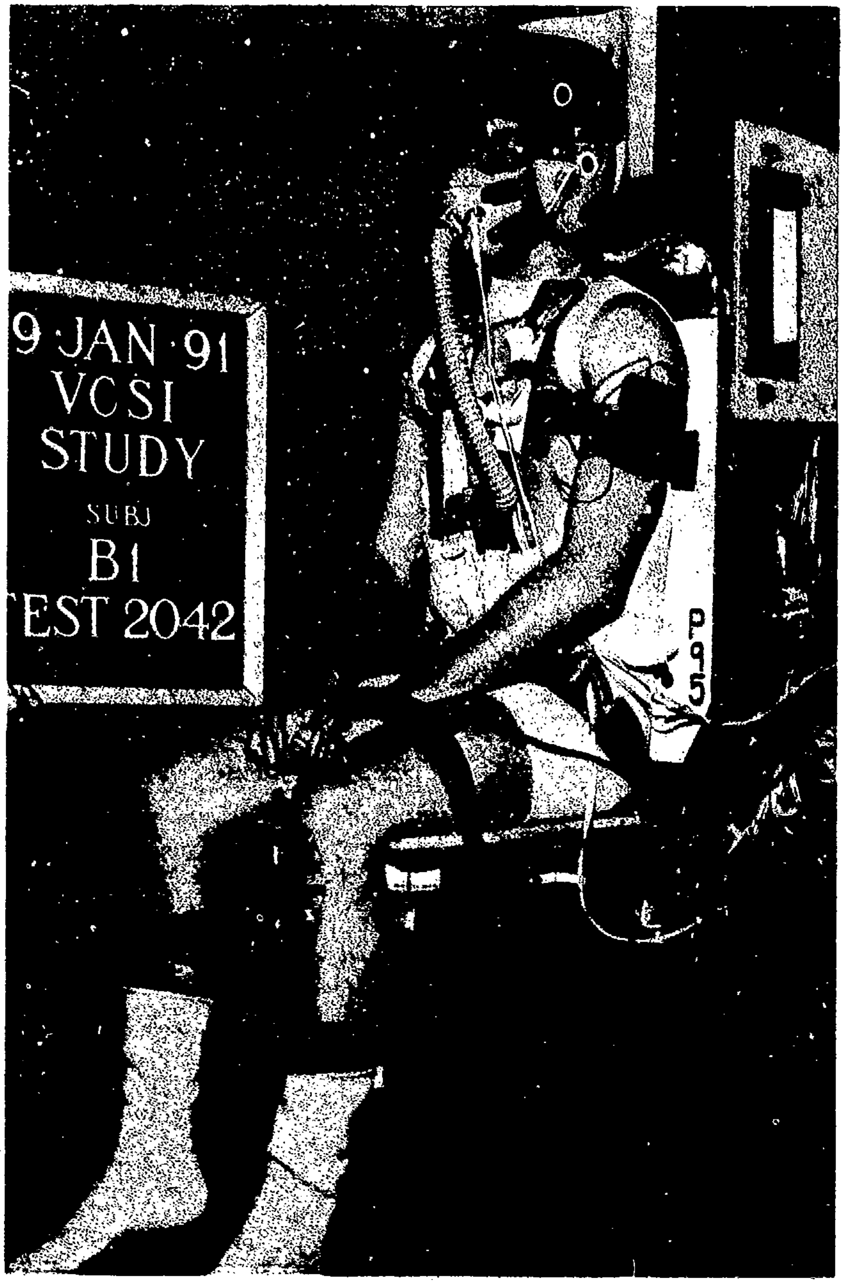

Figure 17. The Vertical Deceleration Tower (VDT) Simulating Ejection Forces

Table 17. Interim Weight/Center-of-Gravity Criteria

EJECTION SEAT	DYNAMIC RESPONSE INDEX (DRI)	MAXIMUM TOTAL HEAD SUPPORTED WEIGHT (LBS)	MAXIMUM NET HEAD GC OFFSET FROM HEAD ANATOMICAL AXIS ORIGIN (IN)		
			X	Y	Z[1]
ACES II	13	5.0	-0.8 to 0.5	±0.15	0.5 to 1.5
B-52	18	* 4.5	-0.8 to 0.25	±0.15	0.5 to 1.5
B-52	18	<4.0	-0.8 to 0.5	±0.15	0.5 to 1.5

[1]Data could not be collected at CGs below 0.7 on the Z axis

preliminary injury criteria at speeds above 450 knots. The conclusion was to restrict I-NIGHTS flight tests to under 450 knots while reinforcing aircraft emergency procedures to take all appropriate measures to slow the aircraft as much as practical prior to ejecting.

The structural integrity of the basic helmet shell was confirmed, however, failure to ancillary portions of two helmets induced high head/neck loads. It was concluded that these portions should be reinforced prior to the flight test phase.

3.2.13 Man/Seat Separation

All of the I-NIGHTS helmets experienced loads/torques and angular accelerations that were less than the preliminary guidelines. It is important to note that the combined riser loads achieved on these 21 tests varied between 2720 lbs and 3920 lbs. Although the combined riser loads are representative of some of the loads that would be attained during actual parachute deployments, they do not approach the peak riser loads that are possible in high speed/high altitude ejections.

The parachute deployment sequence simulated for this series of tests focused on the vertical and 15° off-vertical body positions only. The primary objective was to evaluate parachute riser interference with the various I-NIGHTS helmets. Each of the helmets had acceptable head/neck loads that were less than the reference data point thresholds. Helmet tests showed that the riser interference was slightly more than with the HGU-55/P baseline helmet, but no unsafe conditions surfaced.

Eye relief remains a concern with all vendor systems. Factors such as combiner positions (stowed or unstowed), body position, ejection speed/altitude, and the adequacy of helmet fit are some of the most important factors to consider. Combiner contact was observed on two of the I-NIGHTS systems; GEC and Honeywell. The GEC I-NIGHTS helmet showed a small amount of combiner contact on the left side of the nose on one test. The GEC I-NIGHTS combiners are non-stowable. The Honeywell I-NIGHTS helmet showed a small amount of combiner contact on the left upper cheekbone area. The Honeywell I-NIGHTS combiners are stowable, but is not recommended due to the greater potential for riser interference in the stowed position. A recommendation was made that a protective eyewear assessment be completed to determine the suitability and adequacy of wearing various types of eye protection. The Kaiser I-NIGHTS system did not show combiner contact during these tests, but it is possible that combiner contact with the eye or eye socket area could occur in some ejection profiles. Recommend that the Kaiser combiners be stowed before ejection if time permits.

The head/neck loads for the I-NIGHTS helmets are acceptable when compared to the HGU-55/P helmet within the scope of the conditions used for these tests. However, exposure to combined riser loads greater than 3920 lbs and different random body positions may result in unacceptable loads. In addition, since the data used as a "reference data point" has not been verified, further research is needed to obtain validated injury threshold criteria.

3.2.14 Parachute Deployment

The three I-NIGHTS helmets were considered to have passed parachute deployment tests. However, additional exploration in the area of head/neck load criteria and injury thresholds is recommended.

4. FIT ASSESSMENT PROGRAM

4.1 Introduction

Helmets provided to aircrew members were initially conceived for protection; physical and noise. Future helmets will not only provide protection but will also be used to enhance mission performance. Now, the entire success of the mission may depend on how well the helmet fits the crew member.

Helmet fit was identified as a critical factor in I-NIGHTS ground and flight testing for two reasons. The first reason is that the I-NIGHTS helmets are "exit pupil" systems which provide sensor and/or mission data (HUD symbology) directly to the crew member's eyes. "Exit pupil" means that the human eye must be positioned and maintained within a circular pupil where the image/data is displayed. A set of binoculars and a telescope are good examples of exit pupil systems. When the viewer's eye is correctly aligned within the exit pupil the entire image can be seen. As the eye begins to move out of the exit pupil, the image will dim and eventually disappear. When employing an exit pupil, the helmet must provide a stable platform to minimize alignment deviations. Any deviations will provide a less than optimum display to the crew member.

The second reason fit became a critical factor is helmet size. In its specification, the Navy directed the three helmet vendors to provide a "large" size helmet. The Navy wanted to ensure the helmet would fit all the pilots in it's test program; "one size fits all." Immediately this leads to problems. A small head in a large helmet can provide misleading test results and could result in an injury. The Navy did not provide anthropomorphic data to specify how large was "large." Consequently, all three helmets are not the same size "large."

The HMST Program Office was concerned that test results would not be valid unless some quantitative measure of "good fit" was derived. If varying degrees of fit could be determined, then a test subject could be disqualified as being potentially unsafe or possibly to correlate poor helmet performance directly back to fit. This would dramatically demonstrate the importance of fit. The three most critical elements of a "good fit" are: a) comfort; b) optical alignment/adjustment; and c) stability.

Comfort is the most obvious element of "fit." If the crew member will not, or cannot wear the helmet then the best optics in the world are of no use. The helmet must be comfortable, without hot spots, pressure points or fatigue, for as long as he/she needs to wear it.

Next, the optics have to adapt to the crew member's eyes. Eyes are not completely symmetrical about the centerline of the face. One eye might be a couple of millimeters deeper, higher, or wider from the center line than the other. The optics must align or at least one eye will have a less than optimum image and/or a small tolerance for deviations from the exit pupil. Adjustments (with adequate range of movement) are required to align the optics to each eye for anyone in a particular size category.

The most important element of fit is helmet stability. The helmet can be extremely comfortable and the optics precisely aligned; however, if the alignment cannot be maintained due to helmet slippage under Gs or normal head movement then the system is unusable; most likely at a critical point in the mission.

4.2 Fit Assessment Procedures

Fit assessments were completed to determine the stability of fitted subjects for both ground and flight tests. Data to make this determination was gathered via three means: a) a comfort assessment; b) a stability assessment; and c) a 3D laser scanner (Reference Appendix C). Each test subject was individually fitted and assessed in the three I-NIGHTS helmets. Each fitting ensured that the helmet was optimally positioned on the head and that the optics were correctly aligned as best as possible (keeping in mind the "one size fits all" philosophy).

The comfort assessment consisted of the test subject wearing the helmet for at least one hour (if possible) and then answering specific questions. The questions dealt with the overall feel, earcup feel, pressure points, hot spots, along with neck and/or back discomfort. The subject was allowed to add personal comments covering areas not mentioned; or to reinforce or elaborate beyond that already recorded. The questionnaire is included in Appendix C.

The stability assessment was a measure of the amount of helmet movement under a given load. This was an attempt to gauge how stable the helmet might be during an aircraft maneuver. A force of two and then four pounds was applied to the helmet and the amount of deflection from a "bench mark" was measured. The force was applied to measure forward, backward, and sideward movement.

The third means of collecting data was a laser scanner. The laser scanner is capable of acquiring high resolution, three dimensional (3D) surface data of the head and face. A test subject sat in a chair while a low intensity laser beam scanned around the head providing 3D coordinates of landmarks associated with the head (pupils, tragion, etc.), and with the helmet (optics, chin strap, etc.). These landmarks were then associated with a common axis system for comparing the same subject with different helmets and/or the same helmet with different subjects. An entire subject population can be transformed into the common helmet axis system to examine the variability in which each individual fits into that particular helmet. For example, the variability in the subject's pupil location can be quantitatively measured and used to design the optics' adjustability range requirement.

4.3 Fit Assessment Results

The evaluation of the I-NIGHTS systems included an assessment of the fit of ground and flight test subjects in each of the three I-NIGHTS systems. The fit assessment was conducted in three phases. The initial phase was the gathering of anthropometric data via traditional, manual methods. Three-dimensional anthropometric data was also gathered by means of a Cyberware laser scanner.

Following the collection of the anthropometric information, each subject was also carefully fit in each respective I-NIGHTS helmet. The helmet fitting session began with the subject being fit with the helmet liner provided by each vendor. This liner was then placed in the helmet and the optics were switched on (in a darkened room) and a visual test was administered to ensure proper placement of the subject's liner within the shell of the helmet. The liner and helmet had to be correctly placed before testing could begin.

Each subject wore the system for at least one hour unless circumstances rendered that impossible. During the course of an assessment, evaluations were made in terms of optical adjustment, stability and comfort. Optical adjustment evaluations centered on the issue of whether or not the optical system in the helmet did or did not possess the adjustment capabilities necessary to accommodate each subject. Stability was defined as the degree of stability afforded each subject in the system. Comfort referred to the degree of comfort each subject achieved while wearing the helmet.

In order to understand the following information, it is necessary to explain that the causes of failure were examined both in terms of percentage of failure and by the number of subjects who failed. In so doing, we can see not only the number of subjects who experienced failure, but also cases where subjects experienced failure in more than one category simultaneously.

4.3.1 Consolidated Fit Assessment Results

Table 18 demonstrates the consolidated fit assessment results.

Table 18. Fit Assessment Pass/Fail Results

Vendor System	Subjects Tested	Number Passed	Number Failed
GEC Avionics	36	21	15
Honeywell	33	20	13
Kaiser	36	20	16

4.3.2 Fit Assessment Detailed Results (by Vendor)

Tables 19-21 are categorical listings of the number of subjects who failed the fit assessment. Tables 22-24 represent all of the possible combinations of failure and therefore illustrate cases when subjects failed in single categories and cases in which subjects failed in more than one category simultaneously.

Table 19. I-NIGHTS Ratings by Category (GEC)

Excellent=1 Good=2 Average=3 Fair=4 Poor=5
(Pass = 1, 2 or 3 and Fail = 4 or 5)

GEC COMFORT RATING

Rating	Frequency	Percent
1	11	30.5
2	4	11.1
3	14	38.9
4	1	2.8
5	6	16.7
TOTAL	36	100.0

Frequency Missing = 1 (not tested)

GEC STABILITY RATING

Rating	Frequency	Percent
1	1	2.9
2	12	34.3
3	16	45.7
4	4	11.4
5	2	5.7
TOTAL	35	100.0

Frequency Missing = 2
(1 with no data, 1 not tested)

GEC OPTICAL ADJUSTMENT RATING

Rating	Frequency	Percent
1	13	48.2
2	2	7.4
3	4	14.8
4	1	3.7
5	7	25.9
TOTAL	27	100.0

Frequency Missing = 10
(1 not tested, 9 tested in systems with non-operational NVG)

Table 20. I-NIGHTS Ratings by Category (HON)

Excellent=1 Good=2 Average=3 Fail=4 Poor=5
(Pass = 1, 2 or 3 and Fail = 4 or 5)

HONEYWELL COMFORT RATING

Rating	Frequency	Percent
1	6	18.2
2	5	15.2
3	16	48.5
4	2	6.0
5	4	12.1
TOTAL	33	100.0

Frequency Missing = 4 (not tested)

HONEYWELL STABILITY RATING

Rating	Frequency	Percent
1	3	9.1
2	12	36.4
3	10	30.3
4	6	18.2
5	2	6.0
TOTAL	33	100.0

Frequency Missing = 4 (not tested)

HONEYWELL OPTICAL ADJUSTMENT RATING

Rating	Frequency	Percent
1	16	66.6
2	3	12.5
3	3	12.5
4	1	4.2
5	1	4.2
TOTAL	24	100.0

Frequency Missing = 13
(4 not tested, 9 tested in systems with non-operational NVG)

Table 21. I-NIGHTS Ratings by Category (KAI)

Excellent=1 Good=2 Average=3 Fair=4 Poor=5
(Pass = 1, 2 or 3 and Fail = 4 or 5)

KAISER (NVG) COMFORT RATING

Rating	Frequency	Percent
1	5	13.9
2	8	22.2
3	17	47.2
4	4	11.1
5	2	5.6
TOTAL	36	100.0

Frequency Missing = 1 (not tested)

KAISER (NVG) STABILITY RATING

Rating	Frequency	Percent
1	1	2.8
2	9	25.0
3	16	44.4
4	4	11.1
5	6	16.7
TOTAL	36	100.0

Frequency Missing = 1 (not tested)

KAISER (NVG) OPTICAL ADJUSTMENT RATING

Rating	Frequency	Percent
1	19	79.2
2	2	8.3
3	2	8.3
4	1	4.2
TOTAL	24	100.0

Frequency Missing = 13
(1 not tested, 12 tested in systems with non-operational NVG)

Table 22. Failures for GEC I-NIGHTS Helmet

Possible Reasons for Failure:
Comfort=1, Stability=2, Optics=3, Comfort and Stability=4
Comfort and Optics=5, Stability and Optics=6
Comfort, Stability and Optics=7

Failure Category	Frequency	Percent
1	3	20.0
2	3	20.0
3	4	26.6
4	1	6.7
5	2	13.3
6	1	6.7
7	1	6.7
TOTAL	15	100.0

Frequency Missing = 22
(21 passes, 1 not tested)

Table 23. Failures for Honeywell I-NIGHTS Helmet

Possible Reasons for Failure:
Comfort=1, Stability=2, Optics=3, Comfort and Stability=4
Comfort and Optics=5, Stability and Optics=6
Comfort, Stability and Optics=7

Failure Category	Frequency	Percent
1	3	25.0
2	5	41.7
4	2	16.7
5	1	8.3
6	1	8.3
TOTAL	12	100.0

Frequency Missing = 25
(20 passes, 4 not tested, 1 non-related failure*)

---

* One subject failed because the combiners could not be positioned while the subject was wearing his eyeglasses. This failure is not given much consideration because an evaluation of the I-NIGHTS systems on subjects with eyewear is scheduled at a later date.

Table 24. Failures for Kaiser I-NIGHTS (NVG) Helmet

Possible Reasons for Failure:
Comfort=1, Stability=2, Optics=3, Comfort and Stability=4
Comfort and Optics=5, Stability and Optics=6
Comfort, Stability and Optics=7

Failure Category	Frequency	Percent
1	5	31.3
2	9	56.3
4	1	6.2
5	1	6.2
TOTAL	16	100.0

Frequency Missing = 21
(20 passes, 1 not tested)

5. GENERAL CONCLUSIONS

The following section represents general conclusions from the I-NIGHTS Program which are applicable to future NVG and HMD programs. The I-NIGHTS Program did more than just validate problem areas with HMDs. I-NIGHTS began to explore these areas and define their solution with interim safety criteria. Future programs will continue to refine the interim criteria.

5.1 Optical Characteristics

- Measurements made for this program specifically characterize the performance of the I-NIGHTS units tested.

5.2 Fit Assessment

Fit includes comfort, optical adjustment, and stability and is a critical factor in the system's performance.

- System must be comfortable to wear for several hours.
- System must have adequate range of adjustment to adapt optics to a wide segment of flying population.
- System must remain stable providing maximum optical performance throughout the aircraft's dynamic environment.

5.3 Personal Equipment Integration

- System must be compatible with life support equipment (COMBAT EDGE, SEAWARS, etc.).
- The external battery pack caused some difficulty in finding a safe "storage" location on the crew member. I-NIGHTS temporarily accommodated this problem by having the crew member wear a survival vest with a zippered pocket. However, this may not be a practical 6.4 production solution.

- The ability to perform a valsalva is difficult when the optics are in position and the visor is down and locked.
- Some optical adjustments were difficult while wearing nomex gloves.
- Helmet weight, CG, and lack of adequate fit accelerated the onset of fatigue.

5.4 Aircraft Integration

- NVG compatible cockpit lighting is essential if NVGs are mounted on the helmet.
- Visual obscuration caused by the optics assembly and helmet shell restricted crew member's peripheral vision. This inhibited the crew member from looking under/around the optics to directly view cockpit instruments. The aircrews preferred to look under the optics to minimize head movement.
- Extra effort was required to check the six o'clock position due to helmet size/shape.
- A suitable CRT cable connector (a QDC) is required to be integrated with the parachute harness and ejection seat to facilitate easy ingress and emergency egress.
- External protrusions from the helmet (focus levers, stowed optics) could hinder rapid egress in emergency situations.

5.5 Acoustical Properties

- Data gathered was specific to the units tested and characterize their performance.
- Helmet fit and earcup seal were critical to good sound attenuation performance.

5.6 Altitude Chamber

- The likelihood of fogging is minimal since the helmets are not a closed system like chemical defense respirators.

However, the incidence of fogging could be lessoned by using anti-fogging compound or avoiding sudden temperature changes.

5.7 Dynamic System Performance: Centrifuge

- The oxygen mask was critical under high G loads to the overall stability of the helmet due to the forward CG location of the helmets tested.
- Fit and helmet liner compressibility significantly impacted helmet stability.
- The helmet liner comfort was inversely proportional to helmet stability; the most comfortable liner produced the poorest stability - too much "padding." (see above comment)

5.8 Explosive Atmosphere

- A suitable high voltage QDC is required.

5.9 Crash Landing: Gx Impact

- Additional study is required in the area of head/neck loads versus injury thresholds.

5.10 Ejection: Gz Vertical Deceleration Tower

- Interim head/neck criteria were produced (Table 17).
- Additional study is required in the area of helmet weight/CG versus injury thresholds.

5.11 Windblast

- Deployable, "pop-up," pitot configuration was required to ensure proper pitot sensing of the ACES II ejection seat.

- Structural failure of ancillary portions of the helmet may significantly increase head/neck loads.
- Maximum air speed for flight test phase was limited to 450 KTAS to minimize windblast head/neck loads.
- Additional study is required in the area of head/neck loads versus injury thresholds.

5.12 Man/Seat Separation

- Helmet protrusions (focus levers, stowed optics) may interfere with riser deployment and increase head/neck loads.
- Fit and helmet stability significantly impacted eye relief; protective eyewear may be required.
- Additional study is required in the area of head/neck loads versus injury thresholds.

5.13 Parachute Deployment

- Fit and helmet stability significantly impacted eye relief; protective eyewear may be required.
- Additional study is required in the area of head/neck loads versus injury threshold.

6. REFERENCES

1. F. S. Knox, J. R., Buhrman, C. E. Perry, I. Kaleps, "Interim Head/Neck Criteria," Consultation Report, December 1991 (Appendix I, pp 542).

2. Ibid, (Appendix I, pp 543).

3. Ibid, (Appendix I, pp 549).

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APPENDIX A
OPTICAL CHARACTERISTICS

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APPENDIX A: OPTICAL CHARACTERISTICS EVALUATION

1. INTRODUCTION

Optical devices worn by aircrew members have many properties which impact performance; the performance of the device itself and the performance of the aircrew member. Quantifying the optical characteristics of a new device enables comparison to historical data and to predict, measure, or identify its effect on the crew member's ability to perform the mission. This report describes a laboratory measurement of the optical characteristics of three night vision systems developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. The measurements were accomplished by the Visual Display Systems Branch, Human Engineering Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

2. APPROACH

The optics for each of the three I-NIGHTS helmet designs were evaluated to quantify their optical characteristics. The evaluations were made according to American National Standards Institute (ANSI) procedures and procedures developed by the Visual Display Systems Branch (formerly the Crew Systems Effectiveness Branch), Human Engineering Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio. Further information on these procedures can be obtained by contacting Dr. H. Lee Task at the Visual Display Systems Branch.

3. OBJECTIVES

The objective of this evaluation is measure and define the optical characteristics in the following areas: exit pupil, eye relief, brightness gain, field of view, luminance non-uniformity, modulation contrast, magnification, image rotation, S distortion, optical axes misalignment, horizontal resolution; and vertical resolution.

Performance Overview

GEC - 9G Repeat After Flight Test (HC-130)

	Right	Left
Exit Pupil Diameter	9.5mm	9.4mm
Eye Relief	22.2mm	21.0mm
Brightness Gain (@ 3.7E-04 ft-L)	2551	2580
Field of View	37.7 deg	37.9 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 45.4%	+/- 40.3%
Modulation Contrast		
@ 5 deg	95.7%	97.7%
@ 10 deg	96.8%	96.6%
Magnification	1.00	1.01
Image Rotation	42.4mrad	12.3mrad
Optical Axis Misalignment		
Horizontal	10.9mrad	-4.4mrad
Vertical	-1.5mrad	-10.4mrad
Total	-11.0mrad	11.3mrad
"S" Distortion (peak to valley)	6.6mrad	7.4mrad
Resolution		
Horizontal	20/68	20/60
Vertical	20/54	20/54
Weight	382g	351g

Inspected By: [signature]

Date: 12 JUN 91

Performance Overview

Honeywell - 5H Repeat After Flight test (HC-13

	Right	Left
Exit Pupil Diameter	11.7mm	11.3mm
Eye Relief	37.2mm	36.9mm
Brightness Gain (@ 3.7E-04 ft-L)	2074	2253
Field of View	36.5 deg	37.2 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 84.7%	+/- 76.7%
Modulation Contrast		
@ 5 deg	94.0%	94.0%
@ 10 deg	96.7%	96.6%
Magnification	1.00	1.02
Image Rotation	-31.8mrad	-1.9mrad
Optical Axis Misalignment		
Horizontal	5.6mrad	-10.1mrad
Vertical	1.4mrad	-20.3mrad
Total	5.8mrad	22.7mrad
"S" Distortion (peak to valley)	2.6mrad	4.7mrad
Resolution		
Horizontal	20/135*	20/108*
Vertical	20/68	20/60
Weight	580g	582g

* - goggles appear to have an astigmatism affect resulting in the descripencies between the vertical and horizontal components.

Inspected By: [signature]

Date: 13 JUN 91

Performance Overview

Kaiser - 5K Repeat After flight Test (HC-130)

	Right	Left
Exit Pupil Diameter	12.0mm	12.1mm
Eye Relief	19.9mm	21.6mm
Brightness Gain (@ 3.7E-04 ft-L)	2534	2142
Field of View	31.9 deg	31.5 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 22.1%	+/- 28.9%
Modulation Contrast		
@ 5 deg	95.9%	96.4%
@ 10 deg	91.2%	94.0%
Magnification	1.02	1.02
Image Rotation	5.1mrad	1.0mrad
Optical Axis Misalignment		
Horizontal	-14.6mrad	4.5mrad
Vertical	-14.4mrad	1.4mrad
Total	20.5mrad	4.7mrad
"S" Distortion (peak to valley)	0.90mrad	0.83mrad
Resolution		
Horizontal	20/43	20/34
Vertical	20/34	20/38
Weight	536g	520g

Inspected By: [signature]

Date: 12 JUN 91

Performance Overview

GEC - 6G - Repeat 1 After Flight Test

	Right	Left
Exit Pupil Diameter	9.7mm	9.9mm
Eye Relief	22.8mm	22.5mm
Brightness Gain (@ 3.7E-04 ft-L)	2528	2282
Field of View	38.0 deg	35.3 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 40.0%	+/- 35.2%
Modulation Contrast		
@ 5 deg	96.3%	95.9%
@ 10 deg	97.0%	95.2%
Magnification	0.98	0.94
Image Rotation	4.0mrad	13.6mrad
Optical Axis Misalignment		
Horizontal	2.0mrad	4.2mrad
Vertical	1.1mrad	-0.78mrad
Total	2.3mrad	-4.3mrad
"S" Distortion (peak to valley)	6.0mrad	6.3mrad
Resolution		
Horizontal	20/60	20/54
Vertical	20/54	20/48
Weight	--- Not Measured ---	

Inspected By: Rick T. Hutton

Date: 18 Apr 91

Performance Overview

Honeywell - 8H - Repeat 1 After Flight Test

	Right	Left
Exit Pupil Diameter	12.2mm	11.9mm
Eye Relief	35.2mm	35.9mm
Brightness Gain (@ 3.7E-04 ft-L)	3019	2766
Field of View	36.5 deg	38.2 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 64.8%	+/- 73.7%
Modulation Contrast		
@ 5 deg	93.0%	93.8%
@ 10 deg	95.4%	96.5%
Magnification	1.01	1.02
Image Rotation	8.6mrad	-9.2mrad
Optical Axis Misalignment		
Horizontal	-6.6mrad	-1.3mrad
Vertical	7.8mrad	2.9mrad
Total	-10.2mrad	-3.2mrad
"S" Distortion (peak to valley)	1.3mrad	2.3mrad
Resolution		
Horizontal	20/108	20/86
Vertical	20/77	20/96
Weight (with white sheild)	580g	587g

Inspected By: Rick T. Hunter

Date: 18 Apr 91

Performance Overview

Kaiser - 6K - Repeat 1 After Flight Test

	Right	Left
Exit Pupil Diameter	12.0 mm	11.7 mm
Eye Relief	19.7 mm	19.8 mm
Brightness Gain (@ 3.7E-04 ft-L)	1962	2063
Field of View	32.5 deg	32.3 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 29.3%	+/- 29.9%
Modulation Contrast		
@ 5 deg	93.2%	94.7%
@ 10 deg	93.8%	94.7%
Magnification	1.01	1.03
Image Rotation	3.0 mrad	6.4 mrad
Optical Axis Misalignment		
Horizontal	-1.5mrad	1.4mrad
Vertical	-3.0mrad	0.18mrad
Total	3.4mrad	1.4mrad
"S" Distortion (peak to valley)	0.96 mrad	0.54 mrad
Resolution		
Horizontal	20/43	20/48
Vertical	20/34	20/38
Weight	544g (with reticle)	529g

Inspected By: [signature]

Date: 18 Apr 91

I-NIGHTS Performance Overview
Submitted 25 Jan 91
Det 1, Armstrong Laboratory/HEF

Performance Overview

GEC - 5G

	Right	Left
Exit Pupil Diameter	10mm	9.2mm
Eye Relief	20.4mm	22.5mm
Brightness Gain (3.7E-04 ft-L)	1956	2373
Field of View (Questionable)	36.9 deg	35.0 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 71.9%	+/- 76.3%
Modulation Contrast		
@ 5 deg	97.3%	96.8%
@ 10 deg	99.3%	98.6%
Magnification	1.00	1.02
Image Rotation	10.6mrad	-7.5mrad
Optical Axis Misalignment		
Horizontal	4.2mrad	-9.6mrad
Vertical	-7.7mrad	0.77mrad
Total	-8.7mrad	-9.7mrad
"S" Distortion (peak to valley)	5.3mrad	4.8mrad
Resolution		
Horizontal	20/60	20/60
Vertical	20/54	20/54
Weight Channel	377g	351g
Weight Bracket	108g	

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

GEC - 6G

	Right	Left
Exit Pupil Diameter	10mm	10mm
Eye Relief	18.4mm	17.3mm
Brightness Gain (3.7E-04 ft-L)	2566	2579
Field of View	36.2 deg	34.2 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 37.1%	+/- 34.0%
Modulation Contrast		
@ 5 deg	97.2%	98.3%
@ 10 deg	98.3%	98.3%
Magnification	0.99	0.95
Image Rotation	32.5mrad	12.0mrad
Optical Axis Misalignment		
Horizontal	-1.1mrad	-11.5mrad
Vertical	0mrad	- 9.8mrad
Total	-1.1mrad	15.1mrad
"S" Distortion (peak to valley)	6.2mrad	6.3mrad
Resolution		
Horizontal	20/60	20/60
Vertical	20/60	20/77
Weight	378g	356g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

GEC - 7G

		Right	Left
Exit Pupil Diameter		9.7mm	9.8mm
Eye Relief		18.4mm	17.1mm
Brightness Gain (3.7E-04 ft-L)		2744	2618
Field of View		37.8 deg	36.2 deg
Luminance Non-Uniformity (Center 80% of FOV)		+/- 45.7%	+/- 47.9%
Modulation Contrast	@ 5 deg	96.0%	96.1%
	@ 10 deg	96.8%	96.8%
Magnification		1.01	0.99
Image Rotation		21.5mrad	34.3mrad
Optical Axis Misalignment	Horizontal	-4.0mrad	-9.9mrad
	Vertical	-3.3mrad	3.9mrad
	Total	5.2mrad	-10.6mrad
"S" Distortion (peak to valley)		7.6mrad	10.9mrad
Resolution	Horizontal	20/68	20/60
	Vertical	20/77	20/60
Weight	Has CRT Port NO CRT	378g	383g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

GEC - 8G

	Right	Left
Exit Pupil Diameter	10.0mm	9.8mm
Eye Relief	19.1mm	18.8mm
Brightness Gain (3.7E-04 ft-L)	2433	2229
Field of View	35.4 deg	35.6 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 37.7%	+/- 33.5%
Modulation Contrast		
@ 5 deg	94.4%	95.8%
@ 10 deg	95.2%	95.8%
Magnification	0.98	0.98
Image Rotation	3.9mrad	8.0mrad
Optical Axis Misalignment		
Horizontal	-0.25mrad	1.3mrad
Vertical	-2.6mrad	2.4mrad
Total	2.6mrad	2.7mrad
"S" Distortion (peak to valley)	9.4mrad	2.3mrad
Resolution		
Horizontal	20/68	20/77
Vertical	20/60	20/68
Weight — Has CRT Port NO CRT	382g	383g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

GEC - 9G

	Right	Left
Exit Pupil Diameter	10.1mm	9.4mm
Eye Relief	24.1mm	22.1mm
Brightness Gain (3.7E-04 ft-L)	2440	2849
Field of View	37.3 deg	37.3 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 44.6%	+/- 42.2%
Modulation Contrast		
@ 5 deg	94.9%	95.6%
@ 10 deg	97.4%	96.4%
Magnification	1.00	1.01
Image Rotation	46.9mrad	12.1mrad
Optical Axis Misalignment		
Horizontal	10.9mrad	-2.8mrad
Vertical	-1.9mrad	-14.0mrad
Total	-11.1mrad	14.2mrad
"S" Distortion (peak to valley)	8.0mrad	6.9mrad
Resolution		
Horizontal	20/60	20/54
Vertical	20/54	20/48
Weight	381g with reticle	353g

Inspected By: Lt Richard Hartman

Date: 31 Dec 90

Performance Overview

Kaiser - 5K

		Right	Left
Exit Pupil Diameter		12.0mm	12.0mm
Eye Relief		20.6mm	19.6mm
Brightness Gain (3.7E-04 ft-L)		2760	1994
Field of View		31.8 deg	32.0 deg
Luminance Non-Uniformity (Center 80% of FOV)		+/- 23.3%	+/- 41.0%
Modulation Contrast	@ 5 deg	97.3%	97.1%
	@ 10 deg	93.9%	97.1%
Magnification		1.02	1.02
Image Rotation		0.17mrad	1.7mrad
Optical Axis Misalignment	Horizontal	-14.4mrad	-2.8mrad
	Vertical	-16.1mrad	3.3mrad
	Total	21.6mrad	-4.3mrad
"S" Distortion (peak to valley)		0.66mrad	0.54mrad
Resolution	Horizontal	20/60	20/48
	Vertical	20/54	20/54
Weight		534g	520g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

Kaiser - 6K

	Right	Left
Exit Pupil Diameter	12.0mm	12.0mm
Eye Relief	21.7mm	20.3mm
Brightness Gain (3.7E-04 ft-L)	2180	1964
Field of View	31.0 deg	32.0 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 29.3%	+/- 31.7%
Modulation Contrast		
@ 5 deg	91.1%	97.2%
@ 10 deg	93.2%	99.5%
Magnification	1.00	1.02
Image Rotation	2.9mrad	2.8mrad
Optical Axis Misalignment		
Horizontal	-0.62mrad	-2.2mrad
Vertical	2.3mrad	-0.86mrad
Total	-2.4mrad	2.4mrad
"S" Distortion (peak to valley)	1.3mrad	0.43mrad
Resolution		
Horizontal	20/54	20/77
Vertical	20/43	20/77
Weight	544g	528g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

Kaiser - 7K

		Right	Left
Exit Pupil Diameter		12.1mm	12.0mm
Eye Relief		21.1mm	19.7mm
Brightness Gain (3.7E-04 ft-L)		1933	2022
Field of View (Questionable)		32.1 deg	31.8 deg
Luminance Non-Uniformity (Center 80% of FOV)		+/- 39.1%	+/- 31.7%
Modulation Contrast	@ 5 deg	87.6%	86.5%
	@ 10 deg	98.4%	97.1%
Magnification		1.02	1.02
Image Rotation		7.4mrad	1.0mrad
Optical Axis Misalignment	Horizontal	-4.2mrad	-12.0mrad
	Vertical	-10.0mrad	1.0mrad
	Total	10.8mrad	-12.0mrad
"S" Distortion (peak to valley)		1.0mrad	1.1mrad
Resolution	Horizontal	20/38	20/38
	Vertical	20/34	20/38
Weight	Has CRT Port NO CRT	589g	590g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

Kaiser - 8K

		Right	Left
Exit Pupil Diameter		12.0mm	11.7mm
Eye Relief		20.5mm	19.6mm
Brightness Gain	(@ 3.7E-04 ft-L)	1643	1740
Field of View		31.9 deg	30.6 deg
Luminance Non-Uniformity	(Center 80% of FOV)	+/- 22.3%	+/- 19.9%
Modulation Contrast	@ 5 deg	94.5%	98.4%
	@ 10 deg	92.6%	97.9%
Magnification		1.01	1.02
Image Rotation		5.4mrad	-1.6mrad
Optical Axis Misalignment	Horizontal	2.2mrad	-4.1mrad
	Vertical	0.81mrad	-3.6mrad
	Total	2.4mrad	5.4mrad
"S" Distortion (peak to valley)		0.60mrad	0.41mrad
Resolution	Horizontal	20/54	20/34
	Vertical	20/43	20/34
Weight	HUD port, No CRT	589g	589g

Inspected By: Lt Richard Hartman

Date: 31 Dec 90

Performance Overview

Honeywell - 5H

	Right	Left
Exit Pupil Diameter	11.9mm	11.8mm
Eye Relief	42.8mm	41.9mm
Brightness Gain (@ 3.7E-04 ft-L)	3085	2393
Field of View	36.4 deg	35.4 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 71.9%	+/- 66.8%
Modulation Contrast		
@ 5 deg	94.4%	93.0%
@ 10 deg	95.3%	95.3%
Magnification	1.02	0.99
Image Rotation	2.3mrad	-35.3mrad
Optical Axis Misalignment		
Horizontal	4.8mrad	12.1mrad
Vertical	-12.3mrad	-7.6mrad
Total	-13.2mrad	-14.3mrad
"S" Distortion (peak to valley)	4.4mrad	1.2mrad
Resolution		
Horizontal	20/108	20/86
Vertical	20/77	20/86
Weight (without white shield)	563g	562g

Inspected By: LT RICHARD HARTMAN

Date: 29 NOV 90

Performance Overview

Honeywell - 5H Repeat of Both Channels

	Right	Left
Exit Pupil Diameter		
Eye Relief		
Brightness Gain (@ 3.7E-04 ft-L)		
Field of View		
Luminance Non-Uniformity (Center 80% of FOV)		
Modulation Contrast		
@ 5 deg		
@ 10 deg		
Magnification	1.01	1.01
Image Rotation	25.9mrad	-32.1mrad
Optical Axis Misalignment		
Horizontal	3.2mrad	-1.1mrad
Vertical	2.9mrad	-5.1mrad
Total	4.3mrad	5.2mrad
"S" Distortion (peak to valley)	4.0mrad	1.7mrad
Resolution		
Horizontal	20/86	20/68
Vertical	20/68	20/68
Weight		

Inspected By: Lt Richard Hartman

Date: 31 Dec 90

Performance Overview

Honeywell - 6H

	Right	Left
Exit Pupil Diameter	11.9mm	12.2mm
Eye Relief	38.3mm	40.9mm
Brightness Gain (@ 3.7E-04 ft-L)	1691	1406
Field of View	35.5 deg	36.3 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 72.5%	+/- 59.5%
Modulation Contrast		
@ 5 deg	91.6%	90.3%
@ 10 deg	94.6%	96.4%
Magnification	1.01	0.99
Image Rotation	-2.5mrad	-22.9mrad
Optical Axis Misalignment		
Horizontal	14.3mrad	-2.5mrad
Vertical	-2.6mrad	-3.0mrad
Total	-14.5mrad	3.9mrad
"S" Distortion (peak to valley)	3.6mrad	2.5mrad
Resolution		
Horizontal	20/68	20/86
Vertical	20/86	20/54
Weight (with white sheild)	601g	596g

Inspected By: Lt Richard Hartman

Date: 31 Dec 90

Performance Overview

Honeywell - 7H

		Right	Left
Exit Pupil Diameter		12.0mm	12.0mm
Eye Relief		37.8mm	36.2mm
Brightness Gain (3.7E-04 ft-L)		2387	2699
Field of View (Questionable)		27.3 deg	26.5 deg
Luminance Non-Uniformity (Center 80% of FOV)		+/- 83.0%	+/- 84.4%
Modulation Contrast	@ 5 deg	90.6%	88.2%
	@ 10 deg	94.5%	96.3%
Magnification		1.08	1.03
Image Rotation		50.8mrad	-2.8mrad
Optical Axis Misalignment	Horizontal	39.8mrad	-21.5mrad
	Vertical	-0.82mrad	-11.6mrad
	Total	-39.8mrad	24.4mrad
"S" Distortion (peak to valley)		2.5mrad	1.2mrad
Resolution	Horizontal	20/60	20/77
	Vertical	20/54	20/60
Weight	HUD Port only no CRT	584g	586g

INSPECTED BY: LT RICHARD HARTMAN

DATE: 29 NOV 90

Performance Overview

Honeywell - 8H

	Right	Left
Exit Pupil Diameter	12.0mm	12.0mm
Eye Relief	42.2mm	42.4mm
Brigh^ness Gain (@ 3.7E-04 ft-L)	3265	2966
Field of View	37.8 deg	36.2 deg
Luminance Non-Uniformity (Center 80% of FOV)	+/- 66.0%	+/- 67.7%
Modulation Contrast		
@ 5 deg	94.4%	94.4%
@ 10 deg	95.9%	97.1%
Magnification	1.04	1.03
Image Rotation	29.8mrad	18.9mrad
Optical Axis Misalignment		
Horizontal	-17.6mrad	-25.6mrad
Vertical	-18.4mrad	-10.7mrad
Total	25.5mrad	27.7mrad
"S" Distortion (peak to valley)	1.79mrad	1.32mrad
Resolution		
Horizontal	20/68	20/54
Vertical	20/68	20/48
Weight (with shield)	587g	588g
(without white shield)	566g	-

Inspected By: LT RICHARD HARTMAN

Date: 29 NOV 90

Performance Overview

Honeywell - 8H   Repeat of Left Channel

		Right	Left
Exit Pupil Diameter			
Eye Relief			
Brightness Gain	(@ 3.7E-04 ft-L)		
Field of View			
Luminance Non-Uniformity	(Center 80% of FOV)		
Modulation Contrast	@ 5 deg		
	@ 10 deg		
Magnification			1.03
Image Rotation			13.9mrad
Optical Axis Misalignment	Horizontal		-10.3mrad
	Vertical		-4.6mrad
	Total		11.3mrad
"S" Distortion (peak to valley)			0.65mrad
Resolution	Horizontal		
	Vertical		
Weight	(with shield)		
	(without white shield)		

Inspected By: Lt Richard Hartman

Date: 31 Dec 90

Performance Overview
ANVIS
serial number 0698

	Right	Left	Spec
Exit Pupil Diameter	N/A	N/A	N/A
Eye Relief (Questionable)	26.6mm	27.6mm	15.0mm
Brightness Gain (@ 3.7E-04 ft-L)	2559	2707	not < 2000
Field of View	40 deg	40 deg	40 deg(+1,-2)
Luminance Non-Uniformity (Center 80% of FOV)	-----not measured-----		
Modulation Contrast @ 5 deg	0.963%	0.964%	
@ 10 deg	0.976%	0.978%	
Magnification	1.00	0.98	1.00 (+/- 5%)
Image Rotation	-19.6mrad	-7.70mrad	
Optical Axis Misalignment Horizontal	------not measured-----		
Vertical	**	**	
Total	**	**	
"S" Distortion (peak to valley)	10.2mrad	5.00mrad	not > 1.33mrad
Resolution Horizontal	20/48	20/48	not > 20/45
Vertical	20/48	20/43	not > 20/45
Weight of Binocular without battery pack	677g		not > 550g

Inspected by: Lt Richard Hartman
Date: 4 Dec 1990

********* See Attachment *********

MINIATURE CRT IMAGE QUALITY

MEASUREMENT SYSTEM

MINIATURE CRT IMAGE QUALITY MEASUREMENT SYSTEM

INTRODUCTION

The measurement results for the INIGHTS system cathode ray tubes (CRTs) provide specific information about the CRTs' image quality, from which certain aspects of expected display performance can be inferred. The metrics used for the CRT function tests concentrate on the active raster line and Sinewave Response (SWR). The figures of merit used have wide acceptance within the industry for determining response capabilities of CRTs. However, standards or metrics to determine how "good" or "bad" a specific display is in absolute terms, are not defined at this time. Further, any correlation to operator performance is an even more vague proposition.

SYSTEM

The Miniature CRT Image Quality Measurement System is designed to perform specific measurements on both miniature and sub-miniature CRTs. The system is also flexible enough to perform any conceivable test compatible with luminance measurements. A system diagram is provided on the following page. Three tests will be completed for INIGHTS. They are:

SINEWAVE RESPONSE
LINEWIDTH MEASUREMENT
LINE LUMINANCE TEST

The deflection/video drive electronics is capable of driving high resolution miniature CRTs at various line rates in both raster and calligraphic modes. This equipment is part of the Video Drive Electronics System (VDES) which is designed to provide high quality signals for evaluating CRT characteristics and testing the capabilities of miniature CRTs for visual display applications. The video amplifier drives the CRTs differentially up to +/- 60 volts, which provides a maximum drive of 120 volts. Differential drive requires less power applied to the video amplifier, higher signal-to-noise ratio, and greater bandwidth than single-ended amplifiers (i.e. grid or cathode biased). The bandwidth of the video amplifier is 60 MHz at 3 db down.

HARDWARE

a. Bertan B-Hive controller and housing unit for B-mod/B-pac power supplies.

b. Bertan model 205A-20P 20 KV power supply.

c. Video Drive Electronics System. This system includes the deflection electronics, video drive electronics, and associated power supplies.

d. Photo Research model 1980A photometer . This system uses a slit that is 0.4 x 40 minutes and a 20X microscopic lens. The effective slit width of this system is .1 microns.

e. OPIX IMAGER Pattern Generator

f. LeCroy 9400 digital oscilloscope

g. Klinger model MD-4 controller with X-Z MT160 translation stages capable of .1 micron steps.

h. Hewlet-Packard model 8116A 50 MHz function generator

i. Oriel Model 18011 encoder with motor mikes that provide three degrees of freedom: azimuth, elevation, and roll.

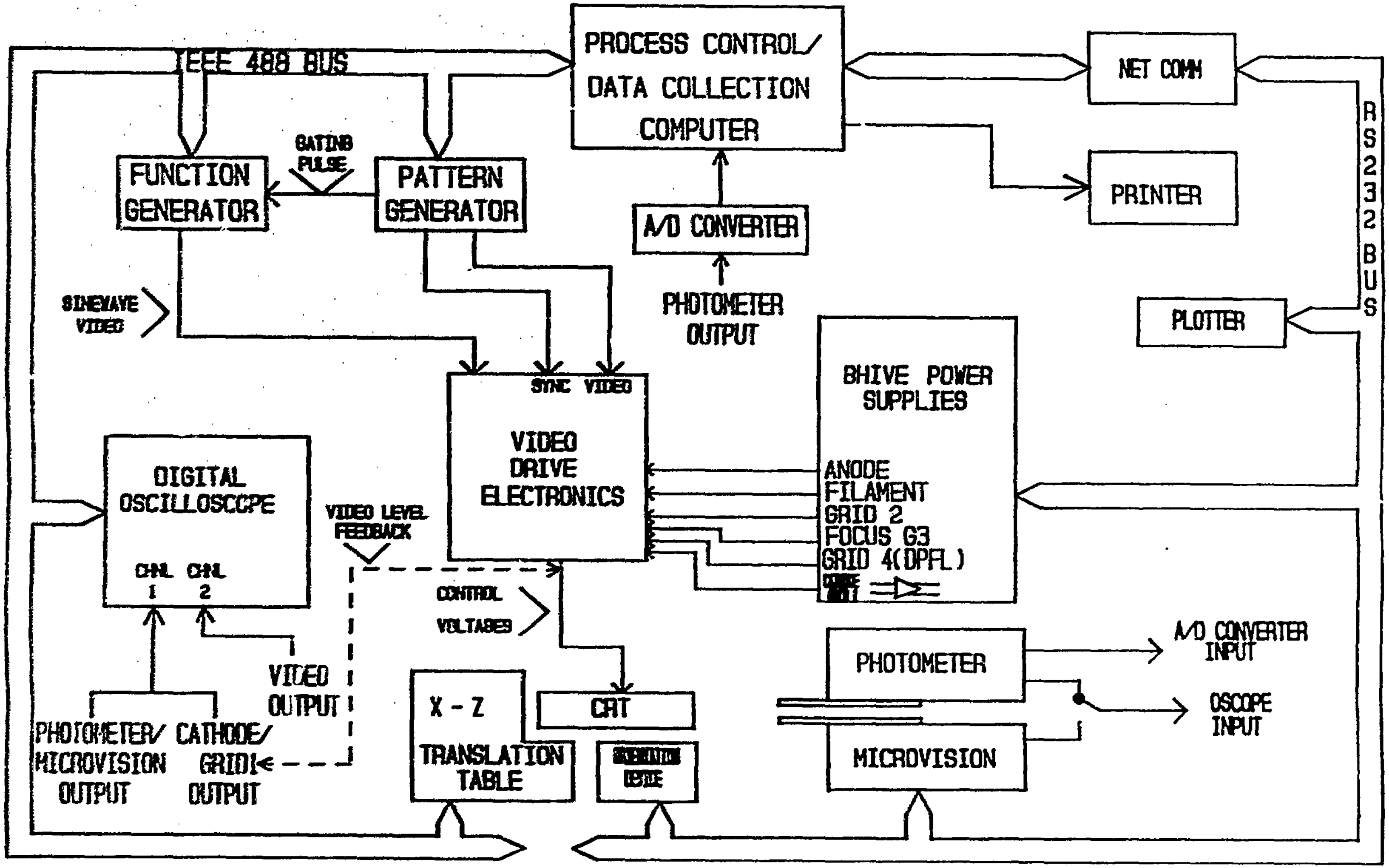
See system diagram on next page.

NOTE: ALL OSCILLOSCOPE MEASUREMENTS WERE MADE WITH A 12 pf 10X PROBE. ALL VOLTAGES SHOWN ON PLOTS SHOULD BE MULTIPLIED BY 10. LUMINANCE VALUES ARE IN CANDELAS PER METER SQUARED (Cd/m^2) UNLESS OTHERWISE SPECIFIED.

CONVERSION FACTOR FROM Cd/m^2 TO FOOT LAMBERTS

$$\text{FOOT LAMBERTS} = (\text{Cd/m}^2)/3.426$$

MINIATURE CRT IMAGE QUALITY MEASUREMENT SYSTEM



MODULATION/LUMINANCE

This section provides information about cutoff, contrast ratios, and luminance output/video drive levels. First, a brief discussion concerning CRT principles is provided in order to enhance understanding of the above topics and other areas contained in this document. Plots are provided from the LeCroy 9400 digital oscilloscope showing drive levels for specific luminance outputs and cutoff. Drive comparison characteristics between CRTs can be easily obtained from these plots.

CRT OPERATION

Figure 1 is a representative bipotential lens miniature CRT design used in Helmet Mounted Display (HMD) systems. Figure 2 is a simpler schematic that will be used to explain necessary details of CRT operation. The electron gun in figure 2 includes a heater, control grid (G1), accelerator grid (G2), and focusing grid (G3). Each grid structure is a metal cylinder with a small aperture or hole in the center.

The control grid has a negative bias with respect to the cathode in order to control the space charge field for the electrons arriving from the heated cathode. The succeeding grids have positive potentials, with the anode at the highest potential to accelerate the electron beam to the screen. Most of the electrons go through the electron gun apertures and form the electron beam shown as a dotted line in figure 2. The electron beam has a complete circuit for current from the screen, which is connected to the anode. The path for electron flow is from the cathode to the screen to the anode and returning to the cathode through the high voltage supply.

Electrons emitted from the cathode tend to diverge, because they repel each other. However, the electrons can be forced to converge to a point by either a magnetic or electric field. This is similar to focusing a beam of light by using a magnifying glass. The focusing system is called an electron lens. A two electron lens, or a bipotential lens system, is described here. The first lensing element is the electrostatic field* between the cathode and control grid produced by the difference in their potential. This voltage focuses the beam to a spot called the crossover point (point P, figure 2) just beyond the control grid. The second lens may be either an electrostatic or magnetic field to focus the beam just before the deflection plates. As a result of the two electron lenses, the beam is focused to a sharp spot of light on the screen.

Details of the first electron lens formed by the electrostatic field between

* Any voltage has an associated electric field, just as any current has an associated magnetic field . When the voltage has a steady state value, its field is electrostatic, meaning that it does not vary with respect to time.

the cathode and control grid is illustrated in figure 3. The positive grid 2 (shown in figure 2) and anode voltage provide a forward accelerating force on electrons emitted from the cathode. The net result is that diverging paths are bent so that the electrons go through the control grid aperture. The diverging beam is focused at point P. This point serves as the point source of electrons to be imaged onto the screen by the second electron lens for a sharp spot. It is important to note that the grid 2 voltage will affect, physically, where the crossover point is located and its size and shape. The value of the grid 2 voltage is critical if the CRT is to be optimized in terms of resolution!

The design of the video amplifier determines how a CRT is driven or operated. There are three different methods that can be used, grid 1 drive, cathode drive, or differential drive. The primary difference between these methods is the polarity with which the video signal is modulated. Grid drive uses negative sync polarity. This means that the blanking level drives the grid 1 voltage more negative than the DC bias, to cutoff the beam current for black. The white peaks in the video signal drive the grid 1 voltage less negative than the DC bias for maximum beam current. The opposite case is used in cathode drive. Cathode drive uses positive sync polarity. This means that the blanking level drives the cathode more positive than the DC bias to cutoff the beam current. The white peaks in the video signal drive the cathode voltage less positive than the bias for maximum beam current. Differential drive combines both cathode and grid 1 drive characteristics, using both negative and positive polarities. Each method has advantages and disadvantages, but we believe that differential drive provides the greatest overall advantages. These advantages were covered under the system description. Figure 4 depicts each of these methods. Grid 1 drive is shown on the left side, cathode drive on the right side, and differential drive combining the two.

The grid 1-cathode bias is a DC voltage that sets the brightness of the entire screen area. The video signal varies the instantaneous values of electron beam intensity to reproduce the details of the video information. Figure 4 illustrates this idea with a video sinewave signal for one horizontal line. The DC bias sets the operating point and the maximum contrast. The peak-to-peak amplitude of the sinewave signal determines the contrast in the picture, with peak white at maximum beam current, for the applied video signal, and black at cutoff, or no beam current. Figure 5 shows both the electrical sinewave signal and the image displayed on the screen area of the CRT. Figure 4 also portrays the beam current contributions from both the grid 1 and cathode elements in the differential video amplifier system [1,2].

CUTOFF

Cutoff is defined as the point where the anode/cathode current is essentially zero for a specific set of grid potentials. Figure 4 shows the point where cutoff occurs. Notice on the graph that the outter plot indicates the maximum contrast available or maximum cutoff voltage (120 volts), for our system. Typically, the Hughes 1380 CRTs cutoff point is represented by the inner plot, which is approximately 60 volts. The first graph in this section, labeled "CUTOFF", shows the cutoff point measured at grid 1 and cathode. This plot was taken from the LeCroy Digital Oscilloscope using a 10X probe. The cutoff voltage is shown under each channel and must be multiplied by 10 because of the probe used. The voltage is the potential difference between the top line (cathode DC bias) and the bottom line (grid 1 DC bias). This voltage defines the maximum contrast adjustment available for the CRT. For a particular type of CRT design, with similar grid potentials, the value of cutoff should not change a significant amount.

However, the value of the cutoff voltage can be increased or decreased by variations in the grid 2 potential. By increasing the grid 2 potential the DC bias or operating point can be increased. This effectively increases the amount of contrast adjustment or raises the cutoff voltage. Decreases in the grid 2 potential have the opposite effect. In the discussion on CRT operation, it was noted that changes in the grid 2 potential affect the crossover point (image point source). The electron beam crossover is used as the object whose image appears on the screen of the CRT. Therefore, the location and size of the crossover are very important in determining the minimum spot size attainable by the focusing techniques (electrostatic or magnetic) [2]. Usually, the manufacturer provides the optimum grid 2 potential, or at least a good approximation, for a specific CRT. In the case of the Hughes 1380 CRTs, only a voltage range was provided. This range was between 300 and 600 volts. Extensive operational testing over the entire grid 2 voltage range would be necessary to determine the most efficient operating grid 2 potential. This would take an inordinate amount of time. A quick preliminary evaluation produced the best results with grid 2 potentials between 350-430 volts. It was found that using the lower range of grid 2 voltages decreases the cutoff voltage or contrast adjustment.

MAXIMUM LUMINANCE

The second plot in this section is labeled "MODULATION AT MAX LUMINANCE". The maximum luminance was measured using the Prichard Photometer, model 1980A. A flat field video signal (this signal illuminates the entire display active area) is displayed on the CRT. The contrast, or video gain, was increased until maximum signal gain was reached. The luminance output at the center of the CRT was then measured. The luminance is provided on this plot in foot lamberts. The modulation signal was measured on the cathode side of the differential video amplifier output. The total modulation voltage was obtained by multiplying the voltage (shown in red on the plot) under either channel by 10 (because of the oscilloscope probe) and then by 2, because only the

the cathode side is measured. Maximum luminance is an indication of a CRT's output capability. Again, referring tp figure 4, the amount of modulation is measured from the DC bias or operating point to the peak amplitude of the video signal.

CONTRAST RATIOS

Contrast ratio is normally defined as the ratio of the excited screen brightness to the level of brightness in the unexcited screen area [2]. This is a measure of the depth of modulation, ratio between light and dark parts of an image, for a particular display. Contrast ratios were measured using a low spatial frequency, 10 cycles per display width (Cy/DW), sinewave videc signal. The plots labeled "MOD CONTRAST" show the modulation required to obtain the luminance output indicated, either 375 or 500 foot lamberts. The contrast voltage was increased until the light output from the displayed bright sinewave image reached 375 and 500 foot lamberts, respectively. Again, figure 5 shows the electrical sinewave video signal and the image seen on the CRT display. The maximum and minimum luminance values were measured at the center of the CRT on adjacent peak white and dark imaged areas. The contrast ratio is obtained from the following formula:

CONTRAST RATIO = MAX LUMINANCE/MINIMUM LUMINANCE

Referring to figure 5, the maximum luminance for the drive signal applied was measured within the light area, near the center of the display. The minimum luminance was measured within the adjacent dark area.

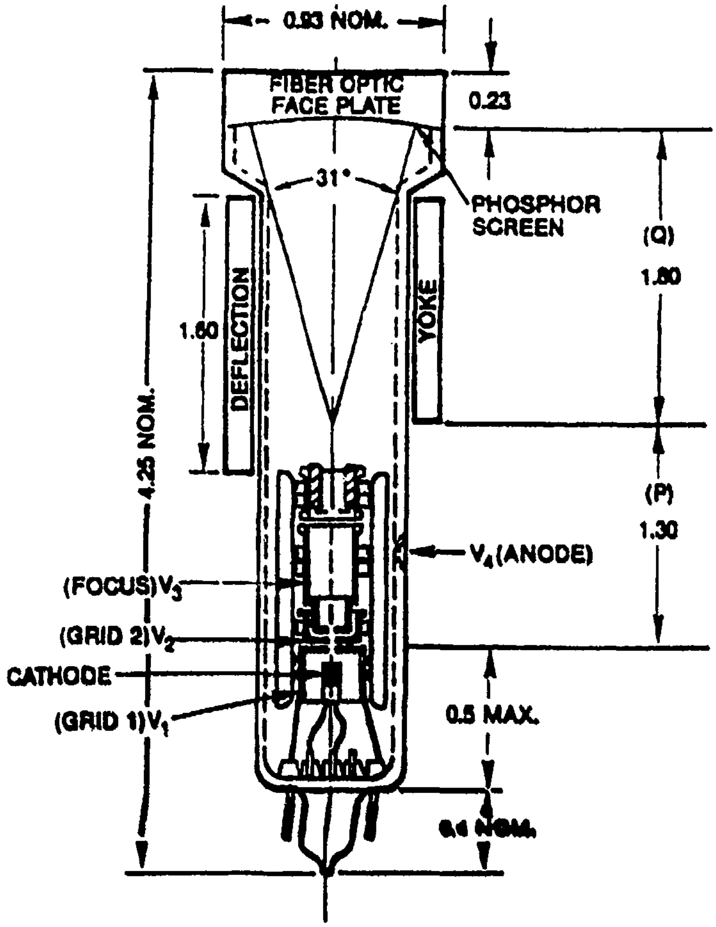


FIGURE 1 - BIPOTENTIAL LENS MINIATURE CRT

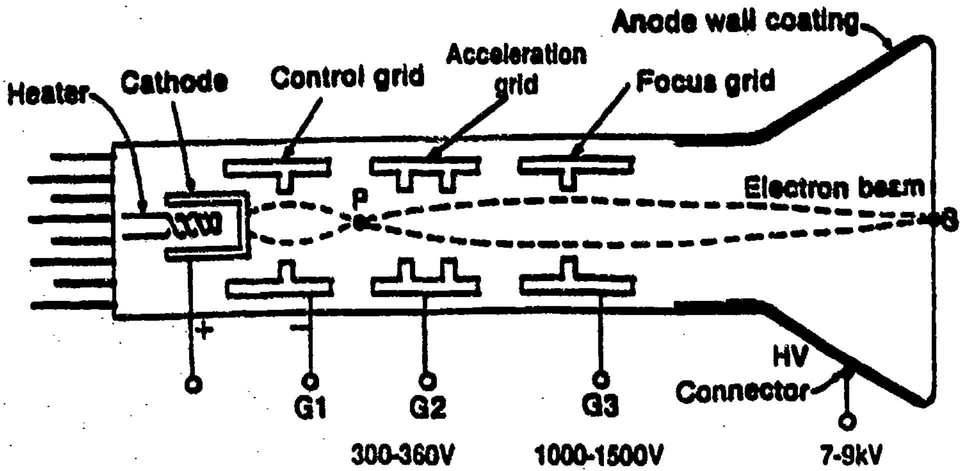


FIGURE 2 - ELECTRON GUN ELEMENTS/ELECTRON BEAM

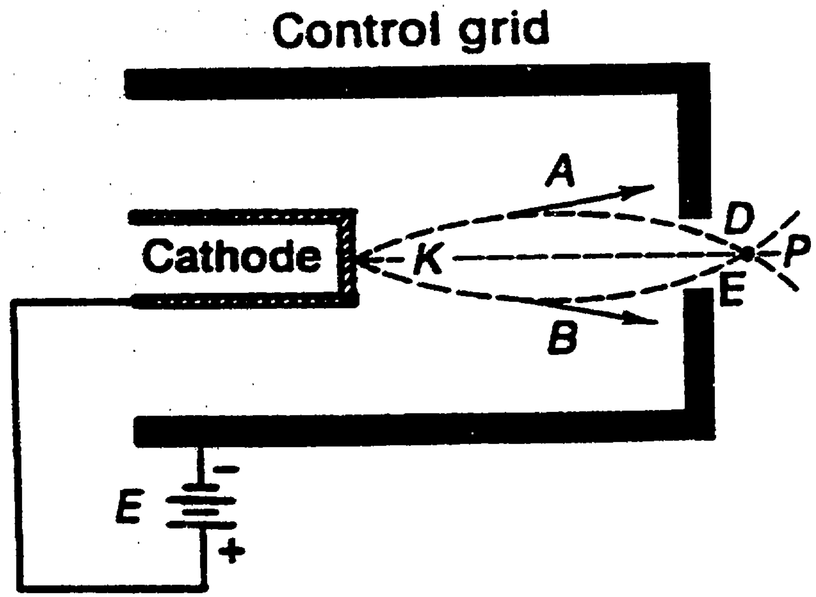
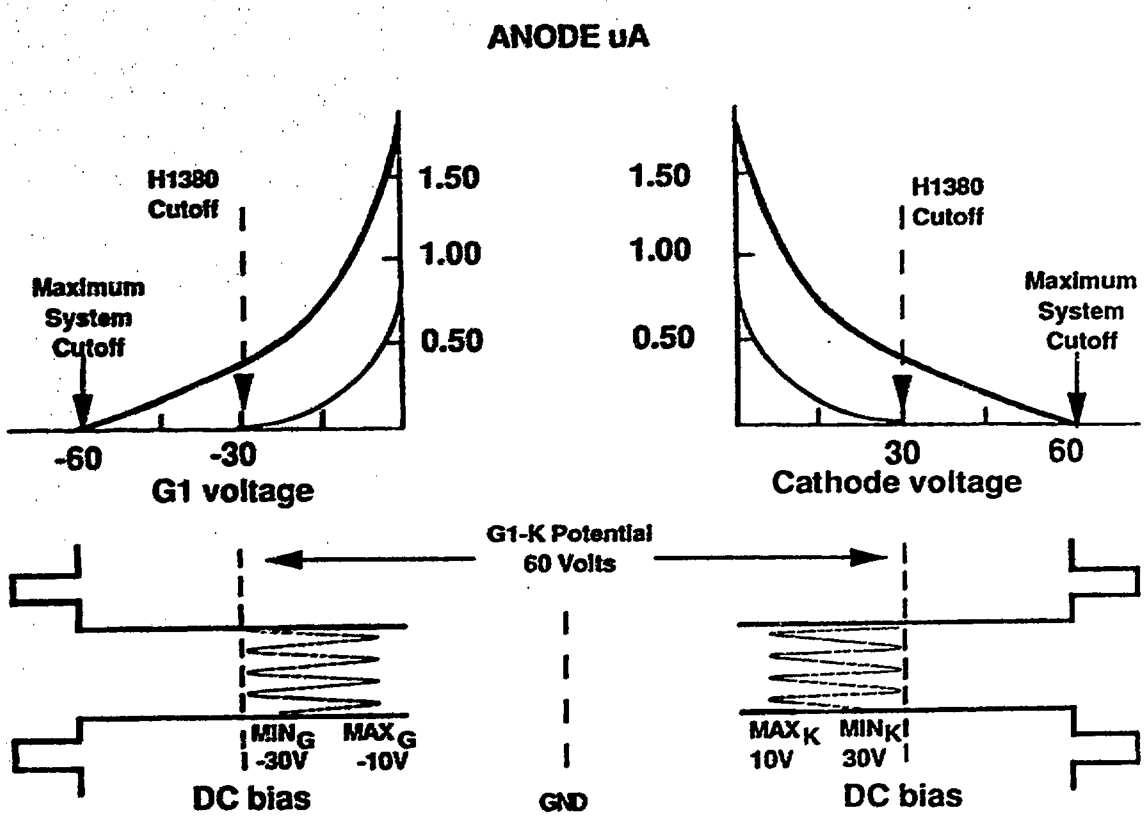


FIGURE 3 - Diverging Beam From K Focused at Crossover Point P



G1 MODULATION = $MAX_G - MIN_G$

= -10V - (-30V) = 20V

K MODULATION = $MAX_K - MIN_K$

= 30V - 10V = 20V

DIFFERENTIAL MODULATION = $MAX_G - MIN_G + MAX_K - MIN_K$

= (-10V - (-30V)) + (30V - 10V) = 40V

FIGURE 4 - How Video Signal Varies Beam Current to Reproduce Picture Information

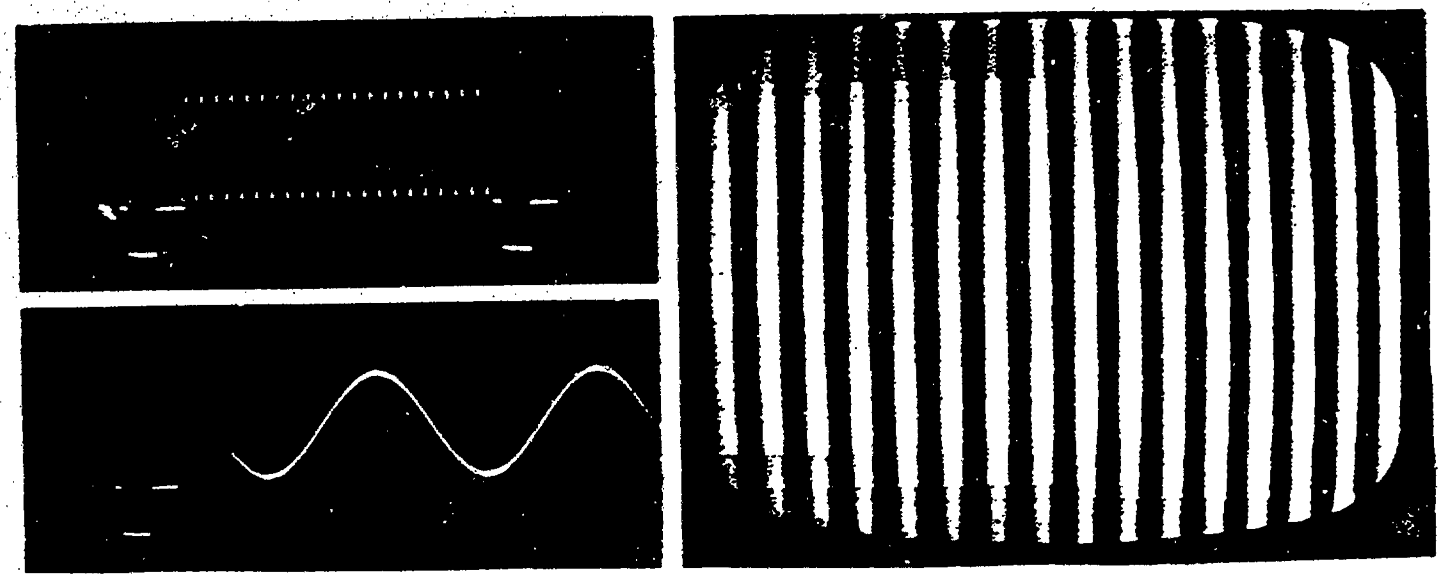
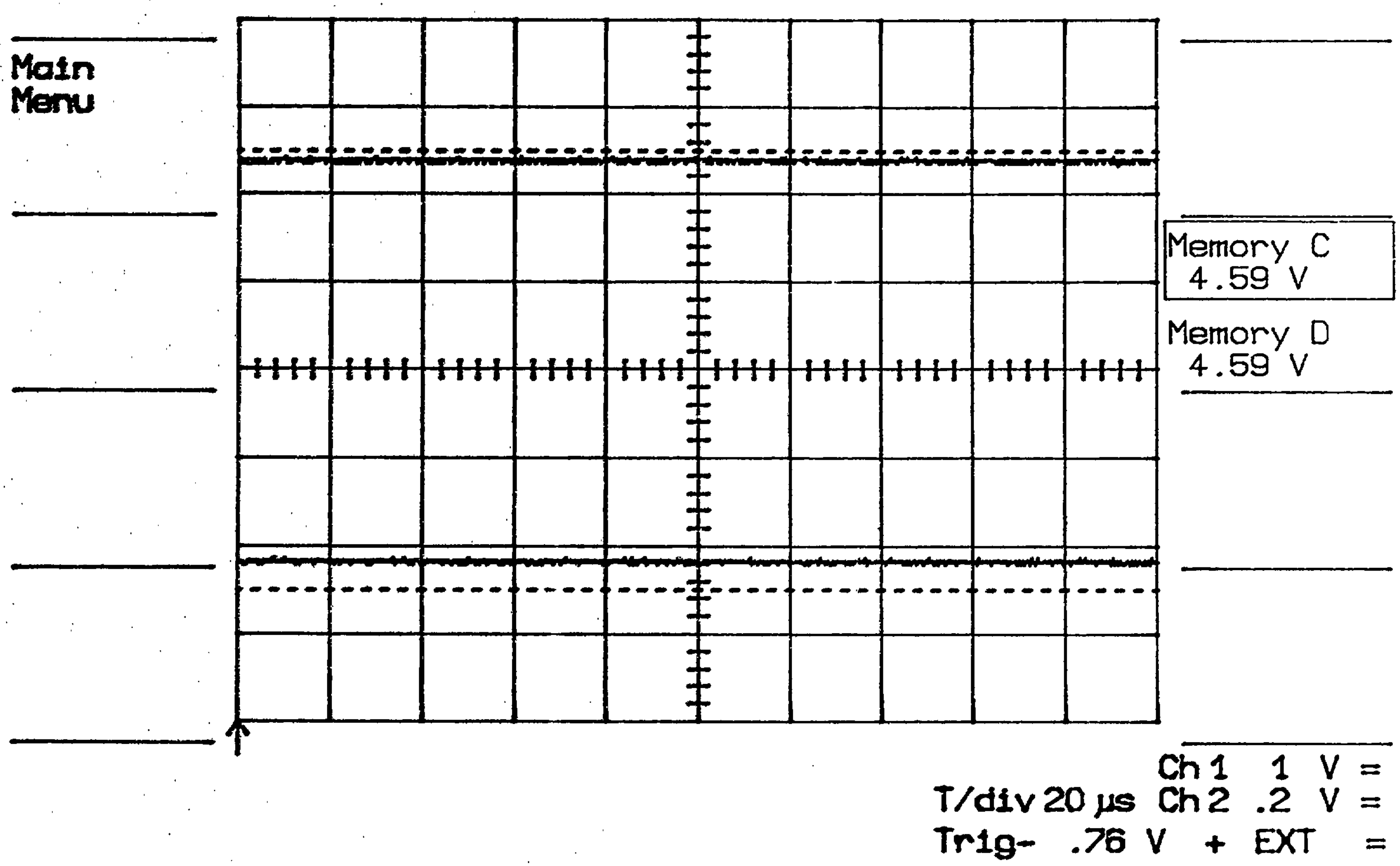
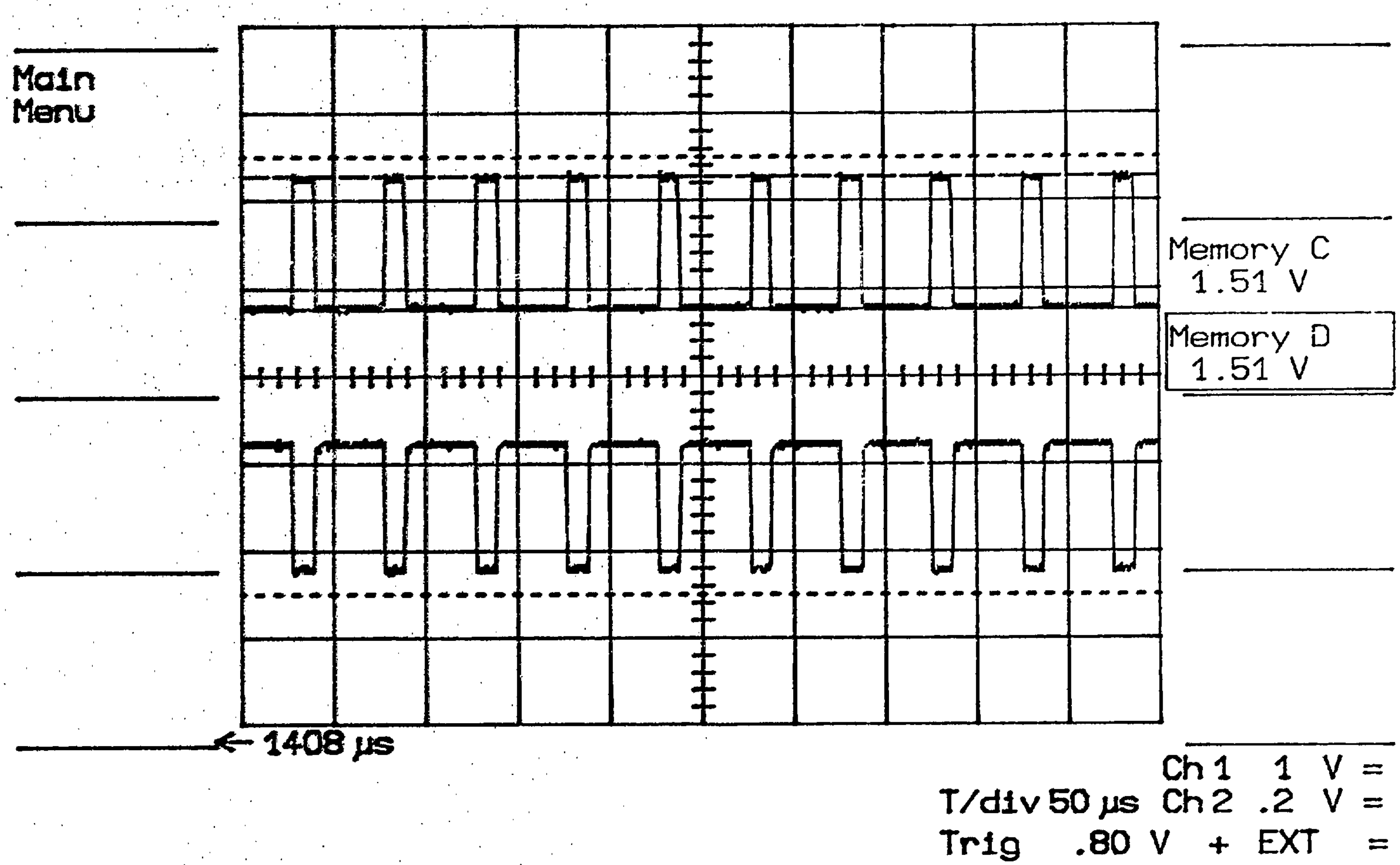


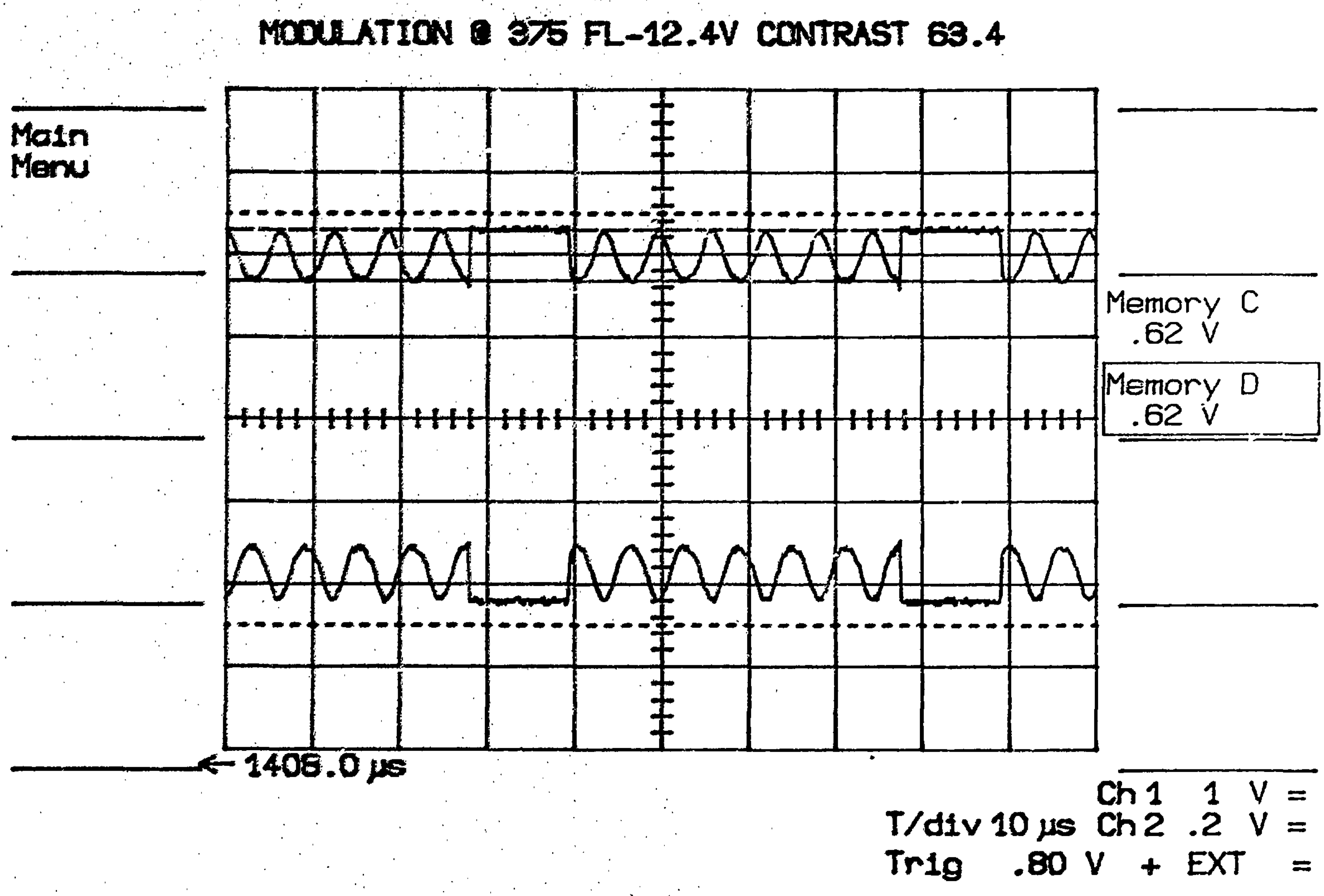
FIGURE 5- ELECTRICAL SINEWAVE VIDEO SIGNAL AND DISPLAY IMAGE

RASTER CUTOFF S/N 004 10X PROBE 45.9 VOLTS

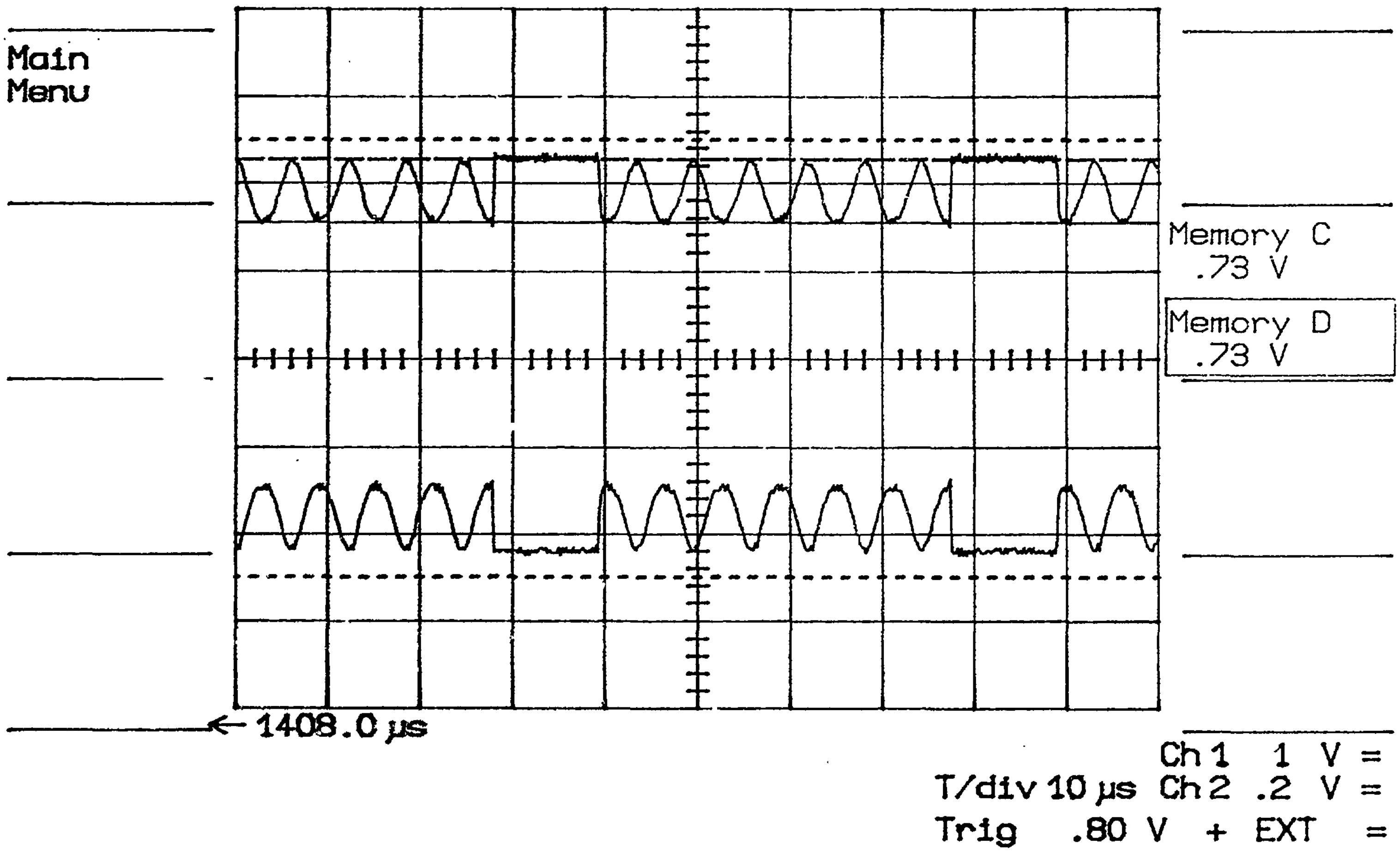


MODULATION @ MAX LUMINANCE/30.2V @ 1739 FL




MODULATION @ 375 FL-12.4V CONTRAST 63.4
Main
Menu
Memory C
.62 V
Memory D
.62 V
1408.0 µs
Ch 1 1 V =
T/div 10 µs Ch 2 .2 V =
Trig .80 V + EXT =

MODULATION @ 500FL-14.6V CONTRAST - 53.8



LINEWIDTH/LINE PROFILE

The linewidth measurements provide a physical representation of the active raster line in the form of a line luminance profile. The active line is scanned in small increments with a luminance detection device such as a photometer or instantaneously acquired by a CCD silicon photodiode array. The line luminance response profiles that are generated show how the profile and linewidth varies as the luminance is increased. Since linewidth is directly related to resolution for a fixed format size, increases in linewidth imply decreased resolution. CRTs that are used in applications with see-through HMDs and ambient light levels that vary significantly (e.g. day-to-night transitions, or vice versa) must have their linewidth optimized to the requirements for the displayed imagery and the information transfer demands of the human-display interface.

Line profiles, at incremental luminance values, were constructed by scanning a line video signal displayed on the miniature CRT with a slit photometer. The line video signal was generated by the OPIX pattern generator at an 875 linerate with a 60 Hz update rate. The active line was scanned with the Prichard 1980A photometer equipped with a 0.4 X 10 minute slit and 20X objective microscopic lens at a step size of 0.5 microns. The initial luminance value was approximately 25 footlamberts. Subsequent line profiles were acquired at 0.025 volt increments in contrast voltage (video gain/modulation) until approximately 500 foot lamberts was reached. The linewidth was obtained from the line profiles and is define as the distance between the points that are 50% down from the peak luminance of the line profile. Figure 6 is a representative line profile showing the peak luminance, 50 % points, and linewidth.

The next four sections provide pertinent information concerning active raster lines. The first section, titled "LINE PROFILES", concentrates on single raster lines. The first graph, labeled "LINEWIDTH PROFILES", is a composite graph of all the line profiles acquired. It shows how the raster line changes as the luminance is increased by incremental changes in contrast (video gain/ modulation). The linewidth information for these profiles is summarized on the graph for easy comparison. The remaining graphs in this section, labeled "LL*.*", are the individual line profiles contained in the composite graph. The second section, titled "LINEWIDTH/LUMINANCE", is a plot of the linewidths versus their corresponding peak luminances. As previously mentioned increases in linewidth over significant variations in luminance will have a degradating effect on the resolution of the HMD system.

The third section, titled "SCAN LINE MODULATION", is the luminance profile of two adjacent active scan lines [3,4]. Excessive scan line structure modulation contrast (SLSMC) can compete with actual video information that is present at the CRT display. Display operating conditions normally require CRT line widths be adjusted so that the scan line structure is not visible, or barely so. However, sufficient dynamic range should be permitted between the maximum and minimum luminance levels, such that usable contrast is maintained between adjacent pixels imaged at different luminance levels on adjacent scan lines. Maximum and minimum acceptable scan line merge conditions, that may provide acceptable performance for the human operator, are shown in figure 7. The merge condition selected should allow a reasonable tradeoff of scan structure contrast and vibration induced artifacts which affect visibility of the scanned image. The first graph in this section labeled "SCAN LINE MODULATION" is a composite of the SLSMC profiles over the same luminance range of the line profiles. The graphs that follow labeled "SCAN LINE MOD LL*.*" are the individual SLSMC profiles.

The fourth section titled "13 KV CRT LINE PROFILE" is a composite graph of the line profiles from a one inch CRT operating with a 13 kilovolt (KV) final anode potential. This graph is provided as a baseline. This 13 KV CRT is of similar size and shape whose primarily differences are a higher anode potential, a modified electron gun (primarily concerned with spacing of triode elements), and a phosphor whose grain size and thickness have been optimized for improved electrical-to-light conversion performance. Raising the final anode potential effectively provides more luminance for the same beam current (video modulation). Linewidth changes for this particular miniature CRT are minimal at luminance levels in excess of 7000 foot lamberts. Also, above 12 kilovolts, space charge spreading effects become negligible with the beam currents and beam travel distances found in miniature CRTs. However, this higher anode potential means that the electron beam will be stiffer requiring higher deflection currents.

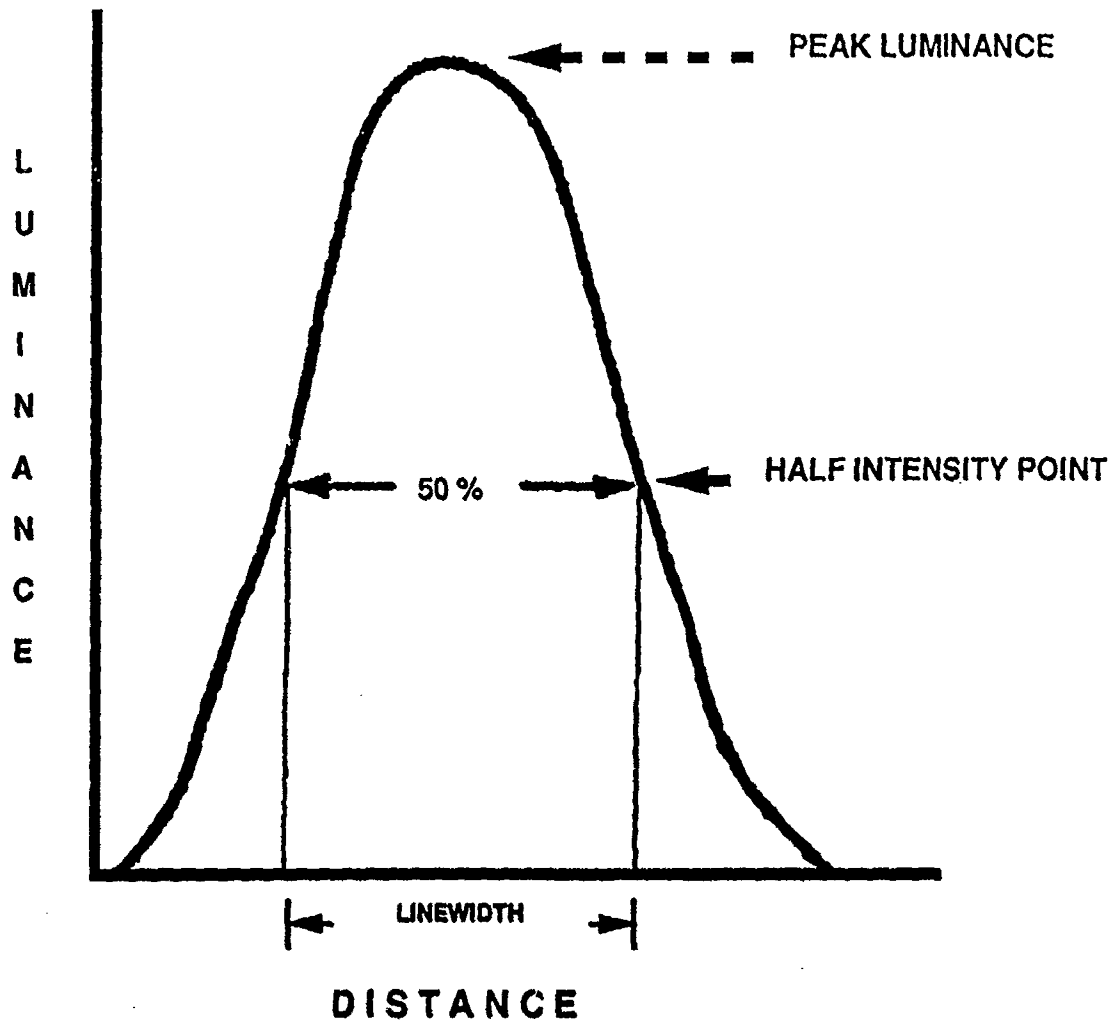


FIGURE 6 - Definition of linewidth from line luminance profile

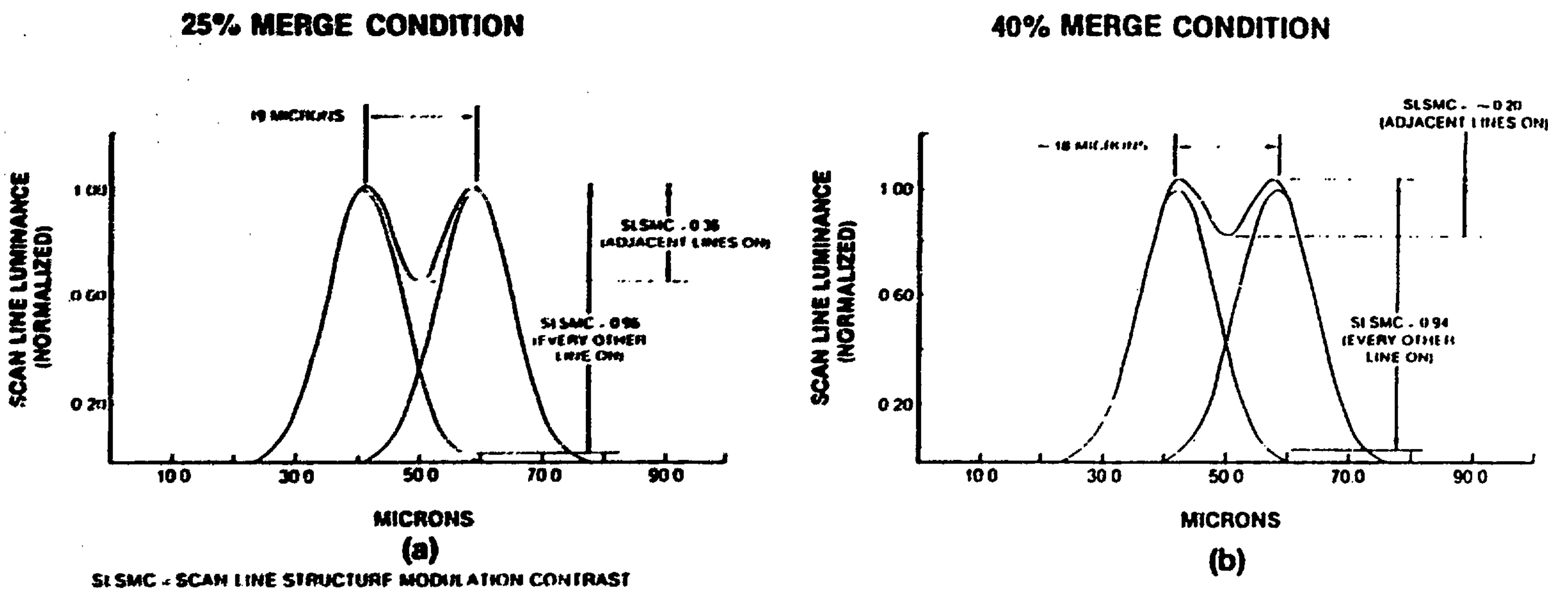
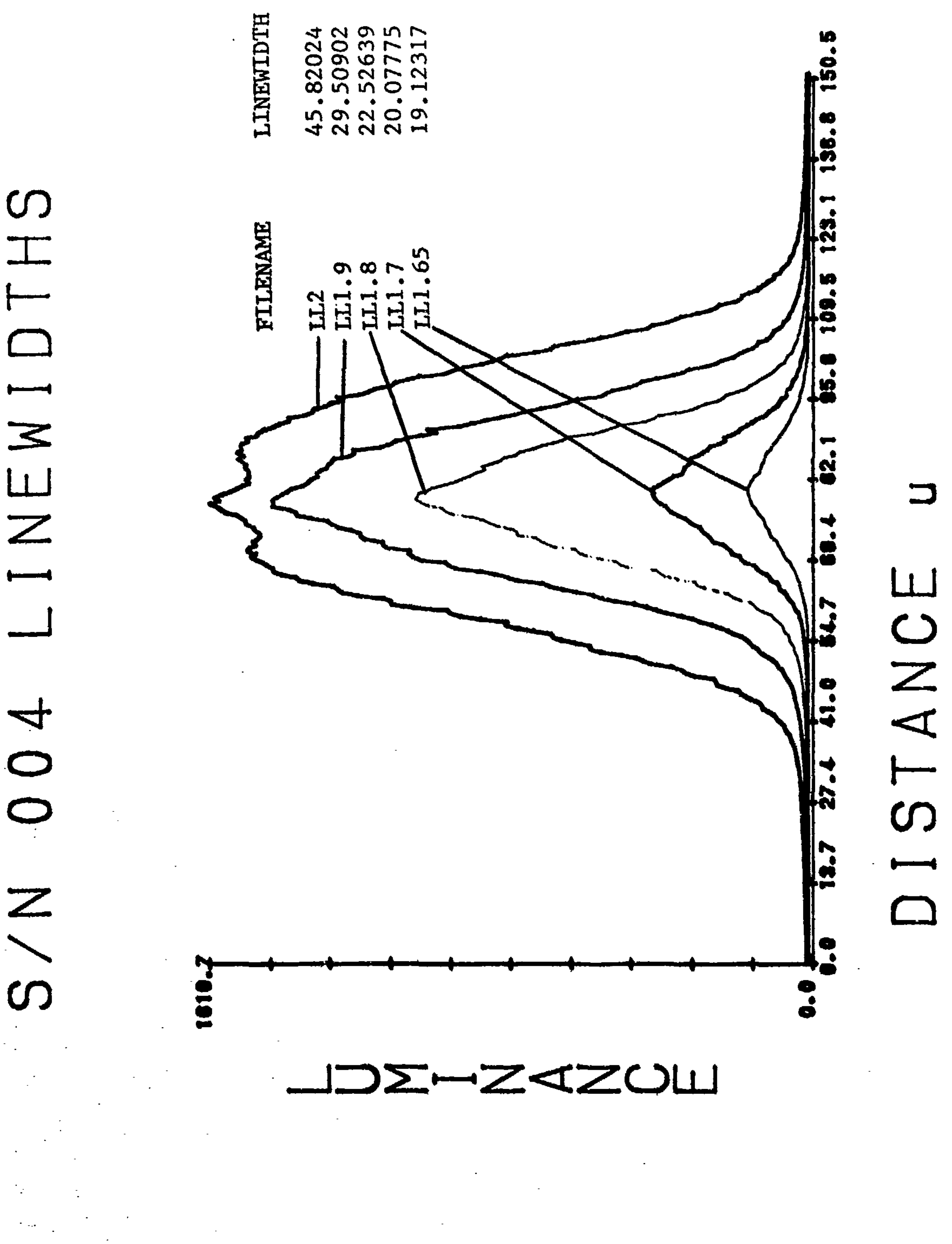


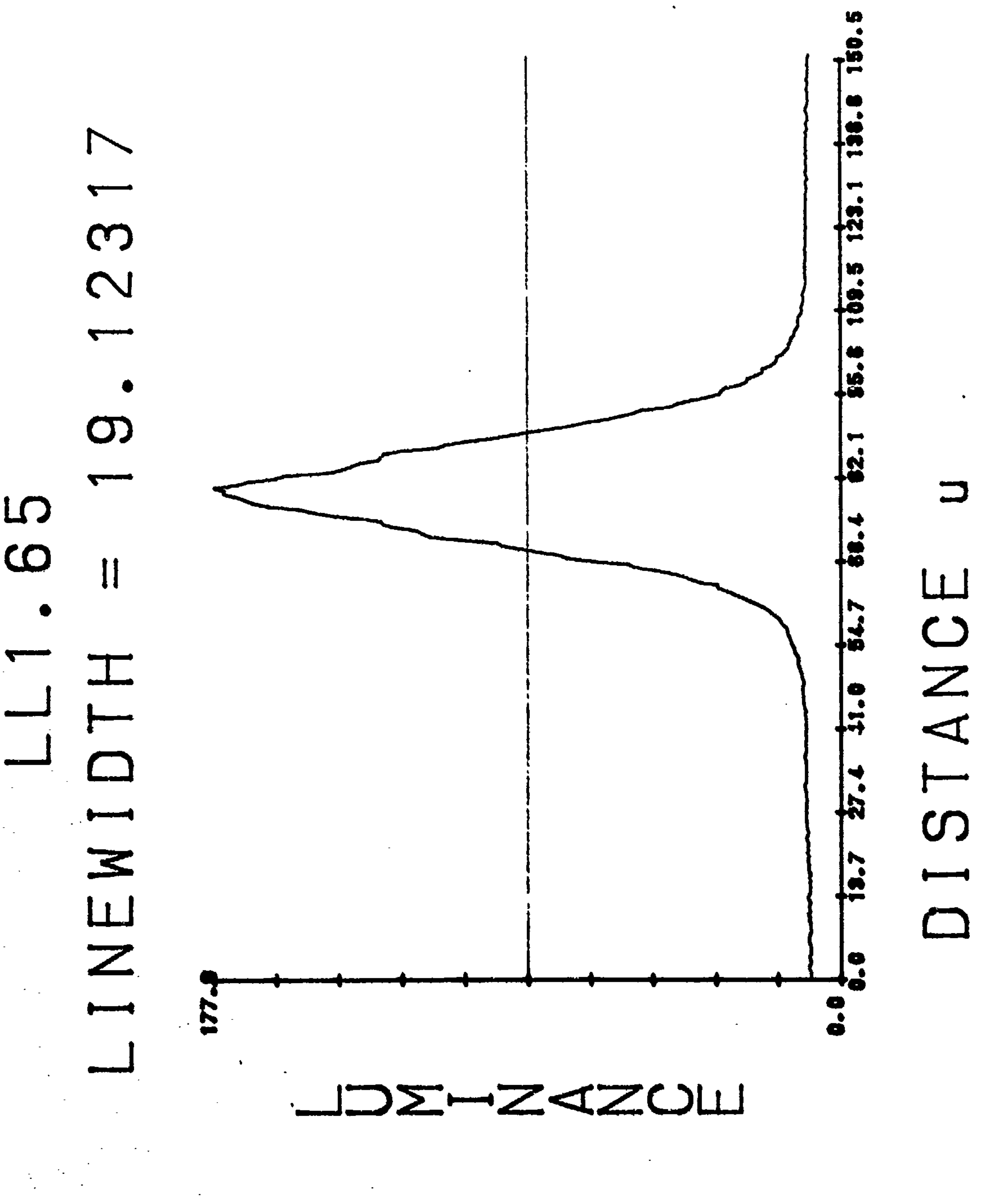
FIGURE 7 - SCAN LINE STRUCTURE MOULATION CONTRAST

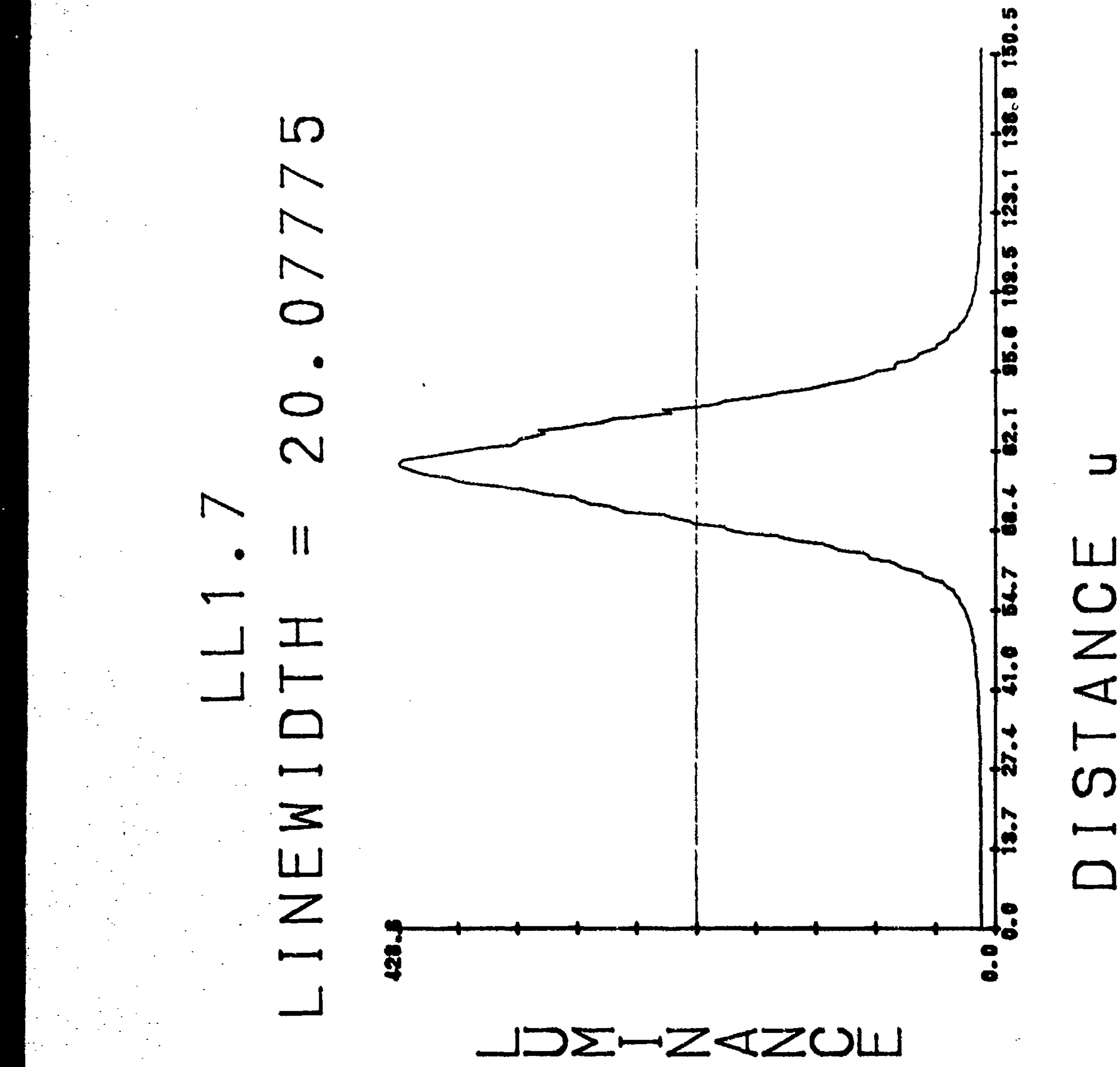
HONEYWELL CRT

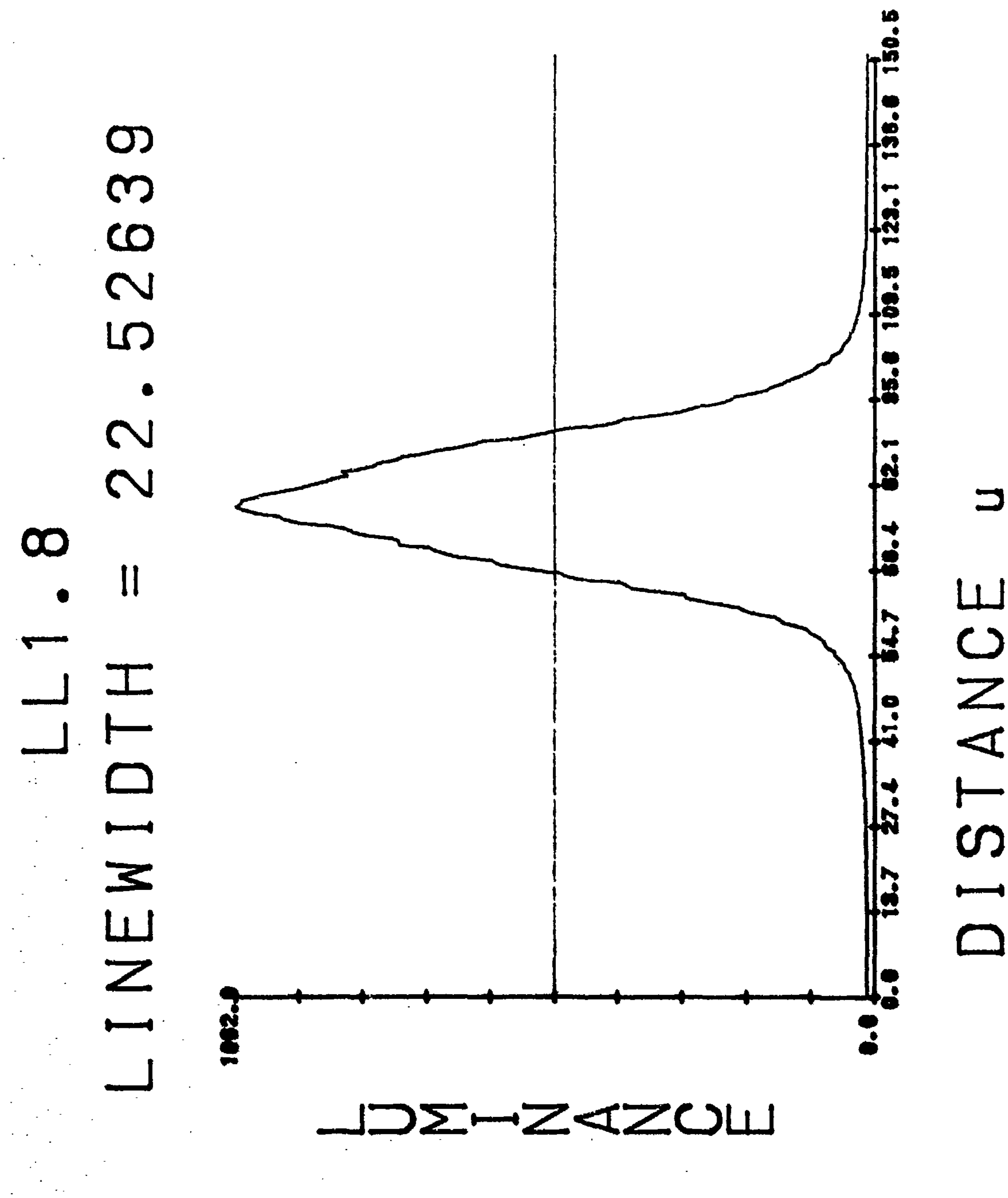
S/N 004



S/N 004 LINEWIDTHS
FILENAME
LINEWIDTH
LL2 45.82024
LL1.9 29.50902
LL1.8 22.52639
LL1.7 20.07775
LL1.65 19.12317
LUMINANCE
1610.7
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


LL1.65
LINEWIDTH = 19.12317
LUMINANCE
DISTANCE u
0.0
0.0
150.5


LL1.7
LINEWIDTH = 20.07775
LUMINANCE
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


LL1.8
LINEWIDTH = 22.52639
LUMINANCE
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
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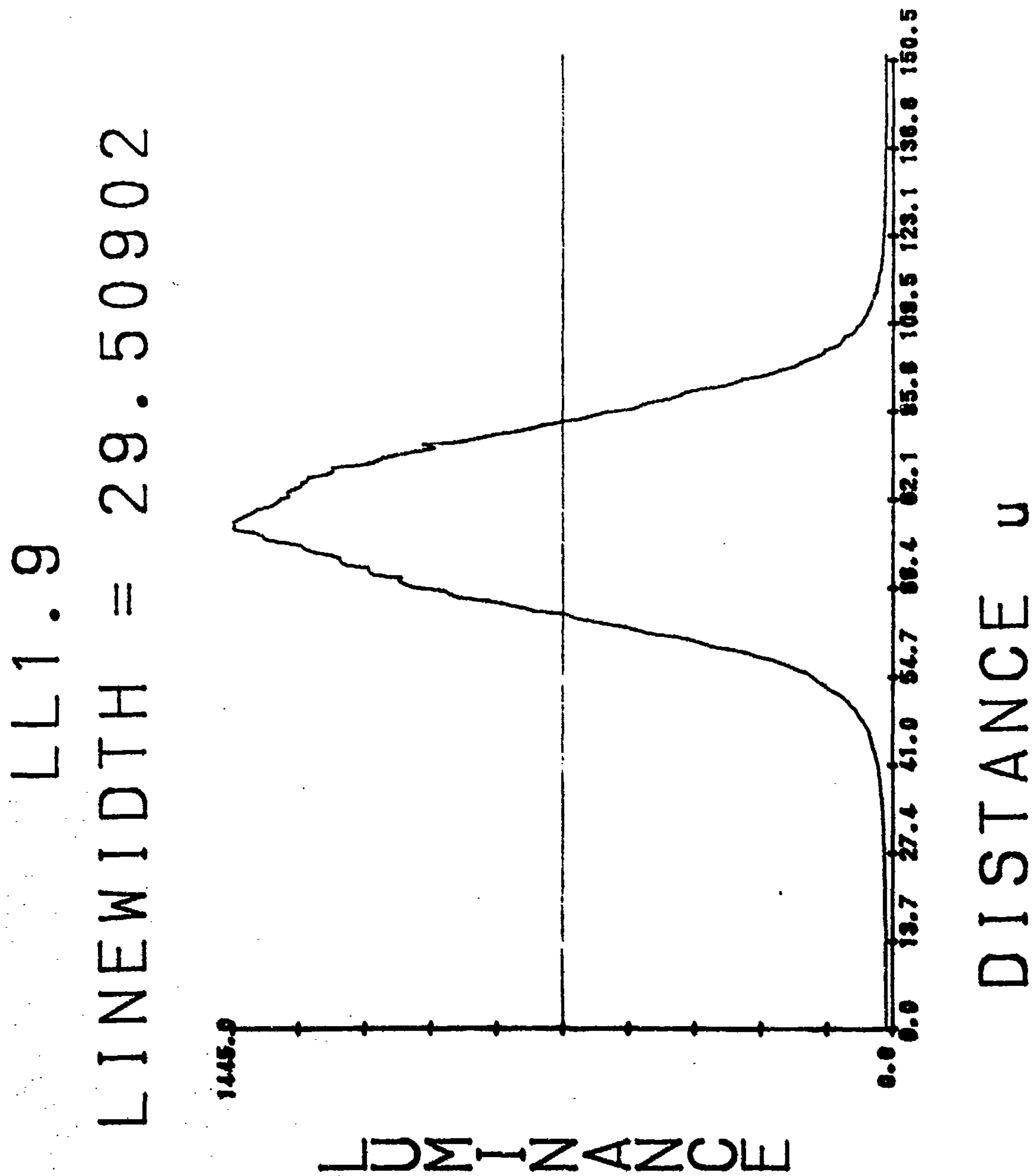
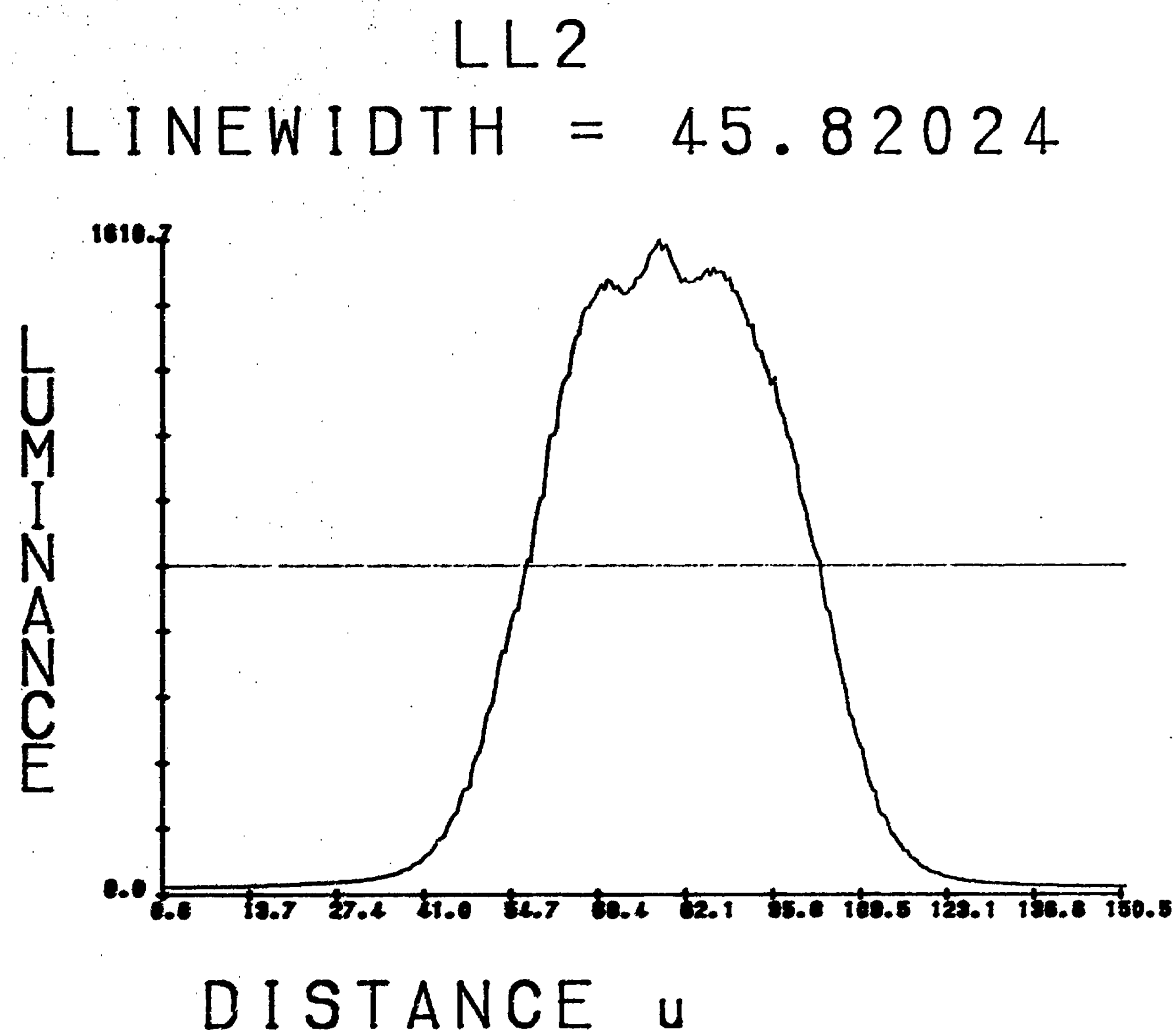
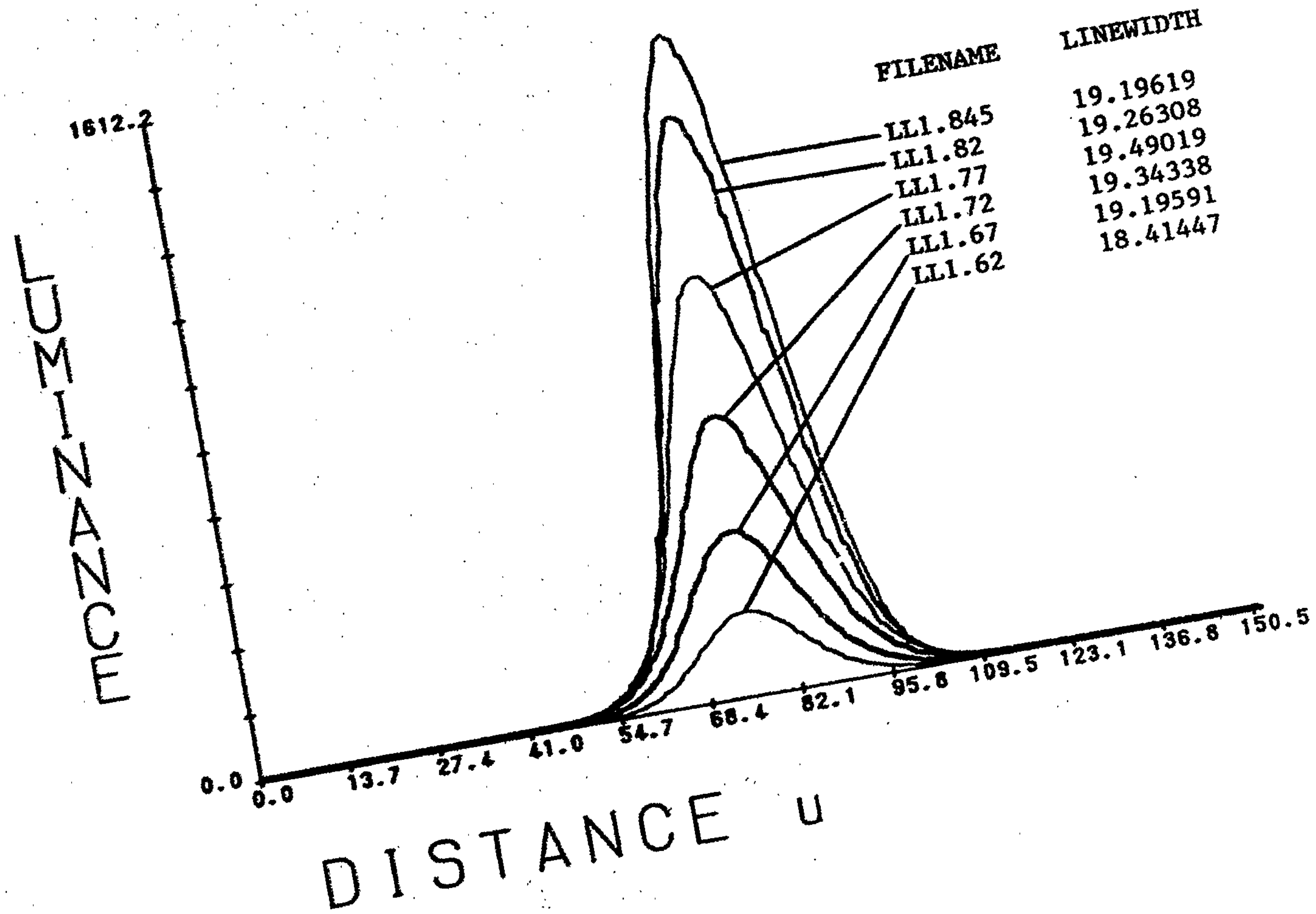
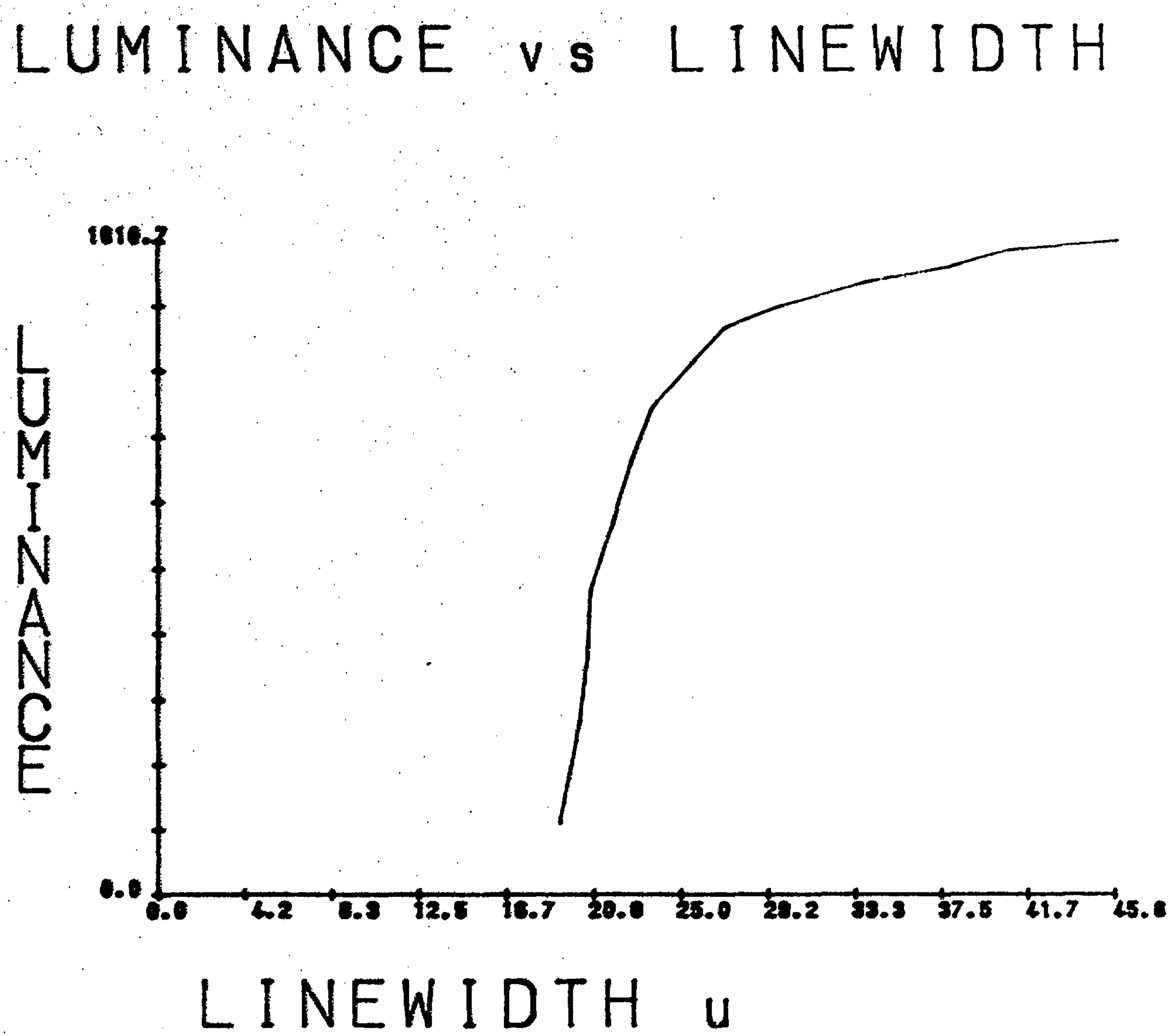
82.1
95.8
109.5
123.1
136.8
150.5


LL1.9
LINEWIDTH = 29.50902
LUMINANCE
1445.0
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

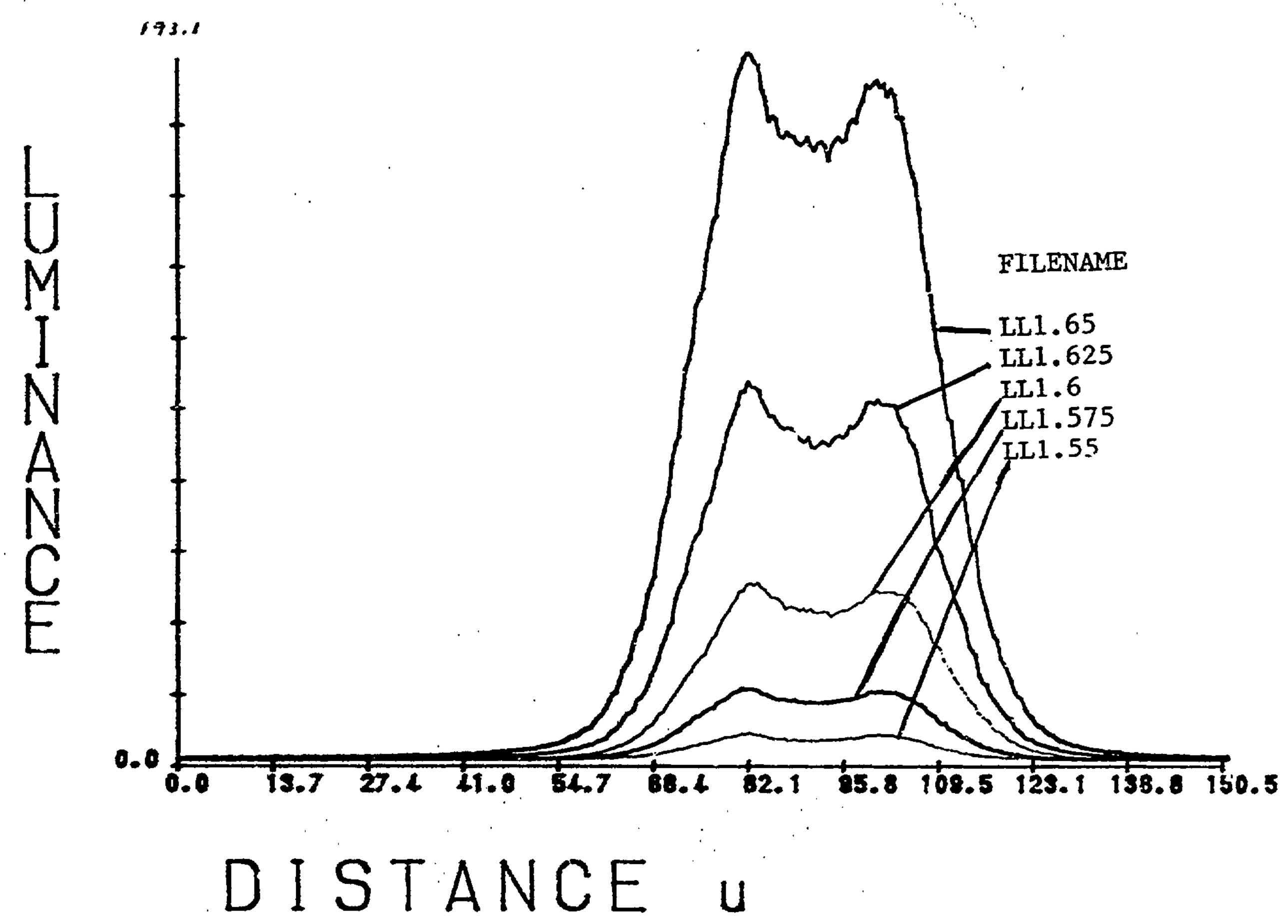

LL2
LINEWIDTH = 45.82024
LUMINANCE
0.0
DISTANCE u

S/N 237 13 KV ANODE



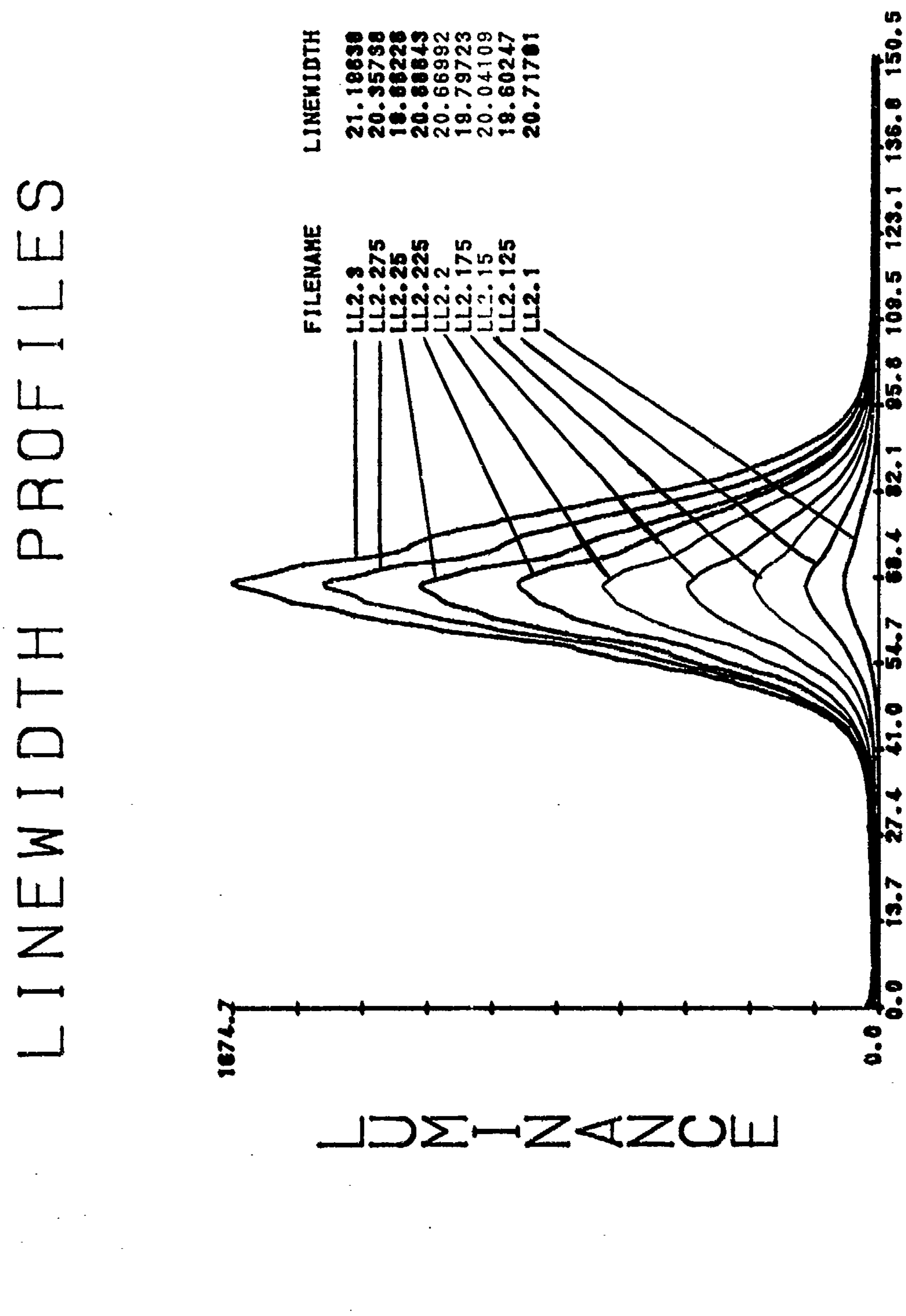

LUMINANCE vs LINEWIDTH
LUMINANCE
0.0
0.0
4.2
8.3
12.5
16.7
20.8
25.0
29.2
33.3
37.5
41.7
45.8
LINEWIDTH u

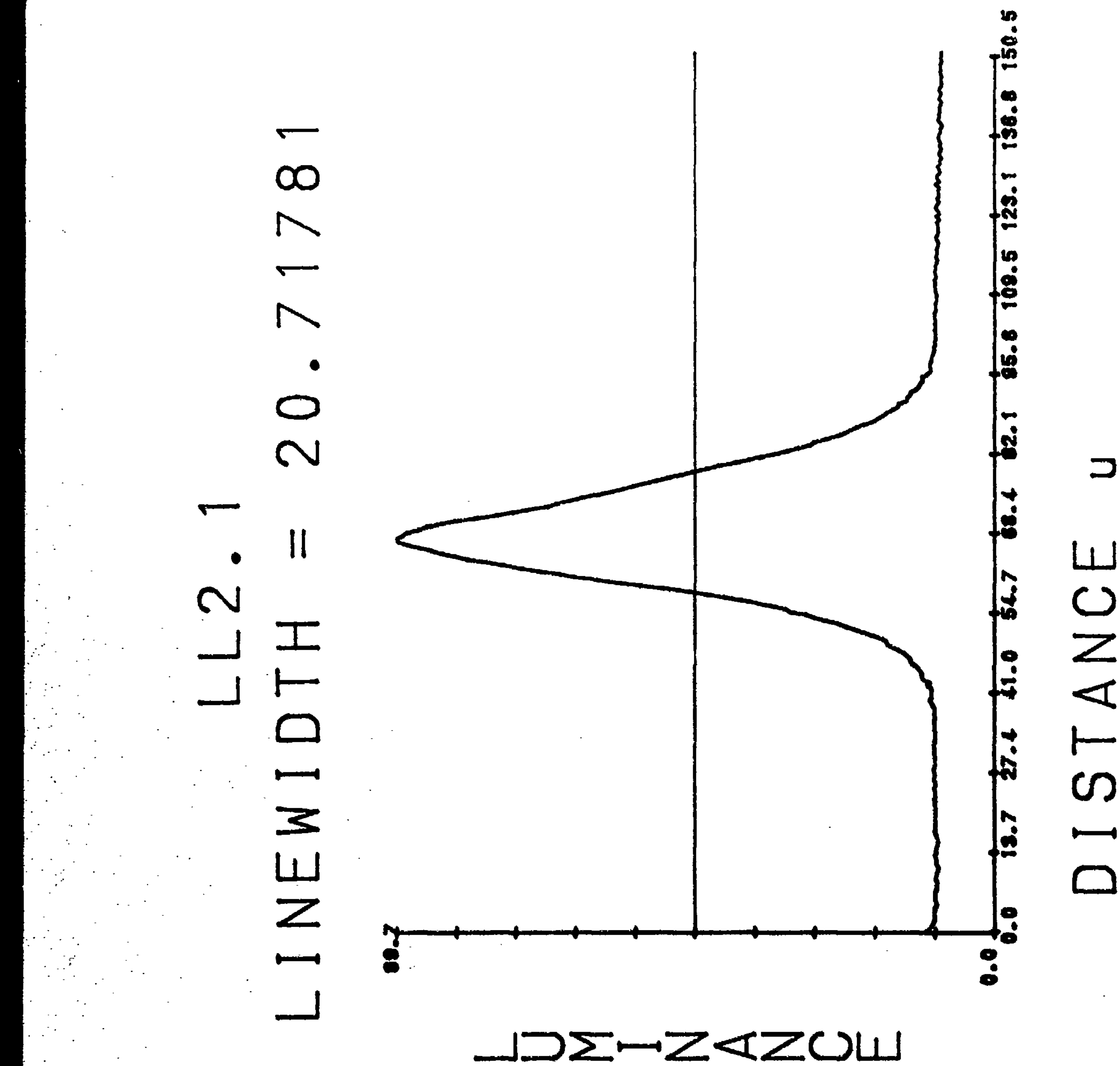
S/N 004 SCAN LINE CONTRAST

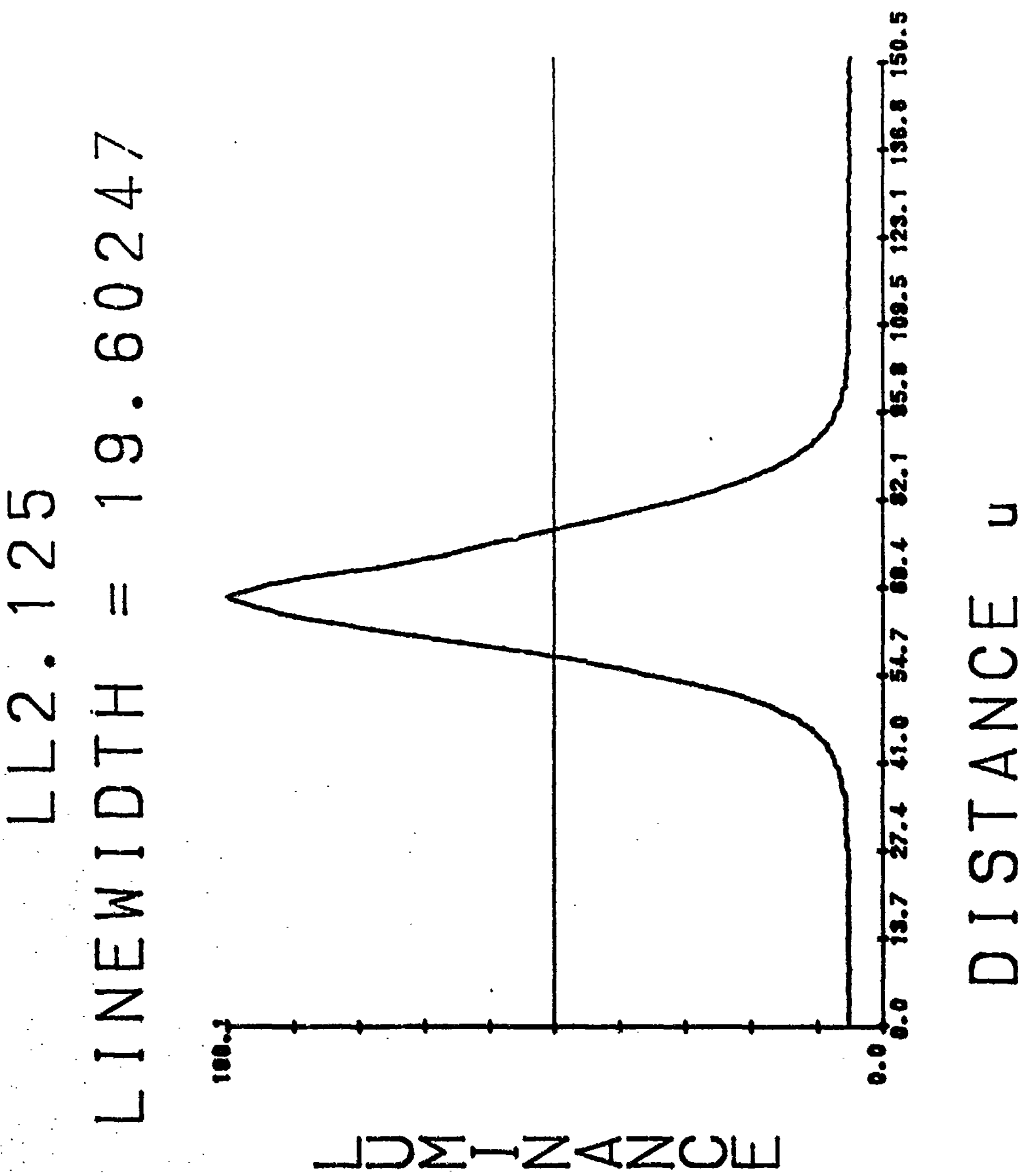


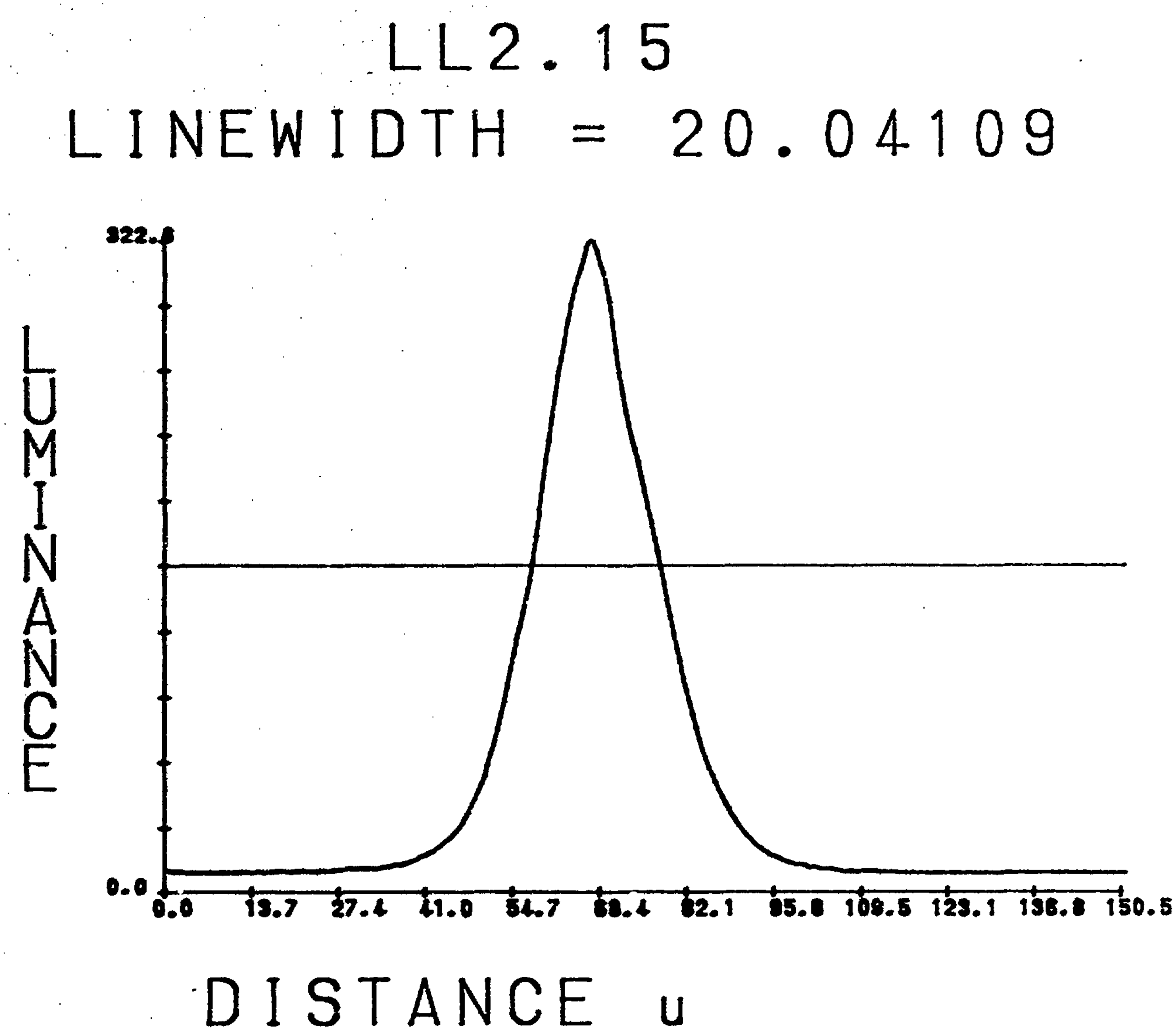
KAISER (HUGHES 1380) CRT

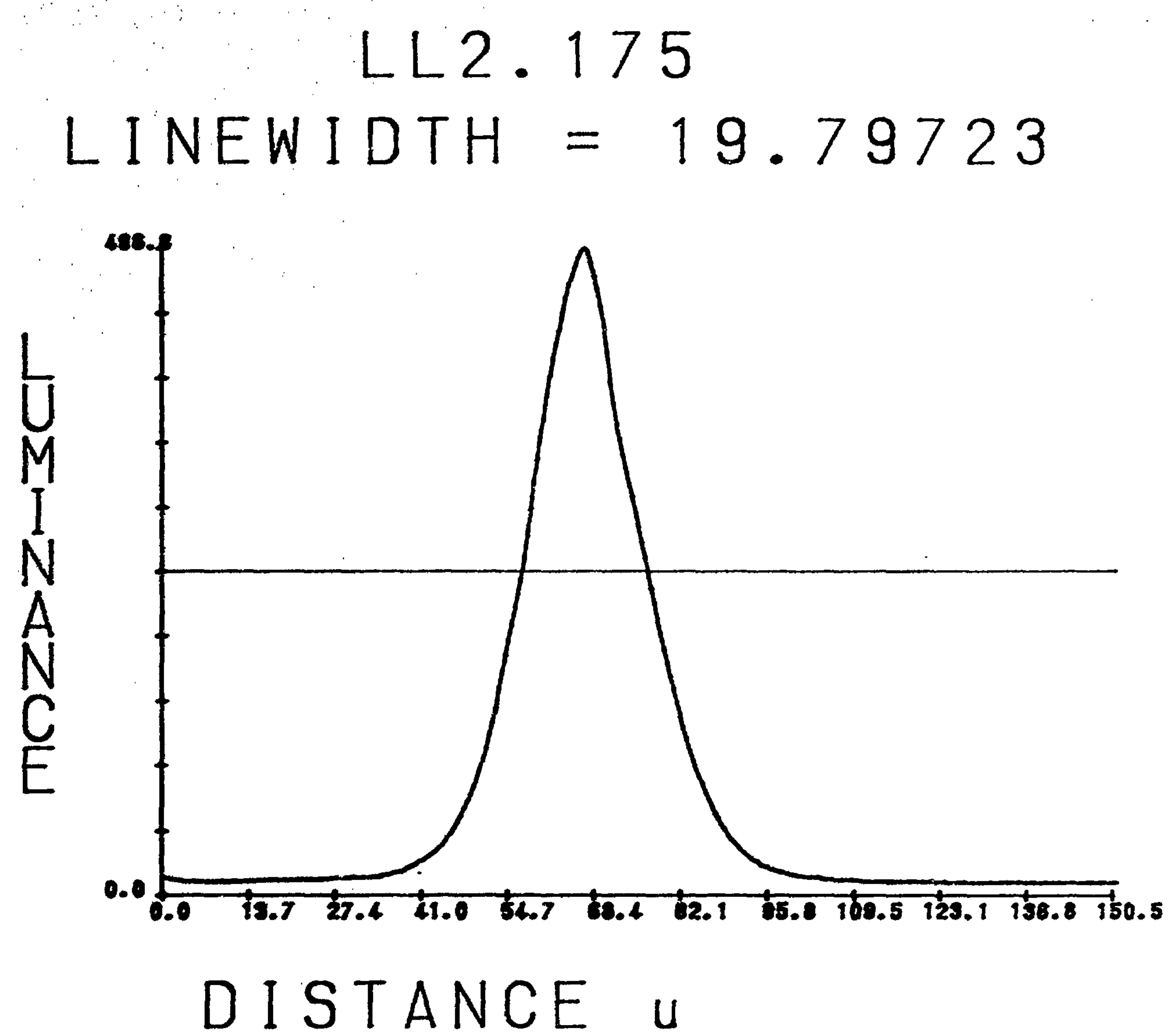
S/N 001


LINEWIDTH PROFILES
FILENAME
LINEWIDTH
LL2.275
LL2.25
LL2.225
LL2.2
LL2.175
LL2.125
LL2.1
20.66992
19.79723
20.04109
19.60247
LUMINANCE
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
82.1
95.8
109.5
123.1
136.8
150.5


LL2.1
LINEWIDTH = 20.71781
LUMINANCE
89.7
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

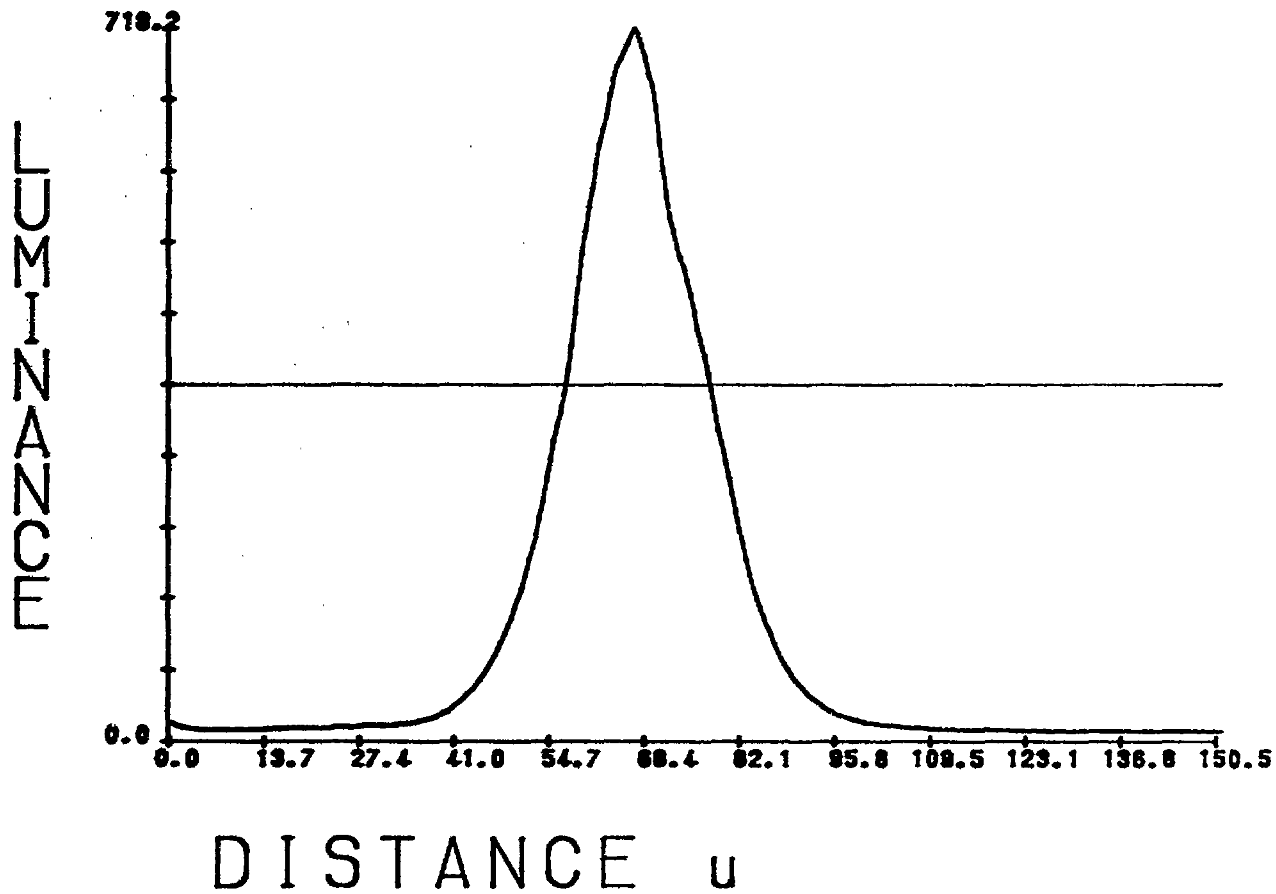

LL2.125
LINEWIDTH = 19.60247
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

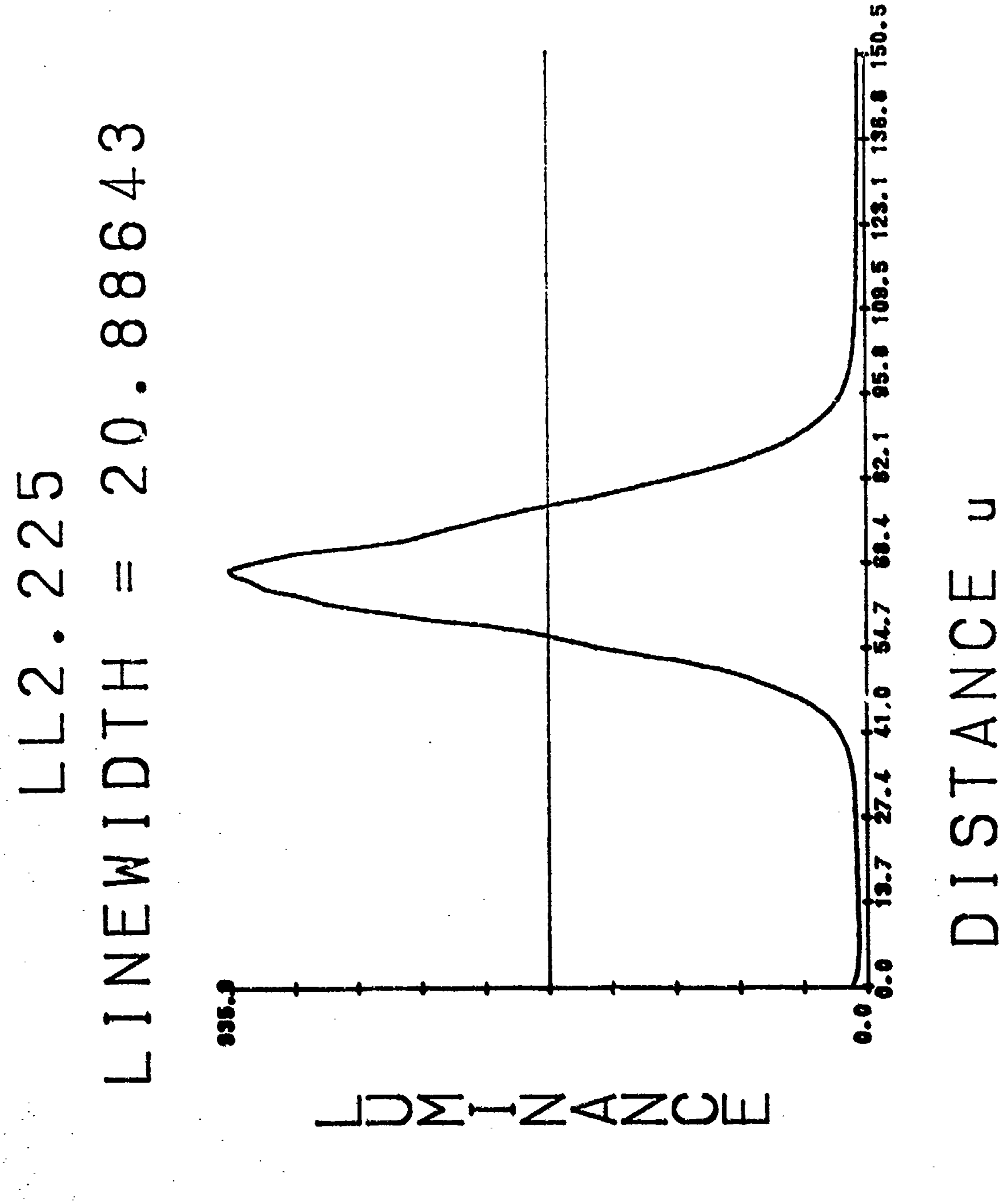

LL2.15
LINEWIDTH = 20.04109
LUMINANCE
0.0
0.0 13.7 27.4 41.0 54.7 68.4 82.1 95.8 109.5 123.1 136.8 150.5
DISTANCE u


LL2.175
LINEWIDTH = 19.79723
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

LL2.2

LINEWIDTH = 20.66992




LL2.225
LINEWIDTH = 20.88643
LUMINANCE
DISTANCE u
0.0
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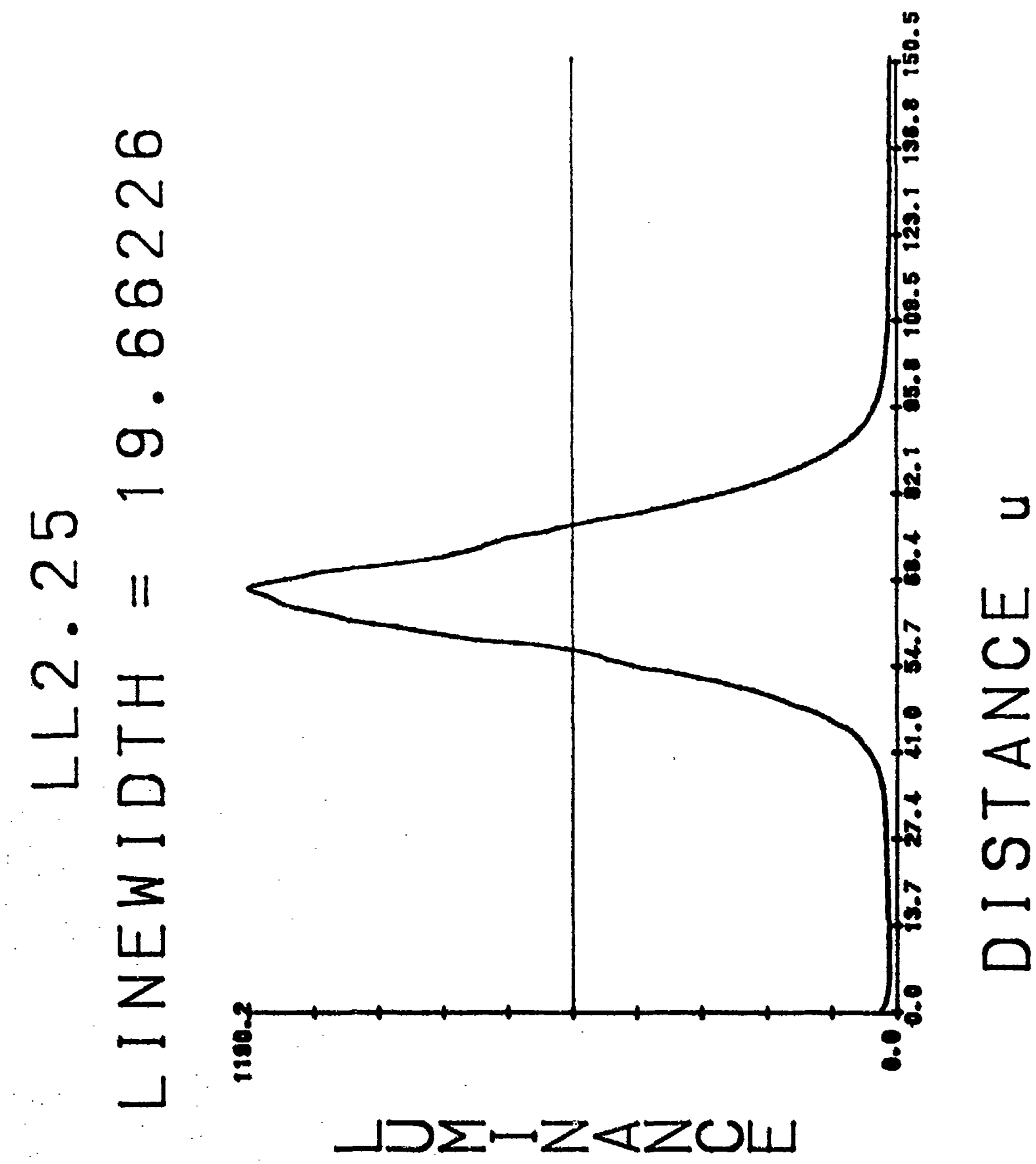
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5



LL2.25
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LUMINANCE
DISTANCE u
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41.0
54.7
68.4
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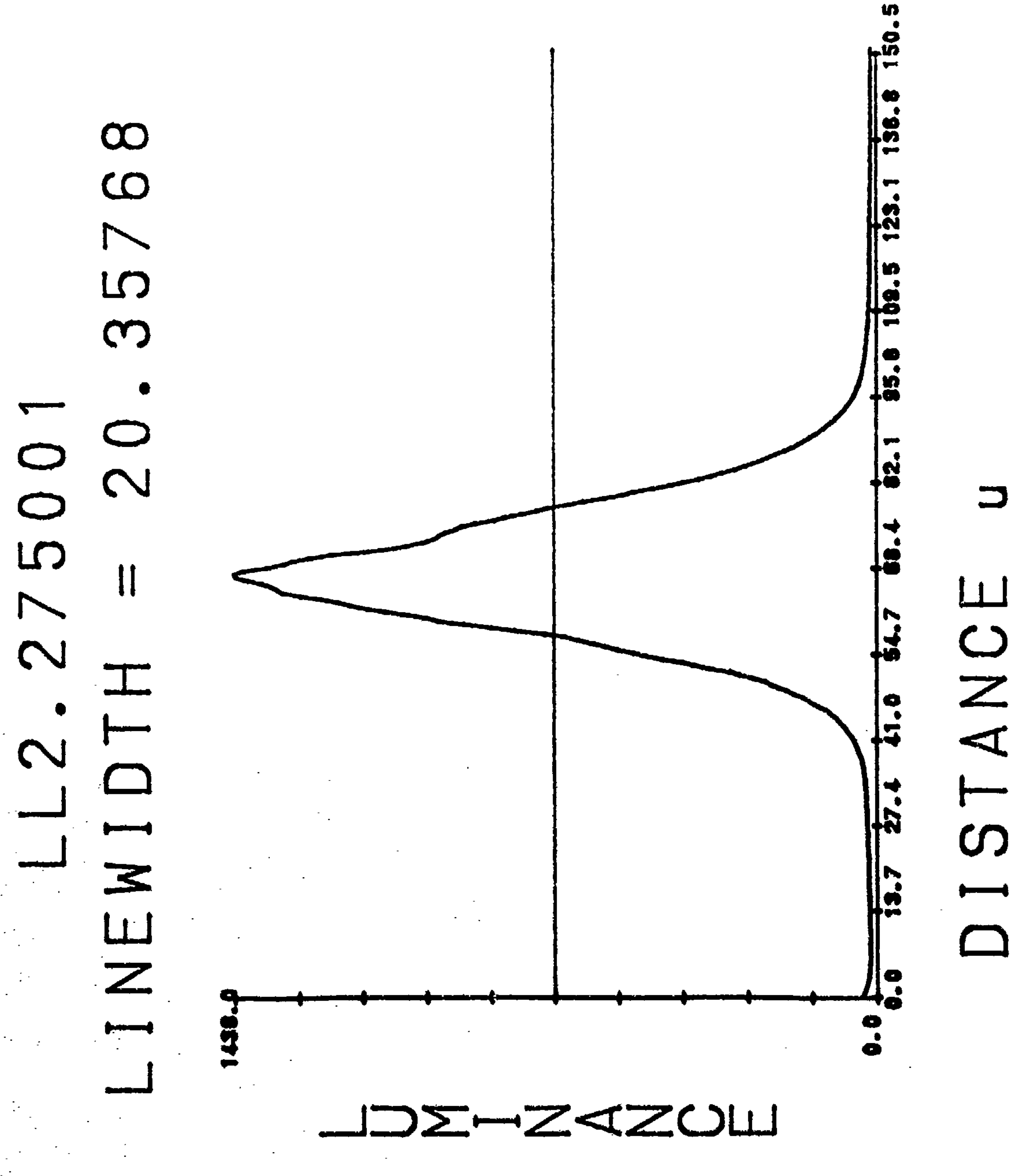
95.8
109.5
123.1
136.8
150.5


LL2.275001
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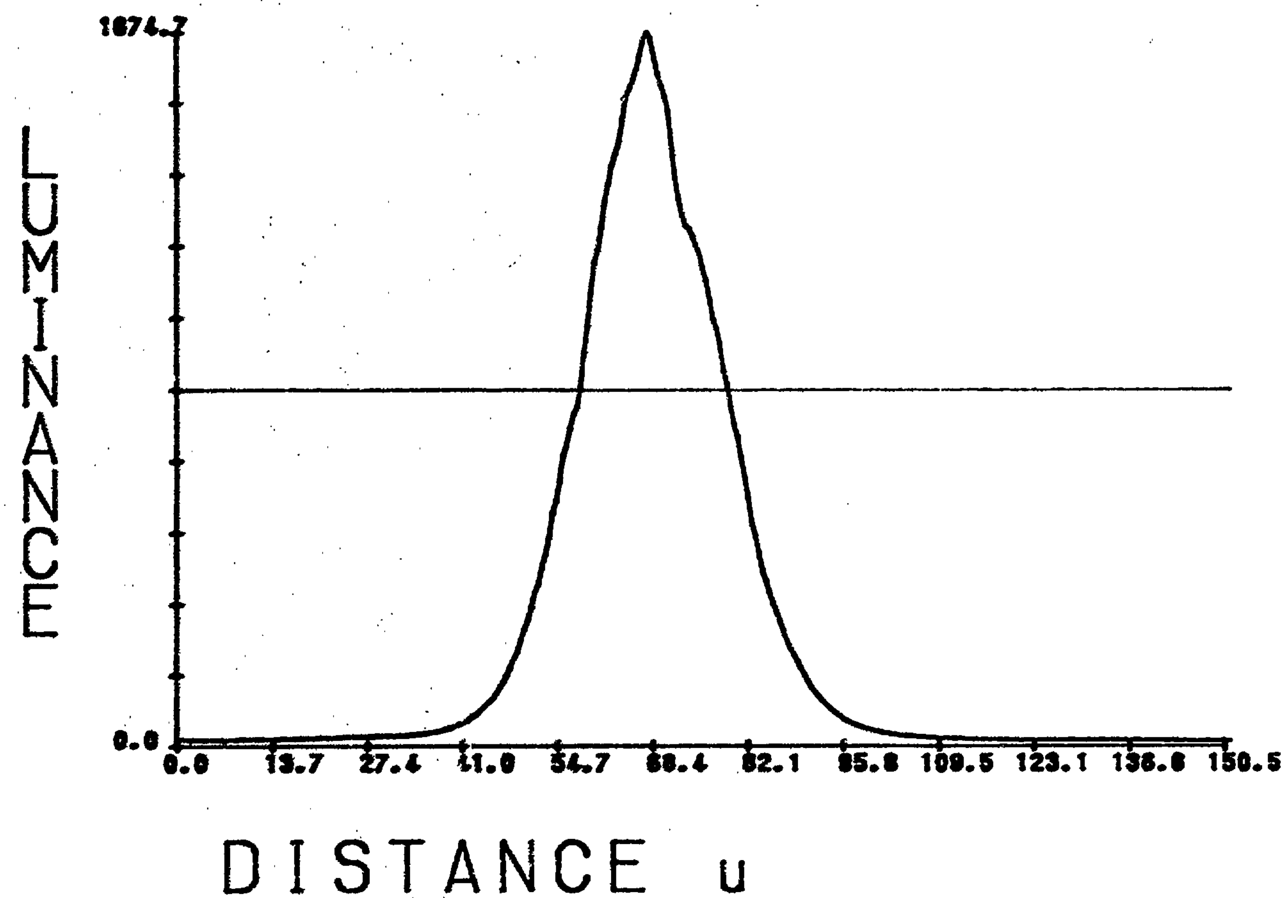
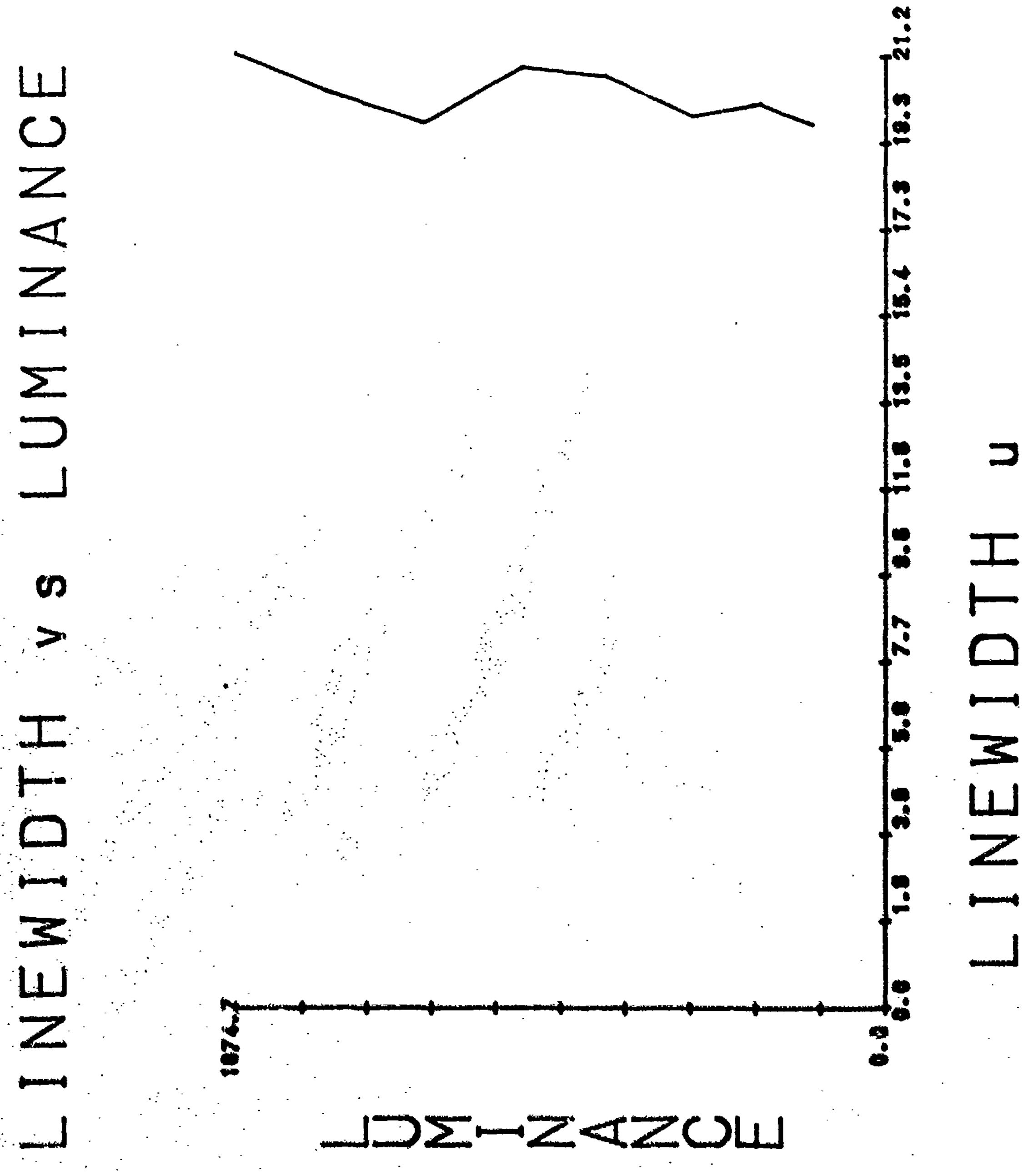
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

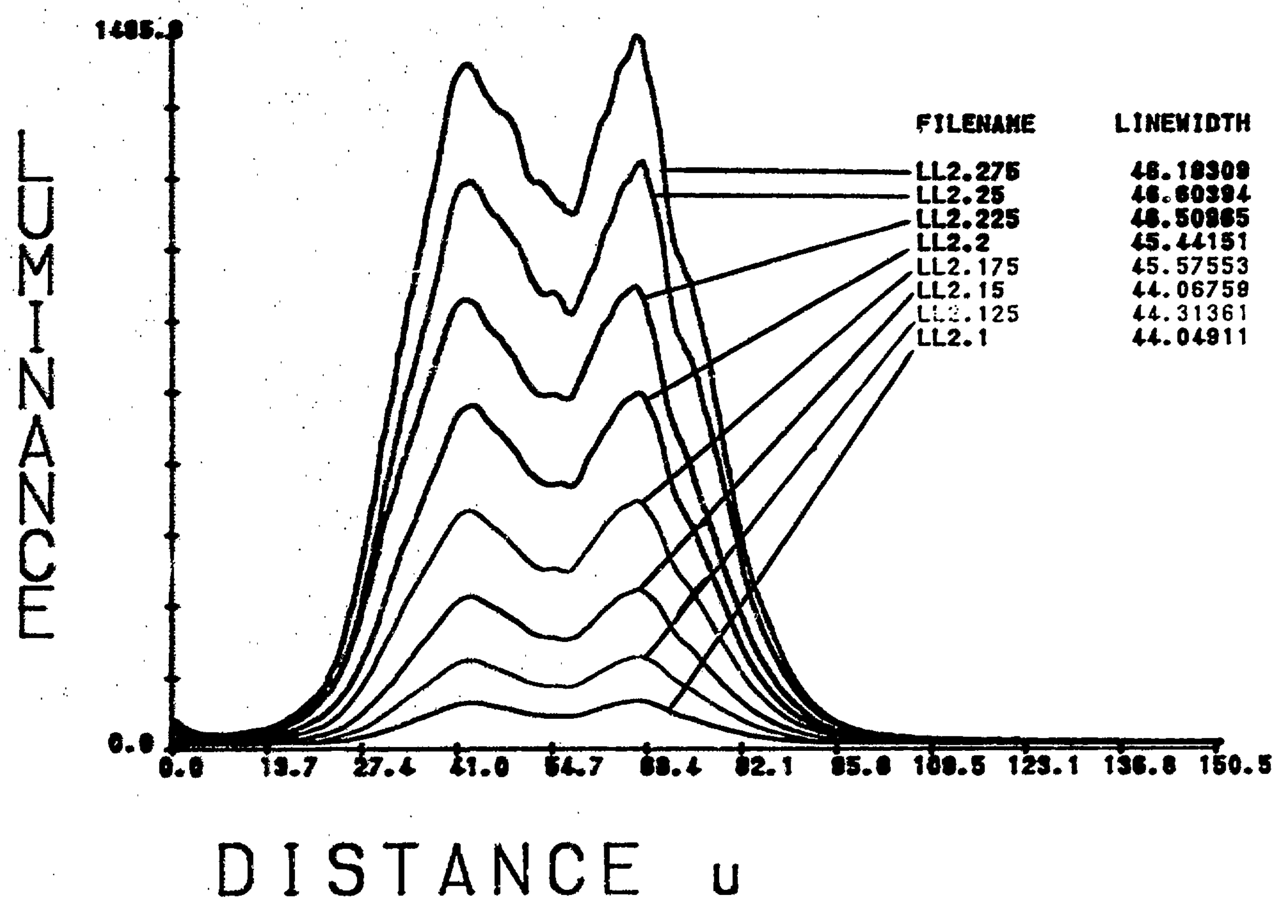
LL2.3

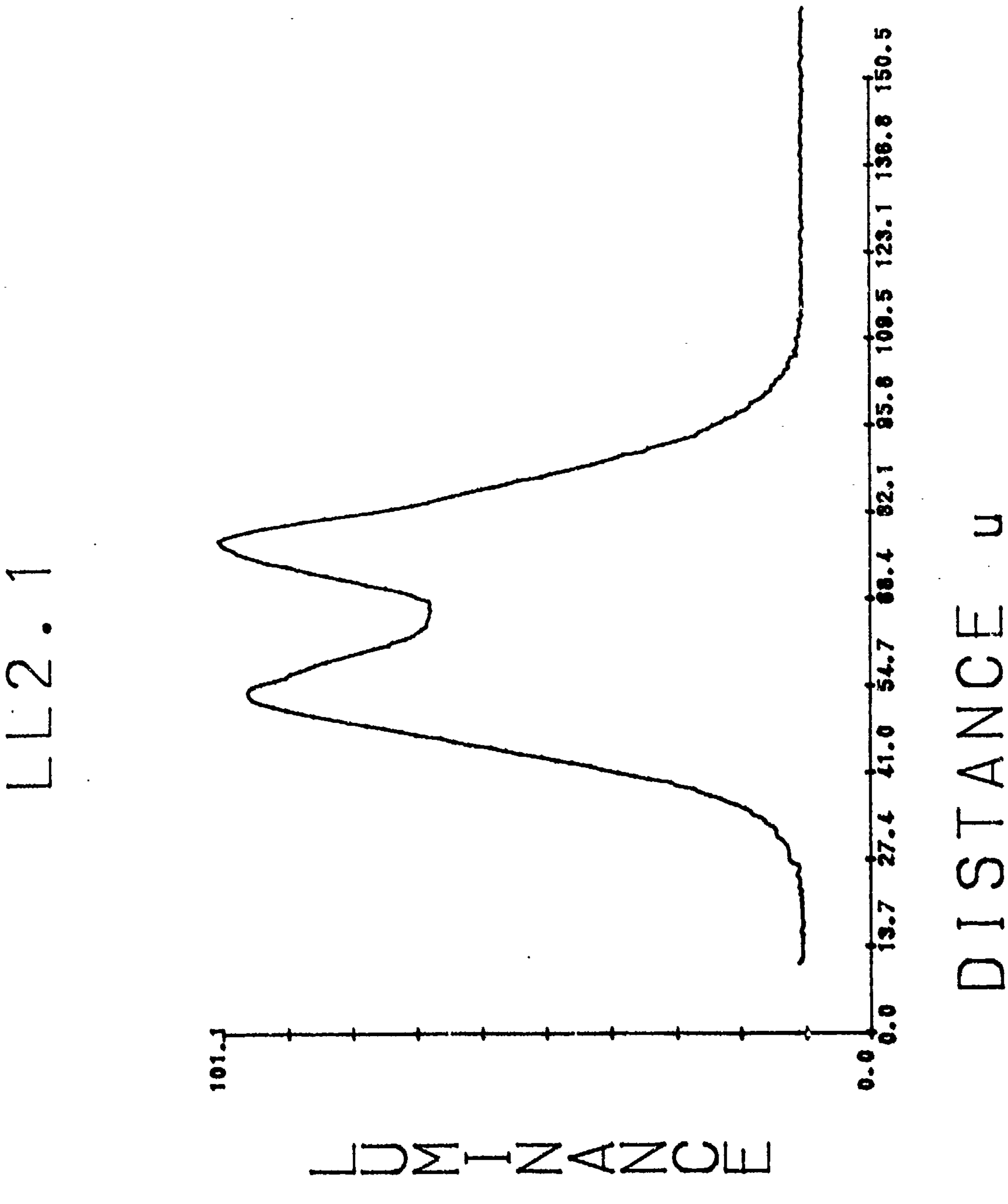
LINEWIDTH = 21.19638



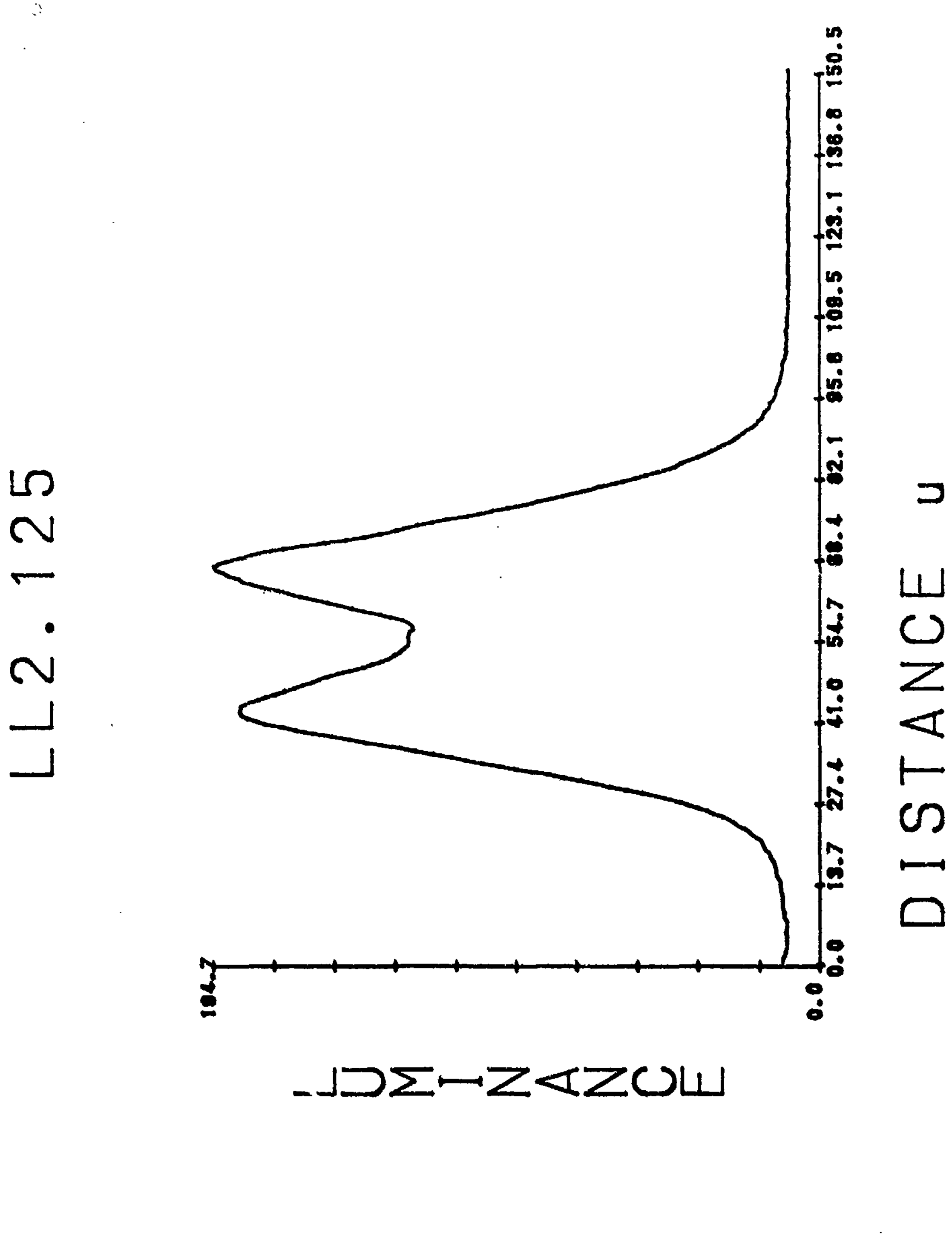

LINEWIDTH vs LUMINANCE
LUMINANCE
LINEWIDTH u
0.0
21.2

SCAN LINE STRUCTURE





LL2.1
LUMINANCE
101.1
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u



LL2.125
LUMINANCE
DISTANCE u
0.0
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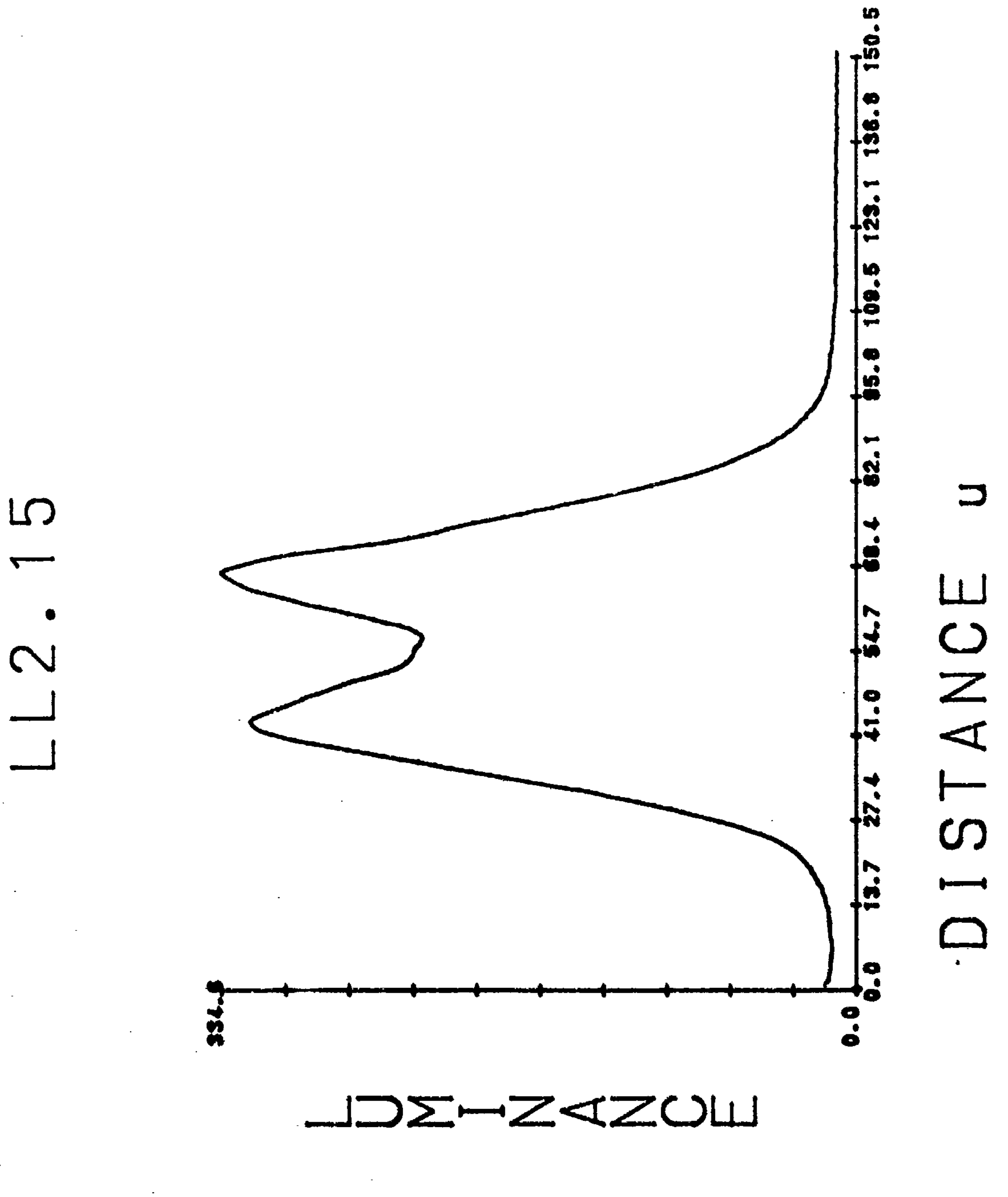
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


LL2.15
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
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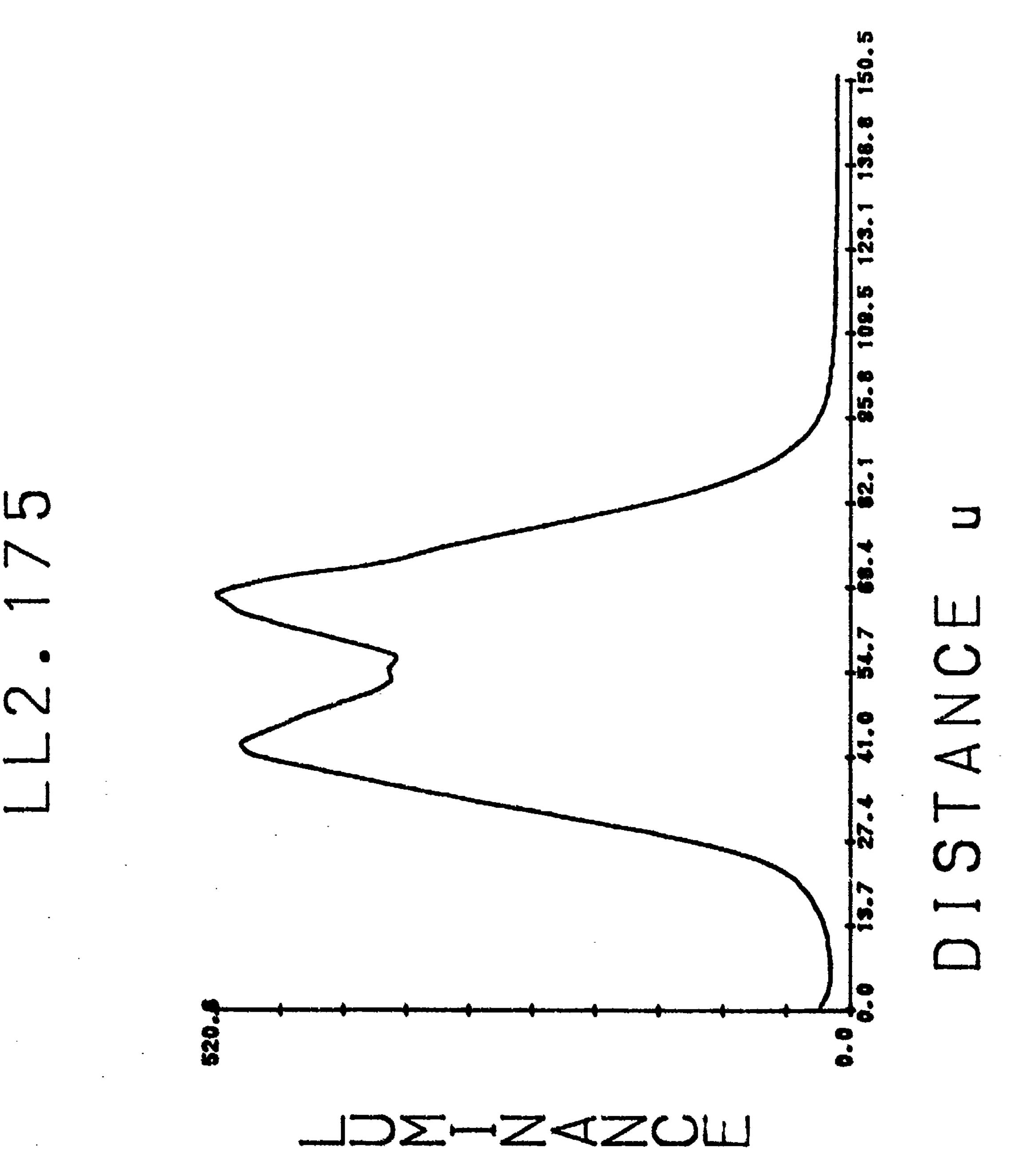
123.1
136.8
150.5


LL2.175
DISTANCE u
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
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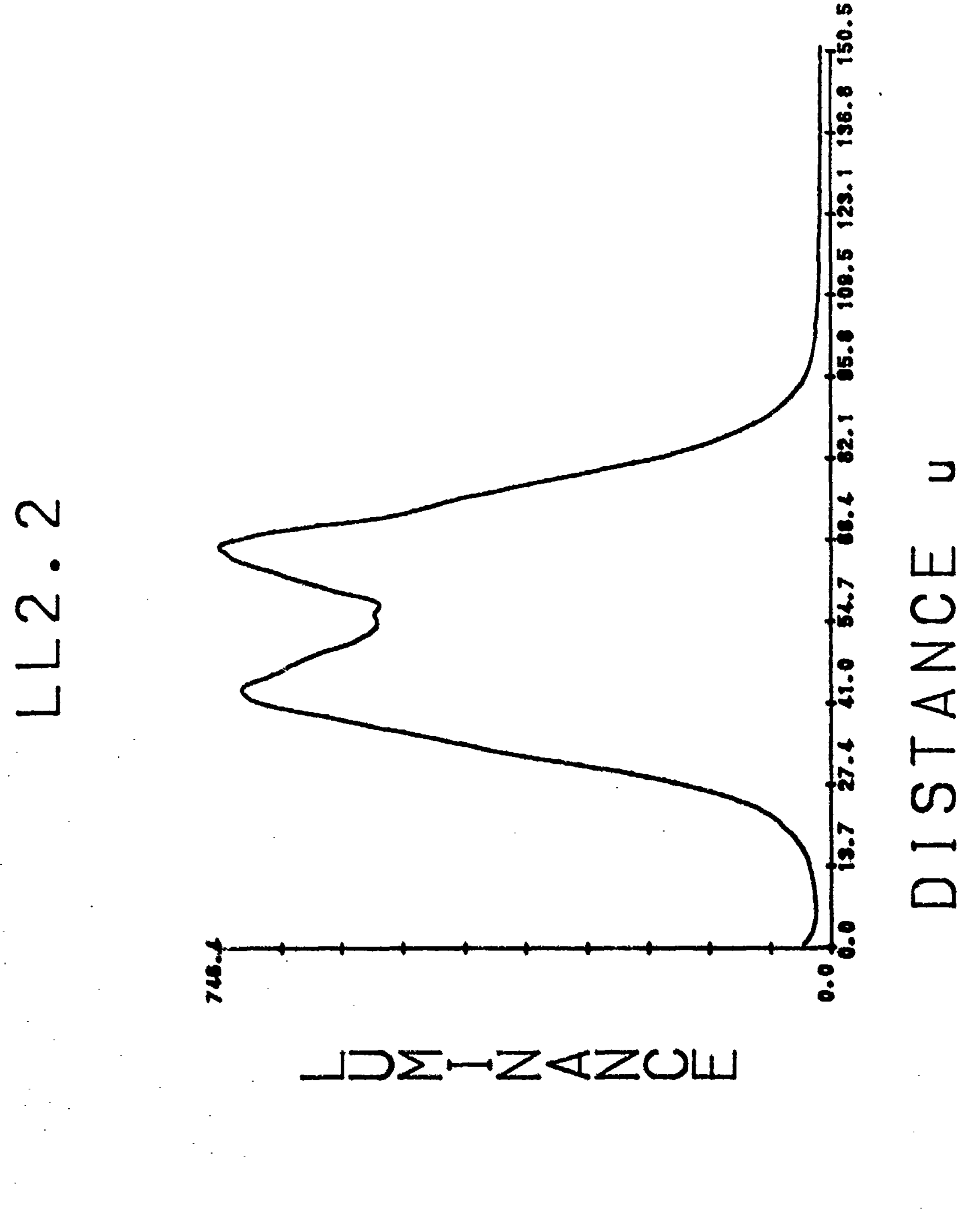
123.1
136.8
150.5


LL2.2
LUMINANCE
0.0
DISTANCE u
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41.0
54.7
68.4
82.1
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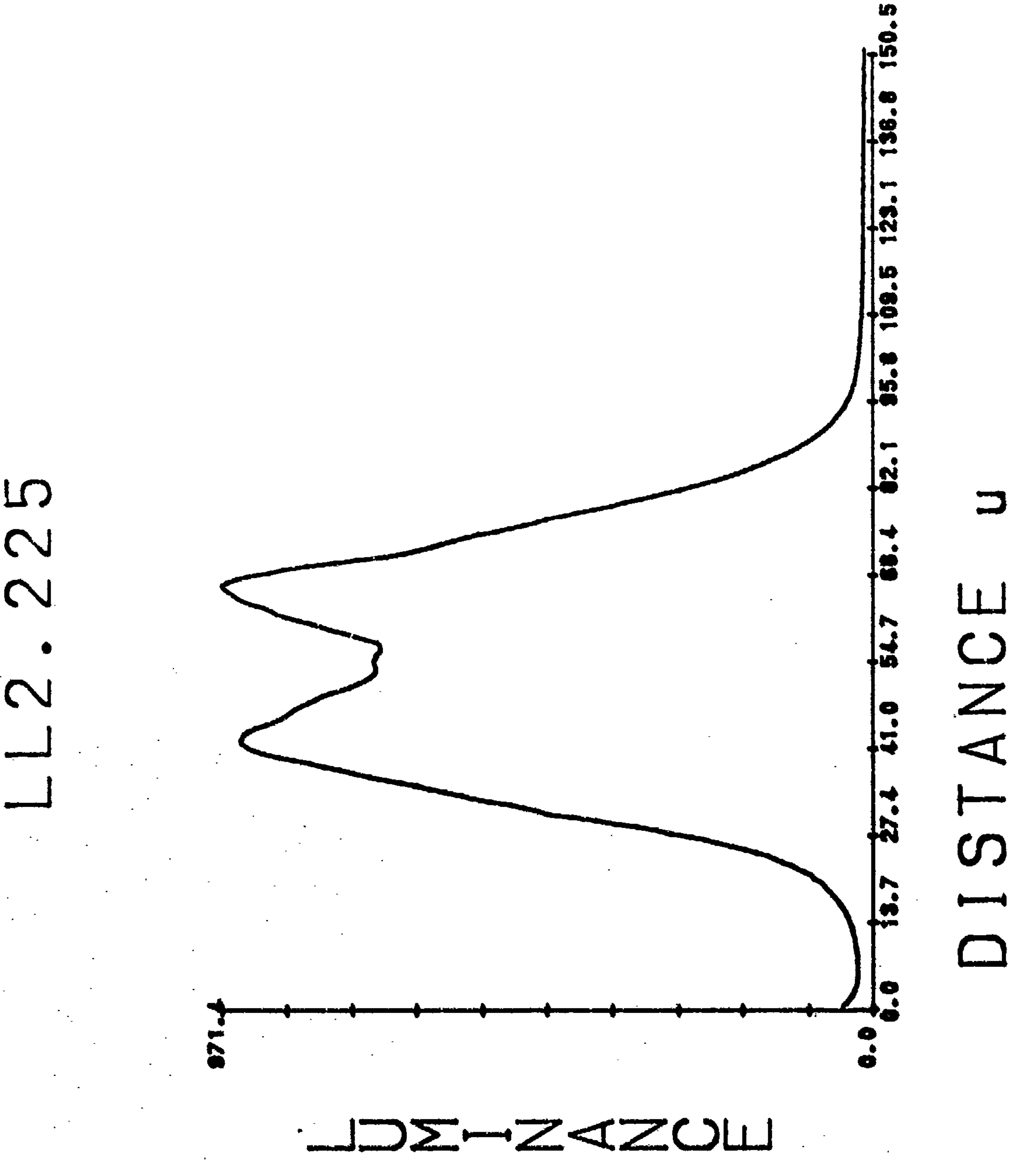
123.1
136.8
150.5


LL2.225
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971.4
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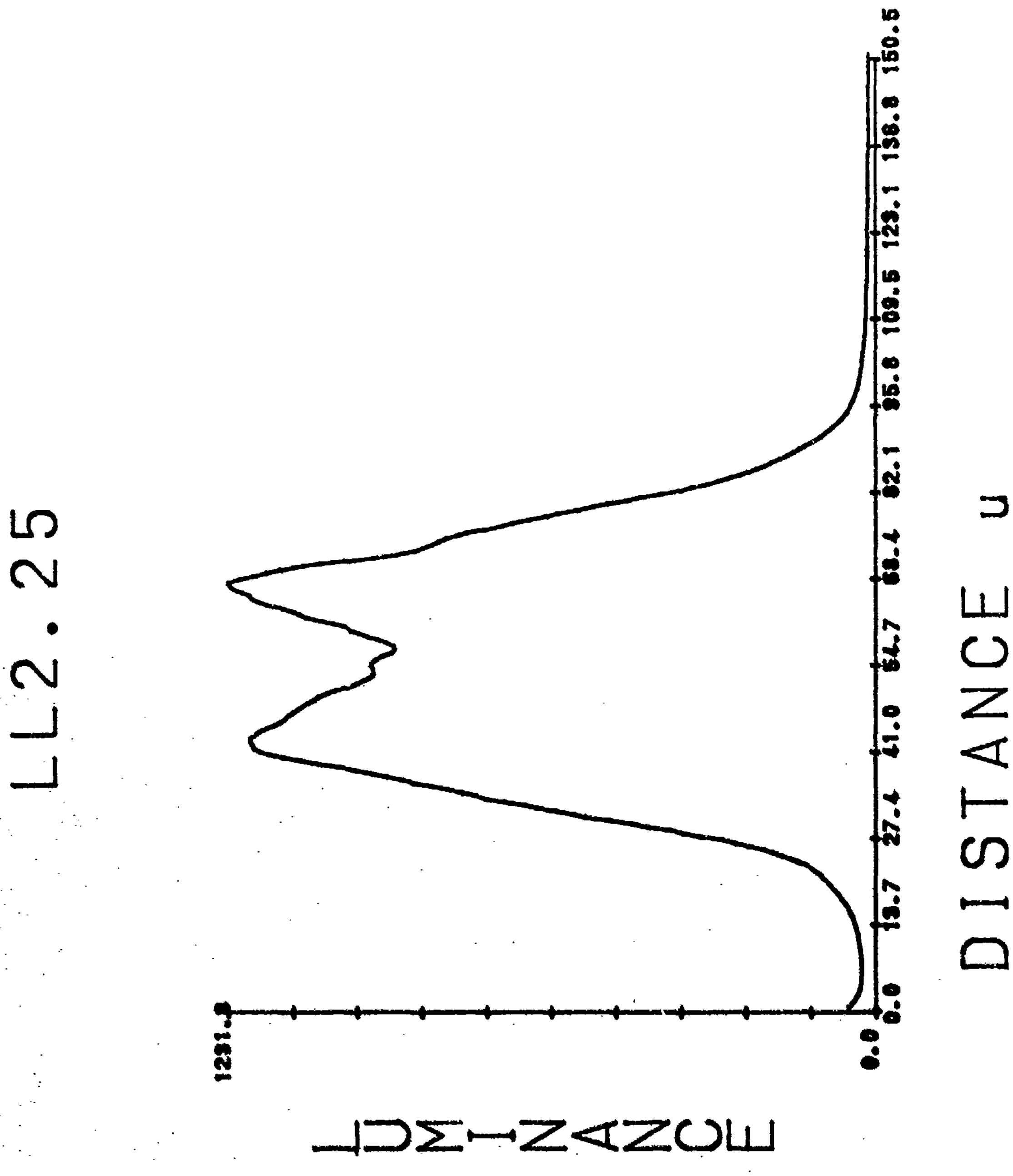
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


LL2.25
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
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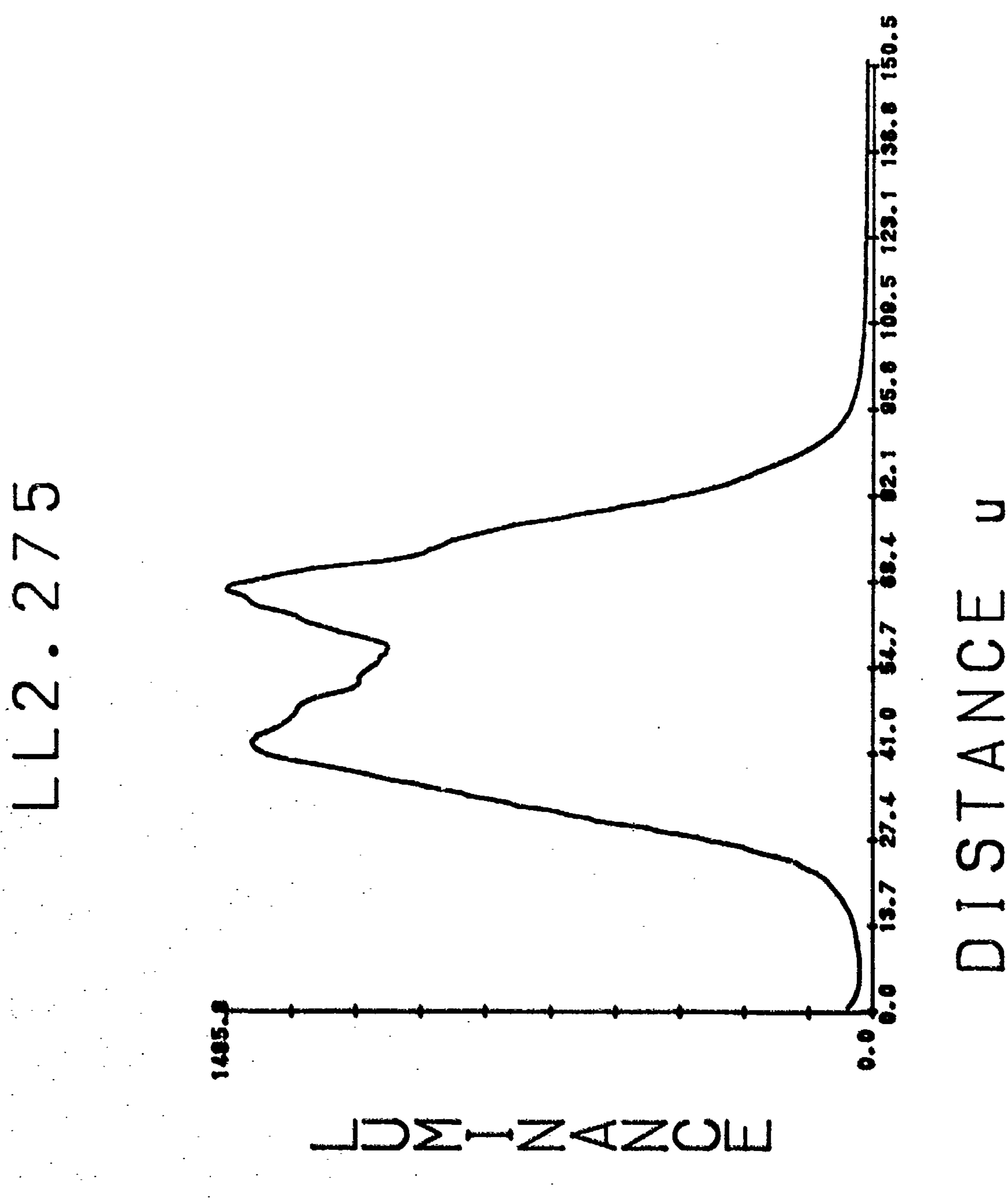
123.1
136.8
150.5


LL2.275
LUMINANCE
1485.9
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
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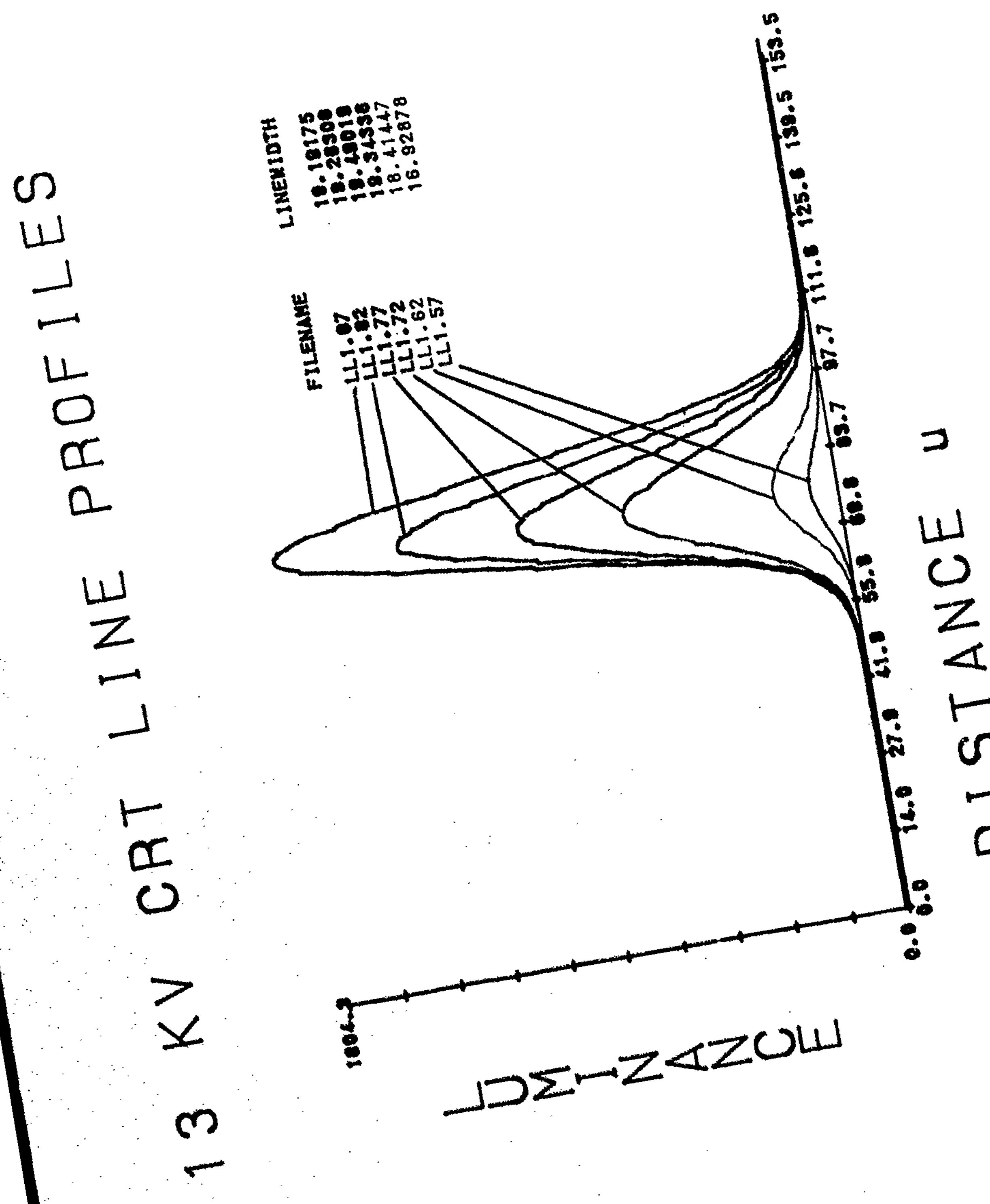
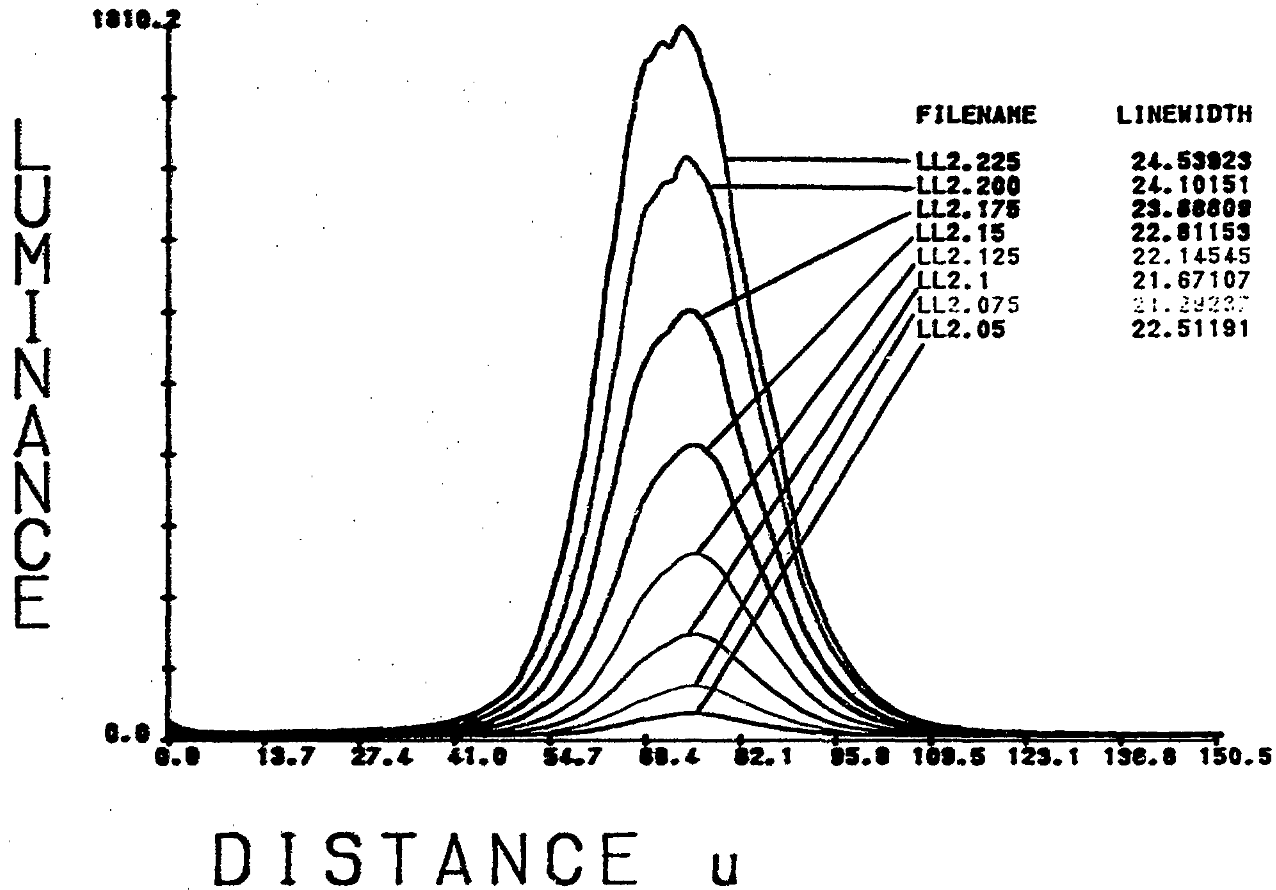
123.1
136.8
150.5

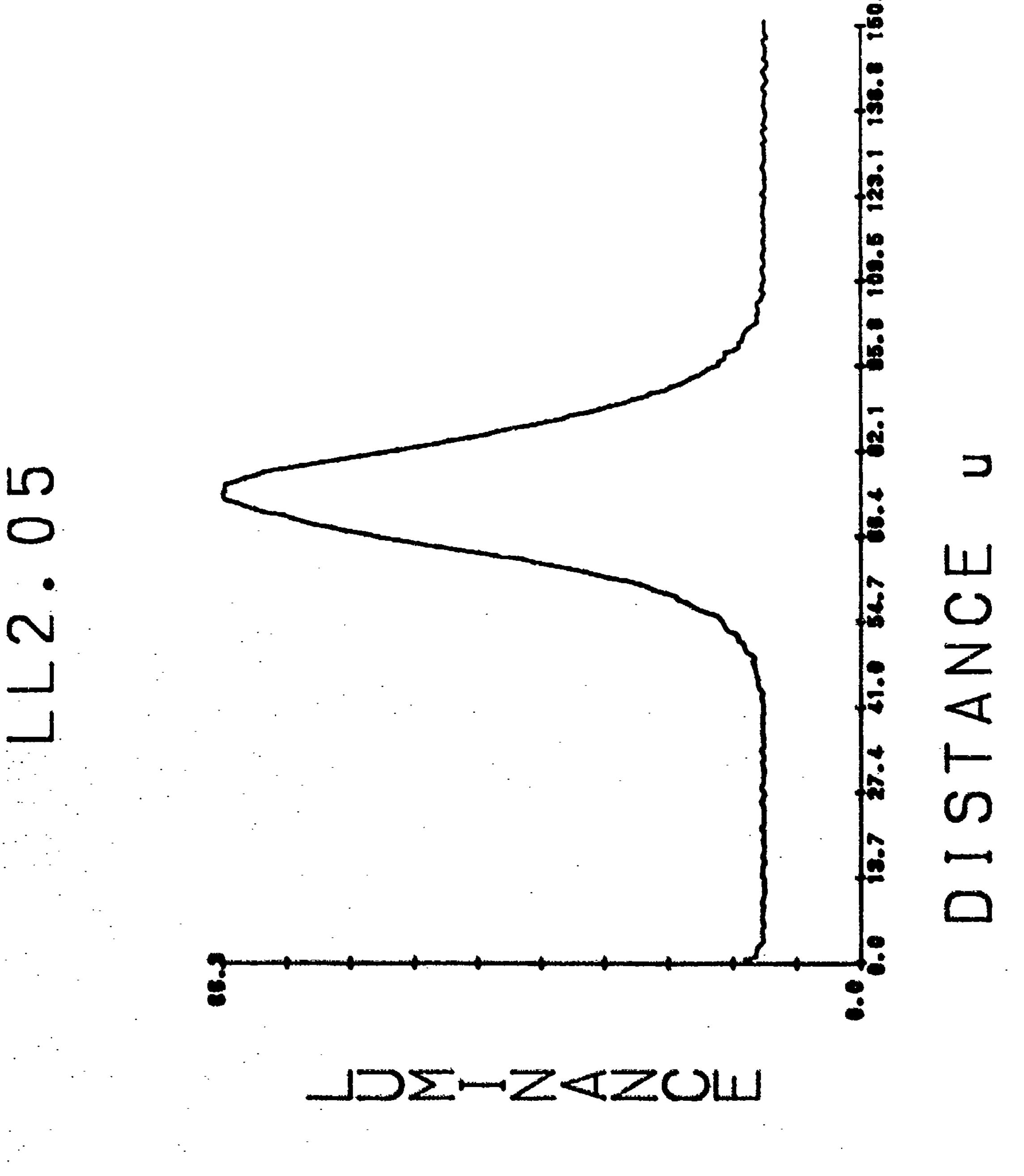

13 KV CRT LINE PROFILES
FILENAME
LL1.87
LL1.82
LL1.77
LL1.72
LL1.62
LL1.57
LINEWIDTH
18.19175
18.28508
18.48018
18.34336
18.41447
16.92878
LUMINANCE
DISTANCE u
0.0
14.0
27.9
41.9
55.8
69.8
83.7
97.7
111.6
125.6
139.5
153.5

KAISER (HUGHES 1380) CRT

S/N 002

LINEWIDTH PROFILES




LL2.05
DISTANCE u
LUMINANCE
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68.4
82.1
95.8
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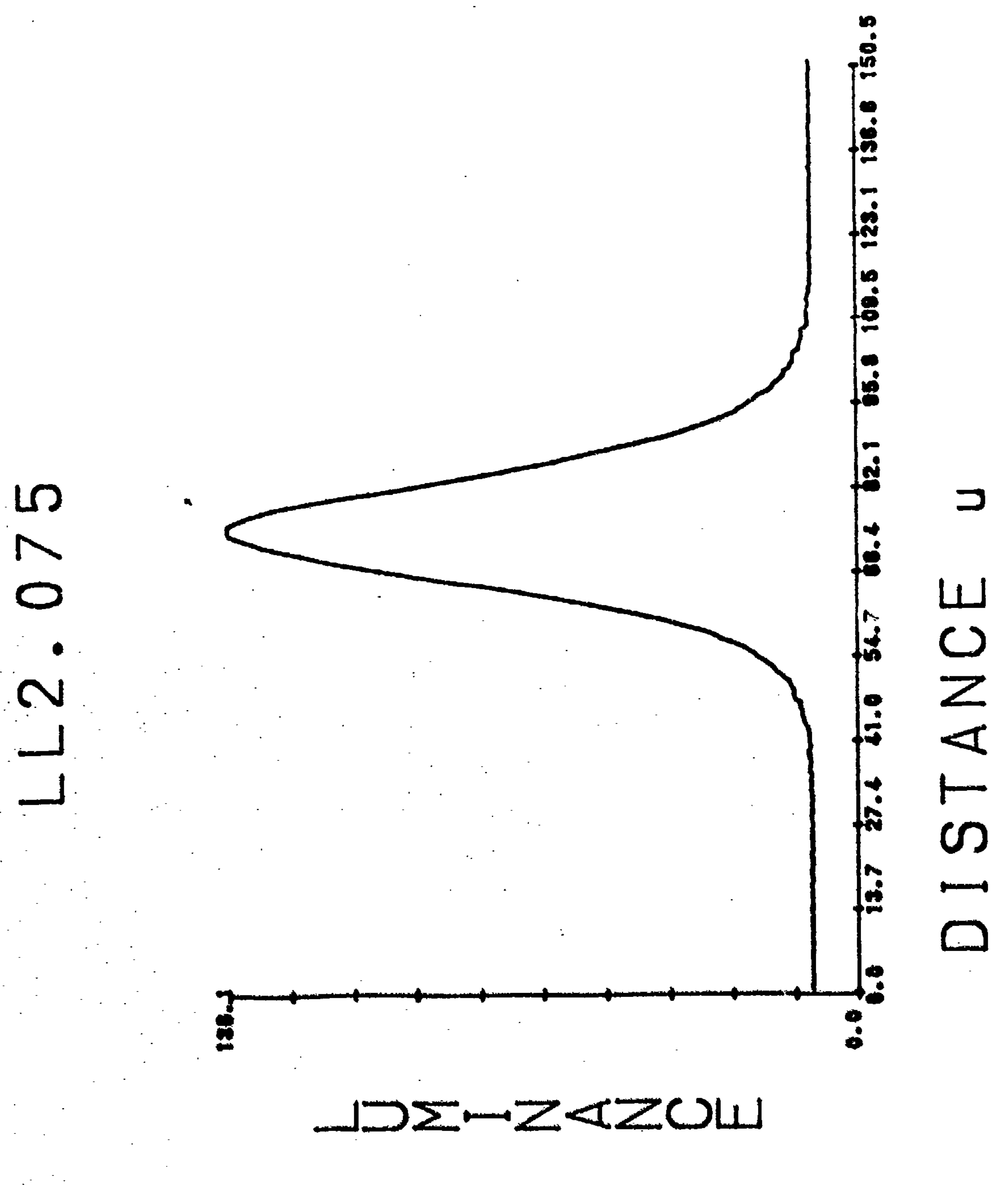
123.1
136.8
150.5


LL2.075
LUMINANCE
DISTANCE u
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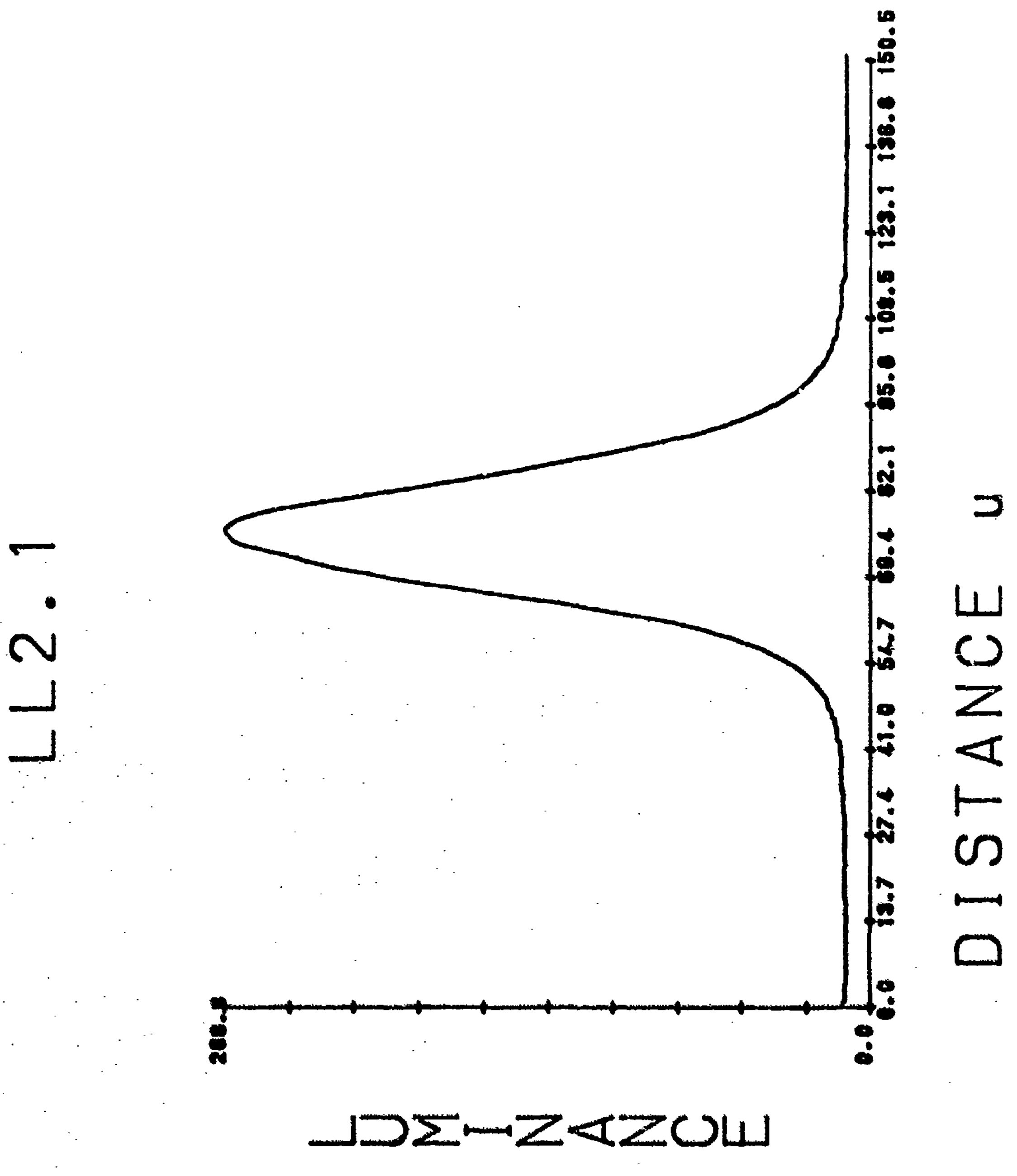
138.1
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5



LL2.1
DISTANCE u
LUMINANCE
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6.0
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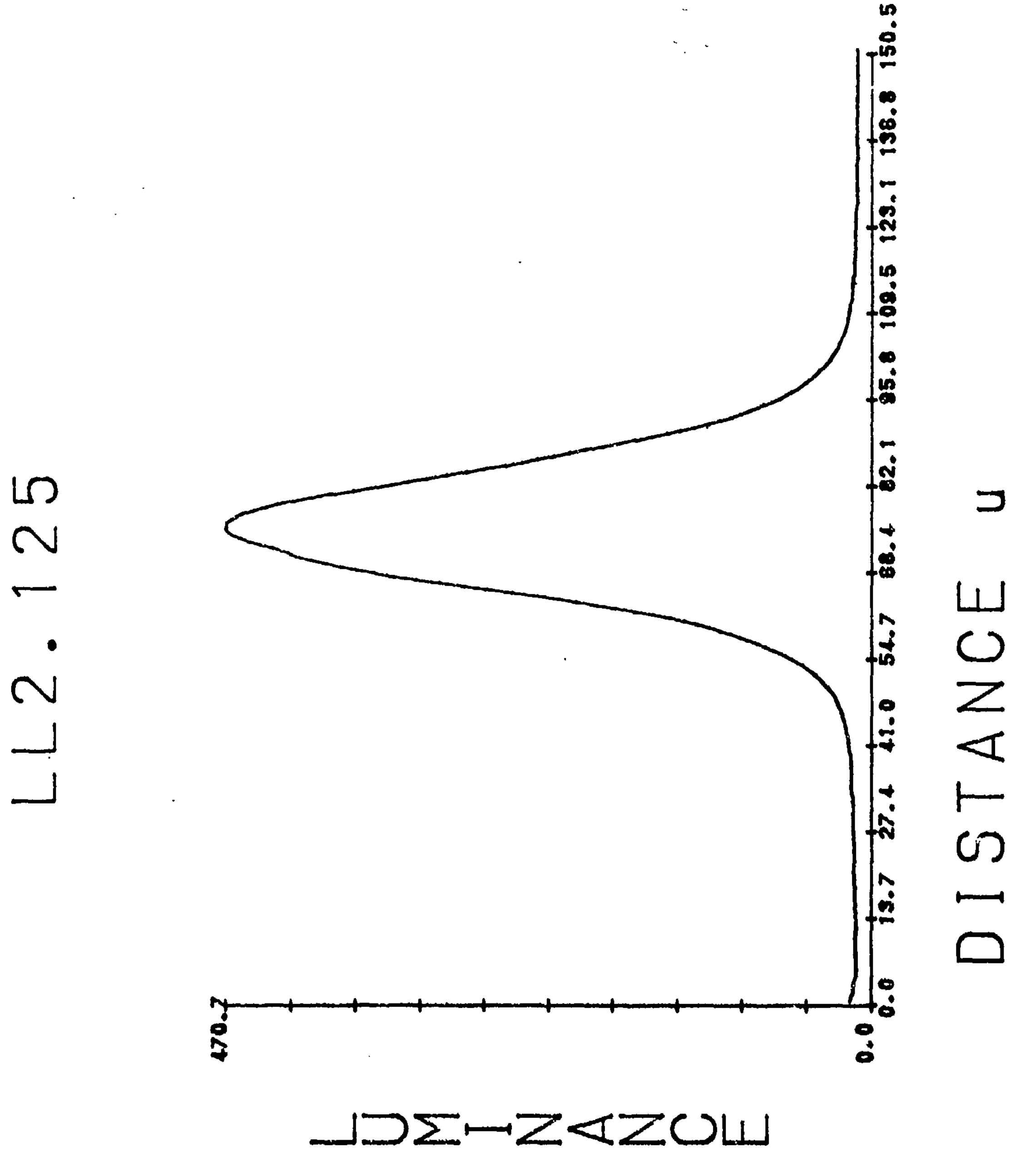
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


LL2.125
LUMINANCE
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0.0
0.0
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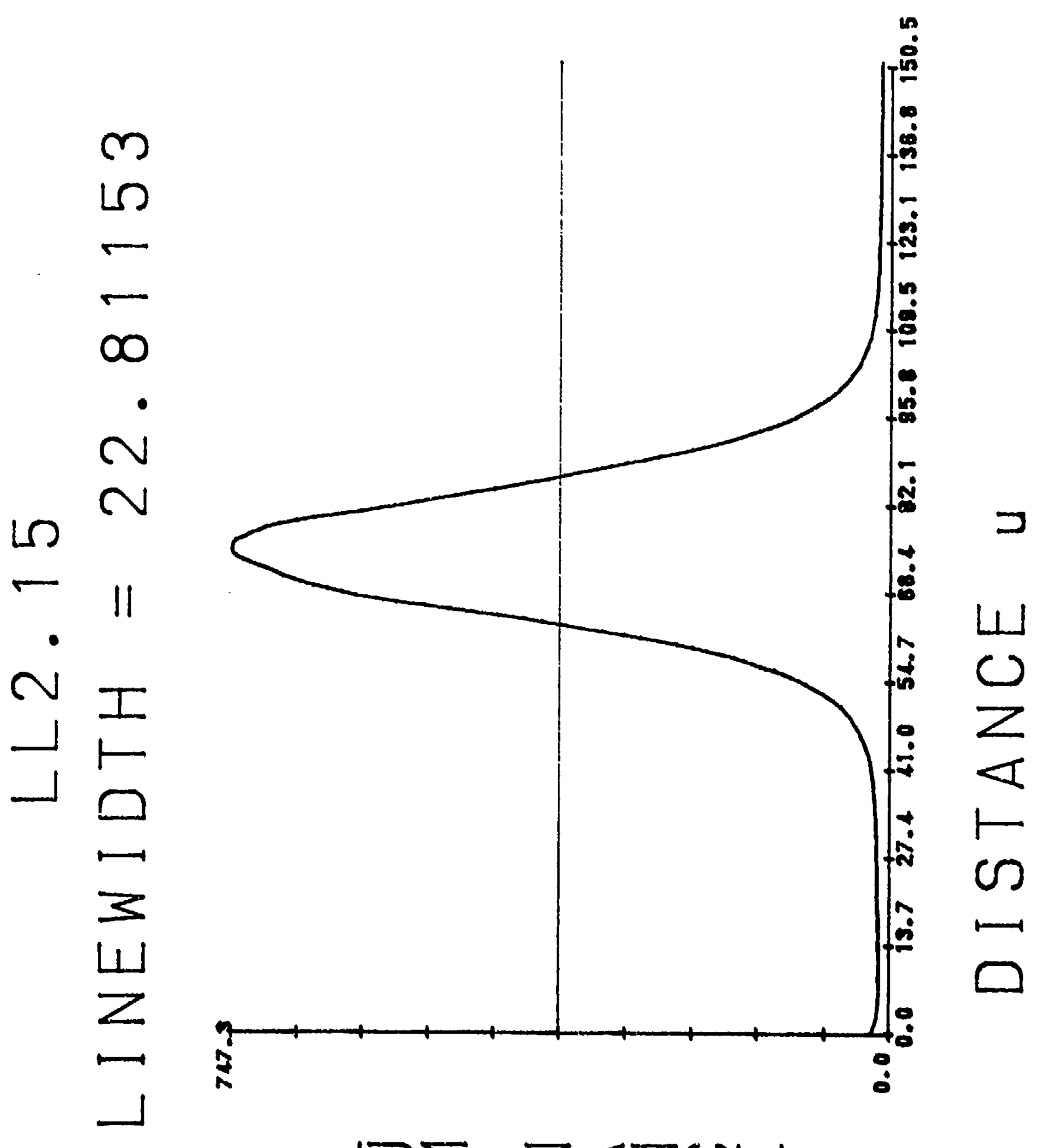
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


LL2.15
LINEWIDTH = 22.81153
LUMINANCE
747.3
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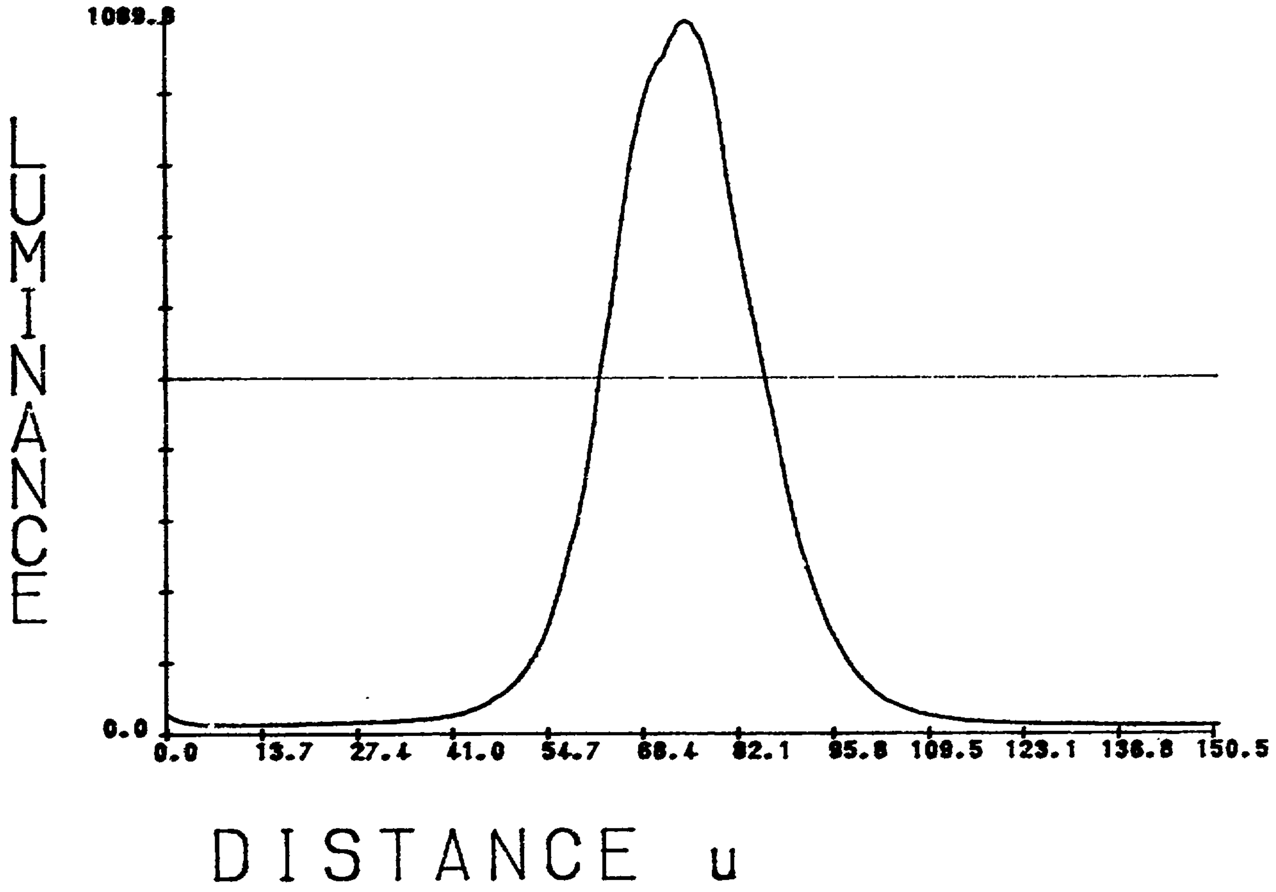
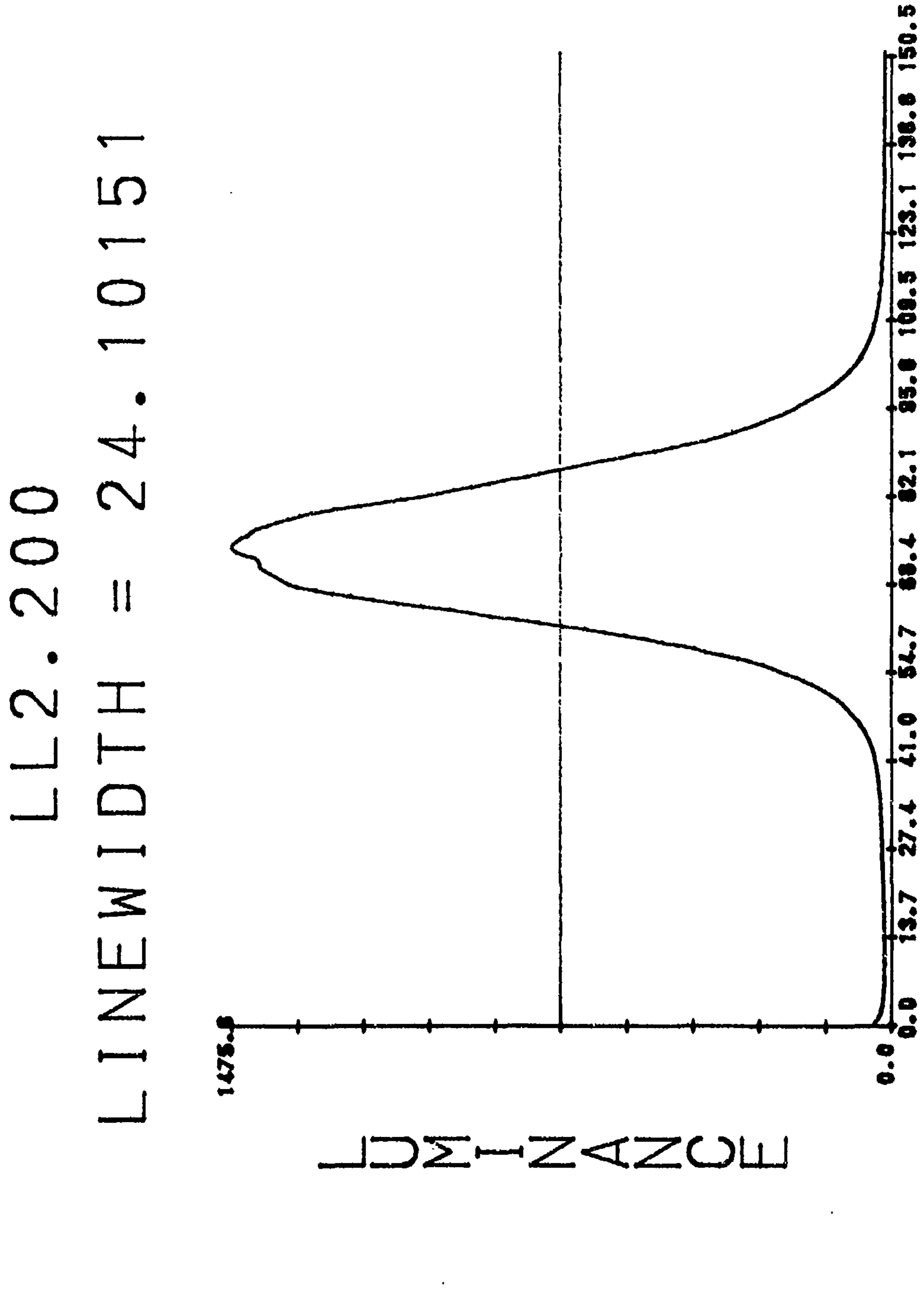
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

LL2.175

LINEWIDTH = 23.68609




LL2.200
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DISTANCE u
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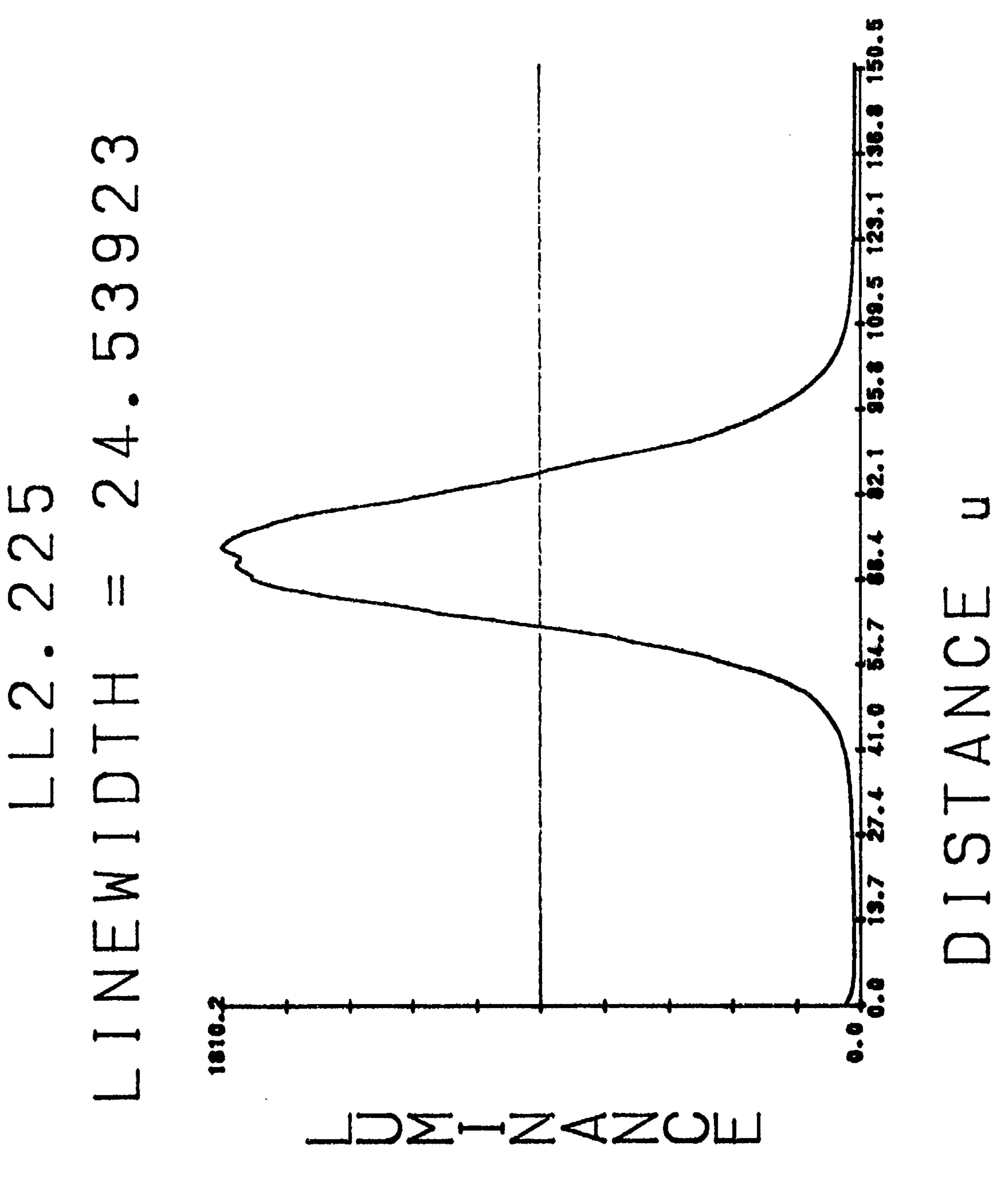
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


LL2.225
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1810.2
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54.7
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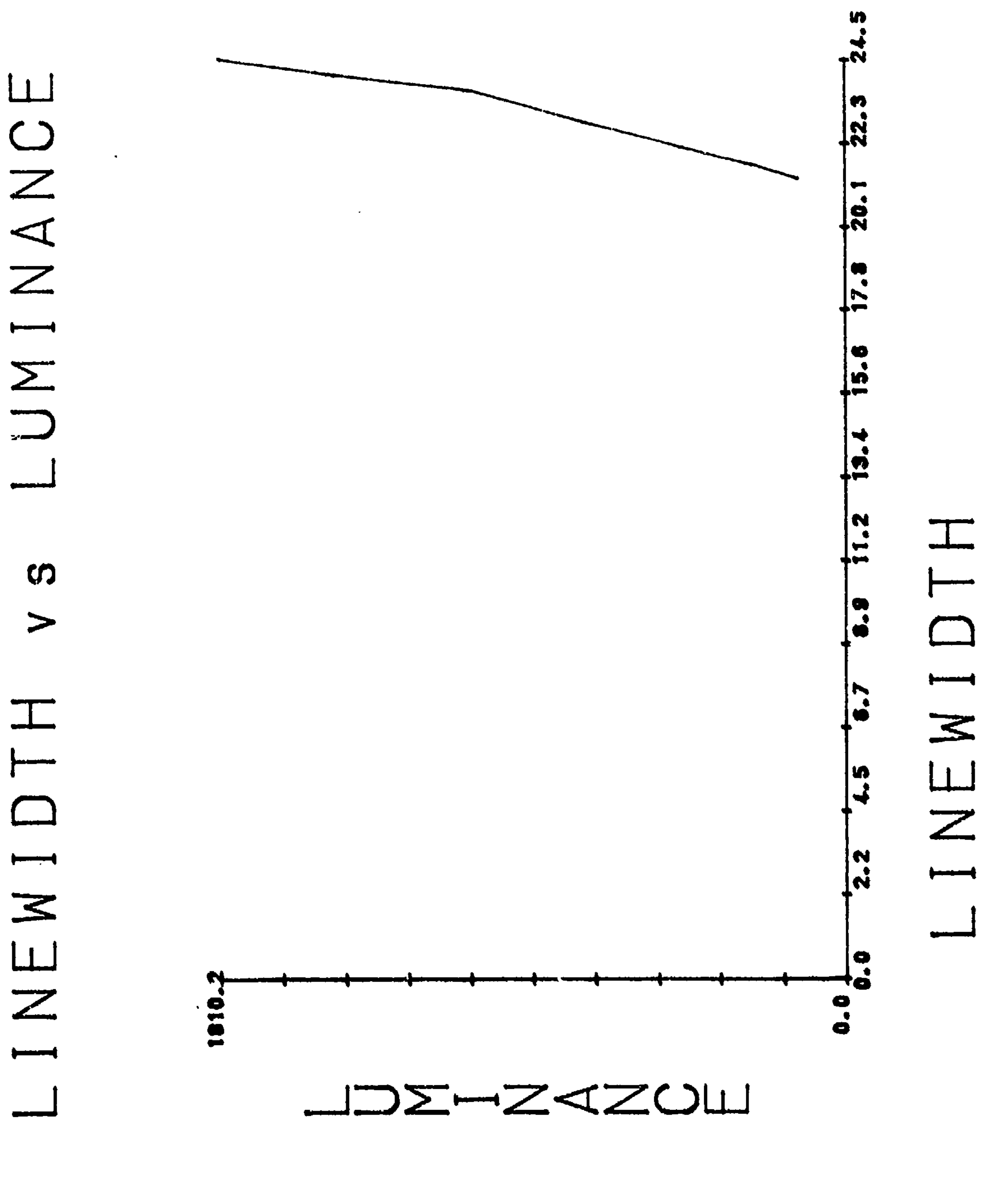
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


LINEWIDTH vs LUMINANCE
LUMINANCE
1810.2
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0.0
2.2
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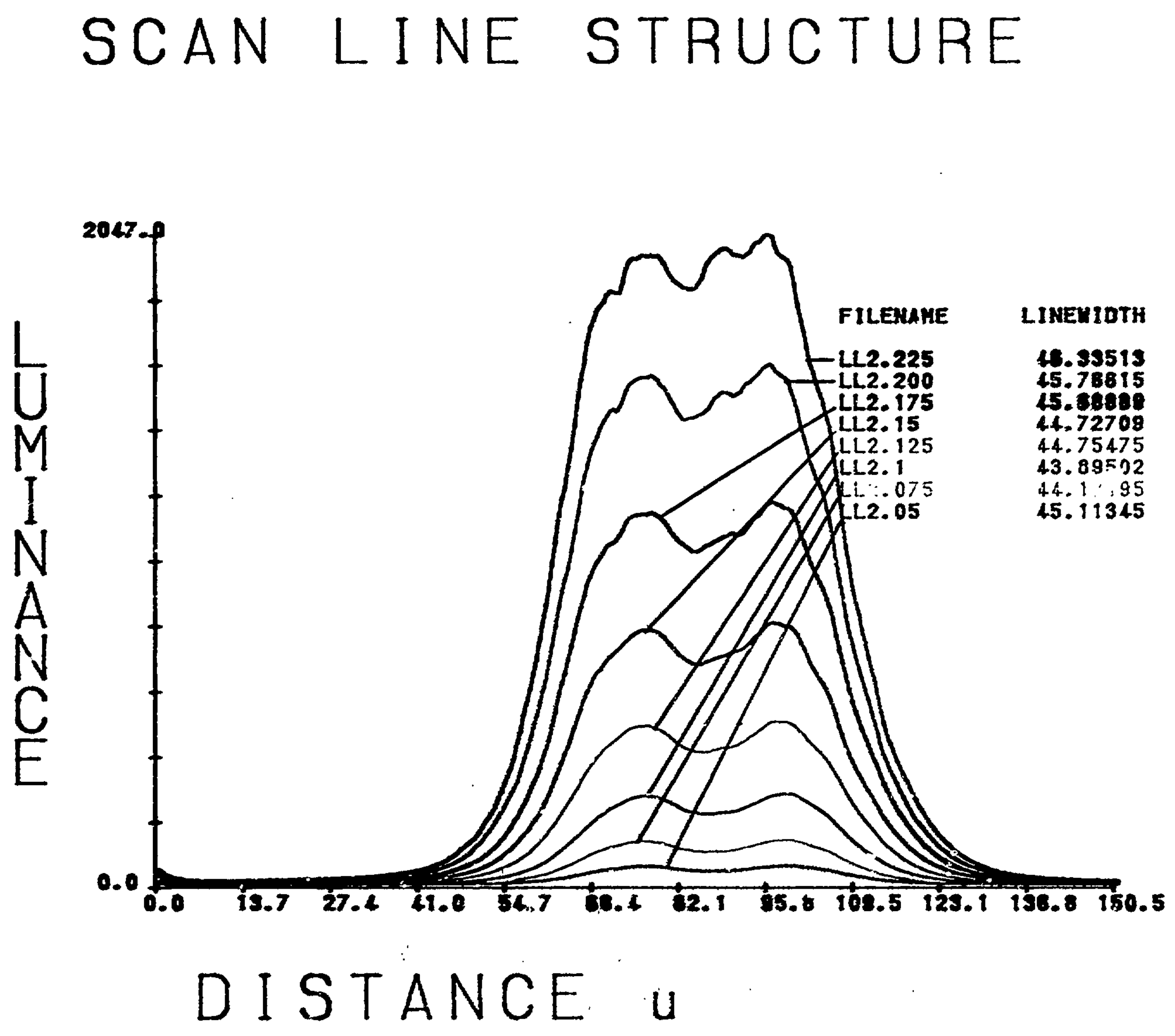
6.7
8.9
11.2
13.4
15.6
17.8
20.1
22.3
24.5
LINEWIDTH


SCAN LINE STRUCTURE
2047.0
0.0
LUMINANCE
FILENAME
LINEWIDTH
LL2.225
LL2.200
LL2.175
LL2.15
LL2.125
LL2.1
LL2.05
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45.11345
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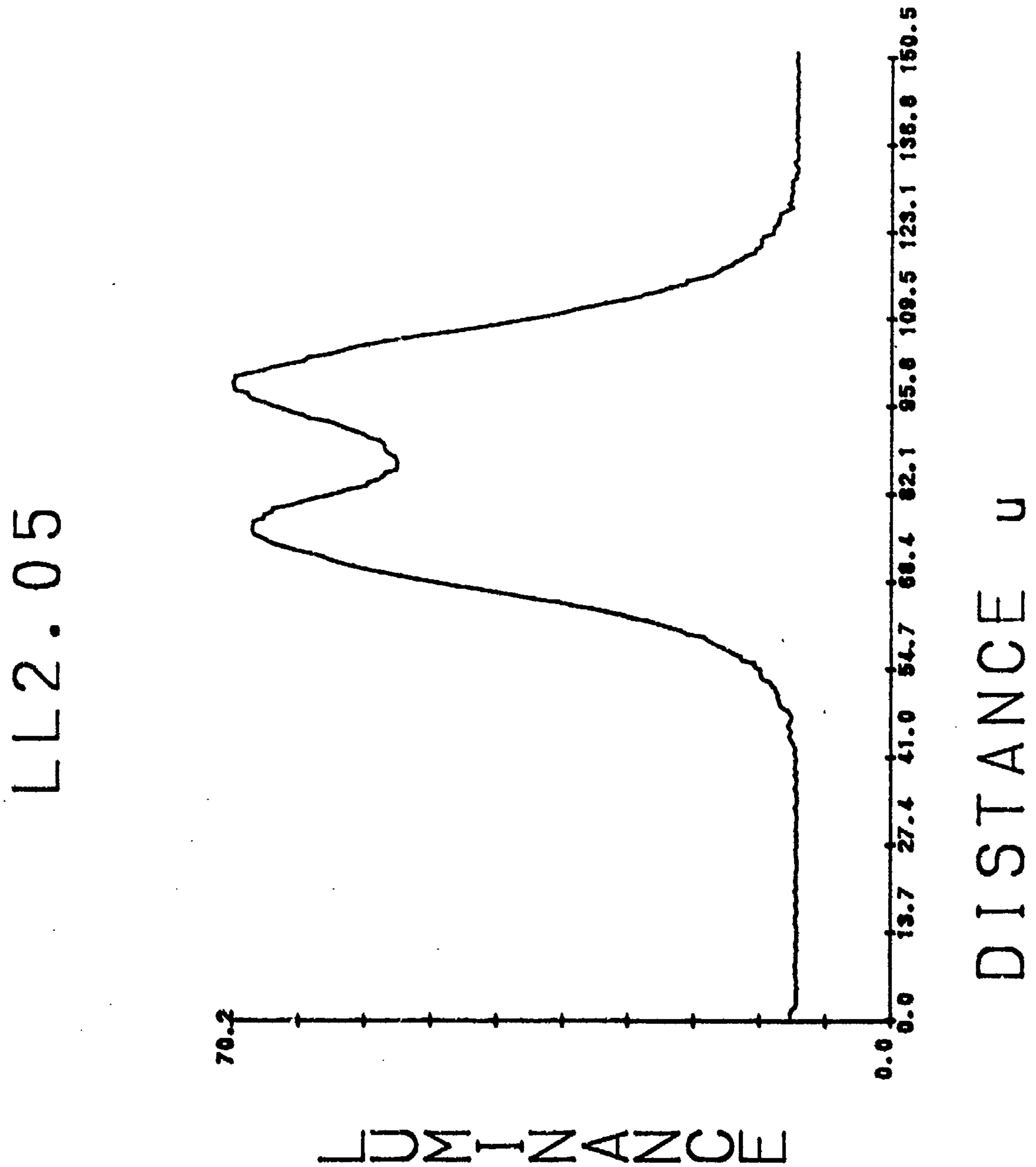
13.7
27.4
41.0
82.1
109.5
123.1
136.8
150.5
DISTANCE u


LL2.05
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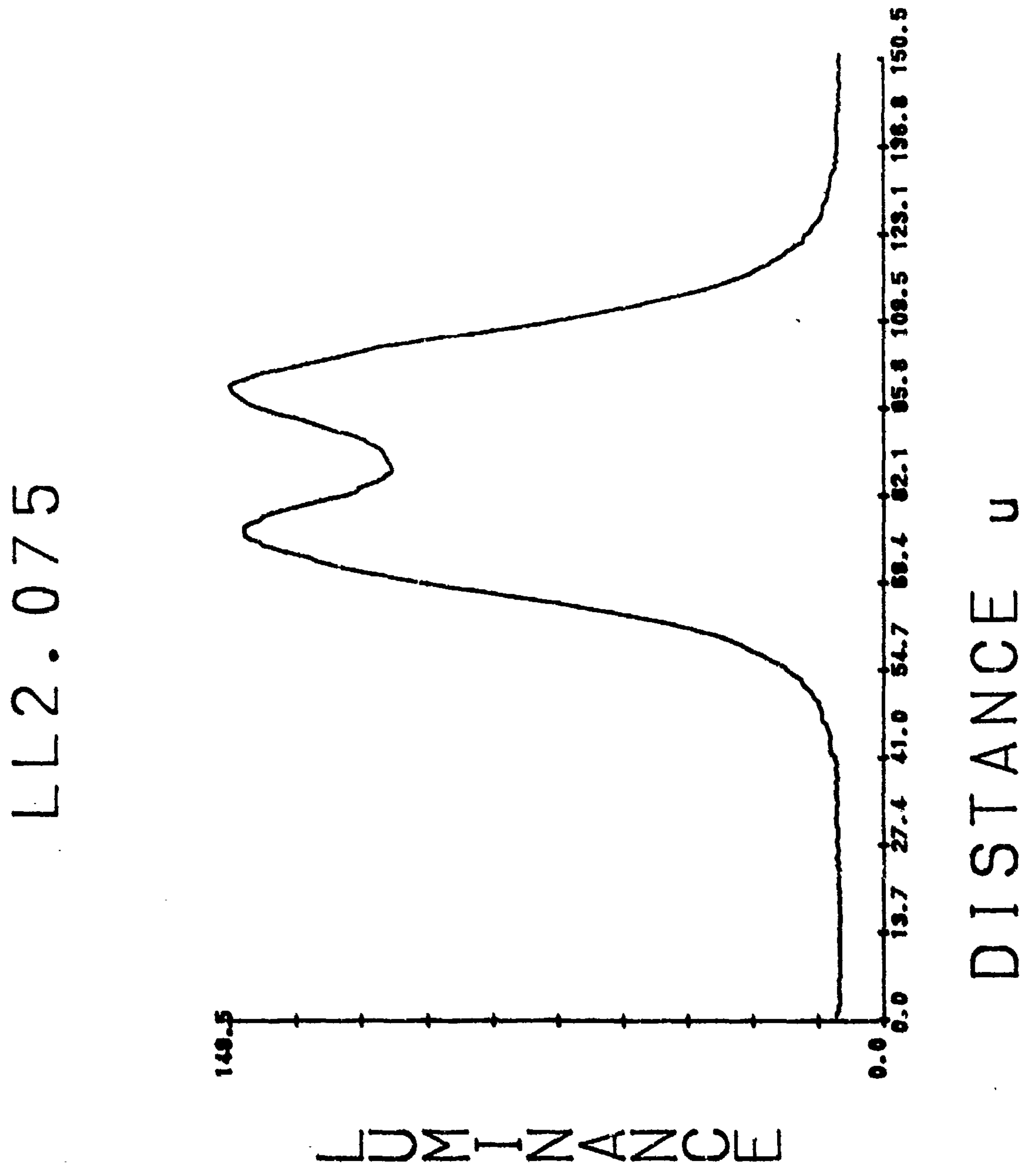
109.5
123.1
136.8
150.5
DISTANCE u


LL2.075
LUMINANCE
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95.8
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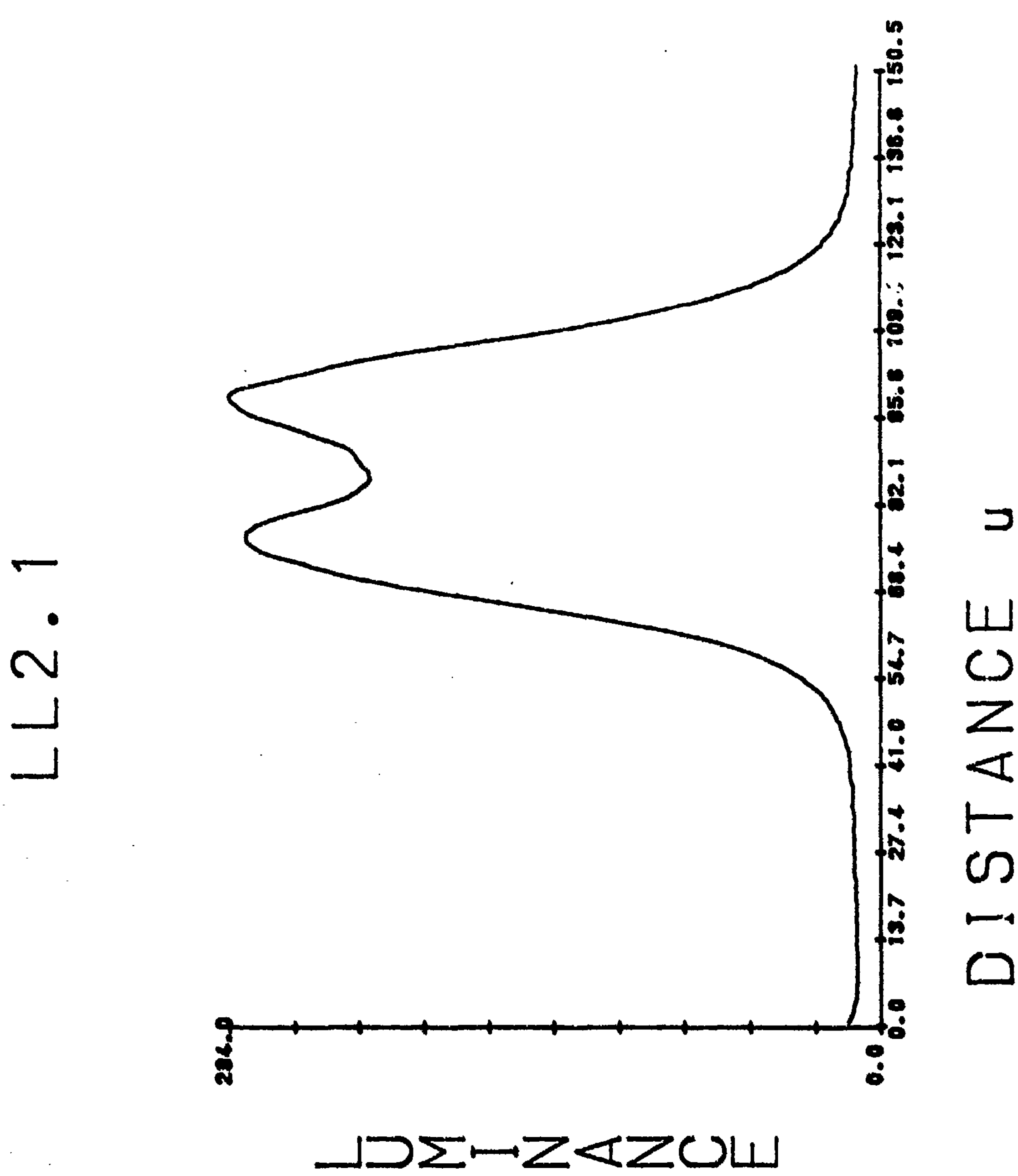
136.8
150.5
DISTANCE u


LL2.1
DISTANCE u
LUMINANCE
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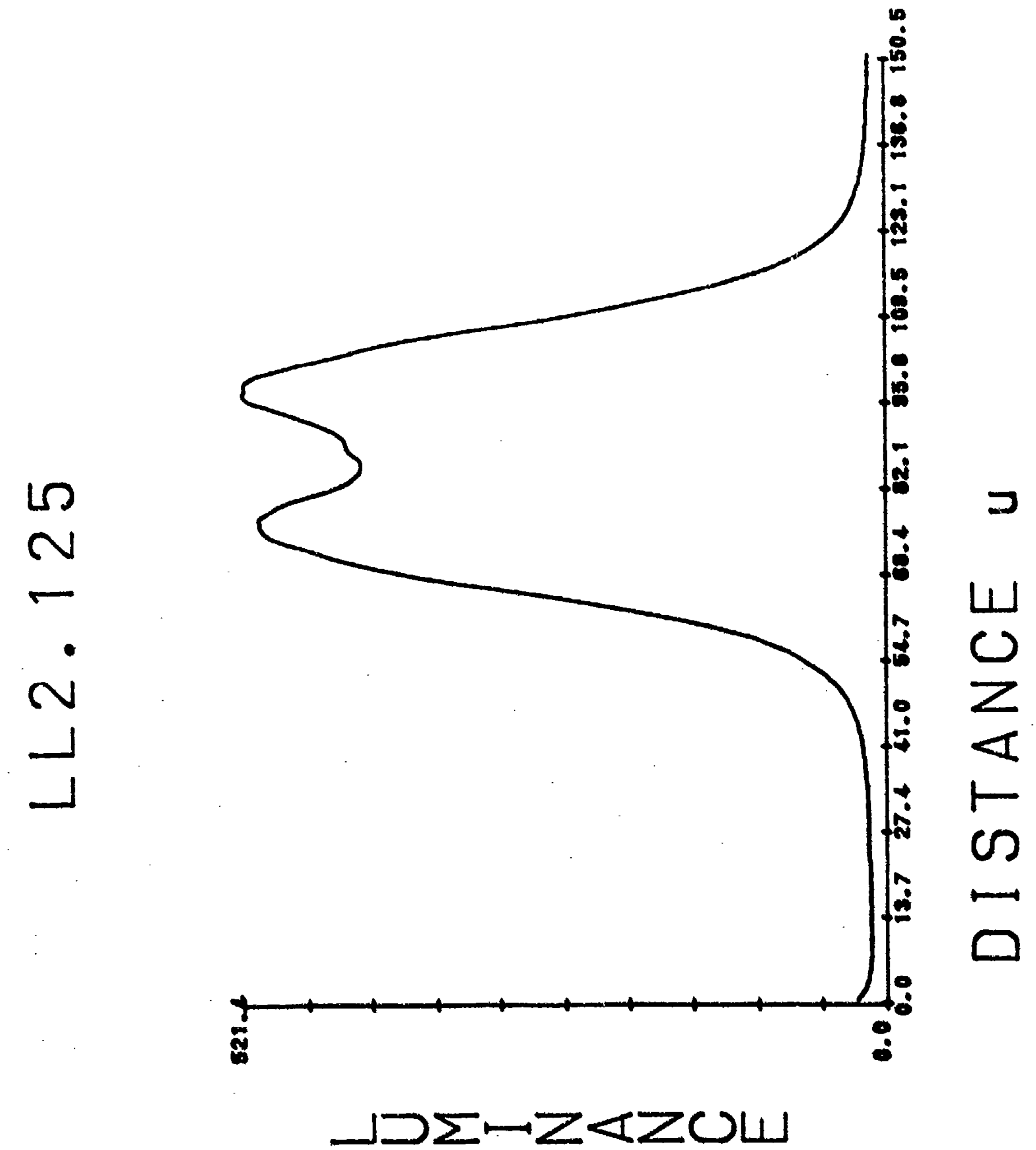
27.4
41.0
54.7
68.4
82.1
95.8
123.1
136.8
150.5


LL2.125
LUMINANCE
521
0.0
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68.4
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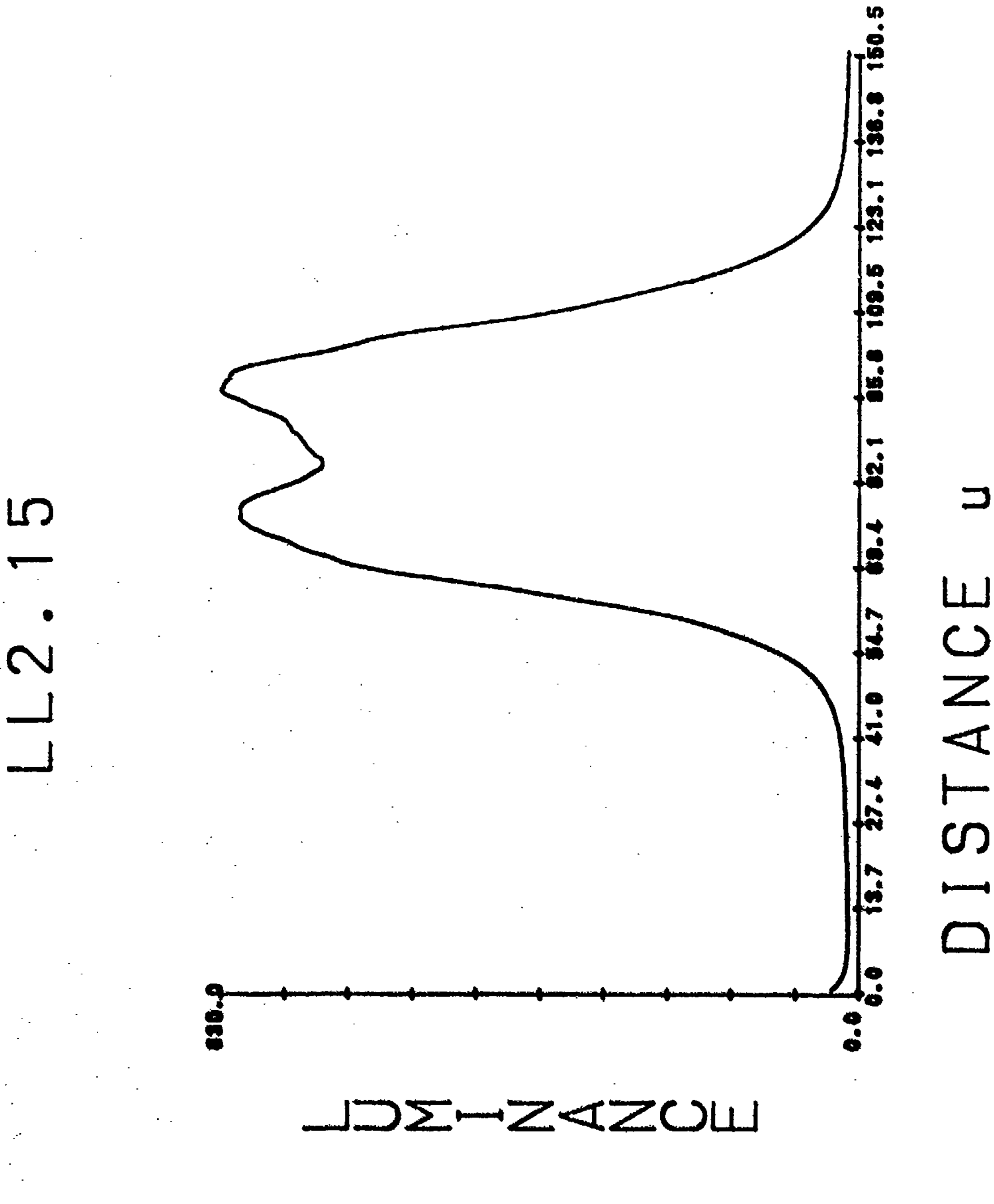
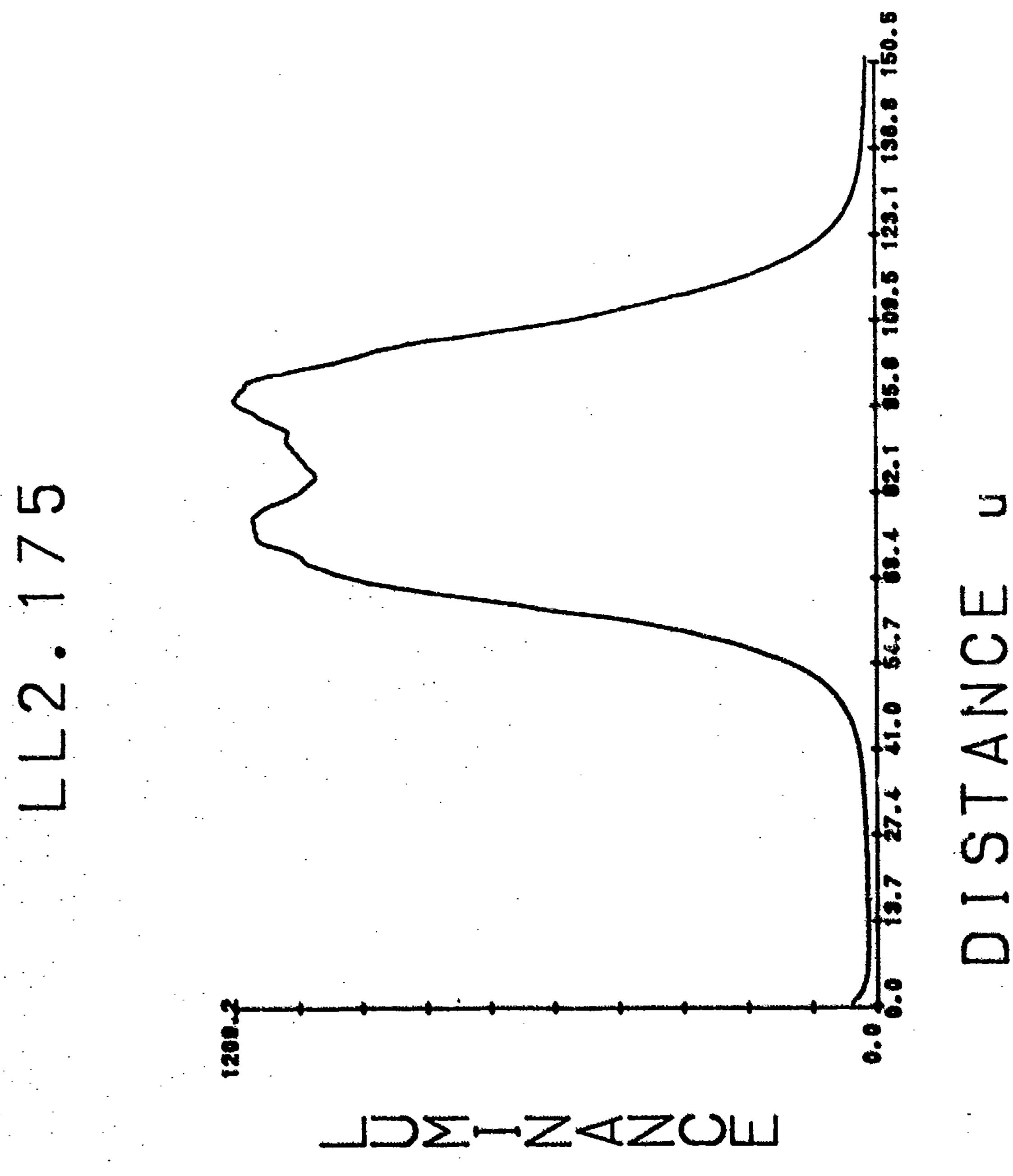
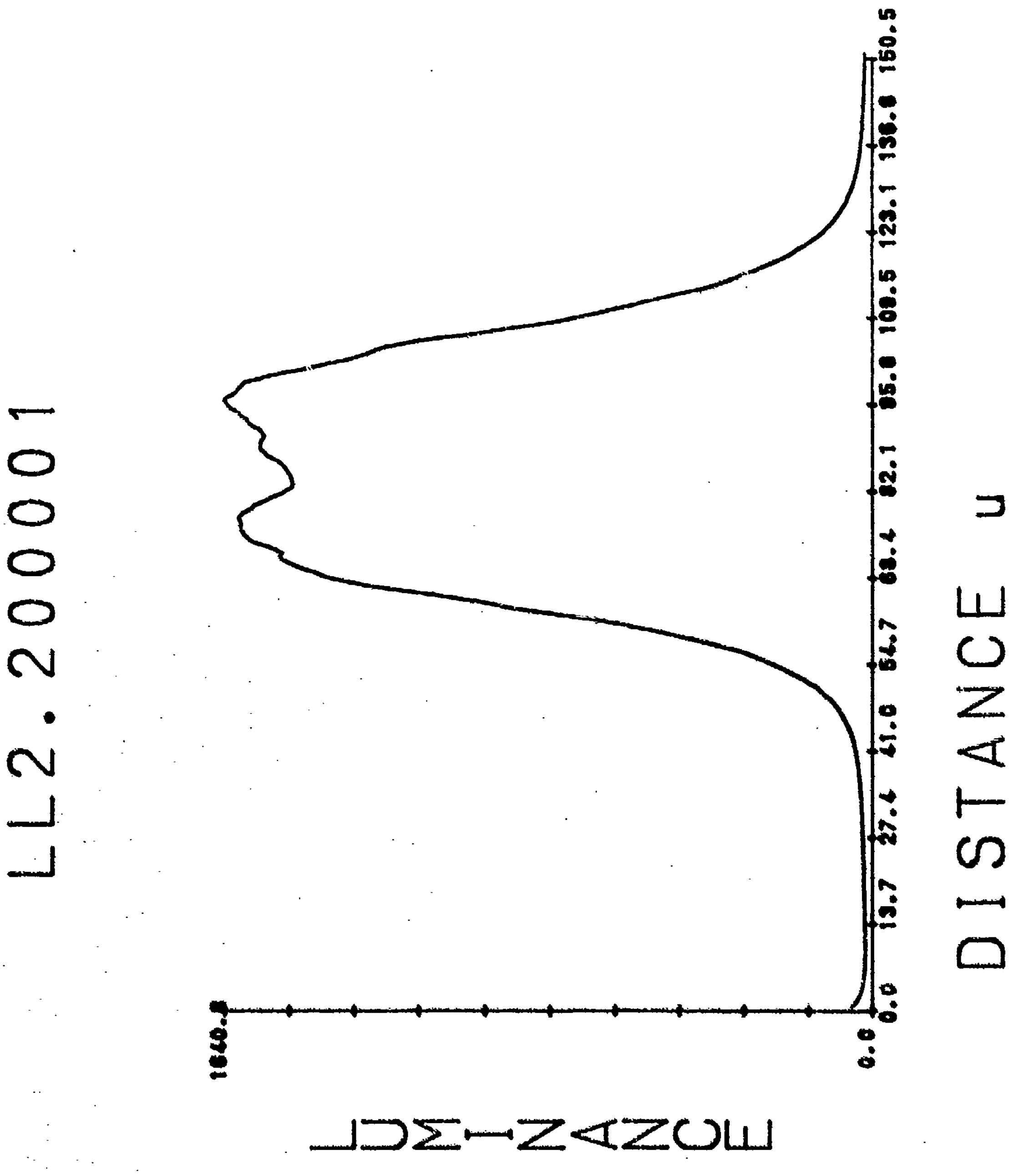
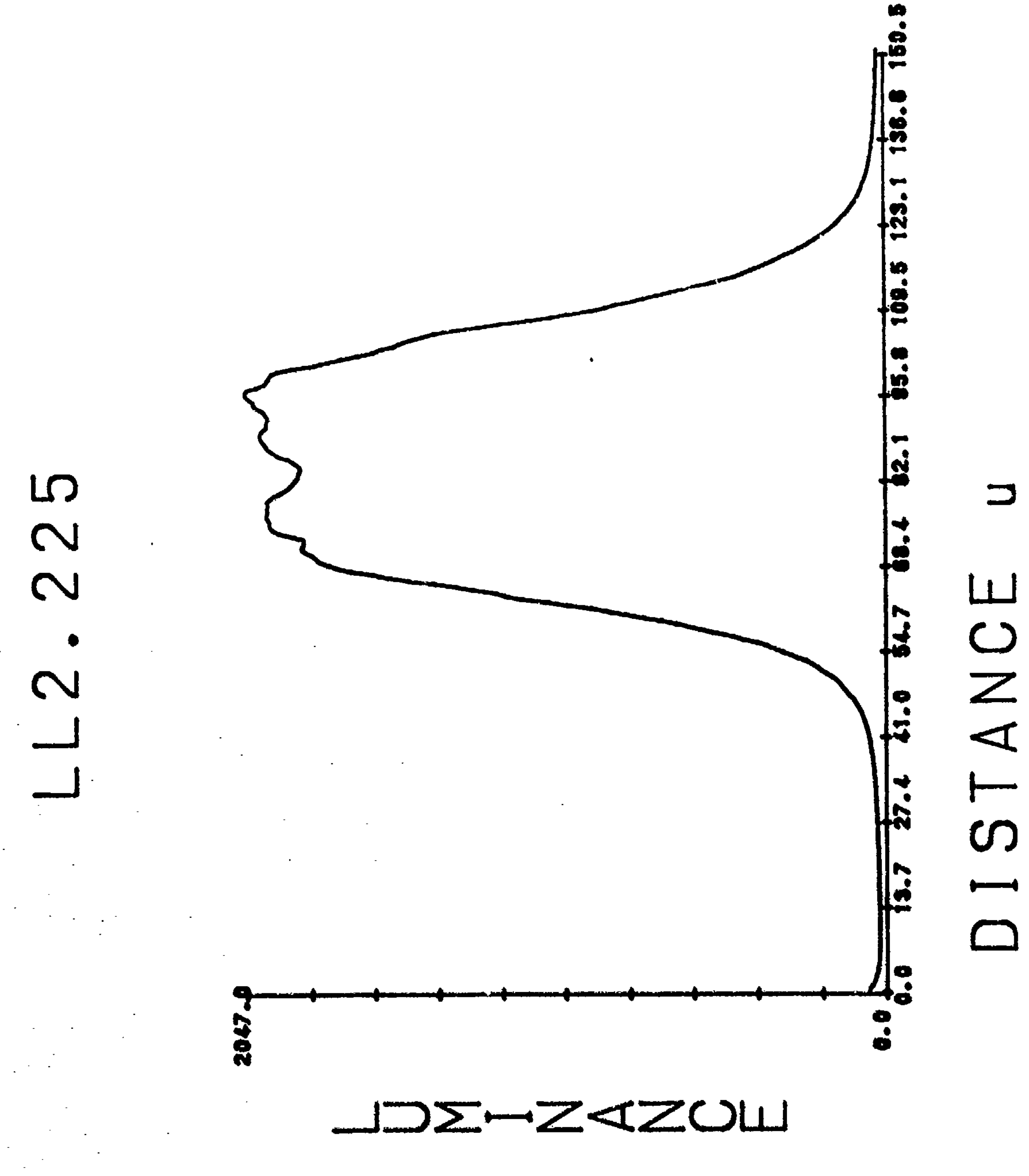
109.5
123.1
136.8
150.5
DISTANCE u


LL2.15
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


LL2.175
DISTANCE u
LUMINANCE


LL2.200001
INTENSITY
DISTANCE u
0.0


LL2.225
LUMINANCE
2047.0
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0.0
13.7
27.4
41.0
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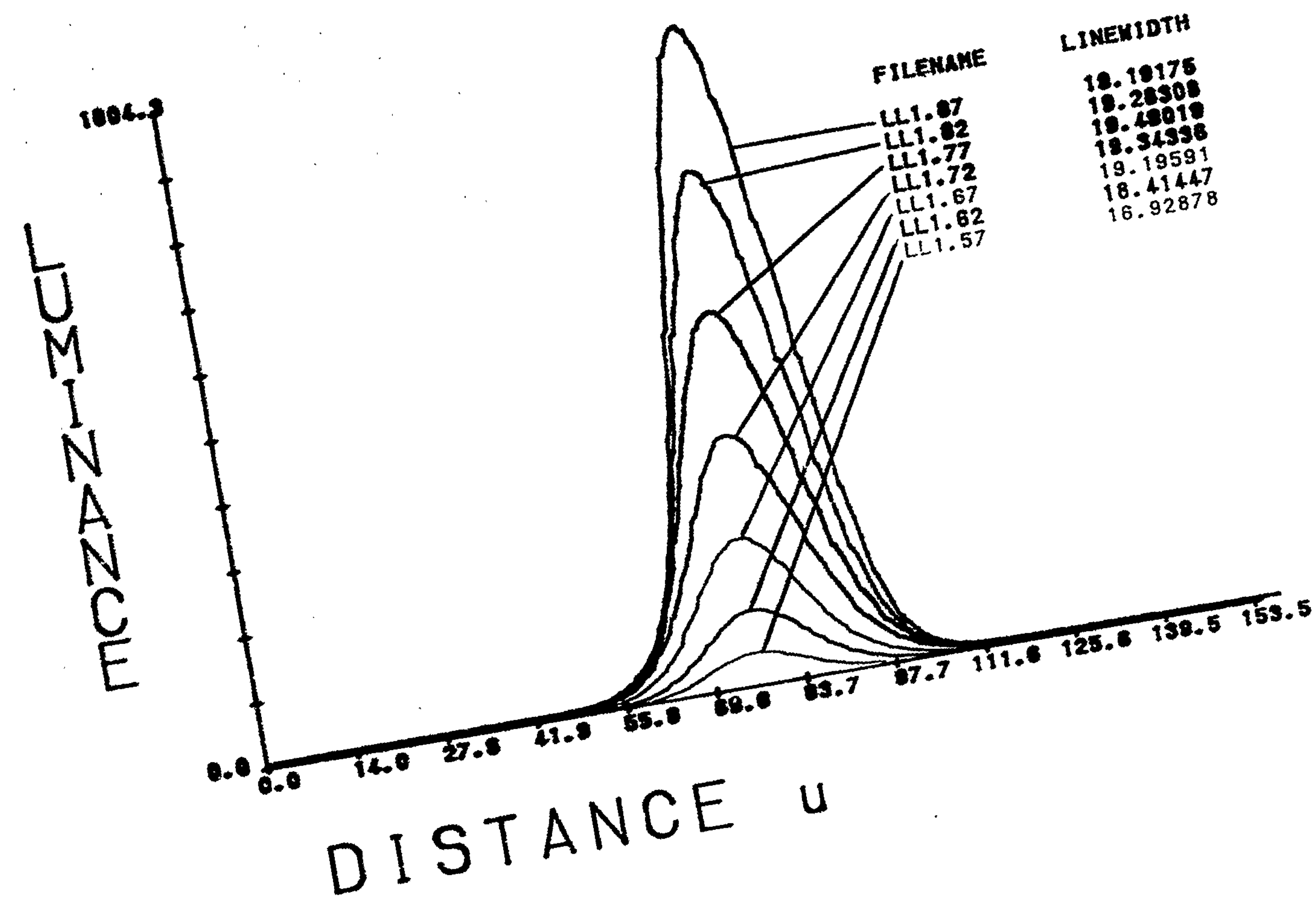
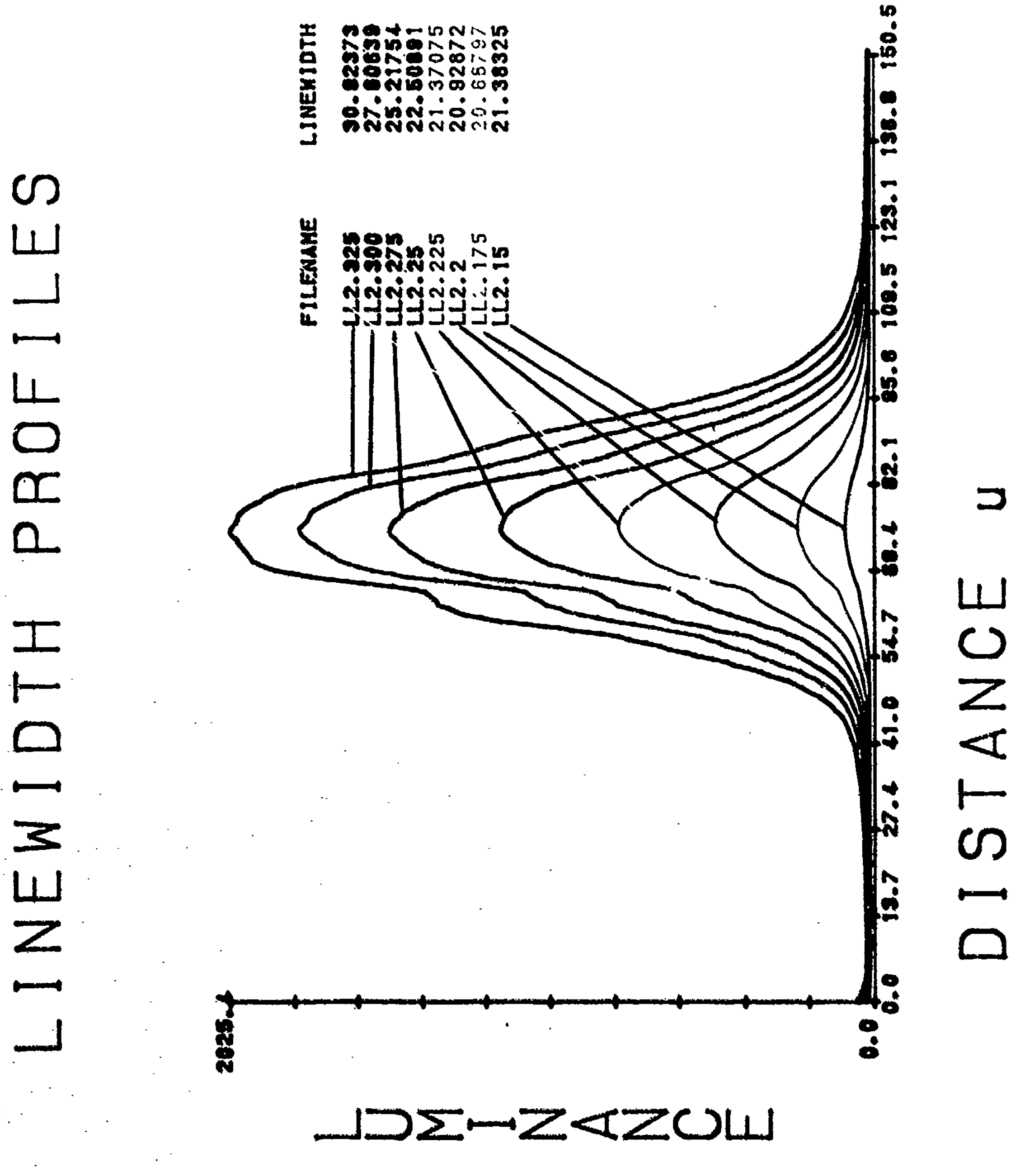
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

13 KV CRT LINE PROFILES



KAISER (HUGHES 1380) CRT

S/N 28007



LINEWIDTH PROFILES
FILENAME
LL2.325
LL2.300
LL2.275
LL2.25
LL2.225
LL2.2
LL2.175
LL2.15
LINEWIDTH
30.82373
27.80639
25.21754
22.50891
21.37075
20.92872
20.65797
21.38325
2025.
0.0
0.0
13.7
27.4
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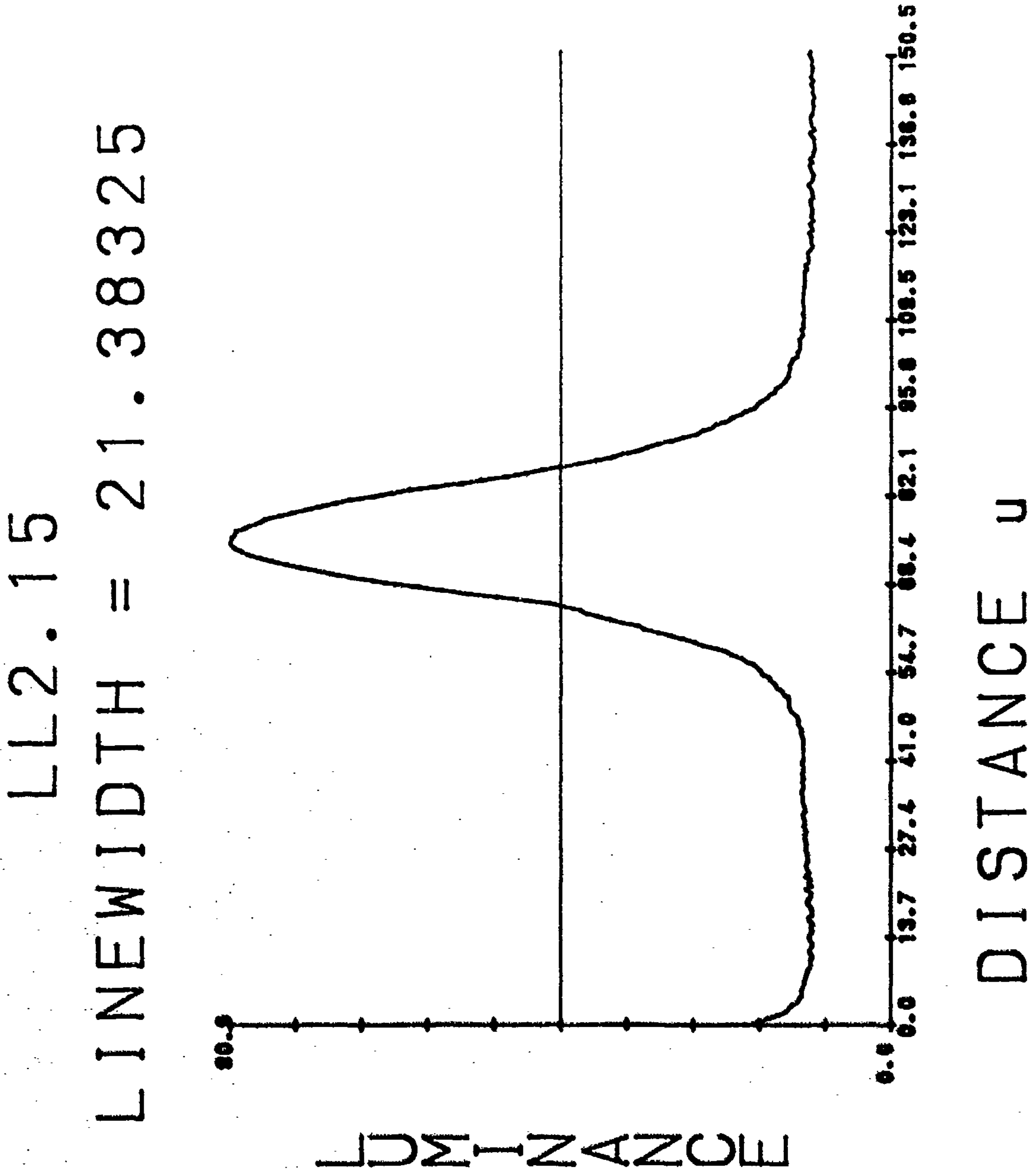
68.4
82.1
95.8
109.5
123.1
136.8
150.5
LUMINANCE
DISTANCE u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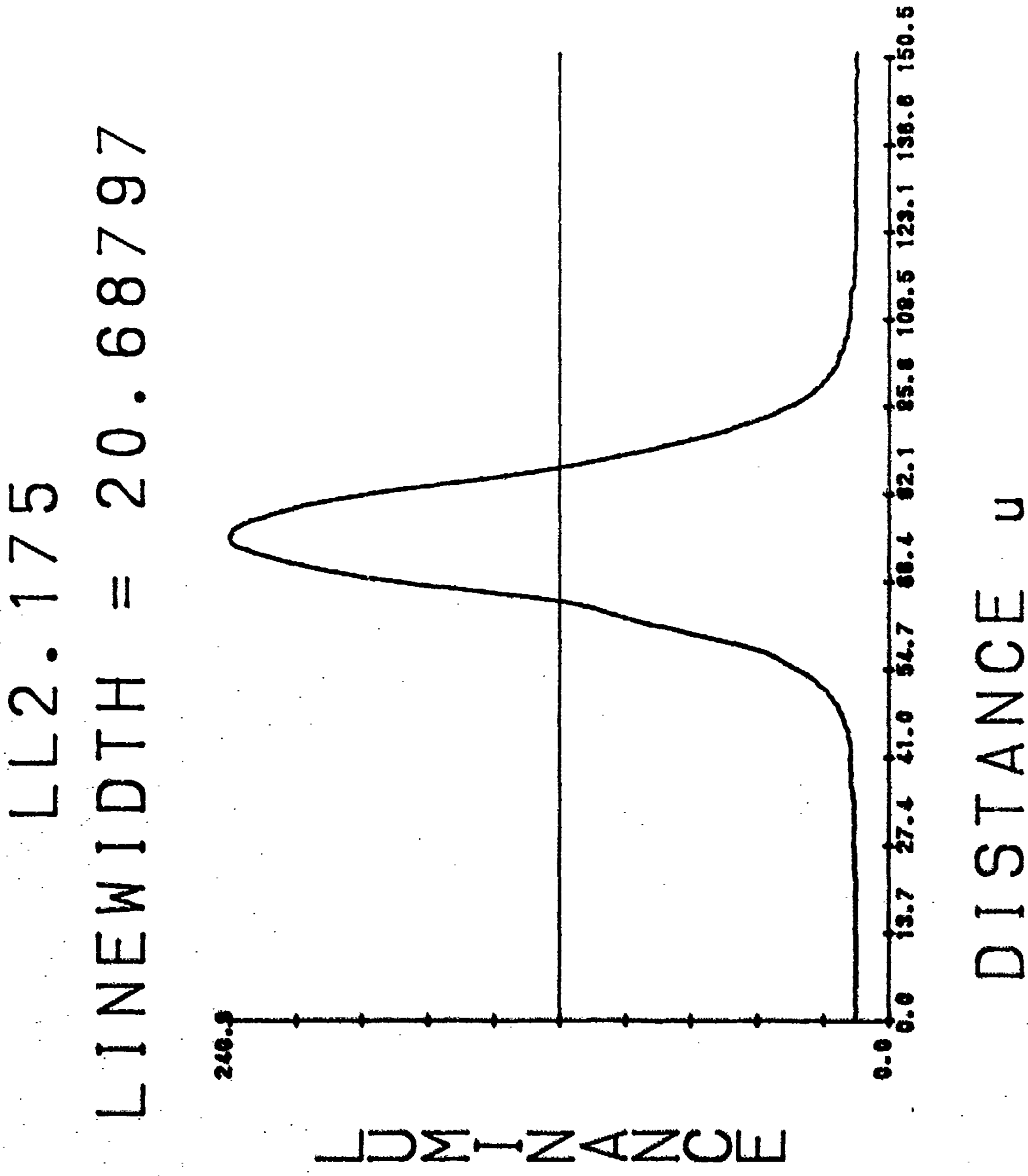
150.5


LL2.175
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DISTANCE u
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27.4
41.0
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95.8
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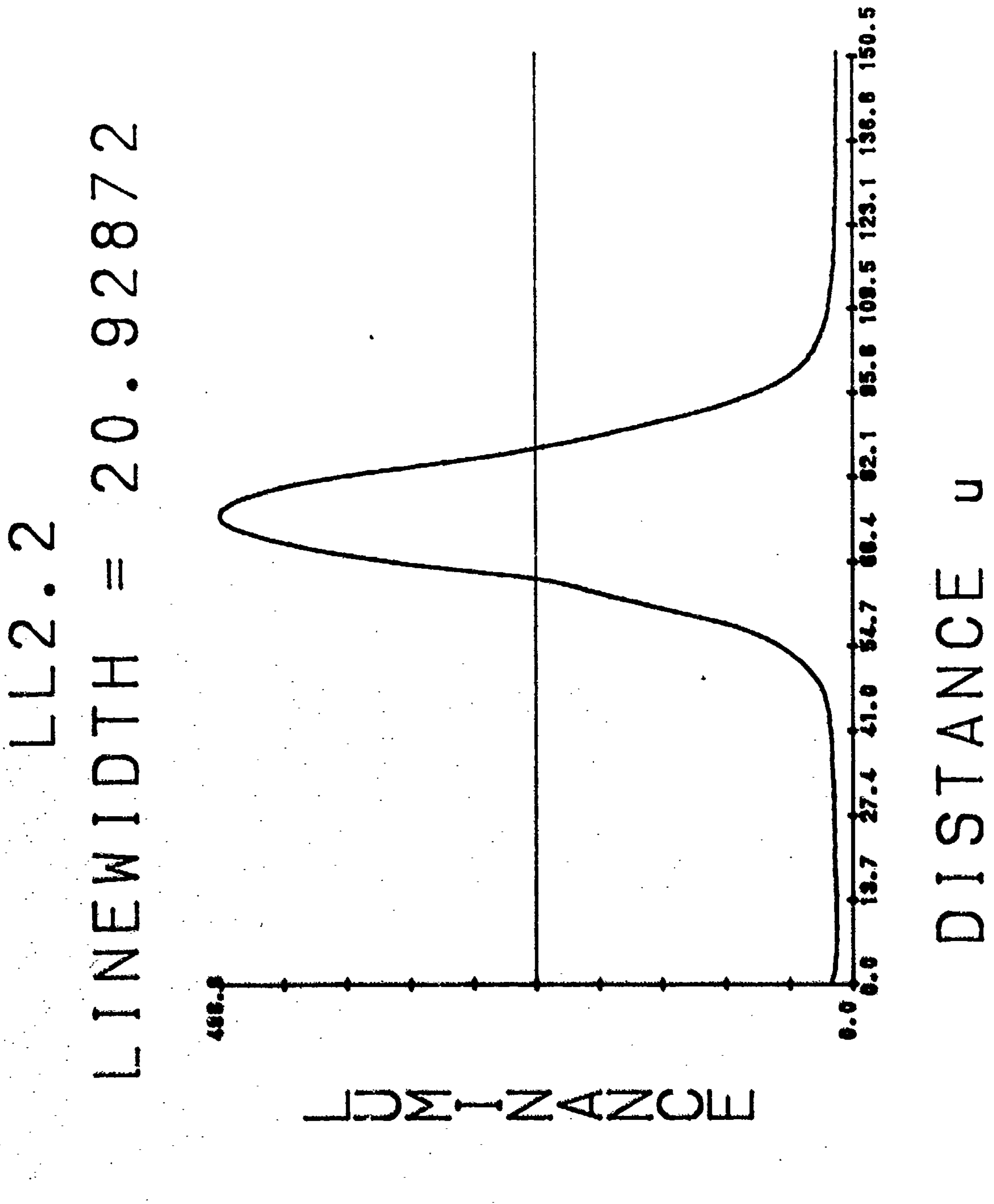
123.1
136.8
150.5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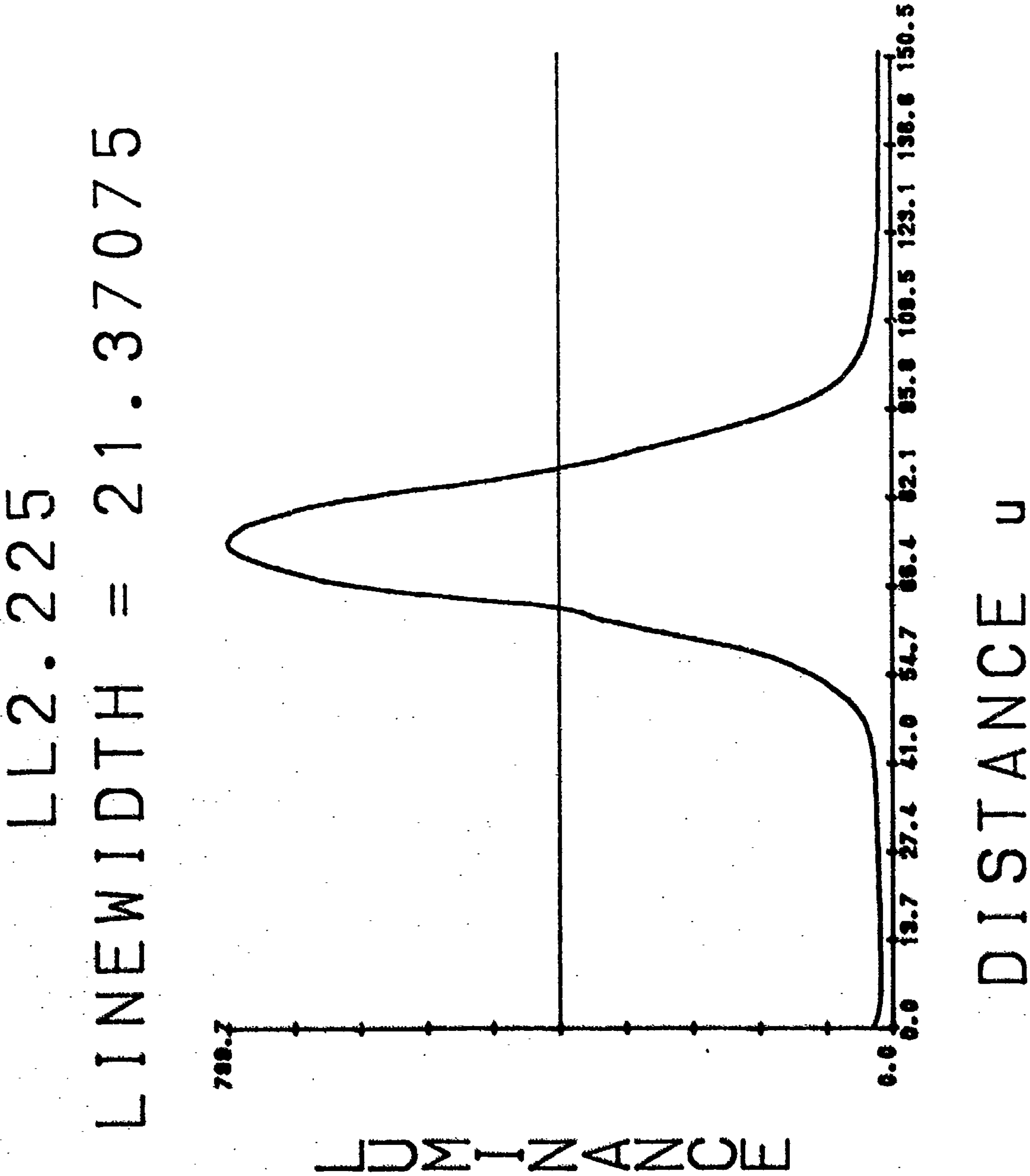
150.5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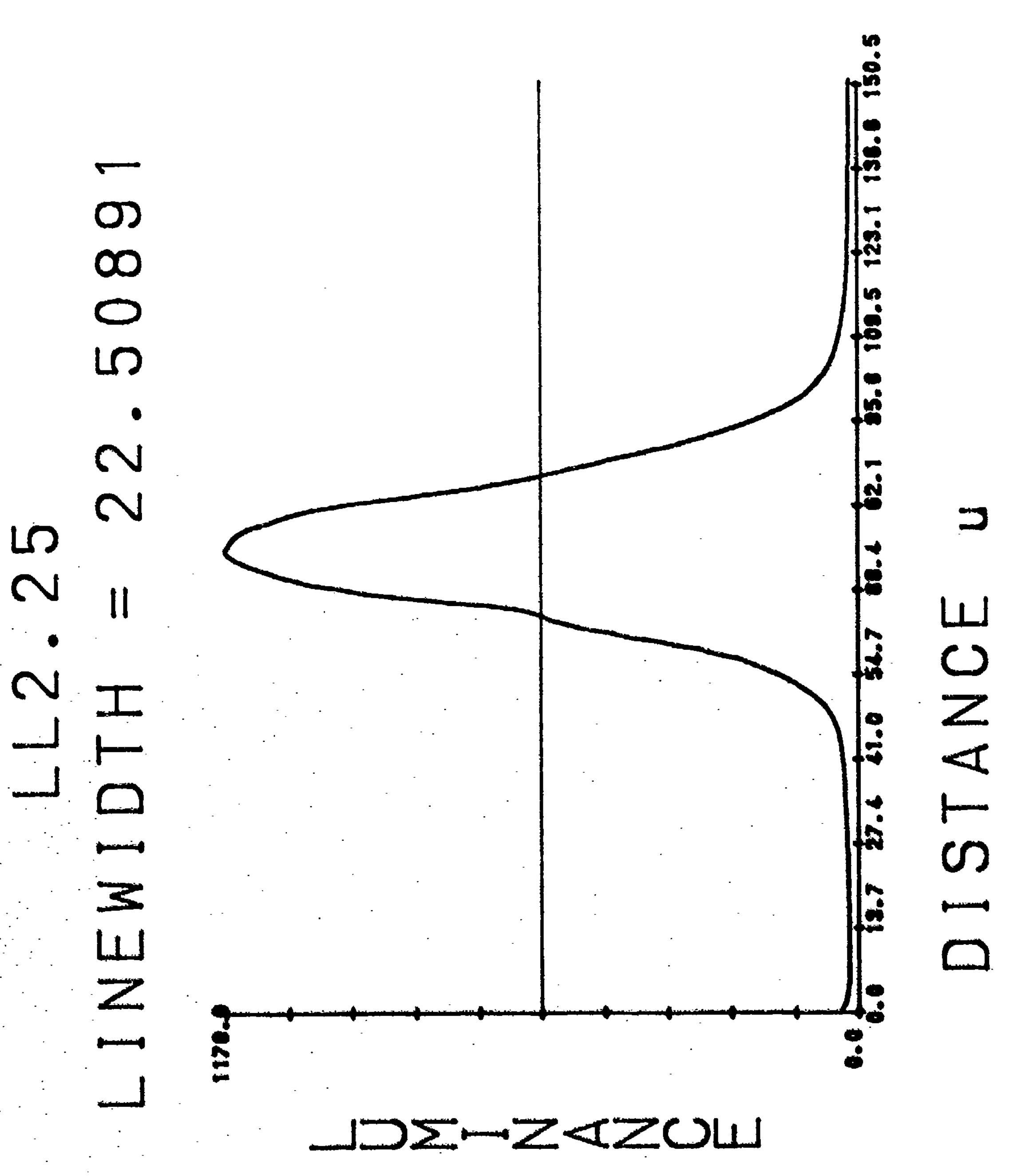
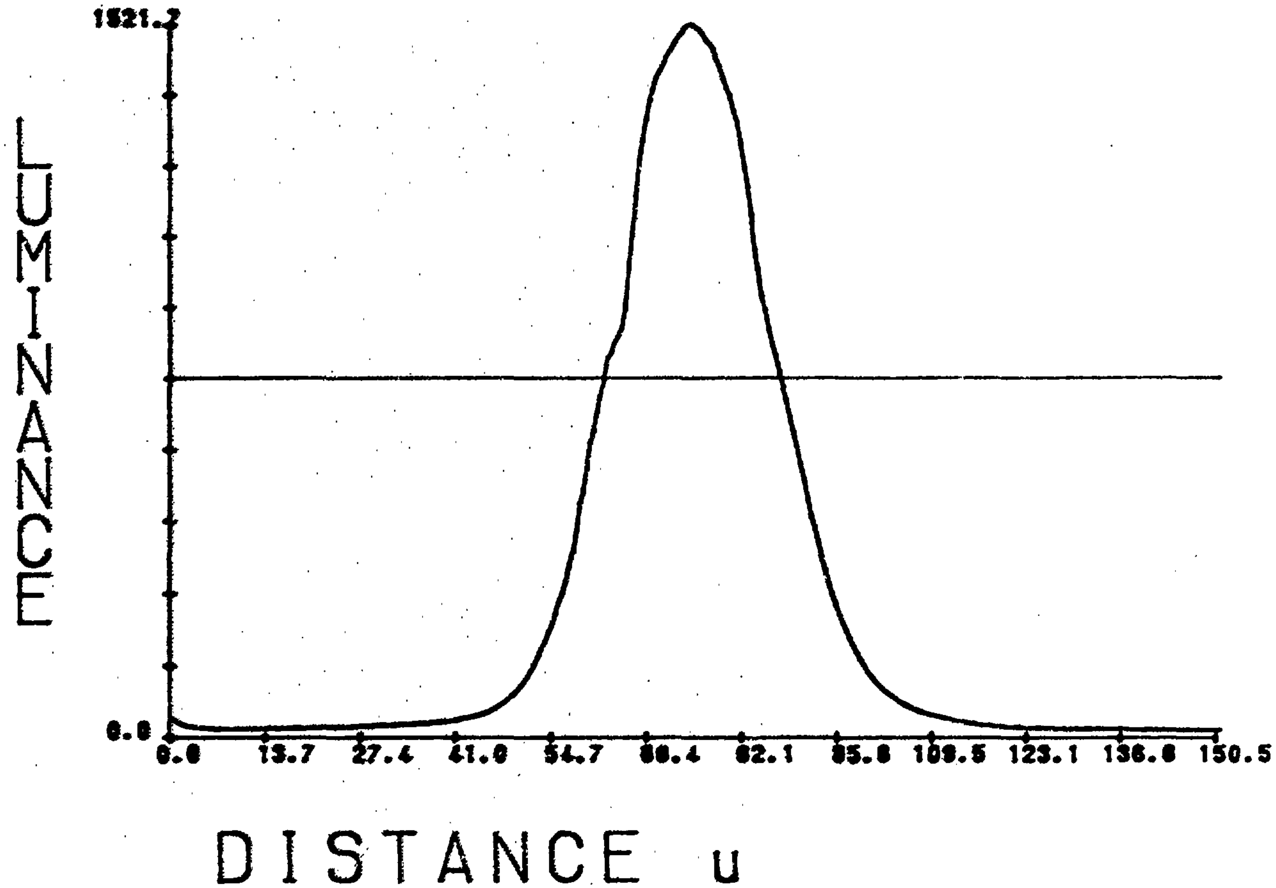
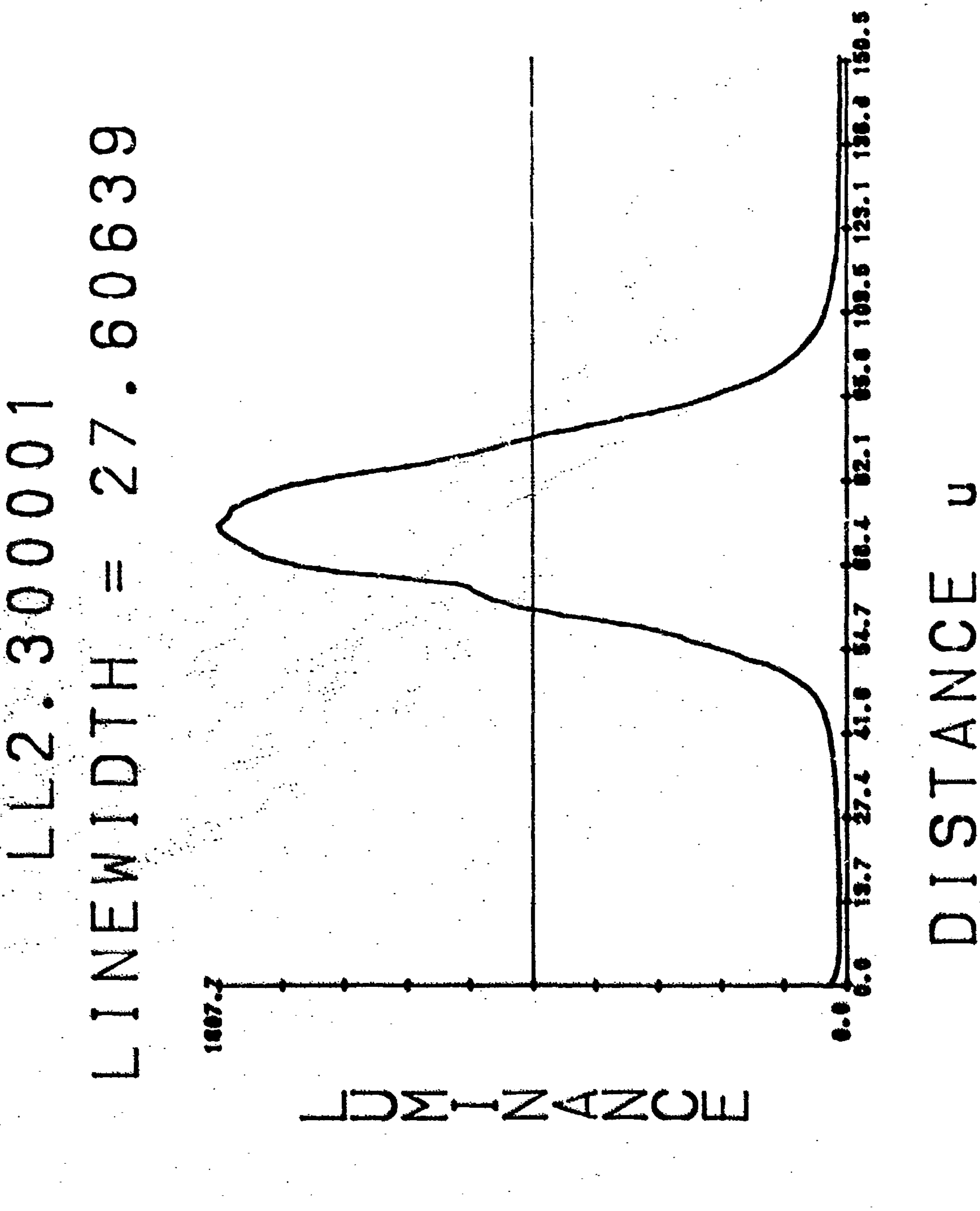
27.4
41.0
54.7
82.1
109.5
123.1
150.5

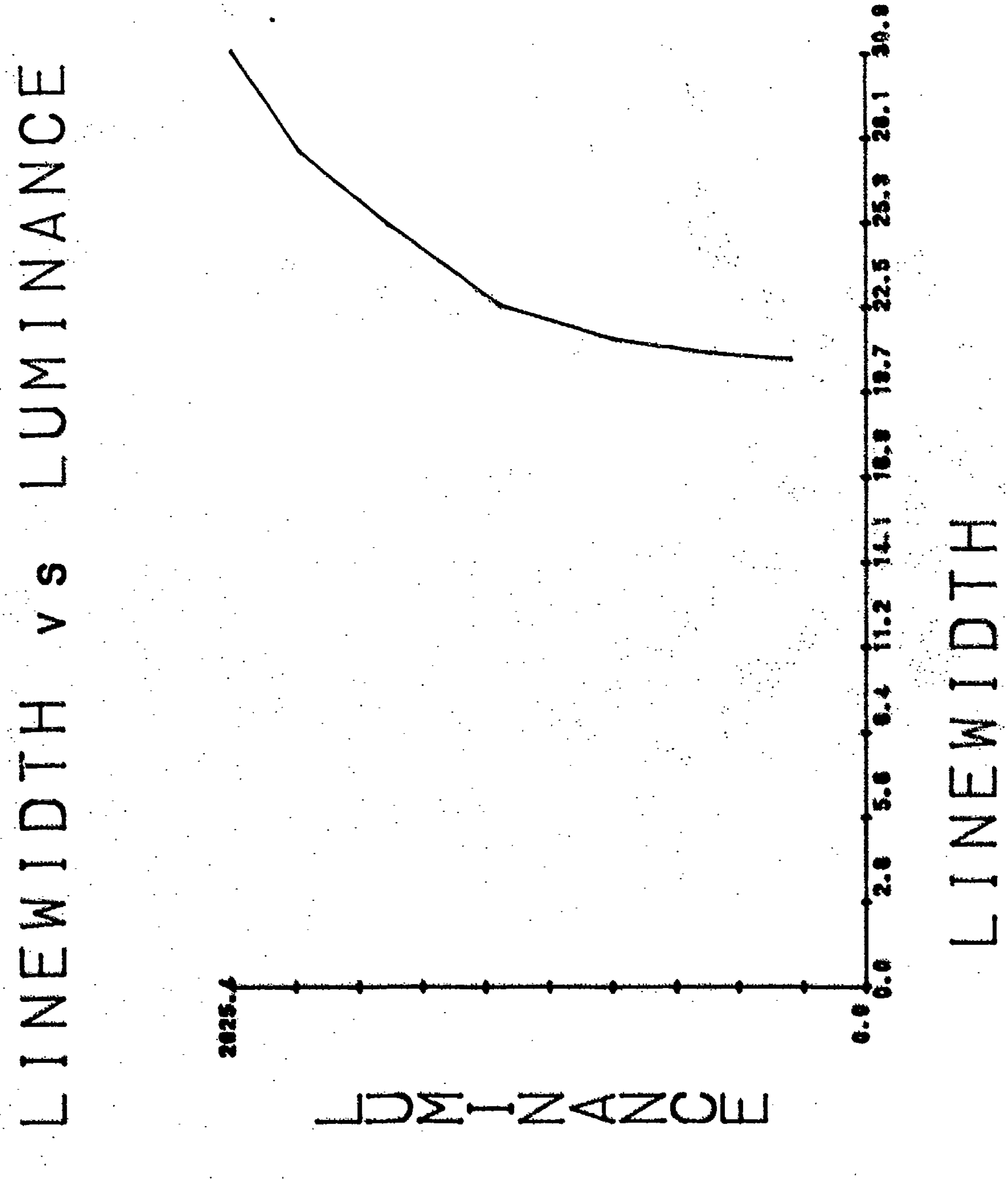

LL2.25
LINEWIDTH = 22.50891
LUMINANCE
DISTANCE u
1170.0
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

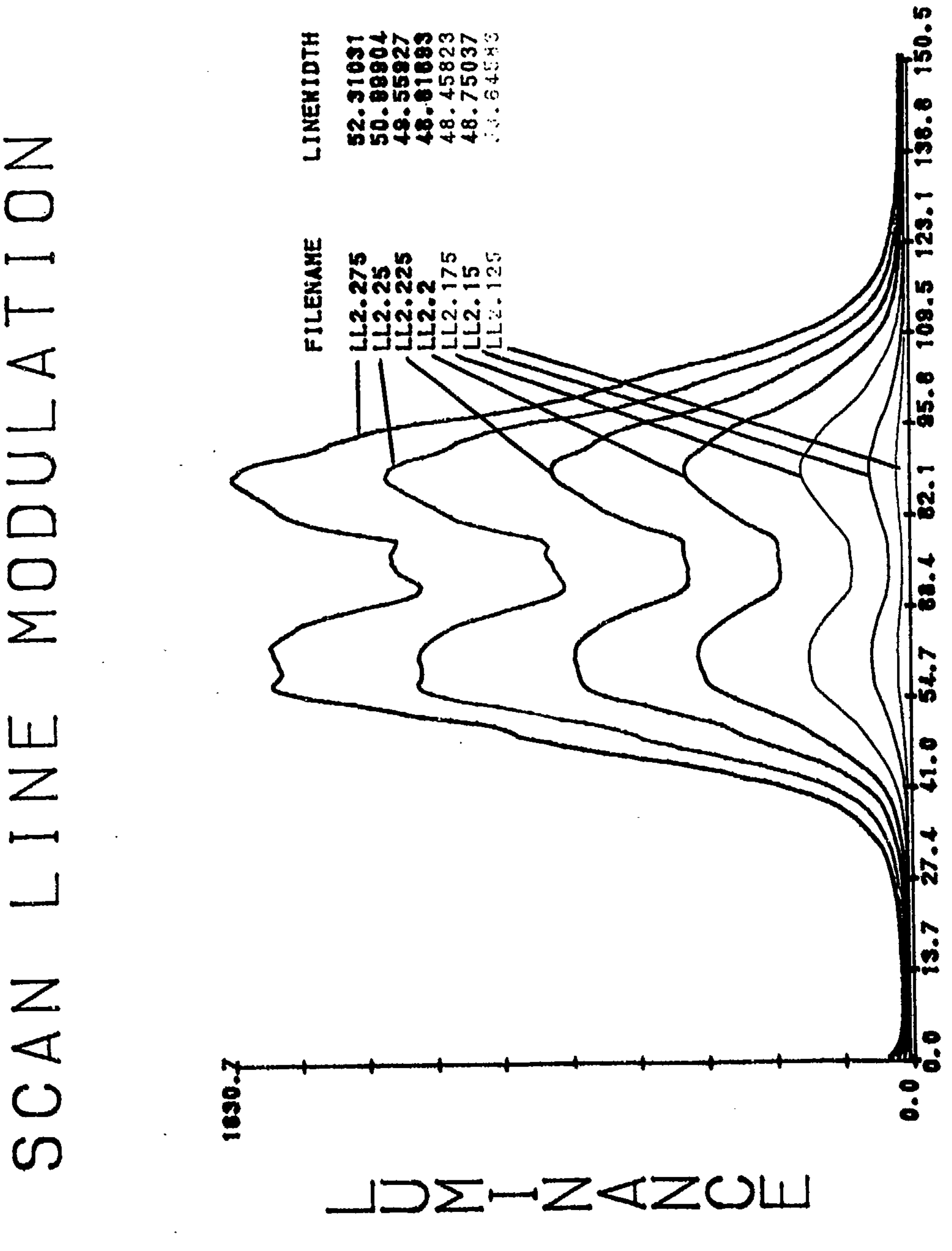
LL2.275001

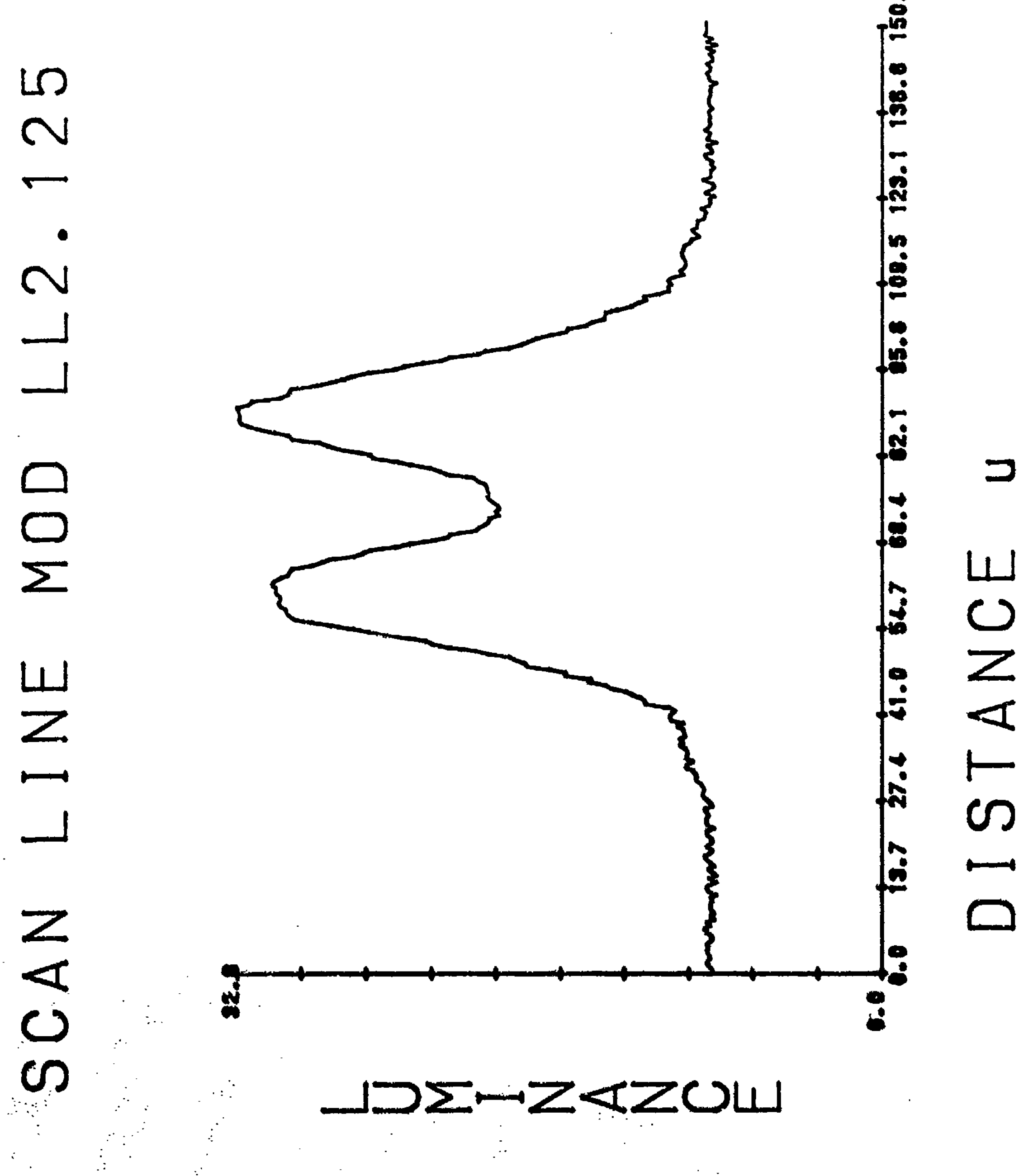
LINEWIDTH = 25.21754

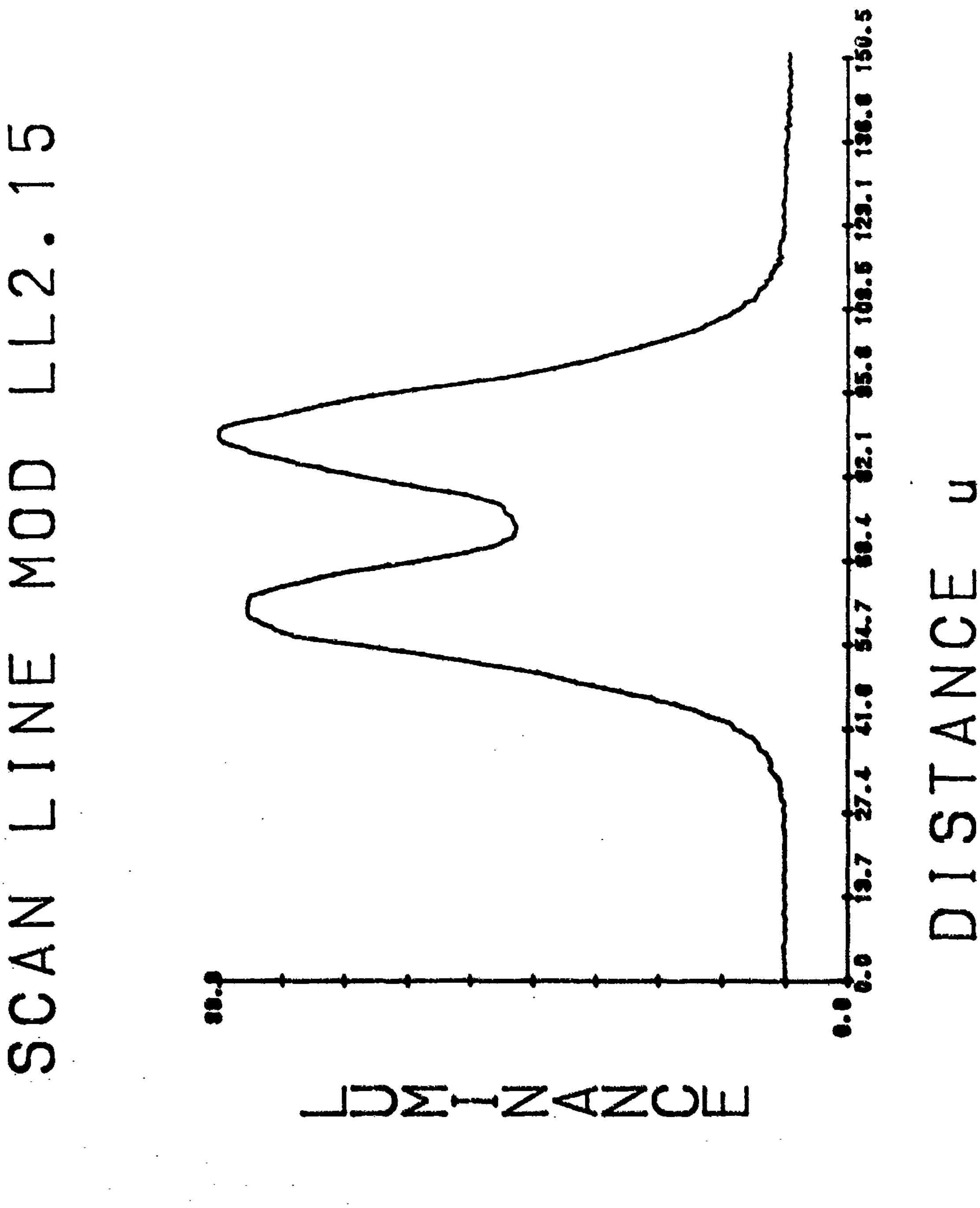


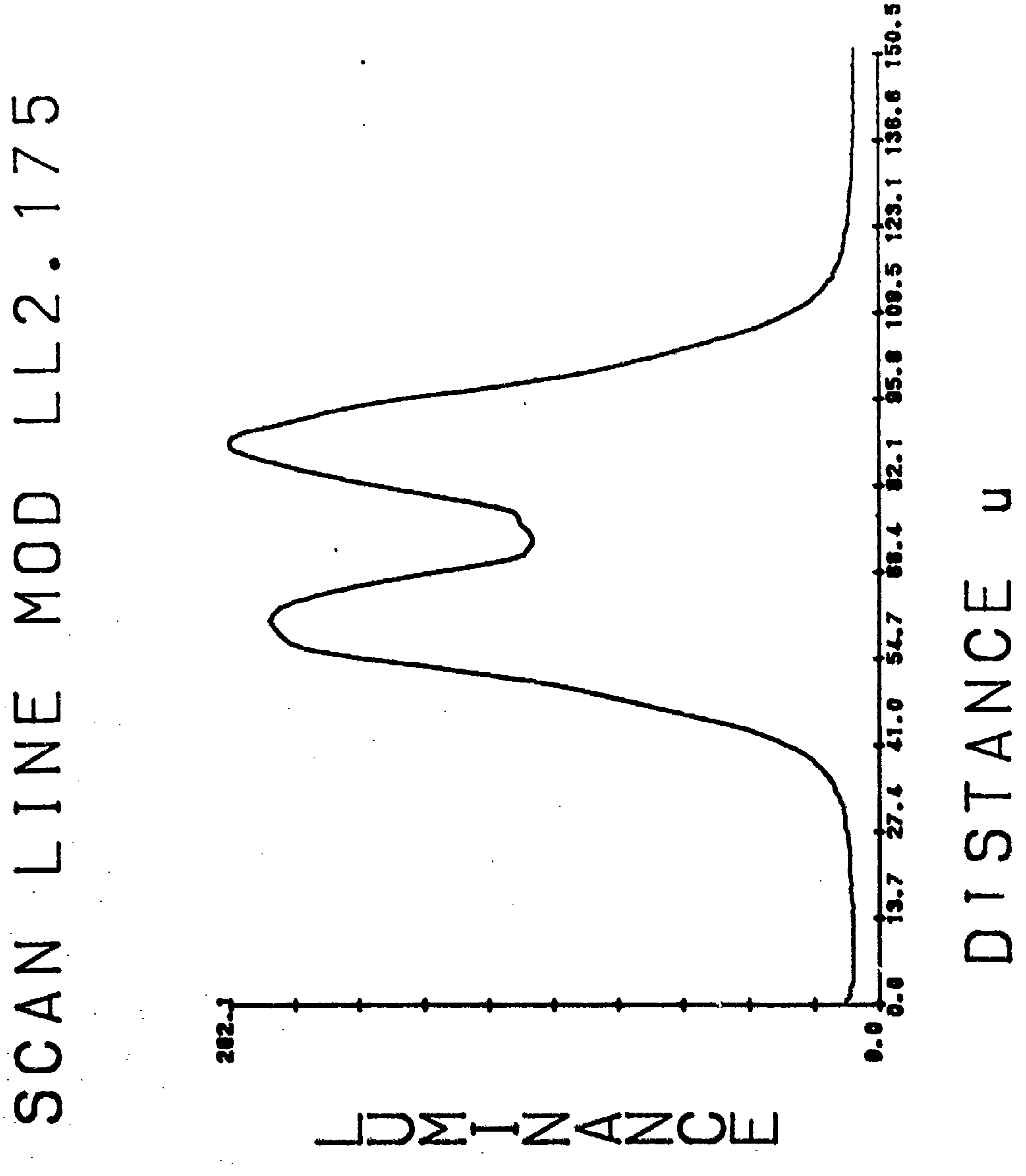

LL2.300001
LINEWIDTH = 27.60639
DISTANCE u
LUMINANCE

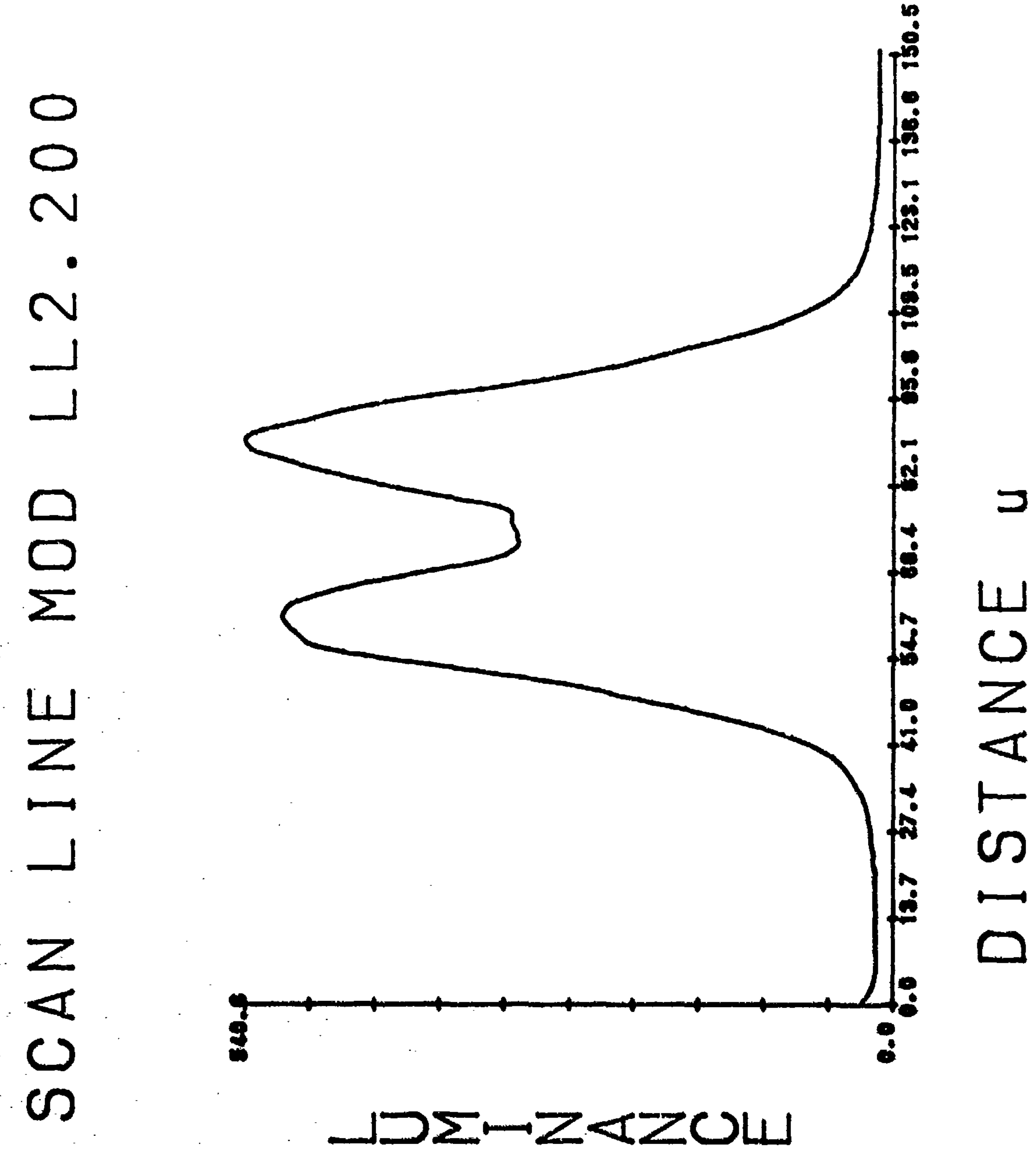

LINEWIDTH vs LUMINANCE
LUMINANCE
2025.4
0.0
0.0
2.8
5.6
8.4
11.2
14.1
16.9
19.7
22.5
25.3
28.1
30.9
LINEWIDTH

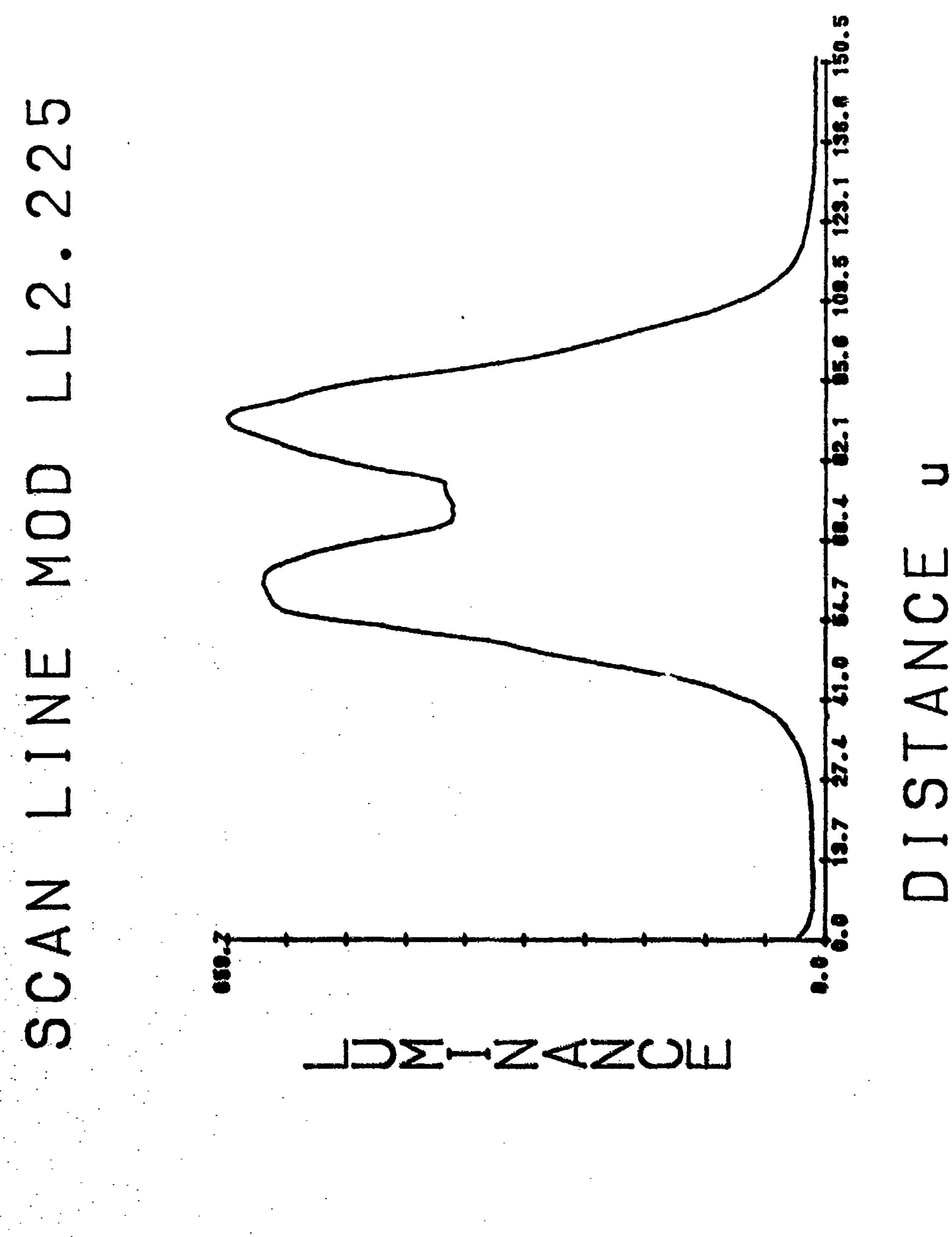

SCAN LINE MODULATION
LUMINANCE
DISTANCE u
FILENAME
LINEWIDTH
LL2.275
52.31031
LL2.25
LL2.225
LL2.2
LL2.175
48.45823
LL2.15
48.75037
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

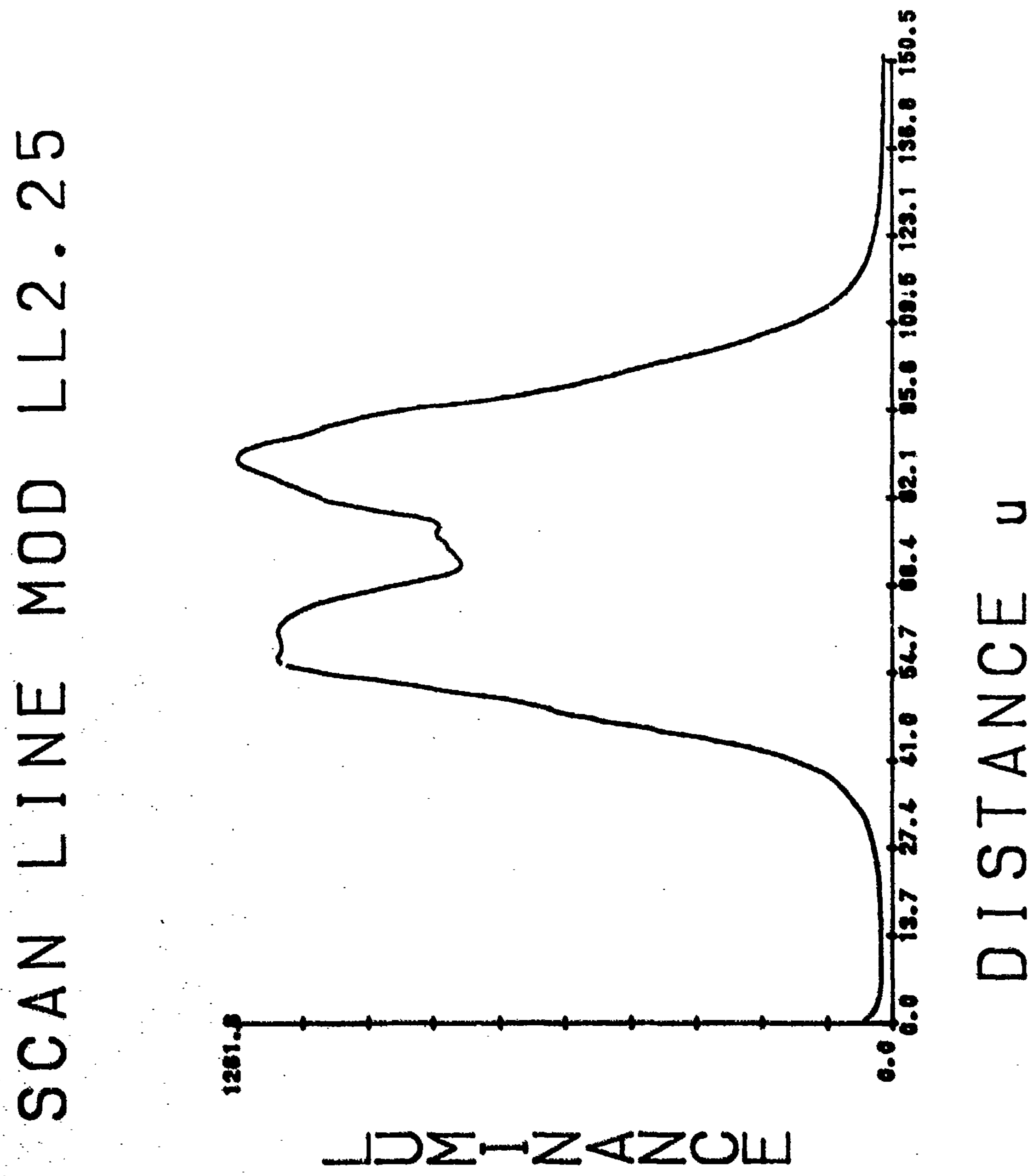

SCAN LINE MOD LL2.125
LUMINANCE
32.8
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


SCAN LINE MOD LL2.15
LUMINANCE
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


SCAN LINE MOD LL2.175
LUMINANCE
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

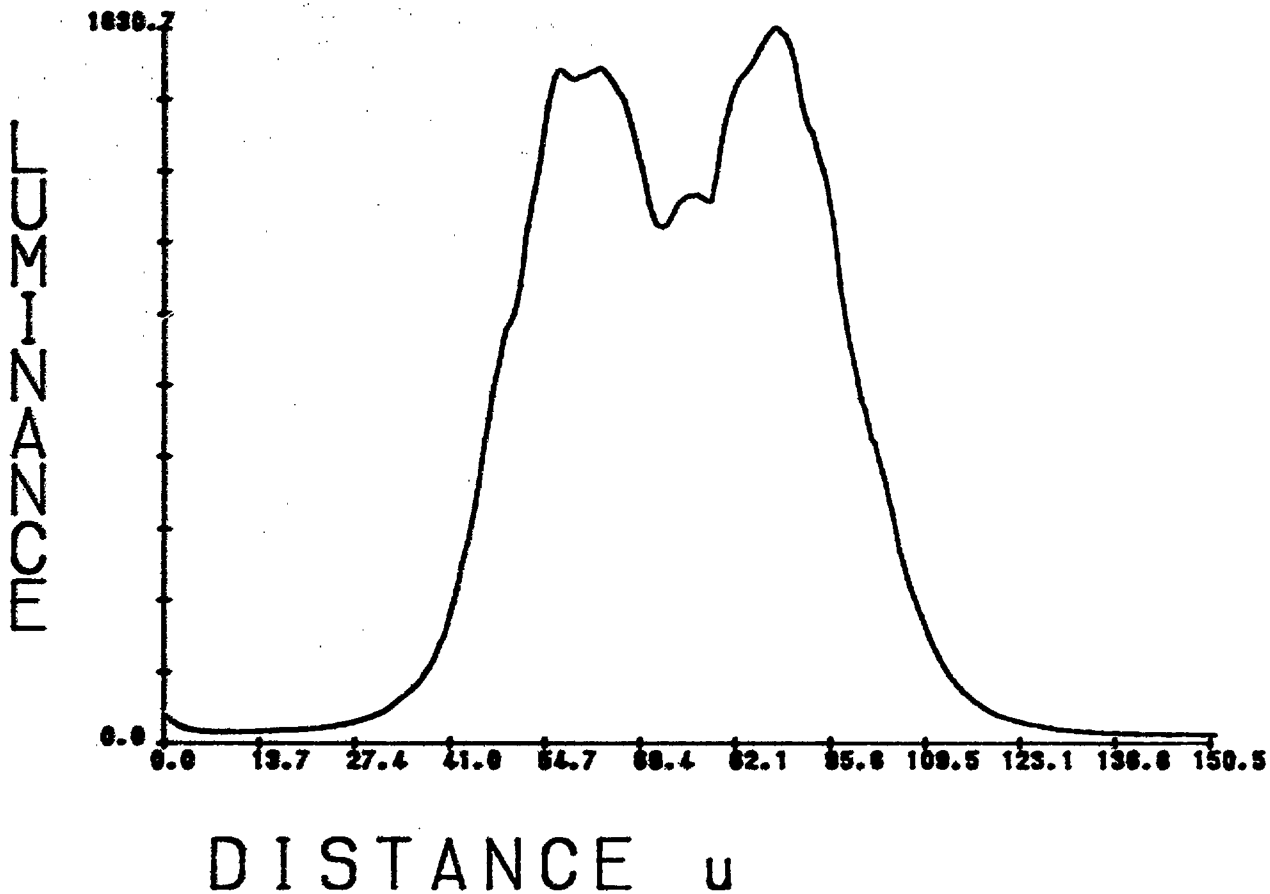

SCAN LINE MOD LL2.200
LUMINANCE
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


SCAN LINE MOD LL2.225
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

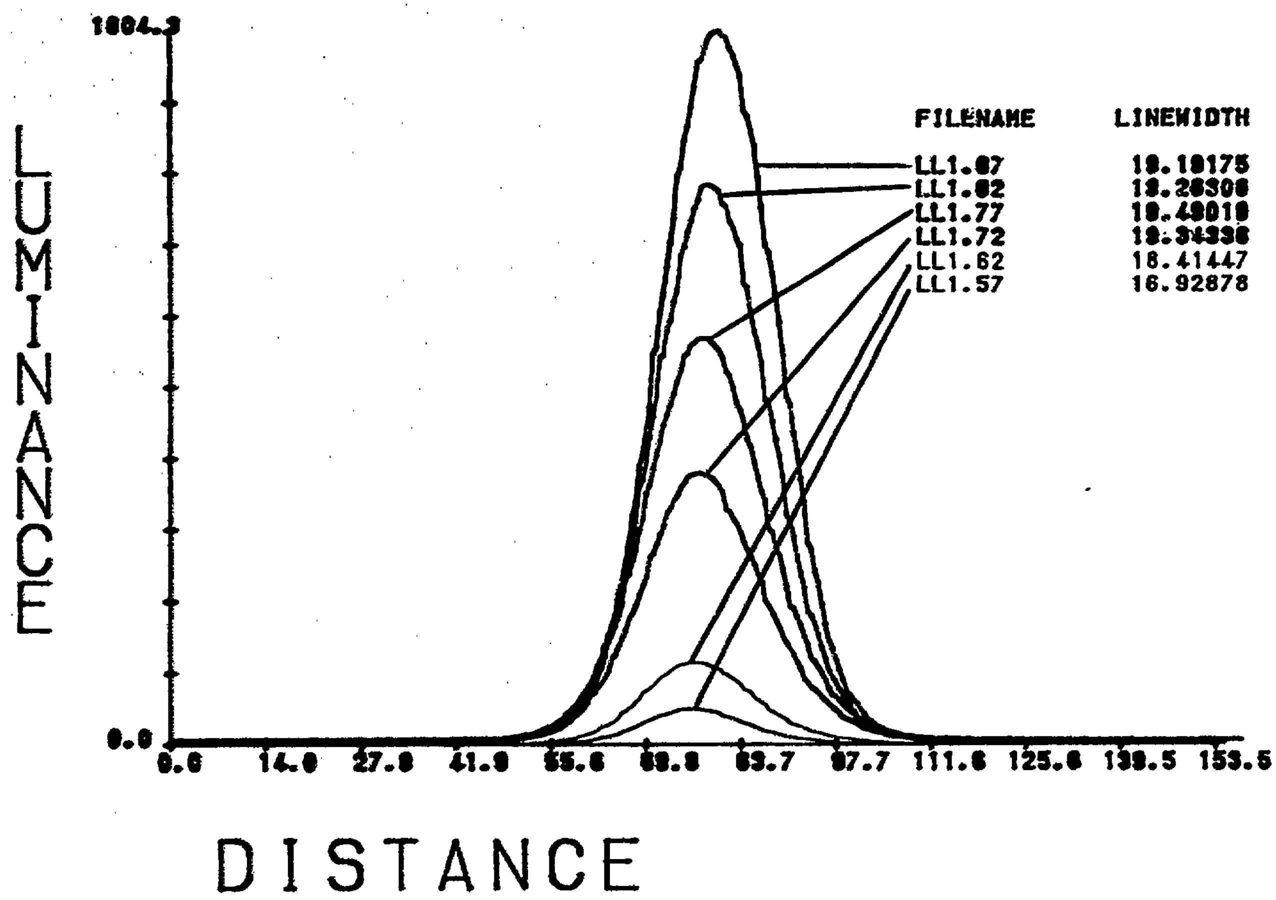


SCAN LINE MOD LL2.25
LUMINANCE
1281.8
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

SCAN LINE MOD LL2.275

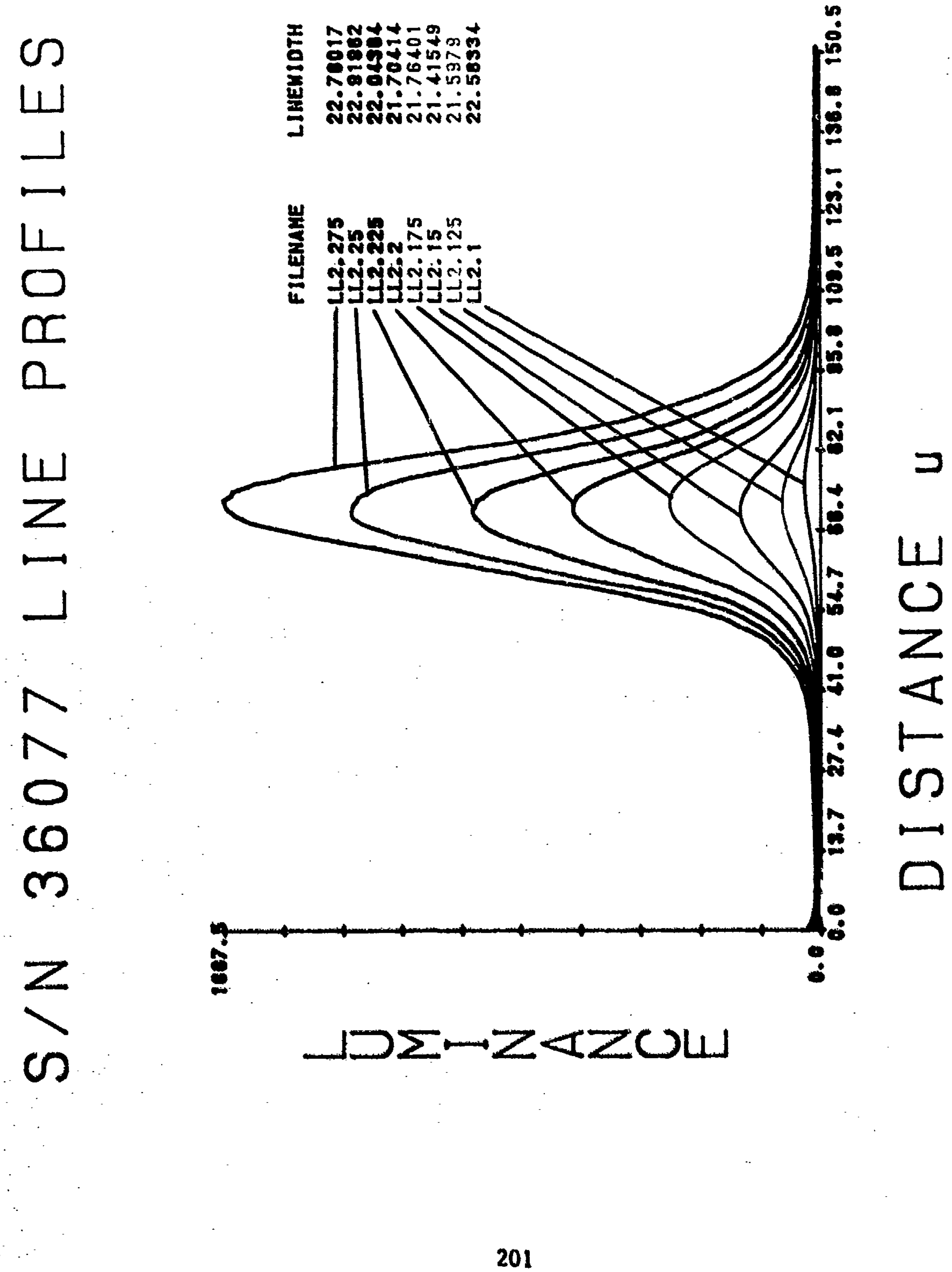


13 KV CRT LINE PROFILES



KAISER (HUGHES 1380) CRT

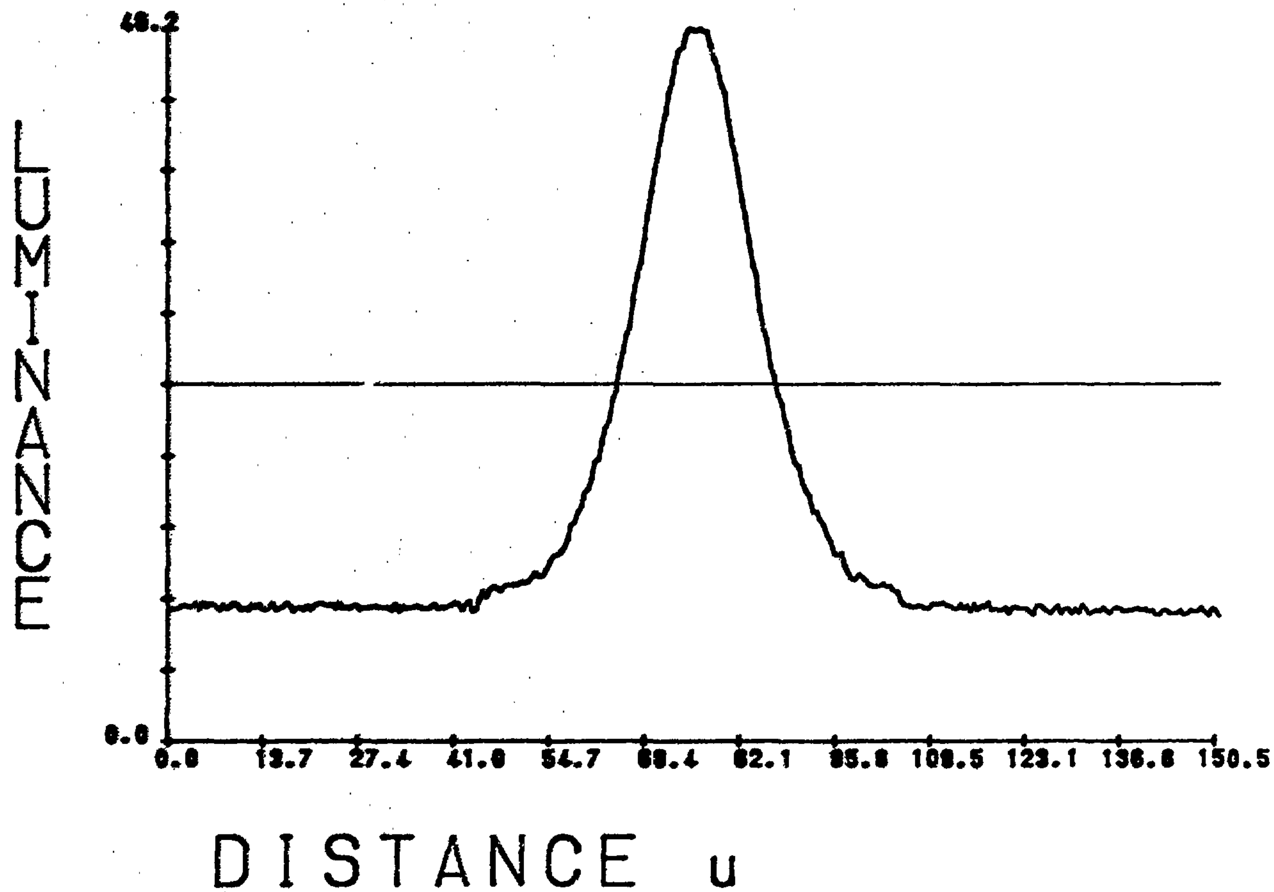
S/N 36077



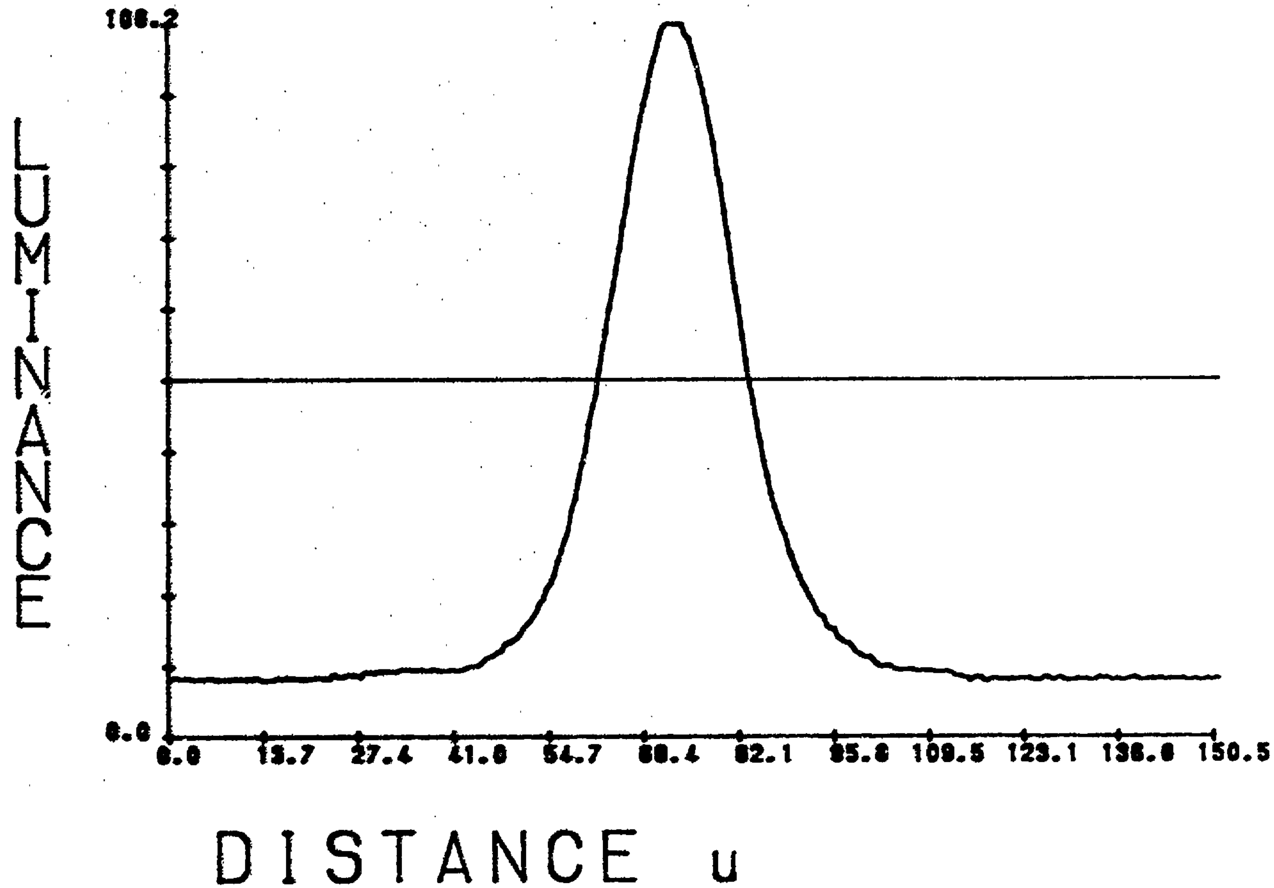
S/N 36077 LINE PROFILES
LUMINANCE
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
FILENAME
LL2.275
LL2.25
LL2.225
LL2.2
LL2.175
LL2.15
LL2.125
LL2.1
LINEWIDTH
22.78017
22.81982
22.04384
21.70414
21.76401
21.41549
21.5979
22.58334

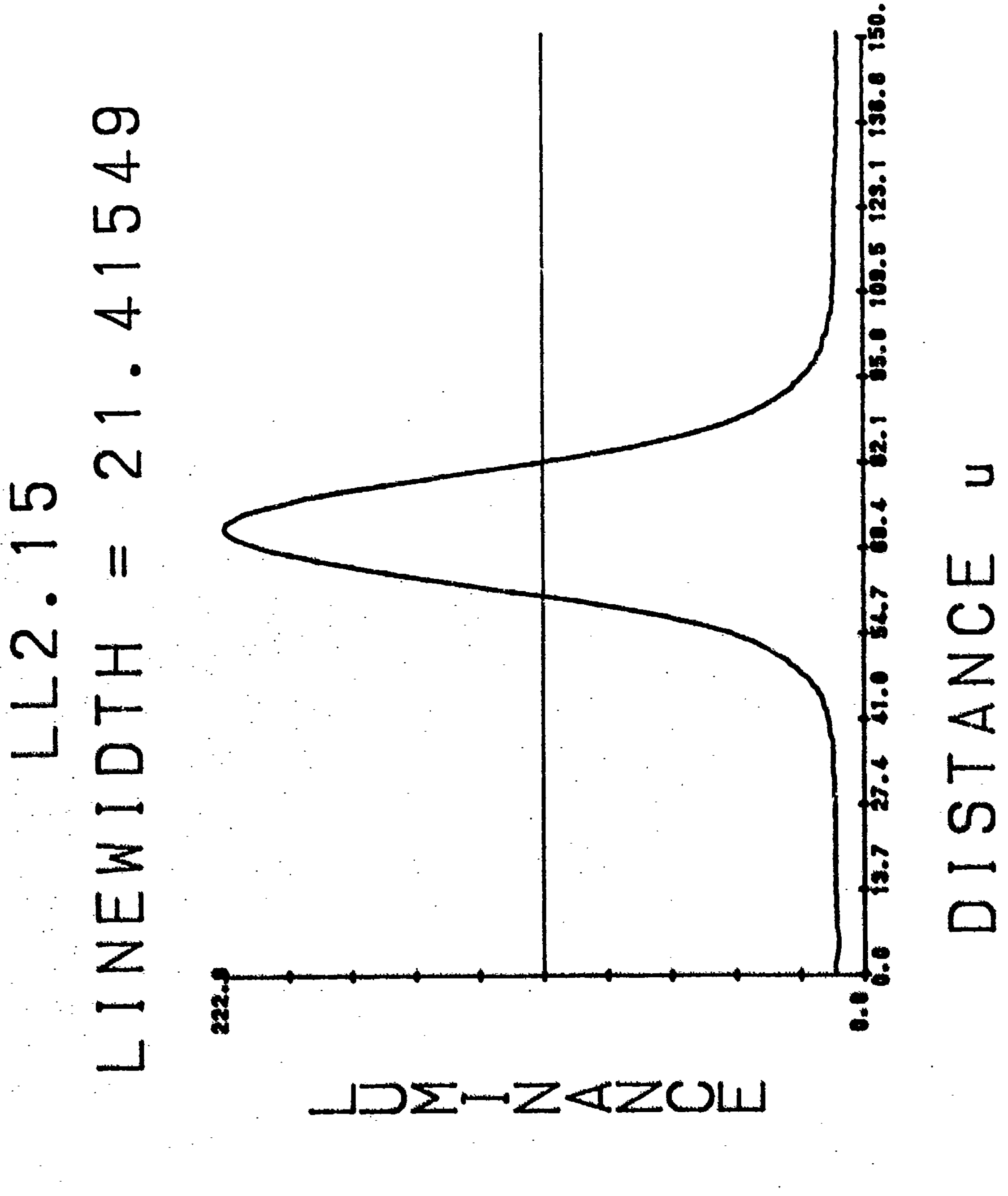
LL2.1

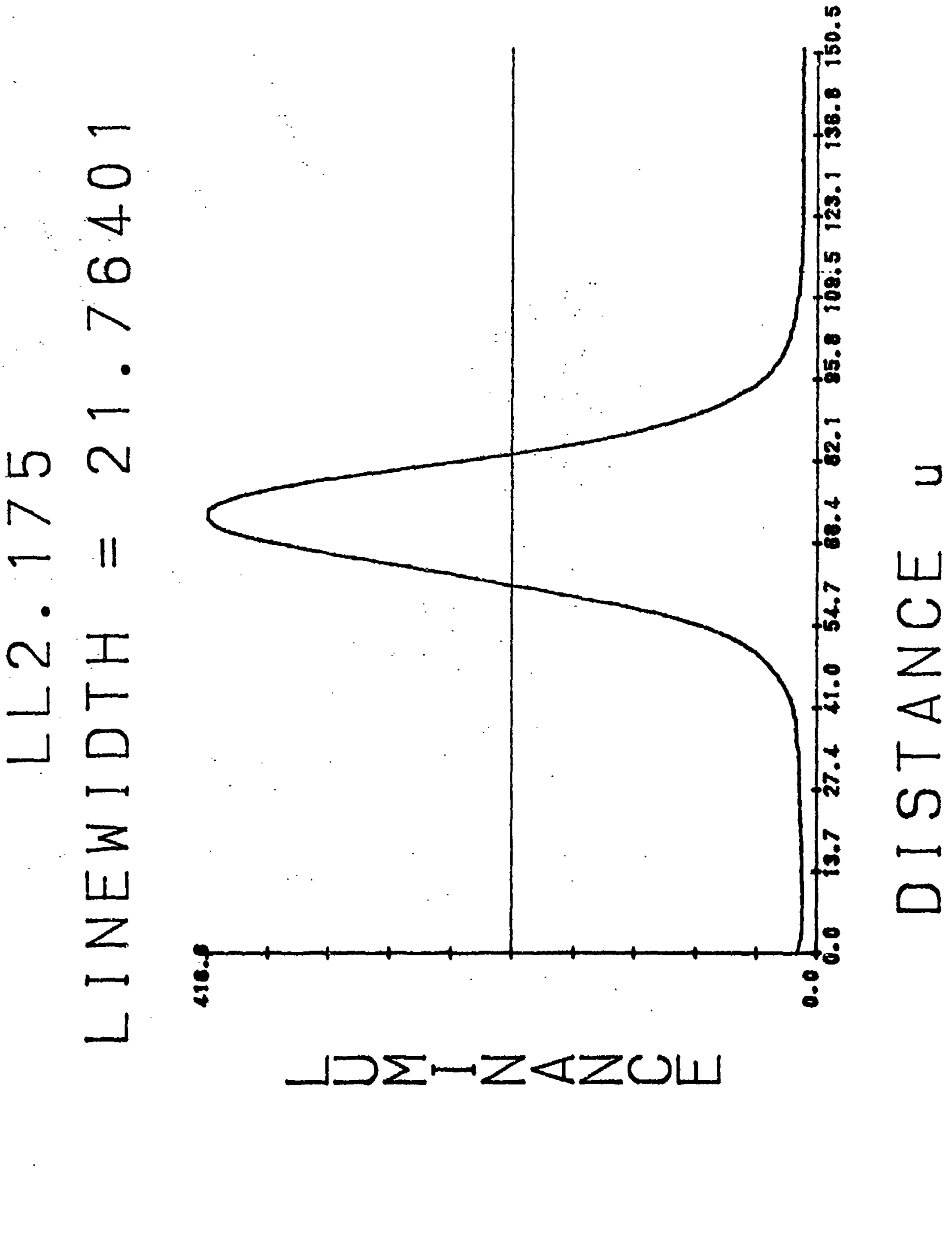
LINEWIDTH = 22.58334

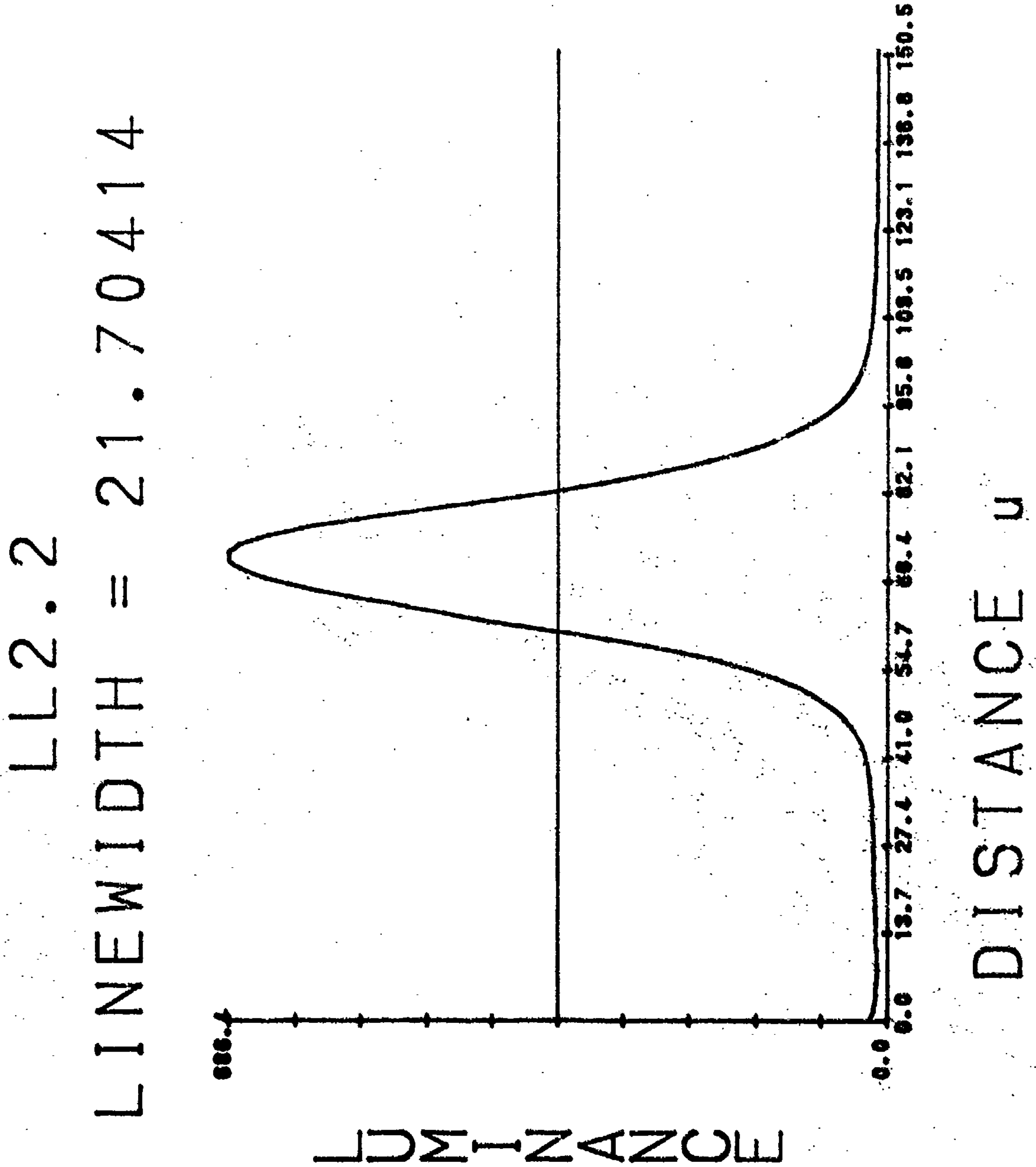


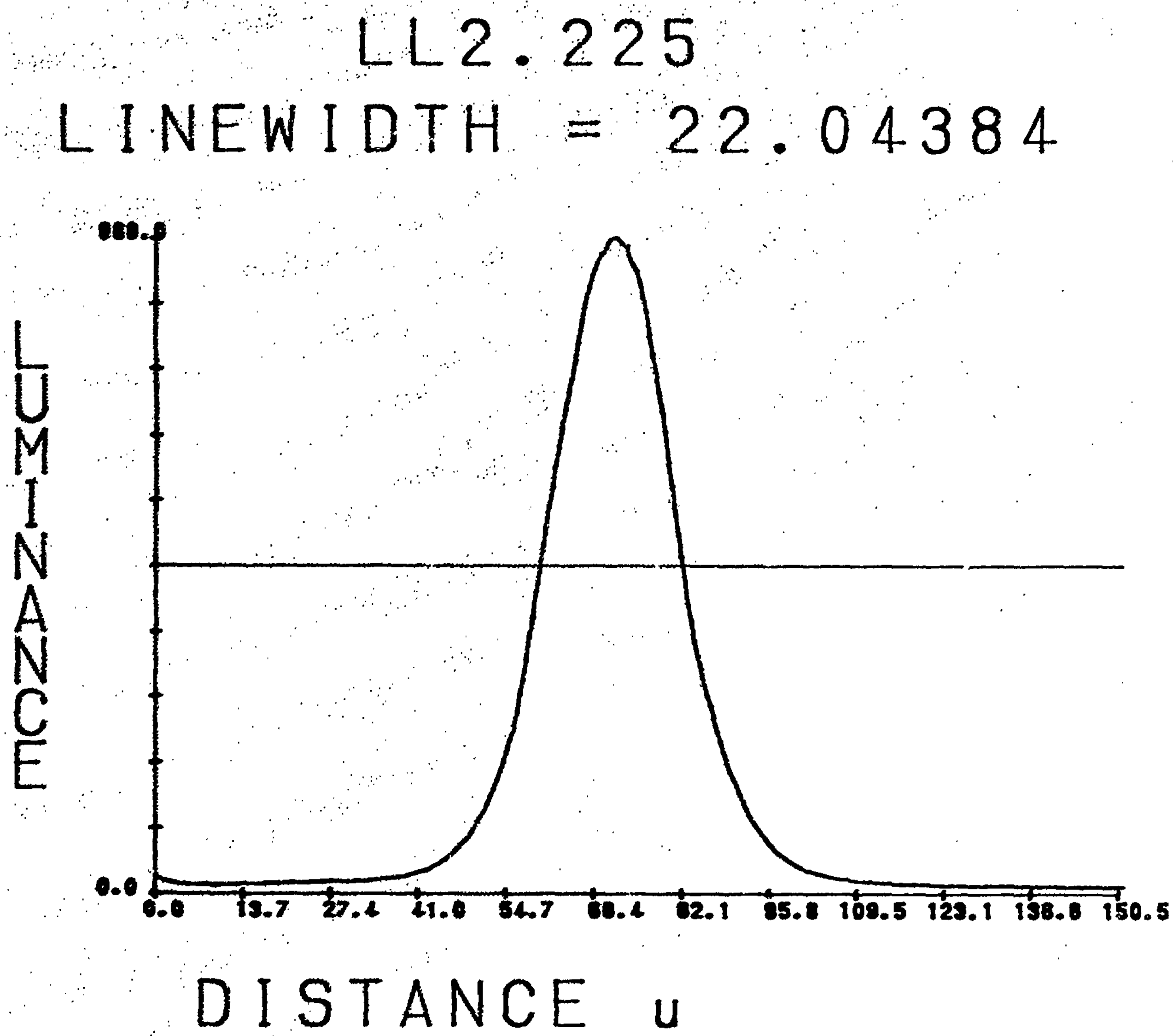
LL2.125
LINEWIDTH = 21.5979

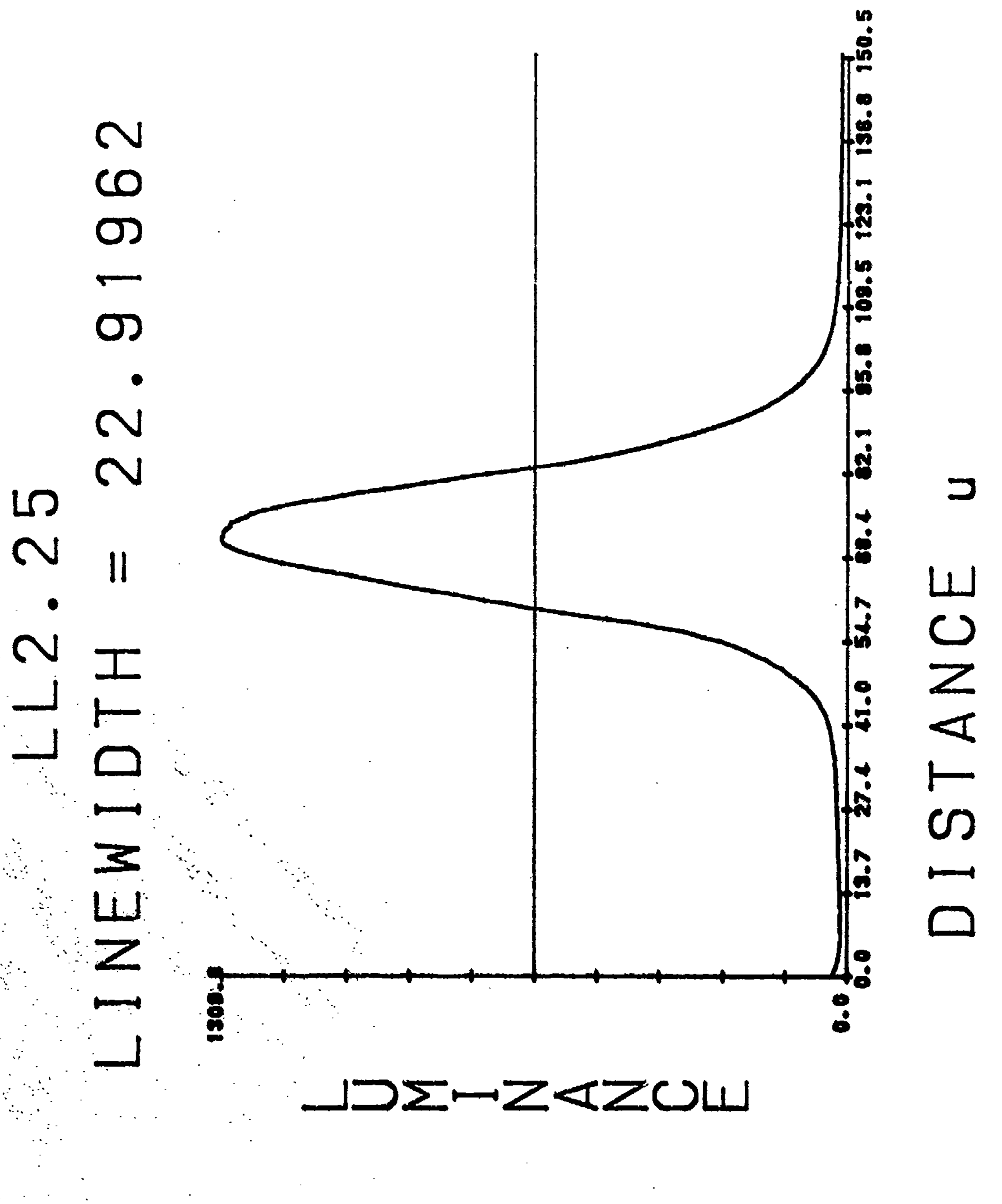


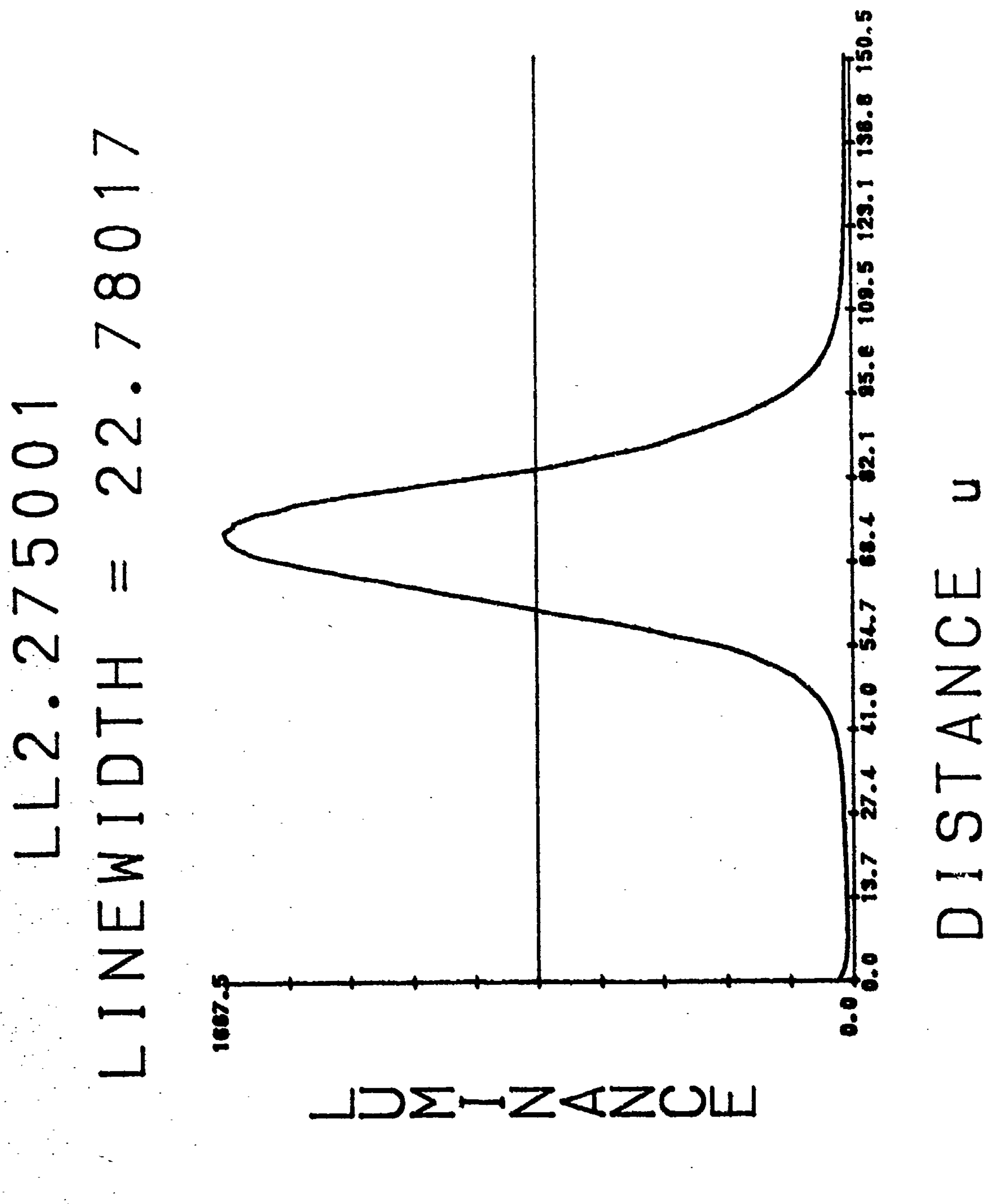

LL2.15
LINEWIDTH = 21.41549
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


LL2.175
LINEWIDTH = 21.76401
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

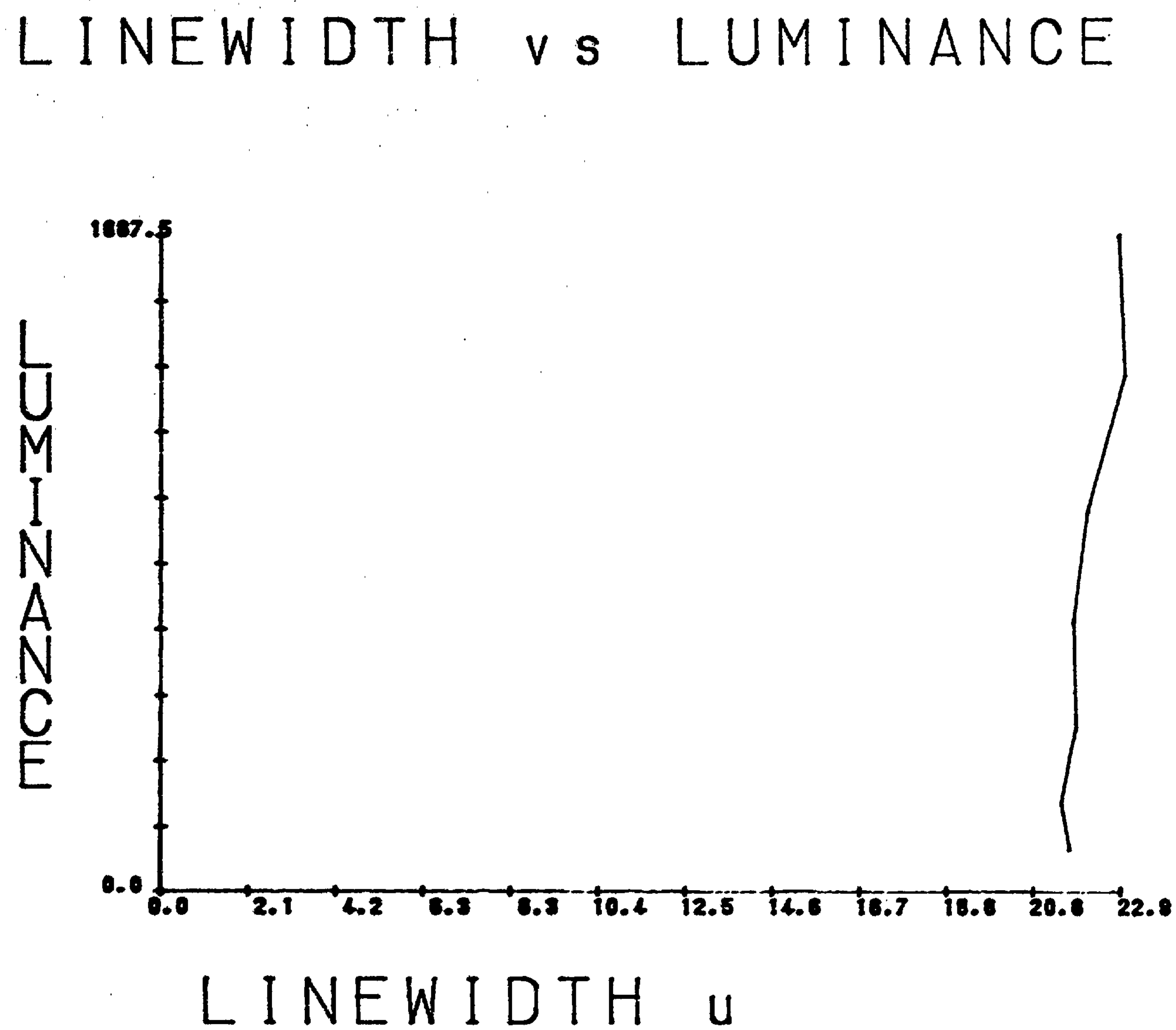

LL2.2
LINEWIDTH = 21.70414
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

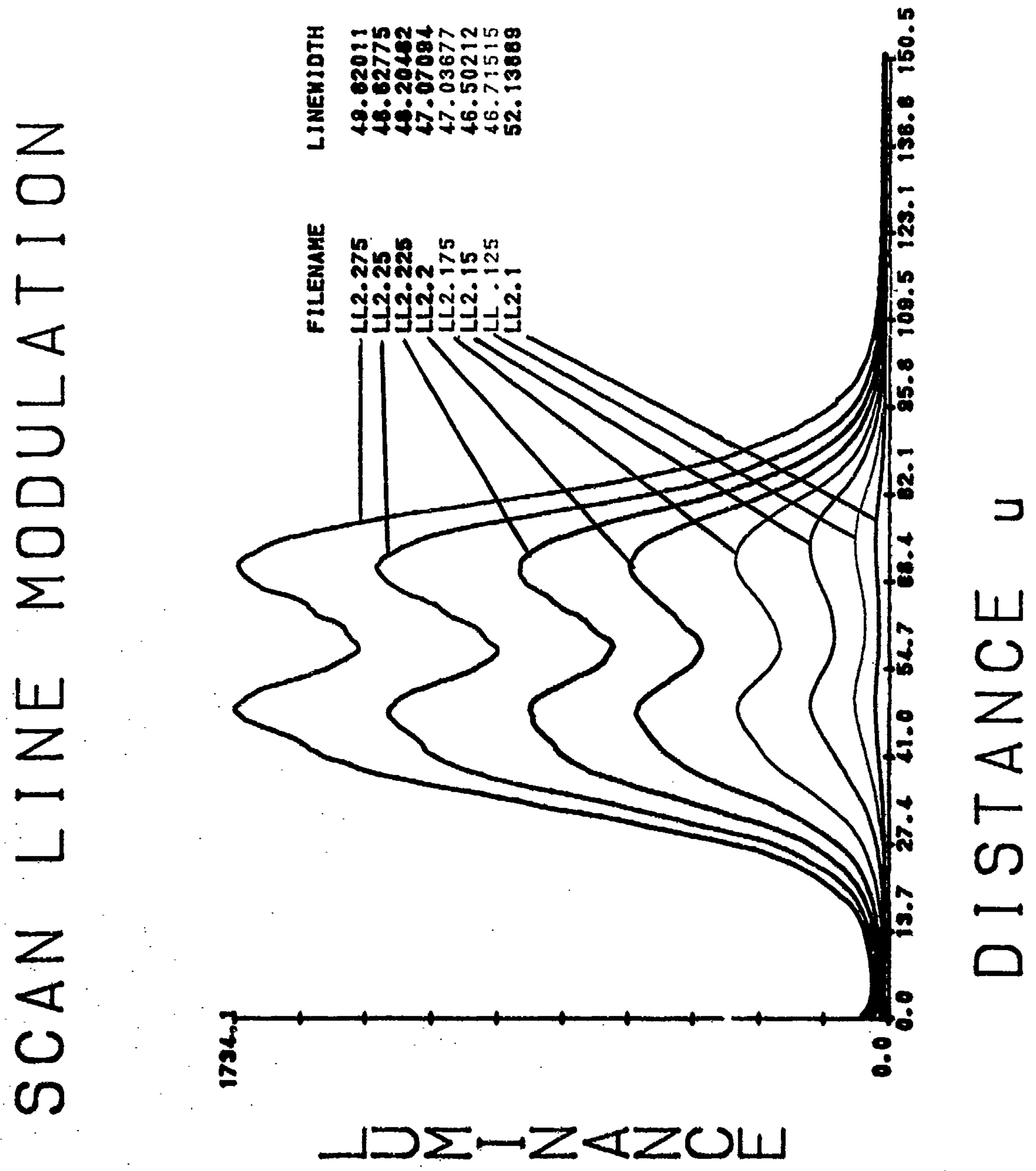

LL2.225
LINEWIDTH = 22.04384
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

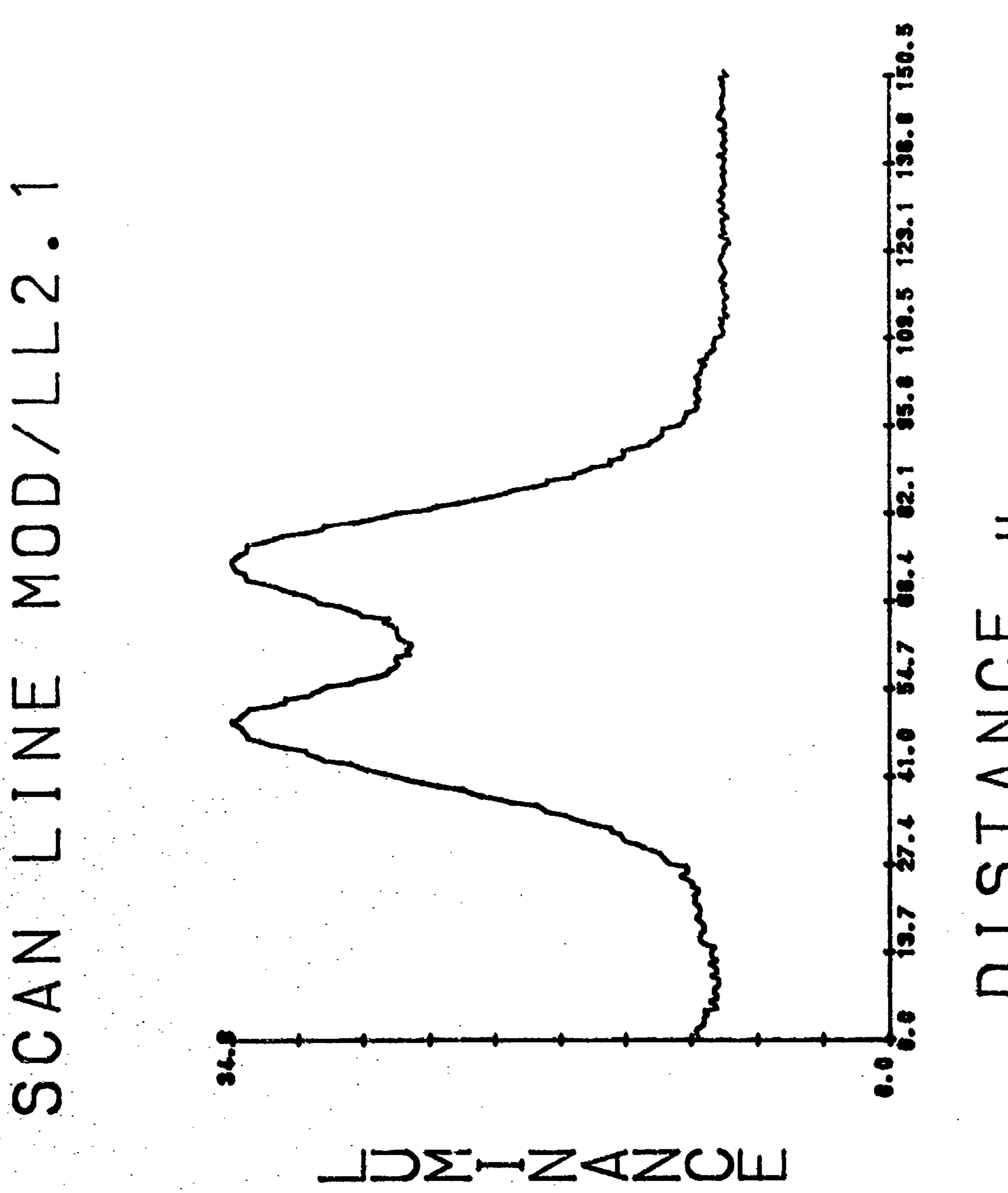

LL2.25
LINEWIDTH = 22.91962
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

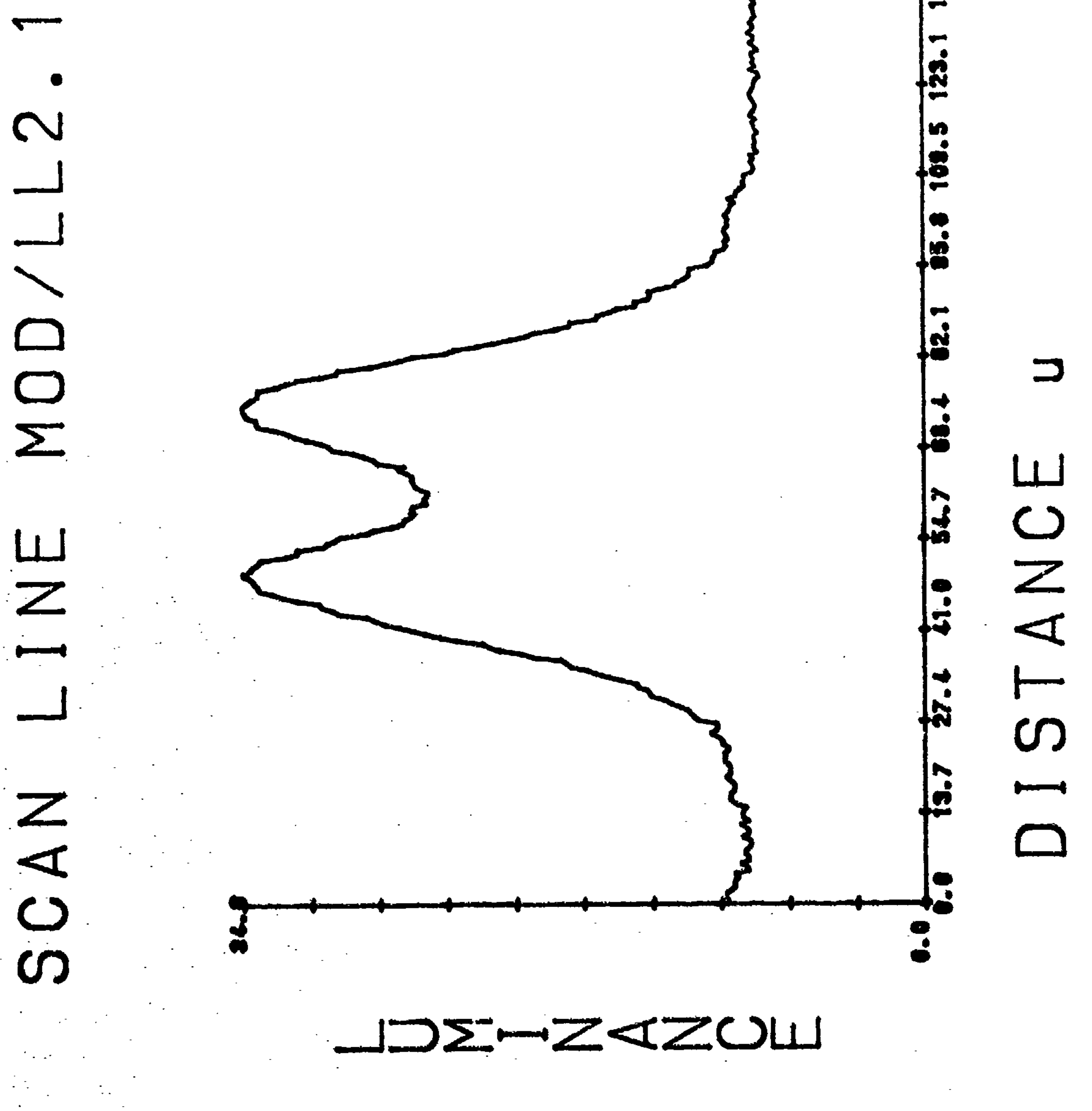


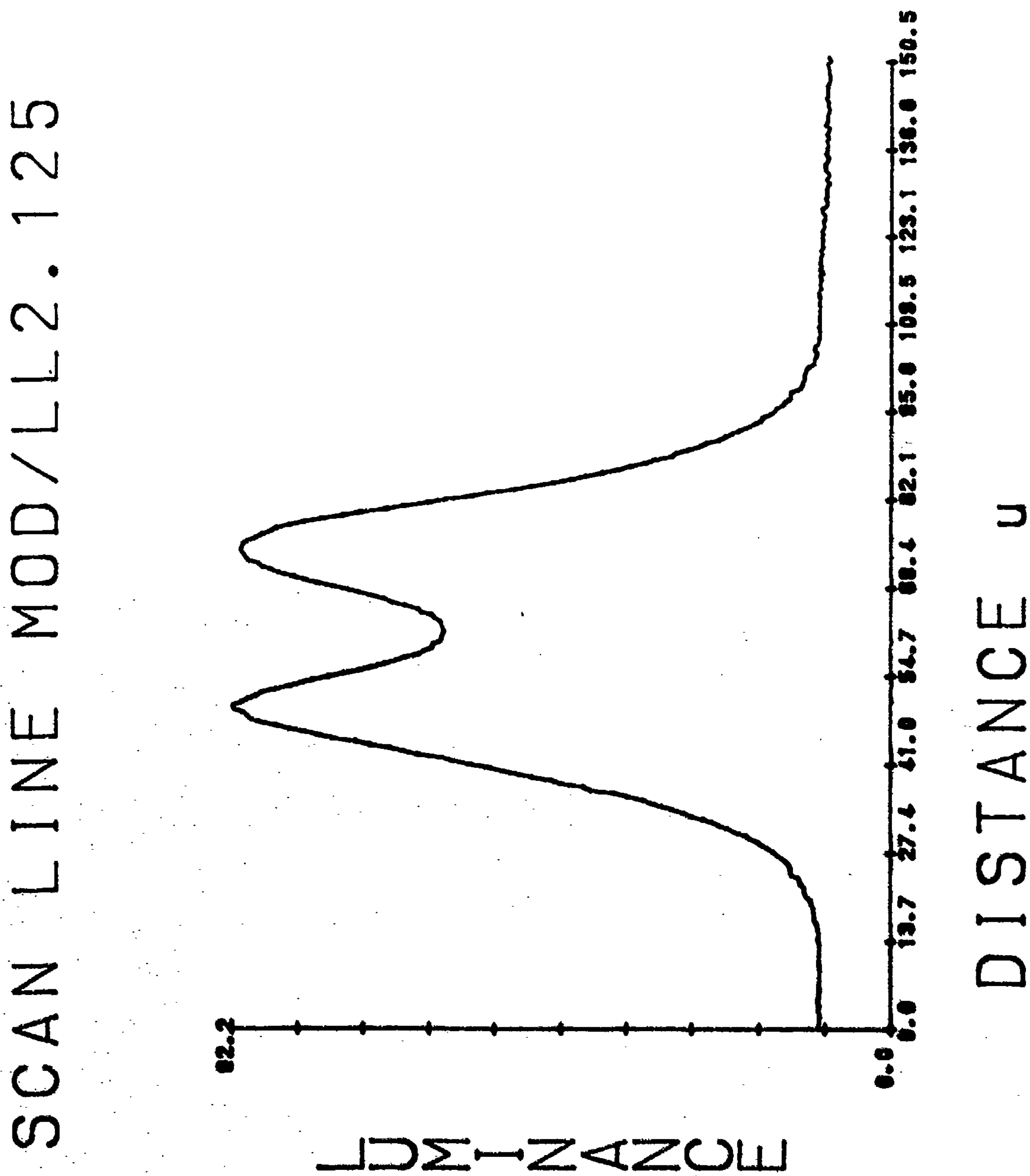
LL2.275001
LINEWIDTH = 22.780017
LUMINANCE
DISTANCE u
1667.5
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.6
109.5
123.1
136.8
150.5


LINEWIDTH vs LUMINANCE
LUMINANCE
0.0
0.0
2.1
4.2
6.3
8.3
10.4
12.5
14.6
16.7
18.8
20.8
22.9
LINEWIDTH u

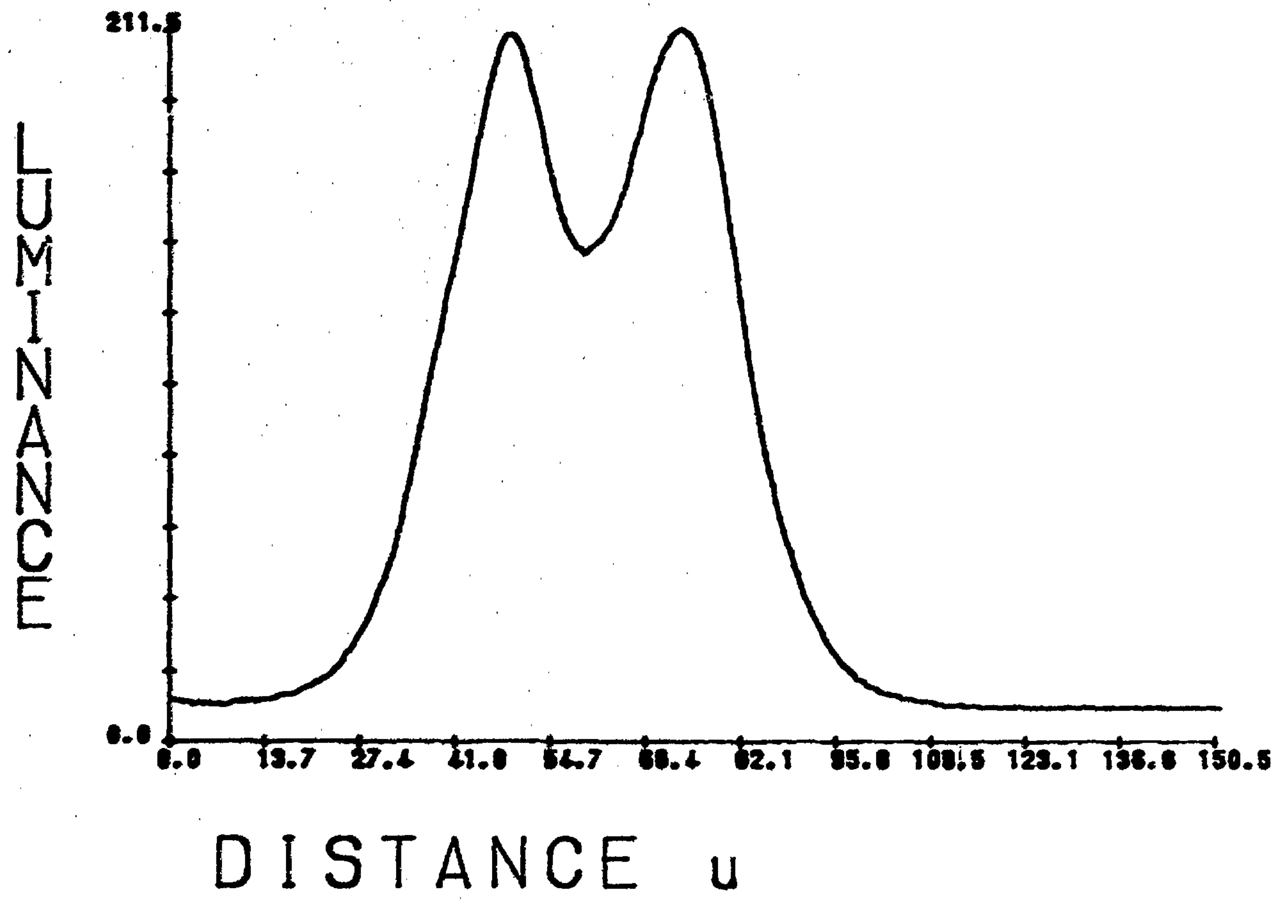

SCAN LINE MODULATION
FILENAME
LL2.275
LL2.25
LL2.225
LL2.2
LL2.175
LL2.15
LL .125
LL2.1
LINEWIDTH
49.62011
48.62775
48.20482
47.07084
47.03677
46.50212
46.71515
52.13889
1734.1
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
LUMINANCE
DISTANCE u

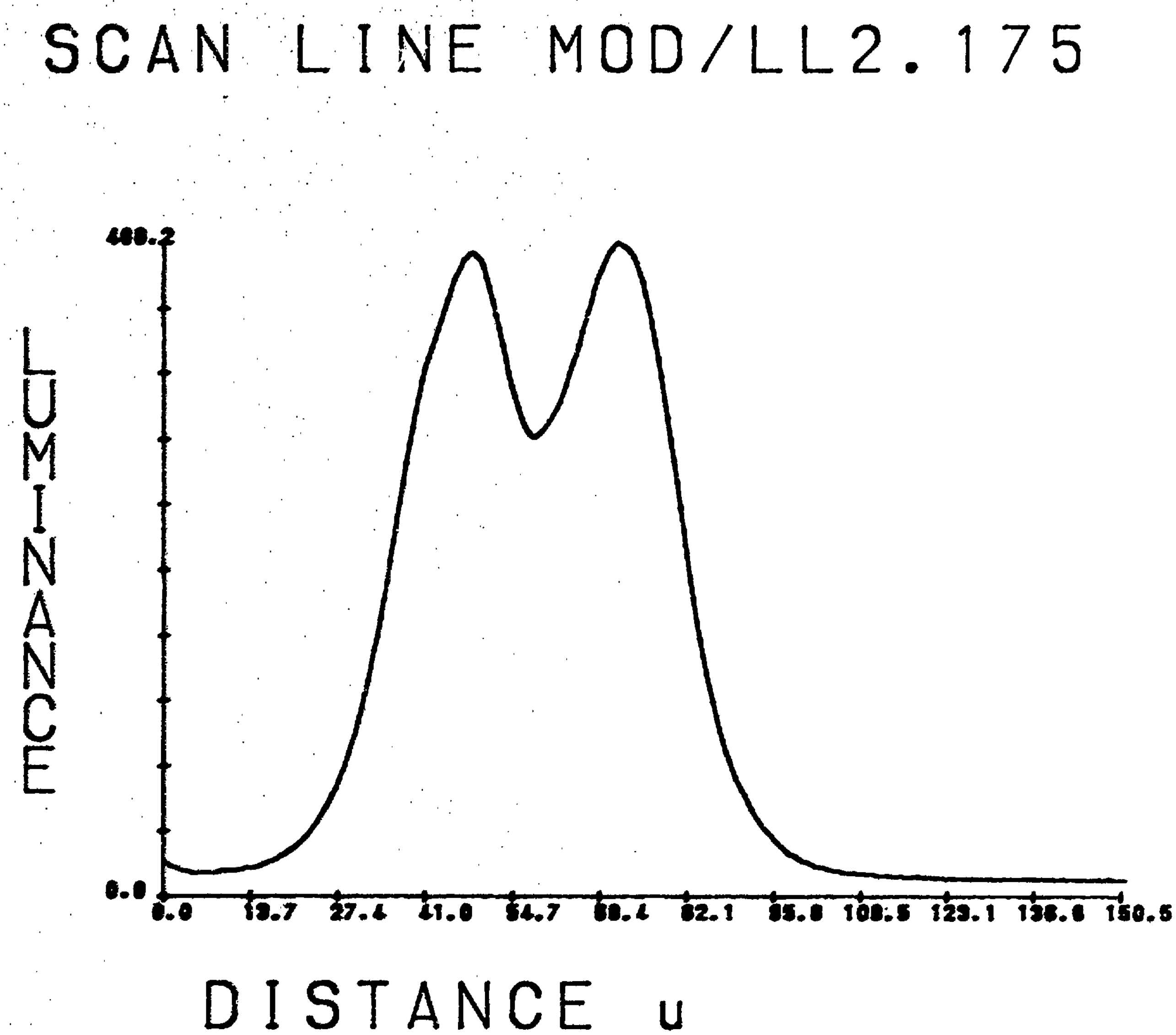

SCAN LINE MOD/LL2.1
LUMINANCE
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

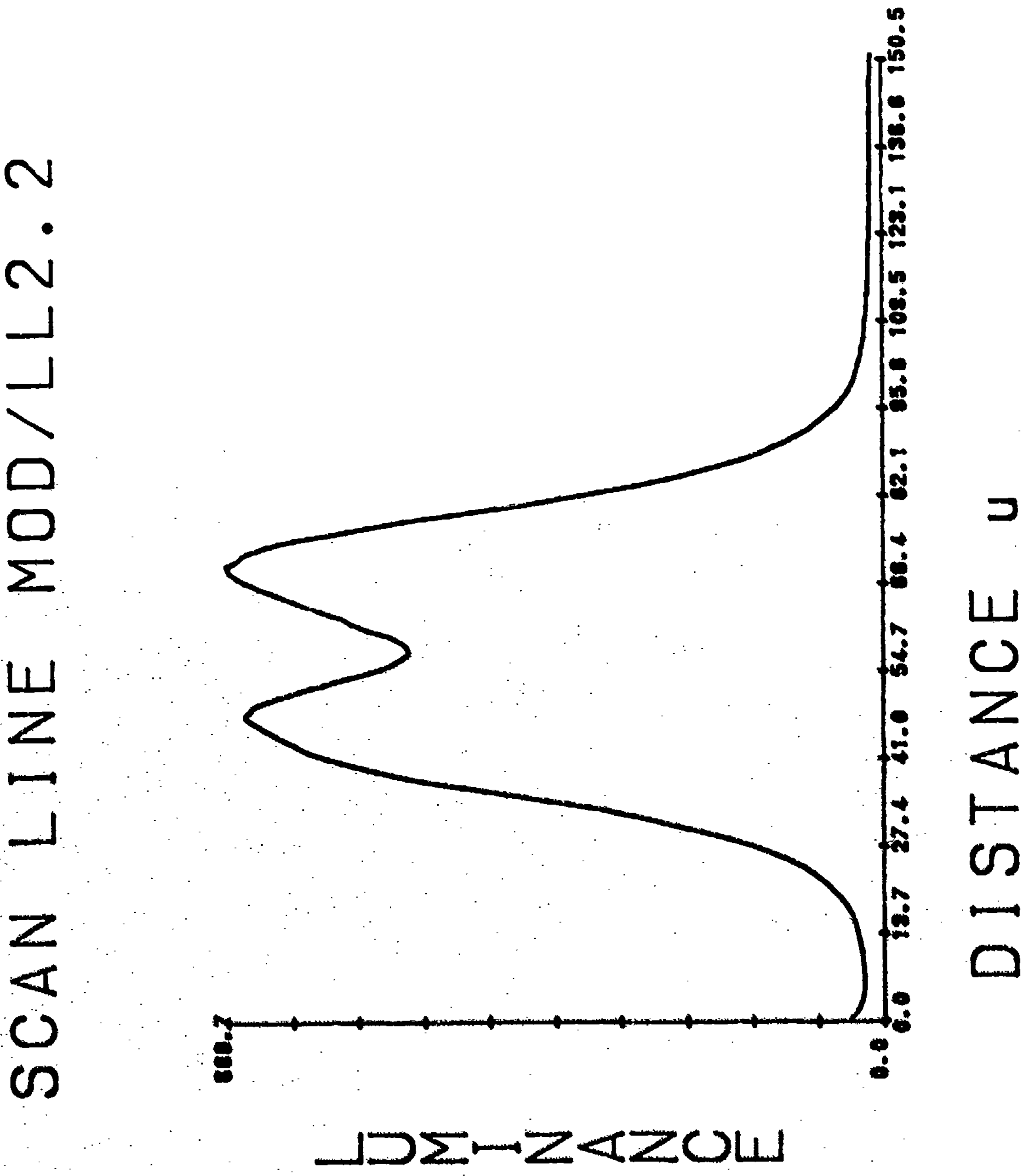

SCAN LINE MOD/LL2.1
LUMINANCE
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

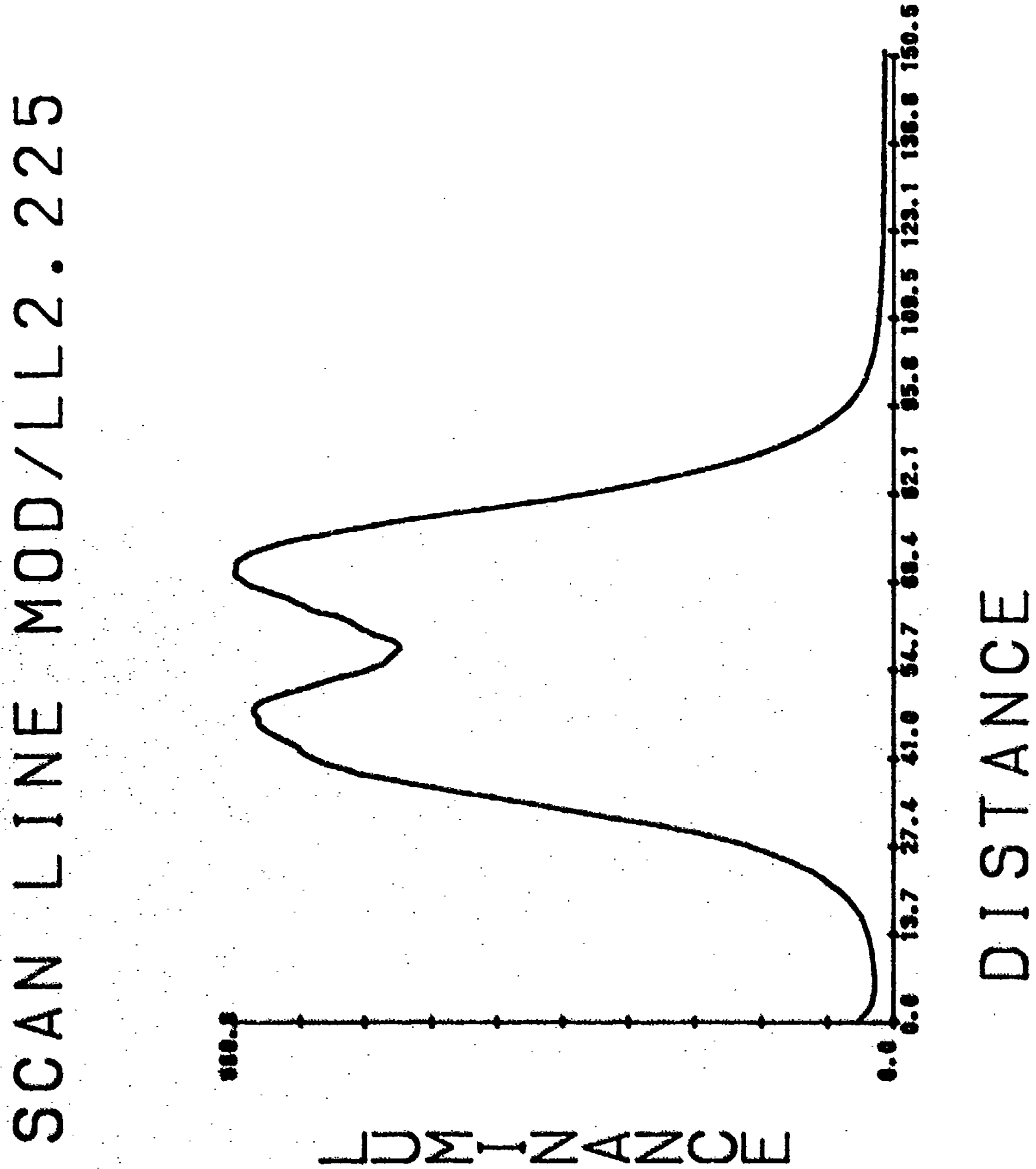

SCAN LINE MOD/LL2.125
LUMINANCE
82.2
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

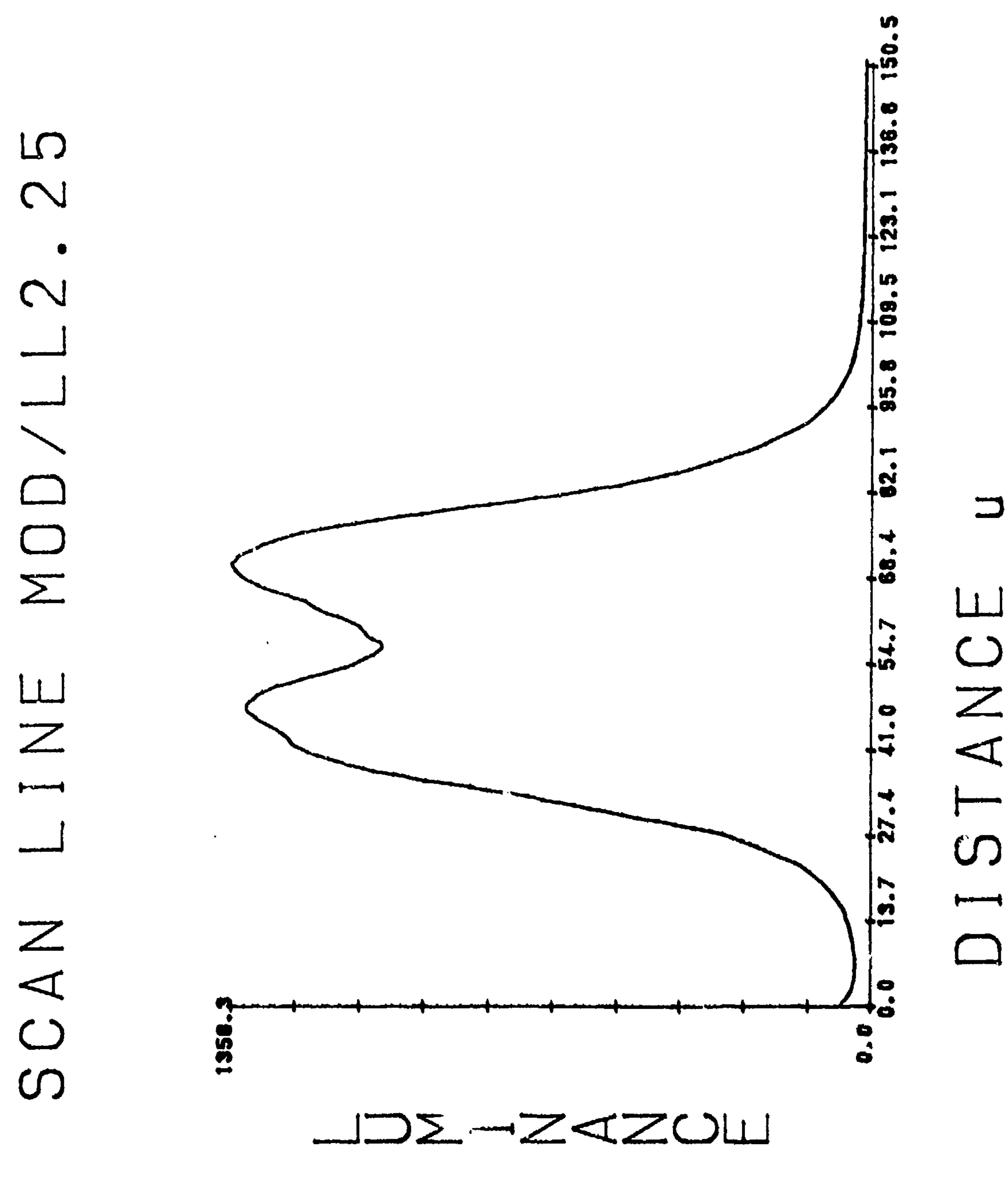
SCAN LINE MOD/LL2.15

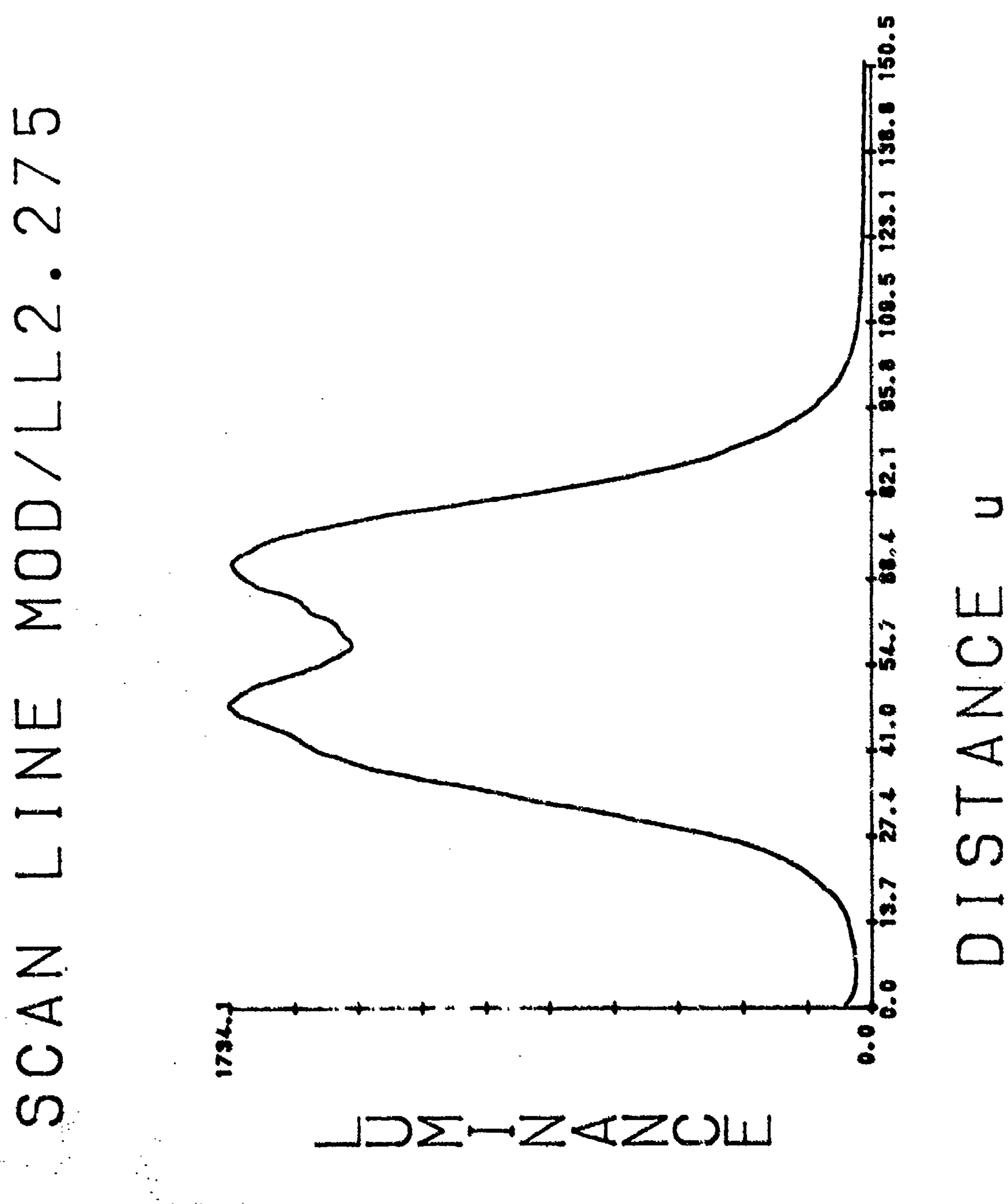



SCAN LINE MOD/LL2.175
LUMINANCE
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u

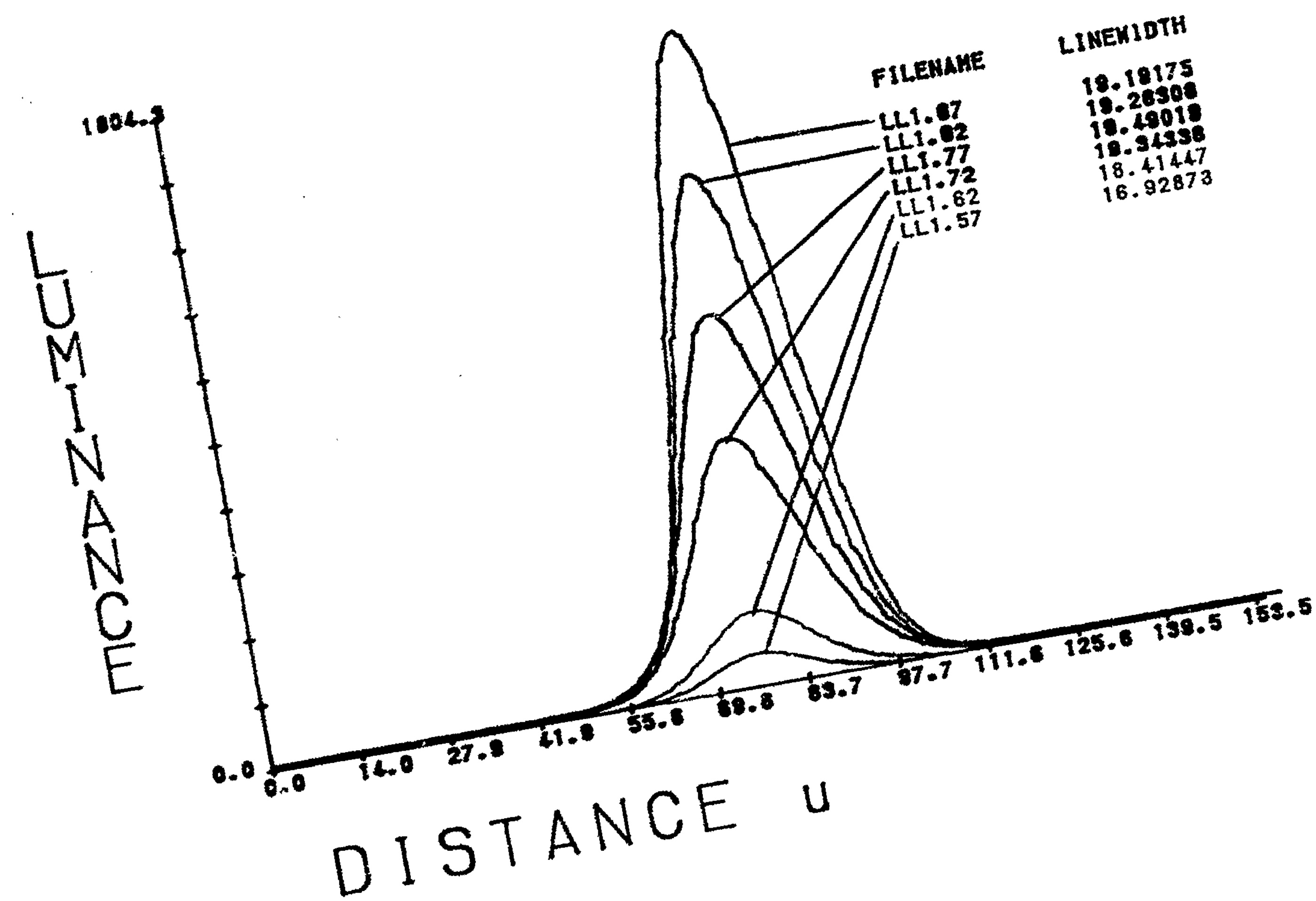

SCAN LINE MOD/LL2.2
LUMINANCE
DISTANCE u
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5


SCAN LINE MOD/LL2.225
LUMINANCE
0.0
DISTANCE
0.0 13.7 27.4 41.0 54.7 68.4 82.1 95.8 109.5 123.1 136.8 150.5


SCAN LINE MOD/LL2.25
LUMINANCE
1358.3
0.0
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5
DISTANCE u


SCAN LINE MOD/LL2.275
LUMINANCE
1734.1
0.0
DISTANCE u
0.0
13.7
27.4
41.0
54.7
68.4
82.1
95.8
109.5
123.1
136.8
150.5

13 KV CRT LINE PROFILES



SINEWAVE RESPONSE

SINEWAVE RESPONSE

Sinewave Response (SWR) is a performance measurement method for CRTs that is well established in the industrial sector. The procedure used to perform this test is established in AAMRL-TR-76-73 [5]. The method is outlined below.

Sinewave Response employs an engineering system measurement technique where a known sinewave signal is introduced at the input of a system and the system response is measured at the output. This technique makes the assumption the system being measured is linear, causal, and continuous. These assumptions are not adhered to in a strict sense for CRT SWR measurements. For CRTs, the amount of modulation observed at the display, after being processed by the associated electronics, is determined by measuring the light and dark sinewave luminance values imaged on the display. Recalling figure 5 from from the line profile section, the sinewave video signal displayed shows both the corresponding light and dark areas considered for measurement. The CRTs' SWR performance is significantly affected by the design and performance of the cable and display electronics. The main cause is the distributed capacitance found in the standard CRT cable. Sinewave Response is a figure of merit used to determine where limiting resolution occurs for future optimization or component replacement.

The input video amplifier signal was provided as shown in figure 8. The procedures described below are illustrated in the block diagram flow chart in figure 9. At an initial spatial frequency of 5 CY/DW the sinewave signal is set to 0.96 volts peak-to-peak and is offset above ground 0.04 volts. This video signal format is used to ensure compatibility with TV cameras or sensors with which the display under test will be used. The 0.04 volt offset eliminates black level clipping of the video signal. This sinewave video signal is measured at the output of the video amplifier to establish a baseline amplitude. Each successive output spatial frequency video signal is adjusted to this baseline. The displayed sinewave on the CRT is measured using a slit photometer and a 20X microscopic objective lens to determine the maximum luminance (Lmax) and minimum luminance (Lmin) values. The modulation contrast (Mc) is calculated using the following formula:

$$Mc = (Lmax - Lmin)/(Lmax + Lmin)$$

The spatial frequency of the sinewave video input is increased until the displayed modulation can no longer be detected and the data are then plotted as modulation contrast versus the associated spatial frequency.

As mentioned previously, the SWR is a measure of the contrast or image quality that is present. It quantitatively defines how crisp or clear a displayed image is on a particular CRT. This relates directly to the discernibility of edges on both high and low contrast images. Since the edges of an image are made up of harmonics throughout the spatial frequency band, it follows that lower modulation percentages produce degradation of image contrast at specific spatial frequencies.

The first graph in this section labeled, "VIDEO AMP INPUT", records the establishment of the input signal to the video amplifier using the procedures described above. The second and third graphs, labeled "VIDEO AMP OUTPUT", provide plots of the output of the video at 25 and 100 foot lamberts, respectively. The amplitude of the video amplifier output signal (the baseline) was maintained by adjusting the input video amplifier signal, as previously discussed. This provided a consistent reference point for the measurement. The results of this procedure are provided in the graphs labeled, "MODULATION CONTRAST". These last two graphs are the SWR for 25 and 100 footlamberts, respectively.

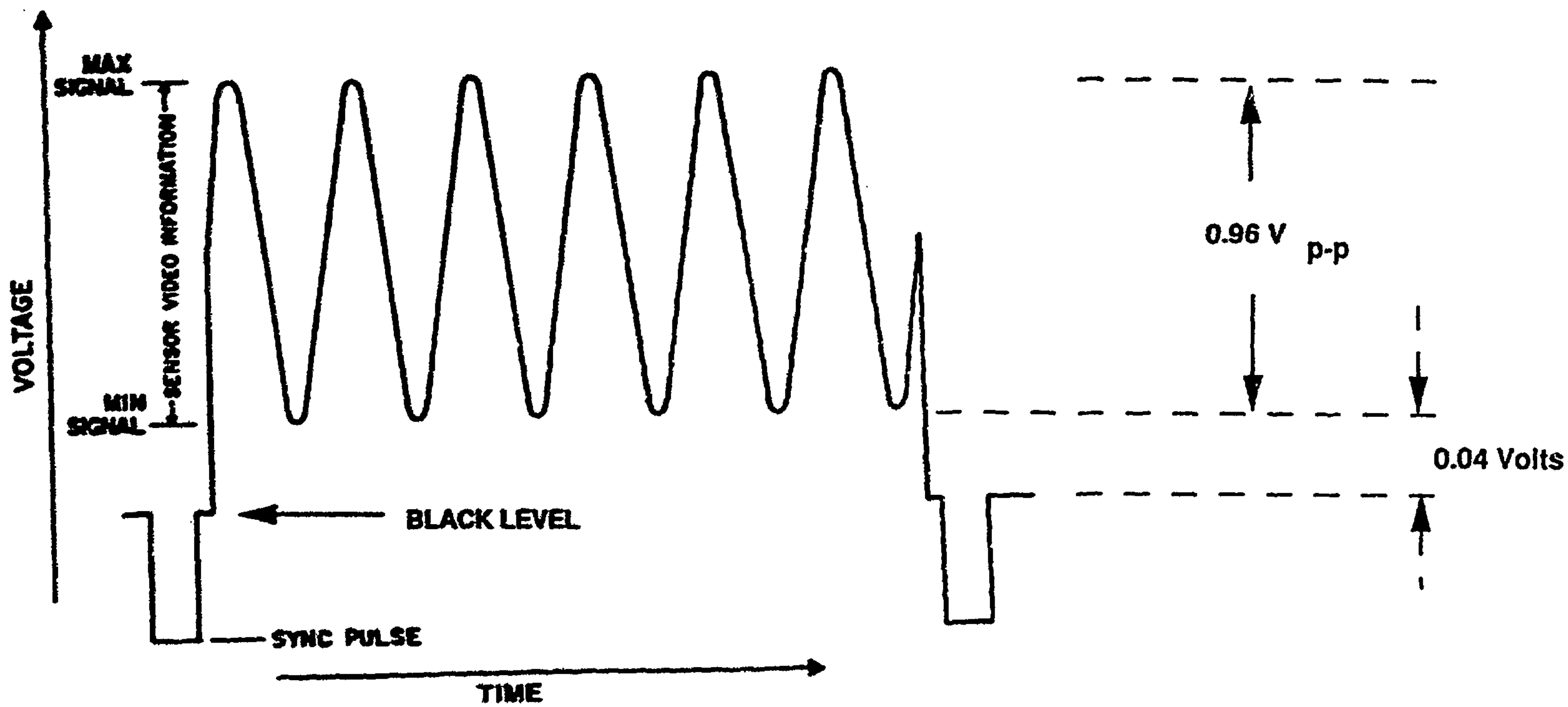


Figure 8 - Electronically Generated Video Sine Wave

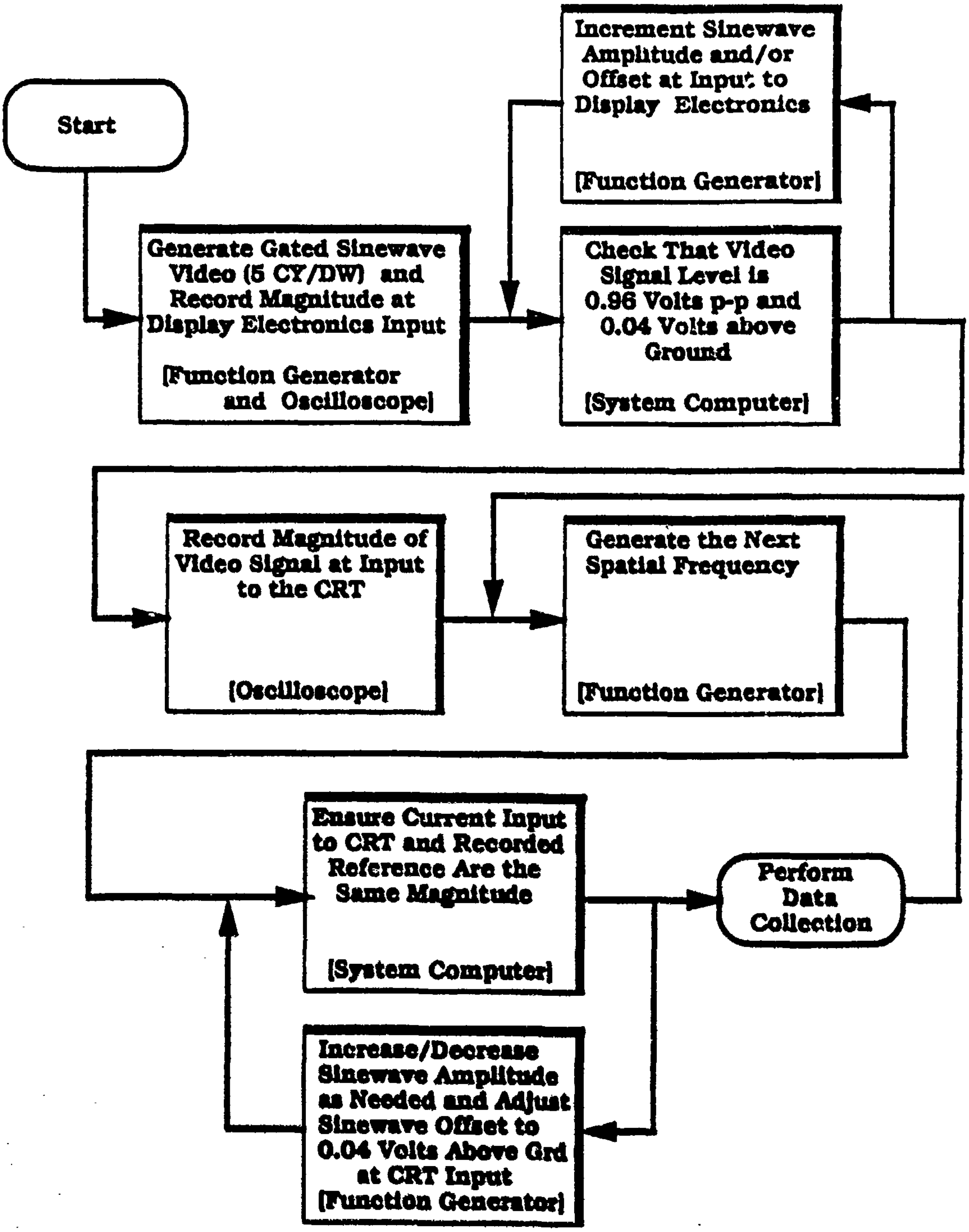
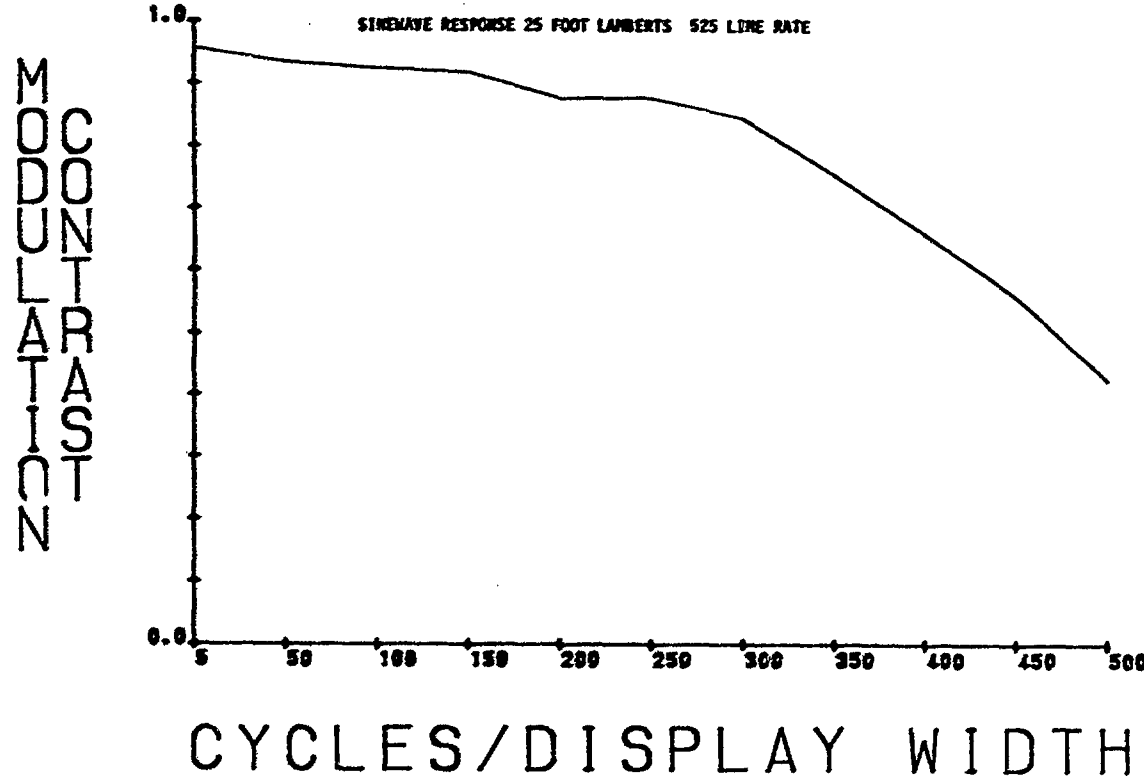


FIGURE 9 - SINEWAVE RESPONSE SIGNAL CONDITIONING BLOCK DIAGRAM

HONEYWELL CRT

S/N 004



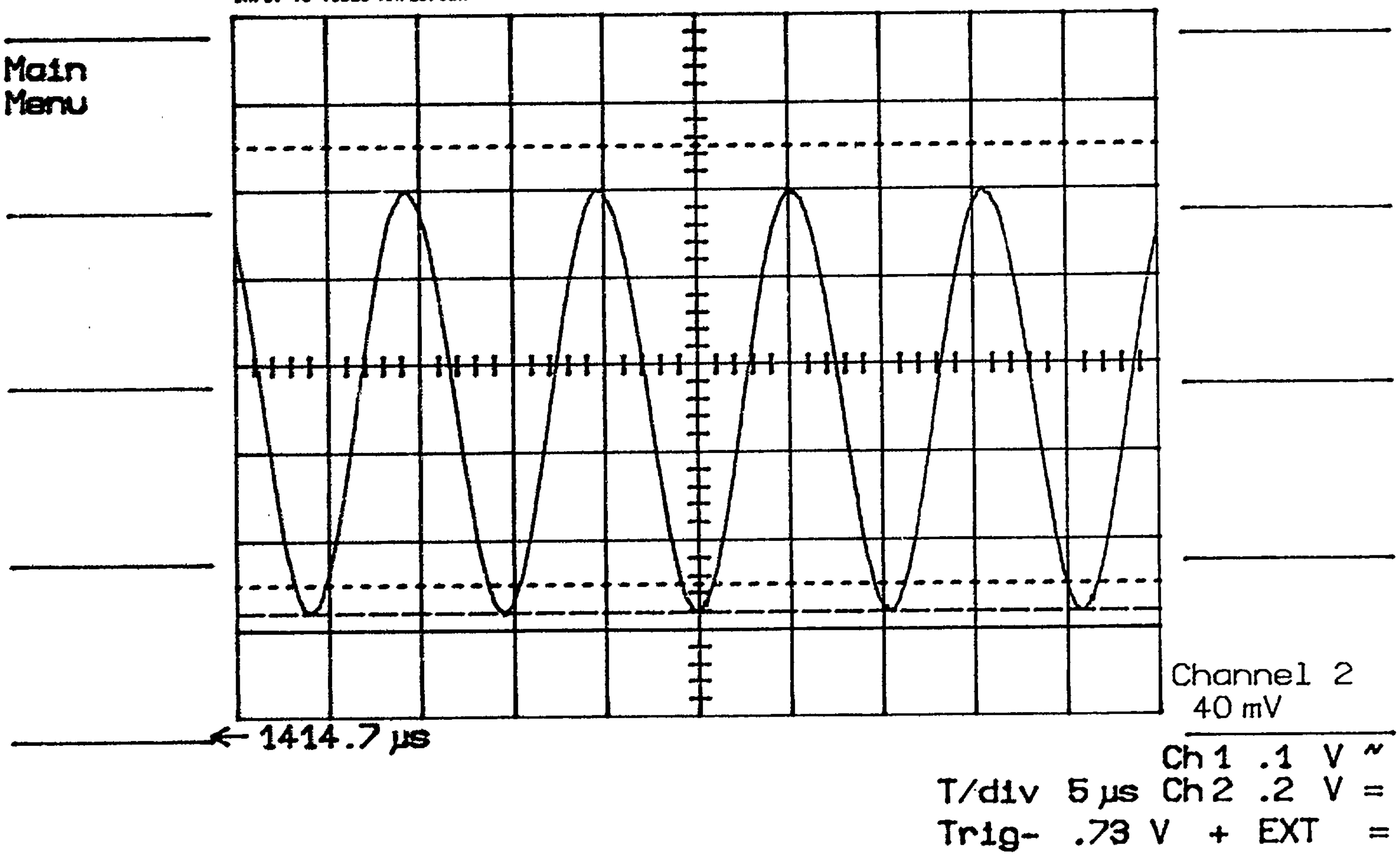
SERIAL #	004
DATE	05-09-1990
ASPECT RATIO	12.3 X 17.0
SCAN POINT	5

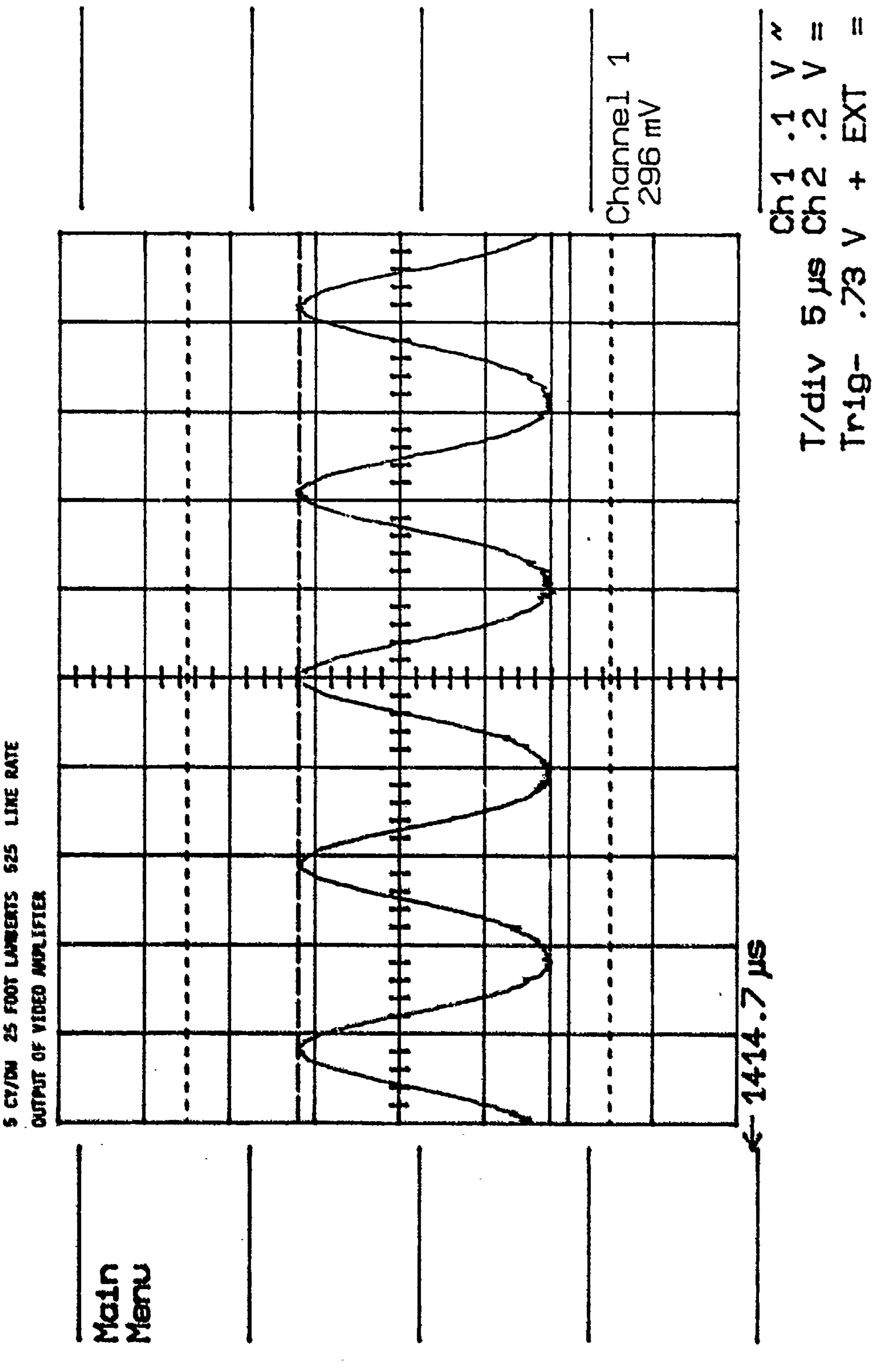
CY/DW	MTF
5	.9569189
50	.9340077
100	.9237688
150	.9178684
200	.8758414
250	.8768417
300	.8433626
350	.7538524
400	.6590883
450	.5588912
500	.4245089

VOLTAGES

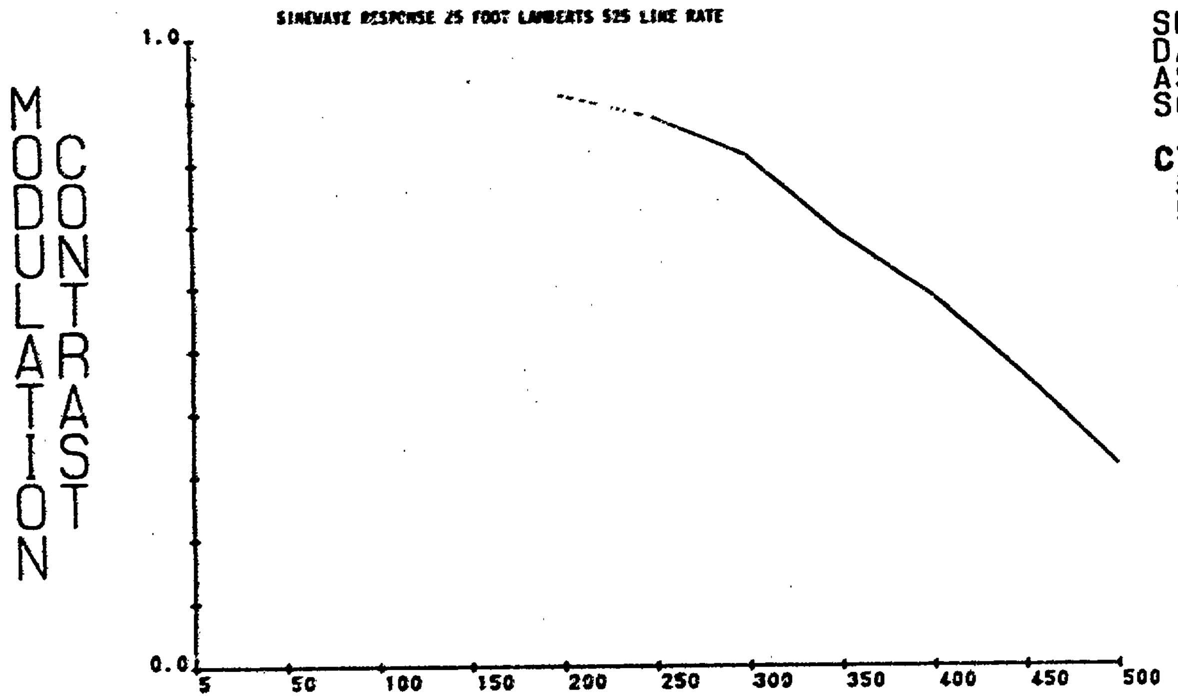
GRID 2	301	GRID 3	1145
GRID 1	.4266667	FILAMENT	10.98
ANODE 30	0	CONTRAST	1.57
ANODE 20	7010	BRIGHTNESS	4.38
HSIZE	.86	HPOS	4.13
VSIZE	2.24	VPOS	.71

5 CY/DM 25 FOOT LAMBERTS 525 LINE RATE
INPUT TO VIDEO AMPLIFIER





5 CY/DW 25 FOOT LAMBERTS 525 LINE RATE
OUTPUT OF VIDEO AMPLIFIER
Main Menu
Channel 1
296 mV
Ch1 .1 V
Ch2 .2 V =
T/div 5 µs
Trig- .73 V + EXT =
1414.7 µs



SERIAL #	004
DATE	05-09-1990
ASPECT RATIO	12.3 X 17.0
SCAN POINT	5

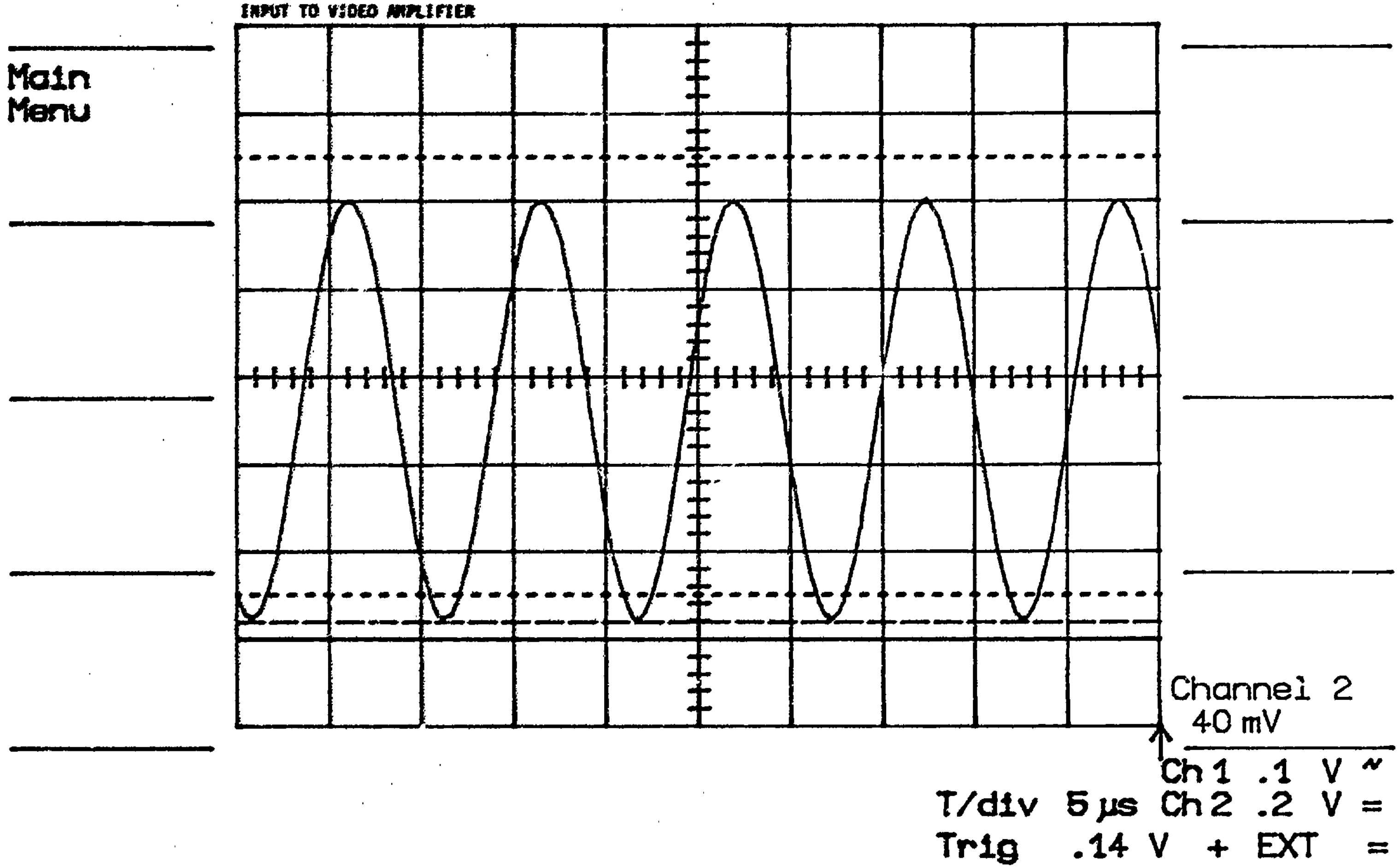
CY/DW	MTF
5	.8760142
50	.85344
100	.833602
150	.8341069
200	.8085871
250	.8743567
300	.8117912
350	.6860955
400	.5857121
450	.4588573
500	.3159778

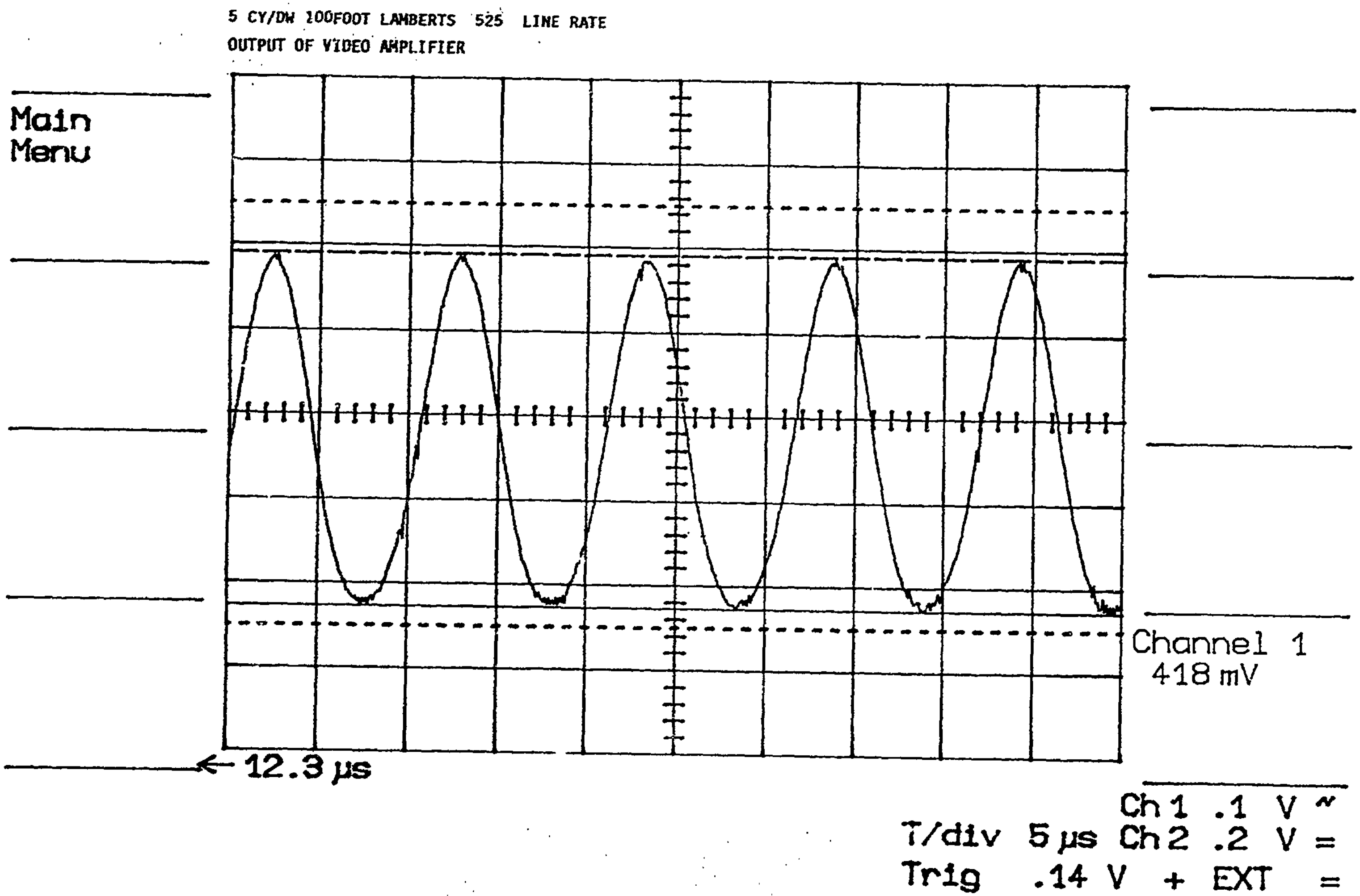
VOLTAGES

GRID 2	301	GRID 3	1145
GRID 1	.4266667	FILAMENT	10.98
ANODE 30	0	CONTRAST	1.63
ANODE 20	7000	BRIGHTNESS	4.38
HSIZE	.86	HPOS	4.13
VSIZE	2.24	VPOS	.71

5 CY/DW 100 FOOT LAMBERTS 525 LINE RATE

INPUT TO VIDEO AMPLIFIER

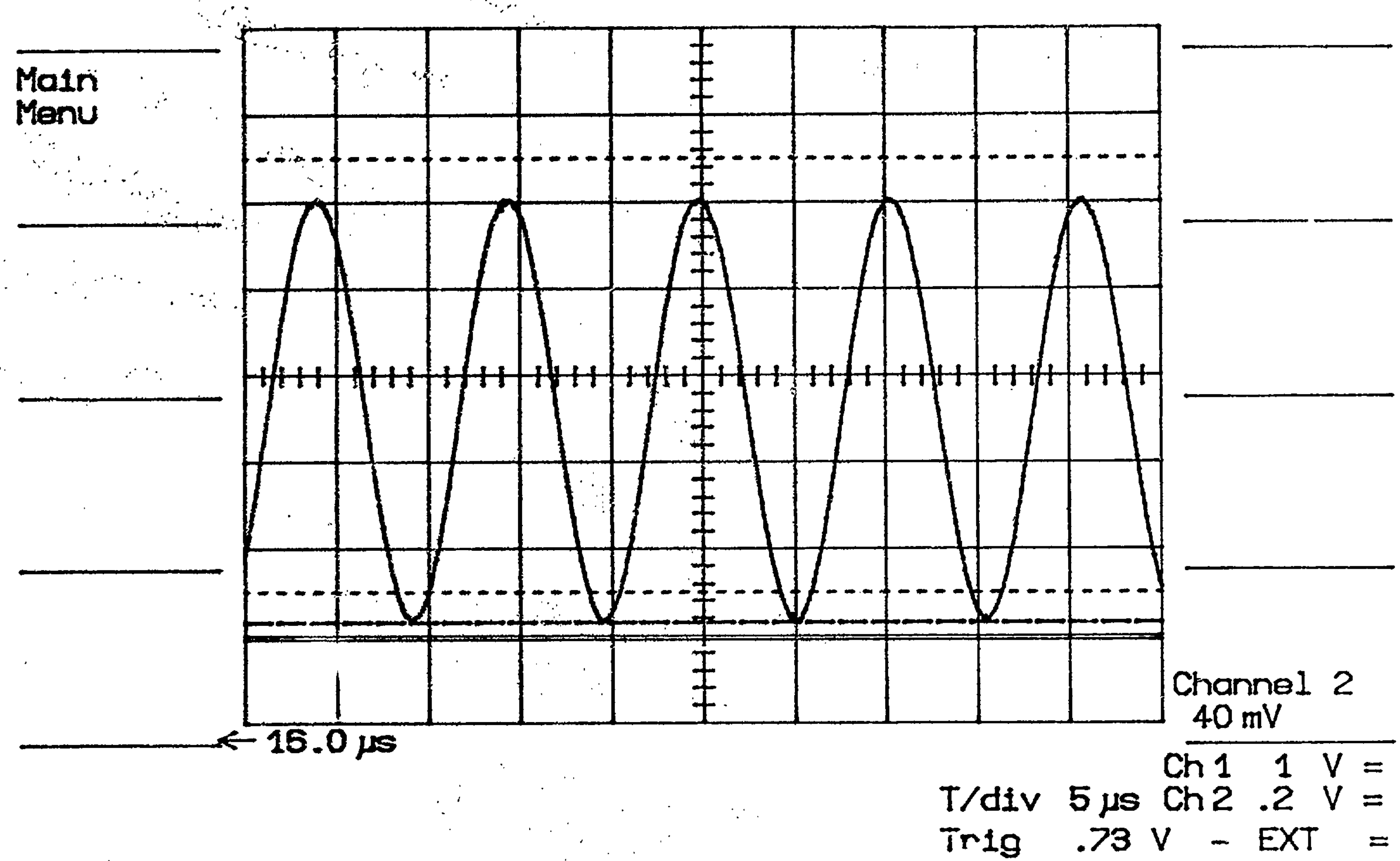



5 CY/DW 100FOOT LAMBERTS 525 LINE RATE
OUTPUT OF VIDEO AMPLIFIER
Main
Menu
Channel 1
418 mV
12.3 µs
Ch1 .1 V ~
T/div 5 µs Ch2 .2 V =
Trig .14 V + EXT =

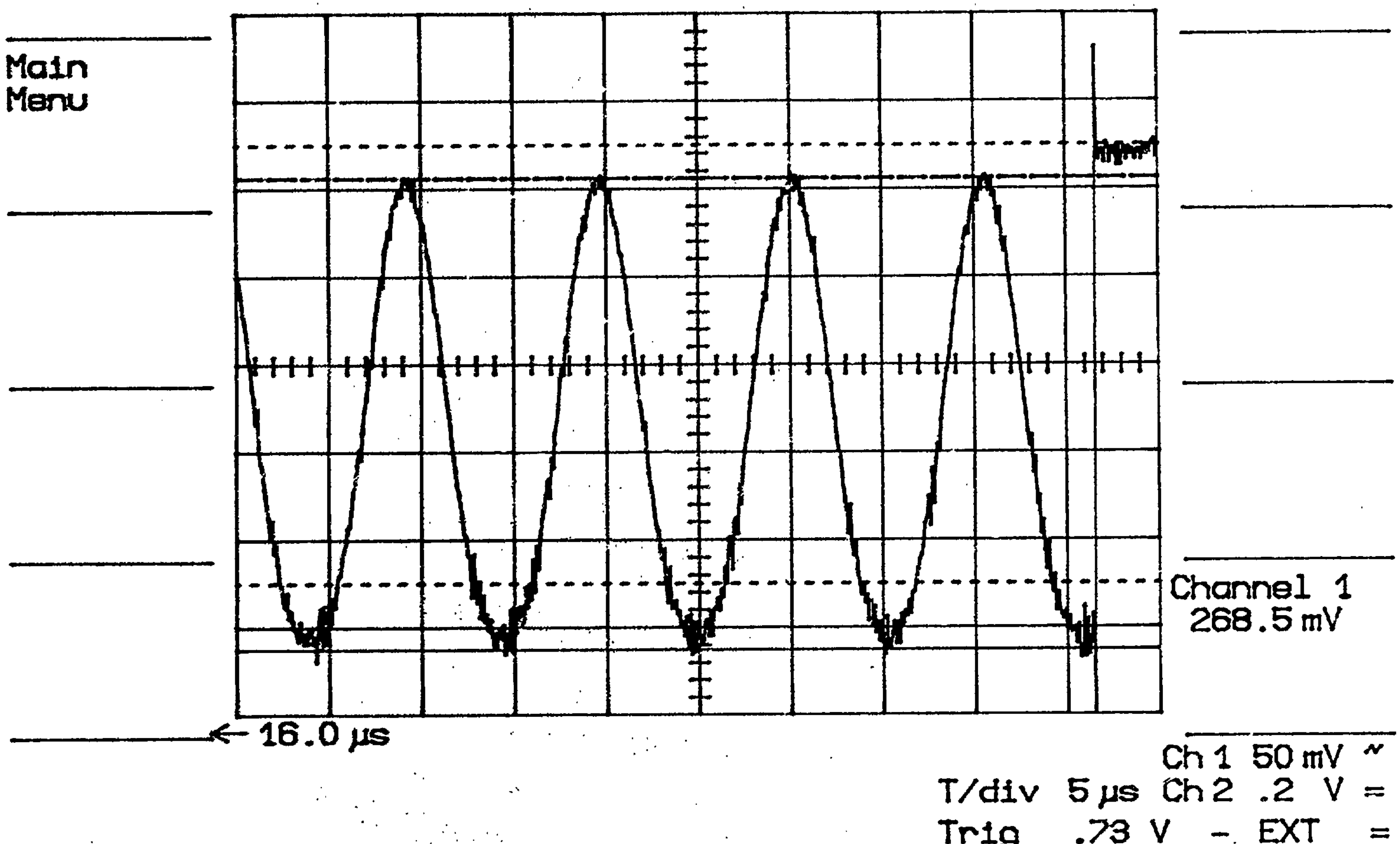
KAISER (HUGHES 1380) CRT

S/N 001

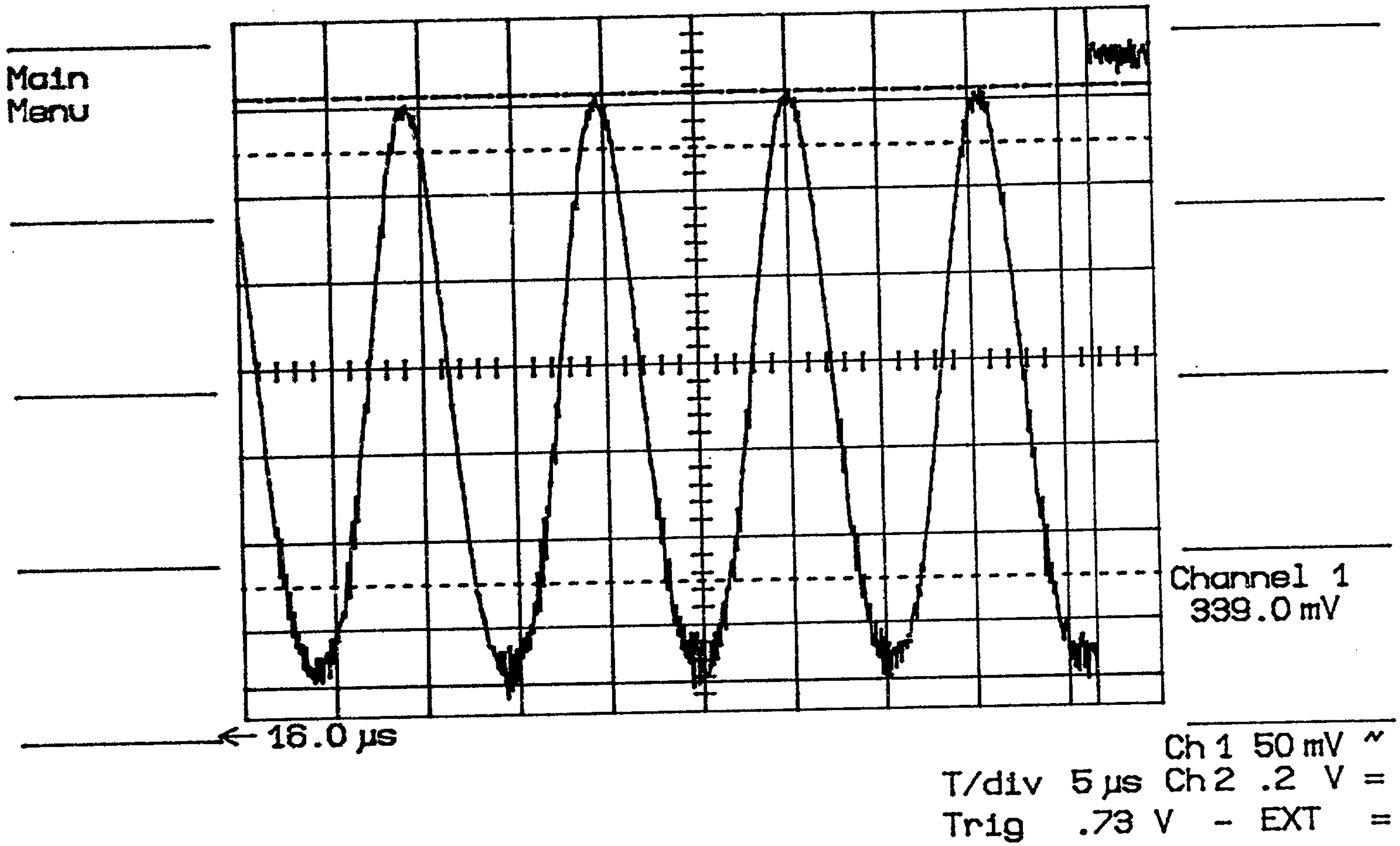
VIDEO AMP INPUT\0.96 Vp-p\0.04 V OFFSET

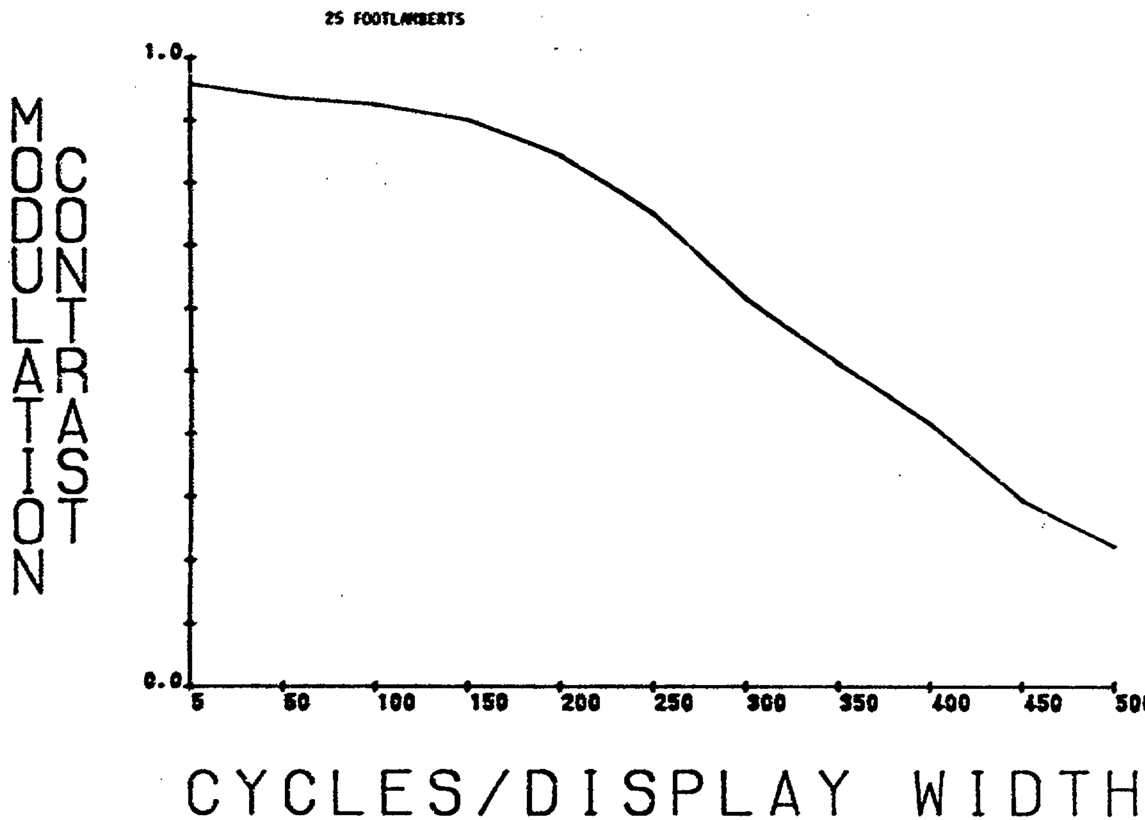


VIDEO AMP OUTPUT/25 FL/2.68 VOLTS



VIDEO AMP OUTPUT/100 FL/3.39 VOLTS



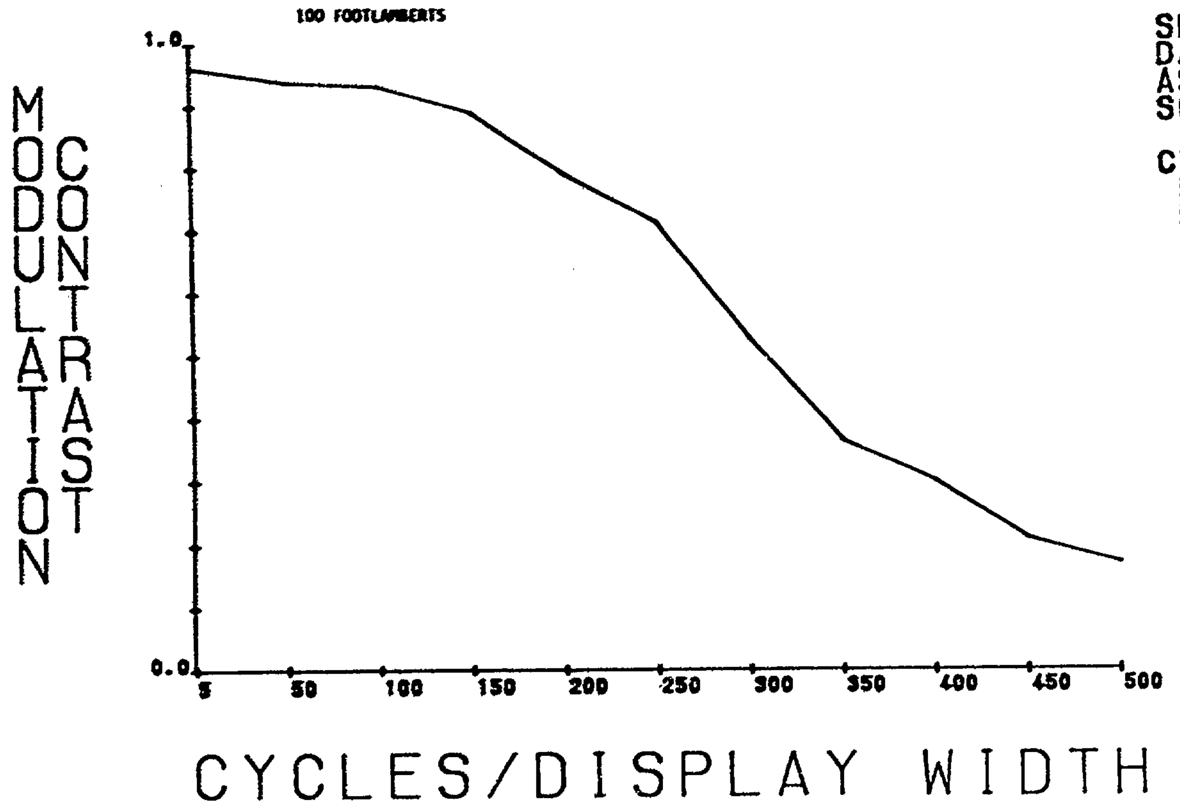


SERIAL #	001
DATE	05-27-1990
ASPECT RATIO	12.8 X 17.0
SCAN POINT	5

CY/DW	MTF
5	.9567589
50	.9351088
100	.9245085
150	.9009168
200	.8438733
250	.751338
300	.615802
350	.5110869
400	.4166705
450	.2943049
500	.2205551

VOLTAGES

GRID 2	435	GRID 3	1454
GRID 1	.48	FILAMENT	10.968
ANODE 30	0	CONTRAST	2.075
ANODE 20	9020	BRIGHTNESS	3.37
HSIZE	3.904	HPOS	2.416
VSIZE	3.965	VPOS	2.69



SERIAL #	001
DATE	05-27-1990
ASPECT RATIO	12.8 X 17.0
SCAN POINT	5

CY/DW	MTF
5	.9572905
50	.9357409
100	.9298337
150	.8870867
200	.7878049
250	.7092482
300	.5263104
350	.364424
400	.299495
450	.2084655
500	.1691323

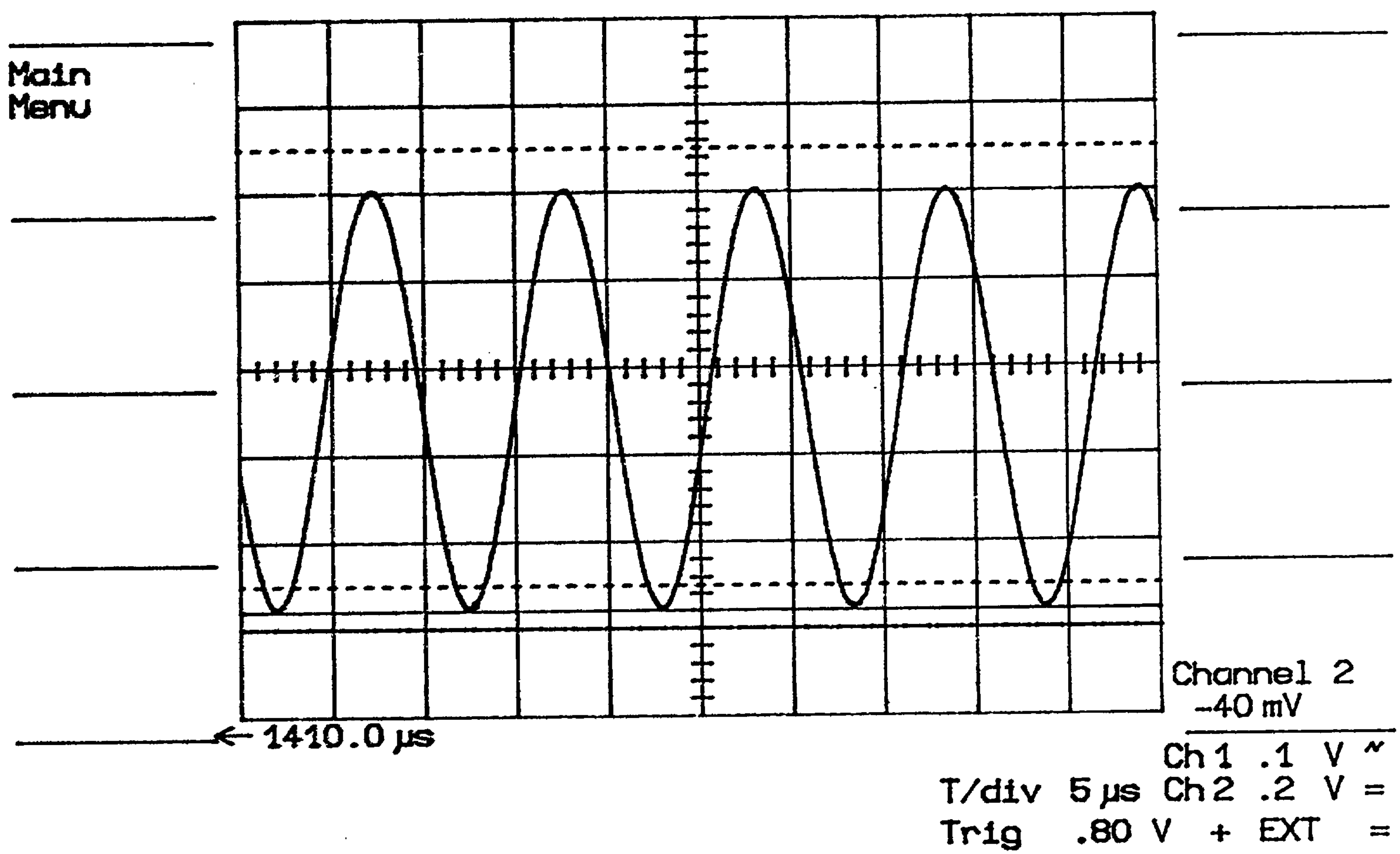
VOLTAGES

GRID 2	435	GRID 3	1454
GRID 1	.48	FILAMENT	10.968
ANODE 30	0	CONTRAST	2.091
ANODE 20	8020	BRIGHTNESS	3.37
HSIZE	3.904	HPOS	2.416
VSIZE	3.965	VPOS	2.69

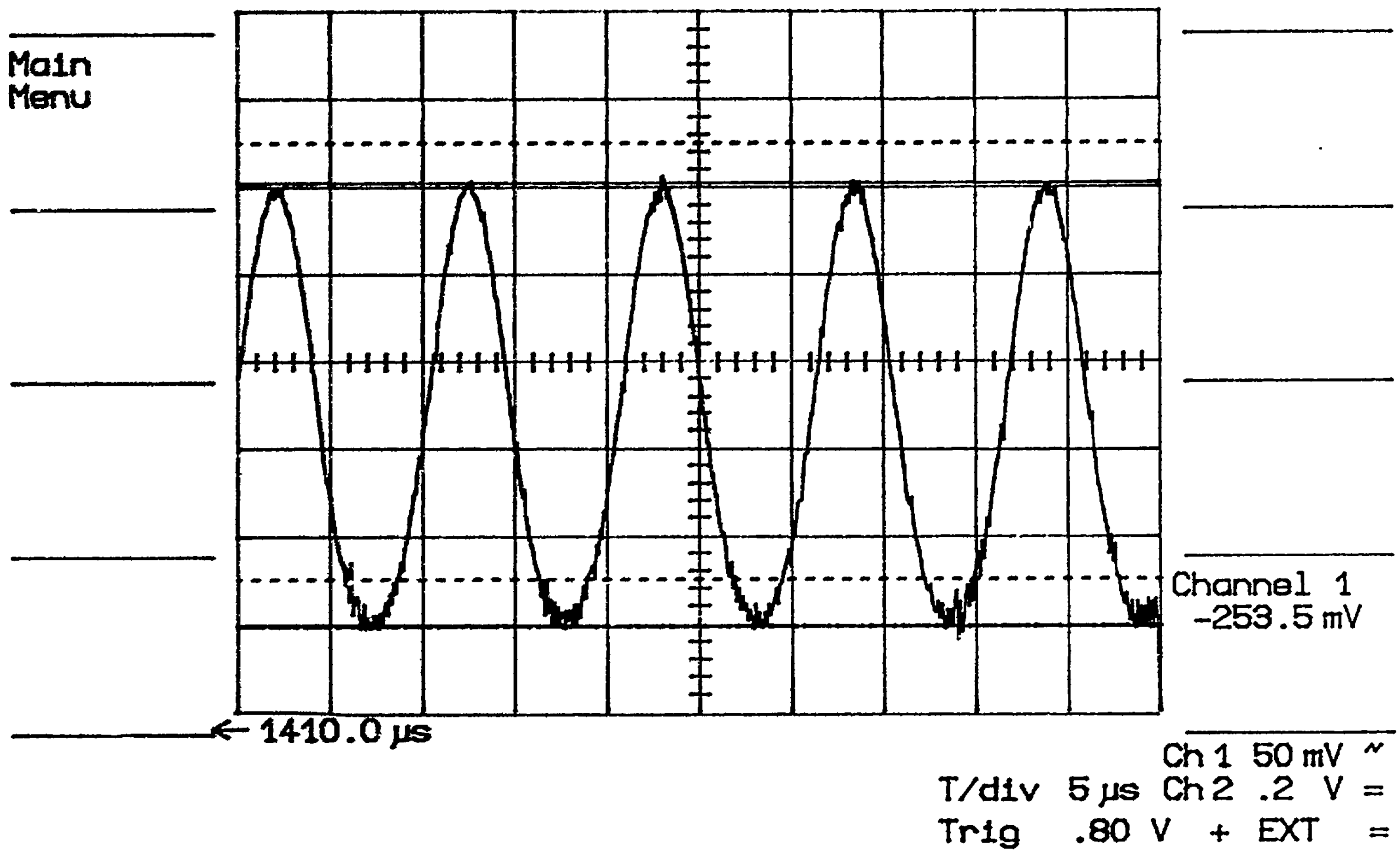
KAISER (HUGHES 1380) CRT

S/N 002

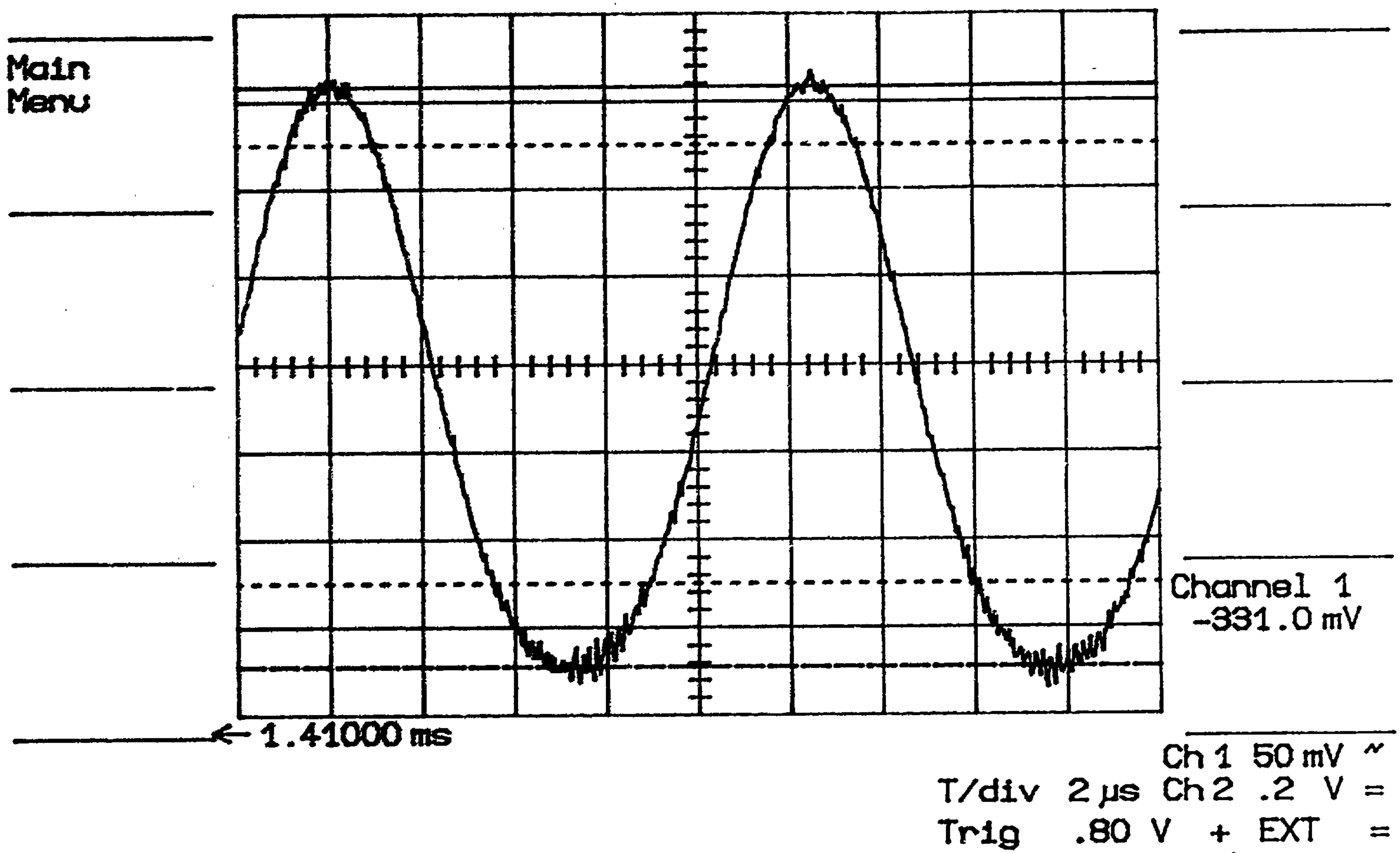
VIDEO AMP INPUT/0.96 Vp-p/0.04 V OFFSET

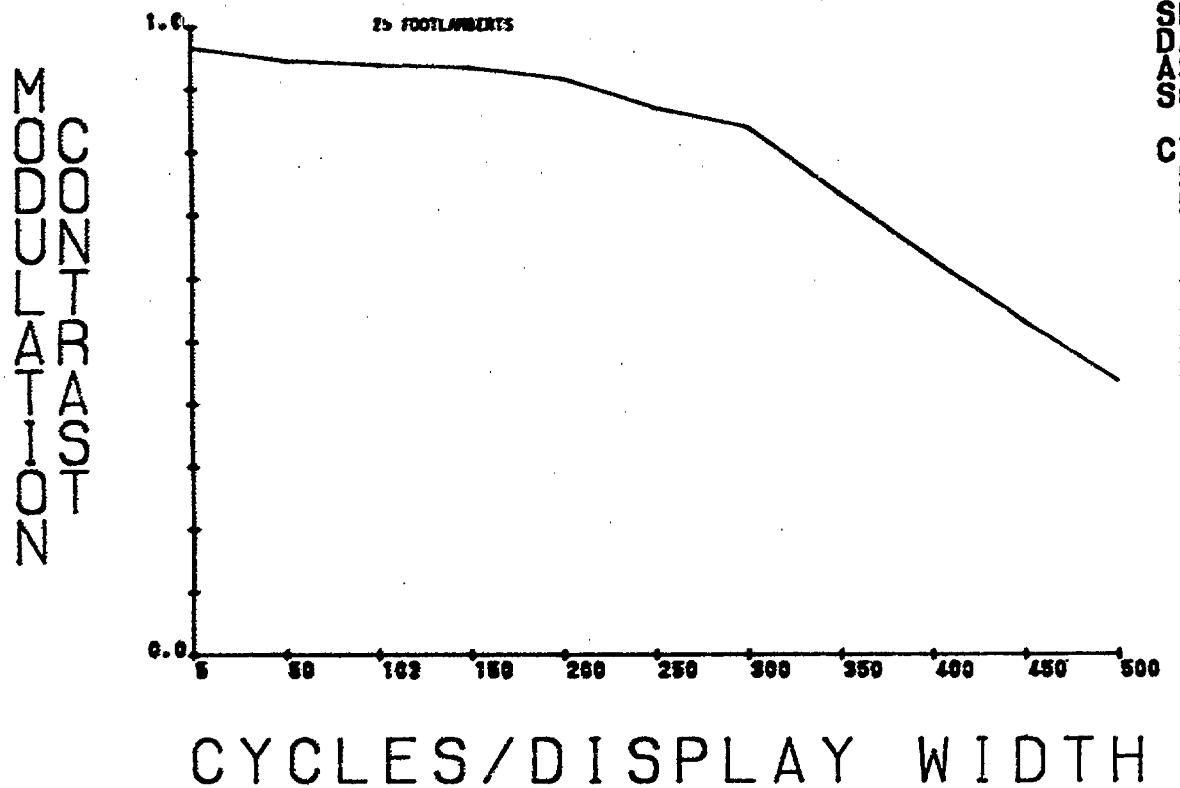


VIDEO DRIVE @ 25FL (10X PROBE) 2.53 VOLTS



VIDEO DRIVE @ 100FL (10X PROBE) 3.31 VOLTS



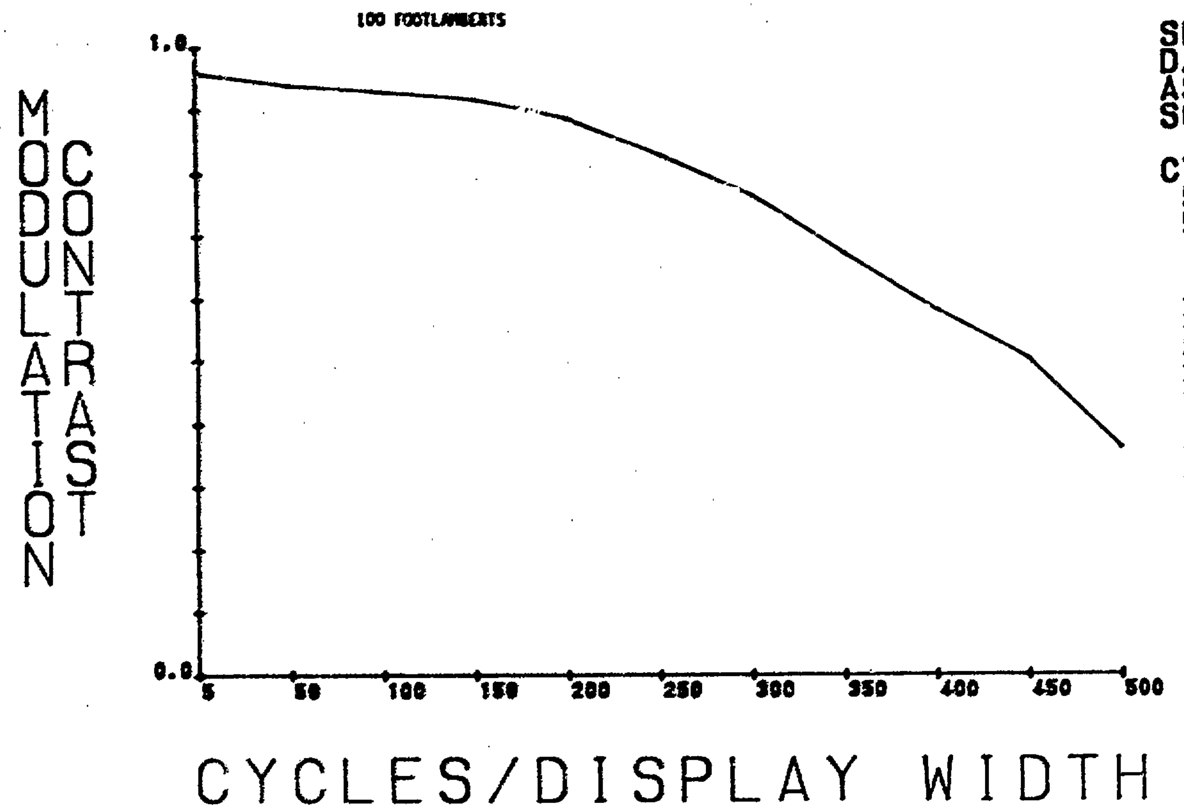


SERIAL #	002
DATE	01-29-1990
ASPECT RATIO	12.6 X 17.0
SCAN POINT	5

CY/DW	MTF
5	.864467
50	.9448432
100	.9373189
150	.9324227
200	.9155036
250	.8688158
300	.8392032
350	.7313433
400	.6308746
450	.5304689
500	.4360555

VOLTAGES

GRID 2	365	GRID 3	1454
GRID 1	.48	FILAMENT	10.972
ANODE 30	0	CONTRAST	2.071
ANODE 20	8030	BRIGHTNESS	3.89
HSIZE	3.964	HPOS	3.346
VSIZE	1.26	VPOS	2.69



SERIAL #	002
DATE	01-29-1990
ASPECT RATIO	12.8 X 17.0
SCAN POINT	5

CY/DW	MTF
5	.8587308
50	.940002
100	.929572
150	.9164501
200	.8872832
250	.8295493
300	.7644058
350	.6715358
400	.5624196
450	.5025907
500	.3607095

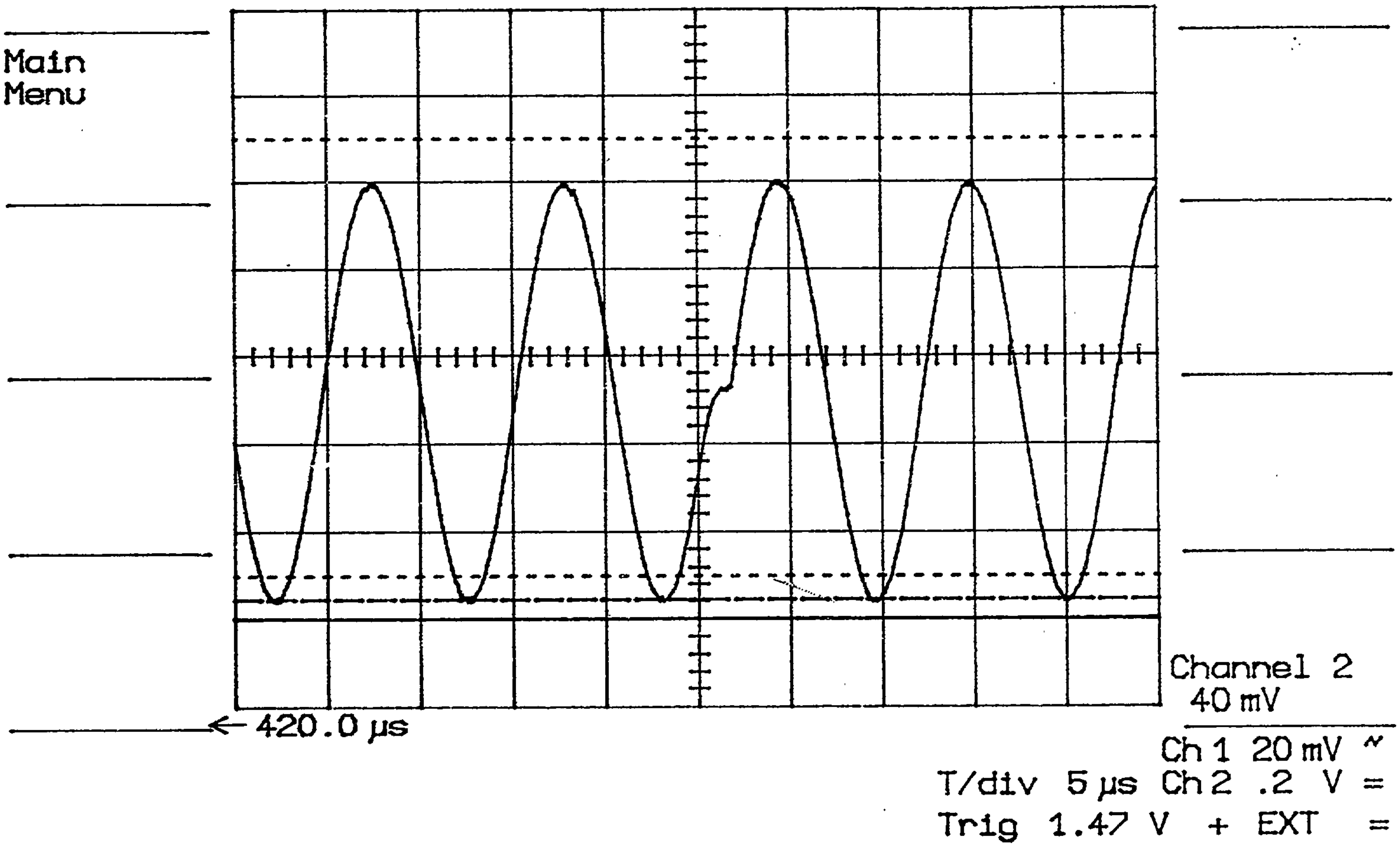
VOLTAGES

GRID 2	365	GRID 3	1454
GRID 1	.48	FILAMENT	10.872
ANODE 30	0	CONTRAST	2.082
ANODE 20	8030	BRIGHTNESS	3.89
HSIZE	3.864	HPOS	3.346
VSIZE	1.26	VPOS	2.69

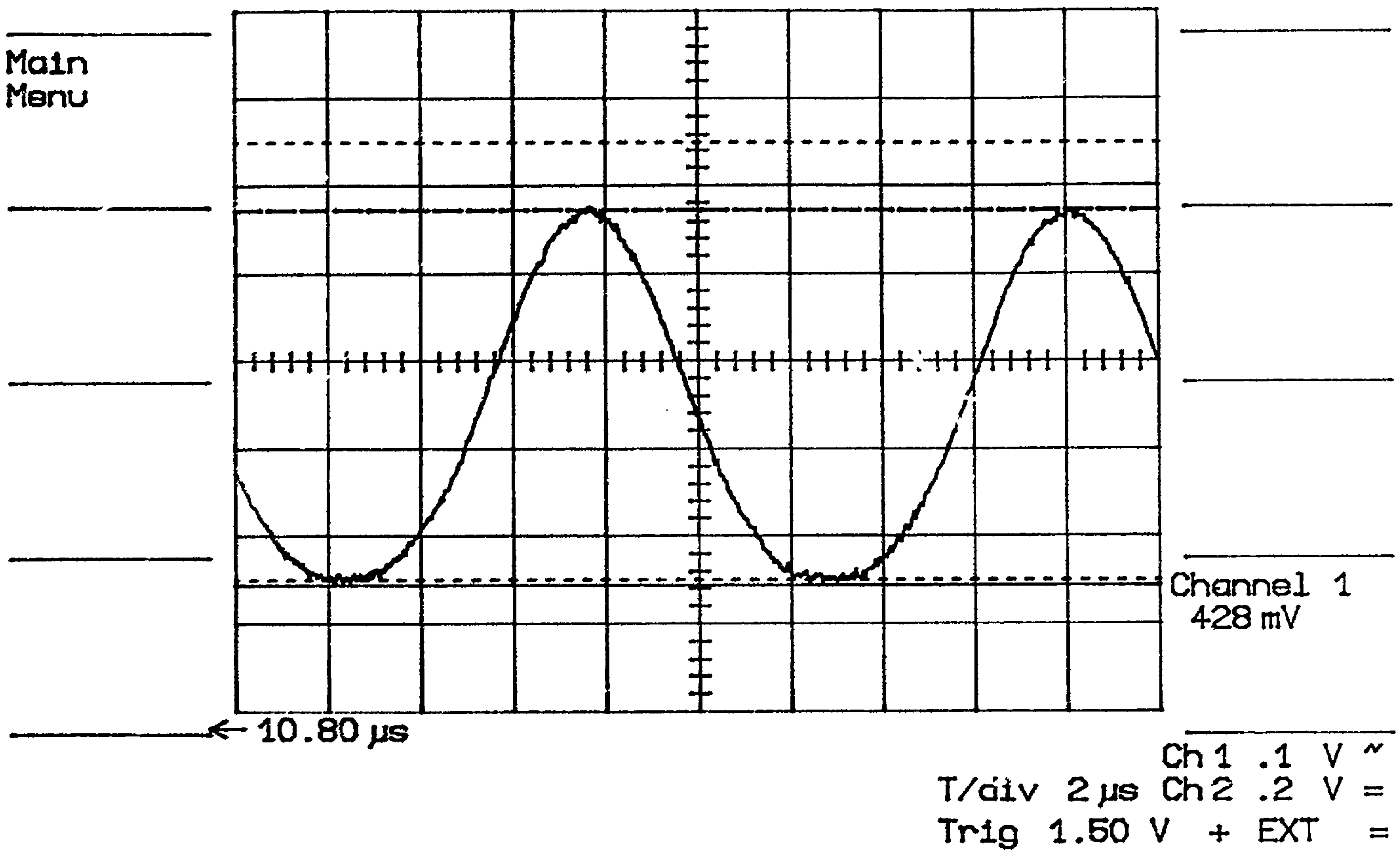
KAISER (HUGHES 1380) CRT

S/N 28007

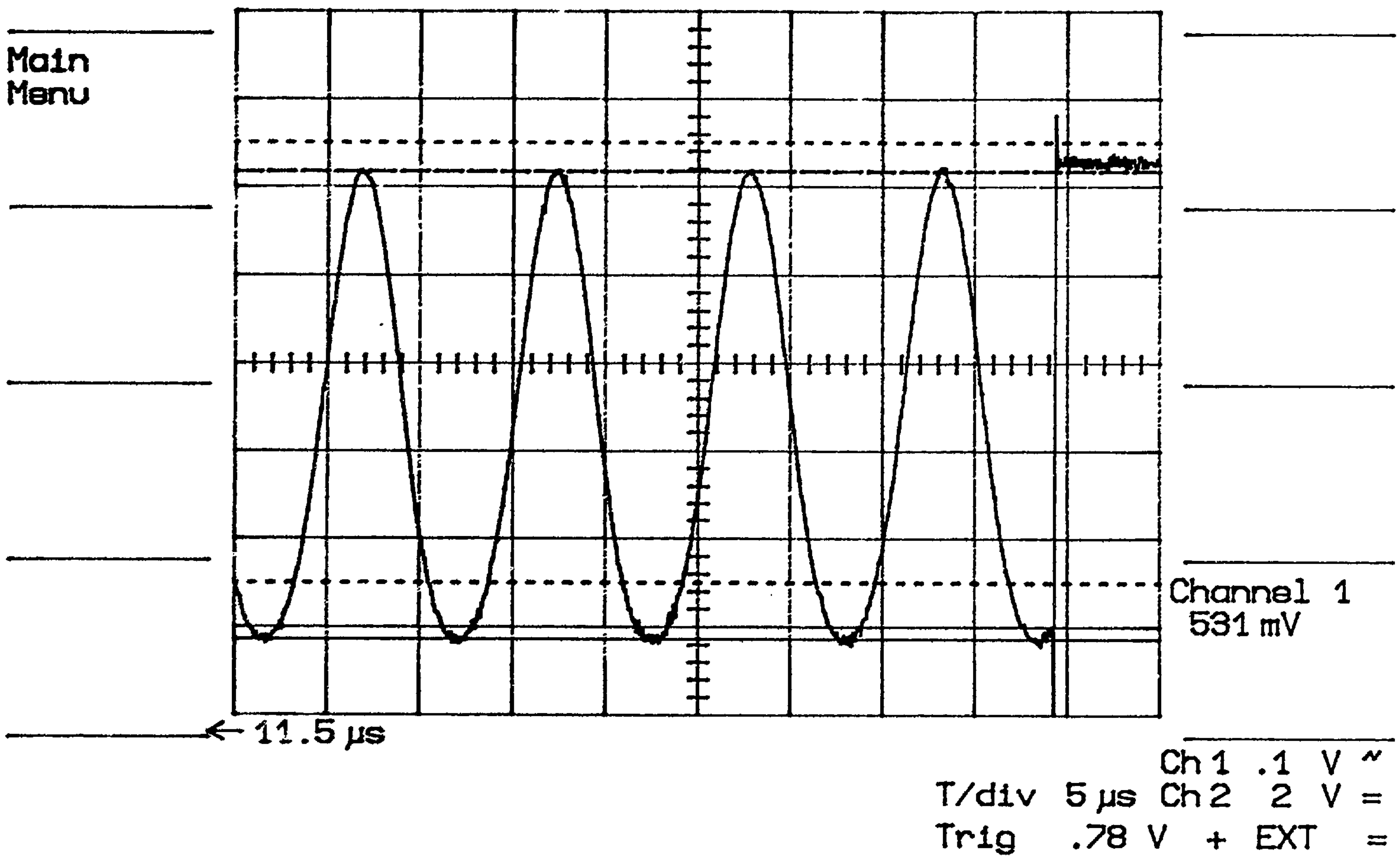
VIDEO AMP INPUT/.96 Vp-p/.040 V OFFSET

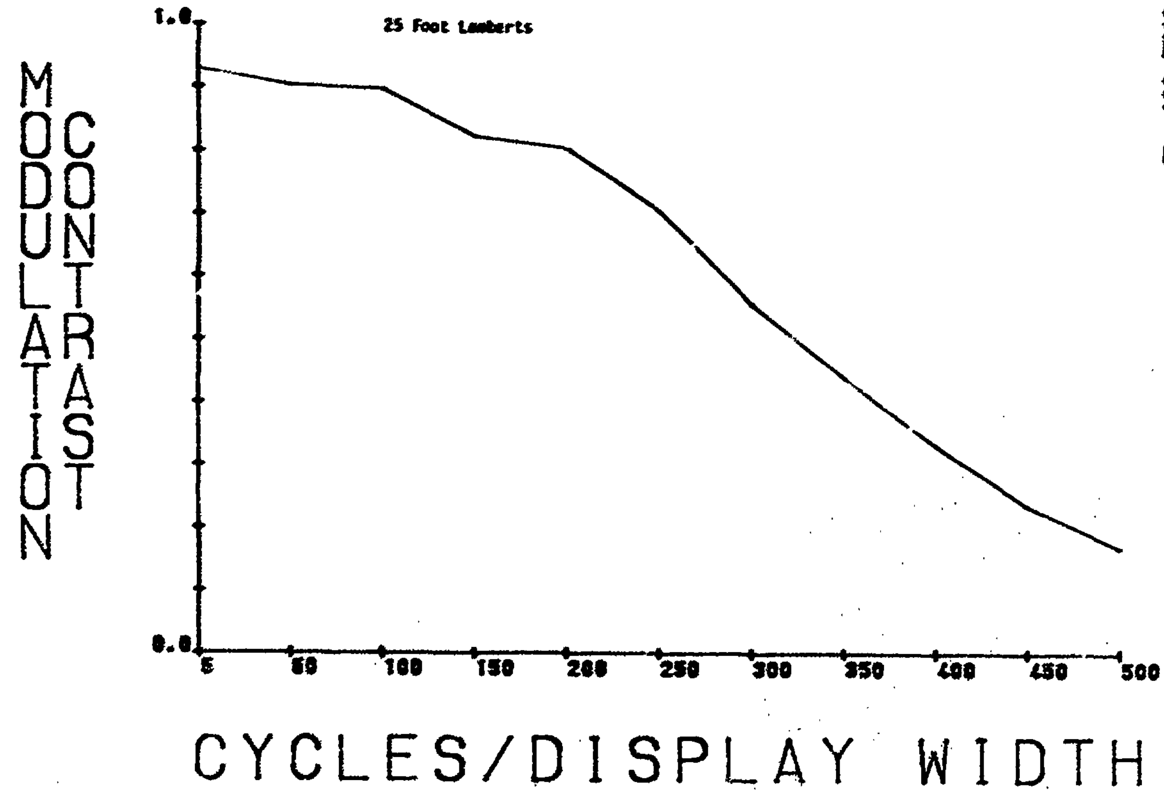


VIDEO DRIVE @ 25FL (10X PROBE) 4.28 VOLTS



VIDEO DRIVE @ 100FL (10X PROBE) 5.31 VOLTS



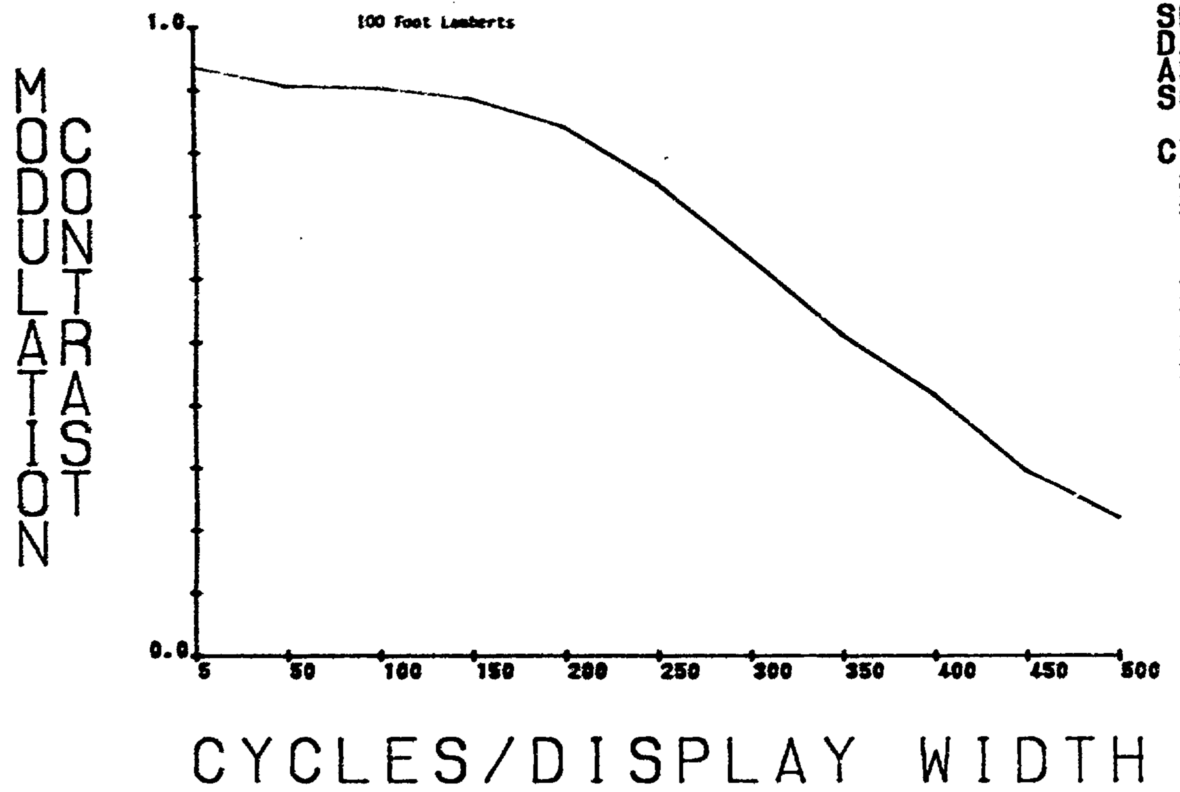


SERIAL #	28007	
DATE	05-22-1990	
ASPECT RATIO	12.8 X 17.0	
SCAN POINT	5	

CY/DW	MTF
5	.9285229
50	.9020866
100	.8967241
150	.8219957
200	.8035463
250	.7044386
300	.5560678
350	.4393663
400	.3310773
450	.2350843
500	.1693839

VOLTAGES

GRID 2	365	GRID 3	1473
GRID 1	.4533333	FILAMENT	10.968
ANODE 30	0	CONTRAST	2.15666
ANODE 20	9020	BRIGHTNESS	3
HSIZE	3.92	HPOS	2.9
VSIZE	1.97	VPOS	2.2



SERIAL #	28007
DATE	05-21-1990
ASPECT RATIO	12.8 X 17.0
SCAN POINT	5

CY/DW	MTF
5	.9343805
50	.8051321
100	.9019608
150	.885084
200	.840328
250	.7513826
300	.6327088
350	.5110868
400	.4168705
450	.2943048
500	.2205551

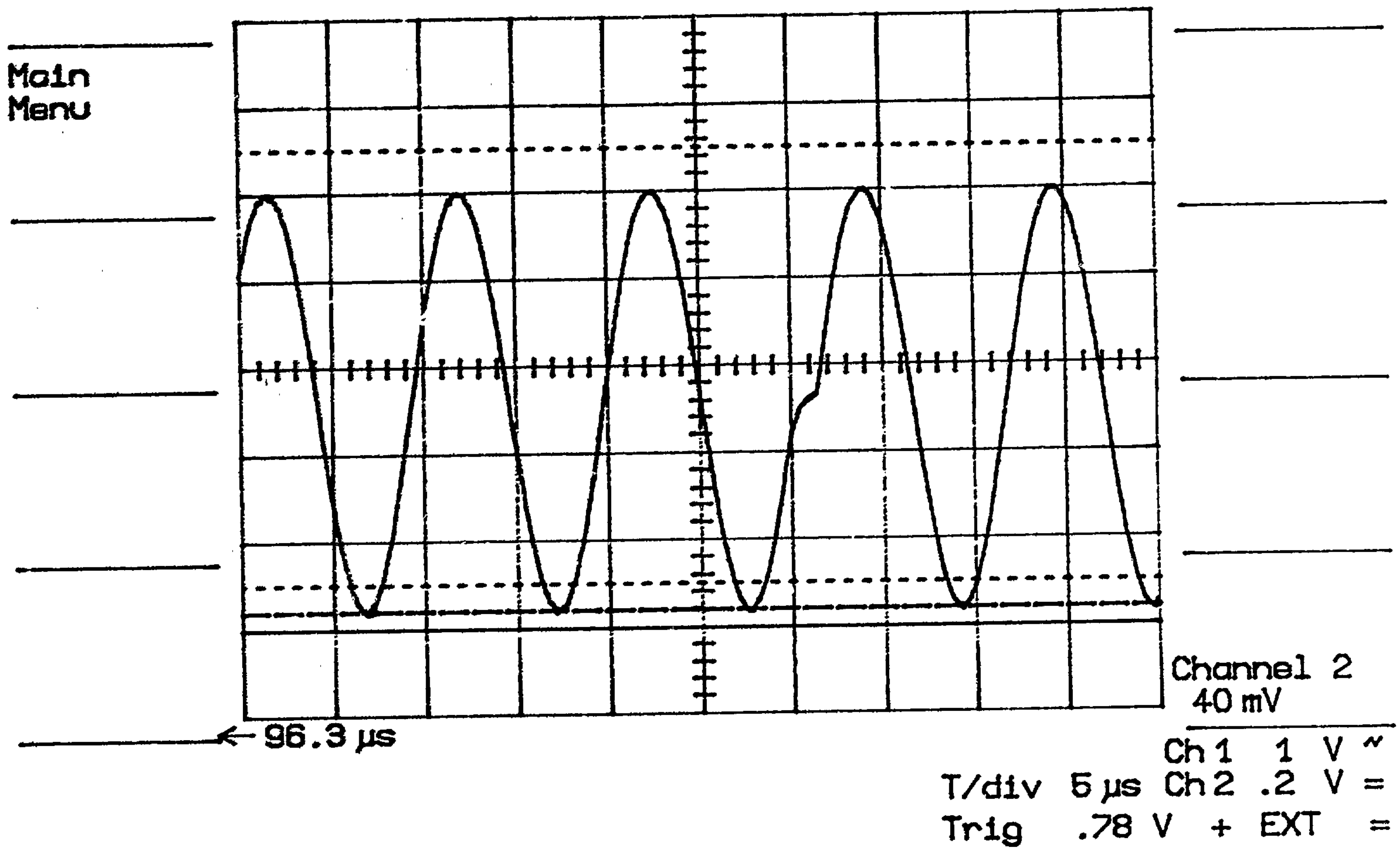
VOLTAGES

GRID 2	370	GRID 3	1473
GRID 1	.4533333	FILAMENT	10.968
ANODE 30	0	CONTRAST	2.10333
ANODE 20	9020	BRIGHTNESS	3
HSIZE	3.92	HPOS	2.8
VSIZE	2.5	VPOS	2.2

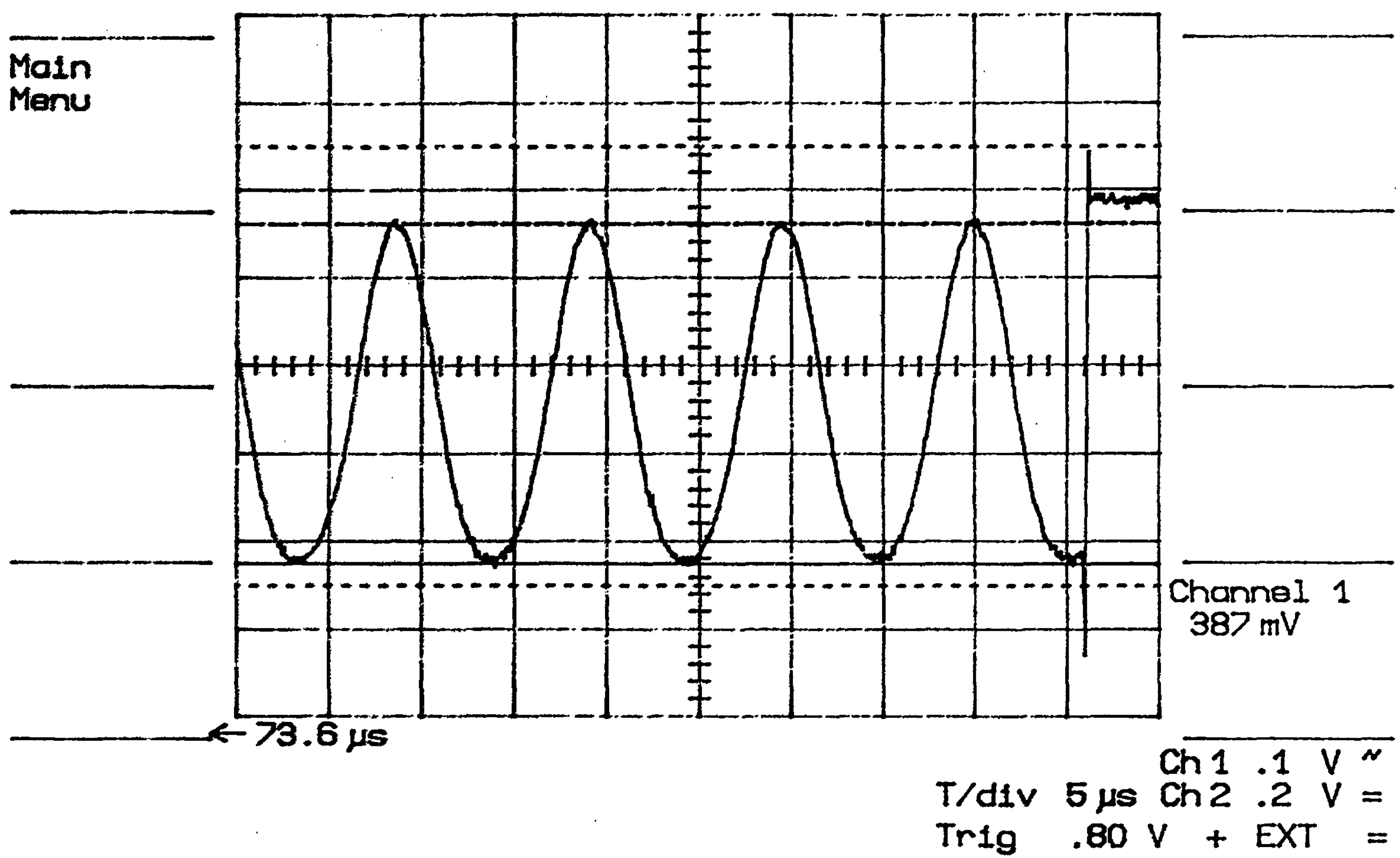
KAISER (HUGHES 1380) CRT

S/N 36077

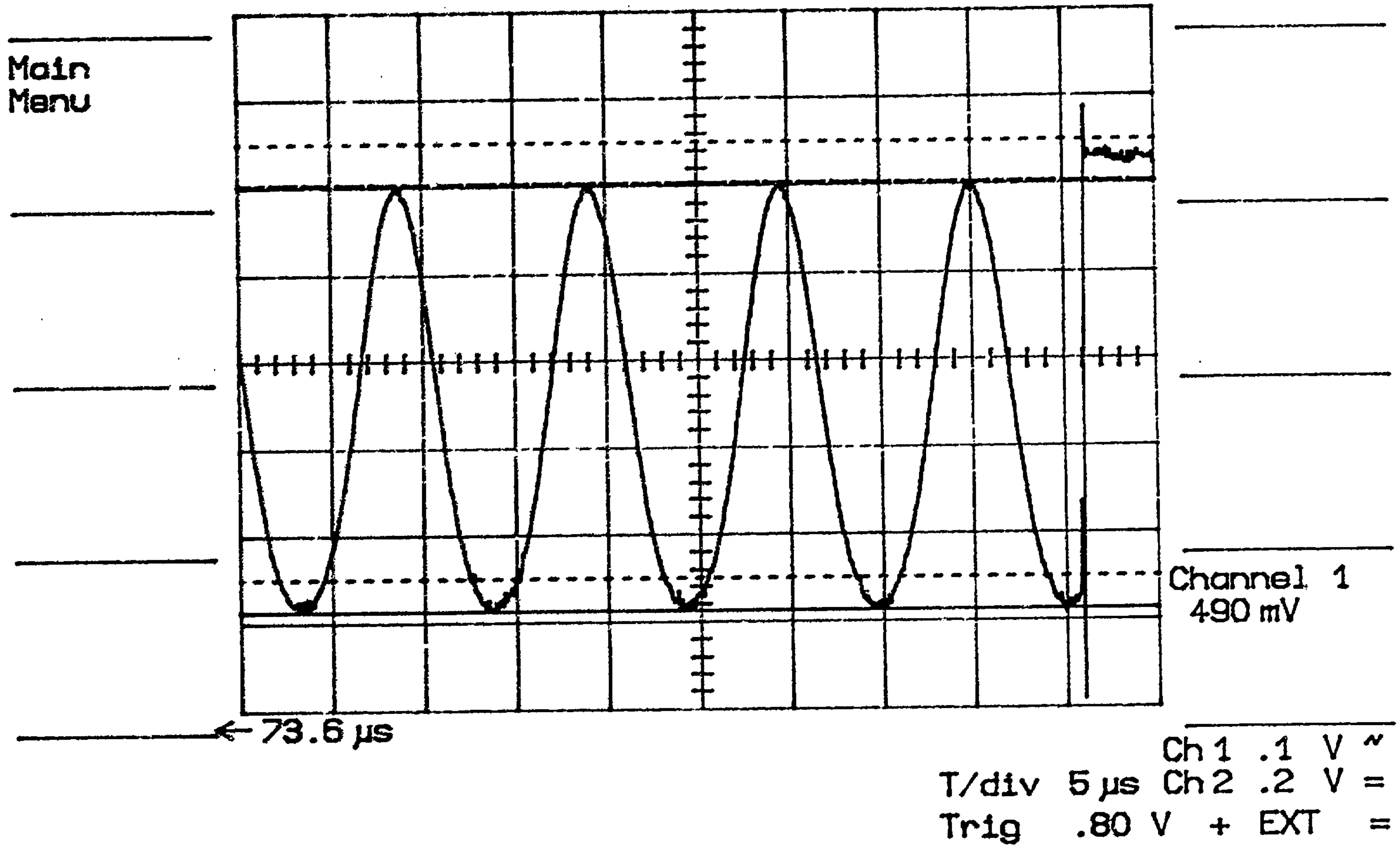
VIDEO AMP INPUT/.96 Vp-p/.04 V OFFSET



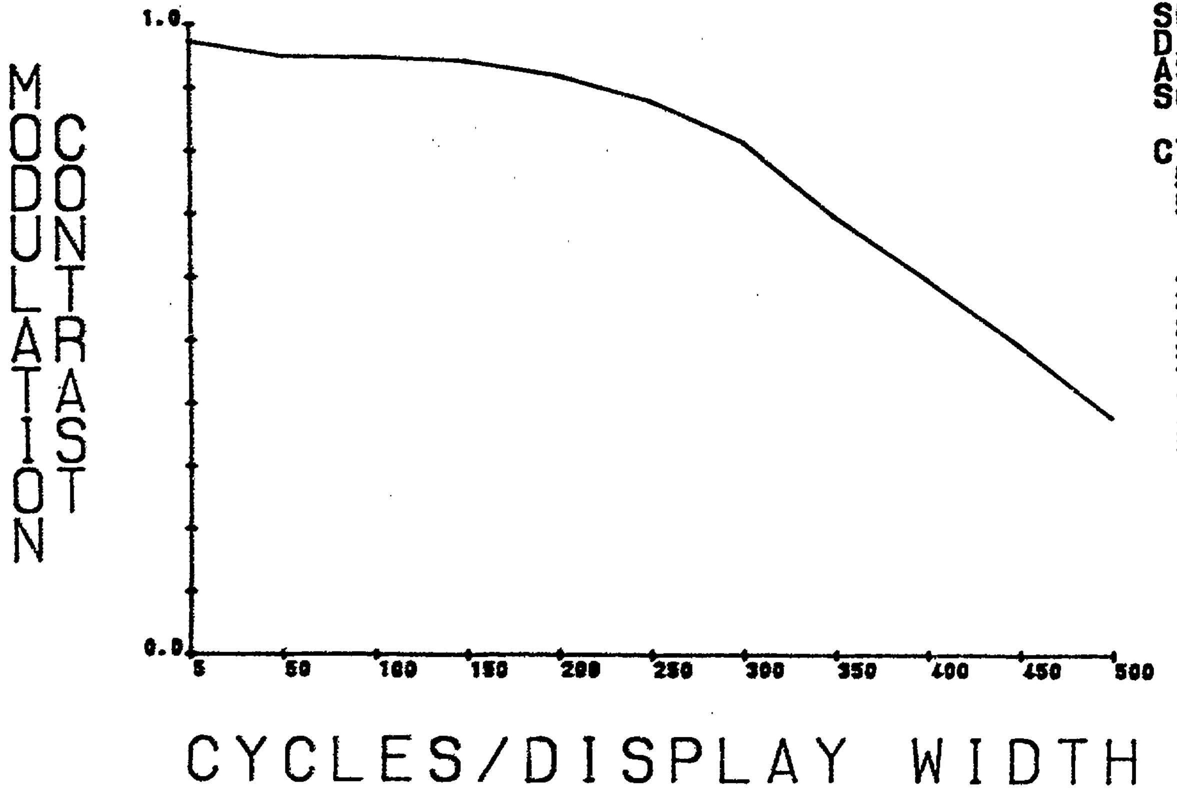
VIDEO AMP OUTPUT - 3.87 VOLTS (10X PROBE)



VIDEO AMP OUTPUT/100 FL/4.9 VOLTS



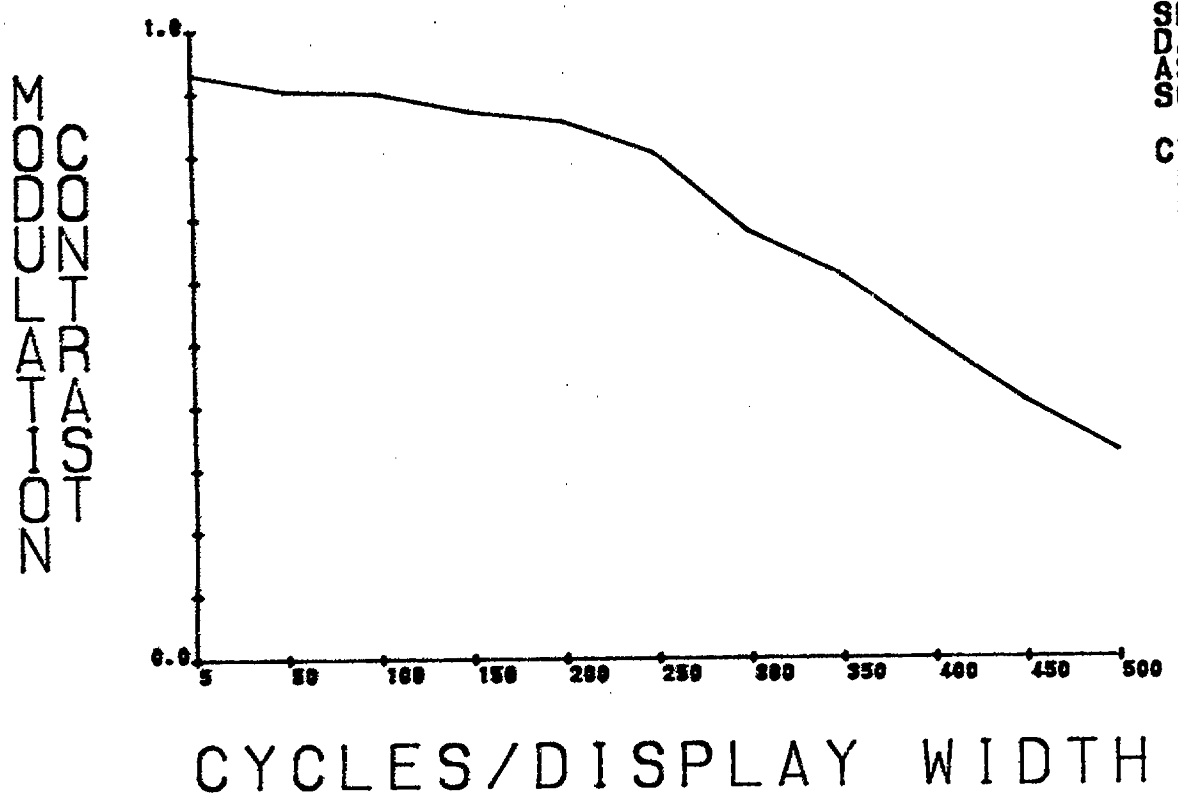
SERIAL #	36077
DATE	05-25-1990
ASPECT RATIO	12.8 X 17.0
SCAN POINT	5



CY/DW	MTF
5	.9596454
50	.9351293
100	.9340382
150	.9268133
200	.9042097
250	.8626805
300	.7982615
350	.6789128
400	.5785002
450	.4732649
500	.3577867

VOLTAGES

GRID 2	365	GRID 3	1473
GRID 1	.48	FILAMENT	10.972
ANODE 30	0	CONTRAST	2.09866
ANODE 20	9030	BRIGHTNESS	3.01
HSIZE	4.01	HPOS	2.45
VSIZE	1.16	VPOS	2.84



SERIAL #	36077
DATE	05-25-1990
ASPECT RATIO	12.8 X 17.0
SCAN POINT	5

CY/DW	MTF
5	.9299294
50	.9035727
100	.8995058
150	.8696874
200	.8538361
250	.8033118
300	.6783447
350	.6098973
400	.5055584
450	.407084
500	.3265418

VOLTAGES

GRID 2	385	GRID 3	1473
GRID 1	.48	FILAMENT	10.972
ANODE 30	0	CONTRAST	2.13866
ANODE 20	9030	BRIGHTNESS	3.01
HSIZE	4.01	HPOS	2.45
VSIZE	1.16	VPOS	2.84

REFERENCES

[1] Grob, Bernard, Basic television, Fourth edition, copyright 1975, pages 190-209, McGraw-Hill

[2] Benson, Blair K., Television Engineering Handbook, copyright 1986, McGraw-Hill

[3] Kocian, Dean F., Design Considerations for Virtual Panoramic Display (VPD) Helmet Systems, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH, 1988

[4] Biberman, Lucien M., Perception of Display Information, Plenum Press, copyright 1973

[5] Task, Harry L., A New Measure of Television Display Quality Relatable to Observer Performance, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH, 1976, AAMRL-TR-76-73.

APPENDIX B
MASS PROPERTIES

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APPENDIX B: MASS PROPERTIES

1. INTRODUCTION

Helmet-mounted systems add to the weight supported by the head. If the weight is excessive or is not evenly distributed about the head it increases the onset of fatigue in aircrew members. Also, the additional weight and its distribution significantly increases the risk of injury during high G maneuvers and emergency situations such as crash landing or ejection. This report describes the weight and center of gravity (CG) measurements taken by the Vulnerability Assessment Branch, Biodynamics and Biocommunications Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

2. OBJECTIVE

The objective of this evaluation is simply to determine the weight and center of gravity of selected I-NIGHTS helmets.

WEIGHT/CG TESTS

I-NIGHTS Safety of Flight

Preliminary Test Plan - Measurement of Inertial Properties

A. INTRODUCTION/BACKGROUND

A series of tests are being planned for evaluating the operational effectiveness and safety of certain helmet mounted systems before they are actually flown in aircraft. This preliminary test plan addresses one of the critical issues necessary for the total evaluation effort (Safety of Flight) by providing for the measurement of the inertial mass properties of the helmet mounted systems along with correlations of mass and mass placement to dynamic test responses. Additionally, this plan will comment in Section VIII on developing a modeling data base that may be used in future analytical simulations of head/neck response to added head encumbrances under whole body exposure to abrupt accelerations.

Six custom helmet prototypes will be delivered for testing to the Biodynamics and Bioengineering Division (BB) of the Armstrong Aerospace Medical Research Laboratory (AAMRL) at Wright-Patterson AFB, OH. Two prototypes will be delivered from each of three vendors: Honeywell, GEC Avionics, and Kaiser. One system will be a Night Vision Goggle (NVG) configuration, the other system contains both display optics and an image source, allowing the system to be used as a NVG, a Helmet Mounted Display (HMD), or as a combination NVG/HMD. Delivery of the NVG mockups will be Dec 89 and the systems will be delivered in Feb 90. The NVG/HMD mockups will be delivered Feb 90 and the systems delivered May 90. Another system, the ITT MERLIN, is being procured by AAMRL and may be ready for testing during FY90. Additionally, a system being developed through a Small Business Innovative Research (SBIR) program may be added to the test matrix at a later date.

I. PURPOSE

A. SCOPE OF PLAN

The additional mass of helmet mounted systems and their center-of-gravity (cg) position relative to that of the head may adversely effect the safety of the crew member and the operational effectiveness of the system under certain force exposure conditions. To quantitatively address possible adverse effects and correlate them to various impact, acceleration, and vibration exposures, their inertial properties must be determined.

A test series will be conducted to measure and report the mass, center of gravity location, magnitudes of principle moments of inertia, and orientation of the principle axes of each helmet mounted system. This data will then be correlated to measured dynamic test responses and compared to previous tests performed without the additional head mounted mass.

B. CRITICAL ISSUES

1. What are the inertial properties of the different helmet mounted systems?

2. How does the addition of the helmet/NVG alter the cg position, moments of inertia, and mass of the pilot head/neck system?

3. How does the addition of the helmet/NVG/HMD alter the cg position, moments of inertia, and mass of the pilot head/neck system?

4. How do the alterations in pilot head/neck inertial properties effect the dynamic response characteristics of the head/neck system?

III. TEST OBJECTIVES

The specific objectives of the test are:

1. To accurately measure the mass properties of the helmet/NVG systems, the helmet/NVG/HMD systems, as well as the add-on NVG system alone and with its designated helmet and necessary configurations.

2. To mathematically combine the mass properties of all the NVG configurations with representative human head mass properties extracted from the stereophotometrically measured subject data base.

3. To correlate this data with measured dynamic test responses done at AAMRL and compare to previous tests performed without the additional head mounted mass.

IV. EXPERIMENTAL DESIGN

A. FACILITIES AND EQUIPMENT

All tests will be conducted in the Manikin Testing Laboratory (MTL) located in Building 824, Area B, Wright-Patterson AFB, OH. The measurements will be made using the Automated Mass Properties Measurement System which consist of the Space Electronics mass properties instrument, a Hewlett Packard microcomputer, an electronic scale and moment table assembly, and an assortment of balsa wood molding fixtures designed to secure the test object(s) during tests. All calculations are made with the use of software associated with the HP-85B, the Zenith Z-100, and the Perkin-Elmer computers resident to BB. For a detailed description of the automated Mass Properties Measurement System used to measure these properties, see Reference 1.

B. EXPERIMENTAL CONDITIONS

The following system configurations will be tested:

Vendor Helmet Configuration	Helmet Only	NVG	HMD	Mask
Honeywell NVG	X			
Honeywell NVG	X			X
Honeywell NVG	X	X		X
GEC Avionics NVG	X			
GEC Avionics NVG	X			X
GEC Avionics NVG	X	X		X
Kaiser NVG	X			
Kaiser NVG	X			X
Kaiser NVG	X	X		X
Honeywell NVG/HMD	X			
Honeywell NVG/HMD	X			X
Honeywell NVG/HMD	X	X		X
Honeywell NVG/HMD	X		X	X
Honeywell NVG/HMD	X	X	X	X
GEC Avionics NVG/HMD	X			
GEC Avionics NVG/HMD	X			X
GEC Avionics NVG/HMD	X	X		X
GEC Avionics NVG/HMD	X		X	X
GEC Avionics NVG/HMD	X	X	X	X
Kaiser NVG/HMD	X			
Kaiser NVG/HMD	X			X
Kaiser NVG/HMD	X	X		X
Kaiser NVG/HMD	X		X	X
Kaiser NVG/HMD	X	X	X	X
ITT MERLIN (if available)	X (55/P)			
ITT MERLIN (if available)	X (55/P)			X
ITT MERLIN (if available)	X (55/P)	X		X

For this test series, the configurations (with the exception of the helmets alone) will be performed with a styrofoam head to properly position the mask and night vision goggles. The inertial properties of the head will be measured and subtracted from the results of the helmet/NVG configurations.

The inertial data can also be combined with manikin head-neck data to evaluate the effect of the head encumbrance. If a comparison is required, a digitization of each helmet with a manikin will be included in the test series.

C. TEST EVALUATION

The test results will be evaluated by comparing configurations measured together against configurations measured separately and then mathematically combined.

V. TEST SCHEDULING

This series of tests will require one week per NVG system. Three weeks will be required for final data analysis, compilation and report preparation. The entire testing effort will take approximately 10 weeks.

VI. COSTS

This series of these will require funds of $12,500.

VII. TEST DOCUMENTATION

The following documents will be maintained:

Calibration Sheets - the calibration results of the system

Inertial Entry Log - the cg offsets, mass, and measured moments of inertia of the test object plus balsa wood box

Inertial Properties Log - the principal moments of inertia and direction cosines of the test object alone

Tables of analyzed data which will include center of gravity location, mass, magnitudes of principal moments, and orientation of principal axes for each configuration.

VIII. POSSIBLE ADDITIONAL AREA OF TESTING

The Modeling and Analysis Branch (AAMRL/BBM) makes extensive use of a three-dimensional, coupled rigid-body simulation program called the Articulated Total Body Model (ATBM). There is an effort under way to model the human head/neck response to abrupt Gz accelerations with added head encumbrances with the ATBM. The head encumbrances being modeled include the HGU-55/P helmet and the EAGLE EYE Concept III NVG, both with and without the MBU-5/P mask. While it would be highly desirable to conduct a complimentary analytical/modeling task as part of this effort, none is proposed. However, as a minimum, the protocols developed within BB should ensure that data collected in the dynamic and inertial measurement tests be sufficiently complete and properly formatted for later analytical/modeling application.

IX. TEST PERSONNEL ASSIGNMENTS

The principal investigator of this effort is Lt Deborah Determan, BBM. Direction to the MTL contractors, who will actually perform the measurements, will be through the MTL facility engineer, Capt Christopher Taylor, BBM.

X. REFERENCE DOCUMENTATION

1. Alberry, C., Whitestone, J., and Lephart, Alan, Ph.D., The Automated Mass Properties Measurement System Testing Procedures, available in draft.

2. Alberry, C., Whitestone, J., and Lephart, Alan, Ph.D., The Automated Mass Properties Measurement System Calibration Report, available in draft.

3. Bartol, A., Whitestone, J., and Lephart, Alan, Ph.D., The Automated Mass Properties Measurement System Accuracy Report, available in draft.

4. McConville, J.T., Churchill, T.D., Kaleps, I., Ph.D., Clauser, C., and Cuzzi, J., Anthropometric Relationships of Body and Body Segment Moments of Inertia, AFAMRL-TR-80-119, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

MASS PROPERTIES ANALYSIS

OF

THE I-NIGHTS HELMET SYSTEMS

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DONNA MILLER, SRL

GREG THOMPSON, SRL

CHRIS ALBERY, SRL

24 July 1991

VULNERABILITY ASSESSMENT BRANCH
BIODYNAMICS AND BIOCOMMUNICATIONS DIVISION
CREW SYSTEMS DIRECTORATE
ARMSTRONG LABORATORY
HUMAN SYSTEMS DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

INTRODUCTION

This report presents the results of inertial properties testing of twelve different night vision goggle (NVG) and head mounted display (HMD) devices from each of the three vendors: GEC, Honeywell, and Kaiser. Helmets were tested from each company in each of the four following categories: NVG mock-up, NVG/HMD mock-up, NVG operational, and NVG/HMD operational. These devices were tested individually in various configurations involving a helmet, a MBU-12/P mask, a visor, a large Hybrid II (ADAM) head, a Hybrid III 5th percentile head, and a custom thermoplastic liner (TPL).

Two critical issues need to be applied to the inertial properties results of these devices. The first is how well do the three vendor's systems meet the specifications listed in the statement of work (SOW). The second is how well do the mass properties of the mock-up systems compare to the operational systems.

PROCEDURES

Each of the twelve helmets was tested in four different configurations. The configurations were tested in the following order. The appropriate vendor's TPL liner for the ADAM head was inserted into the helmet shell. The straps on the helmet were loosened and the ADAM head inserted. The ear cups, webbing, and straps were all fitted for the best possible fit. The optics were aligned with the pupils and when possible the interpupillary distance (IPD) was measured and set to the vendor's specification. The MBU-12/P mask with appropriate vendor's clips was attached to the helmet and fitted to the head. The visor was then pulled down. The helmet axis system and additional reference points were marked and the helmet was secured in the testing box. For the second configuration, the mask and ADAM head were removed without changing any positions of the optics, straps, or liner. The third and fourth configurations were completed similarly to the first two except the small Hybrid III head and TPL were used.

The Hybrid III and ADAM heads were tested independently at the beginning of the test program to provide baseline data on each head. Anatomical landmarks were permanently marked on the heads for digitizing purposes. These points provided a reference for locating the helmet with respect to the head and established the relationship of the helmet mass properties with respect to an anatomical axis system.

A detailed description of the testing procedure and the equipment used is contained in "The Standard Automated Mass Properties

Testing Procedure" (1). The accuracy of the equipment has been evaluated and is documented in "The Standard Automated Mass Properties Testing Accuracy Report" (2). Table 1 lists the 48 different configurations that were tested on the twelve helmets.

Table 1. Helmet Configurations

VENDOR	HELMET	MASK	HEAD	UNIQUENESS
GEC	1-G	MBU-12/P	ADAM 95th	Retested after Mod.
GEC	1-G	-	-	Retested after Mod.
GEC	1-G	MBU-12/P	HYB III 5th	
GEC	1-G	-	-	
HONEYWELL	1-H	MBU-12/P	ADAM 95th	Non-std. Helmet axis
HONEYWELL	1-H	-	-	Non-std. Helmet axis
HONEYWELL	1-H	MBU-12/P	HYB III 5th	Non-std. Helmet axis
HONEYWELL	1-H	-	-	Non-std. Helmet axis
KAISER	1-K	MBU-12/P	ADAM 95th	
KAISER	1-K	-	-	
KAISER	1-K	MBU-12/P	HYB III 5th	
KAISER	1-K	-	-	
GEC	4-G	MBU-12/P	ADAM 95th	
GEC	4-G	-	-	
GEC	4-G	MBU-12/P	HYB III 5th	
GEC	4-G	-	-	
HONEYWELL	3-H	MBU-12/P	ADAM 95th	Non-std. Helmet axis
HONEYWELL	3-H	-	-	Non-std. Helmet axis
HONEYWELL	3-H	MBU-12/P	HYB III 5th	Non-std. Helmet axis
HONEYWELL	3-H	-	-	Non-std. Helmet axis
KAISER	3-K	MBU-12/P	ADAM 95th	
KAISER	3-K	-	-	
KAISER	3-K	MBU-12/P	HYB III 5th	

VENDOR	HELMET	MASK	HEAD	UNIQUENESS
KAISER	3-K	-	-	
GEC	6-G	MBU-12/P	ADAM 95th	
GEC	6-G	-	-	
GEC	6-G	MBU-12/P	HYB III 5th	
GEC	6-G	-	-	
HONEYWELL	5-H	MBU-12/P	ADAM 95th	
HONEYWELL	5-H	-	-	
HONEYWELL	5-H	MBU-12/P	HYB III 5th	
HONEYWELL	5-H	-	-	
KAISER	6-K	MBU-12/P	ADAM 95th	
KAISER	6-K	-	-	
KAISER	6-K	MBU-12/P	HYB III 5th	
KAISER	6-K	-	-	
GEC	8-G	MBU-12/P	ADAM 95th	Optics cable tached
GEC	8-G	-	-	Optics cable attached
GEC	8-G	MBU-12/P	HYB III 5th	Optics cable attached
GEC	8-G	-	-	Optics cable attached
HONEYWELL	8-H	MBU-12/P	ADAM 95th	
HONEYWELL	8-H	-	-	
HONEYWELL	8-H	MBU-12/P	HYB III 5th	
HONEYWELL	8-H	-	-	
KAISER	8-K	MBU-12/P	ADAM 95th	
KAISER	8-K	-	-	
KAISER	8-K	MBU-12/P	HYB III 5th	
KAISER	8-K	-	-	

AXIS SYSTEM DESCRIPTION

The test data are presented with respect to two axis systems: the anatomical and the helmet axis system. A brief description of these systems follows.

Anatomical Coordinate System This axis system is used to compare manikin and human head mass properties. It also serves as a reference for locating various helmet and night vision goggles with respect to a human head. The coordinate system is shown in Figure 1. The anatomical y-axis is defined by a vector from the right to the left tragion. The x-axis is defined by a vector perpendicular to the y-axis passing through the right infraorbital, positive toward the front. The z-axis is defined as the cross product of the 'x' and 'y' axes and is positive out the top of the head. The origin of the system is defined to be at the point of intersection between the y-axis and the vector through the sellion perpendicular to the y-axis.

Helmet Coordinate System This axis system is used to define the mass properties of the helmet or helmet configuration independent of a manikin or human head. Three points were located to define the helmet axis system. The first was located at the center of the ridge roll across the front of the helmet. The second and third points were found by mirroring the following steps on the left and right side of the helmet. A large caliper was used to measure 9.467 in. from the ridge roll just located to the ridge along the bottom of the helmet. From this point an arc with a 3.125 in. radius was drawn on the side of the helmet. From the first point at the center of the front ridge roll, an arc with a 8.467 in. radius was drawn on the side of the helmet. The point of intersection of the arcs form the left and right reference points for the y-axis, positive right to left. The x-axis is perpendicular to the y-axis and passes through the center of the ridge roll. The z-axis is defined as the cross product of the 'x' and 'y' axes and is positive out the top of the helmet. The origin of the axis system is located at the intersection of the 'x' and 'y' axes. Figure 2 shows the helmet coordinate axis system.

RESULTS

The results of the mass properties tests are listed in Tables 2-26. The tables contain weight; center of mass locations in helmet and anatomical coordinate systems; principle moments of inertia; and the cosine tensors used to transform between the coordinate systems.

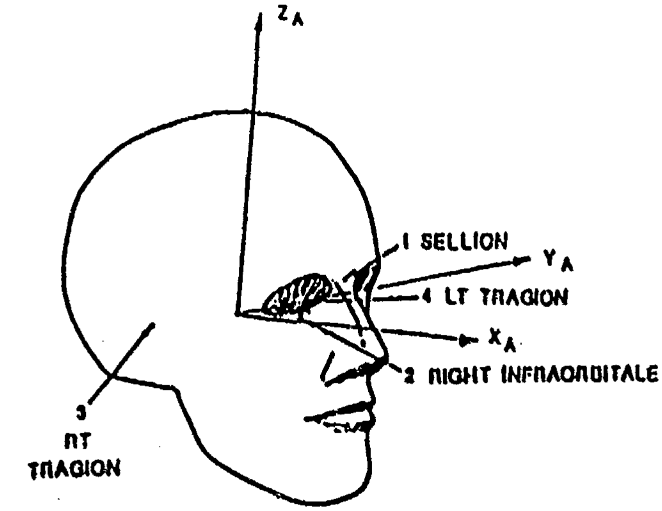

Figure 1. Anatomical Axis System

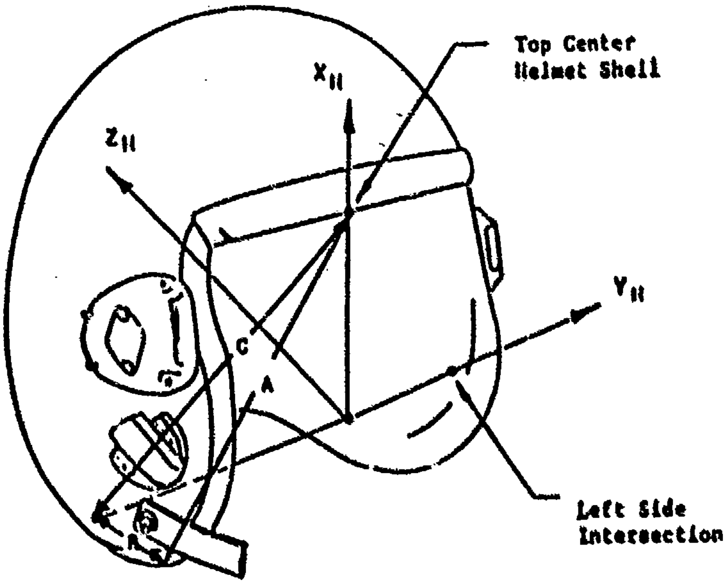

Figure 2. Helmet Axis System

Table 2. GEC 1-G Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask, Retested After Modification

Mass (Lb) : 4.72

Principal Moments of Inertia (Lb/In^2):

X: 98.897
Y: 68.870
Z: 79.481

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.98	-.06	2.34	.31	.07	1.37

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.76832	-0.07307	-0.63597
0.01468	0.99522	-0.09657
0.64002	0.06483	0.76567

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask, Retested After Modification

Mass (Lb) : 14.35

Principal Moments of Inertia (Lb/In^2):

X: 189.650
Y: 184.440
Z: 154.849

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.83	-.02	1.99	2.50	-.01	1.98

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.75493	0.05324	-0.65361
-0.01505	0.99786	0.06369
0.65572	-0.03820	0.75398

Table 3. GEC 1-G Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask, Before Modification

Mass (Lb) : 4.54

Principal Moments of Inertia (Lb/In²):

X: 94.792
Y: 60.602
Z: 78.122

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.05	-.19	2.02	.95	-.21	2.02

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.70848	0.00949	-0.70554
-0.01390	0.99995	-0.00034
0.70555	0.01018	0.70851

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask, Before Modification

Mass (Lb) : 14.20

Principal Moments of Inertia (Lb/In²):

X: 185.333
Y: 176.085
Z: 155.807

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.89	-.02	1.86	.25	-.03	1.09

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.70912	0.00960	-0.70502
-0.01386	0.99990	-0.00039
0.70501	0.01002	0.70906

Table 4. GEC 1-G Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 4.61

Principal Moments of Inertia (Lb/In²):

X: 91.039
Y: 58.629
Z: 75.895

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.05	-.11	2.07	.63	-.33	2.30

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.71371	-0.04120	-0.69926
-0.00507	0.99795	-0.06377
0.70043	0.04894	0.71214

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 13.58

Principal Moments of Inertia (Lb/In²):

X: 161.182
Y: 151.977
Z: 136.496

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.02	.01	1.59	.23	-.18	1.25

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.71379	-0.04159	-0.69911
-0.00494	0.99791	-0.06415
0.70032	0.04924	0.71212

Table 5. Honeywell 1-N Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.16

Principal Moments of Inertia (Lb/In²):

X: 125.653
Y: 58.796
Z: 108.038

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	1.17	.13	-.60	.95	.21	1.37

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.98956	0.01326	-0.14289
-0.01508	0.99976	-0.01150
0.14278	0.01360	0.98959

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 14.73

Principal Moments of Inertia (Lb/In²):

X: 222.132
Y: 167.822
Z: 167.168

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.39	.08	-.88	.13	.06	.90

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.99326	-0.00281	-0.11686
-0.00049	0.99955	-0.02751
0.11696	0.02734	0.99271

Table 6. Honeywell 1-H Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.16

Principal Moments of Inertia (Lb/In²):

X: 105.664
Y: 59.034
Z: 121.718

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	1.09	-.01	-.66	.84	-.12	.71

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.98858	-0.01243	-0.15066
0.00761	0.99948	-0.03215
0.15088	0.03061	0.98806

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.00

Principal Moments of Inertia (Lb/In²):

X: 199.189
Y: 145.734
Z: 148.498

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.66	-.04	-.61	.46	-.20	.77

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.97555	-0.07870	-0.20548
0.06682	0.99569	-0.06417
0.20967	0.04885	0.97657

Table 7. Kaiser 1-K Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 4.81

Principal Moments of Inertia (Lb/In²):

X: 92.418
Y: 60.484
Z: 85.624

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.74	-.09	2.38	1.50	-.06	2.74

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.70803	0.00955	-0.70606
-0.00255	0.99997	0.01042
0.70612	-0.00396	0.70804

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 14.46

Principal Moments of Inertia (Lb/In²):

X: 188.858
Y: 187.229
Z: 167.171

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.12	.07	2.10	.56	.11	1.39

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.70791	0.00945	-0.70631
-0.00308	0.99984	0.01017
0.70663	-0.00512	0.70788

Table 8. Kaiser 1-k Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 4.81

Principal Moments of Inertia (Lb/In^2):

X: 93.320
Y: 59.562
Z: 82.992

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.78	.09	2.35	1.47	-.06	2.46

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.62198	-0.00725	-0.78292
-0.03170	0.99894	-0.03450
0.78241	0.04640	0.62116

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 13.78

Principal Moments of Inertia (Lb/In^2):

X: 165.487
Y: 158.221
Z: 147.049

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.39	.04	2.26	.68	-.06	1.31

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.62218	-0.00676	-0.78280
-0.03226	0.99883	-0.03448
0.78219	0.04670	0.62127

Table 9. Honeywell 3-H / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.71

Principal Moments of Inertia (Lb/In^2):

X: 127.771
Y: 63.906
Z: 140.156

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.87	.07	-.87	.64	-.03	.86

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.99351	0.02236	-0.11215
-0.02180	0.99973	0.00606
0.11218	-0.00358	0.99360

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 15.23

Principal Moments of Inertia (Lb/In^2):

X: 232.497
Y: 167.303
Z: 184.177

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.34	.01	-.95	.25	-.08	.69

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.98692	-0.01932	-0.16025
0.01682	0.99966	-0.01715
0.16049	0.01417	0.98697

Table 10. Honeywell 3-H / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.69

Principal Moments of Inertia (Lb/In^2):

X: 123.056
Y: 61.498
Z: 134.870

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.90	.00	-.82	.64	-.07	.34

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.99082	0.01722	-0.13307
-0.02116	0.99943	-0.02779
0.13262	0.03037	0.99075

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.51

Principal Moments of Inertia (Lb/In^2):

X: 209.731
Y: 145.357
Z: 166.194

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.57	-.11	-.61	.34	-.14	.58

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.98475	0.00083	-0.17469
-0.01051	0.99835	-0.05516
0.17437	0.05607	0.98302

Table 11. Kaiser 3-K Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.84

Principal Moments of Inertia (Lb/In^2):

X: 136.101
Y: 78.151
Z: 114.999

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.30	.04	2.83	.91	.03	2.84

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.70035	0.00465	-0.71364
-0.05232	0.99755	-0.04476
0.71179	0.06865	0.69893

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 15.52

Principal Moments of Inertia (Lb/In^2):

X: 224.884
Y: 208.930
Z: 199.966

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.91	.04	2.25	.41	.03	1.39

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.71109	0.03974	-0.70199
-0.05536	0.99849	0.00058
0.70092	0.03836	0.71216

Table 12. 3-K Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.89

Principal Moments of Inertia (Lb/In²):

X: 112.795
Y: 78.489
Z: 133.205

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.25	.03	2.76	.66	-.14	2.38

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.61225	-0.01548	-0.79046
-0.01059	0.99955	-0.02763
0.79064	0.02537	0.61184

Helmet, 5% TPL, Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.86

Principal Moments of Inertia (Lb/In²):

X: 200.440
Y: 175.698
Z: 179.566

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.24	.00	2.40	.61	-.01	1.41

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.66260	-0.00224	-0.74893
0.00580	0.99991	0.00227
0.74885	-0.00596	0.66270

Table 13. GEC 4-G Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.64

Principal Moments of Inertia (Lb/In²):

X: 101.457
Y: 74.544
Z: 128.836

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.80	.01	2.43	.79	-.05	2.39

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.72337	0.01654	-0.69024
-0.01841	0.99986	0.00464
0.69023	0.00944	0.72357

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 15.28

Principal Moments of Inertia (Lb/In²):

X: 214.409
Y: 198.119
Z: 184.295

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.71	.04	1.97	.32	.00	1.31

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.72298	0.01692	-0.69070
-0.01857	0.99979	0.00512
0.69064	0.00921	0.72314

Table 14. GEC 4-G Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.69

Principal Moments of Inertia (Lb/In²):

X: 96.522
Y: 75.525
Z: 124.765

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.83	-.14	2.39	.28	-.17	2.36

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.78251	-0.19298	-0.59206
0.07348	0.97264	-0.21978
0.61841	0.12834	0.77538

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.66

Principal Moments of Inertia (Lb/In²):

X: 190.870
Y: 168.787
Z: 161.262

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.90	-.03	1.70	.27	-.22	1.26

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.71959	-0.00948	-0.69435
-0.02190	0.99917	-0.03636
0.69415	0.04137	0.71860

Table 15. Honeywell 5-H Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.05

Principal Moments of Inertia (Lb/In^2):

X: 123.286
Y: 56.042
Z: 109.429

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.90	-.02	.35	1.40	.02	2.53

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.91392	-0.01079	-0.40535
0.00905	0.99992	-0.00644
0.40554	0.00217	0.91405

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 14.55

Principal Moments of Inertia (Lb/In^2):

X: 217.237
Y: 170.886
Z: 165.893

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.30	.02	.26	.18	.08	.73

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.91877	-0.01550	-0.39453
0.01806	0.99988	0.00303
0.39435	-0.01006	0.91900

Table 16. Honeywell 5-H Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.03

Principal Moments of Inertia (Lb/In²):

X: 117.816
Y: 56.408
Z: 103.517

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.95	-.22	.32	.64	.02	.76

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.94399	0.04539	-0.32655
-0.05668	0.99806	-0.02509
0.32486	0.04220	0.94479

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.00

Principal Moments of Inertia (Lb/In²):

X: 199.189
Y: 145.734
Z: 148.498

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	.66	-.04	-.61	.46	-.20	.77

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.97557	-0.07863	-0.20552
0.06680	0.99569	-0.06732
0.20962	0.04257	0.97656

Table 17. GEC 6-G Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.03

Principal Moments of Inertia (Lb/In²):

X: 83.277
Y: 67.705
Z: 106.831

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.95	-.05	2.06	1.11	-.13	1.99

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.67991	0.00961	-0.73311
-0.01475	0.99977	-0.00057
0.73306	0.01105	0.68002

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 14.66

Principal Moments of Inertia (Lb/In²):

X: 194.337
Y: 185.259
Z: 163.661

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.73	.02	1.94	.35	-.03	1.04

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.67912	0.00721	-0.73401
-0.01560	0.99991	-0.00453
0.77394	0.01467	0.67925

Table 18. GEC 6-G Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.07

Principal Moments of Inertia (Lb/In²):

X: 82.245
Y: 66.181
Z: 105.663

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.03	.00	2.15	.70	-.23	2.30

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.68299	-0.04355	-0.72910
0.00723	0.99865	-0.05290
0.73028	0.03077	0.68235

Helmet, 5% TPL, 5% Hybrid III Head / MBU-12/P Mask

Mass (Lb) : 14.04

Principal Moments of Inertia (Lb/In²):

X: 170.682
Y: 159.707
Z: 144.160

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.93	.02	1.61	.35	-.18	1.13

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.68325	-0.04343	-0.72880
0.00758	0.99862	-0.05246
0.73022	0.03030	0.68250

Table 19. Kaiser 6-K Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask, Retested After Modification

Mass (Lb) : 5.16

Principal Moments of Inertia (Lb/In²):

X: 109.655
Y: 67.496
Z: 90.314

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.74	-.05	2.42	1.66	-.09	2.95

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.73999	0.01705	-0.67229
-0.02137	0.99981	0.00185
0.67219	0.01304	0.74027

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 14.81

Principal Moments of Inertia (Lb/In²):

X: 198.492
Y: 205.394
Z: 181.059

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.96	-.19	2.04	.60	-.06	1.46

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.74503	0.02956	-0.66642
-0.02997	0.99942	0.01067
0.66625	0.01206	0.74555

Table 20. Kaiser 6-K Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.16

Principal Moments of Inertia (Lb/In²):

X: 104.268
Y: 66.039
Z: 84.903

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.64	-.08	2.40	1.29	-.15	2.28

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.65105	-0.00199	-0.75905
-0.01618	0.99980	-0.01645
0.75888	0.02301	0.71370

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.18

Principal Moments of Inertia (Lb/In²):

X: 174.683
Y: 167.024
Z: 150.686

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.25	-.13	2.28	.51	-.15	1.14

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.64776	0.00347	-0.76187
-0.02025	0.99971	-0.01267
0.76161	0.02352	0.64766

Table 21. GEC 8-G Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 7.25

Principal Moments of Inertia (Lb/In²):

X: 121.553
Y: 143.202
Z: 109.014

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.70	.28	2.77	-.22	.43	1.76

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.68295	0.00833	-0.73046
-0.02174	0.99971	-0.00897
0.73019	0.02207	0.68289

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 17.09

Principal Moments of Inertia (Lb/In²):

X: 282.674
Y: 299.902
Z: 199.630

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.35	-.02	2.40	-.18	.14	1.24

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.68275	0.00810	-0.73067
-0.02167	0.99968	-0.00925
0.73035	0.02228	0.68262

Table 22. GEC 8-G Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 7.32

Principal Moments of Inertia (Lb/In^2):

X: 120.507
Y: 145.848
Z: 193.857

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.55	-.15	2.97	-.86	-.27	1.73

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.67155	-0.06016	-0.73848
0.03129	0.99814	-0.05289
0.74020	0.01248	0.67219

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 16.27

Principal Moments of Inertia (Lb/In^2):

X: 261.703
Y: 236.245
Z: 183.315

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.63	-.08	2.30	-.31	-.17	1.34

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.67184	-0.06077	-0.73831
0.03197	0.99808	-0.05311
0.74010	0.01202	0.67242

Table 23. GEC 8-G Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.78

Principal Moments of Inertia (Lb/In²):

X: 128.327
Y: 66.669
Z: 137.990

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.43	.08	.25	.20	.20	.99

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.96012	0.03701	-0.27724
-0.03200	0.99915	0.02275
0.27775	-0.01295	0.96050

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 15.50

Principal Moments of Inertia (Lb/In²):

X: 241.342
Y: 181.026
Z: 191.008

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.18	.06	-.12	.07	.18	.56

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.95979	0.03817	-0.27836
-0.03311	0.99910	0.02304
0.27896	-0.01289	0.96032

Table 24. Honeywell B-H Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.82

Principal Moments of Inertia (Lb/In²):

X: 139.327
Y: 66.084
Z: 122.761

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.65	.09	.36	.14	-.03	1.23

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.97727	-0.05627	-0.20427
0.04525	0.99726	-0.05781
0.20688	0.04730	0.97726

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.66

Principal Moments of Inertia (Lb/In²):

X: 209.206
Y: 152.450
Z: 166.852

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.50	.03	-.01	.07	-.07	.85

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.97738	-0.05640	-0.20416
0.04548	0.99569	-0.05736
0.20682	0.04670	0.97723

Table 25. Kaiser 8-K Helmet / Adam Configuration

Helmet, 95% TPL, No Head, No Mask

Mass (Lb) : 5.95

Principal Moments of Inertia (Lb/In^2):

X: 136.814
Y: 78.697
Z: 114.566

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.16	.03	2.83	.79	.15	2.76

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.68550	0.04519	-0.72672
-0.03369	0.99893	0.03045
0.72716	0.00365	0.68637

Helmet, 95% TPL, Large Adam Head, MBU-12/P Mask

Mass (Lb) : 15.61

Principal Moments of Inertia (Lb/In^2):

X: 224.462
Y: 205.447
Z: 199.604

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	2.80	.09	2.34	.22	.19	1.44

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.68608	0.04532	-0.72626
-0.03342	0.99892	0.03071
0.72688	0.00312	0.68677

Table 26. Kaiser 8-K Helmet / Hybrid III Configuration

Helmet, 5% TPL, No Head, No Mask

Mass (Lb) : 5.93

Principal Moments of Inertia (Lb/In^2):

X: 134.293
Y: 81.159
Z: 107.275

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	4.23	-.05	2.94	.81	-.27	2.54

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.64684	-0.02658	-0.76220
-0.00514	0.99930	-0.03927
0.76256	0.02924	0.64613

Helmet, 5% TPL, 5% Hybrid III Head, MBU-12/P Mask

Mass (Lb) : 14.90

Principal Moments of Inertia (Lb/In^2):

X: 199.143
Y: 178.933
Z: 174.503

	Helmet Coordinate Axes (in)			Anatomical Coordinate Axes (in)		
	X	Y	Z	X	Y	Z
Center of Mass Location	3.02	-.02	2.47	.39	-.07	1.32

Transformation from Helmet Coordinate to Anatomical Axes:

Cosines

0.64919	-0.00101	-0.76056
-0.01704	0.99969	-0.01582
0.76043	0.02322	0.64911

REFERENCES

1. C. Albery, J. Whitestone, The Standard Automated Mass Properties Testing Procedure, 1988, AAMRL-TR-88-XX (unpublished).

2. A. Lephart, C. Albery, A. Obert, The Standard Automated Mass Properties Testing Accuracy Report, 1989, AAMRL-TR-89-XX (unpublished).

APPENDIX C
FIT ASSESSMENT

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APPENDIX C: FIT ASSESSMENT

1. INTRODUCTION

Helmets and optical devices worn by aircrew members need to be comfortable, stable and fit optically "correct." The three I-NIGHTS helmets were designed to be a size "large." However, one size does not fit all plus each design is a different size "large." A helmet that does not "fit" may produce invalid test results and/or may provide for an unsafe test condition. This report describes a laboratory evaluation of the comfort, fit and stability of the I-NIGHTS helmets. This evaluation was accomplished by the Design Technology Branch, Human Engineering Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

2. APPROACH

Each subject who participates in an I-NIGHTS test, such as vertical deceleration tower, centrifuge or flight test, will undergo a fit evaluation to ensure each of the helmet systems fit.

3. OBJECTIVE

The objective of the fit assessment is to determine for each test subject wearing each of the I-NIGHTS helmet systems that the helmet is comfortable, stable, and fits optically correct.

The Fit Assessment Technical Report titled "Human Integration Evaluation of Three Helmet Systems" was not available at press time. For this report contact:

AL/CFHV
BLDG 248, Area B
WPAFB, OH 45433
ATTN: Ms. Kathy Robinette

APPENDIX D
PERSONAL EQUIPMENT INTEGRATION, AIRCRAFT INTEGRATION, AND ALTITUDE CHAMBER

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PREFACE TO APPENDIX D: PERSONAL EQUIPMENT INTEGRATION, AIRCRAFT INTEGRATION, AND ALTITUDE CHAMBER

The following three test areas address separate facets of helmet-mounted system testing. These areas are: Personal Equipment Integration, Aircraft Integration, and Altitude Chamber. Although they are treated as distinct areas of testing, they were jointly accomplished by two test organizations sharing assets, test personnel, and expertise. However, the results of individual phases of testing under each area are provided in two reports; and by each test organization for the phases of testing that organization was responsible for.

APPENDIX D: PERSONAL EQUIPMENT INTEGRATION

1. INTRODUCTION

Aircrew members work in a hostile world. Not only do they have the possibility that someone might shoot at them, they fly in machines subject to mechanical failure forcing them to eject or crash land. They fly in environments unfriendly to human existence and perform mission tasks under unbearable conditions. To enhance their survival, aircrew members must wear protective gear such as parachutes, life preservers, flak vests, survival vests, G suits, oxygen masks, helmets, and visors. Each additional piece of "armor" cannot conflict or negate another and therefore must be integrated with the crew member. This report describes the effort to integrate the helmet-mounted systems with a limited set aircrew protective gear. The three helmet systems were developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. This effort was jointly conducted by the Crew Systems Branch, Crew Technology Division, School of Aerospace Medicine, Brooks Air Force Base, Texas and the Chemical Defense Branch, 3246 Test Wing, Eglin Air Force Base, Florida.

2. APPROACH

The personal equipment integration evaluation was conducted by having trained life support personnel donn each I-NIGHTS helmet ensuring that the helmet system did not conflict with other protective gear; did not interfere with the performance of normal mission tasks; and did not prevent the performance of emergency procedures. The trained subjects represented aircrew members in the 5th, 50th, and 95th anthropomorphic percentiles (DOD-Handbook - 743 Anthropometry of U.S. Military Personnel). This ensured that crew member size would not be a factor during actual flight testing.

3. OBJECTIVE

The objective of personal equipment integration testing was to demonstrate I-NIGHTS compatibility with:

- the aircrew member
- required life support equipment
- mission essential tasks
- emergency procedures

1. INTRODUCTION

Each new piece of equipment worn by an aircrew member must be integrated into the cockpit. This integration process ensures the equipment is functionally compatible with the crew member and with the systems already on board the aircraft. This report describes the efforts to integrate three helmet-mounted systems with selected Air Force aircraft. The helmet systems were developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. This effort was jointly conducted by the Crew Systems Branch, Crew Technology Division, School of Aerospace Medicine, Brooks Air Force Base, Texas and the Chemical Defense Branch, 3246 Test Wing, Eglin Air Force Base, Florida.

2. APPROACH

Aircraft integration was conducted by having trained life support personnel don each I-NIGHTS helmet and performing various aircrew/aircraft interactions. These interactions include visibility within the cockpit, unobstructed head movement, emergency procedures and electromagnetic interference checks.

3. OBJECTIVES

The objective of aircraft integration is to ensure helmet system/aircraft functional compatibility.

APPENDIX D (Continued): ALTITUDE CHAMBER

1. INTRODUCTION

Aircraft flying at altitudes have pressurized cockpits. These cockpits have the potential to suddenly lose pressurization during a rapid decompression or during certain emergency situations where cabin pressure is intentionally "dumped." Helmet-mounted systems must not be effected by rapid decompression. Its structural components and optical performance should not be degraded. Additionally, the helmet must help to ensure the oxygen mask maintains a good seal around the crew member's face. This report describes the altitude chamber evaluation of three night vision helmet systems developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. The evaluation was accomplished by Crew Systems Branch, Crew Technology Division, School of Aerospace Medicine, at Brooks Air Force Base, Texas.

2. APPROACH

The structural integrity and lens fogging susceptibility of the three I-NIGHTS helmet designs were evaluated in a hyperbaric chamber with rapid decompression of 8,000 to 25,000 feet within one second. Each helmet design received two rapid decompressions.

3. OBJECTIVE

The objective this evaluation was to verify the structural integrity of the helmet designs; to determine any tendency of the optical components to fogging; and helmet comfort in reduced atmospheres.

USAFSAM Safety of Flight Testing of the
Interim-Night Integrated Goggle and Head Tracking System
(I-NIGHTS)
14 June 90

1. Project/Task/Work Unit: 79301175, 79301176

2. Principal Investigators:

a. Under the Generic Altitude Chamber Experimentation Using Human Subject Volunteers Protocol (SAM ACHE 85-18; approved by HQ USAF/SGP, 20 Dec 85): Mr Ronald D. Holden, USAFSAM/VNL/43361, and 2d Lt John T. Crist, USAFSAM/VNL/42256.

b. Under the Generic Cockpit and Equipment Integration Laboratory Protocol (SAM ACHE 82-16; approved by HQ USAF/SGP, 28 Oct 82): 2d Lt John T. Crist, USAFSAM/VNL/42256.

3. Associate Investigator: Col John B. Bomar, Jr, USAFSAM/VNL/43361.

4. Medical Consultants: Base Flight Surgeon, USAF Clinic/SGP, Brooks AFB TX/42859. USAFSAM/VN Medical Monitors (Physician)/42921/43521/43814/43361.

5. Contractor: McDonnell Douglas Aircraft Company, St. Louis MO.

6. Facilities:

a. USAFSAM/VN Experimental Altitude Chambers, Brooks AFB TX.

b. USAFSAM/VN Environmental Chambers, Brooks AFB TX.

c. USAFSAM/NG Arc Perimeter Device, Brooks AFB TX.

d. USAFSAM/VN Cockpit and Equipment Integration Laboratory (CEIL), Brooks AFB TX.

e. Aircraft Test Sites:

MH-53J	Hurlburt Field FL
B-52G/H	Ellsworth AFB SD
A-7 LANA	Davis-Monthan AFB AZ
AFTI/F-16	Edwards AFB CA

7. Project Objectives: Human Systems Division Helmet-Mounted System Technology Systems Program Office (HSD/YAH-HMST) has requested the USAF School of Aerospace Medicine (USAFSAM), Brooks AFB TX to conduct safety of flight testing of the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS). The Crew Technology Division (USAFSAM/VN) will perform ground tests on I-NIGHTS with the following objectives:

a. To demonstrate compatibility of the I-NIGHTS man-side equipment with current altitude protective equipment and life support systems.

b. To demonstrate compatibility of the I-NIGHTS man-side equipment with the aircrew member, cockpit, required life support equipment, and mission essential tasks associated with each crew station.

8. Background and Relevance: I-NIGHTS is a joint USAF and US Navy program to develop an ejection capable night vision goggle (NVG) and binocular helmet-mounted display (BHMD). USAF participation in the I-NIGHTS program is in response to Strategic Air Command SON 309-087 (NVG requirement) and Tactical Air Command A-16 SORD 312-88-1-A (HMD requirement). GEC Avionics Ltd, Honeywell Inc, and Kaiser Electronics are the competing subcontrators tasked by McDonnell Douglas Aircraft Company to design and fabricate the I-NIGHTS NVG and BHMD systems.

Ground tests on the subcontractors' I-NIGHTS prototype systems are necessary to obtain clearance to proceed to advanced development flight test and demonstration as well as to ensure risk reduction to facilitate rapid transition to full scale development.

9. Test Procedures: The Crew Technology Division Crew Systems Branch (USAFSAM/VNL) will conduct I-NIGHTS ground tests on altitude (USAFSAM/VNL Life Support Function) and integration with personal flight equipment (USAFSAM/VNL Cockpit and Equipment Integration Laboratory). Altitude evaluations consist of human interface, altitude/rapid decompression, and valsalva assessment. Integration with personal flight equipment evaluations consists of donning and doffing (non-emergency), ingress and egress (non-emergency), simulated mission tasks, inversion wheel, lens/visor fogging, helmet fitting, chin strap and visor operation, comfort, and unaided field of view assessment.

(1) Altitude Evaluations: The altitude assessment of I-NIGHTS will involve both unmanned and manned testing. This series of tests will evaluate the compatibility of I-NIGHTS with the MBU-12/P oxygen mask, structural integrity of the NVG/HMD and helmet under rapid decompression (loss of cabin pressure), comfort and fit, and ability of the crew member to perform a one-handed valsalva.

Procedure:

Prior to manned evaluations, unmanned testing will be performed using a manikin head form. The I-NIGHTS prototypes will be fitted to the head form and placed in the altitude chamber. The chamber pressure will be brought from ground level to a simulated altitude of 25,000 feet at a standard rate of ascent (5,000 feet/min). The chamber will be returned to 9,500 feet in preparation for rapid decompression (RD). Rapid decompression will occur from 9,500 feet to a peak altitude of 25,000 feet (5 psi differential). Elapsed time of the RD is approximately one second. Testing will be completed upon descent to ground level at a rate of 5,000 feet/min. The I-NIGHTS helmet will be inspected for physical damage at ground level.

The flight profile for the manned evaluations will be to a simulated peak altitude of 25,000 feet. Subjects will be fitted to the I-NIGHTS helmet and MBU-12/P oxygen mask. Exposure to 25,000 feet will involve no 100% oxygen pre-breathing. Each flight will be preceeded by an ear and sinus check to an altitude of 5,000 feet. The assessment will begin with a controlled ascent from ground level to 25,000 feet (5,000 feet/min) to encourage venting of abdominal gas and to allow monitoring of the equipment to ensure normal operation. Following the abdominal check, the chamber will descend to 9,500 feet and then be decompressed to 25,000 feet in approximately one second. Subjects will perform head mobility and oxygen mask seal assessment at peak altitude. Total time at peak altitude will not exceed five minutes. Upon descent to ground level (5,000 feet/min) subjects will attempt to perform a one-handed valsalva while wearing the USAF Nomex flight gloves. The I-NIGHTS NVG/HMD helmet will be visually inspected at ground level for physical damage.

Manned flights of each subcontractor's I-NIGHTS system will involve three subjects. The following data will be recorded during altitude tests: absolute pressure, chamber altitude, mask cavity pressure, mask cavity oxygen concentration, mask cavity carbon dioxide concentration, subjective data.

(2) Integration with Personal Flight Equipment Evaluation: Assessments will be conducted to demonstrate that the I-NIGHTS man-side equipment is compatible with the required life support and mission essential equipment. Compatibility is defined as the ability of the personal flight equipment to provide its function as written in the Technical Order (T.O.) and the ability of the aircrew to accomplish simulated mission tasks.

Procedure:

(a) Trained test subjects, representing approximately the 5th, 50th, and 95th percentiles (weight and stature) of the USAF aircrew population will don I-NIGHTS in the aircraft, perform ingress and strapping in procedures, execute simulated mission tasks, complete non-emergency egress, and doff the system. Mission tasks will be determined by consultations with rated aircrew members at the test sites. Subjects will wear the required personal flight equipment as required for the specific aircraft and/or mission. After each assessment, the I-NIGHTS NVG/HMD helmet will be inspected for any physical damage. Procedures may be modified as appropriate to the aircraft (MH-53J, B-52G/H, A-7 LANA, AFTI/F-16). Percentiles are based on anthropometric tables derived from the 1967 survey of USAF crew members.

Data will be collected on the following: any adverse interaction between the I-NIGHTS man-side equipment and the test subject, the personal flight equipment, and the aircraft cockpit during simulated normal and emergency situations; reduced mobility (head and body); increased thermal loading; ability to complete donn/doffing, ingress/non-emergency egress, and simulated mission tasks (access to emergency and non-emergency controls and displays); comfort; chinstrap and visor operation; visual limitations; any physical damage to I-NIGHTS.

(b) Helmet fitting process evaluation will address the subcontractors' procedures and the capability to provide for personal fit and adjustment to the aircrew member. Data will be collected on the length of time for fitting, ability to fit subjects with various head dimensions, complexity of the fitting procedures (for a level five life support specialist), comfort of the helmet liner and earcups, comfort of nape and chin strap, and the operation of chin strap and visor.

(c) Unaided field of view evaluations will be performed using an arc perimeter device. Measurements will be made with the head fixed, however, eye movement is allowed. Subjects will wear the I-NIGHTS NVG/HMD helmet with visor lowered and MBU-12/P oxygen mask. Twenty-three data points will be collected from the 285 degree to the 255 degree radial at 15 degree increments. A baseline will be established using the same subjects wearing the HGU-55/P helmet with visor lowered and MBU-12/P oxygen mask. The assessment will involve approximately ten subjects.

(d) An inversion wheel assessment will be made using a replica ACES II. Subjects will wear the required personal flight equipment and I-NIGHTS. After strapping in, subjects will be tilted side to side to simulated lateral G (Gy) and then rotated (inverted) to simulate -1.0 Gz. Any adverse equipment interaction and helmet discomfort will be recorded. Three subjects will be used for the evaluation.

(e) Lens/visor fogging evaluations will be conducted as requested by the 3246TW/TZFC, Eglin AFB FL. Two temperature conditions will be assessed: 32 degrees Fahrenheit at 80 % relative humidity, and 75 degrees Fahrenheit at 80 % relative humidity. Subjects will enter the chamber from ambient temperature and humidity conditions. Assessment of air blown over the lens/visor will be performed. Time for fogging to occur and clear will be noted and provided to the 3246TW/TZFC prior to I-NIGHTS jump tests. Testing will be conducted on three subjects.

10. Medical Risk Analysis: All tests will be conducted within the exposure envelopes approved within their respective generic protocols. Hazards normally associated with equipment testing and altitude exposure will apply. When feasible, unmanned testing of each experimental set-up will precede its use with human subjects.

11. Attachments:

a. Generic Protocol-Altitude Chamber Experimentation Using Human Subject Volunteers (SAM ACHE 85-18; approved HQ USAF/SGP, 20 Dec 85)

b. Generic Protocol-Cockpit and Equipment Integration Laboratory (SAM ACHE 82-16; approved by HQ USAF/SGP, 28 Oct 82)

DEPARTMENT OF THE AIR FORCE
ARMSTRONG LABORATORY (AFSC)
BROOKS AIR FORCE BASE, TEXAS 78235-5000

REPLY TO ATTN OF: CFTS

SUBJECT: Evaluations of the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS)

TO: HQ HSD/YAH-HMST
Wright-Patterson AFB OH 45433

1. Attached is a letter report outlining evaluations performed on the I-NIGHTS helmets at Brooks AFB TX, NAS Pensacola FL, Eglin AFB FL, and Eaker AFB AR, during August - December 1990. The Armstrong Laboratory and the 3246th Test Wing conducted the tests to assess optics fogging, structural integrity during a rapid decompression, ejection seat interaction, valsalva capability, unaided field of view, and compatibility with existing life support equipment and crew duties on nonejection (MH-53, MH-60, and HC-130) and ejection (B-52) type aircraft.

2. Helmet fit, comfort, and vision (unaided) problems were experienced throughout the tests. Our findings are listed below:

a. The helmet weight and forward center-of-gravity were uncomfortable, and the adjustment straps were not adequate to prevent the helmet from rolling forward. Better helmet sizing criteria and/or fitting procedures are needed.

b. Unaided field of view was affected by the mounting location of the combiners. Our subjects compensated for reduced visibility by looking over, under, or along the sides of the combiner assemblies. Crewmembers may also have to tilt their head in order to see instruments near the body.

c. Helmet modifications for consideration are: trim visors for better valsalva capability; simplify the visor assembly for one-handed operation; provide tinted visors; improve nape strap; mount chinstrap away from bayonet connections and set release location consistent with the HGU-55/P; provide capability to stow the combiners and make in-flight adjustments (when flight gloves are worn); and provide capability to replace batteries unassisted without having to remove the helmet.

3. If questions arise, please contact Lt John T. Crist (DSN 785-7576) or TSgt Durrell Bess (DSN 240-2256).

RICHARD L. MILLER, PhD
Chief, Crew Technology Division

INTRODUCTION

The Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) was evaluated by the Cockpit and Equipment Integration Laboratory (CEIL) during August - December 1990. I-NIGHTS is a joint USN/USAF program to develop an ejection capable night vision goggle (NVG) and binocular helmet-mounted display (BHMD) system incorported into a custom-designed helmet. Specific satety of flight (SOF) tests conducted by CEIL were: optics fogging, altitude (rapid decompression), inversion wheel, valsalva capability, unaided field of view, and integration with personal flight equipment (PFE) on the MH-53J, MH-60G, HC-130P, and B-52G aircraft.

MATERIALS AND METHODS

Mock-up and operational GEC Avionics Ltd, Honeywell Inc, and Kaiser Electronics I-NIGHTS helmets were provided. The aircraft ground tests were performed at operational bases, all other testing was completed at Brooks AFB TX. None of the subjects at Brooks AFB received custom-fitted helmet liners; qualified life support technicians performed a "best effort" fitting.

Optics Fogging

Optics fogging evaluations were conducted in an environmental chamber at 75 deg F and 32 deg F. Testing was performed at ambient barometric pressure with 80% relative humidity. Three subjects participated in the tests. Each subject and one inside observer monitored fogging of the helmet visor and optical components. MBU-12/P oxygen masks were worn with breathing oxygen supplied by a CRU-73/A regulator at 70 psi inlet pressure. The helmet visor and combiners were lowered and locked. Initially, the subjects maintained mask seal and breathed for four to five minutes. Then the subjects created a slight mask leak over the nose and eyes. After an additional four to five minutes, the regulator was switched to emergency setting for approximately one minute. Fogging was also monitored with the mask hanging from the left bayonet receiver. Each subject breathed for four to five minutes, then placed the regulator in 100% oxygen and emergency settings ("gang load") and attempted to quick don the mask.

Altitude (Rapid Decompression)

Unmanned rapid decompressions (RDs) were conducted in a hypobaric chamber to verify the structural integrity of the helmet shell and optical components. The helmets were mounted on a brass manikin head. Each helmet received two exposures from a simulated altitude of 8,000 to 25,000 feet (5.45 psi differential) in approximately one second. Following each RD, the liner was removed and the helmet shell, optics, and liner were examined for physical damage.

Inversion Wheel

Inversion wheel tests were completed using a replica ACES II ejection seat. Two subjects, approximately the 5th and 95th percentile by weight, stature, and sitting eye height of the aircrew population, were strapped into the seat.

(All percentile dimensions are based on the 1967 anthropometric survey of USAF crewmembers.) Both subjects wore the I-NIGHTS helmets, CWU-27/P flight suit, MBU-12/P oxygen mask, LPU-9/P life preserver, SRU-21/P survival vest, and PCU-15/P torso harness. (The CSU-13B/P anti-G suit was not worn since assessments were being made near the head region.) The seat assembly was rotated to simulated -1.0 Gz and +/- 1.0 Gy.

Valsalva

Valsalva capability assessments were accomplished by qualified hypobaric chamber subjects. Four subjects attempted to perform a one-handed valsalva with the right and left hand while wearing the standard mask. The I-NIGHTS helmet visor and combiners lowered. The subjects also attempted to valsalva with the index fingers ("two-handed valsalva").

Unaided Field of View

Limited unaided field of view measurements were completed using a perimeter device. Three subjects wore the GEC and Honeywell systems and standard mask. (The Kaiser system was not available for testing.) The helmet visor and combiners were lowered and locked. The head was fixed and only eye movement was allowed. A baseline was established with the same subjects wearing the standard HGU-55/P helmet and mask.

Integration with PFE on the MH-53J, MH-60G, and HC-130P

Equipment and crew duty compatibility evaluations were performed on the MH-53J and MH-60G at NAS Pensacola FL and on the HC-130P at Eglin AFB FL. Three test parachutists from the 3246th Test Wing, Eglin AFB FL, volunteered as subjects. The parachutists represented approximately the 5th, 50th, and 95th percentiles by weight and stature of the aircrew population. All subjects wore mock-up systems with custom-fitted liners, flight suit, Nomex flight gloves, and flight boots.

The subjects were evaluated for the ability to perform ingress, strapping-in, access to controls and displays, field of view, and non-emergency egress procedures in the pilot and copilot crew stations. Qualified aircrews from the 9th and 20th Special Operations Squadrons, Hurlburt Field FL, provided support.

Integration with PFE on the B-52G

Equipment and crew duty compatibility evaluations were performed on the B-52G at Eaker AFB AR. Two test parachutists from the 3246th Test Wing participated. The subjects represented approximately the 50th and 95th percentiles by weight and stature of the aircrew population.

Both subjects donned the flight suit, CWU-45/P flight jacket, Nomex flight gloves, flight boots, torso harness, LPU-9/P life preserver, and mask. The 50th percentile subject wore the Honeywell system and the 95th percentile subject wore the GEC and Kaiser helmets. The 95th percentile subject did not have custom-fitted liners.

The subjects were evaluated for the ability to perform ingress, strapping-in, access to controls and displays, field of view, and non-emergency egress in the pilot and copilot crew stations. Qualified B-52G aircrews from the 340th Bombardment Squadron, Eaker AFB AR, provided support.

RESULTS AND DISCUSSION

Optics Fogging

One incidence of fogging occurred at 75 deg F. The lower edge of the GEC visor misted as the subject was redonning his mask. At 32 deg F, fogging developed on all helmet visors along the forehead region, and gradually spread over the eyes when a mask leak was created. The fogging cleared when the regulator was switched to the emergency setting. With the mask hanging, visor fogging occurred near the nose during exhalation; especially on the Honeywell and Kaiser systems. The Honeywell and Kaiser visors are larger than the GEC visor and extend lower on the face providing a greater surface area for fogging to develop.

No fogging resulted at either temperatures if the subject maintained mask seal. All subjects experienced difficulty connecting the mask on the Honeywell helmet due to the combiners setting close to the bayonet receivers, and the subjects required more familiarization with the Honeywell bayonets. Quick mask donning on the Honeywell and Kaiser systems was not possible with the combiners and visor lowered and locked. The GEC visor caused slight interference with quick donning of the mask since the subjects were able to slide the mask under the visor. Additionally, the lower, left mask strap on the GEC helmet set over the chinstrap buckle, requiring removal of the mask before the chinstrap can be unfastened.

Altitude (Rapid Decompression)

The helmets rose slightly during the decompression due to the loose fit of the helmets on the manikin head. However, both the mask and visor assemblies remained firmly attached on the helmet during the RD. No physical damages were found during post-exposure helmet inspection.

Inversion Wheel

No adverse equipment interaction or unusual helmet displacement was noted. However, one subject stated that the weight of the helmets caused some strain on his neck. The helmets did not interfere with the ejection seat as the subjects performed slow head movements. (Fast head movements were not completed to avoid neck injury and damage to the operational systems.)

Valsalva

In general, the subjects had difficulty performing a one-handed valsalva when the visors were lowered and locked. The Honeywell and Kaiser visors presented more difficulty due to the large lens which set low on the face. Likewise, the GEC visor set over the valsalva pads on the mask; however, one subject managed to pull the mask down and complete a valsalva. Another subject performed a valsalva but complained of discomfort from having to reach under the GEC visor. In addition, jaw movements to clear the ears caused some discomfort to one subject as the Honeywell left bayonet pressed against his face.

Unaided Field of View

Figures 1 and 2 are plots from the data collected. The center of the chart represents a position directly in front of the eyes; the 0 deg radial is an arc around the right side at eye level; the 90 deg radial is an arc directly overhead; the 180 deg radial is an arc around the left side at eye level; and, the 270 deg radial is and arc directly below the subject. Measurements of the lower field of view were largely dependent on the fit of the mask. Limitations of the device prevented collection of data near the 270 deg radial.

Integration with PFE on the MH-53J, MH-60G, and HC-130P

No safety hazards were observed at the pilot and copilot crew stations in the three aircraft. Although most crewmembers will don the helmet once seated, the subjects were able to perform ingress and strapping-in procedures while wearing I-NIGHTS. The 5th percentile subject had some problems with the shoulder harness contacting the helmet and causing it to roll forward on her head.

All subjects could see and access the cockpit instruments and controls. The subjects completed instrument cross check by looking above or below the combiners. The GEC combiners restricted upward vision, and the visor mounting brackets affected right- and left-side vision. The Honeywell combiners restricted downward vision. Additionally, the 95th percentile subject's vision was completely obstructed by sunlight hitting the Honeywell combiners. The glare from the combiners created a "prism" effect. (The aircraft was facing the sun during tests with the Honeywell system.) The Kaiser system afforded good visibility for looking above or below the combiners; however, the subjects noted the visor straps (side buckles) interfered with vision on the right and left sides. Conversations with rated aircrews suggest they prefer to look under the combiners to avoid excessive head movement.

An HC-130 pilot commented that special qualification is required for landing the HC-130 while wearing NVGs. The GEC system may present a problem during flight trials since the combiners cannot be stowed. For the Honeywell and Kaiser systems, the aircrews will need to be familiar with one-handed operation of the combiner assemblies. Tinted visors should be provided to avoid similar glare problems experienced during the ground tests. Additionally, I-NIGHTS will not be compatible with the quick don mask on the HC-130.

The GEC and Kaiser chinstrap buckles set close to the helmet shell causing difficulty in fastening the strap. Similiarly, the subjects preferred to have the GEC and Kaiser chinstrap buckles on the right side of the helmet, consistent with the HGU-55/P helmet. If a mask is not worn, the visors on all

I-NIGHTS helmets may contact the face, nose and lips, as it rolls forward. All helmets had a tendency to roll forward on the head.

Integration with PFE on the B-52G

Helmet fit and comfort problems were experienced by both subjects. The 50th percentile subject complained of pain on his nose from the Honeywell system which had rolled forward on his head. The 95th percentile subject felt the Kaiser helmet was not on tight enough, however, all straps on the helmet were fastened. Additionally, the 95th percentile subject suggested the Kaiser nape strap be redesigned to keep the helmet from slipping. The 50th percentile subject felt strain on his neck from the weight of the Honeywell system while being evaluated in the second crew station.

Peripheral unaided field of view was affected by the mounting locations of the combiners. Both subjects compensated for reduced vision by looking over, under, or around the side of the combiner assemblies. The 95th percentile subject felt the GEC combiners limited forward and peripheral vision (while he was looking straight forward) and commented that he did not notice the same problem with the Kaiser helmet. The 50th percentile subject felt the Honeywell system limited his field of view. Additionally, while entering the copilot seat, the 95th percentile subject noted distortions in the GEC combiners whenever he looked to the right.

CONCLUSIONS

Slight visor fogging was observed in the environmental chamber; especially at the colder temperature. The fogging did not completely obstruct the subjects' vision and could be easily cleared by maintaining mask seal, or blowing air over the visor by temporarily switching the regulator in emergency setting. Since the helmets are not a closed system as are chemical defense respirators, the likelihood of fogging is minimal. Furthermore, the incidence of fogging could be lessened by using anti-fogging compound or avoiding sudden temperature changes.

Rapid decompression exposures did not damage the helmet shells, optical components (external), or liner materials. Additional tests of the optical system is recommended to ensure that the systems are still operational.

Verification tests on the inversion wheel did not reveal any interferences between the helmet and flight equipment or the ejection seat. Maintaining head stability was difficult due to the weight of the helmets and may be very uncomfortable if inverted for a prolong period. The size of the helmets and the optical components may contact the seat during quick head movements; especially if the combiners on the Honeywell system are stowed.

Hypobaric chamber subjects had difficulty performing one- and two-handed valsalva with the visors lowered and locked. The large size of Honeywell and Kaiser visors set low on the face, covering the valsalva pads on the mask. Similar complaints were made on the GEC visor; however, one subject was able to valsalva by pulling down on the the mask. Although no problems were experienced when the visors were raised, the Honeywell combiners set close to the mask and may interfere with the crewmember's ability to valsalva.

Unaided field of view measurements indicate peripheral vision from the tested helmets (GEC and Honeywell) is less than that afforded by the HGU-55/P helmet. The mounting locations of the combiner assemblies had a significant impact on the field of view, reducing the upward and side peripheral fields by 10-40 deg and 10-35 deg, respectively.

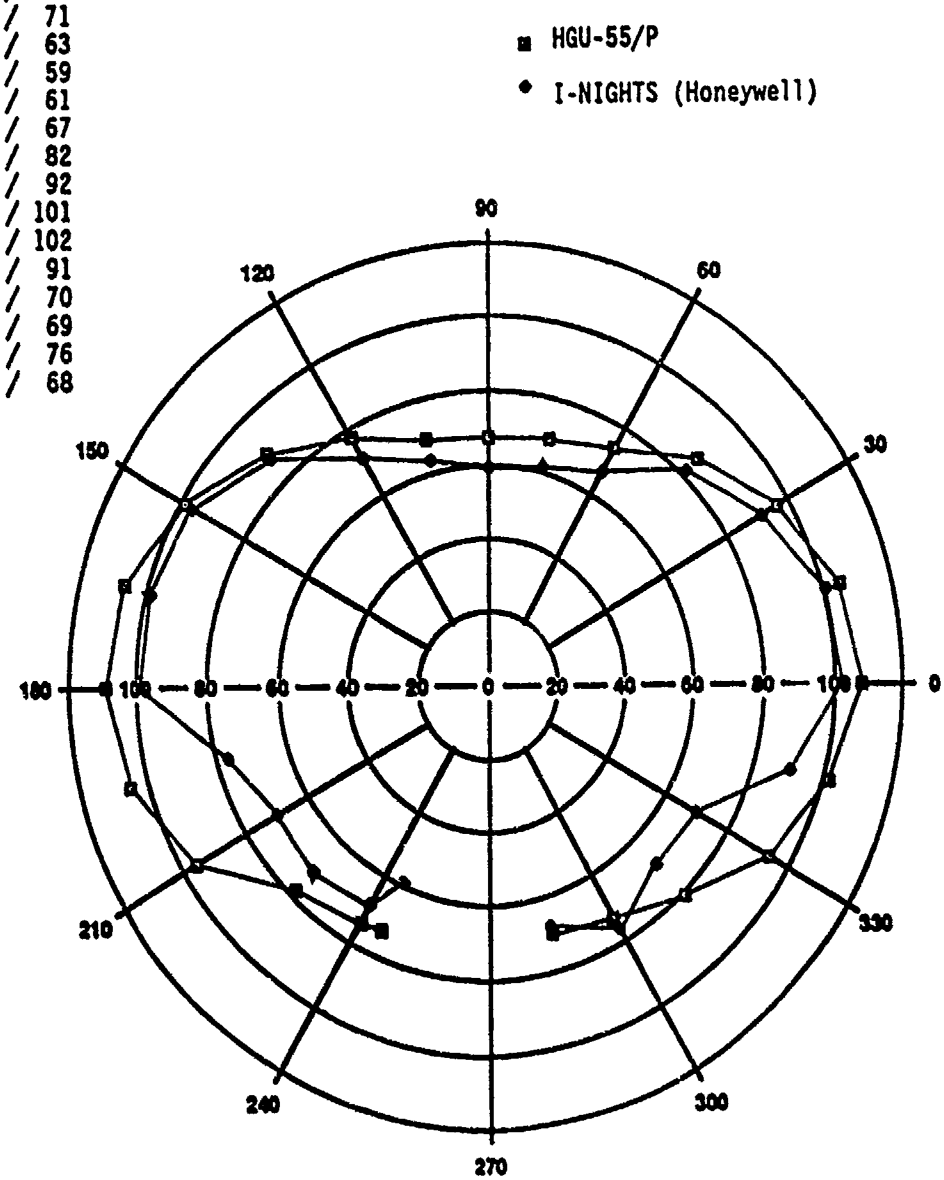
Problems discovered during the integration tests were related to fit, comfort, and vision. In the four aircraft (non-ejection and ejection type) tested the subjects were able to compensate for reduced field of view by looking over, under, or along the sides of the combiner assemblies. Supporting aircrew members stated they prefer to look under the combiners to avoid excessive head movement and lessen neck strain and fatigue. The ability to see under the combiners was difficult with the Honeywell system. Additionally, the poor fit of the systems caused the helmets to roll forward. Helmet slippage was slightly reduced when a mask was worn.

Other comments made included making better, and more functional, nape straps on the Kaiser helmet as well as standardized placement of the chin strap release. Placement of the optics cable will be a problem as well as placement of the battery pack for the Kaiser system. Crewmembers will have to learn to perform one-handed operation of the Honeywell and Kaiser combiners. Furthermore, one-handed operation of the Kaiser visor required additional familiarization with the straps and locking mechanism. The fixed mounting of the GEC combiners may pose a hazard if the crewmember has to move the combiners for better vision. Tinted visors are also required to decrease glare from the combiners during day-to-night operations.

I-NIGHTS Field of View Measurements (Limited Data)

HGU-55/P vs. I-NIGHTS (Honeywell)

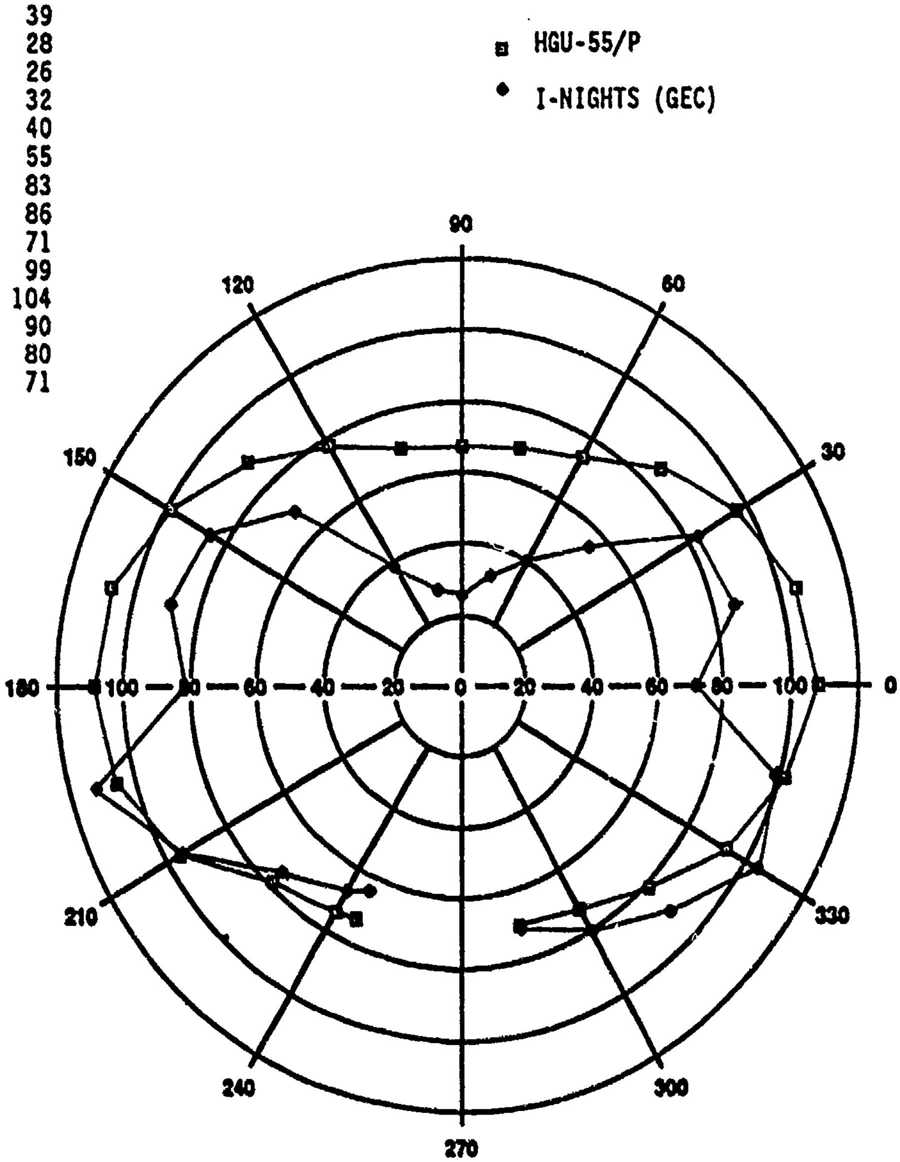
Deg	Measurement (Avg)
245	73 / 59
240	74 / 68
225	78 / 71
210	96 / 70
195	106 / 77
180	109 / 99
165	107 / 99
150	99 / 97
135	89 / 87
120	78 / 71
105	69 / 63
90	67 / 59
75	69 / 61
60	74 / 67
45	86 / 82
30	97 / 92
15	105 / 101
0	108 / 102
345	102 / 91
330	94 / 70
315	81 / 69
300	73 / 76
285	70 / 68



I-NIGHTS Field of View Measurements (Limited Data)

HGU-55/P vs. I-NIGHTS (GEC)

Deg	Measurement (Avg)
245	73 / 64
240	74 / 67
225	78 / 75
210	96 / 95
195	106 / 112
180	109 / 81
165	1C7 / 89
150	99 / 85
135	89 / 69
120	78 / 39
105	69 / 28
90	67 / 26
75	69 / 32
60	74 / 40
45	86 / 55
30	97 / 83
15	105 / 86
0	108 / 71
345	102 / 99
330	94 / 104
315	81 / 90
300	73 / 80
285	70 / 71



DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 3246TH TEST WING (AFSC)
EGLIN AIR FORCE BASE, FLORIDA 32542-5000

REPLY TO
ATTN OF: CC (Mr Lofquest, TZPM, 882-4257)

SUBJECT: Test Directive No. 921AFP05, Interim-Night Integrated Goggle and Head Tracking Systems (I-NIGHTS) Qualification Test

TO:

HSD/YAH-HMST	3246 TESTW/CCU	3246 TESTW/TZ
3246 TESTW/TZF (5)	3246 TESTW/DORF	3246 TESTW/TZPM
AFDTC/SEU (3)	3246 TESTW/DOT	3246 TESTW/TZPT
AFDTC/WE	3246 EMS/MAEA	3246 TESTW/TZSM
3200 SPTW/DW	3246 EMS/MAEM	3246 TESTW/XP
3200 SPTW/LGXP	3246 TESTW/TF (3)	3247 TESTS/DOUD (2)
3200 SPTW/SGP	3246 TESTW/TFOA	3247 TESTS/DOL
3246 TESTW/CA	3246 TESTW/TFOC	3246 TESTS/DOUH

This test has been accepted by the 3246th Test Wing. Implementation action will be taken as specified in the attached test documentation.

RICHARD L. ENGEL, Colonel, USAF
Commander

1 Atch
TD No. 921AFP05

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TZPM (Mr Lofquest, 882-4257) 28 Aug 90

TEST DIRECTIVE NO. 921AFP05

INTERIM-NIGHT INTEGRATED GOGGLE AND HEAD TRACKING SYSTEMS

1. Background Information:

a. Requesting Agency: HSD/YAH-HMST

b. USAF Precedence Rating: 3-06

c. Initial AFDTC Priority: 498

d. Authority:

(1) PMD 2129(7)/63213F, 23 Mar 90

(2) FM 56 2129-09-3692, 17 May 90

e. Description:

(1) The Interim-Nights (I-NIGHTS) helmet design incorporates night vision enhancement capabilities using third generation light intensifier tubes, a helmet tracking provision, a targeting reticle, and modular features for upgrade to a raster/symbology injection capable CRT. The intensified image and targeting reticle is projected onto a transparent combing surface (combiner/visor) to superimpose these images with the real world scene, which is also seen through the combiner/visor. As a result, the pilot is able to view, simultaneously, both the intensified image of the scene outside the cockpit and the aircraft instruments and controls. The system incorporates a user switchable Auto-Scene Reject (ASR) capability which will automatically extinguish the image intensifier tubes whenever the I-NIGHTS forward field of view is within a 4.5 degree arc of a cockpit IR emitter (typically on the Heads-Up Display [HUD].) The impact/penetration protection of the I-NIGHTS should be equivalent or superior to that provided by the HGU-55/P.

(2) This qualification testing will provide data to the program officer for flight safety certification. The test series is a building block test starting with developing don/doff procedures, emergency doff, emergency ground egress, 3 and 12 feet static drop tests, land drags, and land parachute jumps. The water qualification testing will be accomplished later under separate test directive during DT&E. This testing was deferred

(7) Test Design Engineer: Mr L. LeMarchand, 3246 TESTW/TZF, 882-9171

(8) Flight Surgeon: Dr Don Grey, USAF Regn Hosp, Eglin, 3200 SPTW/SGP, 882-5743

b. Test Requester (HSD/YAH):

(1) Acting Program Manager: Lt Karen Cooper, YAH-HMST, AV 785-8416

(2) Test Manager: Mr Ron Gunderman, Ball System Engineering Division, (513) 429-5005/ AV 785-8416

c. Other Key Personnel:

SAM: 1st Lt John Crist, VNL, AV 240-2256

5. Participating Agencies and Responsibilities:

a. The 3246th Test Wing, as the participating test organization, will design and conduct the test, analyze the data, and prepare the final report. The 3246 TESTW/TZF Test Engineer will submit mission requests. (Note: Mission requests will not be submitted until all test hardware/resources are available and allocated to the test or realistic availability/delivery dates have been established.)

b. All AFDTC organizations will support this test according to assigned functional responsibilities. The specific support requirements are outlined in the special planning guidance and attached annexes.

c. The Eglin Radar Control Facility (ERCF) will make available airspace, provide range clearance at the request of the Range Operations Control Center (3246 TESTW/DORS), and provide radar control for test aircraft operations.

d. The HSD/YAH-HMST, as the test requester, will:

(1) Provide funding for all reimbursable direct costs.

(2) Provide sufficient test items of each I-NIGHTS system to conduct the requested testing.

e. The 3246 TESTW/DOL, Life Support Division, will provide:

(1) Test subjects for Qualification Testing.

h. Any organization scheduling VIP visits to observe tests will notify the Test Engineer at least 30 days before the expected visit. The name, rank, organization, and security clearance of each VIP visitor must be furnished not later than 5 working days before the scheduled visit to obtain necessary approvals and site access.

7. Completion/Termination: The procedures for test completion/ termination will be accomplished as outlined in 3246 TESTWR 80-5.

8. Reports: An AFDTC letter report is required 60 working days after completion of active testing. Raw data will be given to the test requester for forwarding to the contractor 5 days after test completion.

9. Security:

a. HAVE HEMP procedures do not apply to this test.

b. Operations Security (OPSEC) has been considered according to AFR 55-30/AFSC Sup 1 and AFDTC Sup 1. The overall classification of this test is unclassified and, although no special OPSEC precautions have been identified by the test requester, all participating organizations are cautioned to exercise stringent OPSEC precautions on all aspects of the conduct of their tasks.

c. No special communications security (COMSEC) precautions have been identified or deemed necessary in the planning and conduct of this test.

e. Security Classification Guidance is not identified for this laboratory program.

Charles Lofquest

CHARLES A. LOFQUEST
Programming Engineer

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1. Method of Test Annex
2. Technical Support Annex
3. Logistics Annex
4. Safety Annex

TD ANNEX A

METHOD OF TEST

TEST DIRECTIVE 921AFP05

Interim-Night Integrated Goggle and Head Tracking System

(I-NIGHTS) Qualification Test

1. INTRODUCTION.

1.1 Background.

1.1.1 The Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) is being developed as part of PE 63231F, Crew Systems and Personnel Protection Technology, Project 3257, Virtual Image Cockpit. Command requirements being supported are SAC SON 309-087 and TAC SORD 312-88-1-A. HSD/YAH is the Test Requester and AFDTC/3246th Test Wing is the PTO.

1.1.2 Qualification testing will be used to produce safety of flight certification.

1.2 Test Objectives.

1.2.1 Demonstrate each candidate system with regard to aircrew survivability during emergency ground egress, parachute deployment, parachute descent, land impact, and during the situation when the test subject is dragged by the parachute.

1.2.2 Collect data on electromagnetic interference/electromagnetic compatibility (EMI/EMC).

1.2.3 Evaluate the ability of the I-NIGHTS disconnect to pass the explosive atmospheric environmental tests in accordance with MIL-STD-810D.

2. TEST ITEM DESCRIPTION. The I-NIGHTS helmet design incorporates night vision enhancement capabilities using third generation light intensifier tubes, a helmet tracking provision, a targeting reticle, and modular features for upgrade to a raster/symbology injection capable CRT. The intensified image and targeting reticle is projected onto a transparent combining surface (combiner/visor) to superimpose these images with the real world scene, which is also seen through the combiner/visor. As a result, the pilot is able to view, simultaneously, both the intensified image of the scene outside the cockpit and the aircraft instruments and controls. The system incorporates a user switchable Auto-Scene Reject (ASR) capability which will automatically extinguish the image intensifier tubes whenever the I-NIGHTS forward field of view is within a 4.5 degree arc of a cockpit IR emitter (typically on the

Test	Testing Organization
1. Wind Blast Tests (Required prior to jumps)	Dayton T. Brown
2. Vision Testing	USAFSAM/(NGOP), Brooks AFB TX
3. Ejection Tower	NADC Warminster PA

4.1.2.4 Procedure 1. Emergency ground egress must be achievable in a reasonable period of time IAW applicable T.O.'s from selected crew stations of representative aircraft to be evaluated during the flight DT&E. The test subjects will be trained life support/survival personnel who will be wearing each of the candidate systems along with representative gear to be worn during the flight DT&E. The ground emergency procedures, as defined in the -1 tech order for each aircraft, will be followed. This portion of the test may be performed in conjunction with USAFSAM/VNL (Brooks AFB) at various locations as the class II mods are installed in the various aircraft.

4.1.2.4.1 Data Required.

4.1.2.4.1.1 A record of all procedures which could/could not be accomplished during ground emergency egress trials or any changes in procedures which would permit a safe emergency egress.

4.1.2.4.1.2 A record of time to accomplish ground emergency egress during each trial.

4.1.2.4.1.3 Video coverage of all ground emergency egress trials, when possible.

4.1.2.4.2 Data Analysis. 3246th Test Wing personnel will review the video tapes, the record of procedures accomplished, and trial times to assess the effect of each system on emergency ground egress.

4.1.2.5 Procedure 2. Test subjects will don each candidate system with representative life support and flight gear for each aircraft to be flown during the flight DT&E. Each person will be suspended above the ground by the parachute risers and will complete post egress procedures according to T.O. 14D1-2-1, change 13, page 3-25. Static drops from distances of 3 and 12 feet will also be accomplished to evaluate the possibility of any part of the system making contact with the test subject's face.

4.1.2.5.1 Data Required.

4.1.2.5.1.1 A record of all post egress procedures (T.O. 14D1-2-1, change 13, page 3-25) which could/could not be accomplished and any changes in procedures.

4.1.2.5.1.2 A record of time to accomplish the post egress procedures.

4.1.2.7.3 Data Required.

4.1.2.7.3.1 Video coverage of jumps using a second jumper wearing a helmet-mounted video camera.

4.1.2.7.3.2 Ground video or 16mm/35mm coverage of landings.

4.1.2.7.3.3 A record of all problems encountered during the jumps, such as visual obstructions and difficulty in completing post-egress procedures.

4.1.2.7.4 Data Analysis. 3246th Test Wing personnel, test parachutists, and parachute technicians will analyze the data to assess the effects of each candidate system on post egress. If problems are encountered during the test trials, more jumps may be required.

4.1.2.8 Potential Hazards. The potential hazards are those normally associated with the flight testing of experimental helmets with the added weight and test hardware as described in paragraph 2.

4.1.3 Criteria. If the candidate I-NIGHTS system causes no interference with the ability of the test subject to conduct existing Technical Order procedures, or interference with the proper operation of the existing aircrew equipment, it will pass. If the system interferes with the proper operation of any existing equipment or the test subjects ability to perform egress or post-egress Technical Order procedure, the system will fail.

4.2 Objective 1.2.2. Collect data on electromagnetic interference/electromagnetic compatibility (EMI/EMC).

4.2.1 Purpose. The purpose of this objective is to report any EMI/EMC interference caused by the system.

4.2.2 Method. A limited EMI/EMC check with the aircraft avionics system will be conducted. All aircraft avionics systems will be sequentially operated while the system is on. Standard aircraft checklist will be used to operate the systems.

4.2.3 Criteria If there is no interference while the I-NIGHTS system is on, the system will pass. If there is interference while the system is on and the interference remains after the system is turned off, it will be a no test. If there is interference with the avionics system only when the I-NIGHTS system is on, it will be a failure.

4.2.4 Resources Required.

4.2.4.1 I-NIGHT System.

4.2.4.2 EMI/EMC checklist.

4.2.5 Data Required.

4.2.5.1 Crewmembers comments.

PREPARED BY:

LUCIEN LeMARCHAND
Test Design Engineer/TZF

COORDINATED WITH:

JOSEPH F. BRIGANTI, Lt Col, USAF
Chief, Munitions Test Division

COORDINATED WITH:

WILLIAM J. SWANK
Chief, Chem Def & Munitions Support

COORDINATED WITH:

RONALD H. ALLEN
Technical Advisor

COORDINATED WITH:

JOHN D. DAVIS, Capt, USAF
3246 TESTW/DOSP

APPROVED BY:

H. DOUGLAS NATION, Technical Advisor
Deputate for Test Engineering

3246 TESTW/TZPT (Mr Sodoma, 882-4851) 21 August 1990

TECHNICAL SUPPORT ANNEX

TEST DIRECTIVE NO. 921AFP05

INTERIM - NIGHT INTEGRATED GOGGLE AND HEAD TRACKING SYSTEM (I-NIGHTS)

QUALIFICATION TEST SUPPORT

1. General. The I-NIGHTS helmet design incorporates night vision enhancement capabilities, a helmet target tracking provision, a targeting reticle and other enhancement features. Up to three candidate systems will undergo qualification testing to demonstrate each system with regard to aircrew survivability, collect data on EMI/EMC and to evaluate the ability of the I-NIGHTS disconnect to pass the explosive atmosphere environmental test. To support the survivability egress testing, the I-NIGHTS, Class II modification will be installed in a number of different aircraft. Testing will be accomplished at Eglin and at various other locations where the Class II modifications have been installed. This will require TDY by support elements from Eglin. Support is required from the Range O&M Contractor, and the Photographic Laboratory Contractor.

2. Support Requirements and Responsibilities.

a. Range Contractor. The Range O&M Contractor will:

(1) Provide and operate the Test Area A-24 Fuze Test Facility to conduct an explosive atmosphere test of the I-NIGHTS disconnect in accordance with Method 511.2, Procedure I of MIL-STD-810D. A suitable fixture and the necessary techniques must be developed for remote operation of the disconnect. The power required through the disconnect and the pin connections are yet to be defined, however, the power is believed to be standard aircraft power. Where possible, provide time correlated 16mm color motion picture coverage (96 frames per second) of the disconnect test.

(2) Provide central timing facility operation in support of high speed camera operations.

b. Photographic Support. The Photographic Laboratory Contractor will provide photographic (still and motion picture) and video documentary support for all phases of the aircrew survivability testing which includes emergency ground egress, parachute deployment and descent, land impact and ground drag testing. The aircrew survivability testing will be conducted at Eglin and at up to three off-Eglin locations which will require TDY support by as many as two people. Separate tasking will be provided through TFOA when the TDY details are known. Support required is as follows:

(1) Video coverage of all ground emergency egress trials

(2) Video coverage of live static drops

LGXP (Ms Daniels, 882-3535) 20 August 1990

LOGISTICS ANNEX

TEST DIRECTIVE JON 921AFP05

INTERIM-NIGHT INTEGRATED GOGGLE AND HEAD TRACKING SYSTEMS

1. General: This annex identifies the logistics support required to conduct subject test and tasks responsible organizations for their support. The estimated test start date is 23 Aug 90.

2. Aircraft:

OWNING COMMAND	TYPE/SERIAL NO.	SORTIES	FLYING HOURS
Test Bed:			
AFSC/AFDTC	UH-1N/Any	10	15

3. MAEMFE, Parachute Shop will provide space to repack/repair parachute recovery system as required. POC is in Bldg 32, 882-2640.

4. Medical:

a. The AFSC Regional Hospital (SGA) will furnish emergency hospital and ambulance support as provided for in AFR 168-6. The phone number for emergency ambulance service is 882-2333. On site standby medical support (ambulance and medical technician) will also be required at Sites C-61 and B-6.

b. The test engineer, Lt Nagel, 882-4322, will:

(1) Provide hospital personnel with the dates and the location at least 24 hours prior to when their support is required.

(2) Submit RESOMS Part A to request this support.

Brenda Daniels
BRENDA DANIELS
Logistics Management Specialist
Logistics Plans Office

David Wheeler
DAVID WHEELER
Chief, Logistics Plans Office
Deputy Commander for Resources

SAFETY ANNEX
TEST DIRECTIVE NO. 921AFP05
INTERIM-NIGHT INTEGRATED GOGGLE AND HEAD TRACKING SYSTEMS

1. The following safety criteria have been established for the conduct of the Interim-Night Integrated Goggle and Head Tracking Systems (I-NIGHTS) test.

2. Test Item and Test Areas.

a. The test item is a helmet mounted night vision device. Three separate designs will be tested.

b. Static drops will be conducted at the life support facility. Drag tests will be conducted behind the Eglin hospital. Live jumps will be conducted on C-61 or TAB 6. Explosive atmosphere tests will be conducted at the Fuze Facility.

3. Danger Area. There are no danger areas associated with this test. During EMI/EMC testing a RF hazard area may be established for operation of onboard aircraft equipment. The hazard area for this equipment is established in the dash -1 T.O.

4. Potential Hazards. A Hazard Review Board (HRB) was conducted for this test to identify the potential hazards and high interest areas. Results of this meeting are contained in the Hazard Analysis Summary (HAS) which is filed in the project folder at 3246 TESTW/TZFC, 3247 TESTS/DOUH and AFDTC/SE. No unacceptable hazards were identified.

5. Safety Requirements.

a. Parachute tests with live personnel will not be conducted until AMRL mannequin tests have been completed and analysis indicates that an adequate degree of safety exists.

b. Parachute tests and drag tests will not be conducted until mannequin tests have established that the helmet mounted test items will not hang up on the parachute.

Prepared by:	Approved by:
RALPH H. REED	WILLIAM B. COLLINS
Directorate of Range Safety	Associate Deputy for Safety

INTERIM-NIGHT INTEGRATED GOGGLE AND HEAD TRACKING SYSTEM (I-NIGHTS)

DATA PACKAGE 91-5

6 JANUARY 1992

MARY WARD
3246 TEST WING/EAFG
EGLIN AIR FORCE BASE, FLORIDA

INTRODUCTION

BACKGROUND

Human Systems Division, Crew Systems and Personnel Protection Technology (HSD/YAH), requested the Munitions Test Division (3246TW/EAFG) to conduct qualification tests to certify that the Interim Night Integrated Goggle Head Tracking System (I-NIGHTS), is safe to fly. Testing began July 1990 and ended May 91. As the Participating Test Organization (PTO), personnel responsible for planning, testing, and report preparation were: Lt Bob Fox (Test Engineer), Mr Bill Beier (Test Support Manager, ISN Corporation), Mr Kelly Oliver (Program Engineer), and Mr Lucien LeMarchand (Test Designer).

TEST OBJECTIVES

1. Collect data on the demonstration of each I-NIGHTS candidate system with regard to aircrew survivability during emergency ground egress, parachute deployment, parachute descent, landing impact, and when the test subject is dragged by the parachute.

2. Collect data on electromagnetic interference/electromagnetic compatibility (EMI/EMC).

3. Evaluate the ability of the I-NIGHTS power connector to pass explosive atmosphere testing in accordance with MIL-STD-810C.

Only one objective, Objective 2, was completed. The necessity for testing Objective 3 was deleted by the test requester since the vendors were already on contract to perform this test. Emergency ground egress, aircraft compatibility, and parachute hanging harness testing were completed as part of Objective 1; however, the remaining tests in Objective 1 were not accomplished due to safety considerations.

TEST ITEM DESCRIPTION

The I-NIGHTS design incorporates night vision enhancement capabilities using third generation light intensifier tubes, a helmet tracking provision, a targeting reticle, and modular features for upgrade to a raster symbology injection capable cathode ray tube (CRT). The intensified image and targeting are projected into a transparent combining surface (combiner). As a result, the pilot is able to simultaneously view both the intensified image of the scene outside the cockpit and the aircraft instruments and controls. The I-NIGHTS incorporates a user controlled Auto-Scene Reject capability which deactivates the image intensifier tubes when the forward field-of-view of the I-NIGHTS is within a 4.5 degree arc of a cockpit Infrared (IR) emitter. This emitter is typically located on the Heads-Up Display (HUD).

There are three vendors for the I-NIGHTS helmets: GEC Avionics, Honeywell, and Kaiser Electronics. The basic elements in each of the systems are the same.

INSTRUMENTATION

The only instrumentation used for this testing consisted of videotape and still photo coverage.

TEST PROCEDURES

AIRCRAFT COMPATIBILITY (OBJECTIVE 1)

Tests were conducted in the A-10 and F-16 simulators and the following aircraft: B-52G, HC-130H, MH-53J and MH-60G to determine if the aircrew could perform their assigned duties while wearing the I-NIGHTS. Test subjects wearing the I-NIGHTS were seated in the assigned position while evaluations were made to determine restrictions in the range of motion and line of sight caused by the I-NIGHTS. These tests were conducted concurrently with emergency egress; therefore, mock-up helmets were used.

EMERGENCY GROUND EGRESS (OBJECTIVE 1)

Tests were performed to determine if an aircrew member wearing the I-NIGHTS could safely egress from the aircraft during a ground emergency using the aircraft dash one emergency procedures. Test subjects wearing the I-NIGHTS in the Helmet Mounted Display (HMD) configuration and the standard aircrew equipment (i.e. survival vest, parachute harness, oxygen mask) were strapped into position and performed emergency ground egress from the simulator/aircraft. Tests were conducted in the HMD configuration since this was deemed the worse case scenario. Due to the destructive nature of the emergency ground egress tests, weight and space mock-up helmets were used for these tests also. Emergency ground egress was performed in the following aircraft/simulators: HC-130, B-52, MH-53, MH-60, and F-16. Typical pass/fail criteria for egress times of fielded equipment is 18 seconds or less for fighter aircraft and 60 seconds or less for non-fighter aircraft.

HANGING HARNESS (OBJECTIVE 1)

Demonstrations were conducted to ensure test subjects could perform post parachute opening procedures as described in T.O. 14D1-2-1 while wearing the I-NIGHTS helmets. Fifth and 50th percentile test subjects, wearing mock-up I-NIGHTS helmets, were suspended from the hanging harness apparatus and performed the following procedures for over land descent to ensure no obstructions existed:

a. Check canopy

b. Visor up and locked

c. Discard oxygen mask

d. Deploy survival kit

e. Pull four-line jettison lanyards

After the above procedures were verified, the following conditions were demonstrated and checked: landing position for going into trees, landing position for going into power lines, and correcting certain malfunctions with the parachute.

ELECTROMAGNETIC COMPATIBILITY/INTERFERENCE (OBJECTIVE 2)

Each test aircraft was towed to an isolated area and aimed away from all field lighting. An initial check was performed on the aircraft electrical system with the I-NIGHTS helmet turned off to ensure no interferences were present. The I-NIGHTS was then turned on and the test subjects monitored both the performance of the I-NIGHTS and the aircraft electrical system to determine if any interference was present. For each specific aircraft, many different aircraft systems were tested to ensure that they were functioning properly. The following aircraft were tested: B-52G, HC-130H, MH-53J, and MH-60G.

TEST RESULTS AND DISCUSSION

AIRCRAFT COMPATIBILITY (OBJECTIVE 1)

A-10 SIMULATOR (BROOKS AFB, TX)

A 50th percentile test subject wore both the GEC and Kaiser candidate I-NIGHTS helmets in the A-10 simulator. Although there was no serious range of motion degradation with either helmet, "checking six" with both helmets required an increased amount of effort. While wearing either the GEC or the Kaiser system, the test subject was able to see all the aircraft controls with a minimal amount of extra head movement. The Honeywell system was not tested due to non-availability.

B-52G (EAKER AFB, AR)

There was no serious range of motion degradation while the 50th percentile test subject wore the GEC, Honeywell, and Kaiser systems. While wearing each of the three systems, the test subject was able to see all aircraft controls with minimal additional head movement.

F-16 SIMULATOR (BROOKS AFB, TX)

There was no serious range of motion degradation when the 50th percentile test subject wore any of the three systems. However, additional effort was required by the test subject to check the six o'clock position. The test subject was able to see all the aircraft controls with minimal extra head movement while wearing each of the three systems.

HC-130H (EGLIN AFB, FL)

There was no serious range of motion degradation when the 50th percentile test subject wore any of the three systems. The test subject was able to see all the aircraft controls with minimal extra head movement while wearing each of the three systems.

MH-53J (PENSACOLA NAS, FL)

There was no serious range of motion degradation when the 50th percentile test subject wore any of the three systems. The test subject was able to see all the aircraft controls with minimal extra head movement while wearing each of the three systems.

MH-60G (PENSACOLA NAS, FL)

There was no serious range of motion degradation when the 50th percentile test subject wore any of the three systems. The test subject was able to see all the aircraft controls with minimal extra head movement while wearing each of the three systems.

EMERGENCY GROUND EGRESS (OBJECTIVE 1)

B-52G (EAKER AFB, AR)

There were no interferences noted during the emergency egress testing in the B-52. The egress times are noted below.

POSITION	HELMET	PERCENTILE	EGRESS TIME (sec)	PASS/FAIL
PILOT	GEC	95	21.8	PASS
	HONEYWELL	50	34.9	PASS
	KAISER	95	21.1	PASS
CO-PILOT	GEC	95	22.7	PASS
	HONEYWELL	50	27.7	PASS
	KAISER	95	23.1	PASS

F-16 SIMULATOR (BROOKS AFB, TX)

The egress time for the 50th percentile test subject wearing the GEC system was 20.5 seconds. There were two minor entanglements noted during this egress: one with the CRT cable and the seat straps and one involving the CRT cable and the oxygen hose. Neither of these entanglements caused any real problems since in both cases the CRT cable pulled loose during normal egress procedures without requiring any additional effort.

The 50th percentile subject was not able to egress from the simulator while wearing the Honeywell system. The connector for one of the CRT cables had slipped down and was caught between the seat and the right-hand console. This probably would not have occurred if the cable had actually been connected to the aircraft.

While wearing the Kaiser system, the 50th percentile test subject exited the simulator in 21.4 seconds. The two CRT cables became entangled with the oxygen hose during egress. This was not a major problem as the cables became untangled during egress without any additional effort.

The emergency egress times noted during this testing were a few seconds longer than the common 18 seconds maximum due to CRT cable entanglements. In order to rectify this entanglement problem, the program office has since designed a protective shroud which covers the power cable, connector, and associated quick release lanyard. This design change, in addition to egress training, should reduce the egress time of the the crew member wearing I-NIGHTS so that it is within the 18 seconds maximum. However, during flight testing, ground egress should be monitored to ensure that the pilot can egress in a timely manner.

HC-130H (EGLIN AFB, FL)

There were no interferences noted during the emergency egress testing in the HC-130H and the egress times are noted below.

POSITION	HELMET	PERCENTILE	EGRESS TIME (sec)	PASS/FAIL
PILOT	GEC	5th	12.2	PASS
	HONEYWELL	5th	11.2	PASS
	KAISER	5th	7.1	PASS
	GEC	50th	7.0	PASS
	HONEYWELL	50th	7.0	PASS
	KAISER	50th	7.0	PASS
	GEC	95th	9.6	PASS
	HONEYWELL	95th	9.0	PASS
	KAISER	95th	8.0	PASS
CO-PILOT	GEC	5th	15.4	PASS
	HONEYWELL	5th	15.7	PASS
	KAISER	5th	11.6	PASS
	GEC	50th	12.0	PASS
	HONEYWELL	50th	11.2	PASS
	KAISER	50th	11.0	PASS
	GEC	95th	13.5	PASS
	HONEYWELL	95th	13.0	PASS
	KAISER	95th	12.5	PASS

MH-53J (PENSACOLA NAS, FL)

An area of concern was found during egress with the GEC system where the visor housing made contact with the overhead rails during window exits. The test subjects were able to compensate for this problem and exit in a timely manner. There were no interferences noted during the emergency egress testing in the MH-53J with the HONEYWELL and KAISER systems. The egress times are noted below.

POSITION	HELMET	PERCENTILE	EGRESS TIME (sec)	PASS/FAIL
PILOT	GEC	5th	8.0	PASS
	HONEYWELL	5th	7.9	PASS
	KAISER	5th	7.2	PASS
	GEC	50th	7.2	PASS
	HONEYWELL	50th	7.9	PASS
	KAISER	50th	7.5	PASS
	GEC	95th	7.4	PASS
	HONEYWELL	95th	5.9	PASS
	KAISER	95th	6.2	PASS
CO-PILOT	GEC	5th	11.2	PASS
	HONEYWELL	5th	10.5	PASS
	KAISER	50th	12.5	PASS
	GEC	50th	9.3	PASS
	HONEYWELL	50th	9.6	PASS
	KAISER	50th	10.0	PASS
	GEC	95th	11.2	PASS
	HONEYWELL	95th	11.3	PASS
	KAISER	95th	11.3	PASS

MH-60G (PENSACOLA NAS, FL)

The SPO requested that we demonstrate egress times on a Night Vision Systems (NVS) helmet, the MERLIN, during this series of testing. No additional reporting (other than egress times) was requested on the MERLIN system. An area of concern was found during egress with the GEC system where the visor housing made contact with the overhead rails during window exits. The test subjects were able to compensate for this problem and exit in a timely manner. There were no interferences noted during the emergency egress testing in the MH-60G with the HONEYWELL, MERLIN, and KAISER systems. The egress times are noted below.

POSITION	HELMET	PERCENTILE	EGRESS TIME (sec)	PASS/FAIL
PILOT	GEC	5th	6.3	PASS
	HONEYWELL	5th	7.1	PASS
	KAISER	5th	7.3	PASS
	GEC	50th	4.2	PASS
	HONEYWELL	50th	4.3	PASS
	KAISER	50th	5.0	PASS
	MERLIN	50th	5.0	PASS
	GEC	95th	5.3	PASS
	HONEYWELL	95th	5.4	PASS
	KAISER	95th	6.2	PASS
	MERLIN	95th	6.3	PASS
CO-PILOT	GEC	5th	6.2	PASS
	HONEYWELL	5th	8.3	PASS
	KAISER	5th	6.3	PASS
	GEC	50th	6.0	PASS
	HONEYWELL	50th	5.3	PASS
	KAISER	50th	5.2	PASS
	MERLIN	50th	6.1	PASS

GEC	95th	5.1	PASS
HONEYWELL	95th	5.4	PASS
KAISER	95th	6.0	PASS
MERLIN	95th	6.2	PASS

HANGING HARNESS (OBJECTIVE 1)

The primary concern discovered while demonstrating this part of the objective was parachute riser interference during the initial snatch force of the deploying parachute. This was noted when the test subjects (5th and 50th percentile) were suspended from the hanging harness apparatus and it was apparent that the risers were making contact with the CRTs. This interference could result in a violent head twist and/or neck snap. Another concern was identified with the 5th percentile test subject. Due to the narrow torso of this size of subject, the risers were inset to an extreme such that the subject was forced to separate them manually to view above. This is a concern for two reasons. First, if riser twisting occurs during opening shock of the parachute, the aircrew member may not be able to correct this condition prior to ground impact. This twisting could cause spinning of the parachute and result in an unstable, uncontrollable condition. Second, having to manually separate the risers while wearing the I-NIGHTS to view above would become exhaustive for the aircrew member.

PARACHUTE DESCENT/PARACHUTE LANDING/PARACHUTE DRAGS (OBJECTIVE 1)

These tests were not accomplished due to the potential for injury that could be caused by unknown loadings on the head/neck during parachute opening shock.

ELECTROMAGNETIC INTERFERENCE/COMPATIBILITY (OBJECTIVE 2)

B-52G (EAKER AFB, AR)

There were not any compatibility or interference problems identified when aircraft No. 0499 was tested in accordance with the test procedures. The following aircraft systems were checked to ensure that they operated properly:

AIC-10 Interphone
ARC-50 HF radio (2 to 30 MHz)
ARC-164 UHF communication radio (225 to 399.975 MHz)
ARN-14 VHF nav radio (108.0 to 111.8 MHz)
ARN-31 glide path radio (331 to 334.7 MHz)
ARN-32 marker beacon (75 MHz)

ARN-118 TACAN (1 GHz)
ASC-19 AFSATCOM (173.045, 243.045 MHz)
APX-64 AIMS (1 GHz)
APN-69 radio beacon (10 GHz)
ALR-20 ECM receiver
ALQ-155 ECM systems 1 through 8, 13, 14
ALQ-153 TWS
ALQ-122 ECM systems 9 and 12
ALQ-117 ECM systems 15 and 16
ASG-15 FCS
ASG-21 FCS
ASQ-151 EVS
Master Expendables Control Panel (MECP)
A/A42G-11 autopilot
Stability Augmentation System (SAS)
AC voltmeter
AC ammeters
Engine oil pressure indicators
Engine oil temperature indicators
Engine pressure ratio indicators
Engine speed indicators

HC-130H (EGLIN AFB, FL)

There were not any compatibility or interference problems identified when aircraft No.2639 was tested in accordance with the test procedures. The following aircraft systems were checked to ensure that they operated properly:

AN/AIC-18A intercom
HF-102 liaison radio
VHF-FM-AN/ARC-186 VHF/FM radio
VHF-AM-AN/ARC-186 VHF command radio
AN/ARC-164 UHF 1 command radio
AN/ARC-164 UHF 2 command system
AN/ARC-164 UHF 3 SATCOM system
AN/ARA-50 direction finder
AN/ARN-118 TACAN
AN/ARN-147 VOR receiver
AN/ARN-6 radio compass
Collins 51Z-4A marker beacon receiver
Collins 51V-4 glide slope receiver
AN/APN-171 radar altimeter
Flight director system
AN/APX-64, 72 AIMS IFF
AN/APN-147 Doppler radar navigation system
AN/ASN-35 Doppler computer system
AN/APN-59B search radar
C-12 compass system
A24G-1A gyro attitude reference system
AN/ASN-90 inertial measuring system

ARN-131 Omega Nav
B-6A Driftmeter

MH-53J (PENSACOLA NAS, FL)

There were not any compatibility or interference problems identified when aircraft #0241 was tested in accordance with the test procedures. The following aircraft systems were checked to ensure that they operated properly:

AN/AIC-133 intercom system
AN/AIC-13 public add. system
AN/UIH-5 loudhailer system
AN/ARC-34, -133 UHF comm. sys.
HF-186/VHF-101 VHF comm. system
HF-103 HF comm system
VHF-AN/ARC-186 FM radio set
AN/ARA-25A UHF D.F.
AN/ARA-59 LF auto D.F.
AN/ARN-65 TACAN 118
VOR-101 omni nav. system
AN/ARN-58 ILS marker beacon
AN/APN-175 radar nav. set
AN/APX-64 IFF
ALR-69 RHAW, RWR
AN/ARD-21 ELF
QRC 83-05 IRCM 157
AN/APN-171 radar altimeter
ISN ENS
J-10 compass system

MH-60G (Pensacola NAS, FL)

There were not any compatibility or interference problems identified when aircraft No. 4472 was tested in accordance with the test procedures. The following aircraft systems were checked to ensure that they operated properly:

AN/AIC-133 intercom system
AN/AIC-13 public add. system
AN/UIH-5 loudhailer system
AN/ARC-34, -133, -164 UHF comm. sys.
URC-108 SATCOM
VHF-186/101 VHF comm. system
ARC-199 HF comm. system
VHF-AN/ARC-186 FM radio set
VHF-AN/ARC-117
AN/ARA-25A UHF D.F.
AN/ARA-59 LF auto D.F.
AN/ARN-65 TACAN 118
AN/APN-175 radar nav. set

AN/APX-64 IFF
AN/APN-171 radar altimeter
ALR-69 RHAW, RWR
ASN-128 INS GPS/Doppler
ASN-43, J-10 Compass Sys/Gyro
FLIR
KG-10 Map display
Bendix 1400 Wx radar

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APPENDIX E
ACOUSTICAL PROPERTIES

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APPENDIX E: ACOUSTICAL PROPERTIES: SOUND ATTENUATI' ' AND SPEECH INTELLIGIBILITY

1. INTRODUCTION

The high levels of noise present in the cockpits of military aircraft may threaten voice communications effectiveness and pose a risk to the hearing of the aircrews. Conventional flight helmets typically provide adequate sound protection to ensure aircrew safety and performance. However, these acoustic characteristics of helmets may be altered by the addition and integration of external systems such as night vision goggles (NVG). This report describes a laboratory evaluation of the noise exclusion properties and the voice communications performance of three integrated NVG helmets which were manufactured by GEC, Honeywell, and Kaiser. These evaluations were accomplished by the Bioacoustics and Biocommunications Branch, Biodynamics and Biocommunications Division, Armstrong Laboratory, located at Wright-Patterson AFB, Ohio.

2. APPROACH

The sound attenuation of the NVG helmets worn by trained subjects was measured in the Sound Protection Measurement Laboratory in accordance with an established American National Standards Institute (ANSI) procedure. The criterion measure was sound attenuation in decibels (dB). The voice communications of volunteer subjects wearing the NVG helmets were measured in relative quiet and in three levels of emulated operational aircraft noise. Volunteers performed as talkers and as listeners under the same noise conditions using standardized speech intelligibility materials. Criterion measures were percent correct responses of the intelligibility measures.

3. OBJECTIVE

The objectives of the study were to define the sound attenuation and to quantify the voice communications performance characteristics of the individual integrated NVG helmets in emulated operational aircraft cockpit noise environs.

TEST PLAN

I-NIGHTS GROUND SAFETY TESTS

SOUND ATTENUATION AND SPEECH INTELLIGIBILITY

MARCH 6, 1990

PREPARED BY:

Mark A. Ericson

MARK A. ERICSON (BBA)

BRANCH APPROVAL (BBA) Charles W Nixon

DIVISION APPROVAL (BB) James W. Brinkley

I-NIGHTS NVG SOUND ATTENUATION AND SPEECH INTELLIGIBILITY

1. Experimental Test Planning Documentation.

a. Test Objective and Purpose.

The objectives of these tests are to measure the hearing protection and voice communication performance of night vision goggles (NVG) headsets from three competing manufacturers. The purposes of the tests are to (a) determine if the headsets meet the hearing protection requirements of MIL-P-38268C and (b) quantitatively measure the intelligibility to estimate the operational performance of the headsets.

b. Experimental Design.

1. Sound Attenuation.

Hearing protector attenuation is measured in accordance with the specific guidelines established by ANSI standard S12.6-1984, Method for the Measurement of Real-Ear Attenuation of Hearing Protectors. The study design of this method is a repeated measures design with each of 10 subjects participating three times in the control condition (open or unoccluded ears) and three times in the test condition (occluded ears, while the device is being worn) at each of nine test signals, for each of the three manufacturers' NVG helmets. The test signals consist of third octave bands of noise with center frequencies at the octave band center frequencies from 125 Hz to 8000 Hz. The experimental design is displayed in Appendix A.

A trial includes measurement of the subject's hearing threshold levels at the nine test signals for an occluded ear condition (subjects wearing the NVG) and an unoccluded ear condition. Each session consists of three trials or three sets of data for each test signal.

Data for each of the three NVG helmets are tabulated and processed to provide means and standard deviations of the attenuation for each test signal. The attenuation or the amount of hearing protection measured is defined as the arithmetic difference between the unoccluded and occluded hearing threshold levels. The Air Force reduces the mean attenuation values by two standard deviations to include 97.72% of the wearers to compensate for variability associated with such factors as fit and head size. Thereby, the actual hearing protector performance in operational noise environs is estimated. The octave band attenuation values ($\bar{x}$ - 2 S.D.) of a device are subtracted from the octave band levels of the noise in which it will be used to determine the octave band noise level under the device. The octave band attenuation data are also used to develop a single number attenuation value that is subtracted from the A-weighted sound level of the noise in which the device may be used to determine the level at the ear. Both the octave band and single number methods are described in AFR 161-35, Hazardous Noise Exposure.

2. Speech Intelligibility.

The speech intelligibility testing employs a balanced, round robin design. Each subject participates as both talker and listener at each of the four noise levels with each of the three NVG being assessed. Experimental conditions are randomized to minimize any possible order effect. The criterion measure is speech intelligibility as measured by the Modified Rhyme Test (MRT) (ANSI S3.2, 1989). The experimental design of all trials is shown in appendix B based on two panels of six subjects each, four noise levels (75, 95, 105 and 115 dB) and three different models of night vision goggles. A total of 144 trials, 48 for each contractor, will be conducted.

c. <u>Experimental Procedures</u>.

1. Sound Attenuation.

The threshold of hearing is measured using the Bekesy tracking method, where the subject continuously changes the level of each test sound from audibility to inaudibility over a period of about 30 seconds. The average of the levels recorded during this period is the hearing threshold. Two subjects alternately participate (one rests while the other tests) in three trials per session with one test session in the morning and one in the afternoon. Ten subjects are scheduled to participate providing a total of 30 measurements to complete the evaluation. Each subject evaluates only one helmet system from each manufacturer per day.

Measurement of the hearing thresholds is fully automated under the control of a personal computer (PC). Once the trial begins, the stimuli are presented sequentially to the subjects, whose responses are stored by the PC for later analysis. Calibration of the total measurement system is also accomplished through the PC prior to the initiation of data collection.

2. Speech Intelligibility.

The speech intelligibility measure is the Modified Rhyme Test, as described in ANSI S3.2-1989, which is simultaneously administered to six subjects over individual listening stations. Each station contains visual displays of the appropriate stimuli and various buttons for recording the responses of the subjects, which are also stored for later analysis. The experimenter monitors subject performance and the experimental conditions during data collection. Speech intelligibility is measured in the presence of four different levels of ambient noise. The spectra and levels of this noise will be calibrated before each test session. The noise exposure conditions experienced by the subjects are well within the allowable limits specified in AFR-161-35 and are non-hazardous. All procedures used throughout this operation are in accordance with AFR 169-3, Use of Human Subjects in RDT&E.

Each intelligibility test session lasts approximately 45 minutes followed by a 10 to 15 minute break. No more than four test sessions are completed per day. At the end of the day, all intelligibility trials for that day are printed out and a backup disc copy is made.

3. Subject Selection.

Volunteer, paid subjects with normal hearing sensitivity and function will be recruited from SRL's subject panel. Subjects are trained to a stable performance plateau on both the sound attenuation and speech intelligibility tasks. Individual subjects may participate in either the attenuation, the intelligibility phases or both. All subjects shall meet the the criteria listed in ANSI S12.6-1984 under section 3.2 - "Listeners" and ANSI S3.2-1989.

d. Test System Requirements.

The Hearing Protection Measurement System (HPMS) and Voice Communications Research Evaluation System (VOCRES) facilities will be utilized to conduct the attenuation and intelligibility tests.

e. Data Processing Techniques.

1. Sound attenuation.

Treatment of the data will be conducted using conventional data processing techniques for calculating means and standard deviations for each test signal, in accordance with those requirements specified in section 7 "Reporting the Data" of ANSI S12.6-1984. Additionally, single number reduction values as defined in AFR 161-35 will be calculated.

2. Speech Intelligibility.

Mean intelligibility scores for each test condition will be computed by averaging data from all talkers. Graphical plots for each NVG test device (3) will display intelligibility versus noise level. Numerical tables of the same data will be printed.

f. <u>Documentation Requirements</u>.

Initial findings will be reported to the program manager within one week of test completion. A final technical report will be delivered to the program manager within 30 days of test completion.

g. <u>Responsibilities of Branch Personnel</u>.

Biological Acoustics Branch personnel are responsible for planning the experiments, obtaining required approval, providing documentation, and monitoring the tests. Branch personnel will also be responsible for interpretation of sound attenuation and speech intelligibility data. Preparation of the test plan and final report are the responsibility of Mr. Mark Ericson. Sgt Don Yeager will assist Lt Denise West with the hearing threshold measurements. Lt West will interpret the attenuation data and assess the amount of allowable noise exposure with each of the night vision goggles. Mr. Ericson will monitor the speech intelligibility testing conducted by SRL. Mr. Richard McKinley will assist Mr Ericson in the interpretation of the speech intelligibility data.

h. <u>Responsibilities of Technical Services Contractors</u>.

Volunteer subjects are provided through the Systems Research Laboratories, the current BB engineering services contractor. The contractor will be responsible for providing the required subjects for each test session. A contract electronic technician will be available to assist with any equipment problems and will be responsible for maintaining the test systems.

Each manufacturer will be responsible for the molding of custom helmet liners for each of the participating subjects. Each manufacturer will send a representative to AAMRL to form the custom liners during May, 1990.

i. Responsibilities of WPAFB Support Organizations.

None.

j. Human Use Protocol.

83-58-06 "Human Exposure to Acoustic Energy."

k. Instrumentation Calibration Procedures.

The Hearing Protection Measuring System calibrating procedures are described in Appendix C. VOCRES calibrating procedures are contained in Appendix D.

l. Instrumentation Calibration Records.

For both the sound attenuation and speech intelligibility testing, calibrations will be recorded at the beginning and end of each test session. Records of calibration for each test will be kept in separate calibration notebooks with the test data.

m. Facility Operational Procedures.

See appendixes C and D.

n. Facility Operational Checklist.

Not applicable.

o. Description of Data Collection Systems.

1. Sound Attenuation.

Hearing threshold level data will be collected and stored by means of a personal computer (PC) and a hard copy output will be retained. Hearing threshold data using the Bekesy tracking method will be collected for each test signal, stored in the PC, and analyzed in accordance with ANSI standard S12.6-1984. Hearing threshold level responses that do not meet the test criteria will be retested, i.e., too wide a range, lack of responses, etc. Attenuation values will be calculated after a complete set of valid data is collected.

2. Speech Intelligibility.

Computer software was developed to facilitate data collection using the Modified Rhyme Test. The system controller generates the test matrix based on inputs from the experimenter. Presentation of the test phrases (individual lists of 50 words) and collection of the subject responses are managed by the system controller. Individual test segments are stored on the system's 20 Mega Byte hard disc and a paper copy backup is generated at the end of each 50 word test. The data may be analyzed at any time, using a variety of standard statistical methods and plotting techniques. This method of data storage and analysis can give preliminary results in near real time.

p. Test Schedule.

1. Sound Attenuation.

Sound attenuation testing will be conducted from 7 JUN through 16 JUN 90.

2. Speech Intelligibility.

Speech intelligibility testing will be conducted from 18 JUN through 16 JUL 90.

q. Safety and Emergency Procedures.

1. In case of a fire alarm, the test conductor will immediately stop the test and instruct/assist the subjects to evacuate the facility.

Emergency evacuation procedures are prominently posted on the wall of the test control room.

2. In case of power failure, emergency lighting will automatically switch on in the test areas. In case of failure of emergency lights, flashlights are available and the test conductor will evacuate the subjects to a safe area.

3. In the event of a malfunction in the sound system, the experiment conductor can immediately turn off all power to the system with an emergency stop button.

4. The subjects are continuously monitored during testing by the experiment controller via video camera/cameras.

2. N/A

3. Principle Investigator: Mr. Mark Ericson

4. On-site Operating Officials:

Sound Attenuation: Primary: Lt Denise West
Alternate: Sgt Donald Yeager

Speech Intelligibility: Primary: Mr. Michael Ward
Alternate: Ms. Emma Grove

APPENDIX A

Sound Attenuation Testing Schedule for I-Night Visions Goggles

Sub #	Trials A	B	C	
1	X/*	Y/#	Z/*	Day 1-am
2	Z/#	X/#	Y/*	
3	Y/#	Z/*	X/*	Day 2-am
4	Z/#	Y/*	X/#	
5	X/*	Z/*	Y/#	Day 3-am
6	Y/*	X/#	Z/#	Day 1-pm
7	X/*	Z/*	Y/#	
8	Z/#	X/#	Y/*	Day 2-pm
9	Y/#	Z/*	X/*	
10	X/#	Z/#	Y/*	Day 3-pm

Key to Symbols
* - unoccluded then occluded
# - occluded then unoccluded

X - Manufacturer #1
Y - Manufacturer #2
Z - Manufacturer #3

	A	B	C	
1	Y/*	Z/#	X/#	Day 3-am
2	X/*	Z/*	Y/#	Day 4-am
3	Z/#	X/#	Y/*	
4	Y/#	X/*	Z/*	Day 5-am
5	Z/#	Y/*	X/#	
6	X/*	Y/#	Z/*	Day 3-pm
7	Z/#	Y/*	X/#	Day 4-pm
8	Y/#	X/*	Z/*	
9	X/#	Y/*	Z/#	Day 5-pm
10	Z/*	X/*	Y/#	

	A	B	C	
1	Z/*	X/*	Y/#	Day 6-am
2	Y/*	X/#	Z/#	
3	X/*	Y/#	Z/*	Day 7-am
4	X/#	Z/#	Y/*	
5	Y/#	X/*	Z/*	Day 8-am
6	Z/#	X/#	Y/*	Day 6-pm
7	Y/#	Z/*	X/*	
8	X/#	Y/*	Z/#	Day 7-pm
9	Z/*	X/*	Y/#	
10	Y/*	X/#	Z/#	Day 8-pm

APPENDIX B: SUBJECT PANEL 1

The following Vocres Directory is HT0140.

Trial #	S/N	Power Ratio	Jammer	Talker	SSid
1.	115 dB	1	1	2-S.Subject2	6C
2.	000 dB	1	1	5-S.Subject5	9I
3.	105 dB	1	1	4-S.Subject4	9J
4.	105 dB	1	1	6-S.Subject6	6F
5.	000 dB	1	1	1-S.Subject1	5D
6.	115 dB	1	1	3-S.Subject3	6I
7.	095 dB	1	1	5-S.Subject5	4E
8.	115 dB	1	1	4-S.Subject4	4G
9.	115 dB	1	1	6-S.Subject6	7D
10.	000 dB	1	1	2-S.Subject2	6B
11.	095 dB	1	1	1-S.Subject1	7G
12.	000 dB	1	1	3-S.Subject3	5B
13.	115 dB	1	1	5-S.Subject5	5E
14.	095 dB	1	1	6-S.Subject6	8B
15.	095 dB	1	1	3-S.Subject3	6J
16.	095 dB	1	1	2-S.Subject2	8D
17.	105 dB	1	1	1-S.Subject1	5H
18.	095 dB	1	1	4-S.Subject4	5I
19.	115 dB	1	1	1-S.Subject1	8G
20.	105 dB	1	1	5-S.Subject5	7F
21.	000 dB	1	1	4-S.Subject4	8I
22.	105 dB	1	1	2-S.Subject2	6E
23.	000 dB	1	1	6-S.Subject6	6G
24.	105 dB	1	1	3-S.Subject3	9C
25.	105 dB	1	2	5-S.Subject5	8C
26.	095 dB	1	2	4-S.Subject4	9D
27.	105 dB	1	2	1-S.Subject1	7B
28.	000 dB	1	2	2-S.Subject2	7C
29.	000 dB	1	2	3-S.Subject3	9F
30.	105 dB	1	2	6-S.Subject6	8F
31.	095 dB	1	2	6-S.Subject6	9G
32.	105 dB	1	2	2-S.Subject2	7E
33.	000 dB	1	2	1-S.Subject1	7H
34.	000 dB	1	2	4-S.Subject4	4B
35.	115 dB	1	2	5-S.Subject5	8J
36.	105 dB	1	2	3-S.Subject3	4D
37.	115 dB	1	2	3-S.Subject3	7J
38.	095 dB	1	2	2-S.Subject2	7I
39.	105 dB	1	2	4-S.Subject4	4F
40.	115 dB	1	2	1-S.Subject1	9H
41.	095 dB	1	2	5-S.Subject5	4I
42.	115 dB	1	2	6-S.Subject6	8H
43.	095 dB	1	2	3-S.Subject3	8E
44.	115 dB	1	2	4-S.Subject4	4J
45.	095 dB	1	2	1-S.Subject1	4C
46.	115 dB	1	2	2-S.Subject2	5F
47.	000 dB	1	2	6-S.Subject6	9B
48.	000 dB	1	2	5-S.Subject5	9E
49.	105 dB	1	3	4-S.Subject4	5C
50.	000 dB	1	3	2-S.Subject2	4H
51.	115 dB	1	3	3-S.Subject3	5J
52.	000 dB	1	3	6-S.Subject6	6H
53.	105 dB	1	3	5-S.Subject5	6D
54.	105 dB	1	3	1-S.Subject1	5G
55.	000 dB	1	3	3-S.Subject3	5E
56.	115 dB	1	3	2-S.Subject2	6I
57.	095 dB	1	3	6-S.Subject6	4E
58.	115 dB	1	3	4-S.Subject4	4G
59.	115 dB	1	3	5-S.Subject5	7D

The following Vocres Directory is HT0140.

Trial #	S/N	Power Ratio	Jammer	Talker	SSid
60.	000 dB	1	3	1-S.Subject1	6C
61.	095 dB	1	3	3-S.Subject3	7G
62.	105 dB	1	3	6-S.Subject6	5C
63.	095 dB	1	3	4-S.Subject4	5D
64.	095 dB	1	3	5-S.Subject5	8B
65.	095 dB	1	3	2-S.Subject2	6J
66.	095 dB	1	3	1-S.Subject1	8E
67.	115 dB	1	3	1-S.Subject1	5I
68.	115 dB	1	3	6-S.Subject6	6B
69.	105 dB	1	3	2-S.Subject2	8H
70.	000 dB	1	3	5-S.Subject5	7F
71.	000 dB	1	3	4-S.Subject4	8J
72.	105 dB	1	3	3-S.Subject3	6E

APPENDIX B: SUBJECT PANEL 2

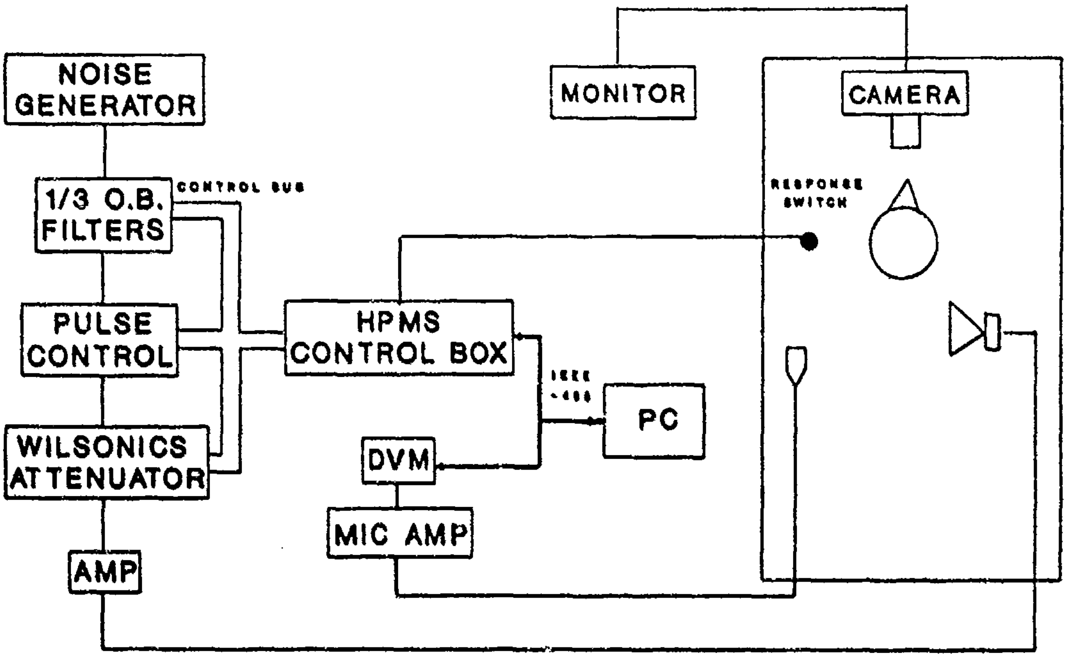
The following Vocres Directory is HT0140.

Trial #	S/N	Power Ratio	Jammer	Talker	SSid
1.	115 dB	1	1	2-S.Subject2	6C
2.	000 dB	1	1	5-S.Subject5	9I
3.	105 dB	1	1	4-S.Subject4	9J
4.	105 dB	1	1	6-S.Subject6	6F
5.	000 dB	1	1	1-S.Subject1	5D
6.	115 dB	1	1	3-S.Subject3	6I
7.	095 dB	1	1	5-S.Subject5	4E
8.	115 dB	1	1	4-S.Subject4	4G
9.	115 dB	1	1	6-S.Subject6	7D
10.	000 dB	1	1	2-S.Subject2	6B
11.	095 dB	1	1	1-S.Subject1	7G
12.	000 dB	1	1	3-S.Subject3	5B
13.	115 dB	1	1	5-S.Subject5	5E
14.	095 dB	1	1	6-S.Subject6	8B
15.	095 dB	1	1	3-S.Subject3	6J
16.	095 dB	1	1	2-S.Subject2	8D
17.	105 dB	1	1	1-S.Subject1	5H
18.	095 dB	1	1	4-S.Subject4	5I
19.	115 dB	1	1	1-S.Subject1	8G
20.	105 dB	1	1	5-S.Subject5	7F
21.	000 dB	1	1	4-S.Subject4	8I
22.	105 dB	1	1	2-S.Subject2	6E
23.	000 dB	1	1	6-S.Subject6	6G
24.	105 dB	1	1	3-S.Subject3	9C
25.	105 dB	1	2	5-S.Subject5	8C
26.	095 dB	1	2	4-S.Subject4	9D
27.	105 dB	1	2	1-S.Subject1	7B
28.	000 dB	1	2	2-S.Subject2	7C
29.	000 dB	1	2	3-S.Subject3	9F
30.	105 dB	1	2	6-S.Subject6	8F
31.	095 dB	1	2	6-S.Subject6	9G
32.	105 dB	1	2	2-S.Subject2	7E
33.	000 dB	1	2	1-S.Subject1	7H
34.	000 dB	1	2	4-S.Subject4	4B
35.	115 dB	1	2	5-S.Subject5	8J
36.	105 dB	1	2	3-S.Subject3	4D
37.	115 dB	1	2	3-S.Subject3	7J
38.	095 dB	1	2	2-S.Subject2	7I
39.	105 dB	1	2	4-S.Subject4	4F
40.	115 dB	1	2	1-S.Subject1	9H
41.	095 dB	1	2	5-S.Subject5	4I
42.	115 dB	1	2	6-S.Subject6	8H
43.	095 dB	1	2	3-S.Subject3	8E
44.	115 dB	1	2	4-S.Subject4	4J
45.	095 dB	1	2	1-S.Subject1	4C
46.	115 dB	1	2	2-S.Subject2	5F
47.	000 dB	1	2	6-S.Subject6	9B
48.	000 dB	1	2	5-S.Subject5	9E
49.	105 dB	1	3	4-S.Subject4	5C
50.	000 dB	1	3	2-S.Subject2	4H
51.	115 dB	1	3	3-S.Subject3	5J
52.	000 dB	1	3	6-S.Subject6	6H
53.	105 dB	1	3	5-S.Subject5	6D
54.	105 dB	1	3	1-S.Subject1	5G
55.	000 dB	1	3	3-S.Subject3	8E
56.	115 dB	1	3	2-S.Subject2	6I
57.	095 dB	1	3	6-S.Subject6	4E
58.	115 dB	1	3	4-S.Subject4	4G
59.	115 dB	1	3	5-S.Subject5	7D

The following Vocres Directory is HT0140.

Trial #	S/N	Power Ratio	Jammer	Talker	SSid
60.	000 dB	1	3	1-S.Subject1	6C
61.	095 dB	1	3	3-S.Subject3	7G
62.	105 dB	1	3	6-S.Subject6	5C
63.	095 dB	1	3	4-S.Subject4	5D
64.	095 dB	1	3	5-S.Subject5	8B
65.	095 dB	1	3	2-S.Subject2	6J
66.	095 dB	1	3	1-S.Subject1	8E
67.	115 dB	1	3	1-S.Subject1	5I
68.	115 dB	1	3	6-S.Subject6	6B
69.	105 dB	1	3	2-S.Subject2	8H
70.	000 dB	1	3	5-S.Subject5	7F
71.	000 dB	1	3	4-S.Subject4	8J
72.	105 dB	1	3	3-S.Subject3	6E

HEARING PROTECTION MEASUREMENT SYSTEM BLOCK DIAGRAM



Appendix C

APPENDIX C

PROCEDURE FOR RUNNING HEARING PROTECTOR ATTENUATION TESTING

1. Turn on the following equipment:

   a. GR 1310 noise generator

   b. 1/3 octave band filter

   c. Wilsonics programmable attenuators

   d. Crown pre-amplifier

   e. HP 3456A digital voltmeter

   f. B&K 2807 microphone power supply

   g. Compaq 386 PC

   h. HP Laserjet printer

2. To run the hearing protector evaluation program:

   a. When "c:" prompt appears on screen type CD \HP_BASIC then press [ENTER].

   b. Type BASIC then press [ENTER].

   c. Type LOAD "HPE" then press [ENTER].

   d. Press [F3] to run the program.

   e. When welcome message appears press [ENTER] to continue.

   f. Main menu should appear, if not, then press [CTRL] and [F10] simultaneously and repeat steps 2a through 2e.

3. Make sure the equipment has warmed up for at least 30 minutes before proceeding.

4. To calibrate the microphone and system:

   a. At the main menu of the computer program type 1 then press [ENTER].

   b. At the calibrate/edit/display menu type 5 then press [ENTER].

c. When asked if you want to proceed with microphone calibration type Y then press [ENTER].

d. When asked if you want to use the same microphone type Y then press [ENTER].

e. When asked if the information on the frequency correction values of the microphone are correct type Y then press [ENTER].

f. When the message "PLEASE PUT ON 94 dB CALIBRATOR" appears have someone place the calibrator on the microphone inside of the test chamber.

g. When the calibrator is in place, press the button on the side of the calibrator to turn on the 1kHz, 94dB pure tone.

h. Have the person exit the test chamber and close the inner and outer door.

i. Press [ENTER] on the keyboard to proceed with calibration.

j. When asked if you want to recalibrate the microphone type N then press [ENTER].

k. Have someone remove the calibrator from the microphone then exit the test chamber and close the inner and outer door.

l. When asked if you want to proceed with system calibration type Y then press [ENTER].

m. When the SPL table is displayed press [ENTER] four times to see the entire table.

n. When asked if you want a hard copy of the SPL table:

   1. Type Y then press [ENTER] if you want a printout.

   2. Type N then press [ENTER] if you do not want a printout.

o. When asked if you want to see the graphs of the SPL table:

   1. If you want to see the graphs then:

a. Type Y then press [ENTER].

b. Press [ENTER] 9 times to see all 9 graphs.

2. If you do not want to see the graphs then type N and press [ENTER] to continue.

p. If the SPL table is not linear:

1. A list of attenuator and frequency settings that are not linear will be displayed.

2. When asked if you want a hardcopy of the nonlinear settings:

a. Type Y then press [ENTER] to get a printout.

b. Type N then press [ENTER] to continue.

q. If the SPL table is linear:

1. The message "SPL TABLE IS LINEAR WITHIN THE .5 dB MARGIN" will appear.

2. Press [ENTER] to continue.

r. When asked if you want to recalibrate the system type N then press [ENTER].

s. At the calibrate/edit/display menu type 6 then press [ENTER] to return to main menu.

5. To collect data:

a. At the main menu type 2 then press [ENTER].

b. At the data collection menu type 2 then press [ENTER].

c. At the experiment menu type 2 then press [ENTER].

d. Press [ENTER] until the message "DO YOU WANT TO CONTINUE WITH CURRENT EXPERIMENT?" appears.

e. Type Y then press [ENTER].

f. When asked to enter the subject number to be tested type the subject number and press [ENTER].

g. When asked which model will be used type in the model number from the displayed list and press [ENTER].

h. A message will appear displaying the trial number. When asked if you want to continue with this trial type Y then press [ENTER].

i. If subject is on the first trial:

   1. When asked which threshold of audibility you want to test first:

      a. Type 1 then press [ENTER] to test occluded threshold.

      b. Type 2 then press [ENTER] to test unoccluded threshold.

j. A message will appear indicating which threshold of audibility the subject is due to be tested for first. When asked if you want to continue with this test type Y then press [ENTER].

k. Position the subject in the chair inside of the test chamber.

l. Instruct the subject on the emergency procedures.

m. Instruct the subject on the use of the head positioning device.

n. Instruct the subject on the task to be performed.

o. If occluded threshold of audibility is being tested:

   1. Instruct the subject on fitting of the hearing protector device.

   2. Have the subject put on the hearing protector device.

   3. Leave both doors of the test chamber open.

   4. Press [ENTER] on the keyboard to generate a test signal.

   5. Have the subject adjust hearing protector device so minimal noise is heard.

   6. When asked if you need the test signal again:

a. If hearing protector has not been adjusted properly type Y then press [ENTER] and go to step 5.o.5.

b. If hearing protector is properly adjusted type N then press [ENTER].

p. Close the inner and outer door of the test chamber.

q. NOTE: In case of an emergency, press the emergency stop button.

r. Press [ENTER] to proceed with testing.

s. When data collection is complete data will be displayed on the CRT. When asked if you want a hardcopy:

1. Type Y then press [ENTER] to get a printout.

2. Type N then press [ENTER] to continue.

t. Let subject out of the test chamber.

u. When asked if you want to test another subject:

1. Type Y then press [ENTER] to test another subject and repeat step 5.

2. Type N then press [ENTER] to continue.

6. When finished, turn off all the following equipment:

a. GR 1310 noise generator

b. 1/3 octave band filter

c. Wilsonics programmable attenuators

d. Crown pre-amplifier

e. HP 3456A digital voltmeter

f. B&K 2807 microphone power supply

g. Compaq 386 PC

h. HP Laserjet printer

APPENDIX D

PROCEDURE FOR RUNNING SPEECH INTELLIGIBILITY TESTING

As soon as you arrive in the morning...

1. Turn on the DC Generator in room 0-24.
   To start - press START.
   press FIELD CLOSING (reading between 25-30 dc volts).

2. In room 0-1, turn on the UHF Signal Generator (the switch is on the front panel from off to on).

3. Also turn on the radios (turn the rotary switch on the front panels from off to main, and turn the switch on front panel above the radios from off to on).

Thirty (30) minutes before the subjects arrive...

1. In the reverberation chamber, turn on the power supply to the desks.

2. In room 0-2, turn on the intercom power (28V dc) (the switch is above the computer).

3. Turn on the Programmable Signal Source.

4. Turn on the Spectrum Analyzer.

5. Turn on the Digital Frequency Analyzer.
   a. Turn on.
   b. Press 1/3 oct filter bandwidth selector.
   c. Press the preamp input.
   d. Set the cursor to a frequency of 1.0 kHz. Using the channel selector.
   e. Check the noise level at the microphone (to do this have someone hold the calibrator to the microphone and press the button) and adjust the Gain Control on the analyzer until 93.6 dB appears on the readout.
   f. Change to 1/1 oct filter bandwidth.
   g. Using the channel selector, move the cursor all the way to the right.
   h. Press the input attenuator switch until the highest scale number on the y axis is 130 dB.

6. Turn on the Stromberg-Carlson.
   a. First make sure that the chamber is empty due to the potentially hazardous noise transient.
   b. Check that all the dials (Line Attenuators and all Input Attenuators) are set at maximum CCW.
   c. Check to see that the power range selector is set to LOW.
   d. Press the red power button.
   e. The pilot light should be lit.
   To increase the noise levels, turn the Input Attenuator (channel 4), Line Attenuator, H.F., and Line Attenuator,

L.F. clock-wise in that order. (For 115-dB-set IA-7, HF-3, LF-15, for 105 dB-set IA-18, HF-3, LF-15, and for 95 dB-set IA-28, HF-3, LF-15, all values are approximate).

7. Turn on the Precision Noise Generator (select 124.3 dB, 50 and pink noise input).

8. Turn on the computer.
   To start-first turn on the disc drive.
   a. Turn on the line power switch on the back of the cabinet.
   b. Wait for the light message on the front panel (DOOR UNLOCKED).
   c. Turn the switch on the front of the cabinet from off to run.
   d. Wait for the light message (DRIVE READY).

   To Turn the Computer on...
   a. Turn the switch on the side from 0 to 1.
   b. Wait for the ready signal i.e. the cursor appears on the CRT.
   c. Type MASS STORAGE IS "C12"
      press Execute
      type LOAD "rSEEK"
      press Execute
      press Run

   TRIAL RUN

   Answer the following questions that appear on the CRT.
   1. Change month, day, hour (0-23), minutes and seconds to present moment. (MM:DD:HH:MM:SS)
   2. Start of rSeek; What is your name?(Name)
   3. Specify file name for the Seek Talk director. (EWC164)
   4. Is this the correct Seek Talk directory? (Yes/No - press k_{14} or k_{15}).
   5. Is the paper perforated for top of page form feeds?(Y/N)
   6. Would you like some practice runs? (Y/N)

IF YES

   7. Number of Subjects? (1-10)
   8. Would you like defaults on the station numbers? (Y/N)
   9. Enter subject number of the talker. (1-10)
   10. Enter the score sheet ID.
   11. Are these trial conditions correct? (Y/N)
   12. When ready to begin press CONT.

AFTER THE RUN

   13. Do you want to give them a break? (Y/N)
   14. Is hardcopy desired for the rest of the output? (Y/N)
   15. Do you have any comments, if so enter them now.
   16. Would you like another practice run? (Y/N)

IF NO PRACTICE RUNS ARE DESIRED

   7. The last trial was trial number x.
   8. The comments for the last trial are.....

9. The time of the last trial was.....The time of today's trial is......
10. Do you want the next trial after x? (Y/N)

IF TRIAL AFTER TRIAL X IS DESIRED...
11. This is the selected trial number.
12. Do you want to run this trial? (Y/N)
13. When ready to begin press CONT.

AFTER THE TRIAL
14. Do you want to store the results? (Y/N)
15. Do you want to give them a break? (Y/N)
16. Is the hardcopy desired for the rest of the output?(Y/N)

IF TRIAL AFTER TRIAL NUMBER X IS NOT DESIRED THEN...
11. Then specify the desired trial number. (Trial number is greater than or equal to 1 but less than or equal to 400)

To restart the program from the beginning.
Hold Down CONTROL
Press STOP
Press RUN (resets)

9. In the Reverberation Chamber (room 0-3), turn on the air supply. START-UP (refer to diagram)
   a. Turn at least one mask to safety.
   b. Making certain that R4 is closed, open (CCW) L1, L2, and L4.
   c. Adjust L3 to desired pressure (150psi)
   d. Close L4.
   e. Open R1, R2, and R4.
   f. Adjust R3 to desired pressure. (140psi)
   g. Return mask to normal.

(If the right system is the system in use, substitute L's for R's and visa versa).

150 psi - system in use.
140 psi - stand-by system.

DESK RESET - If it is necessary to reset the desks, look underneath the desk top for the 3 LED status lights. The reset button is next to the LED's. Press the reset button a few times.

To SHUT-DOWN the system...

1. Turn off the computer
   a. Turn the switch on the side from 1 to 0.
2. Turn the disc drive off.
   a. First turn the switch on the front door of the cabinet from run to off.
   b. Wait for the light message (DOOR UNLOCKED) to appear.
   c. Turn off the line power switch on the back of the cabinet.

<u>CAUTION</u> -- <u>ALWAYS</u> MAKE CERTAIN THE FRONT PANEL SWITCH IS <u>IN THE</u> STOP POSITION BEFORE TURNING OFF THE LINE POWER OR DAMAGE TO THE STORAGE DISC MAY RESULT.

3. Turn off the Precision Noise Generator.
4. Turn off the Stromberg-Carlson
   a. Turn all Line Attenuators to maximum CCW.
   b. Turn all Input Attenuators to maximum CCW.
   c. Depress the red power button.
   d. The power light should go out.
5. Turn off the Digital Frequency Analyzer.
6. Turn off the Spectrum Analyzer.
7. Turn off the Programmablo Signal Source.
8. Turn off the intercom power.
9. Turn off the UHF Signal Generator.
10. Turn off the radios (turn rotary switches from main to off and turn the switch on the panel above the radios off).
11. In the reverberation chamber, turn off the power supply to the desks.
12. Also in the reverberation chamber, turn off the air supply.
    a. Turn at least one mask to safety.
    b. Close L1 and R1.
    c. Monitor pressures at L3 and R3. When the tank side and the outside pressure at L3 and R3 = 0, then close L2, L4, R2, and R4.
       (There is no need to close or adjust L3 or R3).

Finally in room 0-14

13. Turn off the DC Generator.
    a. press STOP.

VOCRES SOUND SYSTEM SOP

1. Check current system log for notices. If system is not operational contact one of the following personnel: Doug Sauer (SRL) or Dave Ovenshire (SRL).

2. Remove interlock key from system panel.

3. Open chamber doors and remove all personnel from room.

4 Ensure that the B&K 4145 microphone and BK-2619 preamplifier is in the chamber (serial numbers____________ &____________, respectively.

5. Connect the BK-2131 analyzer to the microphone via the preamp input.

6. Set the control of the BK-2131 Digital Spectrum Analyzer as follows:

   AC POWER ON
   PRESS RESET SWITCH
   1/3 OB MODE SELECT
   PREAMP INPUT SELECT
   A WEIGHT SWITCH OFF
   1.0 SECOND TIME AVERAGE SELECTED
   SET THE CHANNEL SELECTOR (HIGH LIGHTED BAND ON THE SCREEN) ON THE FULL RIGHT PART OF THE SCREEN-(THE OVERALL SPL LEVEL)

7. VOCRES "INPUT 1" FULLY CCW TO " ". (CCW - COUNTER CLOCK WISE

8. VOCRES "INPUT 2" FULLY CCW TO " ".

9. Ensure that the BAND ATTENUATION Selectors are set to the correct values. (As listed in the operations log book. IF NOT contact personnel listed in step 1.

10. Ensure that the spectrum shaper Spectra Sonics Model 1500 is adjusted to correct levels as listed in the operations log book. If not correct contact the personnel listed in step 1.

11. Set the General Radio 1382 Random Noise Generator to "PINK" noise input.

12. Adjust the General Radio (GR) 1382 to minimum output. Fully CCW

13. Connect the Noise Generator output (top two banna jacks) to the Sound System "Input 1" Note: The lower banna jack must be strapped to the ground of the Noise Generator.

    POWER UP THE FOLLOWING: (All items are 117 VAC unless stated otherwise)

    Left rear of the control rack MASTER switch ON, (AC Power Strip)

    GR-1382 Noise Generator
    EV XEQ-2 Crossover networks (ALL THREE UNITS)
    Spectrum Shaper, Spectra Sound Model #1500

14. Place the "INPUT 1" control to "O"; fully CW (CW=CLOCK WISE)

15. Increase the output level of the Noise Generator until the VU Meter on the system panel reads "O" VU ± 0.8 VU units (record this value for later use).

16. Turn "INPUT 1" down fully CCW to "   ".

17. Insert the key and rotate the key switch to on. Fully CW position.

    NOTE: A signal POP sound should have been heard from the chamber. If not check that all items are on-- IF NOT TURN KEY SWITCH TO THE OFF POSITION BEFORE TURNING ON ADDITIONAL ITEMS. IF THIS IS NOT THE PROBLEM CONTACT PERSONNEL LISTED IN STEP 1.

18. Place "INPUT 1" level to the OVU point obtained in step #15.

19. Note a slight increase in room Sound Pressure Level (SPL).

20. Enter the test chamber and listen for any excessive 60 cycle AC HUM or any tones from the speakers. IF SYSTEM IS NOT NORMAL CONTACT PERSONNEL IN STEP #1.

21. Increase the SPL in the room to 85 dB by monitoring the 2131 analyzer and increasing the "OUTPUT" level control until this level is obtained.

22. Check the quality of the sound by checking the spectrum on the 2131 analyzer. Should be flat within ± 3 dB from 300 Hz to 10.0 kHz. If not contact personnel listed in step #1.

23. Turn down the "OUTPUT LEVEL" to "O".

24. Clear the test chamber of all personnel and shut both doors.

25. Increase the OUTPUT level until 95 dB SPL overall is reached. RECORD OUTPUT LEVEL VALUE.

26. Increase the OUTPUT level until 105 dB SPL is reached. RECORD OUTPUT LEVEL VALUE.

27. INCREASE the OUTPUT level until 115 dB SPL overall is reached. RECORD THE OUTPUT LEVEL VALUE.

28. BRING DOWN THE SOUND LEVEL__

FIRST TURN THE OUTPUT to "   "

THEN TURN THE INPUT 1 to "   "

29. KEY SWITCH TO OFF fully CCW.

30. POWER DOWN ALL AC SYSTEMS LISTED IN STEP #6.

SOP ICS

SET UP FOR STANDARD OPERATION

1. Turn all volume controls on the desks and the operators station to minimum level output. (fully CCW)

2. Connect all headsets, ten desks and one operator. (EG H-157)

3. Turn on intercom power supply. (ON WALL)

4. Select talker by desk number and push in this switch on the intercom control station panel.

5. Have talker press his push to talk button and speak into the microphone at a normal speaking voice.

6. Have all listeners verify that they are receiving the talker via the intercom link. (They will need to adjust the volume controls on their desk).

7. Have the talker and all listeners verify that they can receive the operator at all times.

8. Repeat this procedure for each talker station to be used. (Steps 4 thru 6)

SET UP FOR CALIBRATION OF SOUND PRESSURE LEVELS

1. Connect all headsets that will be used. (Operator and ten desks sets).

2. Connect a pink noise source to the intercom input. (Set noise generator to a 1.5 vp-p level output).

3. Ensure that the intercom power supply is on.

4. Calibrate the General Radio 1933 Sound Level Meter by using BK 4330 microphone level calibrator. (84.0 dB ± 0.5 dB) on the 1 kHz scale SLOW time constant. NOTE: CHECK TEST BATTERIES IN THE SOUND LEVEL METER AND CALIBRATOR by built in test of meter. For the calibrator it is operational if the tone does not turn off once started in less than 20.0 seconds.

5. Measure and record in the calibration folder the output of each desk (right earphone). Use the SLOW overall reading of the meter.

6. If the output of any desk or operator headset is greater than ________ dB maximum sound pressure level or more than ± ________ dB variance for any other desk. DO NOT OPERATE SYSTEM AND NOTIFY PROPER PERSONNEL.

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DATA REPORT

SOUND ATTENUATION AND VOICE COMMUNICATIONS PERFORMANCE OF INTEGRATED NIGHT VISION GOGGLES HELMET SYSTEMS

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SOUND ATTENUATION AND VOICE COMMUNICATIONS PERFORMANCE OF INTEGRATED NIGHT VISION GOGGLES HELMET SYSTEMS

INTRODUCTION

The high levels of noise present in the cockpits of military aircraft may threaten voice communications effectiveness and pose a risk to the hearing of the aircrews. Conventional flight helmets typically provide adequate sound protection to ensure aircrew safety and performance. However, these acoustic characteristics of helmets may be altered by the addition and integration of external systems such as night vision goggles (NVG). This report describes a laboratory evaluation of the noise exclusion properties and the voice communications performance of three integrated NVG helmets which were manufactured by GEC, Honeywell, and Kaiser. These evaluations were accomplished in the Biocommunications Laboratory by personnel in the Bioacoustics and Biocommunications Branch, Biodynamics and Bioengineering Division, Armstrong Aerospace Medical Research Laboratory.

APPROACH

The sound attenuation of the NVG helmets worn by trained subjects was measured in the Sound Protection Measurement Laboratory in accordance with an established American National Standards Institute (ANSI) procedure. The criterion measure was sound attenuation in decibels (dB). The voice communications of volunteer subjects wearing the NVG helmets were measured in relative quiet and in three levels of emulated operational aircraft noise. Volunteers performed as talkers and as listeners under the same noise conditions using standardized speech intelligibility materials. Criterion measures were percent correct responses of the intelligibility measures.

OBJECTIVES

The objectives of the study were to define the sound attenuation and to quantify the voice communications performance characteristics of the individual integrated NVG helmets in emulated operational aircraft cockpit noise environs.

SOUND ATTENUATION

EXPERIMENTAL DESIGN

The sound attenuation provided by the NVG helmets was measured in compliance with the national standard, Method for the Measurement of Real-Ear Attenuation of Hearing Protectors, ANSI S12.6-1984. The experimental design in this standard is a repeated measures design with each of 10 subjects participating three times in the control condition (ears open or unoccluded) and three times in the test condition (ears covered or occluded) at each of nine test signals. The attenuation or amount of sound protection measured is defined as the arithmetic difference between the unoccluded and the occluded hearing threshold levels.

SUBJECTS

Ten subjects, 3 female and 7 male, with a mean age of 26.1 years participated in the evaluation of each of the helmets. Subjects who participated in the sound attenuation evaluations were volunteer government employees. Only government employees participated in the sound attenuation experiment because the issue of contract personnel working with proprietary information had not been resolved at the time of testing.

FACILITY

This experiment was accomplished in the sound protection measurement facility, a reverberant chamber with physical characteristics designed to meet the specifications of ANSI S12.6-1984. The test sounds were pulsed third-octave bands of noise and were produced by a sound system that consisted of a noise generator, third-octave band filter set, calibrated attenuator, power amplifiers, and loudspeakers. Equipment located inside the subject chamber included a video camera (to monitor the subject), subject chair, response button, and a plumb bob used as a reference to position the head of the subject in the sound field. The instrumentation was controlled by a menu driven software program on a Compaq 386 personal computer located outside the chamber. This software program greatly facilitated execution of the study as well as the collection, analysis, and storage of all attenuation data.

PROCEDURES

The general purpose of the experiment and the test procedures were explained to each subject on his/her initial visit. Subjects practiced the hearing threshold measurement procedure until the experimenter determined that their performance qualified them as "trained" subjects. Hearing threshold levels were determined for third-octave bands of noise centered at 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz using the Bekesy tracking method in which the subject controls the level of the test signals using a response button. The level of the signal is always changing; while the response button is depressed the level is decreasing and while the button is not depressed the level is increasing (signal grows louder).

The subject receives the initial test signal at a clearly audible level (suprathreshold). The response button is depressed and held down for as long as the test signal is audible. It is released when the signal is no longer audible and not depressed again until the signal reappears. The response button controls the attenuators which increase or decrease the level of the test signal based on the information (position) from the subject response button. After the hearing threshold level for a test signal is crossed six times the next text signal is presented to the subject. The arithmetic average of the levels at which the response button is activated (on-off) is defined as the hearing threshold level for that test signal and that subject.

In all occluded conditions a noise was presented in the test chamber to assist the subject in the final fitting of the helmet/ear enclosures. The helmet/ear enclosures were adjusted to a position where the noise was minimal. The unoccluded hearing thresholds were measured immediately before or after each set of occluded thresholds. The difference between the open ear threshold and the closed ear threshold for each test signal was scored as the attenuation of the helmet for that individual.

DATA

Sound attenuation data for each of the three NVG helmets were tabulated and processed to provide mean, standard deviation, and mean minus two standard deviation attenuation for each test signal. The mean minus two standard deviation values (data) are required by current Air Force regulations on noise exposure and hearing loss. These values represent the sound attenuation estimated for about 98% of the wearers in operational noise environments when the helmets are worn as they were by the laboratory subjects. The mean values are adjusted by two standard deviations to compensate for variability associated with such factors as fit and head size.

RESULTS

The means, standard deviations, and mean minus two standard deviations sound attenuation data for the helmets are presented in Figures 1, 2, and 3. Table 1 contains the military specification for sound attenuation of helmets and the measured sound attenuation values for each of the NVG helmets in this study.

VOICE COMMUNICATIONS

EXPERIMENTAL DESIGN

The NVG helmet systems were investigated for voice communications effectiveness in three levels of emulated operational tactical aircraft cockpit noise environments. The noise conditions were ambient room noise (about 78 dB), 95 dB, 105 dB, and 115 dB sound pressure level (SPL re 20 uPa) of the cockpit noise. The speech intelligibility obtained by the subjects wearing the helmets was measured using a standard intelligibility test, the Modified Rhyme Test (MRT). This metric is considered the measure of choice for evaluating the performance of military voice communications equipment. The test consists of several lists of one-syllable words, 50 words in each list, which are essentially equivalent in intelligibility to one another. These standard materials are transmitted and received over the candidate communications equipments and the metric is the percent of the words correctly recognized by the listeners. The criterion measure is percent correct, adjusted for correct responses obtained by guessing.

SUBJECTS

Ten normal hearing subjects, 5 female and 5 male, participated in these speech communications evaluations. They were members of a panel of trained subjects who were highly experienced with the research facility and in the evaluation of voice communications systems. All were recruited from the general population and were paid an hourly rate for their participation.

FACILITY

These experiments were accomplished in the voice communications research and evaluation (VOCRES) facility in the Biocommunications Laboratory. This research facility includes the total audio communications link from talker to listener and contains the primary system, operator, and environmental variables that influence voice communications effectiveness. An experimenter station controls ten individual communications stations and a programmable high intensity sound system. All stations are integrated with a Computer Display-Response System in which the central processor is a Hewlett Packard 9845B. Each station contains an LED display which presents information to the subject and a set of keypad response buttons which collect subject response data for input to the processor. Presentation of the speech materials and collection of the response data were automatically controlled by this system.

PROCEDURE

Only two of the NVG helmet systems from each manufacturer were available for these evaluations. Consequently, six of the ten subjects were fitted with the manufacturer's NVG helmets and the remaining four subjects wore the standard HGU-55/P flight helmet. A test paradigm was used in which each of the subjects wearing the NVG helmets participated as talker and as listener (while the others were talkers), while those wearing the HGU-55/P participated only as listeners. This procedure provided speech intelligibility information among the various combinations of these talker and listener conditions.

The individual subjects were fit with the helmets in the manner described in the sound attenuation section of this report except that a noise was not presented to assist in the final fitting. Each of the helmeted subjects occupied one of the ten communication stations in VOCRES for the measurement sessions. Each session involved presentation of a word list on the LED display at the talker's station. The list was presented one word at a time and the talker spoke that word into the mask/microphone. The listeners heard the word and immediately a six-word multiple choice response set appeared on the LED displays in front of the listeners. The listener depressed the response button that corresponded to the word that was recognized as spoken by the talker. Each measure consisted of a list of fifty words. This procedure was repeated until all talkers wearing NVG helmets had completed their communications in all of the noise conditions.

RESULTS

The speech intelligibility scores measured for the various NVG helmet systems in the noise environments are presented in both tabular and graphic form in Figures 4, 5, and 6. The intelligibility scores are the average percent correct responses for the helmet and noise conditions shown. The scores were adjusted for correct answers obtained by guessing.

DISCUSSION

Helmet Fit

Effective sound attenuation and voice communications in noise require a "good" acoustic fit (no leaks or breaks in the earcup seal against the side of the head) of the helmet which translates to good acoustic performance in noise. In helmet systems, the sound protection features for these purposes are determined primarily by the ear enclosures. The helmet systems in this study were fit by government personnel experienced in fitting such personal equipment items. The procedures and materials employed in fitting the helmets varied somewhat from one helmet to another.

Government personnel placed strong emphasis on obtaining a good fit of the ear enclosures and this was successfully accomplished almost without exception. In some instances the helmet fit was considered not fully acceptable, even though the ear enclosures were adjusted to provide a good acoustic seal. The data from the situations where the acoustic fit was questionable were analyzed and shown to not affect the mean performance data for the particular helmet for either sound attenuation or voice communications.

The experienced "fitters" judged that all subjects obtained a good acoustic fit with the Kaiser unit. All but one subject for the sound attenuation had a good fit with the Honeywell. Only one subject obtained a questionable fit with the GEC helmet for the intelligibility measurements, however, this did not affect the intelligibility data.

Sound Attenuation

Military Specification E-83425 sound attenuation values for helmets are contained in the top of the four rows in Table 1. The attenuation values at the test signals from 500 Hz to 4000 Hz are minimum values. The sum values for the three groups of frequencies are also minimum sum values. Both the individual test signal values and the group sum values must be equalled or exceeded to comply with the specification. Sound attenuation measured in this study for the three NVG helmets is displayed in Table 1 along with the Military Specification E-83425 values.

The data in Figure 3 are the mean minus two standard deviation data utilized by the Air Force to estimate allowable durations of exposure to a noise while the sound excluding device (helmet) is worn. An estimation of the maximum duration of daily exposure to the cockpit noises of an F-16A and a B-52H while wearing the respective NVG helmets is summarized in Figure 7. The estimated allowable exposure time will change from one aircraft to another because of differences in the spectra of the respective cockpit noises and in the sound attenuation of the helmet at the various frequencies.

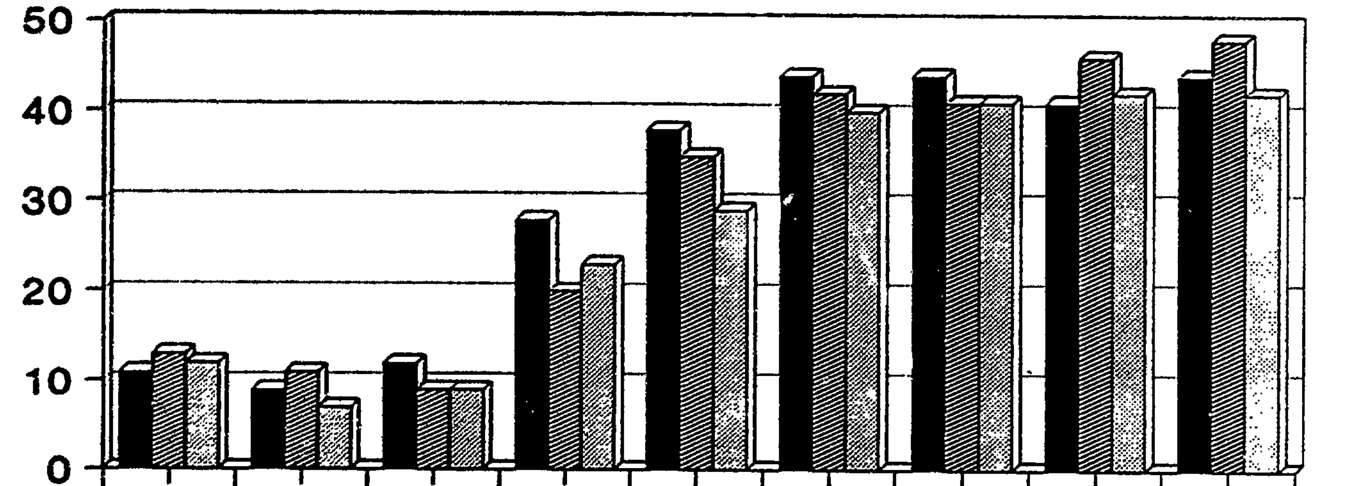
Voice Communications

The standard intelligibility measure (MRT) has been used in the VOCRES facility for numerous investigations of voice communications systems, components, and terminal equipments. Performance measured in the laboratory under these conditions has reportedly been very similar to that subsequently experienced in operational situations. On the basis of these data and experiences over many years, a set of criterion values of the data collected in this laboratory has been adopted as a predictor of expected performance in the operational situation. Systems and components that perform in VOCRES at an intelligibility level of about 70% and below are not acceptable. Those performing in the 70% to 80% range are marginal and their success in the field depends upon the specific conditions under which they are employed. Equipments exhibiting intelligibility performance at about 80% and above are considered to be acceptable under operational conditions.

SUMMARY

Integrated night vision goggles helmets from three different manufacturers were evaluated in the laboratory for sound attenuation and speech intelligibility using standardized measurement procedures. The performance data are summarized and presented in tabular and graphic form. General criteria are described which can be used to estimate the acceptability of that performance in the operational situation.

FIGURE 1
MEAN ATTENUATION

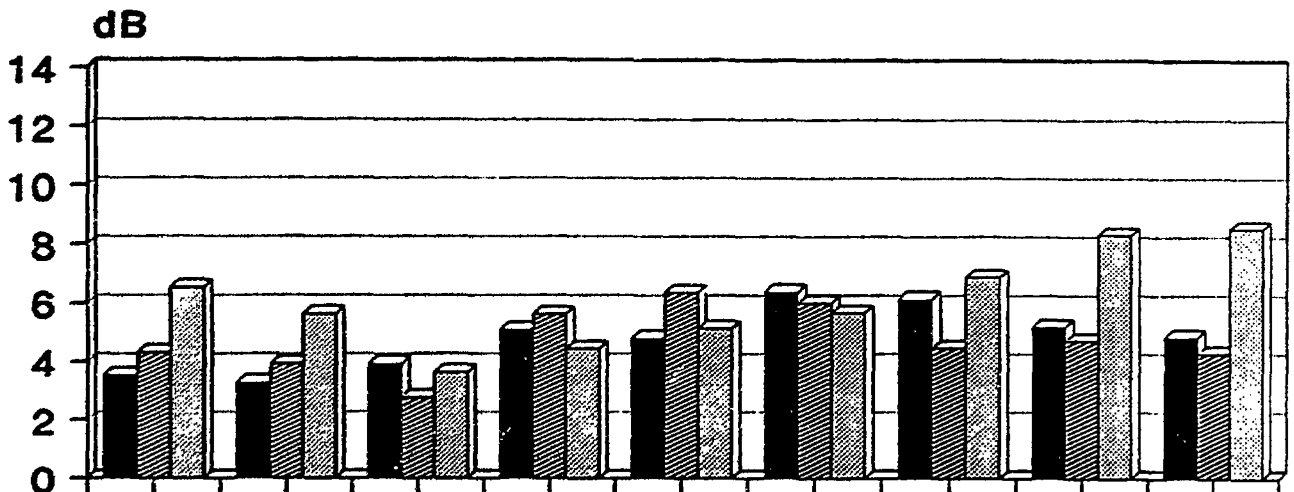


	125	250	500	1000	2000	3150	4000	6300	8000 Hz
KAISER	11	9	12	28	38	44	44	41	44
GEC	13	11	9	20	35	42	41	46	48 dB
HONEYWELL	12	7	9	23	29	40	41	42	42

KAISER GEC HONEYWELL

REAL EAR MEASUREMENTS, ANSI 12.6-1984

FIGURE 2
STANDARD DEVIATION



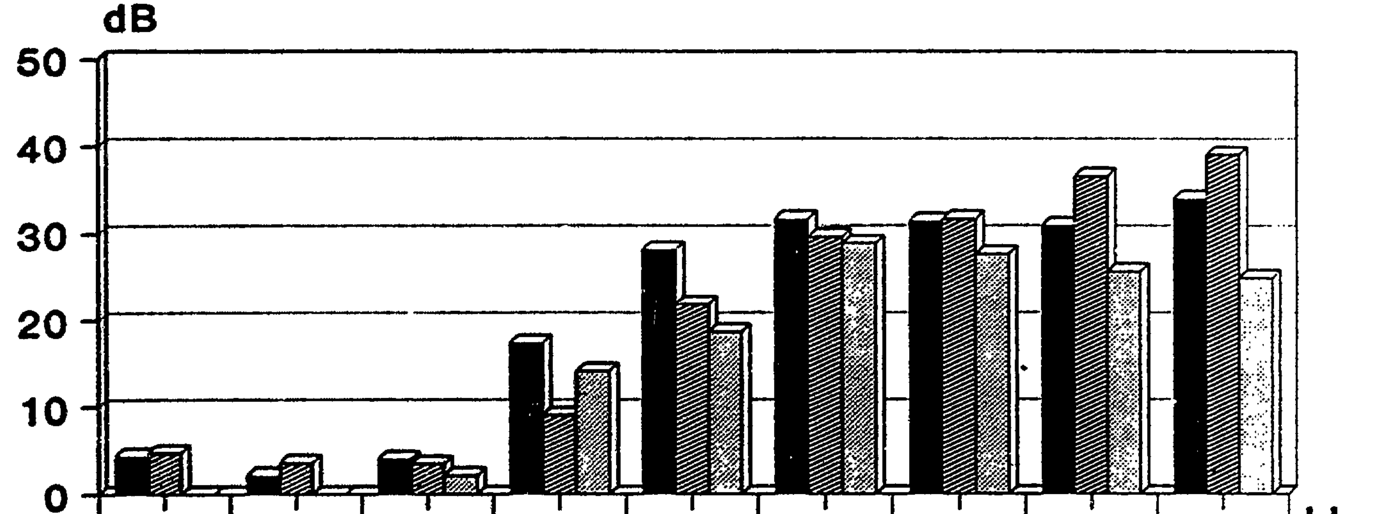
Hz	125	250	500	1000	2000	3150	4000	6300	8000
KAISER	3.55	3.28	3.94	5.1	4.8	6.38	6.15	5.21	4.84
GEC	4.3	3.93	2.76	5.63	6.34	6.01	4.45	4.7	4.26
HONEYWELL	6.52	5.64	3.64	4.43	5.14	5.67	6.89	8.32	8.55

dB

KAISER GEC HONEYWELL

REAL EAR MEASUREMENTS, ANSI 12.6-1984

FIGURE 3
MEAN MINUS 2 STANDARD DEVIATIONS



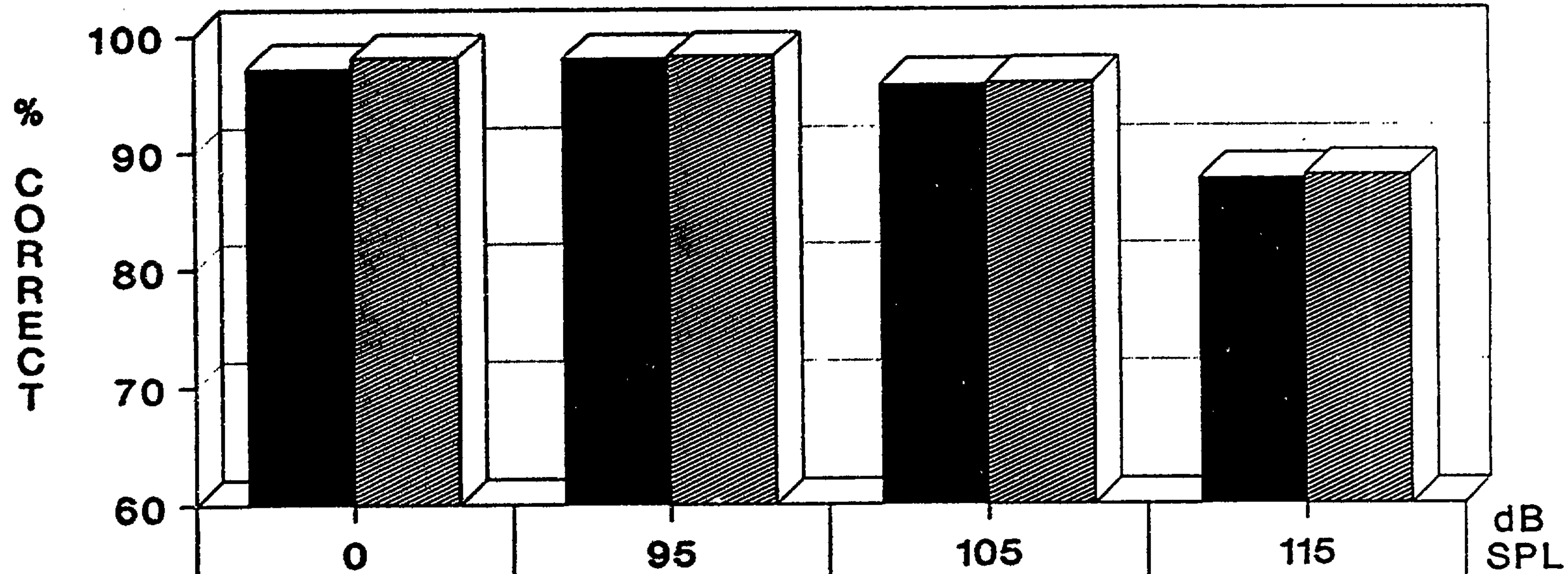
Hz	125	250	500	1000	2000	3150	4000	6300	8000
KAISER	4.37	2.17	4.06	17.43	28.16	31.61	31.37	30.87	33.99
GEC	4.79	3.6	3.5	9.07	21.87	29.64	31.64	36.58	39.02
HONEYWELL	0	0	2.17	14.14	18.69	28.87	27.62	25.62	24.9

dB

KAISER GEC HONEYWELL

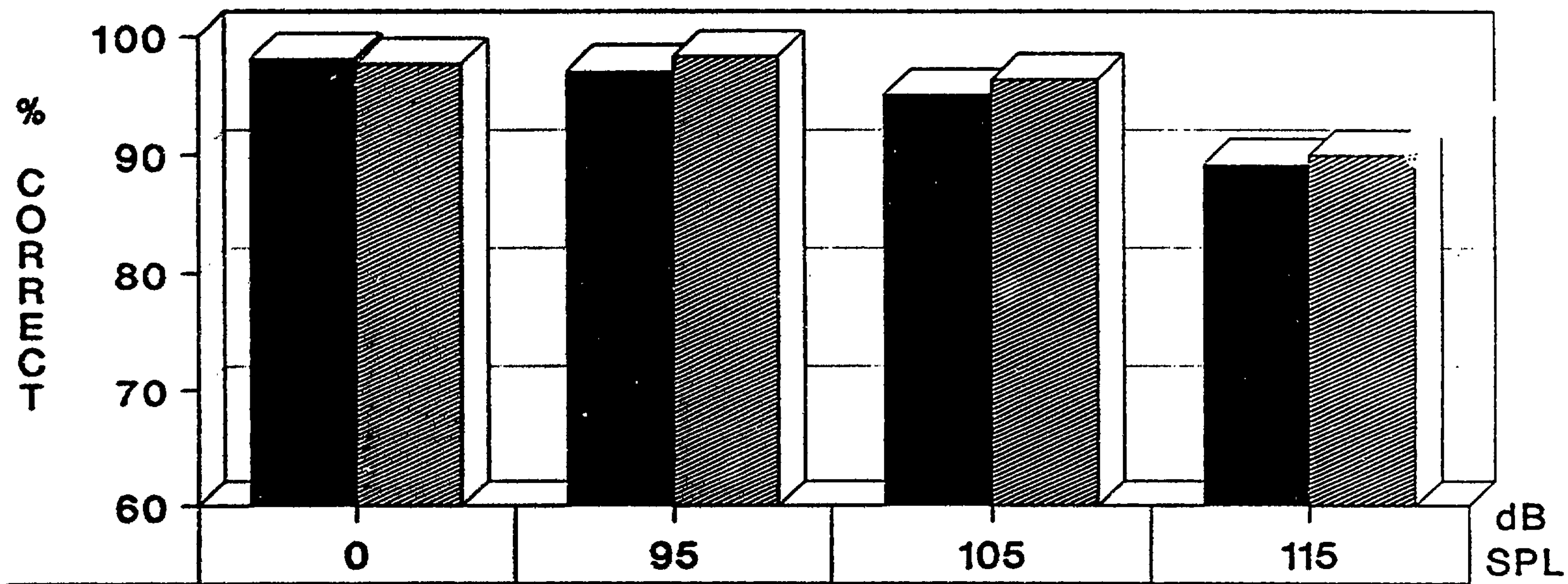
REAL EAR MEAURSEMENTS, ANSI 12.6-1984

FIGURE 4
SPEECH INTELLIGIBILITY
KAISER VS. 55P



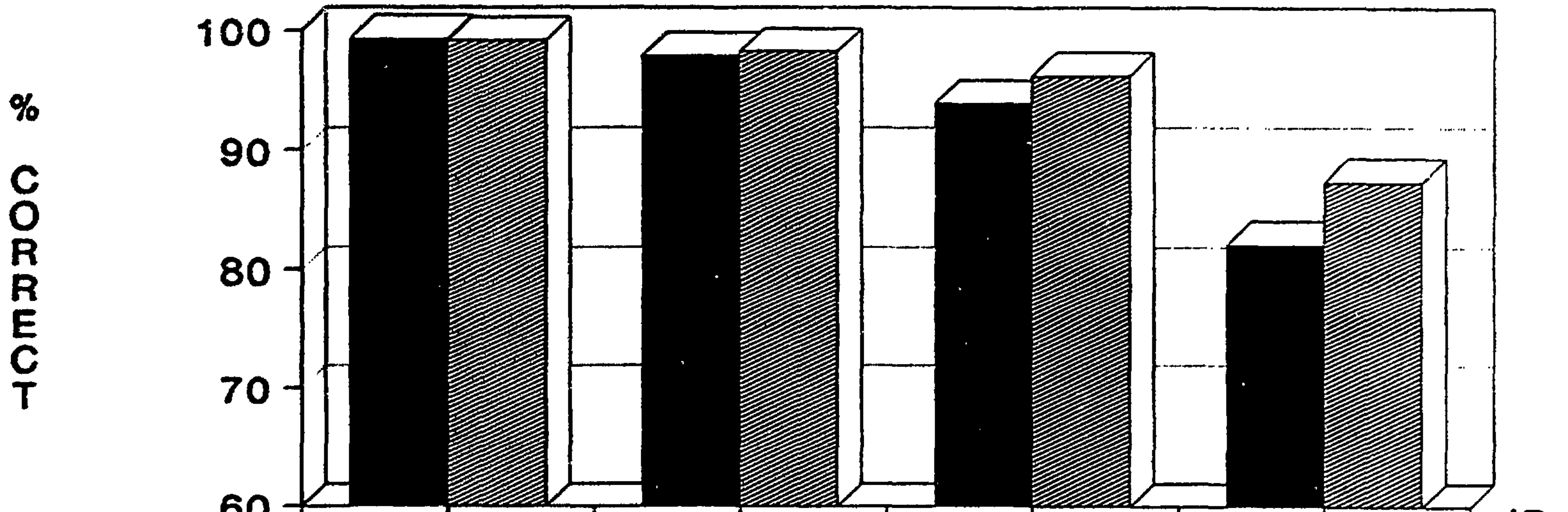
	0	95	105	115
KAISER	97.2	98	95.8	87.6
55P	98.05	98.15	95.9	87.85

FIGURE 5
SPEECH INTELLIGIBILITY
GEC VS. 55P



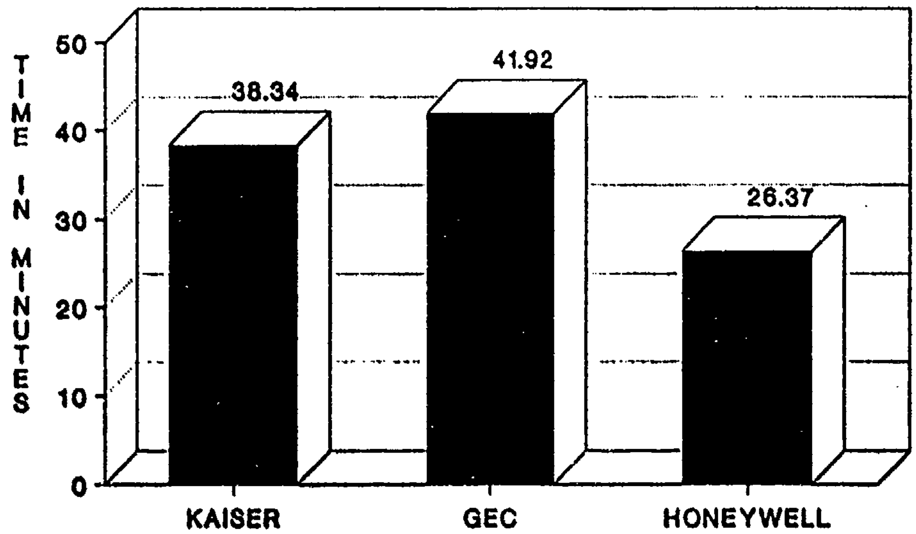
	0	95	105	115
GEC	98.2	97.2	95.2	89.2
55P	97.75	98.4	96.45	89.95

FIGURE 6
SPEECH INTELLIGIBILITY
HONEYWELL VS. 55P

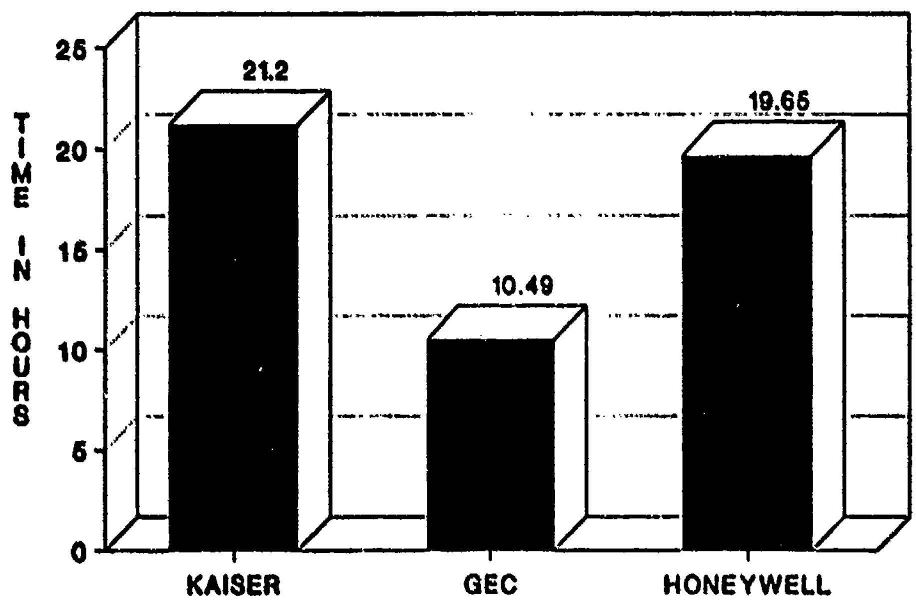


	0	95	105	115
HONEYWELL	99.4	98	94	82.2
55P	99.25	98.3	96.25	87.4

FIGURE 7
MAXIMUM DAILY EXPOSURE DURATION*
F16A PILOT



MAXIMUM DAILY EXPOSURE DURATION*
B52H PILOT



ACCORDING TO AFR 161-35 *

TABLE 1
SOUND ATTENUATION
MIL SPEC FOR HELMETS & I-NIGHT ATTENUATION DATA

	FREQUENCY IN Hz								
	125	250	500	1000	2000	3150	4000	6300	8000
MIL SPEC E-83425			23	32	35	35	35		
	SUM > 23		SUM > 178					SUM > 60	
KAISER	11	9	12	28	38*	44*	44*	41	44
	SUM = 21		SUM = 166					SUM = 85*	
GEC	13	11	9	20	35	42*	41*	46	48
	SUM = 24*		SUM = 147					SUM = 94*	
HONEY-WELL	12	7	9	23	29	40*	41*	42	42
	SUM = 19		SUM = 142					SUM = 86*	

* MEETS MIL SPEC

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APPENDIX F

DYNAMIC SYSTEM PERFORMANCE: CENTRIFUGE

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APPENDIX F: DYNAMIC SYSTEM PERFORMANCE: CENTRIFUGE

1. INTRODUCTION

The Helmet-mounted systems used by aircrew members must be comfortable and remain stable when subjected to the forces of high G maneuvers. Helmet instability could restrict the aircrew from performing certain maneuvers or continuing the mission. This report describes the dynamic centrifuge evaluation of three helmet-mounted systems developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. The evaluation was accomplished by the Combined Stress Branch, Biodynamics and Biocommunications Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

2. APPROACH

The comfort and stability of three I-NIGHTS helmets and the standard Air Force helmet (HGU-55/P) worn by trained subjects was evaluated in the Dynamic Environment Simulator. A unique test setup measured the visible image seen by the test subject while wearing a helmet-mounted system while under various Gz and Gy loadings. As G loadings increase the helmet can shift (instability) and the visible image, as seen by the test subject, can decrease. This decrease in image, call image migration, is a measure of the helmet's instability for a given force component.

3. OBJECTIVE

The objective of this evaluation is to determine the comfort and stability of the I-NIGHTS helmets while encountering simulated flight maneuvers. This determination will aid in a suitability assessment of these helmets for actual flight test.
NOTE: Helmet "A" is GEC. Helmet "B" is Honeywell. Helmet "C" is Kaiser.

2LT Eric L. Scarborough
AAMRL/BBS 54096
14 Aug 89

NVG/HMD CENTRIFUGE TESTING

A. SYNOPSIS

AAMRL/BBS has been asked to provide a test plan summary to address Safety of Flight (SOF) qualification for the I-Nights custom helmet prototypes and the ITT/Merlin add-on in the area of centrifuge testing. This plan will allow for SOF qualification and also establish a database for future testing of Night Vision Goggles (NVG) and Helmet Mounted Display (HMD) systems.

B. CRITICAL ISSUES:

PRIMARY:

1. Does the system operate under sustained acceleration?

2. Does the NVG or NVG/HMD provide an operationally useful display throughout a sustained Gz profile? (Can the pilot feel confident that he/she will receive usable vision/display information during G maneuvers?)

4. Does wearing and using the device affect the pilot's situational awareness adversely?

C. TEST OBJECTIVES

1. Determine that the display/night vision system equipment operates under sustained +/-Gz and +/-Gy.

2. Determine if the display/night vision system provides usable visual information at typical acceleration levels.

3. Investigate pilot's ability to judge his orientation while NVG/HMD is operating.

D. APPROACH

A series tests will be done in the AAMRL/BBS Dynamic Environment Simulator (DES) to test the I-Nights prototypes and the ITT/Merlin prototype. Three tests are proposed, the

E. COST

The costs shown below are broken out to show what each of the three tests will cost separately and also totaled.

1. EQUIPMENT OPERATION TEST
   - CENTRIFUGE TIME
   - MOUNTING
   - CIV LABOR + OVERHEAD

   SUBTOTAL

2. PERFORMANCE TEST
   - CENTRIFUGE TIME
   - LOW LIGHT LEVEL TV CAMERA
   - CIV LABOR + OVERHEAD

   SUBTOTAL

3. SITUATIONAL AWARENESS TEST
   - CENTRIFUGE TIME
   - STATISTICS
   - CIV LABOR + OVERHEAD

   SUBTOTAL

   GRAND TOTAL $

F. SCHEDULE:

AAMRL/BBS will need each device for 3 weeks to accomplish the testing. We feel that we could begin the testing as soon as the helmets, manikin and display electronics are available, and schedule this around our ongoing experiments. Once the centrifuge tests are completed a period of two months will be required for analysis and reporting.

METHODS FOR TEST AND EVALUATION OF NIGHT VISION GOGGLE INTEGRATED HELMETS

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Three Interim Night Integrated Goggle Head Tracking Systems (I-NIGHTS) were evaluated under sustained acceleration in the Dynamic Environment Simulator (DES) centrifuge located at Wright-Patterson AFB, OH. Ten subjects underwent three different high G profiles: a +8Gz maximum profile, a +4Gz maximum profile with mask dangling from the left side of the helmet, and a +4Gz maximum profile with the mask removed from the helmet. Four different helmets were tested; three (A, B, and C) were prototype I-NIGHTS helmets obtained from different manufacturers and the fourth helmet (D) was the standard HGU-55P. Comparisons between helmets A, B, and C revealed that subjects wearing helmet A experienced the greatest amount of image migration for all acceleration profiles. Helmet B was impacted most by "goodness of fit" during the conditions where the mask was either dangling from the helmet, or removed. Of the three I-NIGHTS helmets, helmet C performed the best in terms of helmet and image stability.

INTRODUCTION

When night vision goggle (NVG) capability was taken from the ground troop scenario and introduced into the flight regime, NVGs were mounted forward on standard helmets for visual access by the pilots. Problems with forward-mounted NVGs included altered helmet center-of-gravity (Rash and Martin, 1988), visibility problems concerning limited peripheral vision and low signal-to-noise ratios of the projected visual scene (Brickner, 1989), basic helmet instability which influenced vision and safety of escape sequences (Darrah, Seavers, Wang and Dew, 1986; Cammarota, 1985) and component integrity under acceleration (Cammarota, 1985). Efforts by the U.S. Air Force and Navy to address the above issues resulted in the development of Interim Night Integrated Goggle Head Tracking Systems (I-NIGHTS) developed by three separate manufacturers. The systems included NVGs integrated directly into the helmets, hopefully improving visual quality and helmet stability. The three I-NIGHTS helmets were evaluated and compared to each other, as well as to the standard flight helmet under sustained acceleration in the Dynamic Environment Simulator (DES) centrifuge (Figure 1) located at Wright-Patterson Air Force Base, Ohio. This test & evaluation effort was conducted in an attempt to quantify the effects of high G forces on I-NIGHTS component integrity, helmet stability, and migration of the intensified image in relation to the human field-of-view before the systems are deployed in operational aircraft.

METHODS

Unmanned Component Integrity Testing

The first evaluation concerned testing the I-NIGHTS helmets under +Gz for component integrity. A manikin was seated and strapped into the cab, and each of the I-NIGHTS helmets was placed on the manikin's head. After exposure to +9Gz, the helmets were removed and examined for damage. The evaluation then passed into manned testing after component integrity was established (all three I-NIGHTS helmets passed this test).

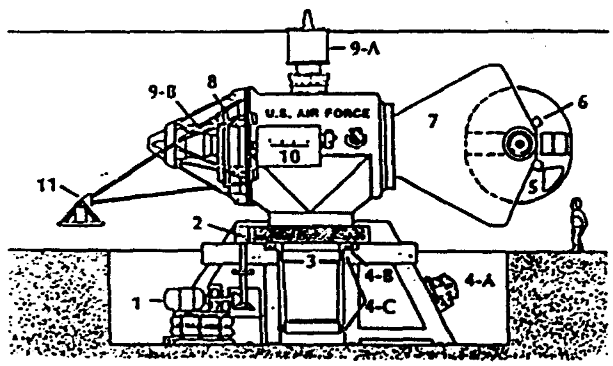

FIGURE 1. The Dynamic Environment Simulator (DES). 1) Main arm drive motor; 2) Drive pinion; 3) Main rotating trunion and bull gear; 4a) Hydraulic pumps; 4b) Thrust pad; 4c) Upper and lower radial pads; 5) Cab; 6) Cab drive motor; 7) Fork; 8) Fork drive motor; 9a) Main arm slip rings; 9b) Fork slip rings; 10) Motor driven counterweight; 11) Aft-mounted platform.

Manned Testing

Subjects. Eight male subjects and two female subjects, ages 24 to 37, were obtained from the Acceleration Subject Panel (all had passed extensive medical examinations). Subjects also underwent a fit assessment for each I-NIGHTS helmet and were classified into one of two categories: 1) fit failure, and 2) fit pass. It should be noted here that not all 10 subjects were able to undergo acceleration with all three helmets for various reasons (subject attrition, unavailability of helmets, etc.). For helmet A, 10 subjects were included, for helmet B, 8 subjects, and for helmet C, 9 subjects.

High G Profiles. Subjects randomly underwent three different high G profiles: 1) +8Gz maximum (onset rate=+0.1Gz/sec; offset rate=-0.5Gz/sec), 2) +4Gz maximum (onset/offset rate=+/-0.5Gz/sec) with mask dangling from the left side of the helmet, and 3) +4Gz maximum (onset/offset rate=+/-0.5Gz/sec) with mask removed from the helmet. Lights within the DES cab were extinguished and subjects were monitored via low light-level television cameras.

Helmets. Four different helmets were tested. Helmets A, B, and C were prototype I-NIGHTS helmets obtained from different manufacturers. Helmet D was the standard HGU-55P helmet.

Experimental Set-up. The experimental set-up is shown in Figure 2. Migration of the intensified image was obtained by having subjects manipulate a circle displayed on the centrifuge visual display system via a control stick, while simultaneously keeping a helmet-mounted pointer light within a target in the middle of the screen (Figure 3). Subjects were instructed to place the circle within the area on the screen which was visible to them.

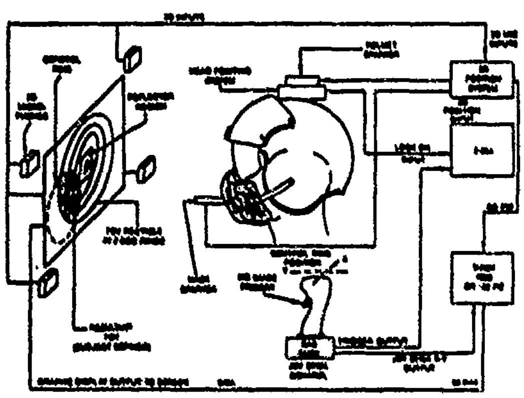

FIGURE 2. Data Collection Set-Up.

Off-center displacement of the circle was then calculated, but only if the pointer light was located within the target on the center of the screen (which assured that displacement data were collected only while subjects' helmets were in an upright position). This displacement was taken as a measure of NVG image migration during acceleration. In addition, subjective opinions of helmet shift, the need to reposition the helmet after acceleration, and presence/absence of discomfort were also obtained.

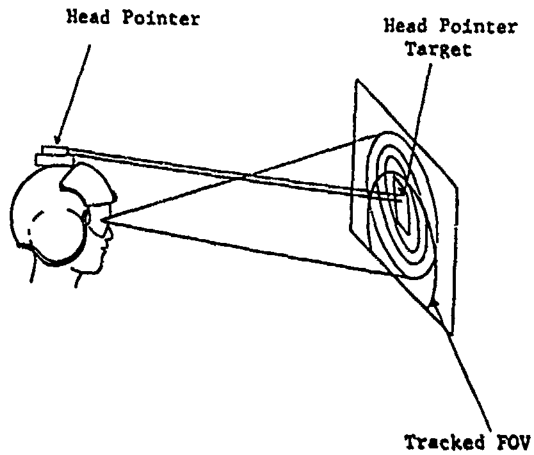

FIGURE 3. Head Pointer/Target and Tracked FOV.

RESULTS

Comparison of Standard to the I-NIGHTS: Measurement Validity

The first statistical analyses concerned the comparison of the standard helmet to the three I-NIGHTS helmets as a check on measurement validity (the standard helmet, while possessing no NVG capability, should outperform the I-NIGHTS helmets in terms of image migration and subjective opinions of helmet shift, etc.). The standard helmet was superior to all of the I-NIGHTS helmets in terms of image migration according to t-tests ($p < 0.05$) comparing each helmet with the standard during the +8Gz profile and the two +4Gz profiles. Image migration was virtually nonexistent for the standard helmet, which was expected. In addition, Wilcoxon rank scores obtained from the subjective measures showed that the standard helmet was more comfortable and stable under acceleration than the I-NIGHTS helmets. Having established evidence of measurement validity in this way, the following results focus on comparisons between the I-NIGHTS helmets without the standard included.

Comparisons Between I-NIGHTS Helmets

Effects of Fit Assessment. For the +8Gz profile, none of the helmets showed a significant advantage or disadvantage for pass/fail of fit for image migration. For the two +4Gz profiles, helmet B showed a significant difference for pass/fail of fit (Figure 4). Those subjects with a pass rating on fit had less image migration than those with a fail rating for both the mask dangling and mask removed conditions according to t-test probabilities. Helmets A and C showed no such effects. Unfortunately, analyses broken down by fit assessment had such small N sizes for the pass and fail categories that further statistical comparisons by fit assessment were rendered invalid. The statistics reported below were performed for data collapsed across fit category.

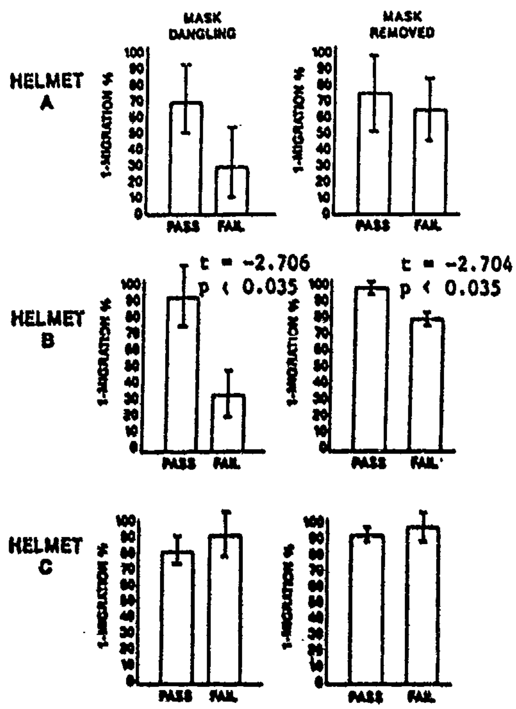

FIGURE 4. Effects of Fit Assessment for Both +4Gz Profiles (Mask Dangling and Mask Removed).

+8Gz Profile. Comparisons of image migration between helmets A, B, and C resulted in an interaction between +Gz level and helmet type, $F(14,105)=5.19$, $p < 0.0001$ (see Figure 5). According to paired comparisons, helmet A performed worse than helmets B and C at +Gz levels of 5 to 8, whereas there were no differences between B and C at any +Gz level.

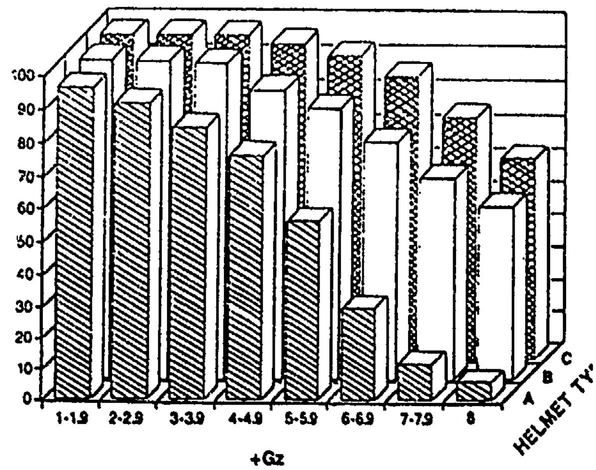

FIGURE 5. The Effects of Up to +8Gz on the Three I-NIGHTS Helmets.

+4Gz Profiles. When comparing the effects of having the mask dangling from the helmet or removing the mask, only helmet B showed significant effects for image migration (Figure 6). For helmet B, the weight of the mask dangling from the helmet caused more image migration than when the mask was removed.

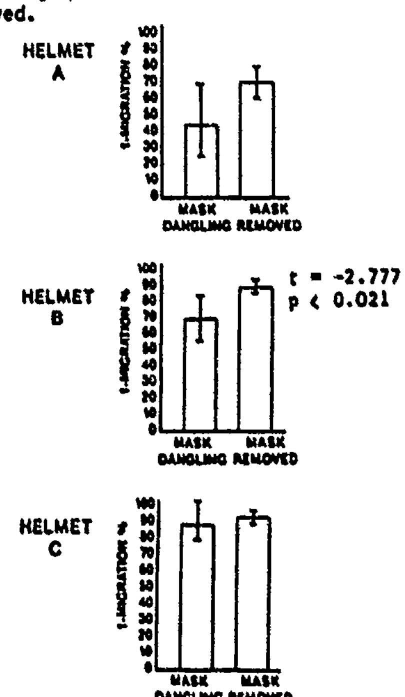

FIGURE 6. The Effects of Mask Dangling or Mask Removed Under +4Gz.

T-tests for all possible combinations of the three helmets revealed a greater degree of image migration for helmet A when compared to C for both the mask dangling and mask removed conditions (Figure 7.) No other comparisons were significant.

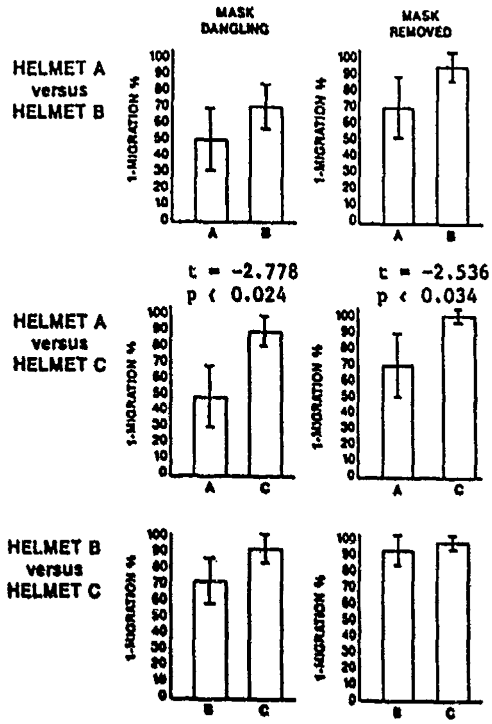

FIGURE 7. Comparisons of I-NIGHTS Helmets by Mask Dangling or Mask Removed Under +4Gz.

Subjective Evaluations. Wilcoxon rank score comparisons of subjective ratings between helmets A, B, and C showed no significant differences for any comparisons. However, discernible patterns were apparent within the raw data. Table 1 shows the patterns for subjective helmet shift. Subjects wearing helmet A seemed to experienced the greatest amount of helmet shift for the +8Gz and +4Gz mask dangling profiles. Table 2 shows subjective opinions of image migration. Image migration appears to be greater for helmets A and B during the +8Gz and +4Gz mask dangling profiles. Table 3 shows the patterns for the need to reposition the helmet after acceleration. It seems that subjects needed to reposition helmet A more often than B or C after acceleration during all profiles. According to Table 4, subjects apparently experienced a slight increase in discomfort while wearing helmet C.

TABLE 1. Subjective Helmet Shift.

"Did the helmet shift during acceleration"?

	+8Gz		+4Gz Mask Dangling		+4Gz Mask Removed	
	Y	N	Y	N	Y	N
Helmet A	10	0	10	0	7	3
Helmet B	4	4	6	2	4	4
Helmet C	5	4	5	4	5	4

TABLE 2. Subjective Image Migration.

"Did you lose any field-of-view"?

	+8Gz		+4Gz Mask Dangling		+4Gz Mask Removed	
	Y	N	Y	N	Y	N
Helmet A	10	0	10	0	7	3
Helmet B	8	0	7	1	5	3
Helmet C	6	3	6	3	4	5

TABLE 3. Need to Reposition Helmet.

"Did you need to reposition helmet after acceleration"?

	+8Gz		+4Gz Mask Dangling		+4Gz Mask Removed	
	Y	N	Y	N	Y	N
Helmet A	10	0	10	0	6	4
Helmet B	5	3	4	4	2	6
Helmet C	5	4	5	4	1	8

TABLE 4. Discomfort.

"Did you experience any discomfort"?

	+8Gz		+4Gz Mask Dangling		+4Gz Mask Removed	
	Y	N	Y	N	Y	N
Helmet A	3	7	3	7	3	7
Helmet B	4	4	4	4	4	4
Helmet C	6	3	6	3	5	4

Conclusions. The above experimental tools allowed for the quantification of differences between three I-NIGHTS helmet designs under sustained acceleration. As expected, the standard helmet out-performed all three I-NIGHTS helmets in terms of image migration, repositioning of helmet and downward shift (of course, the standard helmet provided no night vision capability). In terms of image migration, helmet A exhibited the poorest performance when compared to B and C. In addition, the effects of "goodness of fit" impacted helmet B during the conditions when the mask was either dangling from the helmet or removed. Fit issues for helmet B must be addressed. While helmet C performed the best in terms of image migration and fit, there seemed to be a slight increase in discomfort while wearing this helmet during acceleration.

ACKNOWLEDGEMENTS

The authors wish to thank Steve Bolia of Systems Research Laboratories, Inc., for assistance with the hardware set-up, and Maj Steve Popper and MSgt Bob Raymond of Armstrong Laboratory, Det 1, for subject panel medical monitoring and scheduling.

NOTE

For further information concerning the issues of Helmet Mounted Systems T&E send a standard blank VHS video cassette to: Kathy McCloskey, AL/CFBS, Wright-Patterson AFB, OH 45433-6573.

We will send you the taped version of the 5th Interservice/Industry Acceleration Colloquium entitled "Augmented and Advanced Helmets in a Dynamic Acceleration Environment."

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RESULTS AND IMPLICATIONS OF THE I-NIGHTS NVG TEST STRUCTURE

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ORAL PRESENTATION FOR THE I-NIGHTS COLLOQUIUM

OVERHEAD 1

This portion of the presentation deals with the night vision goggle results, and the implications of these results, obtained from the test structure Bob Esken has just defined.

OVERHEAD 2

To reiterate, tracked image migration measures were obtained from subjects wearing all three I-NIGHTS prototype helmets, A, B, and C, as well as the standard helmet, during 7 different acceleration profiles. The first was the positive 8 Gz gradual onset run. We also examined image migration during the offset portion of this profile. The second was a simulated aerial combat maneuver profile, or SACM. The SACM consisted of alternating G-peaks. We examined the effects of the SACM profile both in terms of G-peak level, and order of appearance. We used these two analyses to determine the relative effects of absolute G-level versus the effects of accumulated exposures. The third and fourth were positive 4 Gz profiles where the mask was either dangling from the left side of the helmet, or removed altogether. These profiles were used to emulate a helicopter scenario, as well as slower aircraft such as bombers, where pilots sometimes remove a mask bayonet and let the mask dangle during various portions of their sorties. The fifth and sixth were positive and negative, or left and right, 1.5 Gy profiles, and the seventh was a negative 1 Gz profile. These three profiles were used to emulate side-to-side and foot-to-head forces sometimes found in helicopters during nap-of-the-earth flight, and high-performance aircraft, especially during supermaneuvers, such as the Cobra.

OVERHEAD 3

Recall that time-on-target measures were obtained via the head-mounted pointer system which Bob had explained earlier. We hypothesized that total percentage of time-on-target might correlate with neck strength of the subjects, especially under increased G-forces. We collected static neck strength forces in four directions; specifically, forward, backward, left, and right.

OVERHEAD 4

This vu-graph shows the experimental set-up for obtaining neck strength values in pounds. A simulated ACES II seat, with a 30 degree seatback angle, was used. Subjects were seated and the head band was placed around the head at forehead level. The band was attached to the load cell mounted on the wall to the side of the seat. The connection between the head band and load cell was a chain which had no "give," so that subjects were pushing against an unmovable strap (which elicited isotonic, or static, force generation). The output to the load cell was processed by a computer we obtained from Dr. Joe McDaniel of the Human Engineering Division here at Det 1. A conversion program within the computer automatically transformed the load cell information into force in pounds.

OVERHEAD 5

A subjective questionnaire was given to each subject after he or she had completed all seven profiles. Thus, four separate questionnaires were obtained (one for each I-NIGHTS helmet and the standard). A total of 31 items were included in the paper-and-pencil form, but only a few of the results will be presented today due to time constraints.

OVERHEAD 6

As can be seen, the experimental design was a pseudo-random matrix. Condition orders 1, 2, and 3 were randomly assigned by subject. The order in which subjects wore the helmets was also randomized. Not all subjects completed each cell due to subject attrition, helmet availability, and problems with fit for those subjects who wore glasses. Subsequently, 10 subjects were included for helmet A, 8 subjects for helmet B, and 9 subjects for helmet C.

OVERHEAD 7

Subjects ran the standard HGU-55P helmet for all profiles as a check on measurement validity. The standard outperformed all three I-NIGHTS helmets in terms of image migration, helmet stability, and subjective evaluations. Of course the standard helmet offered no night vision capabilities, yet served to suggest a degree of validity in our measurement techniques.

OVERHEAD 8

The results for the positive 8Gz gradual onset profile concerning image migration are shown here. There was a significant interaction between helmet type and G-level. According to paired comparisons, helmet A had more image migration than B and C at G-levels of 5 to 8, whereas there were no significant differences between B and C at any G-level.

OVERHEAD 9

For the offset portion of the positive 8Gz profile, there was a significant main effect for helmet type. Helmet A had more image migration than B or C. In addition, there was a significant main effect for G-level. At G-levels of 7 to 4 for all 3 helmets, image migration was worse than at 2 to baseline during offset.

OVERHEAD 10

This table shows the G-levels where subjects completely lost the night vision goggle image. For helmet A, 9 out of 10 subjects lost visuals at a mean G-level of 6.12. For helmet B, 3 out of 8 subjects lost visuals at a mean G-level of 6.33. And for helmet C, 2 out of 9 subjects lost visuals at a mean G-level of 7.45.

OVERHEAD 11

There was some question as to whether or not visuals would return as G was offloaded. For helmet A, only one of the 9 subjects who lost visuals recovered at lower G-levels. For helmet B, only one of the 3 subjects recovered, and for helmet C, one of the 2 recovered visuals.

OVERHEAD 12

For the SACM profile, the effects of G-level can be seen. There was a significant interaction between G-level and helmet type. Image migration was worse for helmets A and B during G-levels above 4. Helmet C did not show this effect.

OVERHEAD 13

There was also an interaction for order effect and helmet type for the SACM profile. Image migration was worse during the third to last peak for helmets A and B, while for helmet C there were no order effects.

OVERHEAD 14

For the positive 4Gz mask dangling profile, there was a significant effect of helmet type concerning image migration. Image migration was worse for helmet A than for helmet C.

There were no significant differences between helmets for the positive 4Gz mask removed profile.

OVERHEAD 15

For the positive and negative 1.5Gy profiles there were no significant differences concerning image migration between the three I-NIGHTS helmets. However, for the negative Gz profile, helmet C was worse in terms of image migration than helmets A and B. This was the only profile in which helmet C was worse than either A or B.

OVERHEAD 16

When we performed regression analyses concerning the relationship between time-on-target and neck strength, the only condition which showed an effect was the positive 1.5 Gy profile, and THEN only for helmet A. During this condition, subjects were turned on their left side. The seat configuration was such that there was an arm rest and force stick on the right side, but none on the left. Consequently, when subjects were turned on their left sides, they had nothing to hold on to and steady themselves. In addition, helmet A was the most unstable of the three helmets. The degree of neck strength each subject possessed predicted the amount of time they could hold the head-mounted pointer on the target, at least for helmet A. For forward and backward neck strength, the R-squared values for time-on-target were 0.6675 and 0.7378, respectively.

OVERHEAD 17

For leftward and rightward neck strength, R-squared values for time-on-target were 0.5679 and 0.6868, respectively.

OVERHEAD 18

Selected items from the subjective questionnaire showed results that in some instances conflicted with the above image migration patterns, in some cases confirmed the patterns, and in others showed no differences one way or another. This vu-graph depicts the responses to the question of helmet weight. Helmet A is rated heavy or very heavy by 7 of the 10 subjects. For helmets B and C, the distribution suggests relatively neutral ratings.

OVERHEAD 19

This vu-graph depicts the responses to the question of helmet stability. Helmet A is rated unacceptable by 6 of the 10 subjects. Helmet B is rated good to excellent by 5 of the eight subjects. Helmet C is rated good to excellent by 4 of the 9 subjects, with 3 of the subjects remaining neutral.

OVERHEAD 20

Although the following results present no discernible patterns, other than a slight advantage for helmet B, they are important in terms of safety-of-flight. Neck discomfort DURING acceleration was rated maximal to strong only a total of 4 times for all three I-NIGHTS helmets.

OVERHEAD 21

Neck discomfort AFTER acceleration was rated moderate to none by the majority of subjects for all three I-NIGHTS helmets, with only a total of 3 ratings of strong to maximal neck discomfort.

OVERHEAD 22

Subjects were asked if they would recommend each helmet for use in helicopters. For helmet A, 4 recommended use, 4 did not, 1 remained neutral, and 1 abstained from rating. For helmet B, 6 recommended use, 1 did not, and 1 remained neutral. For helmet C, there was almost an even split between recomendation and rejection of the helmet for use in helicopters.

OVERHEAD 23

Subjects were also asked if they would recommend each helmet for use in high-performance aircraft. Results differed from those obtained with the helicopter question. The majority of subjects would NOT recommend helmets A or C for use in the cockpit. For helmet B, there was an almost even split between recommendation and rejection for use in high-performance aircraft.

OVERHEAD 24

The overall pattern of results for the three I-NIGHTS helmets are shown in this table. Briefly, helmet C outperformed helmets A and B in terms of image migration for the positive Gz profiles. The side-to-side profiles, positive and negative Gy, showed no discernible patterns, and are not given here. For the negative 1 Gz profile, helmet C showed a clear disadvantage. The degree of neck strength seemed to impact only helmet A in terms of being able to keep the head steady, at least for bodily displacement to the left side. Overall, helmet C performed the best and helmet A the worst, for positive Gz forces.

OVERHEAD 25

The interesting thing about the subjective data is that they do not always support the ordering of helmets by the image migration data outlined above. For weight and stability, subjective patterns DO support the migration results. For neck discomfort there are no discernible patterns. For recommendations for use in the helicopter, the order of helmets B and C were switched, with B superior to C. For recommendations for use in the high-performance aircraft, helmets A and C are equally rejected.

The reasons for this last result were ascertained through discussions with the subjects during the debriefing period. Overall, helmet A performed the worst in terms of image migration and helmet stablility, which directly led to its rejection for use in the cockpit. Helmet C, on the other hand, performed the best for image migration and stability during positive Gz, but was the least comfortable. Subjects felt that the stability of helmet C was due to the fact that it was extremely tight on the head, So tight in fact, that it was uncomfortable for even short periods of time. This perception was the reason why most subjects rejected it for use in the cockpit.

OVERHEAD 26

The implications of these findings for the three prototype helmets are summarized here. Briefly, assuring only helmet stability under high positive Gz of course does not assure that the helmet will be acceptable to the pilot population. Comfort seems to be a strong player in acceptability issues. There seems to be an inherent trade-off, at least for these three I-NIGHTS prototypes, between stability on the head, and comfort. For the pilot, the way in which this trade-off is resolved is of the utmost importance.

Thank you.

TRACKED IMAGE MIGRATION

Results were obtained from the following profiles:

- +8Gz Maximum
  - onset
  - offset

- Simulated Aerial Combat Maneuver (SACM)
  - G-level Magnitude Effects
  - Accumulative Order Effects

- +4Gz Mask Dangling

- +4Gz Mask Removed

- -1.5Gy

- +1.5Gy

- -1Gz

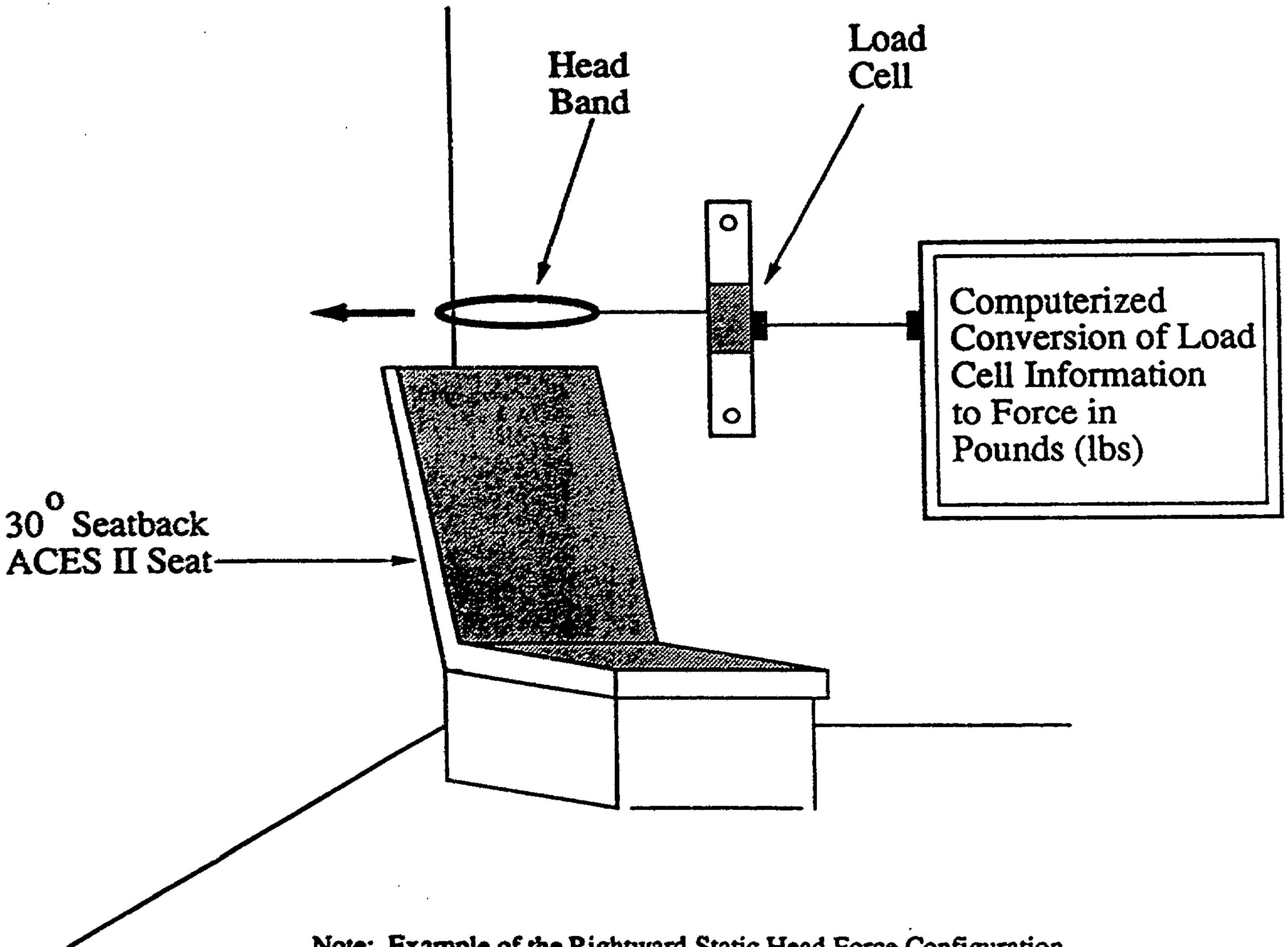
TIME-ON-TARGET

- Time-on-target data were regressed with neck strength data (in force lbs.)

- Neck strength data were obtained from static neck forces in 4 directions:

  - Forward
  - Backward
  - Leftward
  - Rightward

NECK STRENGTH SCHEMATIC



Note: Example of the Rightward Static Head Force Configuration.

SUBJECTIVE EVALUATION

- A paper-and-pencil questionnaire was administered for each helmet after subjects finished all profiles.

- A total of 31 items were included in the questionnaire.

EXPERIMENTAL MATRIX

SUBJECT	COND.	DAY 1	DAY 2	DAY 3	DAY 4
		HELMET	HELMET	HELMET	HELMET
1	1	A	B	C	D
2	3	D	C	B	A
3	2	A	D	B	C
4	3	C	D	A	B
5	2	B	A	D	C
6	1	D	B	C	A
7	1	C	B	A	D
8	3	B	A	D	C
9	2	A	C	B	D
10	3	C	D	A	B

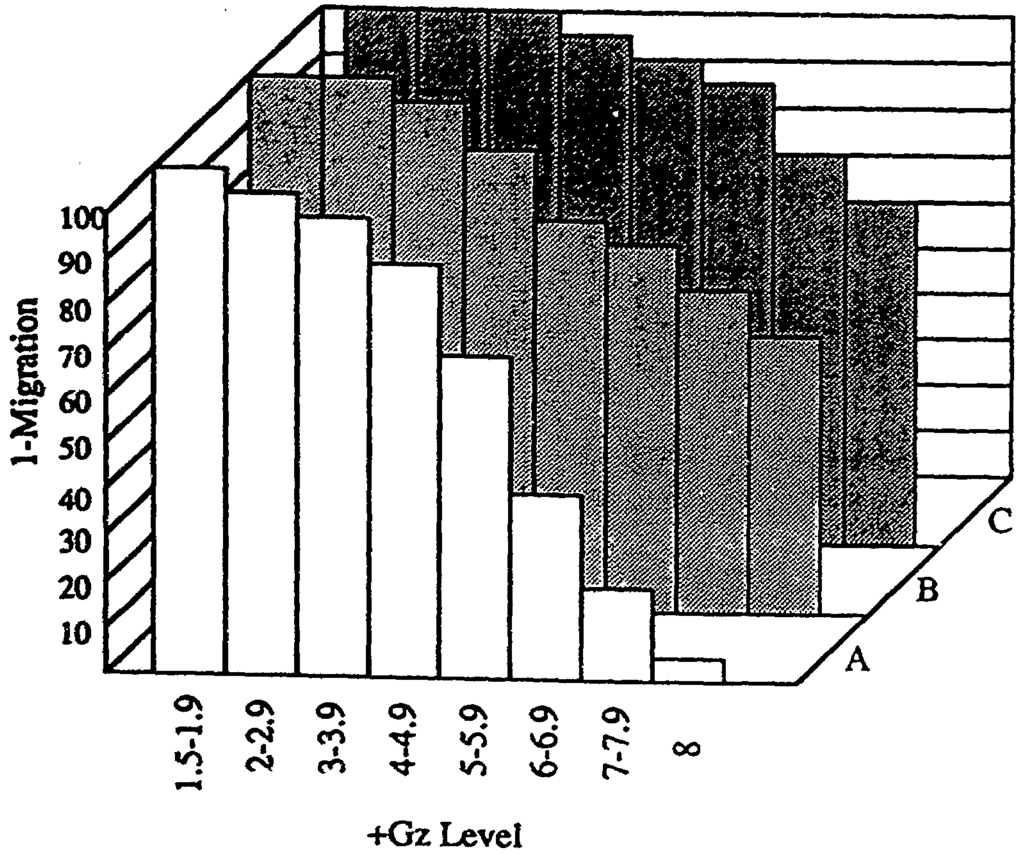
CONDITION KEY:
1: +8Gz, -1.5Gy, SACM, +1.5Gy, -1Gz, +4Gz, +4Gz
2: +8Gz, SACM, -1Gz, -1.5Gy, +1.5Gy, +4Gz, +4Gz
3: +8Gz, -1Gz, +1.5Gy, SACM, -1.5Gy, +4Gz, +4Gz

MEASUREMENT VALIDITY

- Subjects also wore the standard HGU-55P helmet throughout all conditions as a check on measurement validity.

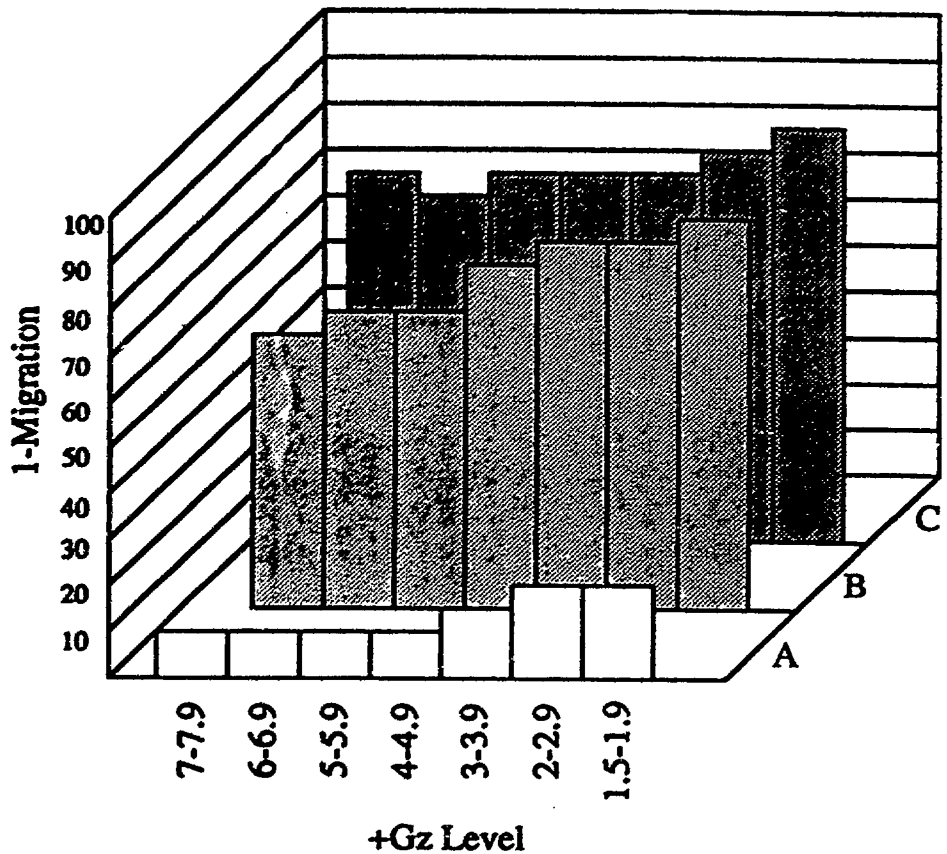
- The standard "outperformed" all three I-NIGHTS helmets for all measures.

+8Gz ONSET



100
90
80
70
60
50
40
30
20
10
1-Migration
1.5-1.9
2-2.9
3-3.9
4-4.9
5-5.9
6-6.9
7-7.9
8
+Gz Level
A
B
C

+8Gz OFFSET



1-Migration
100
90
80
70
60
50
40
30
20
10
7-7.9
6-6.9
5-5.9
4-4.9
3-3.9
2-2.9
1.5-1.9
A
B
C
+Gz Level

Night Vision Goggle (NVG) Evaluation.
+Gz Level Where Subjects Lost Visuals for the +8Gz GOR Profile.

	HELMET		
Subject Number	A	B	C
1	5.0	4.8	did not lose
2	5.4	8.0	did not lose
3	7.0	did not lose	did not lose
4	6.1	X	did not lose
5	5.0	did not lose	7.1
6	7.1	did not lose	did not lose
7	did not lose	did not lose	did not lose
8	6.9	6.2	7.8
9	6.6	did not lose	did not lose
10	6.0	X	X
	mean = 6.12 range = 5.0-7.1	mean = 6.33 range = 4.8-8.0	mean = 7.45 range = 7.1-7.8
	Note: 9 of 10 subjects lost visuals (90%)	Note: 3 of 8 subjects lost visuals (37.5%)	Note: 2 of 9 subjects lost visuals (22.2%)

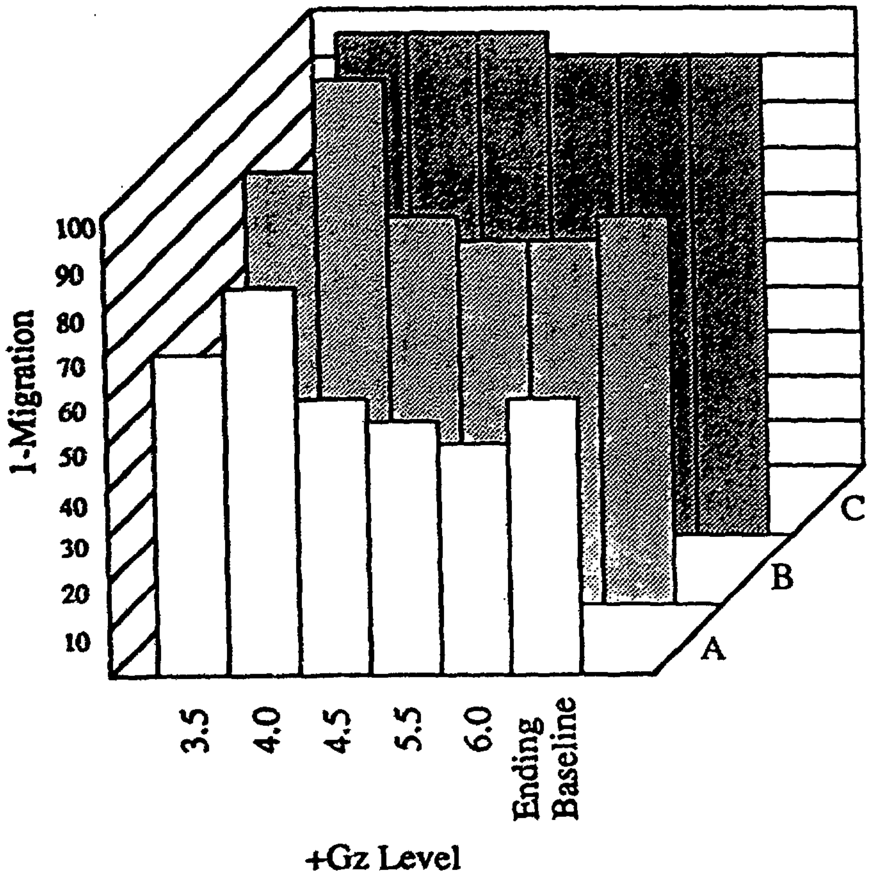
X = *missing data*

Night Vision Goggle (NVG) Evaluation.
+Gz Level Where Subjects Recovered Visuals During Offloading of G-Force for the +8Gz GOR Profile.

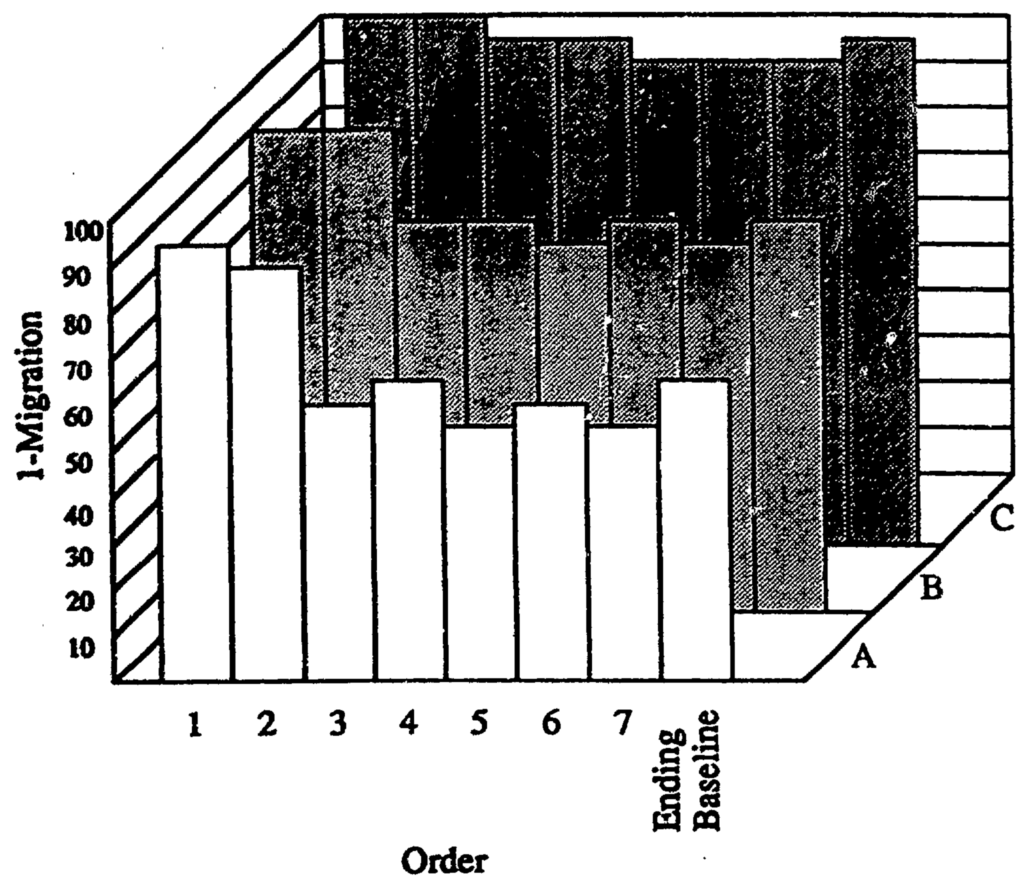
	HELMET		
Subject Number	A	B	C
1	never recovered	never recovered	did not lose
2	never recovered	32% recovered at +4Gz 88% recovered at +1.5Gz	did not lose
3	never recovered	did not lose	did not lose
4	never recovered	X	did not lose
5	never recovered	did not lose	never recovered
6	never recovered	did not lose	did not lose
7	did not lose	did not lose	did not lose
8	never recovered	never recovered	76% recovered at +1.5Gz
9	12% recovered at +3Gz 81% recovered at +1.5Gz	did not lose	did not lose
10	never recovered	X	X
	Note: of the 9 subjects who lost visuals, 1 recovered at lower G-level (11.1%)	Note: of the 3 subjects who lost visuals, 1 recovered at lower G-level (33.3%)	Note: of the 2 subjects who lost visuals, 1 recovered at lower G-level (50%)

X = *missing data*

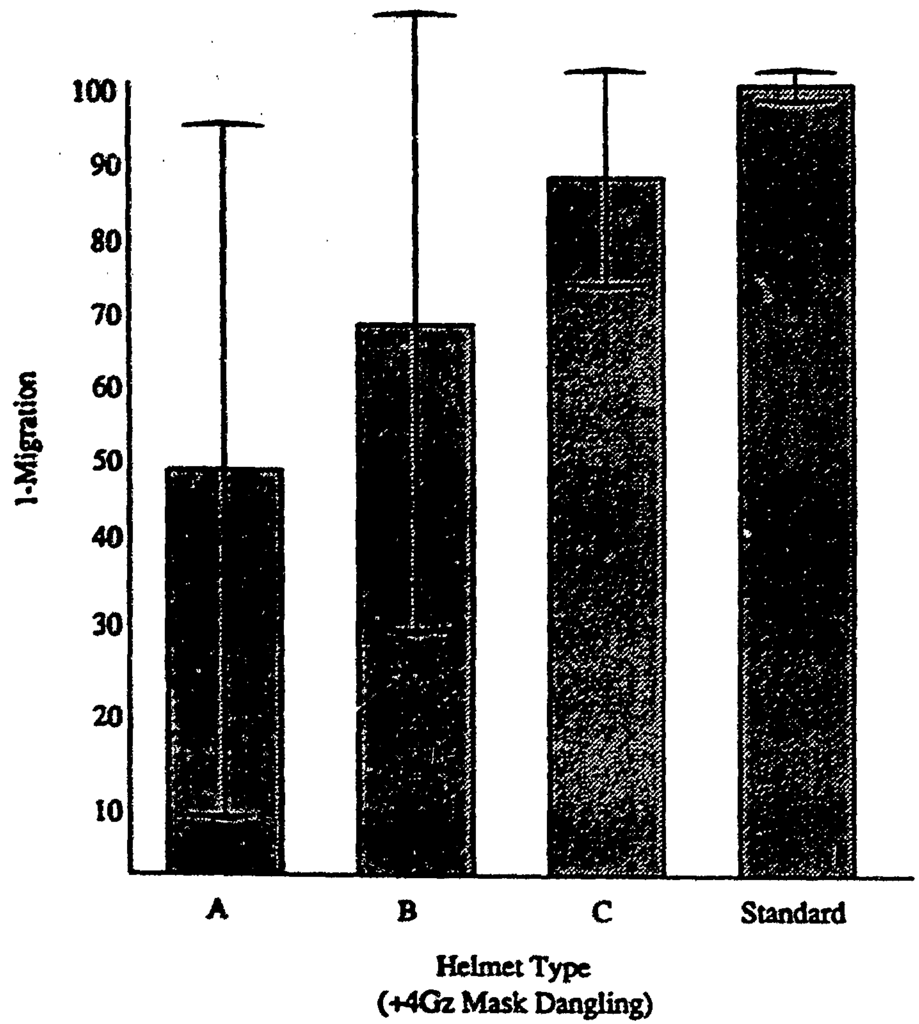
SACM G-LEVEL EFFECTS



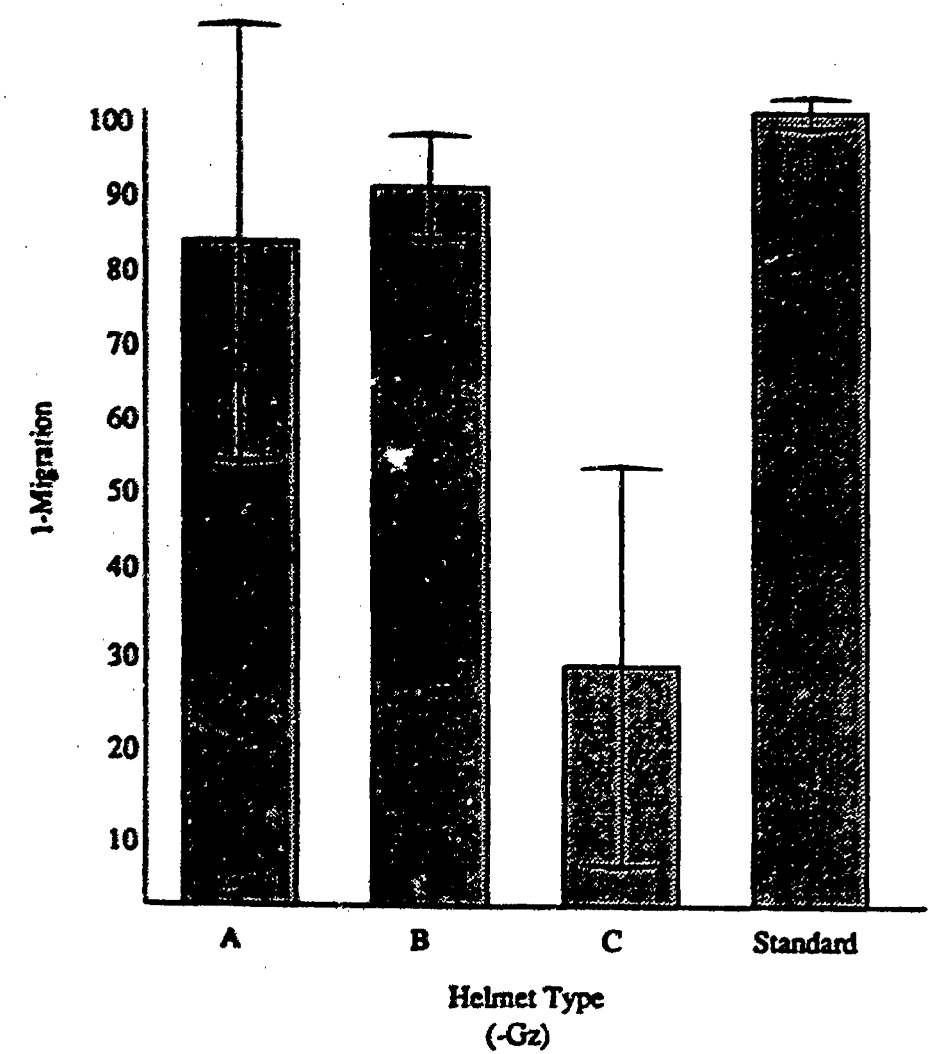
SACM ACCUMULATIVE EFFECTS



+4Gz MASK DANGLING FROM HELMET



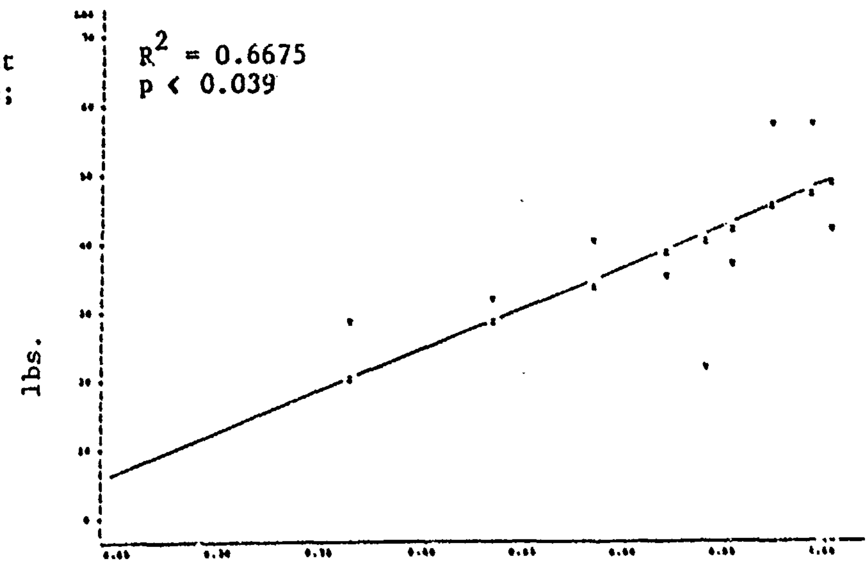
-1Gz PROFILE



100
90
80
70
60
50
40
30
20
10
1-Migration
A
B
C
Standard
Helmet Type
(-Gz)

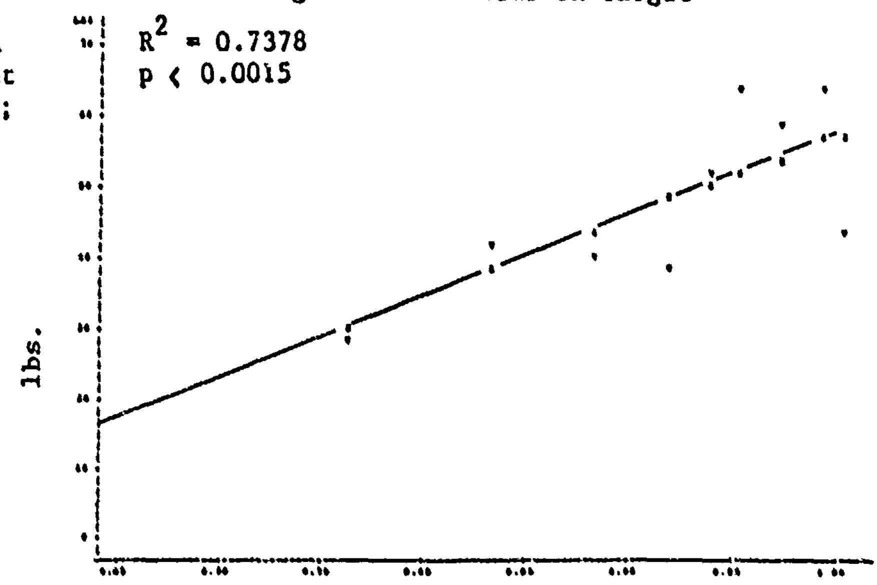
TIME-ON-TARGET REGRESSED WITH NECK STRENGTH FOR THE +1.5Gy PROFILE

a) FORWARD NECK STRENGTH crossed with time on target during the +1.5 Gy profile; helmet A.



Percentage of Total Time on Target

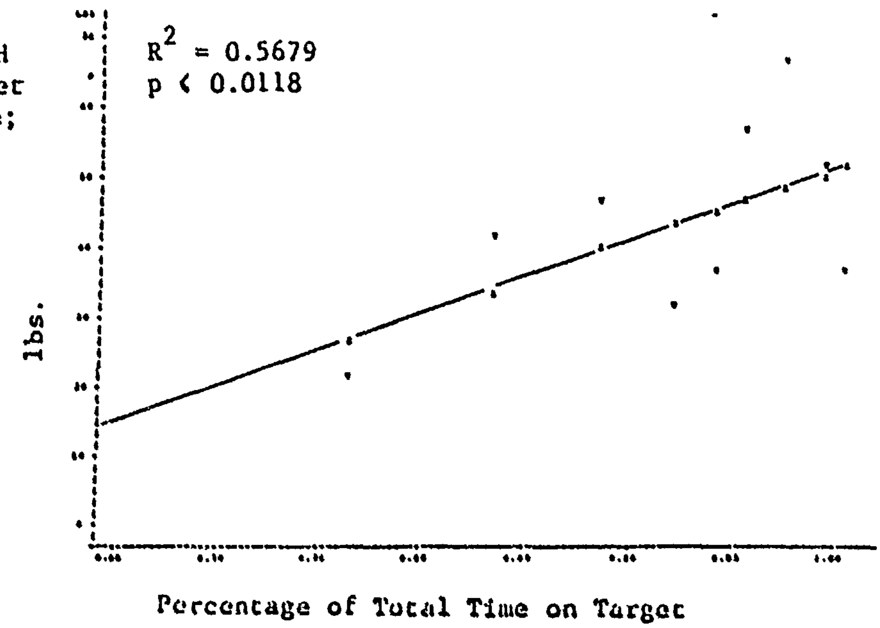
b) BACKWARD NECK STRENGTH crossed with time on target during the +1.5 Gy profile; helmet A.



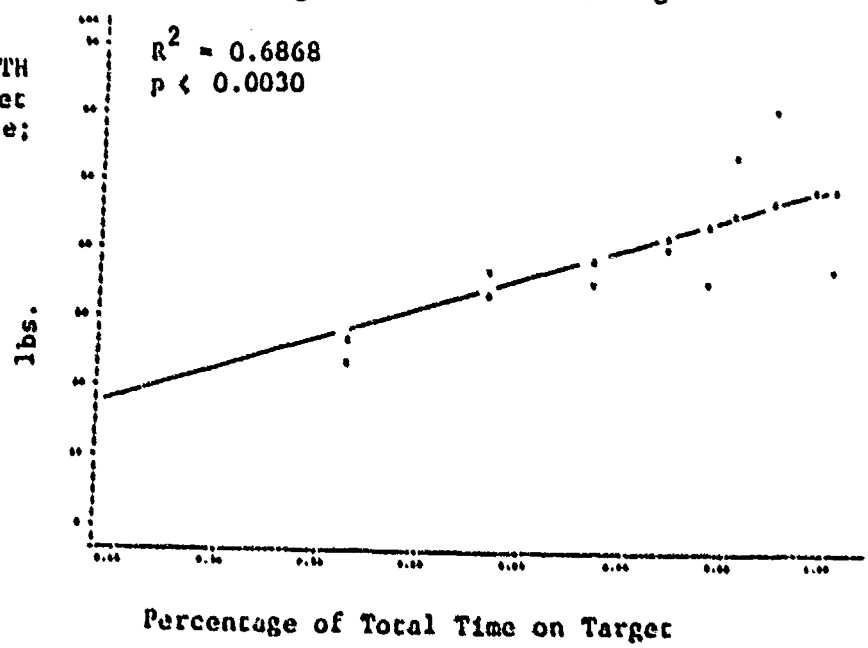
Percentage of Total Time on Target

TIME-ON-TARGET REGRESSED WITH NECK STRENGTH FOR THE +1.5Gy PROFILE (cont.)

c) LEFTWARD NECK STRENGTH crossed with time on target during the +1.5 Gy profile; helmet A.

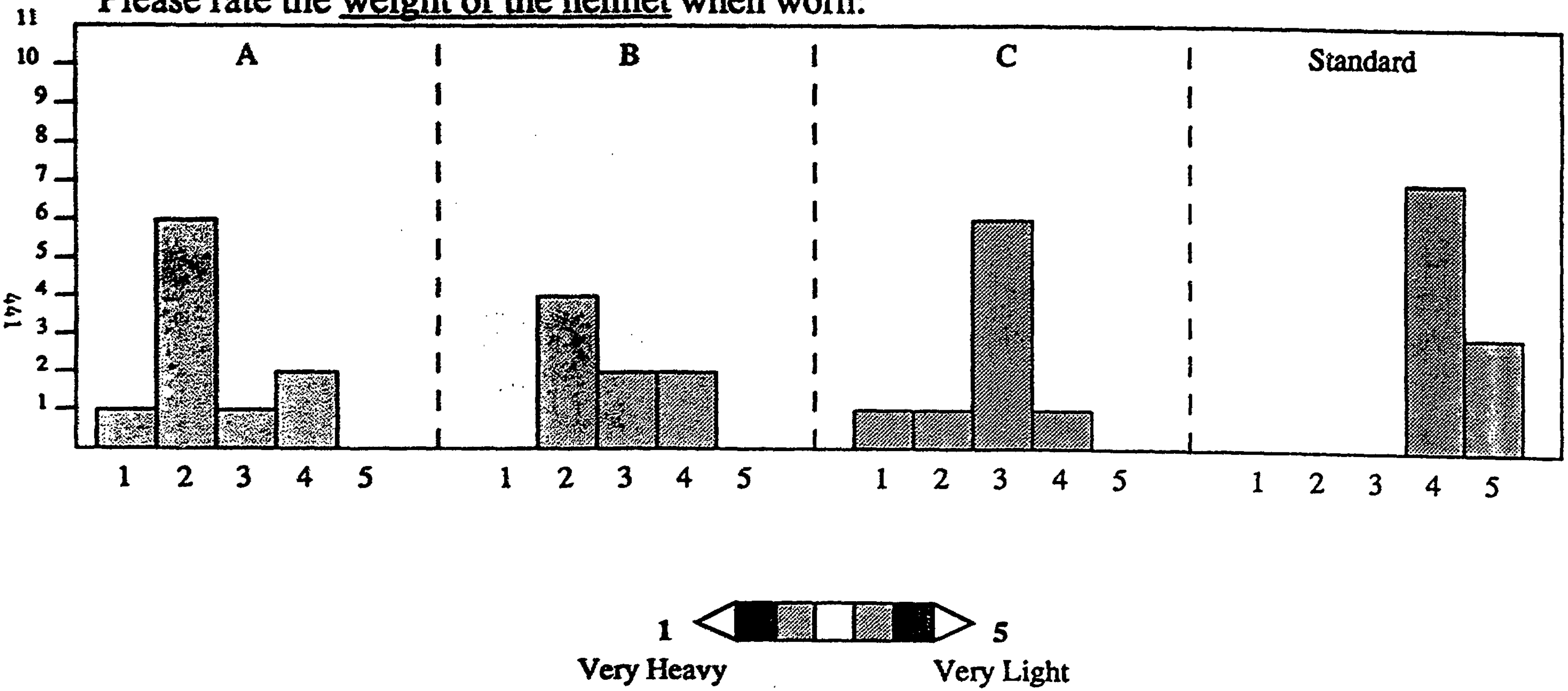


d) RIGHTWARD NECK STRENGTH crossed with time on target during the +1.5 Gy profile; helmet A.



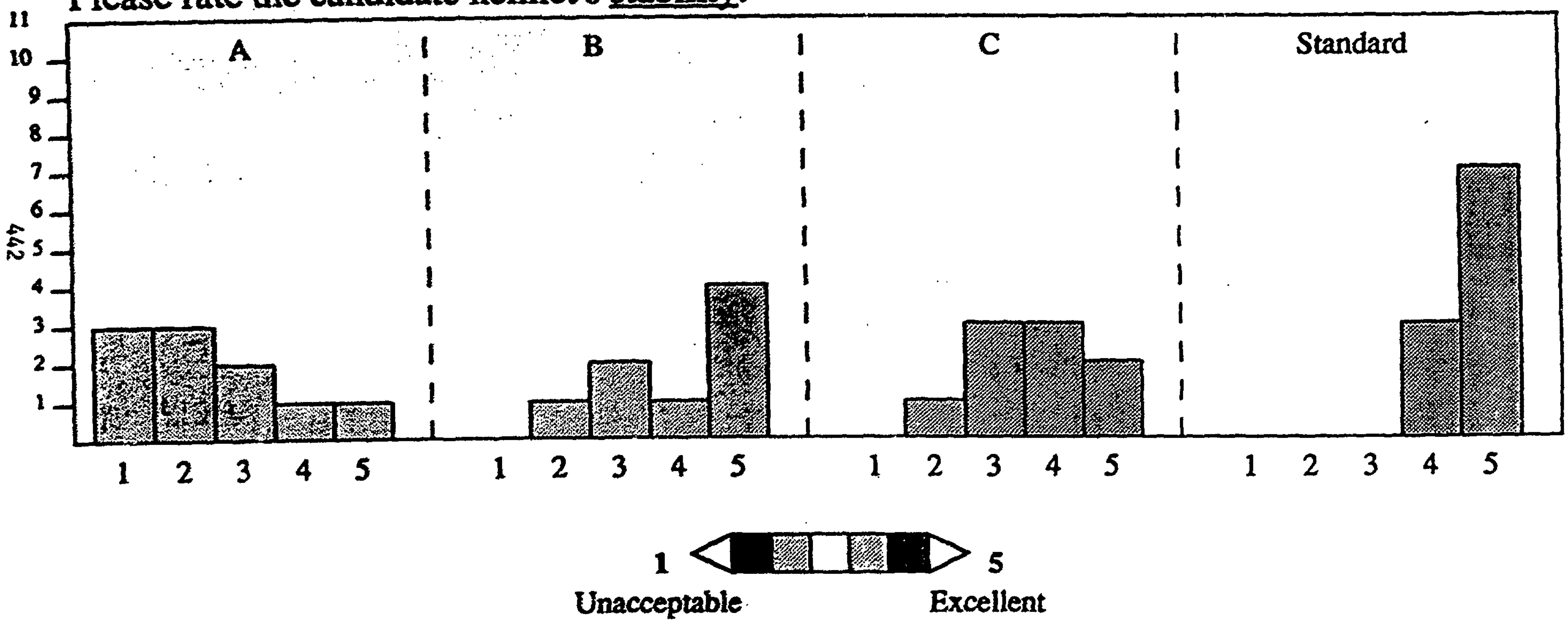
SUBJECTIVE RESPONSES CONCERNING WEIGHT

Please rate the weight of the helmet when worn:



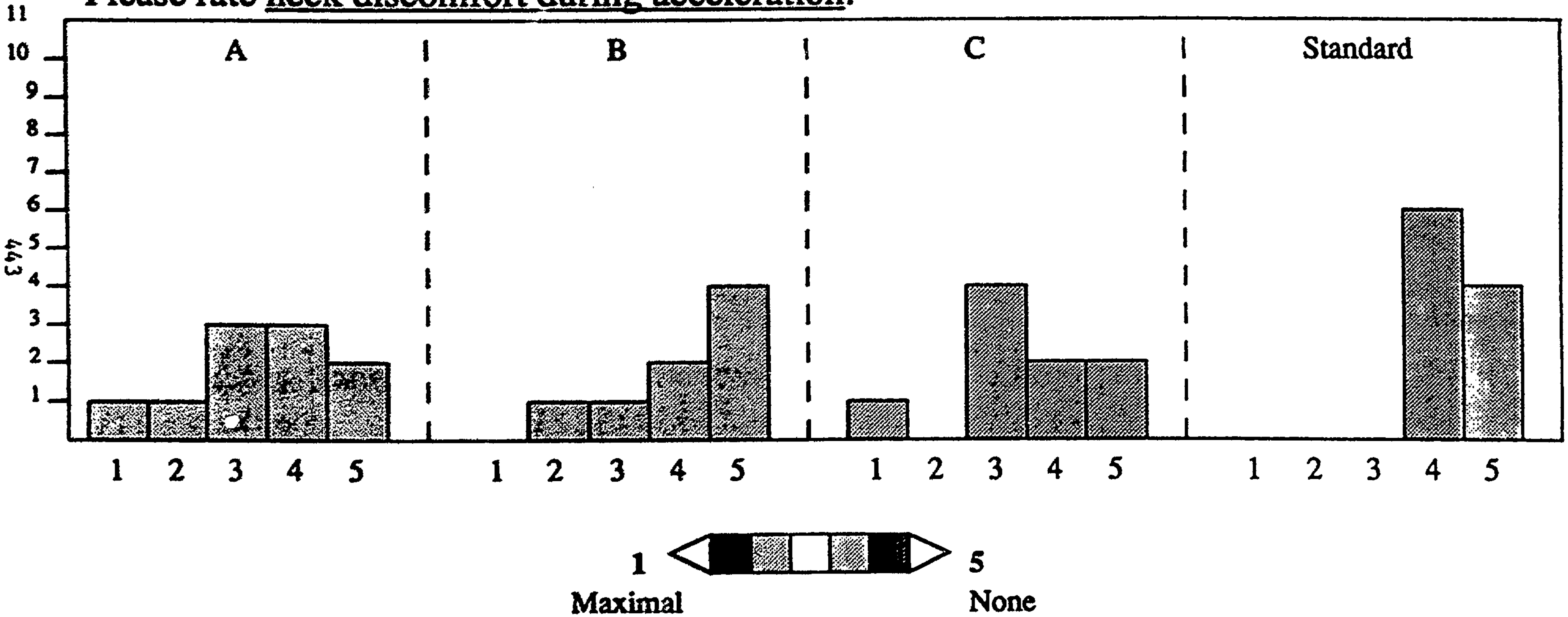
SUBJECTIVE RESPONSES CONCERNING STABILITY

Please rate the candidate helmet's stability:



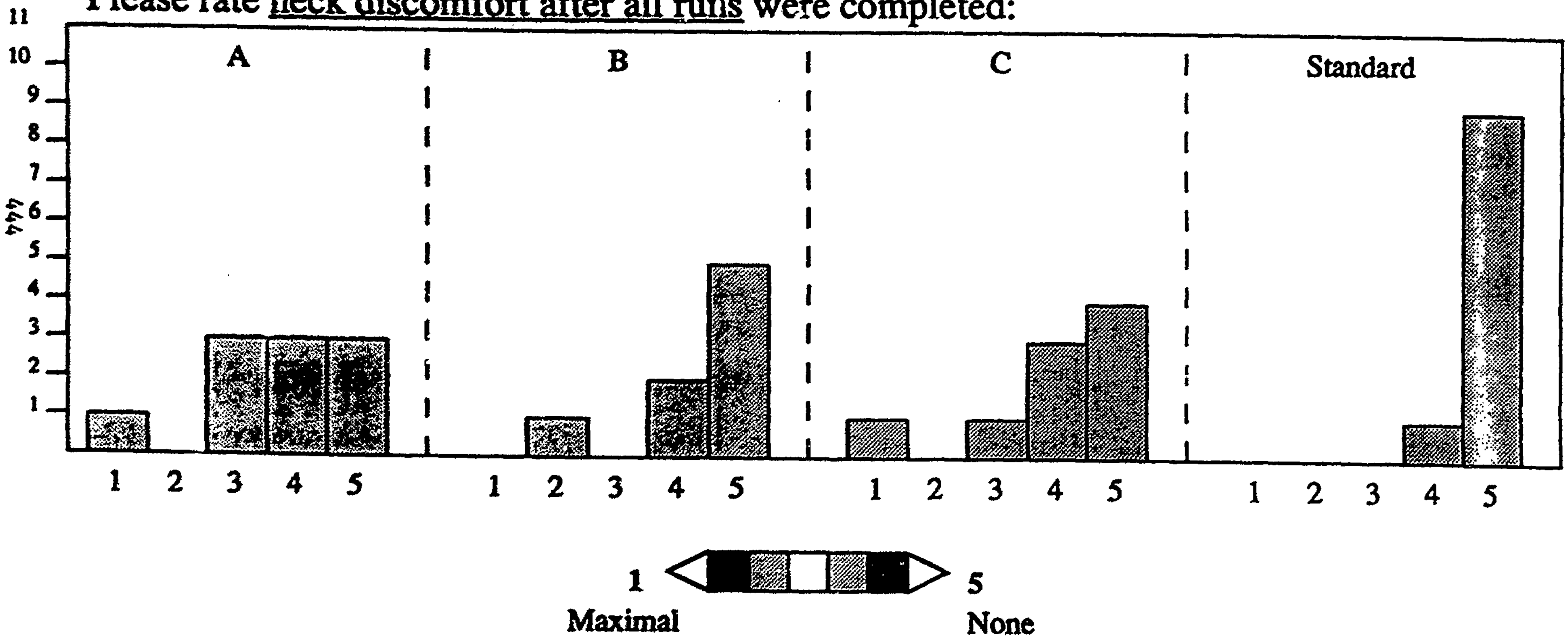
SUBJECTIVE NECK DISCOMFORT DURING ACCELERATION

Please rate neck discomfort during acceleration:



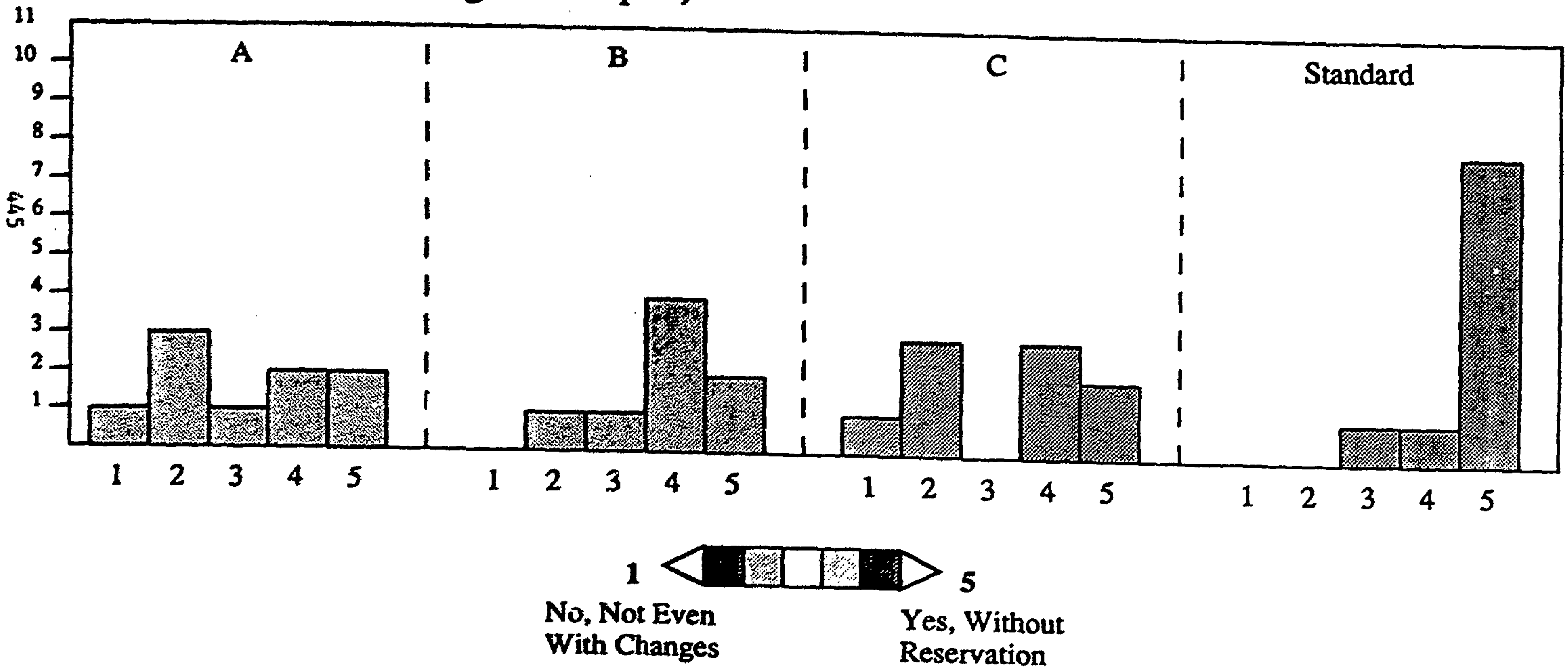
SUBJECTIVE NECK DISCOMFORT AFTER ACCELERATION

Please rate neck discomfort after all runs were completed:



RECOMMENDATIONS FOR USE IN HELICOPTERS

Would you recommend the use of this helmet under 3 to 6 +Gz acceleration (emulating a helicopter)?



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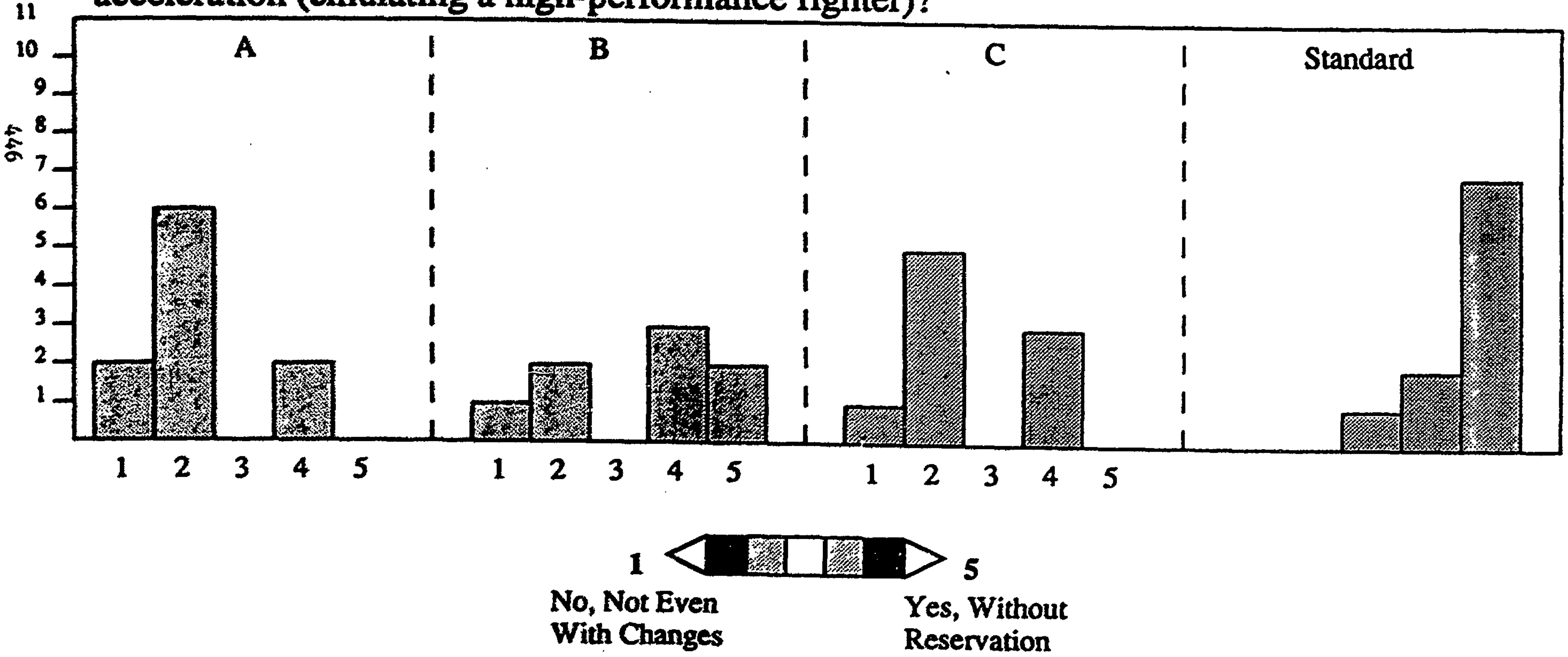
RECOMMENDATIONS FOR USE IN FIGHTER COCKPIT

Would you recommend the use of this helmet under 6 to 9 +Gz acceleration (emulating a high-performance fighter)?



OVERALL PATTERNS FROM IMAGE MIGRATION AND TIME-ON-TARGET DATA

	HELMET ORDER		
	Inferior	Neutral	Superior
IMAGE MIGRATION			
+8Gz Onset/Offset	A	--	B, C
SACM	A, B	--	C
+4Gz Mask Dangling	A	B	C
-1Gz	C	A, B	--
TIME-ON-TARGET			
Neck Strength	A	--	--

OVERALL PATTERNS FROM SUBJECTIVE EVALUATION

	HELMET ORDER		
	Inferior	Neutral	Superior
Helmet Weight	A	B	C
Helmet Stability	A	B, C	--
Neck Discomfort	--	--	--
Recommended for Helicopters	A	C	B
Recommended for High-Performance Aircraft	A, C	B	--

IMPLICATIONS

Acceptance Issues as Obtained From the Present Study:

- Helmet and Image Stability
- Comfort
- Trade-offs Between the Two

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APPENDIX G
EXPLOSIVE ATMOSPHERE

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APPENDIX G: EXPLOSIVE ATMOSPHERE

1. INTRODUCTION

An attempt to reduce aircrew workload while improving performance is being answered by displaying cockpit information directly on the crew member's helmet. Some helmet-mounted displays (HMD) require a high voltage cable connection between the helmet and the aircraft. The cables must easily connect/disconnect to permit the crew member to enter and exit the cockpit. During emergency conditions explosive gases can collect in the cockpit. However, disconnecting the high voltage HMD cables should not ignite these gases. This report describes the evaluation of the high voltage connector used on three helmet-mounted systems developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. This evaluation was conducted by GEC Avionics under subcontract from General Dynamics for Wright Laboratory's Advanced Flight Test Integrator (AFTI) Program (WL/FIGX).

2. APPROACH

Explosive atmosphere testing was performed inside a vacuum test cell. The pressure altitude and fuel/air mixture were set to simulate potentially explosive conditions encountered by F-16 aircraft. The male/female ends of the HMD high voltage connector was powered up and then pulled apart. Any arcing of the high voltage leads would ignite the fuel/air mixture creating an explosion.

3. OBJECTIVE

The objective of this testing was to verify the safety of the high voltage HMD connector in the presence of a potentially explosive atmosphere.

GEC Avionics Limited
Airborne Display Division
Rochester Kent

GEC AVIONICS

Date: JUNE 1991
Copy No.
Page i

All enquiries related to this publication should be referred to:

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GEC Avionics Limited
Airport Works
Rochester Kent ME1 2XX
England
Tel. (0634) 844400 Tlx. 96304

DOCUMENT No. 29/4777/1/07/90 Rev - Amdt.1

AFTI/F-16 CAS HEAD MOUNTED

SIGHT AND DISPLAY SYSTEM

CONTRACT No. F33615-89-C-3600

SAFETY OF FLIGHT TEST PROCEDURE

(ENVIRONMENTAL)

contains:
6 pages front matter
63 pages text and figures
69 pages total

Prepared by: G J GALLAGHER — Title: SNR DEVELOPMENT ENGINEER

Approved by: B L RIGGALL — Title: CONSULTANT ENG (MECH)

Approved by: H C HOPKINSON — Title: PROJECT MANAGER

LIST OF EFFECTIVE PAGES

Insert latest changed pages. destroy superseded pages.

TOTAL NUMBER OF PAGES IN THIS PUBLICATION IS 69 CONSISTING OF THE FOLLOWING

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(i), (ii), 2, 3, 4, 7, 8, 10, 12, 13, 15, 29, 44 — Amdt.1 June '91	-				

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7.5 Explosive Atmosphere Testing

7.5.1 Apparatus

The Explosive Atmosphere testing facilities shall be a self-contained unit consisting of a well lit test chamber equipped with a system for the mixing and circulation of explosive air-

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field vapour mixtures. An explosive relief valve system and a vacuum pump to permit the simulation of altitude. The design shall conform in general to that detailed in paragraph 8.5 of this document.

7.5.2 Fuel

The fuel used shall be gasoline, grade 100/130 octance conforming to MIL-G-5527, see Table 4.

7.5.3 Instrumentation

The following instruments shall be provided:

a) Altimeters to read 0-80,000 feet. Tolerance +1%.

b) Two maximum pressure indicators to read 0-350 psi. Tolerance ± 1 psi.

c) Chamber air temperature indicator to read 0-260°C (0-500°F). Tolerance ± 1.1°C (± 2°F).

d) Chamber wall temperature indicator to read 0-260°C (0-500°F). Tolerance ± 1.1°C (± 2°F).

e) Fuel temperature indicator to read 0-38°C (0-100°F). Tolerance ± 1.1°C (± 2°F).

f) Vapouriser air temperature indicator to read 0-260°C (0-500°F). Tolerance ± 1.1°C (± 2°F).

g) Vapouriser media temperature indicator to read 0-260°C (0-500°F). Tolerance ± 1.1°C (± 2°F).

h) Fuel quantity gauge (calibrated for fuel of 0.704 SG at 15.5°C (60°F) and reading in pounds of fuel (0-0.5 pounds).

j) Fuel inlet pressure indicator to read 0-100 psi. Tolerance ± 1 psi.

k) Heater thermostat to control over the temperature range 0-260°C (0-500°F). Tolerance ± 1.1°C (± 2°F).

7.5.4 Pre-Test Requirements

A Full Acceptance Test shall be performed on the System or LRU prior to the explosive atmosphere test, in accordance with paragraph 4 of this document, and the results recorded.

7.5.5 Procedure

The LRU shall be installed in the test chamber in such a manner that normal electrical operation is possible. Power leads and interconnecting cables shall be introduced into the chamber via "stuffing boxes".

The external covers of the LRU shall be loosened to ensure adequate circulation of the explosive mixture.

The LRU shall be subjected to a limited functional check in accordance with paragraph 5.1 of this document and the results recorded.

Determine the weight of fuel necessary to produce an air-vapour ratio of 13 to 1 at the desired test altitude from consideration of the chamber column, fuel temperature and specific gravity chamber air and wall temperature, test altitude etc.

The test shall be conducted at the following simulated test altitudes, ground level, 10,000, 20,000, 30,000, 40,000 and 50,000 ft.

Step 1 - The test chamber shall be sealed and the ambient temperature within shall be raised to 55° ± 3°C. The temperature of the LRU and the chamber walls shall be permitted to rise to within 11°C of that of the chamber ambient air, prior to introduction of the explosive mixture.

Step 2 - The internal test chamber pressure shall be reduced sufficiently to simulate an altitude approximately 10,000 feet above the desired test altitude. The weight of fuel necessary to produce an air-vapour ratio of 13 to 1 at the desired test altitude shall be determined from consideration of chamber volume, fuel temperature and specific gravity, chamber air and wall temperature, test altitude, etc. A time of 3 ± 1 minute shall be allowed for introduction and vapourization of the fuel. Air shall be admitted into the chamber until a simulated altitude of 5,000 feet above the test altitude is attained.

Step 3 - Operation of the LRU shall be commenced, all making and breaking electrical contacts being actuated. If high temperature components are present a warm up time of 15 minutes shall be permitted. If no explosion results, air shall be admitted into the chamber so as to steadily reduce the altitude down past the desired test altitude to an elevation 5,000 feet below that altitude but not to exceed a pressure of 1 atmosphere. The operation of the LRU shall be continuous throughout this period of altitude reduction and all making and breaking electrical contacts shall be operated as frequently as deemed practicable.

Step 4 - If by the time the simulated altitude has been reduced to 5,000 feet below the test altitude, no explosion has occurred as a result of operation of the LRU the potential explosiveness of the air-vapour mixture shall be verified by igniting a sample of the mixture with a spark gap or glow plug. At pressure altitudes of 20,000 feet, or higher, the attainment of ignition at any altitude shall be sufficient evidence that the mixture was ignitable even though ignition was not obtained at some other point in the vicinity of the test altitude. At any altitude below 20,000 feet, the mixture sample shall ignite at the point within 3,000 feet of the test altitude. If the air-vapour mixture is not found to be explosive, the test shall be considered void and the entire procedure repeated.

7.5.6 Post Test Requirement

On completion of the test the LRU or System shall be subjected to a Full Acceptance Test, in accordance with paragraph 4 of this document, and the results recorded.

7.5.7 Failure Criteria

If the test items cause an explosion at any altitude they shall be considered to have failed the test and no further tests need to be attempted before modification.

7.5.8 Report of Results

A test report shall be compiled and submitted to General Dynamics within 30 days of the completion of the test. The test report shall include as a minimum the following information:

a) Number and/or description of the product tested.

b) Results of all operational tests and observations.

c) Calculations of weight of fuel to produce the required air-vapour ratio. (Table 4)

d) Record of all test chamber conditions taken from the chamber instrumentation.

e) Failure reports and analysis as applicable.

Table 4 Fuel Requirements for Explosion Proof Test

Requirements	Grade 100/130	Requirements	Grade 100/130
Distillation:		Color	Green
Fuel evaporated, 10 percent min at	167°F (75°C)	Dye content:	
Fuel evaporated, 40 percent max at	167°F (75°C)	Blue dye, max:	
Fuel evaporated, 50 percent min at	221°F (105°C)	lb/1,000 bbl	0.435
Fuel evaporated, 90 percent min at	275°F (135°C)	gm/100 gal (US)	.470
End point max.	338°F (170°C)	mg/liter	1.241
sum of 10 percent and 50 percent		mg/gal (UK)	5.642
evaporated temperature, min	307°F	Yellow dye, max:	
Residue, vol. max percent	1-1/2	lb/1,000 bbl	0.546
Distillation loss, vol, max, percent	1-1/2	gm/100 gal (US)	0.590
Gravity, API degrees		mg/liter	1.56
Existent gum, max, mg/100 ml	3.0	mg/gal (UK)	7.092
Potential gum, 16 hr aging, max, mg/ 100 ml	6.0	Tetraethyllead content, max	
Precipitate, max, mg/100 ml	2.0	ml/gal (US)	4.60
Sulfur, max, percent by wt.	0.05	ml/gal (UK)	5.52
Reid vapor pressure at 100°F, max, psi	5.5	ml/liter (millions)	1.22
Freezing point, max	-76°F (-60°C)	Knock rating, lean mixture	
Copper, strip corrosion, ASTM		Aviation method, min	7/100
		Motor method, min	100
Classification, max	No 1		
Water reaction		Knock rating, rich mixture	
Interface rating, max	2	Supercharge method, min	130
Vol change, max, ml	2		
Heating value:			
Net heat of combustion, Btu/lb, min	18,700		
or aniline-gravity product, min	7,500		

PAGES 47-52 ARE NOT APPLICABLE.

frequency is to be accurate to ±1Hz up to 50Hz and ±2% from 50Hz to 5000Hz and shall also be calibrated every 26 weeks.

The Log Voltage Converter shall be calibrated every 26 weeks to an accuracy of 0.2dB (2%).

Other vibration equipment that is not calibrated shall be checked prior to each test, e.g. X-Y Plotter.

8.4 Mechanical Shock

The GAv Vibration system described in paragraph 8.2 or equivalent will be used for this test with the Digital Control System in the transient shock mode.

8.5 Explosion-proof Equipment (Figure 23)

Situated at I.A.B.G. Munich, W.Germany.

9. FAILURE REPORTING

9.1 Failure Definition

An LRU failure is the cessation of ability of that unit to meet the limited functional or acceptance test identified by Paragraphs 4 and 5 of this Procedure, essential to satisfactory operation, not re-obtainable through permissible re-adjustment of operator controls. The built-in test/self test functions shall be considered during an LRU Failure.

9.2 Failure Action

9.2.1 In the event of failure the following action shall take place:

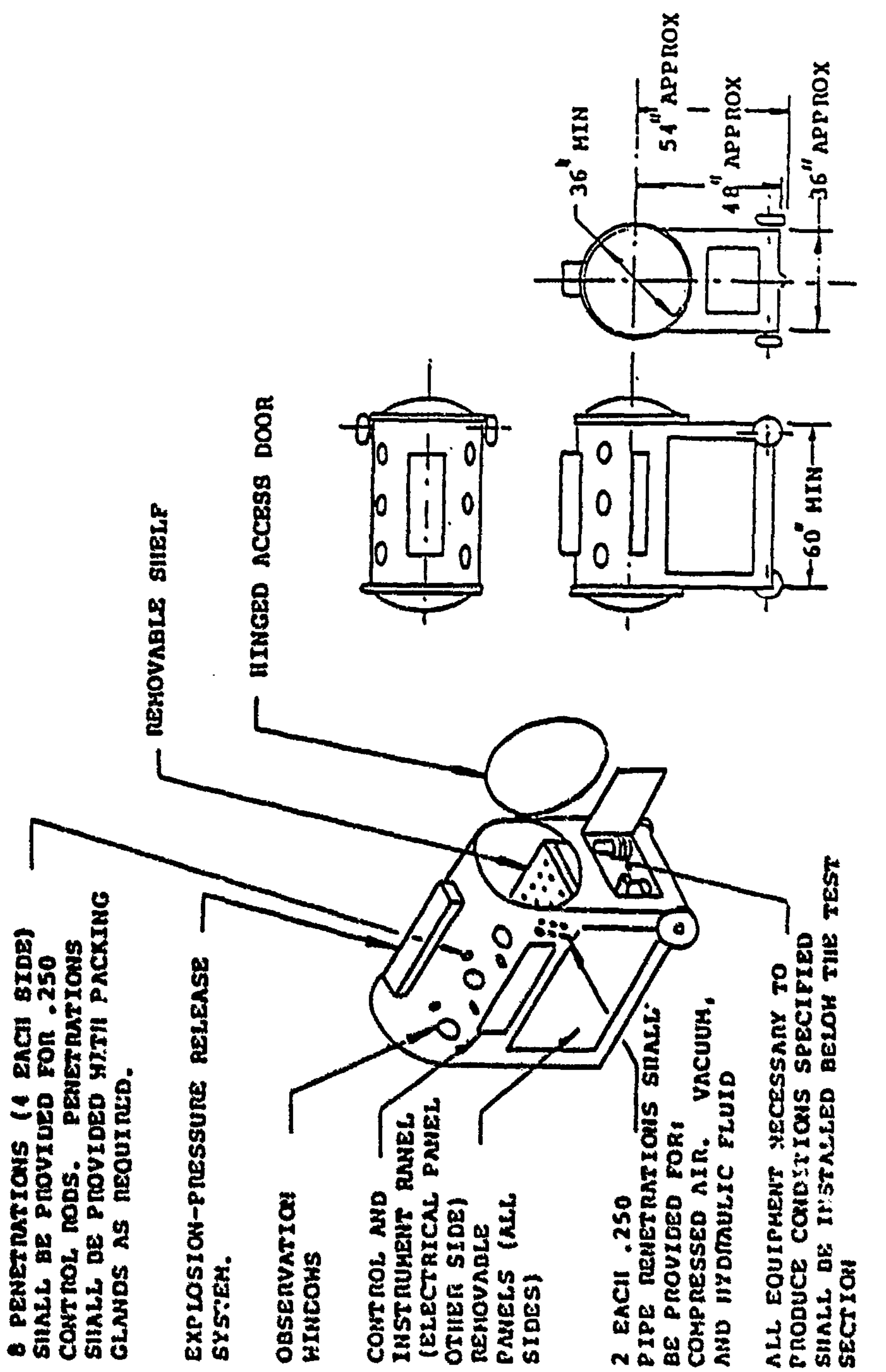

Figure 23 Explosion Proof Test Chamber

GEC Avionics Limited
Airborne Display Division
Rochester Kent

GEC AVIONICS

SAFETY OF FLIGHT TEST CERTIFICATE

GEC Avionics hereby certify that the:

AFTI/F-16 CAS Head Mounted
Sight and Display System

comprising the following units:

Helmet Mounted Display Unit (HMD)	Part No. 229-047545-01
HMD Electronics Unit (EU)	Part No. 51-066-01
HMD Interface and Control Unit (ICU)	Part No. 92-054-01

have been subjected to, and satisfied the Safety of Flight Requirements defined in the Qualification Test Procedure 29/4777/1/07/90
The test reports relevant to this certificate are:

Vibration	29/5268/1/09/91
Explosive Atmosphere	29/5269/1/09/91
Temperature/Altitude	29/5270/1/09/91
Explosive Decompression (HMD)	29/5271/1/09/91
Crash Safety (HMD)	29/4668/1/04/90
VIBRATION (HMD)	29/5297/1/10/91 29/4668/1/04/90
Crash Safety (Analysis Report, ICU)	29/5213/1/08/91
Wind Loading (Analysis Report, HMD)	29/5267/1/09/91

(continued Overleaf)

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GEC Avionics Limited
Airborne Display Division
Rochester Kent

GEC AVIONICS

Contract No.
F33615-89-C-3600
Document No.
29/5272/1/09/91
Rev - Page Att 1-8

ENVIRONMENTAL "QUICK LOOK" TEST REPORT

1. Q.L.R. NUMBER AFTI HMD/07	2. DATE 25-10-91
3. SYSTEM NAME AFTI/F-16 CAS HMD	4. L.R.U. TITLE HELMET MOUNTED DISPLAY
5. L.R.U. PART NUMBER 229-047545-01	6. TEST PHASE SOF ☑ QUAL. ☐

7. TEST PERFORMED

EXPLOSIVE ATMOSPHERE TEST IN ACCORDANCE WITH PARAGRAPH 7.5 OF DOCUMENT No 29/4777/1/07/90

8. RESULT OF TEST:

LIMITED FUNCTIONAL TEST	PASS ☑	FAIL ☐
ACCEPTANCE TEST	PASS ☑	FAIL ☐

9. DESCRIPTION OF FAILURES (if applicable):

NONE

10. REMARKS:

11. SIGNATURES:

C. Cl[illegible] (signature)

TEST ENGINEER

HCHolm[illegible] (signature)

AFTI/F-16 PROJECT MANAGER

TEST MONITOR (IF AVAILABLE)

GEC Avionics Limited
Airborne Display Division
Rochester Kent

GEC AVIONICS

Contract No.
F33615-89-C-3600
Document No.
29/5272/1/09/91
Rev - Page Att 1-9

ENVIRONMENTAL "QUICK LOOK" TEST REPORT

1. Q.L.R. NUMBER AFTI HMD/08	2. DATE 25-10-91
3. SYSTEM NAME AFTI/F-16 CAS HMD	4. L.R.U. TITLE INTERFACE AND CONTROL UNIT
5. L.R.U. PART NUMBER 92-054-01	6. TEST PHASE SOF ☒ QUAL. ☐

7. TEST PERFORMED

EXPLOSIVE ATMOSPHERE TEST IN ACCORDANCE WITH PARAGRAPH 7.5 OF DOCUMENT No 29/4777/1/07/90

8. RESULT OF TEST:

LIMITED FUNCTIONAL TEST	PASS ☒	FAIL ☐
ACCEPTANCE TEST	PASS ☒	FAIL ☐

9. DESCRIPTION OF FAILURES (if applicable):

TFRR No AFTI HMD-01

10. REMARKS:

11. SIGNATURES:

G. [signature]
TEST ENGINEER

H C Hodkinson [signature]
AFTI/F-16 PROJECT MANAGER

TEST MONITOR (IF AVAILABLE)

GEC Avionics Limited
Airborne Display Division
Rochester Kent

GEC AVIONICS

Contract No.
F33615-89-C-3600
Document No.
29/5272/1/09/91
Rev - Page Att 1-10

ENVIRONMENTAL "QUICK LOOK" TEST REPORT

1. Q.L.R. NUMBER AFTI HMD/09	2. DATE 25-10-91
3. SYSTEM NAME AFTI/F-16 CAS HMD	4. L.R.U. TITLE ELECTRONICS UNIT
5. L.R.U. PART NUMBER 51-066-01	6. TEST PHASE SOF ☑ QUAL. ☐

7. TEST PERFORMED

EXPLOSIVE ATMOSPHERE TEST IN ACCORDANCE WITH PARAGRAPH 7.5 OF DOCUMENT No 29/4777/1/07/90

8. RESULT OF TEST:

LIMITED FUNCTIONAL TEST	PASS ☑	FAIL ☐
ACCEPTANCE TEST	PASS ☑	FAIL ☐

9. DESCRIPTION OF FAILURES (if applicable):

NONE

10. REMARKS:

11. SIGNATURES:

[signature]

TEST ENGINEER

H C Hoscinson [signature]

AFTI/F-16 PROJECT MANAGER

TEST MONITOR (IF AVAILABLE)

APPENDIX H
CRASH LANDING: Gx IMPACT

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APPENDIX H: CRASH LANDING: Gx IMPACT

1. INTRODUCTION

Aircrew members are subject to rapid decelerations during crash landings and ditchings. This is an especially important concern for non-ejection seat aircraft such as transports and helicopters. Rapid decelerations induce high G forces to the body in the direction of travel: Gx. Any additional weight provided by a helmet-mounted system only serves to magnify the forces imparted to the head and neck. This report describes the evaluation of the forces imparted to the head and neck under the conditions of rapid deceleration. This evaluation was accomplished by the Bio-mechanical Protection Branch, Biodynamics and Biocommunications Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

2. APPROACH

The head/neck forces were simulated by fitting an anthropomorphic manikin with an I-NIGHTS helmet-mounted system. The manikin was then dynamically subjected to Gx forces similar to those encountered in an auto-rotation crash landing of a helicopter. Force data was measured and recorded from inertial load cells located at the manikin's occipital condyle.

3. OBJECTIVE

The objective of this test is to quantify the head/neck forces experienced by an aircrew member during crash landing while using I-NIGHTS helmet and compare the data with the standard Air Force helmet (HGU-55/P). An ancillary objective was to ensure the structural integrity of the helmet system.

MEMO FOR THE RECORD 20 NOV 1990

SUBJECT: I-NIGHTS -Gx Test Plan Amendment

1. Due to the destruction of two I-NIGHTS systems during -Gx testing at the 20 G impact level, it has been decided by HSD/YAH-HMST to reduce the effort to a 15 G profile. The 20 G profile was a simulation of a worse case accleration encountered during an emergency helicopter landing. The 15 G profile will be a simulation of a 50th percentile fixed wing emergency landing and a 50th-95th percentile helicopter emergency landing. The test matrix is also being expanded to include impact tests with the Aviators Night Vision System (ANVIS).

2. The new matrix will be as follows...

I-NIGHTS -Gx IMPACT PROGRAM TEST MATRIX

TEST CELL	ACCELERATION LEVEL	HELMET	# TEST
A1	15 G	HGU-55/P	3
B1	15 G	I-NIGHTS G	3
C1	15 G	I-NIGHTS H	3
D1	15 G	I-NIGHTS K	3
E1	15 G	HGU-55/P (MERLIN)	3
F1	15 G	HGU-55/P (EAGLE EYE)	3
G1	15 G	ANVIS	3

3. If there are any questions regarding this change, please contact the undersigned at 53122.

CHRIS E PERRY
Crew Protection Branch
Biodynamics and Bioengineering Division

TEST PLAN

-Gx TESTS OF PROTOTYPE VISUALLY COUPLED SYSTEMS IN SIMULATED HELICOPTER CRASHES

1 November 1990

Prepared by:

Chris Perry
Joseph Strzelecki

COORDINATION: AAMRL/SE ______________________ DATE: 30 Nov 90

APPROVED BY: HSD/YAH-HMST ______________________ DATE: 13 Nov 90

APPROVED BY: AAMRL/BBP ______________________ DATE: 1 Nov 90

APPROVED BY: AAMRL/BB ______________________ DATE: 16 Nov 90

Crew Protection Branch
Biodynamics and Bioengineering Division
Harry G. Armstrong Aerospace Medical Research Laboratory
Human Systems Division
Wright-Patterson Air Force Base, Ohio

TABLE OF CONTENTS

1.0 SCOPE OF PLAN

This plan describes the experimental design, experimental procedures, test equipment requirements, data processing techniques, and documentation requirements to compare the force and acceleration effects of a baseline helmet and various helmet-mounted visually coupled systems on the head and neck of a crewmember in a simulated helicopter crash environment. The responsibilities of branch personnel, technical service contractors, and base support organizations in the implementation of the test plan are described. Applicable supporting documents such as instrumentation calibration procedures, records of facility operational procedures/checklists, and a description of data collection systems are cited for reference purposes.

2.0 SPONSOR OF TESTS

These tests are sponsored by HSD/YAH-HMST to obtain data on the effect of visually coupled systems on crew safety during -Gx impacts.

3.0 CRITICAL ISSUES

A critical issue is a question that must be answered before the overall worth or feasibility of a system's capabilities can be determined or estimated. The critical issue that will be addressed by this test program is:

> What effect do the various visually coupled systems have on crewmember head/neck forces and accelerations when compared with a baseline case in which no visually coupled system is present?

4.0 OBJECTIVES OF TESTS

The objective of these tests is to measure and compare head accelerations and neck forces for the baseline case to each case in which a different visually coupled system is worn.

5.0 EXPERIMENTAL DESIGN

5.1 The test program is designed to meet the objectives by subjecting an anthropomorphic manikin fitted with a test helmet to a high-energy acceleration pulse. The test helmets shall consist of: (1) a HGU-55/P as a baseline system, (2) a single night vision Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) helmet from each of the three I-NIGHTS vendors, (3) the MERLIN night vision system mounted on a HGU-55/P helmet, and (4) the EAGLE EYE night vision goggle system mounted on a HGU-55/P helmet.

5.2 Test Parameters

5.2.1 The acceleration magnitude will be 20 +2/-1 G in the -x direction.

5.2.2 Pulse shape will be half-sine (pin 2).

5.2.3 Pulse duration will be .20 seconds.

5.2.4 Velocity change will be approximately 88 ft/sec.

5.3 The test matrix is given in Table 1. Each cell in the table will be run a minimum of three times, assuming the necessary data is collected.

I-NIGHTS -Gx IMPACT PROGRAM TEST MATRIX

TEST CELL	ACCELERATION LEVEL	HELMET	# TEST
A	20 G	HGU-55/P	3
B	20 G	I-NIGHTS G	3
C	20 G	I-NIGHTS H	3
D	20 G	I-NIGHTS K	3
E	20 G	HGU-55/P (MERLIN)	3
F	20 G	HGU-55/P (EAGLE EYE)	3

6.0 TEST METHOD AND MATERIALS

6.1 Tests will be conducted on the AAMRL Horizontal Impulse Accelerator. The experimental test fixture will be the 40-G seat, mounted on the Impulse Acceleration Sled and modified to represent the generic aircraft seat geometry specified in MIL-S-9479B(USAF). The large prototype ADAM will be used for all tests. The manikin will be dressed in modified long underwear and the required helmet (indicated by test cell) for all tests.

6.2 A standard USAF double shoulder strap and lap belt configuration will be used to restrain the manikin. The restraint system will be preloaded to 20 ± 5 lbs at all anchor points.

7.0 EVALUATION CRITERIA

7.1 A successful test is one where:

7.1.1 There is no structural failure of the restraint system, manikin, or helmet-mounted visually coupled systems.

7.1.2 All data channels are present and continuous

7.2 A no-test is one where:

7.2.1 The required acceleration level is not achieved.

7.3 Any other result is a not-fully-successful test which may or may not be repeated at the discretion of the principal investigator.

8.0 ADDITIONAL COSTS DUE TO ABORTS, CANCELLATIONS, OR FAILURES

In accordance with AFSC Regulation 172-8 and Air Force Regulation 80-28, the customer (HSD/YAH-HMST) will be billed for the additional costs related to aborts, cancellations, and failures.

9.0 ELECTRONIC DATA PROCESSING

9.1 Electronic Data Handling

The transducer signals shall be handled by the on-board Automatic Data Acquisition and Control System (ADACS). Signal conditioning, filtering, amplification, and digitizing (at a rate of 1000 samples/sec) shall take place on-board the test fixture. The digitized data shall be transmitted to the computer room for storage on digital magnetic tape or a VAX disc and shall be processed later by the VAX computer system.

9.2 Photogrammetric Data

9.2.1 After the high-speed films have been processed, the data will be digitized by the Automatic Film Reading (AFR) system and recorded on magnetic tape or on a PDP-11/34 disc. The x and y coordinate resolution is 0.025 percent of the major film dimension. The photo flash zero and LED TBAR photographic timing system will be used and synchronized with the electronic data. Each test will be positively identified by appropriate numeric characters visible within each camera view. These data will then be recorded on magnetic tape or a VAX disc.

9.2.2 The lens focal length, camera make, camera model, and a sketch showing the dimensions of the cameras with respect to the reference points of the seat (i.e. neutral seat reference point, plane of seat pan, plane of seat back, plane of symmetry, and plane of sled floor) shall be documented by DynCorp and verified by the contract monitor. The photo-flash zero and LED TBAR photographic timing system shall be used and synchronized with the electronic data.

10.0 TEST FACILITIES DOCUMENTATION

10.1 Documentation on the Horizontal Impulse Accelerator is located at the operator's station. This book contains the following information:

10.1.1 Test Log - Documents basic machine and test parameters for each test and preliminary basic test data. Logs are stored in the Impact Information Center which is maintained by the Operations and Maintenance Contractor.

10.1.2 Checklists - Checklists are provided for each station. The checklists shall be used by station operators during each test.

10.1.3 Operating Procedures - Detailed procedures for operating the various stations are available at each station with references to specific subsystem information. The operating procedures include an abort sequence to be used in cases of aborted tests.

10.1.4 Maintenance Instructions - Detailed maintenance information and inspection interval. Documents last inspection.

10.1.5 Maintenance Log - Documents failures, data regarding failure, and corrective action. Provides a history of accomplished maintenance.

10.3 Computer Log

This log is maintained to identify data channels and processing parameters. These records are redundant but provide back-up and data verification.

10.4 Instrumentation Program Requirements

This document identifies all of the program data points as well as the sensitivities, gains, calibration values, and filters used. The particular transducer and associated electronics for each data point are also identified. This document will be used in the instrumentation room until a program change requires a new document to be generated, at which time it will be filed in the Impact Information Center. This document is essential to data recovery.

10.5 Test Conductor's Checklist

The test conductor shall note any deviations from the test plan, comments during testing, and special problems encountered during the experimentation or data processing on the checklist.

10.6 Photogrammetric Records

The operations and maintenance contractor, DynCorp, shall collect and maintain records that describe the positions, models, lenses and speeds of the photogrammetric cameras. They shall also maintain records of the positions of the photogrammetric targets mounted on each subject. The photogrammetric analysis techniques shall also be documented by the operations and maintenance contractor. The documentation shall be suitable for publication within an AAMRL-TR and shall be provided to the principal investigator for analysis at the completion of testing. The records shall then be stored with the workunit case files.

10.7 Computer Plots and Printouts

The data plots and printouts from the data-processing computer shall be provided to the principal investigator for filing with the workunit file until they are assembled for the final report.

10.8 Final Report

The objectives, test methods, results, and conclusions of this test program will be documented in a final report. The report will be prepared by the investigators in accordance with Laboratory standards for technical reports. The report will be published as an AAMRL technical report after review and approval by Laboratory management. Clearance of the report for release outside the Air Force will be through ASD/PA.

11.0 TEST PERSONNEL ASSIGNMENTS

11.1 Branch Personnel

11.1.1 Principal Investigator - Mr Chris Perry

11.1.2 Associate Investigator - Mr Joseph P. Strzelecki

11.1.3 Test Conductors - CMSgt Phillip Lashley and Mr Joseph P. Strzelecki

11.1.4 Facility Operating Official - CMSgt Phillip Lashley

11.1.5 Safety Officer - The safety officer for each test shall be appointed by the test conductor and approved by the Branch Chief.

11.1.6 Facility Engineer - Mr Carl Toler

11.1.7 Impulse Accelerator Operator - Qualified operators have been designated by the Branch Chief and documented by letter.

11.2 Contractor Personnel

11.2.1 Facility Operation

The facilities will be operated under Contract F33615-86-C-0531 supervised by Mr Marshall Miller or his designated alternate. The contract is technically monitored by Mr Chris Perry.

11.2.2 Instrumentation Operation

The electronic instrumentation will be operated under Contract F33615-86-C-0531 by DynCorp. CMSgt Lashley will perform instrumentation calibration and operations inspections to assure the accuracy of the data and adherence to operational procedures.

11.2.3 Electronic Data Conversion

Electronic data conversion will be accomplished under Contract F33615-86-C-0531 by DynCorp. CMSgt Lashley will be responsible for the final quality-assurance inspection of the processed data.

11.2.4 Photogrammetric Data Processing and Analysis

DynCorp will be responsible for the locating and documentation of photogrammetric targets. When requested photogrammetric data will be processed by DynCorp personnel using the Automatic Film Reading System. CMSgt Lashley will be responsible for the final quality-assurance inspection of the processed data.

11.3 Technical Photographic Services

High-speed motion picture camera and still photo coverage will be provided by the Technical Photo Service of ASD. Scheduling arrangements will be made by the test conductor. DynCorp personnel will assist the photo monitor to assure that the photographic films are of adequate quality for automatic data processing. CMSgt Lashley will be responsible for quality assurance inspection of the photographic films and prints.

12.0 BRIEFING OF TEST PERSONNEL

12.1 All Branch personnel shall be briefed on their duties and responsibilities by their supervisors or designated senior Branch personnel. The Facility Operating Official will assure that all test personnel have been adequately briefed and have a working knowledge of the test plan.

12.2 All contractor personnel will be briefed on any hazards associated with the tests and their duties by their supervisors. The contract technical monitor will assure that the contractor supervisors are fully informed by weekly meetings with the contractor while the tests are in progress.

13.0 SAFETY AND EMERGENCY PROCEDURES

13.1 Hazards to operators and other test personnel will be minimized by ensuring that no personnel are to be within the yellow lines or down track from the leading edge of the sled after pressurization of the Impulse Accelerator is initiated. Safety interlocks and latches will be used in accordance with established facility operating procedures and checklists referenced elsewhere in this test plan.

13.2 Damage to test manikins and minor damage to the facility are to be expected if catastrophic failure of a lap belt should occur. This has occurred frequently at higher G levels. A catastrophic failure is, however, unlikely in this testing, as the shoulder straps have been proof tested at 40 G and the lap belt will be checked out at 20 G with a GARD manikin prior to use of the ADAM.

13.3 The risk category for this test program (overall risk) is 3C, which is defined by MIL-STD-882B to be undesirable and requiring management approval.

13.4 The Horizontal Impulse Accelerator Safety Permit was approved 21 February 1989. A hazard analysis was performed as part of the Safety Permit Request.

13.5 Emergency procedures are defined in the attached fire evacuation plan (See Attachments 4 and 5).

14.0 ACCESS TO THE TEST AREA

14.1 Access to the test area during testing will be restricted to Horizontal Impulse Accelerator Facility operations personnel and representatives from HSD/YAH, AAMRL/HE, and AAMRL/BBP.

14.2 The facility safety officer is responsible for securing the test area and the restriction of visitors. Exceptions to the visitor restrictions shall be approved by the Biomechanical Protection Branch Chief, the Facility Operating Official, or the Test Conductor. Visitation by contractor personnel other than DynCorp shall not be permitted without the permission of the principal investigator.

15.0 LABORATORY ENVIRONMENT

15.1 The temperature and humidity of the laboratory test area, instrumentation room, and data processing room shall be maintained within a range of 60 to 80 degrees F and 40 to 60% relative humidity during their use.

15.2 Instrumentation shall be operated for a minimum period of one hour prior to testing to stabilize its performance.

16.0 REFERENCES TO OTHER DOCUMENTATION

16.1 Impact Facility Operations Manual - This document contains the test logs, checklist, operating procedures, maintenance instructions, and maintenance logs for the particular test facility, safety station and medical monitor's station. This document will be maintained at the test facility.

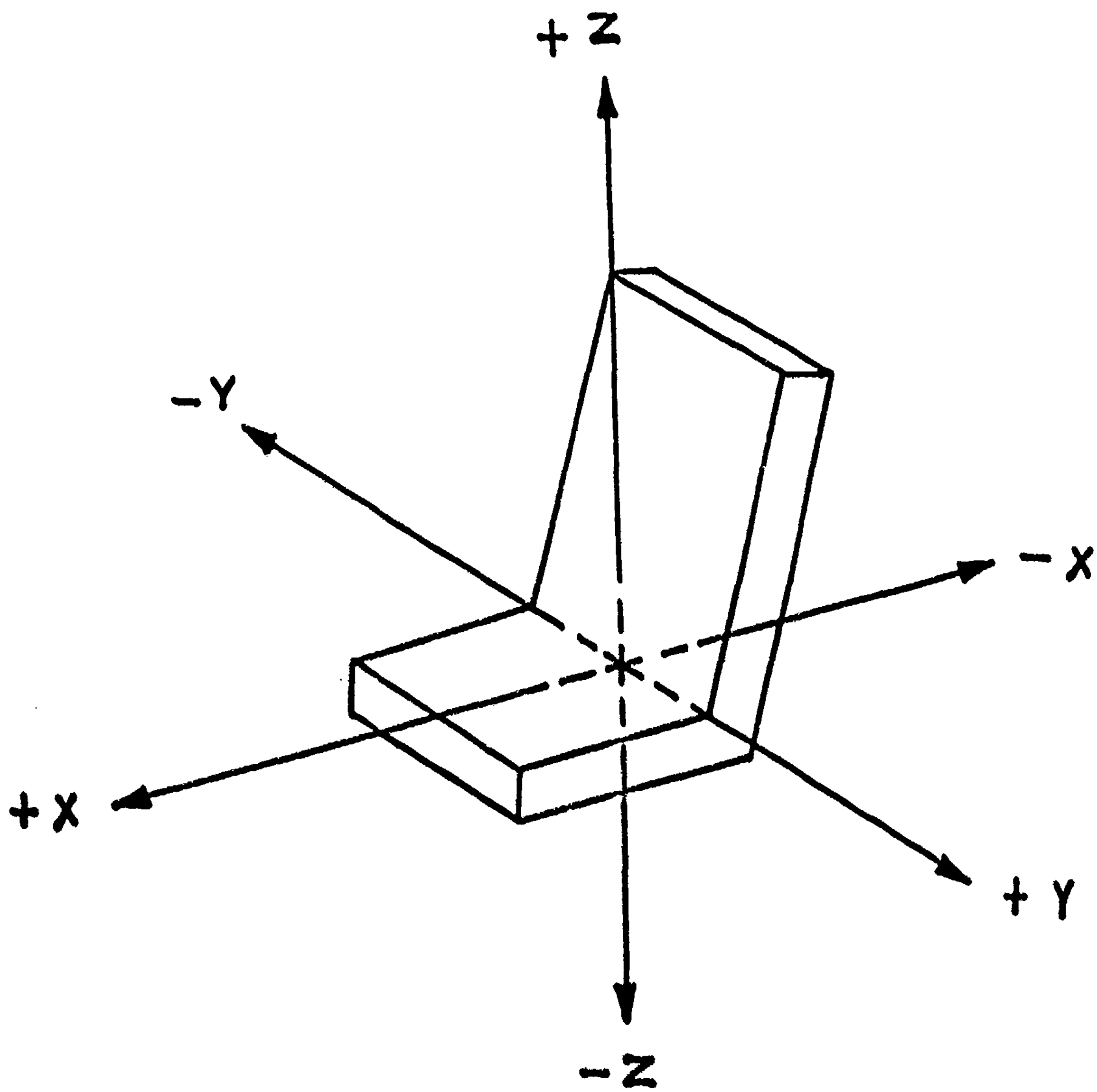
16.2 Instrumentation Operations Manual - This manual contains the test logs, checklists, operating procedures, maintenance instructions, and maintenance logs for the instrumentation systems and will be maintained in the instrumentation room.

16.3 Instrumentation Program Sheet - This document identifies all instrumentation requirements, specific data points, and all electronics associated with each data point. The current program sheet will be maintained in the instrumentation room; all others will be filed in the Impact Information Center maintained by DynCorp.

ELECTRONIC DATA CHANNEL REQUIREMENTS

CHANNEL	PARAMETER MEASURED	DYNAMIC RANGE	FREQUENCY RESPONSE
1	Sled X	28 G	DC-120 Hz
2	Head X Accel	34 G	DC-120 Hz
3	Head Y Accel	30 G	DC-120 Hz
4	Head Z Accel	68 G	DC-120 Hz
5	Head Ry Accel	5000 rad/sec^2	DC-120 Hz
6	Chest X Accel	30 G	DC-120 Hz
7	Chest Y Accel	18 G	DC-120 Hz
8	Chest Accel	68 G	DC-120 Hz
9	Chest Ry Accel	4000 rad/sec^2	DC-120 Hz
10	Shoulder X Load	1000 lb	DC-120 Hz
11	Shoulder Y Load	500 lb	DC-120 Hz
12	Shoulder Z Load	1200 lb	DC-120 Hz
13	Neck X Force	2500 lb	DC-120 Hz
14	Neck Y Force	2500 lb	DC-120 Hz
15	Neck Z Force	3000 lb	DC-120 Hz
16	Neck My Moment	5600 in-lb	DC-120 Hz
17	Lumbar My Moment	18000 in-lb	DC-120 Hz
18	Velocity	80 ft/sec	DC-60 Hz
19	Event		DC-2000 Hz

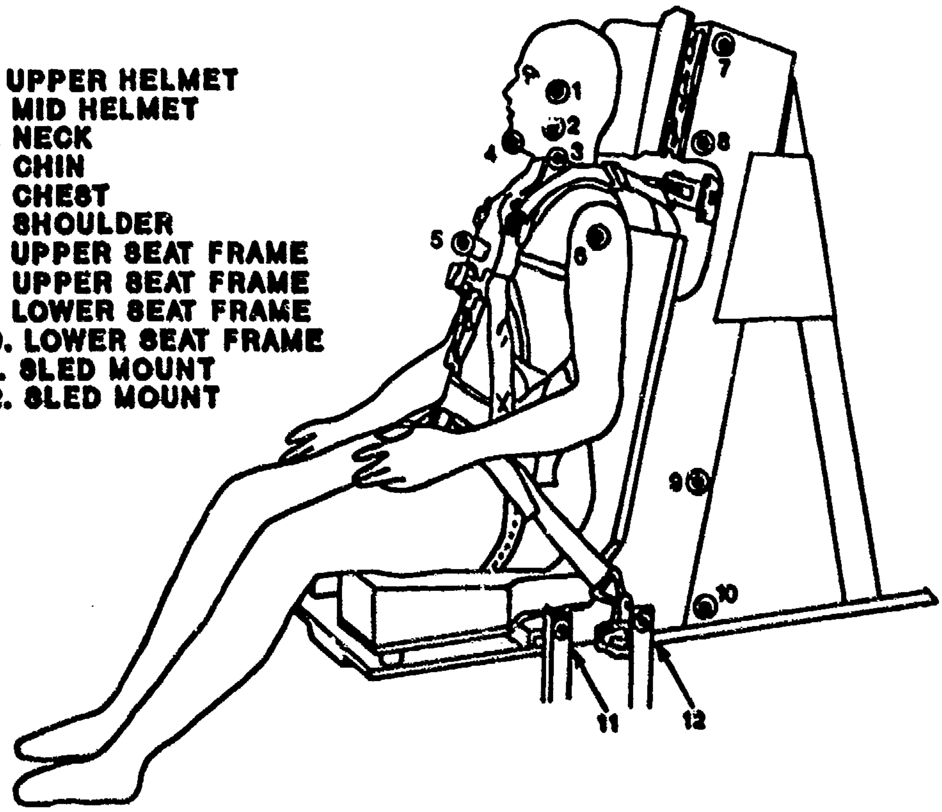
AAMRL/BBP COORDINATE SYSTEM



* The seat/man origin will be at the center of the line intersecting the planes of the seat back and seat pan.

PHOTOGRAMMETRIC FIDUCIAL LOCATIONS

1. UPPER HELMET
2. MID HELMET
3. NECK
4. CHIN
5. CHEST
6. SHOULDER
7. UPPER SEAT FRAME
8. UPPER SEAT FRAME
9. LOWER SEAT FRAME
10. LOWER SEAT FRAME
11. SLED MOUNT
12. SLED MOUNT



HORIZONTAL ACCELERATOR SLED

AEROSPACE MEDICAL RESEARCH LABORATORY		Title IMPULSE ACCELERATOR TEST CONDUCTOR CHECKLIST	
		Approved By	Date
		P. Coneley	15 June 89
Page	Effective Date	L. Sperlin	16 June 89
1 of 3	14 June 1989		

Test Program						
Test Number						
Date						
Systems and Data Review						
Harness Type and # of belt						
Subject Number						
Subject Weight						
Test G Level						
Test Velocity						
Cell						
Firing Pin						
Set Pressure						
Load Pressure						
Checklists						
Whip Cable						
VDT Wheel						
Backrest F15 or F4						
Ballast Secured						
Ballast Secured						
Zeros						
Cameras Loaded						
Subject Harness Adjusted						
Legs Adjusted						

AEROSPACE MEDICAL RESEARCH LABORATORY		Title IMPULSE ACCELERATOR TEST CONDUCTOR CHECKLIST	
		Approved By	**Date**
		P. Lovelly	15 June 89
Page	**Effective Date**	[signature]	16 June 89
2 of 3	14 June 1989		

Shoulder Harness Balanced						
Preloads (10 ± 2 lbs)						
Belt Marked						
Chest Pack						
Fiducials						
Transducer Cables						
Harness, Locks, Pads						
Pretest Photo						
Photo Board Removed						
Emergency Brakes						
Cameras Safe						
Safety Ready						
Sled-Clear and Safe						
Lights						
Camera Station						
Video						
Instrumentation Ready						
Computer Ready						
Test/Abort						
G Level						
Velocity						
Rise Time						

AEROSPACE MEDICAL RESEARCH LABORATORY		Title IMPULSE ACCELERATOR TEST CONDUCTOR CHECKLIST	
		Approved By	Date
		P. [illegible]	15 June 89
Page	Effective Date	[illegible]	16 June 89
3 of 3	14 June 1989		

Run Time ____ ____ ____ ____ ____ ____

Measure Slippage ____ ____ ____ ____ ____ ____

Damage Check and Photos ____ ____ ____ ____ ____ ____

REMARKS: ____

FIRE EVACUATION PLAN

1. This fire evacuation plan is for the Horizontal Impulse Accelerator experimental area during hazardous and non-hazardous experiments where humans are used as subjects.

a. Subjects will be notified to evacuate by the evacuation alarm siren which is presently installed in Building 824 and/or the public address system.

b. The closest evacuation alarm button is on the south wall of Room 132. The closest automatic system to notify the fire department is on the northeast wall of Room 133. The fire department will also be notified by telephone from the instrumentation room by dialing 117.

c. There are four evacuation routes from the experimental area:

1. Through Room 132 and out the exit on the south side of the building.

2. Through Room 134 (Compressor Room) and out the south side.

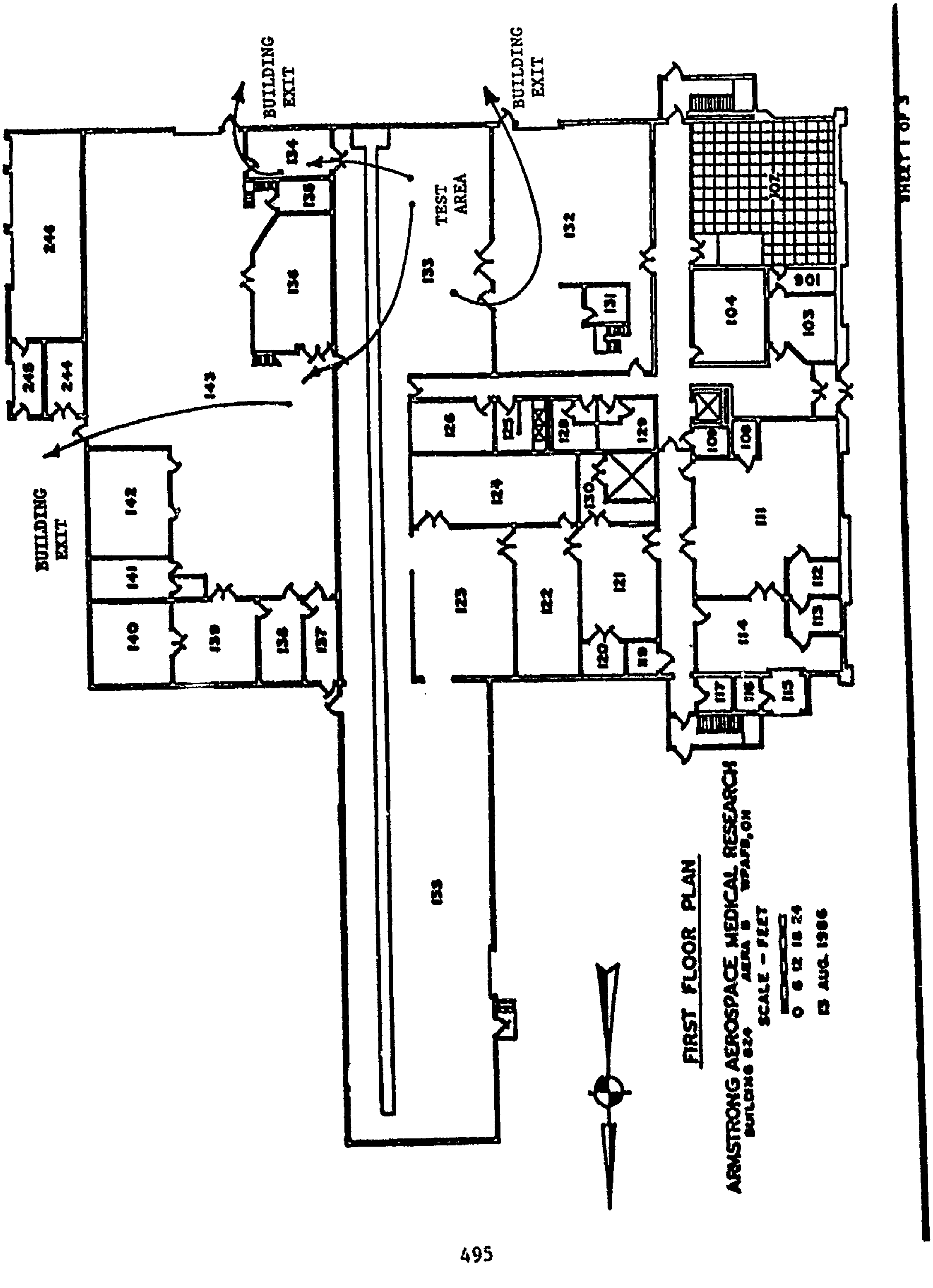
3. Through the northeast exit of Room 133.

4. Through Room 143 and out the exit on the east side.

2. The Horizontal Impulse Accelerator safety monitor will unlock the secured doors and insure the implementation of this plan in the event of an emergency.

Laurence J. Specker

LAWRENCE J. SPECKER, Acting Chief
Biomechanical Protection Branch
Biodynamics & Bioengineering Division


BUILDING EXIT
BUILDING EXIT
BUILDING EXIT
TEST AREA
FIRST FLOOR PLAN
ARMSTRONG AEROSPACE MEDICAL RESEARCH
BUILDING 824 AREA B WPAFB, OH
SCALE - FEET
0 6 12 18 24
13 AUG. 1986

SECTION 3

Gx IMPACT SLED TESTS

(19 NOV - 27 NOV 90)

Memo for the Record 30 Nov 1990

Subject: Horizontal Accelerator Testing of Helmet-Mounted Visually Coupled Systems - Preliminary Summary

1. A test program was initiated to assist in the determination of the effects helmet-mounted visually coupled systems (night vision devices or enhanced display devices) have on the risk of injury during a crash impact or emergency landing with either a fixed-wing aircraft or a helicopter. The test program used AAMRL/BBP's Horizontal Impulse Accelerator (HIA) to produce a simulated aircraft crash acceleration profile (-Gx, 20G impact, 0.200 second pulse duration) with various helmets and helmet-mounted NVG systems. The objective of the tests were to measure and compare head accelerations and neck loads for a baseline helmet and a baseline visually coupled system (Aviators Night Vision System... ANVIS) to several prototype visually coupled systems. The ANVIS system was to be used as a baseline system because of the Army's large data base of flight and accident data; however, ITT (the manufacturers of the system) were unable to provide a mock-up system and the ANVIS was deleted from testing. The test program met this objective by subjecting an instrumented manikin to a high-energy pulse delivered by the HIA in the -Gx direction. Each helmet system was to be tested three times. The helmet systems participating in the test program were: (1) the three I-NIGHTS night vision only systems, (2) a Merlin system mounted on a HGU-55/P helmet, (3) an Eagle Eye system mounted on a HGU-55/P helmet, and (4) the baseline HGU-55/P helmet. Data analysis consisted of means and standard deviations for each helmet and a comparison of the means to the baseline system.

2. Testing of the various helmet-mounted visually coupled systems was started and completed in Nov 1990. Testing at the 20G impact level was completed with a standard helmet (HGU-55/P) and one of the I-NIGHTS systems (GEC); however, two of the I-NIGHTS systems (Honeywell, Kaiser) did not complete the three test series because of failure of the structural integrity of the mock-up optics systems. The failures points were noted and the appropriate documentation photos were taken. The remaining systems were not tested at 20G because of the potential for structural failure. It was decided to decrease the impact level to 15G which was determined to be a better example of a helicopter and/or a fixed-wing emergency landing (the 20G impact level was found to be an extreme case!).

3. At 15G, all the I-NIGHTS systems survived the three test series. The additional systems (Eagle Eye mock-up on a -55/P, and a Merlin system mock-up on a -55/P) suffered a failure on their initial test. In each case, the failure was due to a weakness in the structural integrity of the optical system attachment points. Again, all failures were noted and the appropriate photos were taken.

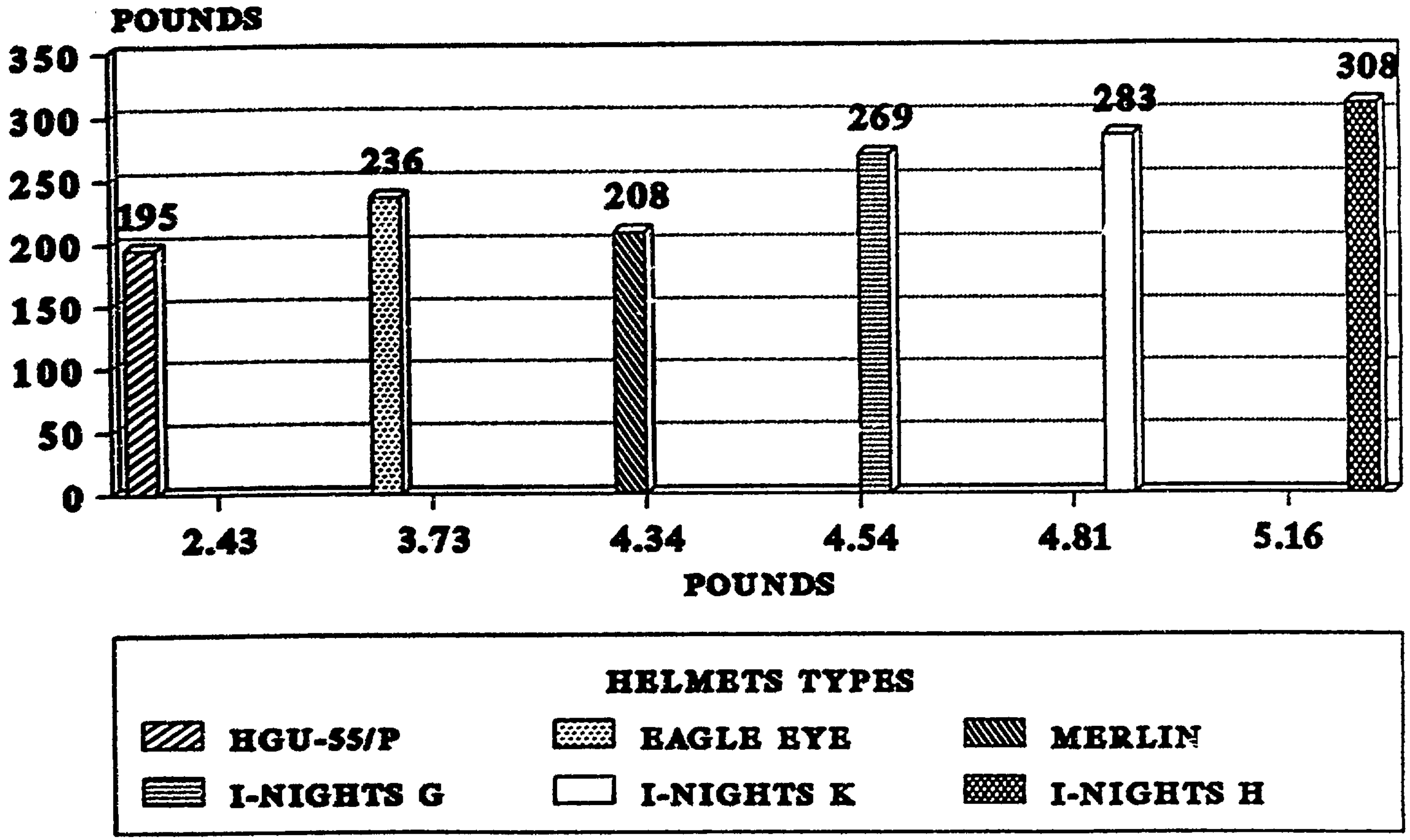
4. The tolerance of the neck to impact accelerations is expressed in terms of the loading, both shear (x-axis) and axial (z-axis) forces, at the occipital condyles. Recommended tolerance levels from NBDL have been determined form dynamic tests on cadavers and are the maximum levels without producing ligament or bone damage. These values, although considered to be conservative, will be used as a point of comparison when

the -Gx neck loads are discussed. The -Gx impacts produce head rotation forward during the impact phase, and this in-turn produces tensile loading on the cervical spine and the occipital condyle. The I-NIGHTS systems developed greater tensile loads on the neck than either the baseline helmet or the baseline-mounted optical systems, the Merlin and the Eagle Eye. The loading appeared to correlate with the weight of the helmet system as shown in the attached bar graph (z-axis loading vs helmet weight). However, all the values were less than the ~~NBDL maximum~~ tolerance level of approximately 551 lbs. With respect to the shear loads, again the I-NIGHTS systems on the average developed greater loads than the baseline helmet systems, however, there was not as good of a degree of correlation with helmet weight as the z-axis data showed. The x-axis data did produce two helmets (both I-NIGHTS helmets) that exceeded the NBDL maximum tolerance level of 437 lbs as shown on the second bar graph (x-axis loading vs helmet weight). This could be due to the moment-of-inertia of the systems as well as ~~there~~ir increased weight. Data analysis is continuing by correlating the neck loads to the center~~-of-gravity and the mass moment-of-inertia of the helme~~t systems.

CHRIS E PERRY
Crew Protection Branch
Biodynmics and Bioengineering Division

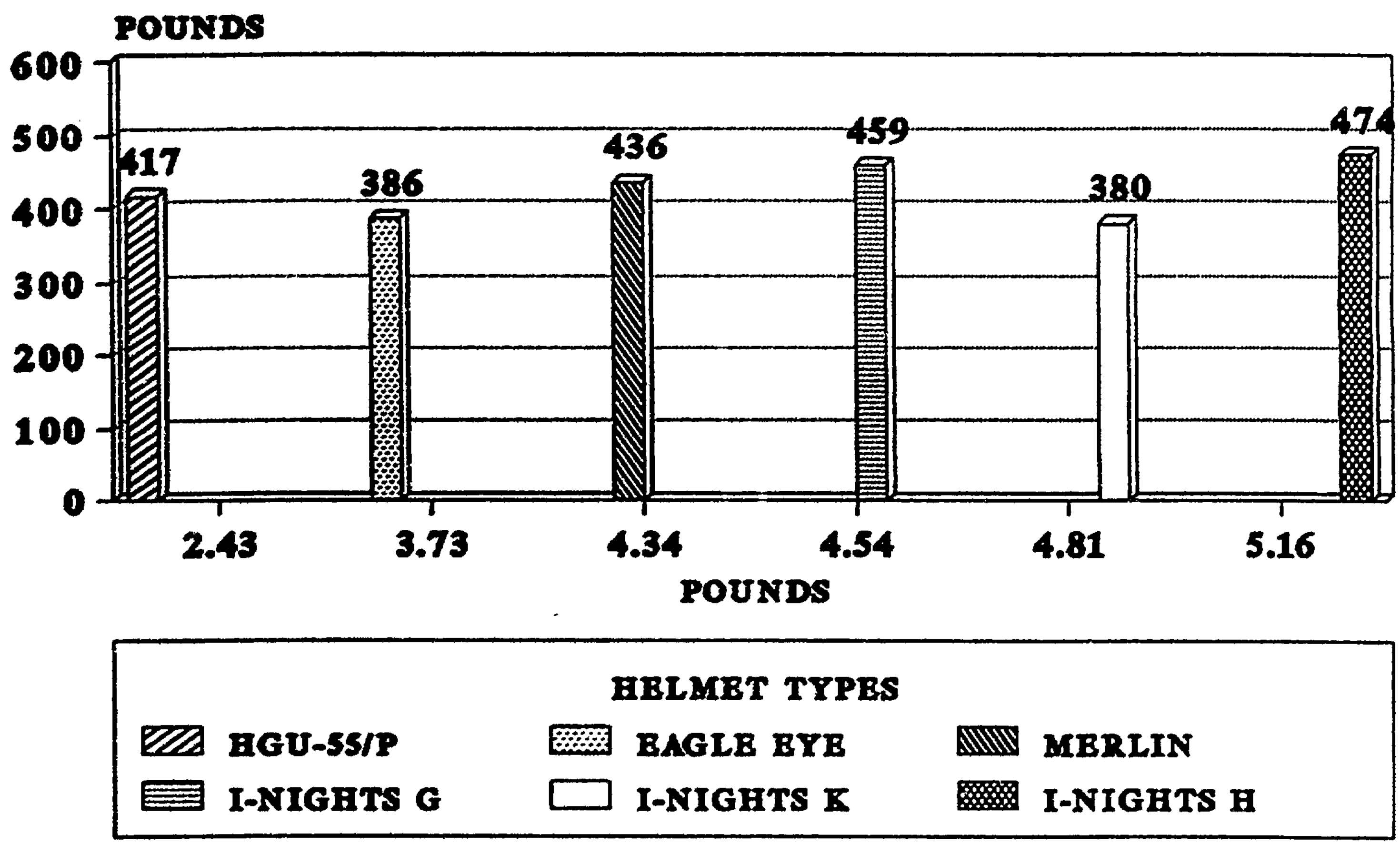
HELMET NECK LOADING

Z-AXIS NECK LOADING vs HELMET WEIGHT



TEST CONDITIONS: NO MASK, 15G IMPACT

HELMET NECK LOADING
X-AXIS NECK LOAD vs HELMET WEIGHT



TEST CONDITIONS: NO MASK, 15G IMPACT

APPENDIX I

EJECTION: G_z VERTICAL DECELERATION TOWER

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APPENDIX I: Gz VERTICAL DECELERATION TOWER

1. INTRODUCTION

Aircrew members are subject to rapid accelerations during aircraft ejections. These accelerations include high G forces to the body as the ejection seat moves up the rails and exits the aircraft. Any additional weight provided by a helmet-mounted system dramatically magnifies the forces imparted to the head, neck and spine. This report describes the evaluation of the forces experienced by the aircrew member's head and neck during ejection. This evaluation was accomplished by the Biomechanical Protection Branch, Biodynamics and Biocommunications Division, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio.

2. APPROACH

Rapid acceleration forces were measured by fitting human subjects and an instrumented manikin with each of the three I-NIGHTS helmet-mounted system designs. The human subject or manikin was then strapped into an ejection seat and subjected to ejection forces. Human subjects were tested up to 10 Gz and the manikins from 6 Gz to 20 Gz. Accelerometers placed about the head recorded the moments of inertia for analysis.

3. OBJECTIVE

The objective of this evaluation is to measure and analyze the forces encountered when ejecting from an aircraft while wearing an I-NIGHTS helmet-mounted system. The analysis will aid in the determination of safe to fly criteria.

TEST PLAN

FOR

EVALUATION OF THE EFFECTS OF VISUALLY COUPLED SYSTEMS ON HUMAN RESPONSE DURING +Gz IMPACT ACCELERATIONS

Workunit: 72313101

Prepared by: Chris E. Perry
Karin R. Getschow, Lt

June 1990

APPROVED BY: ______________________ DATE: 24 Jul 90
AAMRL/DBP

APPROVED BY: Peter A. Lurker DATE: 15 Aug 90
AAMRL/BB

COORDINATION: ______________________ DATE: __________
AAMRL/SE

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1.0 INTRODUCTION

1.1 Scope of Plan

This plan describes the experimental design, methods, and procedures, test equipment, data processing requirements, documentation requirements, and safety procedures for an experiment to evaluate the effects of helmet mounted visually coupled systems on human dynamic response to +Gz impact accelerations. The responsibilities of branch personnel, technical service contractors, and base support organizations in the implementation of this test plan are described. The test plan has been prepared in accordance with AFAMRL Regulation 80-6.

1.2 Synopsis of Effort

The experimental effort will measure the effects of a prototype visually coupled system (VCS) on the head and neck response to various +Gz impact accelerations. The effort will be conducted in two phases. Phase I will provide manikin head and neck dynamic response properties with various prototype VCS. Phase II will explore the human head and neck dynamic response with various prototype VCS. The continuation of the test program into Phase II will be contingent upon analysis of Phase I data.

2.0 SPONSOR

These tests are funded under Project 7231, Task 723131, and Workunit 72313101. A satellite study is being funded by Fiscal Year 90 Laboratory Director Funds (LDF) ILIRBB03.

3.0 RESEARCH REQUIREMENT

3.1 Background

The mission profiles of some military aircraft equipped with ejection seats are currently being expanded for more demanding operations. To improve pilot performance during these extreme flying conditions, research is being conducted investigating the use of helmet mounted VCS. VCS include integrated night vision devices and helmet mounted displays. During these demanding operations, the use of ejection seats for emergency escape could occur. If present VCS helmet systems were in use during an emergency escape, the potential exists for an unacceptably high rate of major injury or fatality. The potential increase in the injury and fatality rate would be due to the increased mass and moment of inertia that the VCS imposes on the head. This increased mass and altered weight distribution could also effect the dynamic response of the ejectee's head and neck.

3.2 Purpose and Relevancy

The purpose of this experimental effort is to acquire data to develop the human head and neck dynamic response parameters to determine the effects of VCS helmet systems on emergency escape with ejection seats. This will require the measurement and analysis of the human head and neck response to whole-body +Gz impact accelerations with various VCSs. The acquired data will also be used to refine models of human impact response. These models will then be available for any future development of ejection compatible VCS helmet systems. This effort will also assess and compare the impact responses of humans and manikins.

3.3 Critical Issues

The critical issues that will be addressed by this test program and subsequent analytical efforts using the collected data are summarized as follows:

a. What are the acceleration response characteristics of the human body, specifically the head and neck, to +Gz impact conditions with helmet-mounted VCSs?

b. How well does an anthropomorphic manikin, specifically the Hybrid III neck, mimic the acceleration response characteristics of the human body to +Gz impact conditions with VCSs?

c. What is the linearity between the response characteristics of the human head and neck and the response characteristics of an Advanced Dynamic Anthropomorphic Manikin (ADAM) head and neck?

d. How linear are the response characteristics of the ADAM head and neck to a wide range of +Gz impact accelerations with various VCS systems?

e. What are the Articulated Total Body (ATB) model coefficients that best fit the human body response characteristics, specifically the head and neck response, to +Gz impacts with various VCSs?

f. What are the ATB model coefficients that best fit the response characteristics of the ADAM head and neck to +Gz impacts up to 20 G with various VCSs?

g. Is the helmet/mask/VCS combination structurally adequate to withstand +Gz impacts up to 20 G?

4.0 TEST OBJECTIVES

4.1 Specific Objectives

The specific objectives of this research investigation are:

a. To determine the ejection capability of helmet mounted VCSs by measuring the human head and neck dynamic response to whole-body +Gz impact accelerations.

b. To quantitatively determine the structural adequacy of the VCS/mask/helmet combination to +Gz impacts up to 20 G.

c. To subjectively determine the comfort and fit of the VCS/mask/helmet combination both statically and during +Gz impact accelerations.

d. To collect electromyography data on the neck muscles of human volunteers during +Gz impact accelerations with various VCS systems.

4.2 Secondary Objectives

The secondary objectives of this experimental effort will be accomplished by subsequent analysis of the data that will be collected. These objectives are:

a. To provide a data base that can be used to refine the dynamic response coefficients of the ATB model.

b. To evaluate the linearity of the ADAM head and neck responses to a broad range of +Gz impact accelerations, and to evaluate the linearity between these responses and the human head and neck responses.

5.0 EXPERIMENTAL DESIGN

5.1 Experimental Hypotheses

The hypotheses that are being tested by this experiment are:

a. The amplitude of the measured human mechanical responses (head accelerations, neck forces, restraint forces, neck muscle activity) will vary as a function of whether or not VCSs are used during various +Gz impact accelerations.

b. The ADAM head and neck will not exhibit human-like dynamic response characteristics; therefore, the measured responses of the ADAM (head, neck) and the human subjects will be significantly different.

5.2 Null Hypotheses

In order to evaluate the significance of the above hypotheses using statistical techniques, the following null hypotheses have been developed:

a. There is no difference in the amplitude of the measured human mechanical responses as a function of testing with and without VCSs at various +Gz impact accelerations.

b. There will be no difference between the measured responses of the ADAM head and neck and the human subjects.

5.3 Summary of Technical Approach

A series of short-duration, +Gz acceleration tests will be conducted with volunteer subjects and anthropomorphic manikins using the

AAMRL Vertical Deceleration Tower (VDT). The experimental conditions will vary in acceleration magnitude, and type of head encumbrance (helmet, mask, etc.). The acceleration waveform will approximate a half-sine pulse. A minimum of ten volunteer subjects will be exposed to each test condition. The experiment will be divided into two phases. During the first phase, a large ADAM will be exposed to all the acceleration magnitudes in a progressive order. Data from test cell C, which represents a worst-case operational condition in terms of the Dynamic Response Index (DRI), will be compared to the data collected in cells X, Y, A, and B. If specified head and neck response data from cell C is greater than the corresponding response data in cells X, Y, A, and B, then the effort will not continue into Phase II. If the specified head and neck response data is less than the corresponding response data in cells X, Y, A, and B, then testing will proceed into Phase II which will expose the human subjects to test cells A, B, X1, and all of Y in a random order. Exposure to cells A and B will start after completion of the orientation test conditions (cells X and Y). The manikins and human subjects will be tested in a seated posture and restrained to an uncushioned, rigid seat. As noted in the experimental matrix, the headrest shall be in line with the seatback, and the seatback angle shall be 0 degrees. Measurements will include carriage acceleration and velocity, seat acceleration, ADAM neck and spine loads, head and chest accelerations, neck muscle electromyograms, and seat and restraint forces. The data will be evaluated by various statistical techniques including standard t-test and Wilcoxon signed rank test.

5.4 Experimental Matrix

The experimental design is summarized in the following table. Three vendors will each be suppling two prototype VCS helmet systems. One system will be a night vision device only system, while the second system will be a night vision device and helmet mounted display combination. Each vendor is designated by a Roman numeral as shown by the test matrix.

TABLE 1. I-NIGHTS TEST PROGRAM VISUALLY COUPLED SYSTEM IMPACT TEST MATRIX

SEAT ACCEL (G)	NO NVG	NVG PROTO. I	NVG PROTO. II	NVG PROTO. III	NVG/HMD PROTO. I	NVG/HMD PROTO. II	NVG/HMD PROTO. III
6		X1	X2	X3	X4	X5	X6
8		Y1	Y2	Y3	Y4	Y5	Y6
10	A	B1	B2	B3	B4	B5	B6
15	C	D1	D2	D3	D4	D5	D6
20		E1	E2	E3	E4	E5	E6

* All tests will be at 0° seat back angle
* Cell A will use a HGU-55/P helmet and a MBU-12/P mask
* Cell C (baseline tests) will use a HGU-26/P helmet and a MBU-5/P mask
* Large ADAM will run in all test cells (Phase I)
* Human subjects will run in Cells A thru B6 with X1 and all Y as orientation cells (Phase II)

6.0 EXPERIMENTAL METHODS

6.1 Impact Facility and Equipment

All tests will be conducted using the AAMRL Vertical Deceleration Tower (VDT) facility, Building 824, Area B, Wright-Patterson AFB, Ohio. The experimental test fixture will be the VIP seat mounted on the VDT carriage assembly in an upright position and will provide a +Gz acceleration vector. The VDT metering pin to be used shall be pin #102. The manikins and human subjects used in this test program shall be restrained using a standard USAF double shoulder strap and lap belt configuration. The restraint harness straps will be pretensioned to 20 $\pm$ 5 lbs at each attachment point prior to each impact test. Each of the subject's (humans and manikins) legs shall be restrained by a single strap that encircles the subject's ankles and is attached to the carriage. Another strap shall cross the subject's thighs and attach to the seat pan posterior to the knees. Each of the subject's hands shall also be placed under the thigh restraint resting on the knees with a closed fist and the knuckles up. The upper arm shall be parallel to the body axis with elbows bent and the arm relaxed.

6.2 Subjects

Manikin and human subjects will be used in the tests.

6.2.1 Manikin. The large ADAM manikin will be used during this test program.

6.2.2 Human Volunteer Subjects. The human subjects will be volunteers from the AAMRL Impact Acceleration Test Panel. The subjects will be wearing cutoff long underwear and socks.

6.3 Data Acquisition

The following measurements shall be made:

6.3.1 Electronic Data. The electronic data channel assignments are specified in attachment 1. The right-handed coordinate system shown in attachment 2 shall be used. Transducer excitation, signal amplification, filtering, digitizing, and transmission shall be provided by the on-board portion of the Automated Data Acquisition Control System (ADACS). The electromyography portion of the data collection shall be excited and amplified by an independent on-board system with hard-wire transmission to an analog data acquisition system.

6.3.2 Accelerometer Mounting Techniques for Human Subjects. A triaxial accelerometer array will be mounted to a bite-block, which will be individually fabricated for each subject by the medical technician. Prior to each test, the medical technician will determine that the condition of the bite-block is satisfactory. If the bite-block has deteriorated, a new bite-block will be made. The triaxial accelerometer array fixed to the bite block will be held within a plexiglass block to provide electrical isolation of the device from the subject. A second triaxial accelerometer array will be mounted to the subject's chest with a Velcro chest strap. In addition, an angular accelerometer will be attached to the bite block and also to the chest pack.

6.3.3 Electrode Mounting Techniques for Human Subjects. Twelve surface electrodes will be adhered to the skin over the specified points of three pairs of neck muscles. The skin in the vicinity of the electrode will be abraded and coated with a conductive gel to reduce the electrical resistance.

6.3.4 Accelerometer Mounting for Manikins. In each test using an ADAM, a triaxial accelerometer array will be mounted within the manikin's head and a chest accelerometer array will be attached by means of a Velcro strap around the manikin's chest. An angular accelerometer will also be mounted within the head.

6.3.5 Photogrammetric Data. Photogrammetric data will be collected prior to the release of the carriage as well as during the impact event. The photogrammetric data will be recorded by two 16-mm, high-speed (500 frames/sec) cameras mounted on the test fixture at oblique and right angles to the subject. The photogrammetric data will consist of displacement-time histories of photogrammetric targets mounted on the test seat, carriage assembly, and test subject. The positions of the targets shall be as illustrated in attachment 3. The positions of the photogrammetric targets used in the tests with manikins shall be the same as those used in the tests with volunteers.

6.3.6 Video Coverage. A video camera will be mounted in an off-board position to provide test documentation. The system that will be routinely used will have immediate playback capability. At or near the end of the test program a video shall be recorded to document the test preparations, test fixtures, and the test as well as provide a brief narrative of the test purpose.

6.3.7 Still Photography. The pre-impact position of the subject will be documented by still photographs before each test. The photograph shall include a placard listing the designation of the test (VCSI STUDY), the test number, the subject's code, and the date.

6.3.8 Subjective Response Questionnaire. Immediately following each test, the subject will be required to fill out a questionnaire describing his or her subjective response to the test. The questionnaire is included as attachment 4.

6.3.9 Other Physiologic Data. Electrocardiograms will be recorded before, during, and after each test. Electrodes will be placed on the subject by a medical technician prior to each impact. The EKG signal will be hardwired through the instrumentation room to the recording station. The EKG oscillograph recording will be inspected and approved by the medical monitor before the subject is tested. Standing blood pressure will also be obtained and recorded on the subject's medical records by the medical technician prior to each test.

6.4 Pre-Test Experimental Procedures

6.4.1 Proof Tests. A proof test will be conducted at a test level of 26 G to insure the integrity of the test equipment and of the test fixture. This test will be done prior to testing with the ADAM and the volunteer subjects and will be accomplished with the ADAM. The results of these tests, including structural effects and photogrammetric data, will be reviewed by the facility engineer and the investigators.

6.4.2 Experimental Level Tests. Impact tests will be accomplished at each experimental condition with an ADAM prior to tests at that set of conditions with volunteers.

6.4.3 Review and Approval of Pre-Test Data. Electronic and photogrammetric data from at least one of the fully instrumented manikin tests will be processed and the data reviewed to assure adequacy of the data prior to human tests. The film and processed data will be reviewed by the photo monitor, investigators, and contractor photogrammetric data analysis personnel.

6.5 Test Procedures

6.5.1 Manikin Tests. The procedures for tests with ADAM are summarized as follows:

a. The first test of the day will consist of a facility check test. The ADAM will be used for this test. The mechanical systems and data will be reviewed before the start of the ADAM tests for that day.

b. After the ADAM is properly dressed, the manikin will be placed onto the seat. All internal manikin sensors will then be properly interfaced for data collection. The lap belt and shoulder harness will then be attached and preloaded to 20 ± 5 lbs. Care shall be taken to assure that the ADAM's buttocks are firmly against the seat. Once properly restrained, the appropriate head encumbrance equipment (as determined by the test matrix) should be carefully placed on the manikin's head. Also, the oxygen hose (in tests requiring a mask) should be securely attached to the restraint harness using a velcro restraint strap.

c. The manikin's hands will be placed in its lap with the upper arms parallel to the seatback. At this point, the Velcro hand and leg restraints shall be properly positioned.

d. After the manikin is properly positioned and prepared for impact, a still photograph will be taken from the side view.

e. The carriage will be raised to its proper drop height as determined by the required impact magnitude. The safety officer will check all safety systems and assure that the VDT test area is secure.

f. If all safety systems continue to be okay, the test conductor will instruct the VDT operator to activate the automatic countdown. At T = 0, the carriage will release allowing it to free-fall to impact.

6.5.2 Human Volunteer Tests. The procedures for tests with volunteer subjects are summarized as follows:

a. The first test of the day will consist of a facility-check test. The ADAM will be used for this test. The mechanical systems and data will be reviewed before the start of the human tests for that day.

b. Each subject will receive a briefing on the test procedures, requirements and medical risks prior to their exposure.

c. Immediately prior to each human impact test, the voluntee̊r subject shall undergo a short battery of tests to measure his or her maximum voluntary contractions (MVCs) of the neck muscles. The MVCs of the sternocleidomastoid, splenious capitus, and trapezius paired muscles shall be measured at four head angles in the ± x direction (flexion, extension).

d. After the subject is properly dressed (including chest pack and physiologic equipment) and medical checks are completed, the subject will be instructed to position himself on the carriage seat. The lap belt and shoulder harness will then be attached and preloaded to 20 ± 5 lbs. Care shall be taken to assure the subject's buttocks are firmly against the seat. Once properly restrained, the appropriate head encumbrance equipment (as determined by the test matrix) should be carefully placed on the subject's head. Also, the oxygen hose (in tests requiring a mask) should be securely attached to the crew-60 mounted on the restraint harness.

e. After the subject is properly positioned and restrained, a still photograph will be taken from the side view.

f. The subject will be asked to place his fists (knuckles up) in his lap. The hand and leg restraints (Velcro straps) will then be properly positioned over the subjects lower and upper leg.

g. Each subject will then be provided with an abort switch from the control and safety system of the VDT. The switch will be held in the subject's right hand and must be depressed for the test to proceed.

h. The carriage will be raised to its proper drop height as determined by the required impact mangitude. The subject will be instructed by the test conductor to hold the abort switch when ready. The safety office will check all safety systems and assure the test area is clear.

i. If all safety systems continue to be okay, the test conductor will instruct the VDT operator to activate the automatic countdown, which at T = 0 will release the carriage allowing it to free-fall to impact.

6.6 Post Test Procedures

After the impact of a human subject has occured, the following procedures should be used:

a. The medical monitor will determine if the subject is uninjured. If an injury is apparent, then the medical monitor will take charge and commence with the emergency procedures (see attachment 5). If an injury is not apparent, the medical monitor will instruct the mechanical technician to release the subject from the restraint system.

b. The medical monitor will then perform a brief examination including blood pressure and EKG check.

c. Upon completion of the examination, the subjective response questionnaire will be given to the subject by the medical technician.

d. After completion of the questionnaire, the subject will be instructed to dress and to contact the medical monitor or the Impact Acceleration Stress Panel physician if symptoms develop.

6.7 Environment

The temperature and humidity of the instrumentation room and data processing room shall be maintained within a range of 60 to 80 degrees F and 40 to 60% relative humidity during the program. DynCorp personnel shall notify CMSgt Lashley or his designated alternate if the temperature or humidity cannot be maintained within these limits.

6.8 Test Scheduling

The impact tests shall be scheduled over an eight to ten-week period. The schedule shall be discussed during weekly meetings with the investigator personnel, support personnel, and contractors. The services of Tech Photo shall be scheduled by CMSgt Lashley or his designated alternate.

7.0 DATA ANALYSIS REQUIREMENTS

7.1 Test Evaluation Criteria

The collected data shall be used to evaluate the adequacy of each test prior to further tests. This evaluation shall be accomplished on the basis of a set of "quick-look" data or, if available, a complete set of data.

7.1.1 Successful Test. A successful test is a test in which:

a. All electronic data channels were present and continuous.

b. All photogrammetric data were successfully collected.

7.1.2 No Test. A no test is a test that does not meet the requirements of the test plan and must be repeated. A no-test will be declared if failure occurs in either the data collection system or the photogrammetric system resulting in insufficient data to permit adequate and satisfactory analysis of the test. A no-test will also be declared if the subject or any of AAMRL'S test personnel stop the test. A no-test will also be declared if the subject assumes an improper body position prior to the initiation of the test.

7.1.3 Not-Fully-Successful Test. A test that fails to meet the requirements of a "successful test", yet is not classified as a "no-test", shall be called a "not-fully-successful test". This classification of test shall be made by the decision of the principal investigator on the basis that: sufficient useful data have been collected. It may not be necessary to repeat a not-fully-successful test.

7.2 Statistical Techniques

To evaluate the experimental hypotheses and to describe and evaluate the collected data, the following techniques shall be used:

7.2.1 Analysis of Paired Data. Data for comparative evaluation shall be analyzed by means of the Wilcoxon paired-replicate rank test. Correlations shall be evaluated using a variance-ratio F test. The 95% confidence level for a two-tailed test is the chosen level of statistical significance.

7.2.2 Analysis of Central Tendency. Means and standard deviations shall be calculated for all sets of data from each test cell.

7.2.3 Data Computation Requirements. The data analysis shall include computation of resultant head acceleration, resultant chest acceleration, resultant shoulder strap force, vertical seat pan force, resultant seatpan force, and Dynamic Response Index (where omega = 52.9 and cbar = 0.224) from the z-axis acceleration of the seat. The displayed data should be arranged to show grouped data such as right force, left force, center force, and summation in a quadripartite format (four plots per page). The plots to be arranged in this fashion include:

a. head x, y, z, and resultant accelerations
b. chest x, y, z, and resultant accelerations
c. x, y, z, and resultant lap belt forces
d. x, y, z, and resultant shoulder harness forces
e. left, right, center, and summation of seat z-axis forces
f. right x-axis, left x-axis, y-axis, and resultant seat forces
g. x, y, and z carriage acceleration, and seat z-axis acceleration
h. Ry accelerations for the head, chest, and seat

In addition, the following plots of manikin data should also be grouped in a quadripartite format:

a. neck x, y, z, and resultant forces
b. lumbar x, y, z, and resultant forces

7.2.4 Electromyography Analysis. The electromyography data shall be analyzed using an Integrated Threshold Detector method developed by Dr Repperger (AAMRL/BBS). Recruitment patterns, along with power and frequency distributions, shall be determined using the more traditional Integrated EMG method. Results from the two methods shall be compared.

8.0 DATA PROCESSING REQUIREMENTS

8.1 Electronic Data Handling

The transducer signals shall be handled by the on-board Automatic Data Acquisition and Control System (ADACS). Signal conditioning, filtering, amplification, and digitizing (at a rate of 1000 samples/sec) shall take place on-board the test fixture. The digitized data shall be transmitted to the computer room for storage on digital magnetic tape or a VAX disc and shall be processed later by the VAX computer system.

8.2 Photogrammetric Data

After the high-speed films have been processed, the data will be digitized by the Automatic Film Reading (AFR) system and recorded on magnetic tape or on a PDP-11/34 disc. The x and y coordinate resolution is 0.025 percent of the major film dimension. The photo flash zero and LED TBAR photographic timing system will be used and synchronized with the electronic data. Each test will be positively identified by appropriate numeric characters visible within each camera view. These data will then be recorded on magnetic tape or a VAX disc.

9.0 TEST DOCUMENTATION REQUIREMENTS

9.1 Vertical Deceleration Tower

Documentation of the VDT is located in the operator's station. This book contains the following information:

9.1.1 Test Log. Documents the machine operating parameters and conditions for each test. The logs are stored in the Impact Information Center and are maintained by the operations and maintenance contractor.

9.1.2 Checklists. Checklists are provided for each station and are used by the station operators during each test.

9.1.3 Operating Procedures. Detailed procedures for operating the various stations are available at each station with references to specific subsystem information. The operating procedures include an abort sequence to be used in cases of aborted tests.

9.1.4 Maintenance Instructions. Detailed maintenance information and the inspection interval are documented here. Last inspection date is also documented.

9.1.5 Maintenance Log. Documents failures, dates of failures, corrective actions and date. Provides history of accomplished maintenance.

9.1.6 Test Conductor's Checklist. The test conductor shall note on the checklist (attachment 6) any deviations from the test plan or special problems encountered during the experimentation or the data processing.

9.2 Electronic Data

The following documentation of the electronic data systems and procedures shall be maintained:

9.2.1 Instrumentation Program Requirements. This document identifies the transducer and associated electronics for each data channel in addition to the sensitivities, gains, calibration values, and filters used. This document will be filed in the Impact Information Center.

9.2.2 Transducer Calibration. Each transducer maintained by DynCorp will be calibrated before and after the test program to check sensitivity, frequency response, and resonant frequency in accordance with the standard practice instructions of calibration procedures for each transducer type. Calibration records of individual transducers as well as the standard practice instructions are maintained in the Impact Information Center. For this test program, a record will be made identifying the data channel, transducer manufacturer, model number, serial number, date and sensitivity of pre-calibration, date and sensitivity of post-calibration, and percentage change. Pre- and post-calibration information is maintained with the program data.

9.2.3 VAX Log. This log is maintained to identify data channels and processing parameters. These records are redundant, but provide backup and data verification.

9.2.4 VAX Plots and Printouts. The data plots and printouts from the VAX shall be given to CMSgt Lashley for review. They shall then be given to the principal investigator or designated associate for analysis. The records shall be permanently stored within the Branch.

9.3 Photogrammetric System Documentation

The following documentation of the photogrammetric systems and procedures shall be maintained:

9.3.1 Camera Description and Location. DynCorp personnel shall provide documentation of the manufacturer, model, operating speed, lens focal length, and position of each camera; and the positions of the photogrammetric targets mounted on each subject. The documentation shall include a sketch showing the dimensions of the cameras with respect to the reference points of the seat (i.e. neutral seat reference point, plane of seat pan, plane of seat back, plane of symmetry, and plane of carriage).

9.3.2 Photogrammetric Techniques. The photogrammetric analysis techniques shall also be documented. This documentation shall be suitable for publication within an AAMRL technical report and shall be provided to the principal investigator for review and approval at the completion of testing.

9.4 Subject Anthropometry

The anthropometric data for the test subjects shall be documented as follows:

9.4.1 Volunteer Subjects. The anthropometric data for each volunteer shall be obtained by AAMRL/HEG, filed in the work unit case file, and entered into the Biodynamic Data Bank. A separate file of anthropometric data will be maintained by the medical technician, who will prepare individual and collective summaries of the anthropometric data at the completion of testing. The records shall then be stored with the project case files.

9.4.2 Manikin Subjects. The anthropometric data for each manikin shall be collected, recorded in the Biodynamics Data Bank, and stored with the project case files.

9.5 Medical Records

The following medical records shall be provided:

9.5.1 Medical Test Log. Medical records will be maintained by the medical technician. The records will contain test number, cell of experimental design matrix, test level, and medical adverse effects of the test. It will be signed by the medical monitor and principal investigator.

9.5.2 Consent Forms. Consent forms will be read and signed by each volunteer prior to participation in these tests. The forms will be filed by the medical technician in the subject's folder.

9.5.3 SF600, Health Record—Chronological Record of Medical Care. Shall be maintained by the medical technician for each subject. An entry will be made on this form after each impact exposure, in accordance with AAMRL Reg 161-1. When complete, this document will be forwarded to the Outpatient Records Department of the Medical Center for inclusion in the subject's medical record.

9.5.4 Impact Test Data Sheet. Shall be filled out by the medical monitor following each test. This record will document any adverse medical effects of the test. The pre- and post-test EKG tracings will be attached to this form, which will be placed in the subject's folder after each test.

9.6 Reporting

The following reporting requirements shall be met:

9.6.1 Post-Test Documentation. Immediately after each test the test conductor shall document any deviations from the test plan, unanticipated test results, or problems encountered in carrying out the test procedures. This information will be provided to the principal investigator, or if unavailable, to the associate investigators as soon as possible and before the next test with a human subject if the finding could influence the outcome of the next test.

9.6.2 Test Methods. The operations and maintenance contractor will document all aspects of the test methods prior to completion of testing. The documentation will include the geometry of the seat and restraint systems, location of the seat with respect to the carriage, the harness materials, and the location of the instrumentation transducers. Thorough documentation of the electronic and photogrammetric data processing techniques shall also be accomplished by DynCorp. This documentation shall be suitable for publication in an AAMRL technical report and shall be provided to the investigators for review.

9.6.3 Incident and Mishap Reporting. See AFR 169-3 for injuries and AFR 800-16 for equipment damage reporting requirements.

9.6.4 Technical Report. The investigator personnel assigned to this test program are responsible for the documentation of the experimental results within an AAMRL technical report.

9.7 Disposition of Test Plan

The original copy of this test plan shall be filed in the R&D workunit case file. A copy will also be provided for storage within the Biodynamics Data Bank.

10.0 TEST PERSONNEL ASSIGNMENTS

10.1 Laboratory Personnel.

a. Principal Investigator - Mr Chris E. Perry

b. Associate Investigators - Lt Karin Getschow
Lt Dena Bonetti

c. Medical Monitors - Maj Cynthia N. Taylor,
or other qualified physician

d. Test Conductors - Mr Carl Toler
1Lt Karin R. Getschow
Mr Joseph P. Strzelecki (After training)
CMSgt Phillip A. Lashley
Mr John Buhrman (After training)
2Lt Dena Bonetti (After training)

e. Facility Engineer - Mr Carl G. Toler

f. Facility Operating Official - CMSgt Phillip A. Lashley

g. Safety Officer - The safety officer for each test shall be appointed by the test conductor from the list of qualified personnel specified in the Branch file entitled "Installations Management".

h. Medical Technician - SSgt Jeffrey D. Briggs

10.2 Contractor Personnel

a. Vertical Deceleration Tower - Qualified operators are designated in the "Installations Management" file in the Branch office.

b. Operations and Maintenance Functions - The Scientific Services Division of the DynCorp Corporation shall provide operation and maintenance of the facilities under Contract No. F33615-86-C-0531. The Engineering Supervisor for DynCorp is Mr Marshall Miller. This contract is technically monitored by Mr. Chris Perry and requests for support shall be managed by him.

10.3 Quality Assurance Inspections

DynCorp shall perform quality assurance inspections to assure the accuracy and reliability of the electronic instrumentation and data processing operations. CMSgt Lashley (or designated alternate) shall perform Air Force inspection of instrumentation calibration and data processing systems operations to assure the accuracy of the electronic data and adherence to operational procedures.

10.4 Photogrammetric Data Collection and Processing

The personnel of DynCorp will be responsible for the locating and documentation of photogrammetric targets on all test subjects. Photogrammetric data will be processed by personnel of the DynCorp Corporation using the Automatic Film Reader. DynCorp will be responsible for quality assurance inspection of the photogrammetric data.

10.5 Technical Photographic Services

High-speed motion picture camera and still photo coverage will be provided by the Technical Photo Service of ASD. Scheduling arrangements will be made by the test conductor. DynCorp personnel will assist the photo monitor to assure that the photographic films are of adequate quality for automatic data processing. CMSgt Lashley will be responsible for quality assurance inspection of the photographic films and prints.

11.0 SAFETY AND EMERGENCY PROCEDURES

11.1 Briefing of Test Personnel

All Branch and contractor personnel shall be briefed on safety and emergency procedures by their supervisors.

11.2 Test Area Access

The safety monitor is responsible for securing the test area and restricting visitors. Only visitors approved by the Biomechanical Protection Branch Chief or the test conductor shall be permitted in the test area. No unauthorized photography shall be permitted.

11.3 Hazards to Operators and Test Personnel

Hazards to operators and other test personnel will be minimized by ensuring that no personnel are within the designated yellow lines around the VDT prior to the release of the carriage. Safety measures will be used in accordance with established facility operating procedures and checklists referenced elsewhere in this test plan.

11.4 Risk Category

The risk category for this program is IIIC, which is defined by MIL-STD-882B to be undesirable and requiring management approval at the Division level.

11.5 Damage to Test Equipment and Facility

Damage to the test equipment, manikins, and minor damage to the facility is expected to occur only if catastrophic failure of the restraint harness should occur. This has not occurred at the acceleration levels that will be used during this program. The risk of catastrophic failure has been reduced by using a restraint harness that has been designed to carry loads approximately ten times higher than expected and by conducting dynamic proof-load tests of the equipment at one and one-half times the highest load levels expected during the test program. Furthermore, the restraint loads will be evaluated after each test and compared to the strength of the restraint harness materials.

11.6 Safety Permit

The Vertical Deceleration Tower and the test fixtures to be used in this test program were granted a safety permit by the AAMRL Technical Safety Committee on 31 January 1989. In addition, the test fixture was rated for human tests on the same date. A hazard analysis was performed as part of the original Safety Permit.

11.7 Emergency Procedures

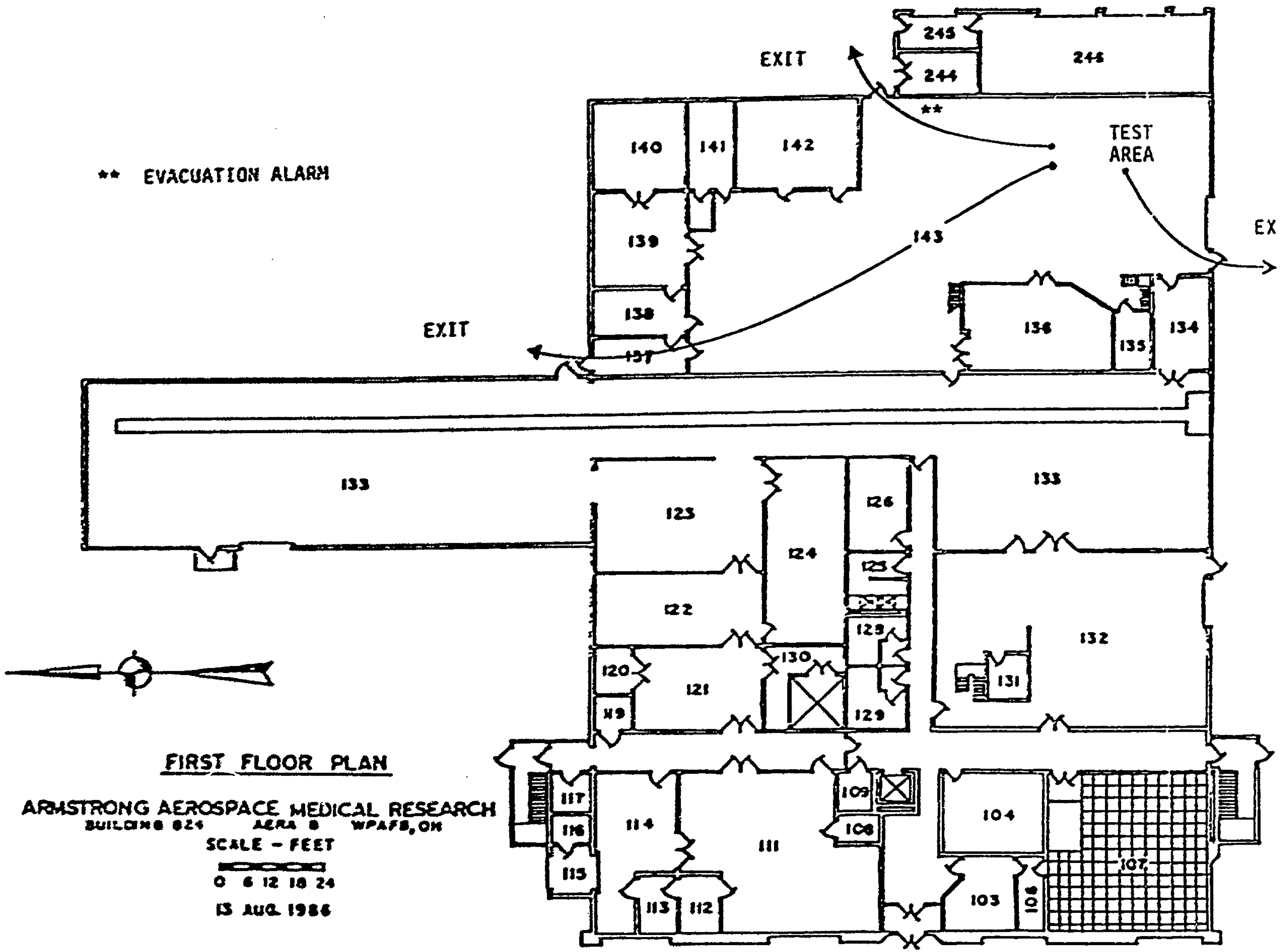
Emergency procedures are defined in the attached emergency procedures checklist and fire evacuation plan (see attachments 6 and 7). Test personnel shall practice the emergency procedures under the direction of Capt Cynthia Randall prior to commencement of tests with human subjects.

12.0 REFERENCES

1. Hearon, B.F., "Generic Impact Acceleration Protocol, 1988-89", AAMRL Protocol No. 84-01-03.

2. Medical Protocol 89-7-01, Evaluation of the Effects of Visually Coupled Systems on the Human Dynamic Response During +Gz Accelerations Impct With Assessment of Neck Muscle Biodynamics, 6 Jun 90.

3. Manrating and Safety Documentation. Information on the impact facility is available within the AAMRL/BBP files on "Installations Management".



** EVACUATION ALARM

FIRST FLOOR PLAN

ARMSTRONG AEROSPACE MEDICAL RESEARCH
BUILDING 824 AREA B WPAFB, OH
SCALE - FEET
0 6 12 18 24
13 AUG. 1986

ELECTRONIC DATA CHANNEL REQUIREMENTS

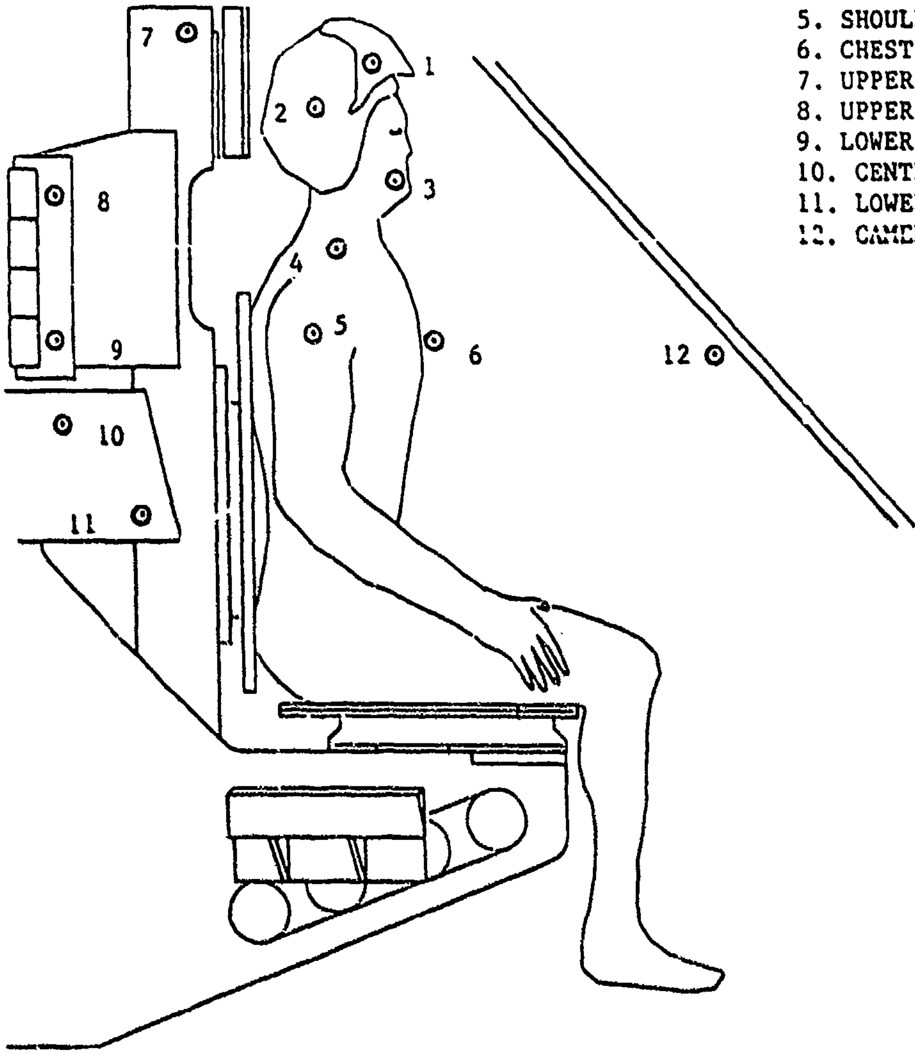
CHANNEL	PARAMETER	DYNAMIC RANGE	FREQUENCY RANGE
1	Carriage X	28 G	DC-120 Hz
2	Carriage Y	24 G	DC-120 Hz
3	Carriage Z	40 G	DC-120 Hz
4	Head X Accel	34 G	DC-120 Hz
5	Head Y Accel	30 G	DC-120 Hz
6	Head Z Accel	68 G	DC-120 Hz
7	Head Ry Accel	5000 rad/sec^2	DC-120 Hz
8	Chest X Accel	30 G	DC-120 Hz
9	Chest Y Accel	18 G	DC-120 Hz
10	Chest Z Accel	68 G	DC-120 Hz
11	Chest Ry Accel	4000 rad/sec^2	DC-120 Hz
12	L Seat Z Force	2500 lb	DC-120 Hz
13	R Seat Z Force	2500 lb	DC-120 Hz
14	C Seat Z Force	5000 lb	DC-120 Hz
15	L Seat X Force	1000 lb	DC-120 Hz
16	R Seat X Force	1000 lb	DC-120 Hz
17	Seat Y Force	1000 lb	DC-120 Hz
18	L Lap X Load	2000 lb	DC-120 Hz
19	L Lap Y Load	1000 lb	DC-120 Hz
20	L Lap Z Load	1800 lb	DC-120 Hz
21	R Lap X Load	2000 lb	DC-120 Hz
22	R Lap Y Load	1000 lb	DC-120 Hz
23	R Lap Z Load	1800 lb	DC-120 Hz
24	Shoulder X Load	1000 lb	DC-120 Hz
25	Shoulder Y Load	500 lb	DC-120 Hz
26	Shoulder Z Load	1200 lb	DC-120 Hz
27	Seat X Accel	17 G	DC-120 Hz
28	Seat Y Accel	18 G	DC-120 Hz
29	Seat Z Accel	30 G	DC-120 Hz
30	Seat Ry Accel	1700 rad/sec^2	DC-120 Hz
31	Upper Headrest X Force	600 lb	DC-120 Hz
32	Lower Headrest X Force	600 lb	DC-120 Hz
33	Neck X Force	2500 lb	DC-120 Hz
34	Neck Y Force	2500 lb	DC-120 Hz
35	Neck Z Force	3000 lb	DC-120 Hz
36	Neck My Moment	5600 in-lb	DC-120 Hz
37	Lumbar X Force	7000 lb	DC-120 Hz
38	Lumbar Y Force	7000 lb	DC-120 Hz
39	Lumbar Z Force	8500 lb	DC-120 Hz
40	Lumbar My Moment	18000 in-lb	DC-120 Hz
41	Velocity	80 ft/sec	DC-60 Hz
42	Event		DC-2000 Hz

PHOTOGRAMMETRIC FIDUCIAL LOCATIONS

PROGRAM: VERTICAL IMPACT OF VISUALLY COUPLED SYSTEMS (VCSI)

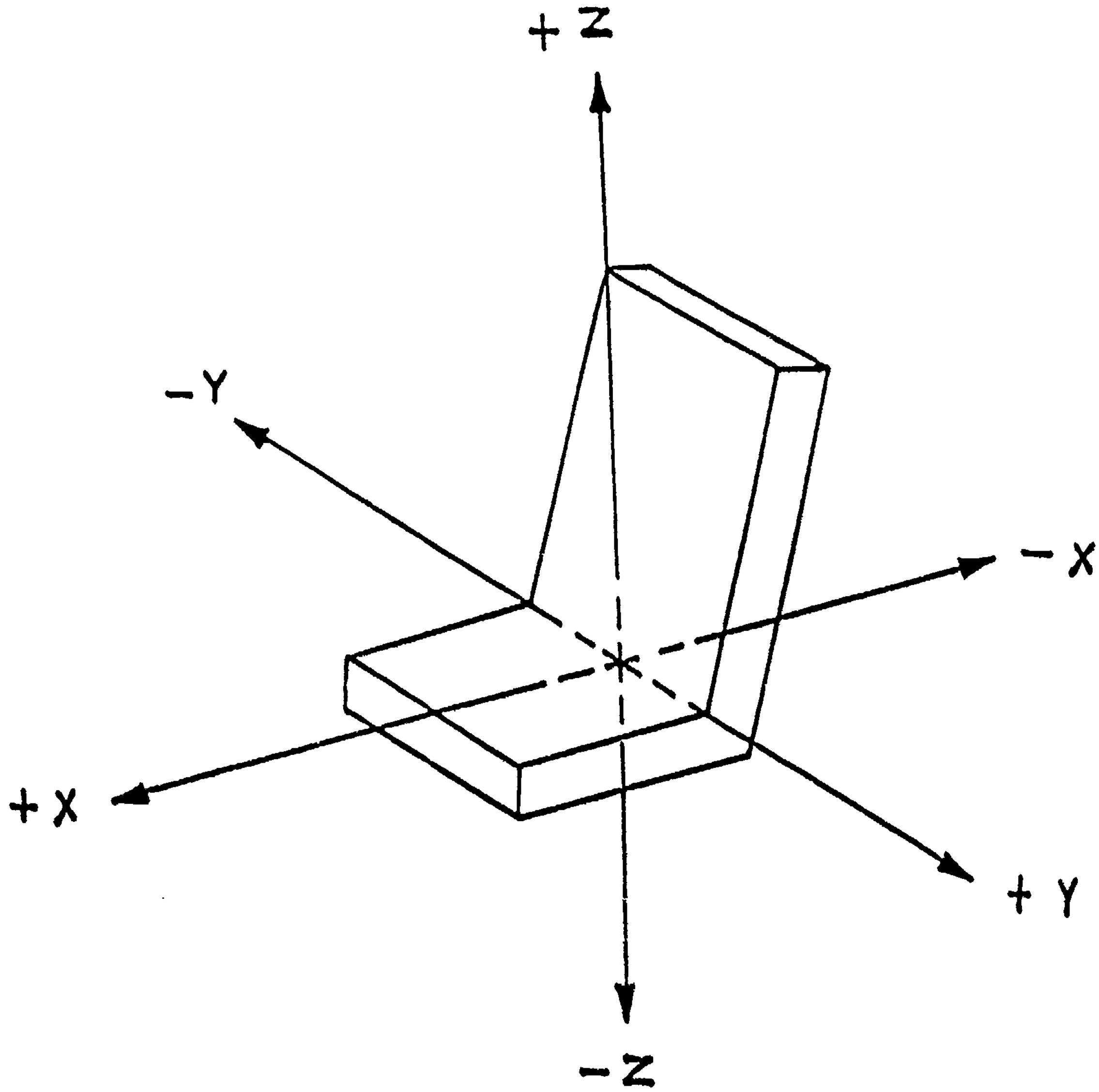
FACILITY: VERTICAL DECELERATION TOWER

START DATE: TBD **INITIAL TEST NUMBER:** TBD



1. UPPER HELMET
2. LOWER HELMET
3. MASK
4. NECK
5. SHOULDER
6. CHEST
7. UPPER FRAME
8. UPPER NUMBER PLATE
9. LOWER NUMBER PLATE
10. CENTER FRAME
11. LOWER CENTER FRAME
12. CAMERA STRUT

AAMRL/BBP COORDINATE SYSTEM



* The seat/man origin will be at the center of the line intersecting the planes of the seat back and seat pan.

SUBJECTIVE RESPONSE QUESTIONNAIRE

DATE: ________________ SUBJECT ID: ______ TEST NO.: _________ CELL NO.: ______

We would like to obtain your subjective response to the impact test you have just completed. Please relate your experience to either end of the scales below as follows: 3 = very closely related; 2 = closely related; 1 = slightly related; and 0 = neutral. Circle the number which best describes your immediate impression for each of the following:

<u>IMMEDIATE PRE-IMPACT</u>

Overall Physical Impression of Seat and Restraint Harness								
Comfortable	3	2	1	0	1	2	3	Uncomfortable
Overall Physical Impression of Helmet/mask/VCSs								
Comfortable	3	2	1	0	1	2	3	Uncomfortable
Anxiety Level								
Low	3	2	1	0	1	2	3	High
Level of Consciousness								
Alert	3	2	1	0	1	2	3	Confused

<u>DURING IMPACT</u>

Shoulder Harness Pressure								
Low	3	2	1	0	1	2	3	High
Lap Belt Pressure								
Low	3	2	1	0	1	2	3	High
Crotch Strap Pressure								
Low	3	2	1	0	1	2	3	High
Mask Pressure								
Low	3	2	1	0	1	2	3	High
Helmet Pressure (if applicable)								
Low	3	2	1	0	1	2	3	High
Head Displacement								
Small	3	2	1	0	1	2	3	Large
Neck Comfort								
Comfortable	3	2	1	0	1	2	3	Uncomfortable
Back Comfort								
Comfortable	3	2	1	0	1	2	3	Uncomfortable
Acceleration								
Smooth	3	2	1	0	1	2	3	Abrupt
Impact Level								
Low	3	2	1	0	1	2	3	High
Your Physical Response								
Mild	3	2	1	0	1	2	3	Severe

IMMEDIATE POST-IMPACT

Overall Physical Well Being								
Comfortable	3	2	1	0	1	2	3	Uncomfortable
Anxiety Level								
Low	3	2	1	0	1	2	3	High
Level of Consciousness								
Alert	3	2	1	0	1	2	3	Confused

COMPARISON WITH PREVIOUS TEST

More Severe	3	2	1	0	1	2	3	Less Severe

COMMENTS

____

____

____

____

Following Your Final Run:

Was there a perceptable difference between running with the HGU-55/P and the VCS prototype systems?

(NO) (YES)

AEROSPACE MEDICAL RESEARCH LABORATORY		Title VERTICAL DECELERATION TOWER TEST CONDUCTORS CHECKLIST	
		Approved By	Date
		[signature]	29 Aug 89
Page	Effective Date		
1 of 3	29 August 1989		

Test Program ______ ______ ______ ______ ______ ______

Test Number ______ ______ ______ ______ ______ ______

Date ______ ______ ______ ______ ______ ______

Subject Number ______ ______ ______ ______ ______ ______

Subject Weight ______ ______ ______ ______ ______ ______

Type Helmet ______ ______ ______ ______ ______ ______

Night Vision goggles (Y/N) ______ ______ ______ ______ ______ ______

Test G Level ______ ______ ______ ______ ______ ______

Drop Height ______ ______ ______ ______ ______ ______

Cell ______ ______ ______ ______ ______ ______

Plunger Number ______ ______ ______ ______ ______ ______

PRETEST CHECKLIST

Checklists ______ ______ ______ ______ ______ ______

Emergency Room Alerted ______ ______ ______ ______ ______ ______

Whip Cable ______ ______ ______ ______ ______ ______

Headrest Position ______ ______ ______ ______ ______ ______

Zeroes ______ ______ ______ ______ ______ ______

Cameras ______ ______ ______ ______ ______ ______

Lights ______ ______ ______ ______ ______ ______

Camera Station ______ ______ ______ ______ ______ ______

Velocity Wheel ______ ______ ______ ______ ______ ______

Video ______ ______ ______ ______ ______ ______

Harness/Helmet ______ ______ ______ ______ ______ ______

Chest Pack ______ ______ ______ ______ ______ ______

AEROSPACE MEDICAL RESEARCH LABORATORY	Title VERTICAL DECELERATION TOWER TEST CONDUCTORS CHECKLIST	
	Approved By	Date
	[signature]	29 Aug 89
Page: 2 of 3	Effective Date: 29 August 1989	

Fiducials

Preloads

EKG Transmitter

Mouth Pack

Transducer Cables

Subject Switch

Harness, Locks, Pads

Medical Check

Subject Briefed

Pretest Photo

TEST CHECKLIST

Tower Area Clear

Water Level

Safety Pin/Splash Doors

Safety Bar Removed

Drop Height Confirmed

Drop Area Clear

Safety Ready

Medical Ready

Video Ready

Photo Ready

Computer Ready

Subject Ready & Positioned

Jumpers Installed

AEROSPACE MEDICAL RESEARCH LABORATORY	Title VERTICAL DECELERATION TOWER TEST CONDUCTORS CHECKLIST	
	Approved By	Date
	[illegible]	29 Aug 89

Page	Effective Date		
3 of 3	29 Augeust 1989		

Instrumentation Ready ____ ____ ____ ____ ____ ____

Camera Lights ____ ____ ____ ____ ____ ____

Time of Impact ____ ____ ____ ____ ____ ____

"G" Level ____ ____ ____ ____ ____ ____

POST-TEST CHECKLIST

EKG and B/P ____ ____ ____ ____ ____ ____

Medical Exam ____ ____ ____ ____ ____ ____

ABORT PROCEDURE

28 VDC Power Off ____ ____ ____ ____ ____ ____

Subject's Position Maintained ____ ____ ____ ____ ____ ____

Jumpers Removed ____ ____ ____ ____ ____ ____

Carriage Lowered ____ ____ ____ ____ ____ ____

Safety Pin Installed ____ ____ ____ ____ ____ ____

REMARKS: ____

AEROSPACE MEDICAL RESEARCH LABORATORY	Title: VERTICAL DECELERATION TOWER MEDICAL EMERGENCY PROCEDURES	
	Approved By	Date
Page: 01 of 01		
Effective Date: 27 July 1989	[signature]	27 July 89

1. Medical monitor declares medical emergency.

2. Operator technician will secure his station, making sure all impact facility equipment is in a safe condition.

3. Tower technician & medical technician move platform next to Vertical Deceleration Tower (VDT) carriage.

4. Medical monitor removes subject's mouth pack and begins treatment.

5. Medical technician carries medical kit to platform and assists medical monitor.

6. Test conductor moves EKG machine next to platform.

7. Safety monitor notifies emergency room (73333), requesting ambulance dispatch.

8. Control console operator notifies Branch office.

9. Medical technician removes subject's helmet when so instructed by medical monitor.

10. Medical technician places cervical collar around subject's neck.

11. Tower technician removes instrumentation from subject. If necessary, tower technician will use large scissors (located in medical kit) to cut restraint straps and chest instrumentation from subject, when instructed by medical monitor.

12. Test conductor will provide backboard and stretcher.

13. Medical technician and tower technician will install backboard (KEDS Board).

14. Medical monitor and medical technician will install headband.

15. Safety monitor will open exit doors and direct ambulance/emergency personnel.

16. Subject removal from test fixture:
   a. Medical technician and tower technician will rotate subject.
   b. Test conductor will control top of backboard and operator technician will control subject's legs.
   c. Medical technician and tower technician will lean subject back and lift backboard for placement on stretcher.

AEROSPACE MEDICAL RESEARCH LABORATORY	Title: VERTICAL DECELERATION TOWER MEDICAL EMERGENCY PROCEDURES	
	Approved By	Date
Page: 01 of 01 — Effective Date: 27 July 1989	[signature]	27 July 89

POWER OUTAGE MEDICAL EMERGENCY AT HEIGHT

This describes the emergency procedure in the event that we have a medical emergency when the subject is elevated on the Vertical Deceleration Tower (VDT) and at the same time we have a power outage.

1. Medical monitor declares medical emergency.

2. Operator technician will secure his station, making sure all impact facility equipment is in a safe condition.

3. Tower technicians move platform next to VDT carriage.

4. Medical technician or medical monitor climbs the VDT, assesses subject's medical condition, attaches hoist and guide rope to subject's harness, and releases shoulder harness and lap belt.

5. Safety monitor notifies emergency room (73333), requesting ambulance dispatch.

6. Control console operator notifies branch office.

7. Tower technicians will lower subject to VDT platform.

8. Test conductor moves EKG machine and medical emergency cart to platform.

9. Safety monitor will open exit doors and direct ambulance/emergency personnel.

10. Emergency medical personnel will load subject into the ambulance and proceed to the hospital.

FIRE EVACUATION PLAN

1. This fire evacuation plan will be used for the Vertical Deceleration Tower experimental area during hazardous experiments (see attached floor plan).

* Personnel will be notified to evacuate by the evacuation alarm siren which is presently installed in Building 824 and/or by the public address system.

* The closest alarm button for building evacuation and to notify the fire department is on the east wall of Room 143. The fire department can also be notified by telephone from the instrumentation room (Room 136) by dialing 117.

* There are three evacuation routes from the experimental area:

1. Through the exit door on the south side of Room 143.

2. Through the exit door on the east side of Room 143.

3. Through the exit door on the north side of Room 143.

2. The safety monitor will unlock any secured doors and insure the implementation of this plan in the event of an emergency.

LAWRENCE J. SPECKER, Chief
Biomechanical Protection Branch
Biodynamics & Bioengineering Division

DEPARTMENT OF THE AIR FORCE
ARMSTRONG LABORATORY (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

4 FEB 1992

REPLY TO ATTN OF: CF

SUBJECT: Interim Head/Neck Criteria

TO: HSD/YA

Attached you will find a copy of the Interim Head/Neck Criteria report developed by my staff based on their review of the literature, accident data, and data from our ongoing experimental program. As stated in my letter of 11 September 1991, the criteria relate only to the catapult phase of ejection and do not consider later events in the escape sequence. The criteria represent the best estimates at this time, but I expect the relationships between head mounted mass, center of gravity, and biodynamic response to be further clarified as our experimental program progresses. As documented in the FY92 Human Systems Technology Area Plan, my directorate plans to provide definitive Added Head Mass guidelines by FY96.

JAMES W. BRINKLEY, SES
Director
Crew Systems

1 Atch
Interim Head/Neck Criteria

cc: HSD/YAG (Capt Schueren)
HSD/YAG (Capt Hetland)
AL/CFA-HMST (Scott Hall)

INTERIM HEAD/NECK CRITERIA

Consultation Report
December 1991

Francis S. Knox III
John R. Buhrman
Chris E. Perry

Escape and Impact Protection Branch
Biodynamics and Biocommunications Division

Ints Kaleps

Vulnerability Assessment Branch
Biodynamics and Biocommunications Division

CREW SYSTEMS DIRECTORATE
ARMSTRONG LABORATORY
HUMAN SYSTEMS DIVISION
WRIGHT-PATTERSON AFB OH 45433

EXECUTIVE SUMMARY

Introduction

The lack of criteria for helmet design was the subject of an Air Force Inspection and Safety Center (AFISC) tasking (12 September 1989). In response to the tasking from AFISC, Drs Kaleps and Knox (Crew Systems Directorate, Armstrong Laboratory) prepared a two-phased research program to develop more realistic design criteria. This program was submitted for review in April 1990. Final review at SAF/AQP resulted in no direction or funding.

Using funding provided by the Helmet Mounted Systems Technology Program, reallocating 6.2 program contract funds and personnel within the Crew Systems Directorate (AL/CF), and modifying research priorities within the Biodynamics and Biocommunications Division (AL/CFB), the Crew Systems Directorate was able to initiate a limited experimental and analytical parametric study to develop interim head and neck criteria.

Additional requests for criteria were received from HSD/YAG in the form of informal requests from Capt Schueren, the HSD/YA representative on the F/A-16 Night Attack HMD program, Capt Hetland, HSD/YAG program manager for Night Vision Systems, and Capt Cooper, program manager of Helmet Mounted Systems Technology (AL/CFA-HMST) Advanced Development Program Office (ADPO). AL/CFB has provided continuing support to "safe-to-fly" determinations for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) program under AL/CFA-HMST. Recently, the request for interim weight criteria for Helmet Mounted Displays (HMD) was formalized in a letter (dated 15 August 1991) from Lt Col Gregory, HSD/YAG to Mr Brinkley, AL/CF. Mr Brinkley replied to that letter on 11 September 1991. An unapproved, draft Interim Head/Neck Criterion Report was given to Lt Col Gregory on 13 September 1991. After review, the original draft was completely rewritten to include additional information from the literature, accident reports, and ongoing laboratory studies. This document represents the approved version of interim head/neck criteria.

Problem

The problem is to define specifications for allowable head mounted mass and center-of-gravity (CG) location which are safe for the catapult phase of ejection. These specifications are needed for various procurement packages for helmet mounted night vision and display systems.

Approach

This study was conducted by: 1) reviewing information published in the literature, 2) reviewing data from aircraft mishaps, and 3) by analyzing data being collected in a parametric study of head-mounted mass and CG location. In this latter study instrumented manikins and human volunteer subjects are being subjected to +Gz accelerations which provide the same probability of spinal injury as an ACES II ejection seat or, in the case of the manikins, as a B-52 seat. Both manikins and humans wear a helmet with a movable weight to simulate various combinations of total mass and CG location. Compression and shear forces and torques at the joint between the head and neck are measured in the manikin and calculated from measured head acceleration for the human. The resulting values are compared with safe exposure levels from human experiments and injury levels from cadaver experiments compiled by the Naval Biodynamics Laboratory from their own work and that of Mertz and Patrick at Wayne State University.

Results and Discussion

Literature. Data found in the literature were inadequate to define a relationship between head-mounted mass and CG location and probability of injury during ejection from USAF aircraft. Recommendations ranged from 3.5 lbs total head-supported weight by a Navy panel of experts to 5.39 lbs based on a constant moment model of Haley and McEntire at the US Army Aeromedical Research Laboratory (USAARL) for the Comanche Helicopter. The critical experiment relating comfort and fatigue to head-mounted mass and CG has not been performed except for helicopters and that study by Maj Butler has yet to be published.

Mishaps. Data from USAF, Navy, Canadian, British, Norwegian, and Swedish accidents were reviewed. No direct causal relationships have been established between head-mounted mass and the incidence of major neck injury. USAF, Navy, British, Norwegian, and Swedish sources report that pilots wearing standard flight helmets are subject to minor neck injury (sprains and strains) at rates (30% to 60%) which increase when flying high performance aircraft, e.g., F-16 during air combat maneuvers. There have been a few cases of neck (cervical spinal) fracture during such maneuvers. There is concern voiced by these authors regarding placing too much weight on the head, but there are no data upon which to build a predictive model.

Experimental. Experiments, conducted by Perry and Buhrman in the Escape and Impact Protection Branch of Armstrong Laboratory, are building a database upon which to develop the needed predictive models. Obergefell, Self, and Kaleps, in the Vulnerability Assessment Branch of Armstrong Laboratory, have been testing modifications to the Articulated Total Body Model in a parallel effort. Manikins and volunteer human subjects are being exposed to +Gz acceleration (like the catapult phase of ejection) while wearing various prototype night vision/HMD helmet systems or a special helmet with a movable mass. The resulting neck forces and torques are compared with values known to be safe or which approach injury level. These threshold values, assembled by the Naval Biodynamics Laboratory, are thought to be conservative and not definitive but are the best available.

The laboratory data show that seat acceleration, head-mounted mass and CG location interact such that for some CG locations it is possible to carry more mass and still maintain neck forces and torques at acceptable levels provided an ACES II seat is used. The manikin data are complete at this writing, but only a few human subjects have completed the study. The recommendations presented below are based on an analysis of this incomplete data set in order to provide guidance to meet HSD/YAG, F-16 Night Attack program deadlines.

Recommendations. Interim Criteria are recommended as summarized in the following table.

EJECTION SEAT	MAXIMUM TOTAL HEAD SUPPORTED WEIGHT (LBS)	MAXIMUM NET HEAD CG OFFSET FROM HEAD ANATOMICAL AXIS ORIGIN (IN)		
		X	Y	Z[1]
ACES II	5.0	-0.8 to 0.5	±0.15	0.5 to 1.5
B-52	4.5	-0.8 to 0.25	±0.15	0.5 to 1.5
B-52	(4.0	-0.8 to 0.5	±0.15	0.5 to 1.5

[1]Data could not be collected at CGs below 0.7 on the Z axis

NOTE: Lighter helmets (3.5 to 4.0 lbs) recommended to enhance overall aviators' performance. Critical experiments are needed to optimize comfort and performance vs weight and CG

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ATTACHMENTS

INTERIM HEAD/NECK CRITERIA

Problem: Night Vision Devices (NVD) and/or Head Mounted Display (HMD) Systems are being developed to enhance aviators' night and IFR condition flying capabilities. Even though there are currently no established criteria for allowable limits on mass and mass center-of-gravity (CG) location for such Helmet Mounted Systems, it is often assumed that adding mass to the flight helmet will result in a corresponding increase in the risk of injury during emergency escape. The Crew Systems Directorate has been asked by the Helmet Mounted Systems Technology Advanced Development Office (HMST-ADPO), the Hq HSD/YA and the F-16 System Program Office (Night Attack Program) to develop head mounted mass and center of gravity location criteria for inclusion in the specification for future head mounted systems.

Approach: In response to requests for interim guidance on allowable helmet mounted mass and mass CG location, an ad hoc Committee was formed in the Spring of 1990 to recommend criteria after 1) reviewing experimental studies and modeling efforts reported in the literature, 2) reviewing published and unpublished accident data, and 3) evaluating the results of recent and ongoing laboratory studies of head/neck biodynamic response. The recommendations will be for interim criteria because laboratory studies are not complete.

Results and Discussion: The literature was found to provide some insight to the problem but was lacking in solid quantitative data with which to build a relationship between helmet mass, CG location, and probability of neck injury.

Schall (16) and Andersen (2) reported that neck injuries as severe as cervical vertebral fractures can occur even with normal helmets during rapid onset, high G accelerations encountered during air combat maneuvers. However, instances of vertebral fractures are rare. Strains and sprains appear to be more common with instances as high as 50 or 60 percent of 437 aviators flying F-5, F-15, and F-16 fighter aircraft reporting at least one instance of neck injury during the past year in an anonymous survey questionnaire (VanderBeek) (19).

Guill (6) has reported a low incidence of neck fracture upon ejection (28/1677) from Navy aircraft, but states that causal factors are "many and varied". He makes no attempt to relate head mounted mass as a causal factor except to state in his conclusions that, "We are also of the opinion that a significant portion of the "serious "ejection associated" neck injuries are in fact likely to have been induced by the inflight maneuvering/ gyrating forces imposed upon the aircrew prior to ejection or during ejection. These, we believe, are especially significant and require consideration as helmets become the handy means for mounting sight and other needed equipment upon the aircrew."

Anton (3) of the United Kingdom, in reviewing the biodynamic implications of helmet devices cites Aghina (1) who found 8 times more minor (strain/sprain) neck injuries in F-16 pilots than in F-104 pilots. But Anton was not able to find any severe neck injuries unless the head had also struck something. His consideration of helmet mass and center of gravity led him to recommend a helmet/NVG system which is less than 4 lbs with a center of gravity near that of current helmets. This latter recommendation was based largely on operational grounds citing studies by Phillips and Petrofsky (12) on helmet mass and neck fatigue.

Sturgeon (17) of Canada also reported no cervical injuries in 78 ejections among Canadian pilots. Sandstedt (15) of Sweden cited 83 successful and 9 fatal ejections using seats with Dynamic Response Indexes (DRIs) averaging 21.[1] In the Swedish case, there were no cervical fractures due to ejection force and only 25 percent incidence of transient (1-2 day) sore necks even though the Swedish helmets were reported to weigh 6.17 lbs. (However, independent measurement of the standard Swedish flight helmet, used by ejectees, in our laboratory indicated a total head mounted mass of 5.53 lbs).

A recent review of 200 ACES II ejections in USAF aircraft where aviators wore HGU-55/P or HGU-26/P helmets showed no cervical fractures during the initial phase of ejection (Tong, MFR 1991) (18).

Thus, with regard to accident data, we find that the data are difficult to interpret, are often not presented in a way that is useful for the present purposes and indicate that severe neck injury is relatively infrequent while minor strains and sprains appear to be more frequent and are qualitatively related to aircraft maneuverability, body position, awareness, and helmet weight.

There have been three efforts to look at helmet weight in sustained G environments (Darrah (4), Glaister (5), and McCloskey (9)). Extra mass tends to reduce G tolerance, especially in maintaining head position. Darrah reported that peak tolerance

---

[1]For the uninitiated, the Dynamic Response Index (DRI) is a number which is proportional to peak load in a simple mechanical model (mass, spring, damper) of the human spine during acceleration. The DRI has been related to the probability of thoracolumbar spinal fracture during ejection seat use. The USAF use of the DRI to evaluate ejection seats is embodied in Military Specification: Seat System: Upward Ejection, Aircraft, General Specification For 1072, MIL-S-9479B(USAF). The relationship between the DRI and probability of injury is shown in Figure 1.

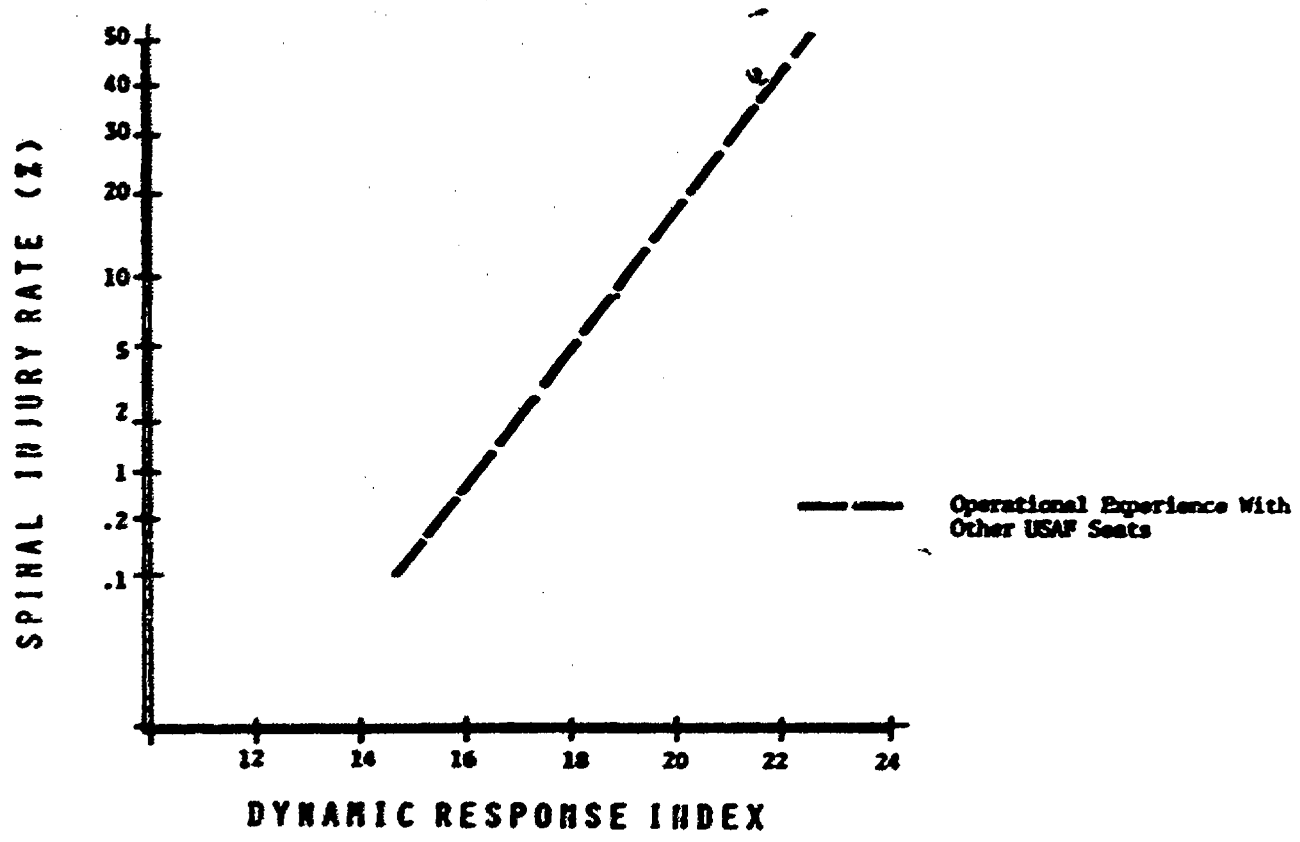


FIGURE 1. SPINAL INJURY RATE FROM OPERATIONAL EXPERIENCE VS DYNAMIC RESPONSE INDEX

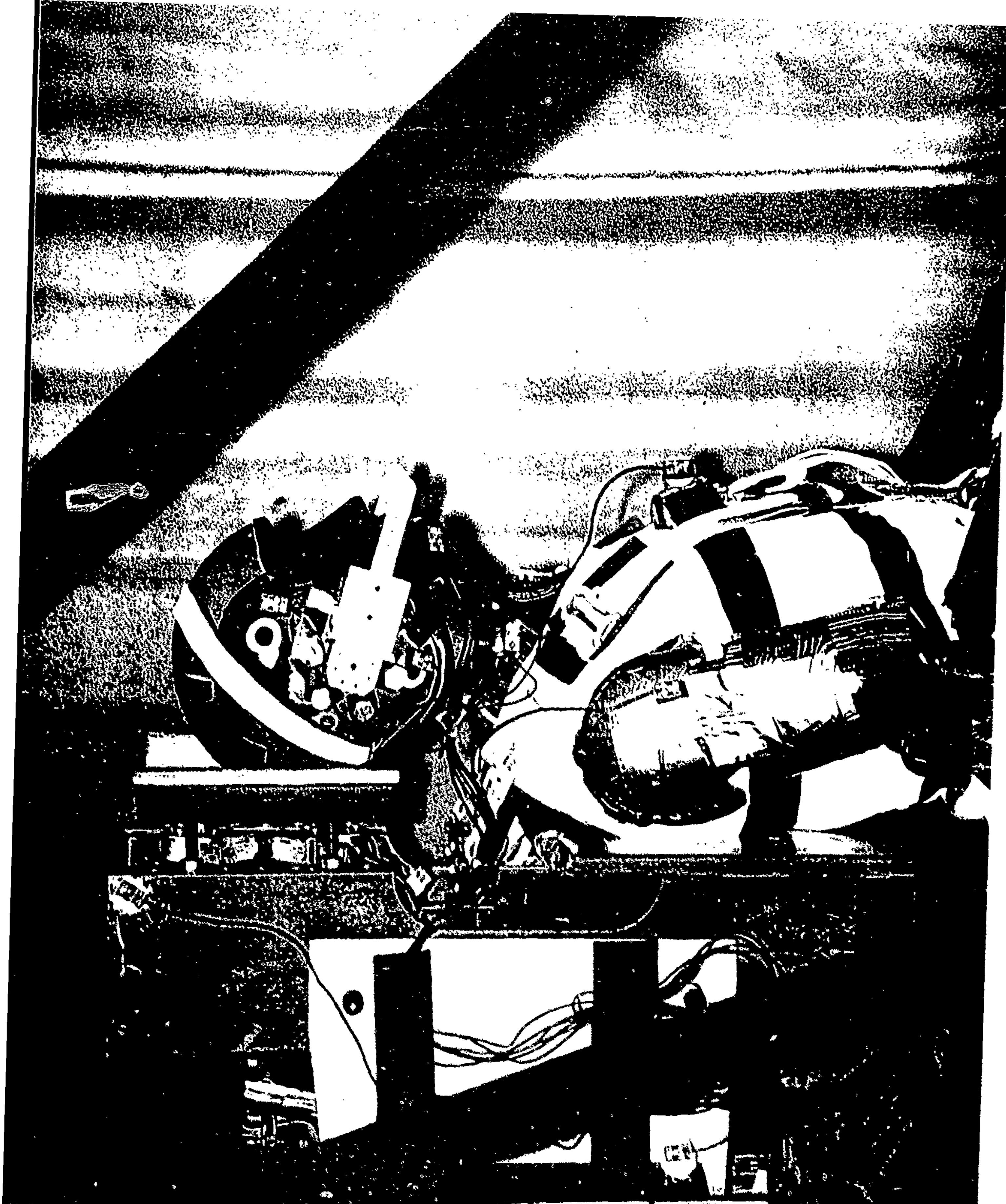
to maintaining head position under sustained acceleration was seen with the center of gravity 2 cm back of the atlas.

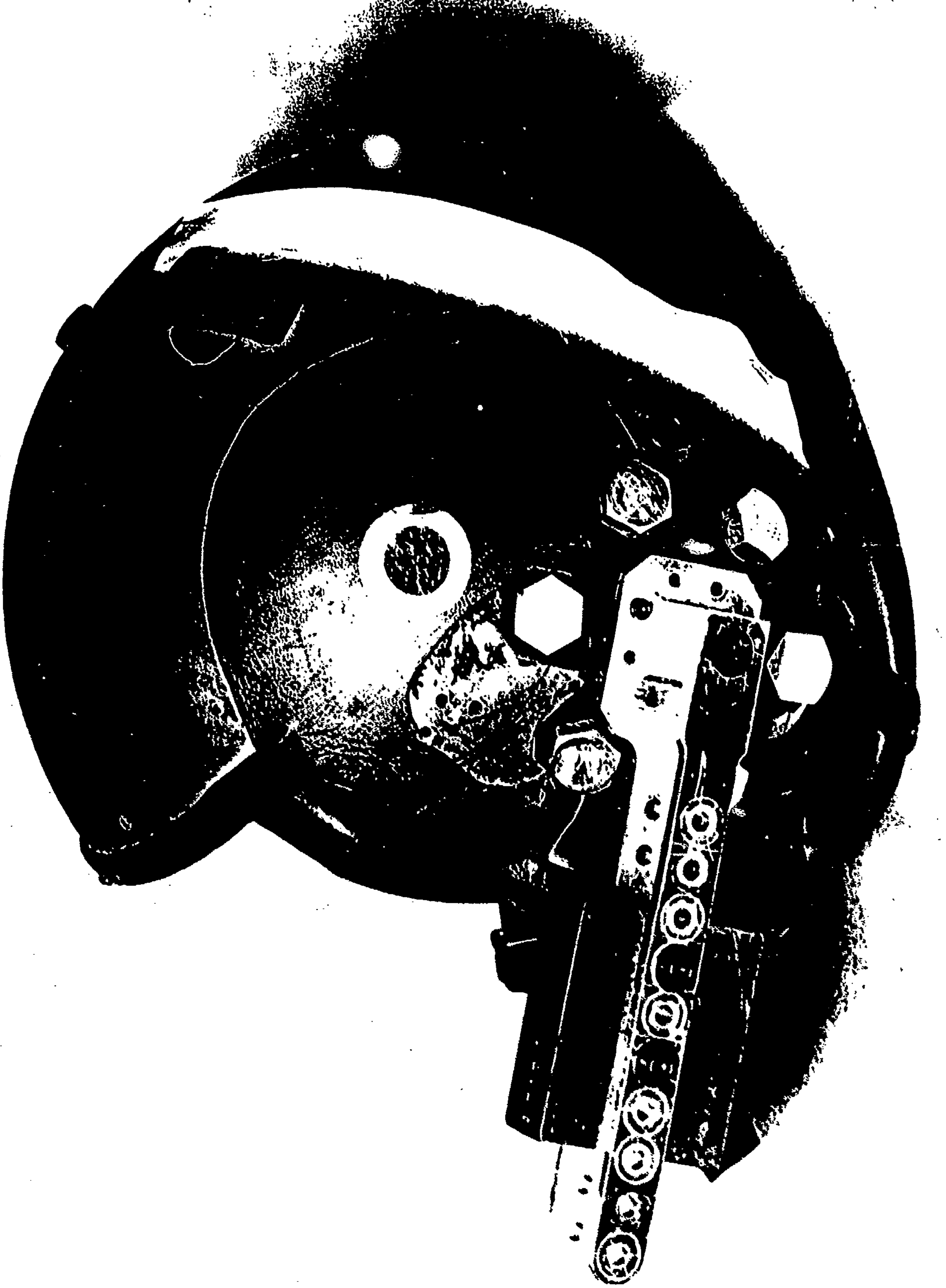
Other authors such as Privitzer et al (13), King et al (7), and Darrah have conducted modeling efforts using either the Head Spine Model or in Darrah's case, the Articulated Total Body (ATB) Model. Privitzer reported a maximum "safe" head supported mass of 5.28 lbs while King reported that vertebral disk and facet forces decreased as the center of gravity was shifted back with respect to the head center of gravity by 12.5 mm. These modeling efforts show general trends towards greater forces and moments at the occipital condyles with increased mass which is to be expected. But the relationship between model predictions and injury is not adequately established to provide tolerance criteria.

In an effort to begin acquiring a biodynamic database relating helmet mass properties, acceleration, and head/neck response, the Escape and Impact Protection Branch (CFBE) has conducted three studies; the last of which is continuing. The first study experimentally evaluated a weight and space mockup of a low profile NVG. The second study evaluated three prototype Interim Night Integrated Goggle Head Tracking Systems (I-NIGHTS) with NVGs and three I-NIGHTS prototypes with NVGs and HMDs. These systems (including mask) ranged up to 6.95 lbs total head supported weight. The current study is a parametric study in which a HGU-55/P helmet has been modified to accommodate a movable weight which allows independent parametric changes in head supported mass and center of gravity locations (see photo).

In these studies an ADAM manikin wearing the head mounted systems was subjected to +Gz accelerations of 6-20 G (for 10 G pulse: peak G was 10.92 $\pm$ 0.41 G, rise time of 66.8 $\pm$ 0.76 ms, duration of 214 ms and peak velocity of 26.99 $\pm$ 0.07 fps) prior to human volunteers being subjected to the accelerations 6, 8, and 10 G peak while wearing the systems. The accelerations were provided by the Vertical Deceleration Tower (VDT). Forces and moments were measured at the base of the head in the ADAM manikin, using a Denton load cell. Contact point of helmet is + 3/4" from seat back (See Figure A-14a in attachment 2). Effective forces and moments for the human volunteers were calculated from measured head accelerations (see Summary Report by Chris Perry (Atch 2) for details of the experimental procedures and results). Measurements on page 78 (-0.31") are referenced to load cell to seat back. However, spacers were added to extend headrest forward. Also, helmet does not touch deepest part of headrest.

In these studies, compression force (Fz), shear force (-Fx), and bending moment (-My), all increased with increasing helmet weight. However, both shear force and bending moment were shown to be well within the safe limits referred to below, even with helmet weights approaching seven pounds. Compression force Fz





measured in the ADAM and calculated in the human correlated well in the common Gz exposure range (Fig 2). It is assumed that this correlation is valid also at higher Gz levels; therefore it is assumed that the Fz measured in the manikin at +15 Gz is an acceptable prediction of the force that would occur in a human exposed to 15 Gz.

The results are summarized in Figures 2, 5, 6, 7, and 8. As a frame of reference, the Naval Biodynamics Laboratory (11) cites human volunteer data published by Mertz and Patrick which indicates that Fz of at least 250 lbs can be tolerated without injury. Mertz and Patrick (10) also published data collected from tests of cadavers which indicate that 400 lbs is a threshold for ligamentous damage. Both these criteria are viewed as the best available, but conservative and not totally definitive. Referring to Figure 2, we see that at 10 Gz, which has the same DRI as an ACES II ejection seat (Figure 3), helmets weighing less than 6 lbs produce only marginally greater loads than currently used helmets. They are near or below the 250 lb criterion of Mertz and Patrick and well below the Swedish safe experience exposure limits. Likewise, helmets weighing less than 5 lbs when subjected to 15 +Gz, which on the VDT has the same DRI as a B-52 seat (Figure 4), should not be expected to cause ligamentous damage and should produce forces equivalent to or lower than those experienced by Swedish ejectees.

The position of the center of gravity of the helmet with respect to the head center of gravity, referred to here as CG shift, can have a significant effect on the limits referred to above. Figures 5-8 show that significant increases in compression force Fz were obtained in 10 G and 15 G manikin tests for both x-axis and z-axis CG shifts which could add 50 lbs or more of compression force to the values in Figure 2. While the 10 G exposures would still be within safe limits even with 7 lb helmets, the 15 G exposures would begin to exceed the 400 lb safe limit with helmet weights greater than 4.0 lbs (See Figure 2). Maintaining the helmet center of gravity within an optimal range, however, prevents much of this additional loading and would allow the compression force to remain under 400 lbs for helmet weights up to 4.5 lbs.

Conclusions: The literature and accident statistics have proven to be useful only in pointing out some general qualitative observations. There seems to be a tendency for the neck to be more severely stressed as indicated by sprains and strains in more highly maneuverable, high G onset, aircraft, and there is a general impression that heavier helmets are not desirable. When the total operational envelope and fatigue are taken into account, experts from the United Kingdom recommend helmets around 4 lbs. The United States Army recently recommended to the Comanche Program Manager helmets weighing from 3.3 lbs to 5.39 lb based on a constant moment model (8). The Navy, through an expert panel, recommended a 3.5 lb limit on head mounted weight (See attached). No group has published the critical experiment to answer the question of mass vs fatigue and performance. Butler at USAARL has looked at this issue for helicopters and we are awaiting the final report of his study.

The experiments conducted by Perry and Buhrman on the Vertical Deceleration Tower provide the most comprehensive set of data to date. Data collected to date indicate that, for ejection seats with DRIs equal to or less than 18 (e.g. B-52), helmets which weigh less than 4.5 lbs, and have combined head and helmet center of gravity within a box defined by -0.8 to 0.25 inches on the x anatomical axis (Figure 9) and 0.5 to 1.5 inches on the z-axis are likely to exhibit a risk of injury, based on compression loads, which is only marginally different from current helmets (HGU-55/P, HGU-26/P). With the CG extended forward to 0.5 inches on the x-axis, helmets weighing less than 4.0 lbs would not exceed the 400 lb compression force limit. Data from the parametric study further suggest that for seats like the ACES II, with DRIs of 13 or less, acceptable compression loads are seen for helmets of 5 lbs and CG locations defined by the same limits of -0.8 to 0.5 inches on the x-axis and 0.5 to 1.5 inches on the z-axis.

Work of Petrofsky and Phillips, Darrah, and Glaister indicate that helmets weighing 4 lbs or less will be necessary to maintain performance for the required future mission durations. But the critical experiments have not been done to define head mounted mass limits and CG locations based on fatigue and performance.

Recommendations: It is recommended that as an interim criteria: total head supported mass be less than 4.5 lbs with a combined helmet/head center of gravity located between -0.8 and 0.25 inches along the x-axis, and between 0.5 and 1.5 inches along the z-axis, for safety during the catapult phase of escape using seats with DRI no greater than 18. For helmets weighing less than 4.0 lbs, the helmet/head center of gravity limit in the x-axis can be extended forward to 0.5 inches. For seats with DRI not greater than 13, helmets can weigh 5 lbs with the center of gravity located between -0.8 and 0.5 inches along the x-axis and between 0.5 and 1.5 inches along the z-axis. It is assumed that mass is distributed such that the center of gravity is symmetrical, ± 0.15 inches, with respect to the x-z plane. These recommendations relate only to the catapult phase of ejection and not to other phases of the escape sequence. In general it is recommended that helmet systems be lighter, 3.5 to 4.0 lbs, in order to enhance overall pilot acceptance under in-flight conditions.

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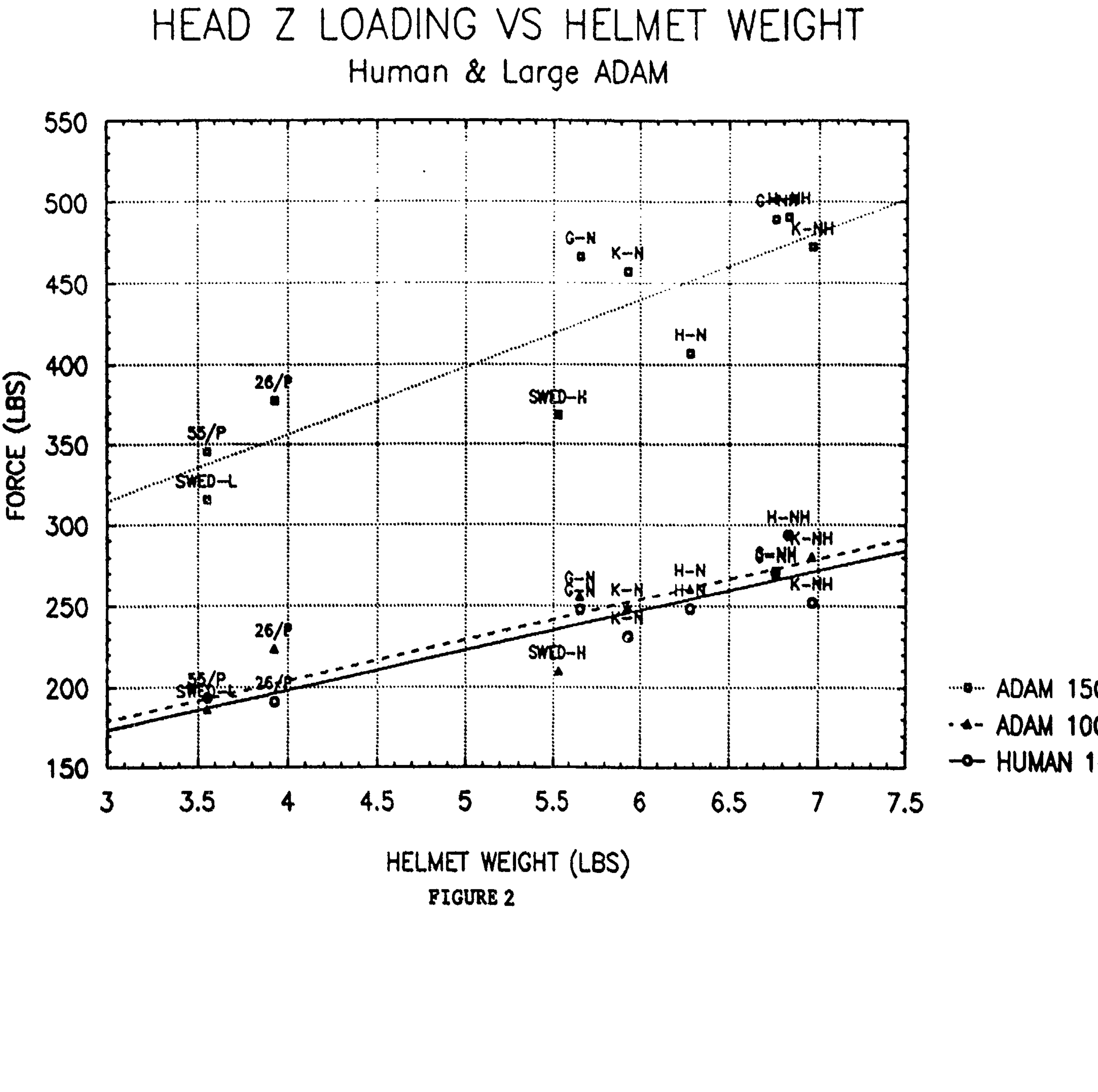

HEAD Z LOADING VS HELMET WEIGHT
Human & Large ADAM
FORCE (LBS)
HELMET WEIGHT (LBS)
550
500
450
400
350
300
250
200
150
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
G-N
K-N
H-N
26/P
SWED-H
55/P
SWED-L
K-NH
H-NH
G-NH
ADAM 15
ADAM 10
HUMAN 1
FIGURE 2

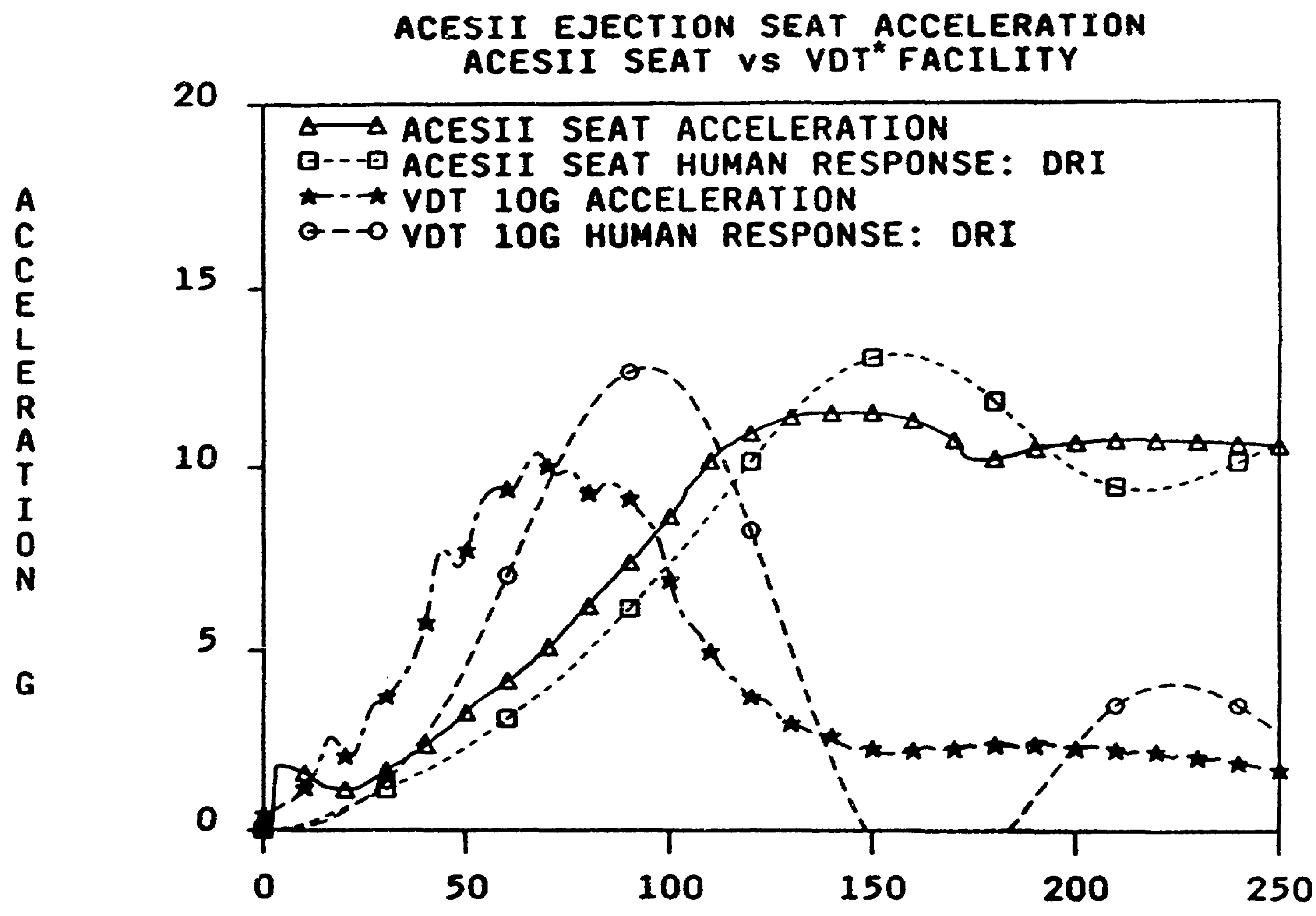


FIGURE 3

*VDT = Vertical Decéleration Tower

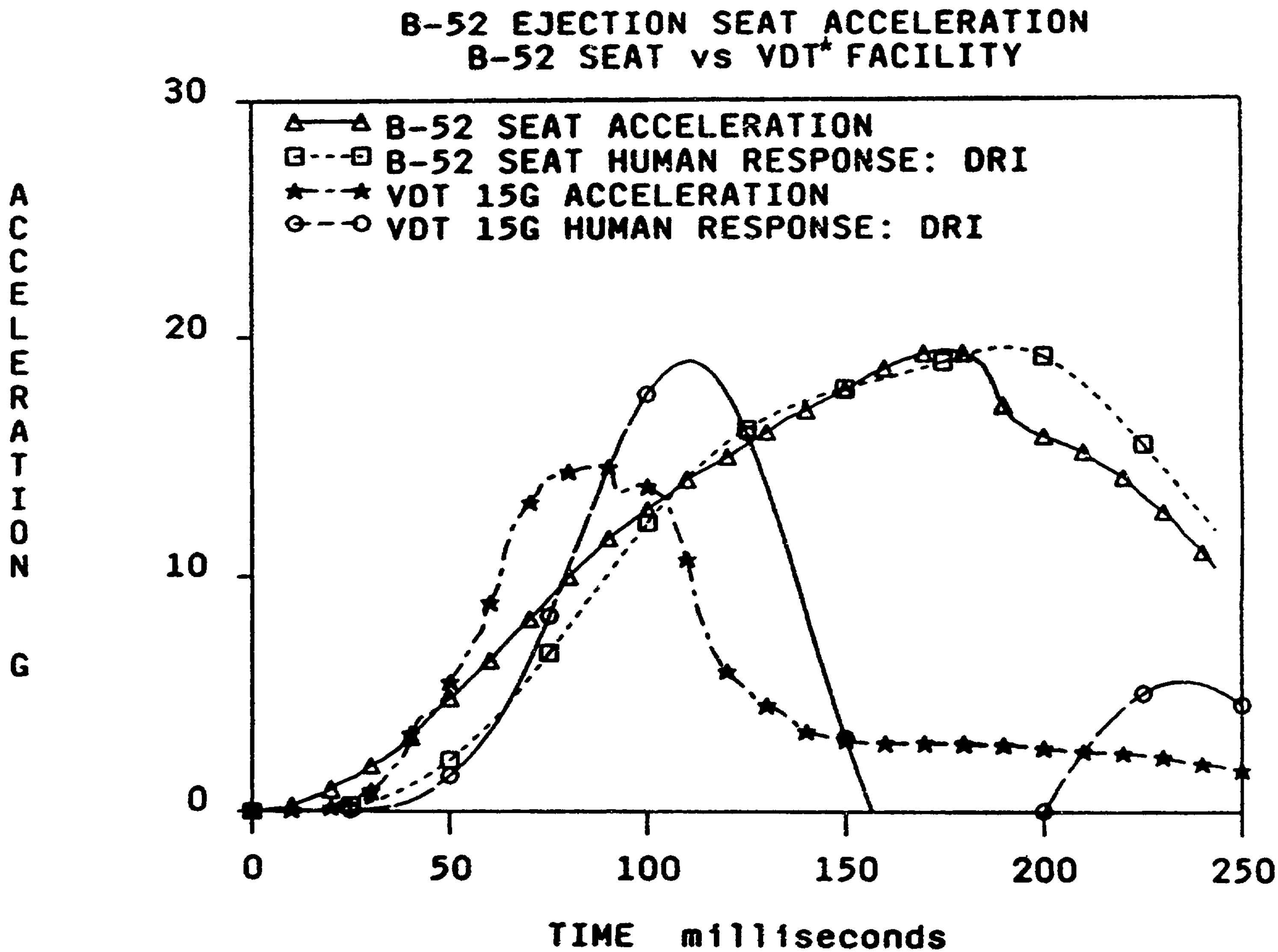
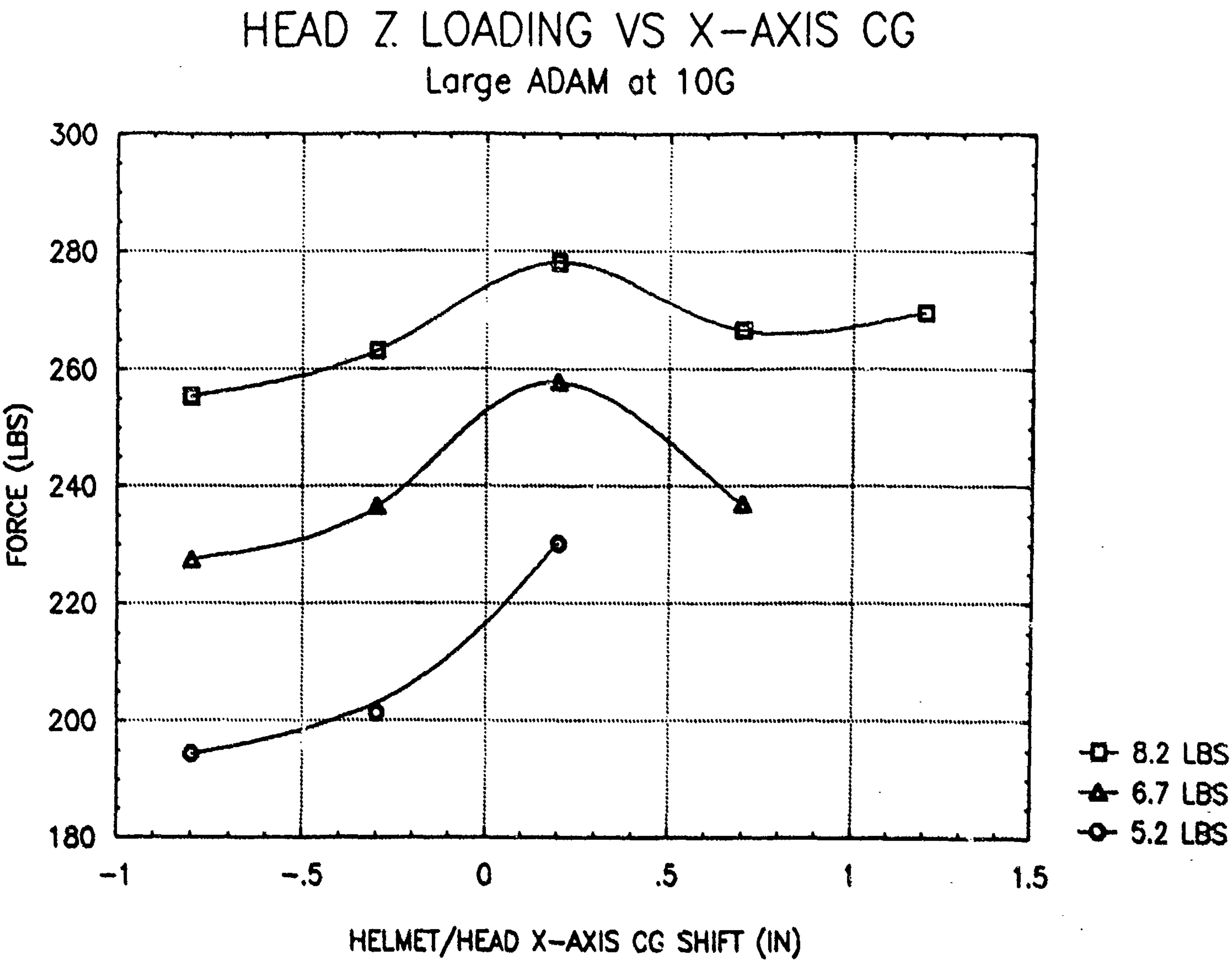


FIGURE 4

*VDT = Vertical Deceleration Tower


HEAD Z LOADING VS X-AXIS CG
Large ADAM at 10G
300
280
260
240
220
200
180
FORCE (LBS)
-1
-.5
0
.5
1
1.5
HELMET/HEAD X-AXIS CG SHIFT (IN)
8.2 LBS
6.7 LBS
5.2 LBS
FIGURE 5

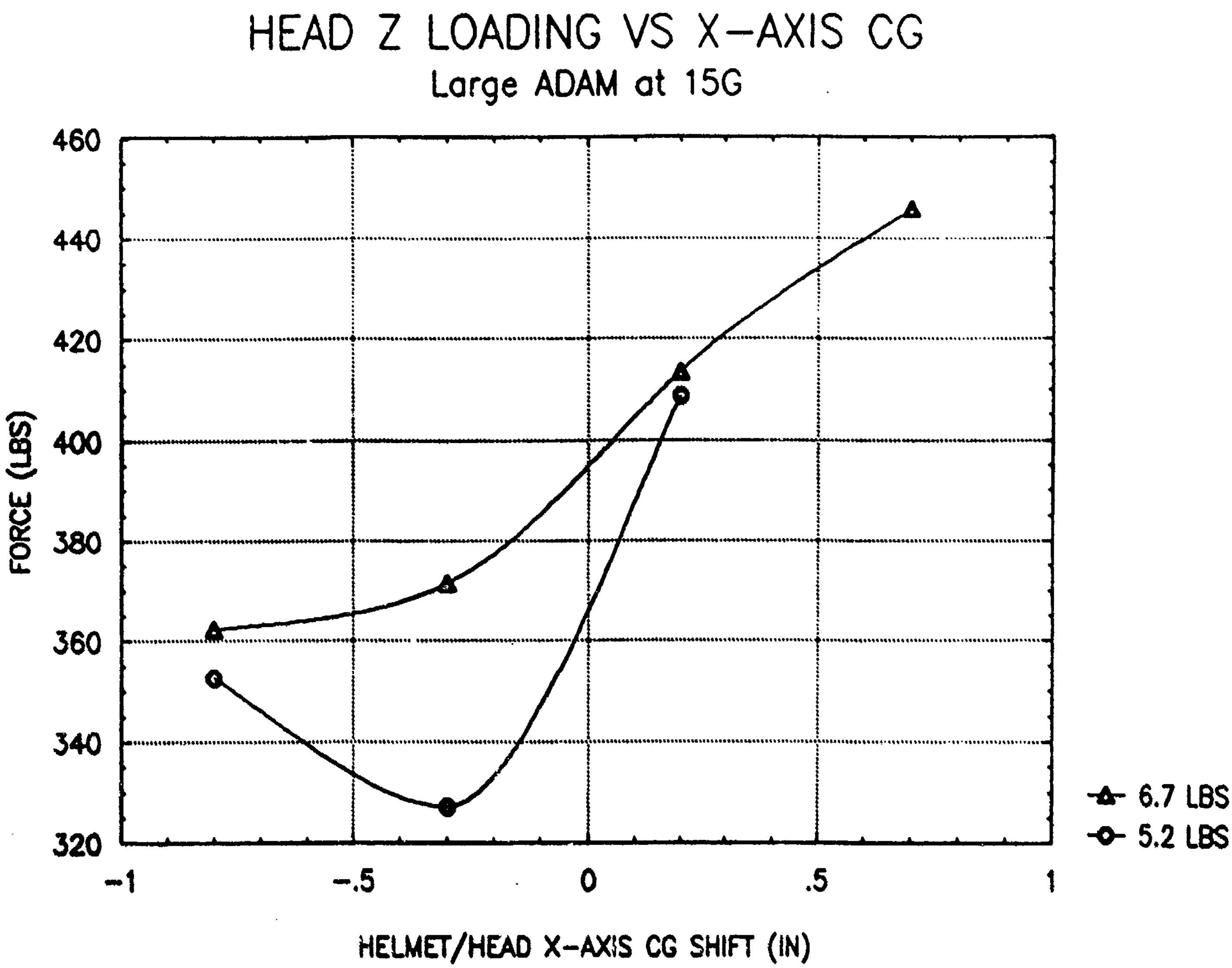

HEAD Z LOADING VS X-AXIS CG
Large ADAM at 15G
FORCE (LBS)
460
440
420
400
380
360
340
320
-1
-.5
0
.5
1
6.7 LBS
5.2 LBS
HELMET/HEAD X-AXIS CG SHIFT (IN)

FIGURE 6

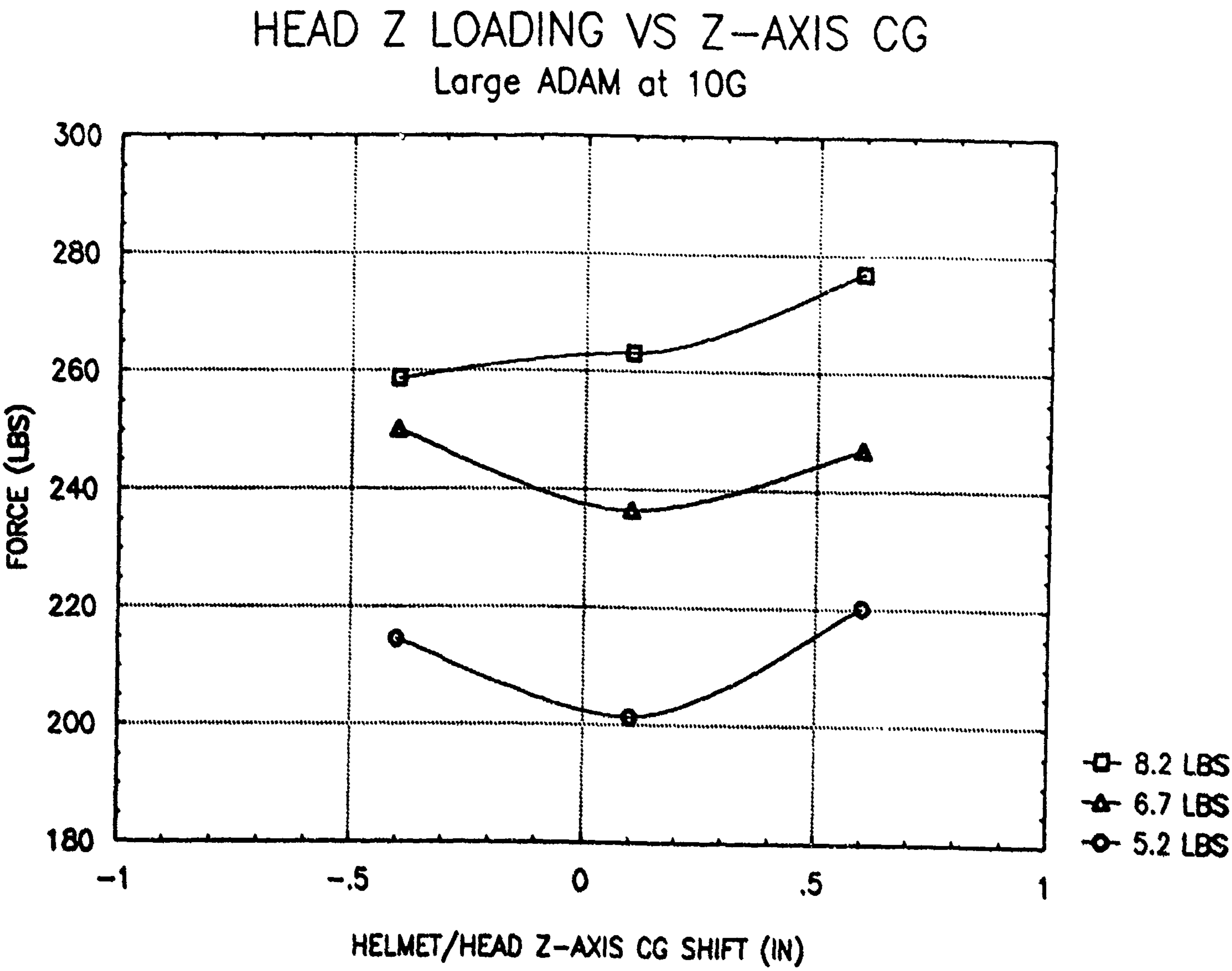

HEAD Z LOADING VS Z-AXIS CG
Large ADAM at 10G
FORCE (LBS)
300
280
260
240
220
200
180
-1
-.5
0
.5
1
8.2 LBS
6.7 LBS
5.2 LBS
HELMET/HEAD Z-AXIS CG SHIFT (IN)

FIGURE 7

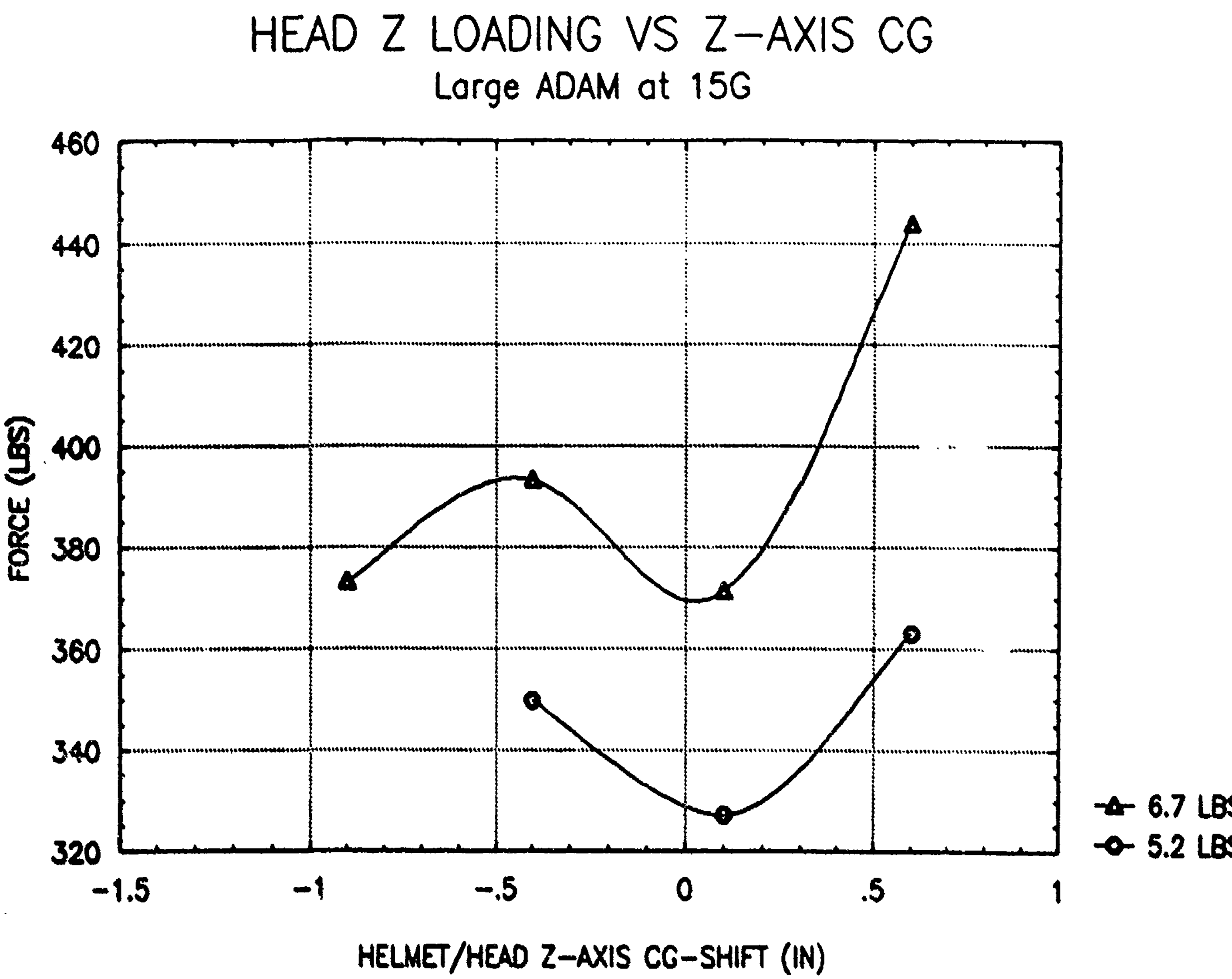

HEAD Z LOADING VS Z-AXIS CG
Large ADAM at 15G
FORCE (LBS)
460
440
420
400
380
360
340
320
-1.5
-1
-.5
0
.5
1
HELMET/HEAD Z-AXIS CG-SHIFT (IN)
6.7 LBS
5.2 LBS

FIGURE 8

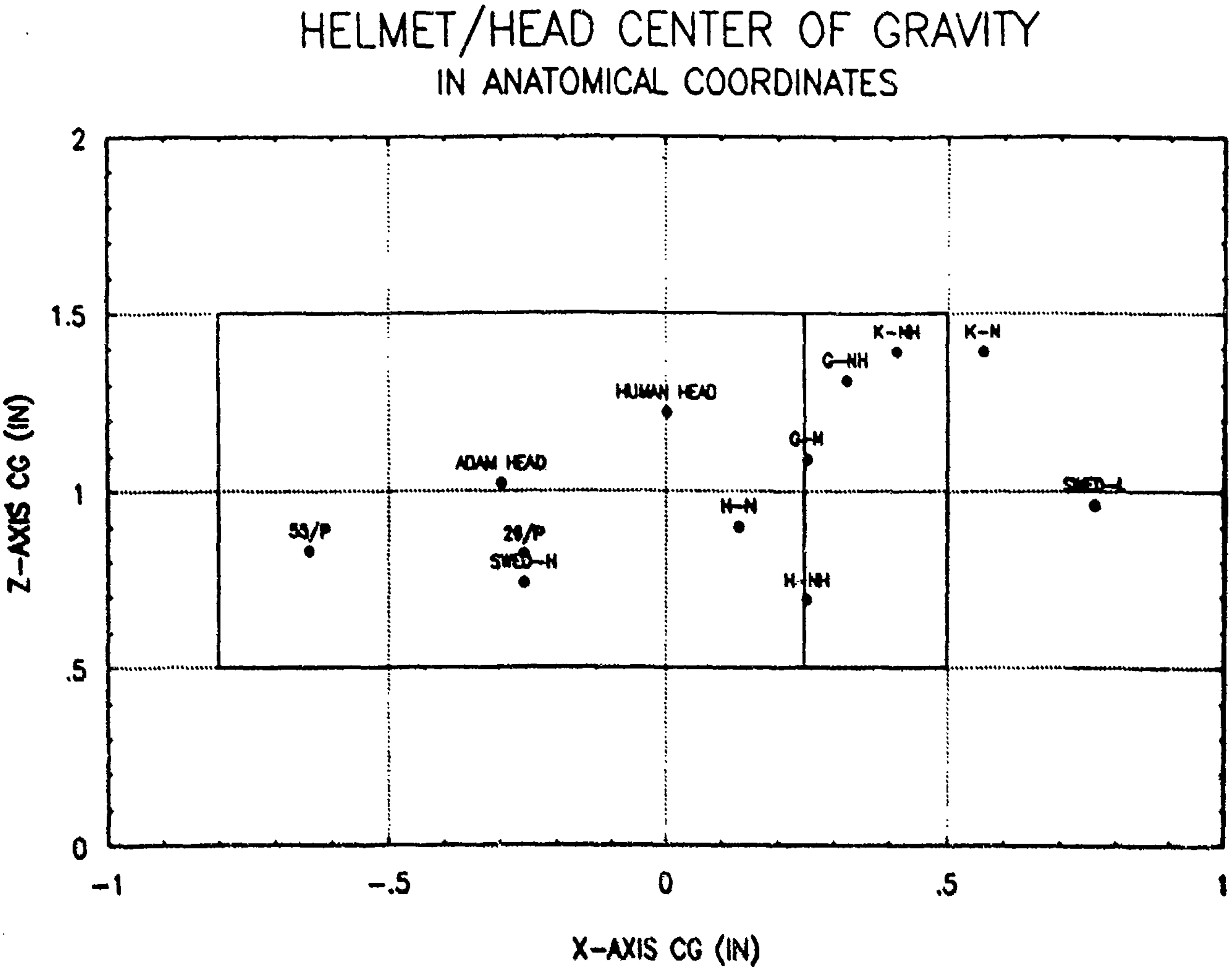


FIGURE 9

INNER BOX: CG limits for 4.5 lb helmet for B-52 ejections

OUTER BOX: CG limits for 4.0 lb helmet for B-52 ejections and
CG limits for 5.0 lb helmet for ACES II ejections

The head anatomical coordinate axes system is defined as:

Y axis - vector from right tragion to left tragion
X axis - normal from Y axis to right infraorbitale
Z axis - X x Y
Origin - intersection of Y axis and a normal passing through sellion

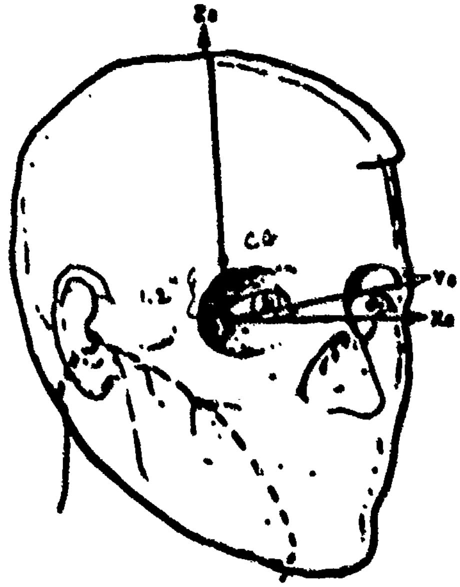
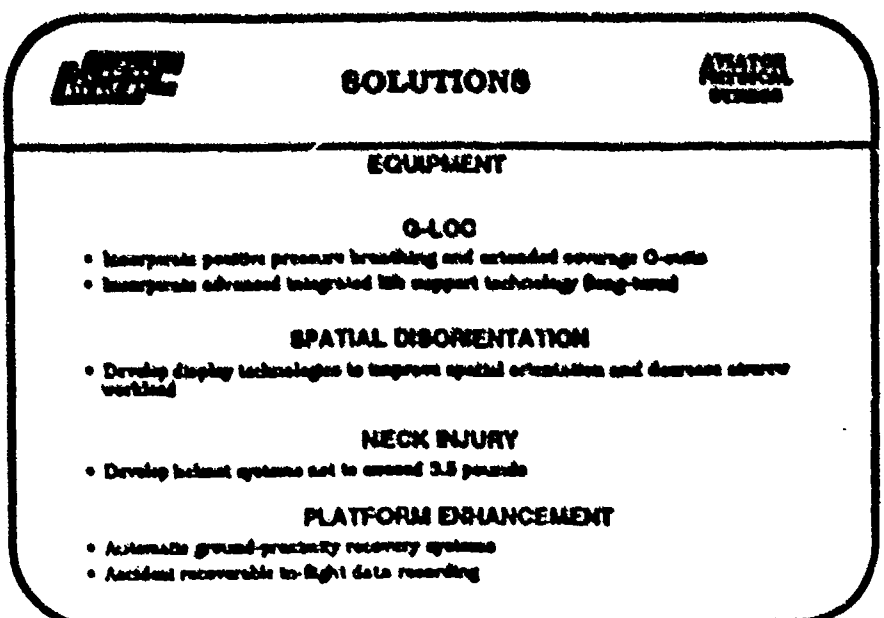


FIGURE 10

NECK INJURY

It is recognized that numerous compromises are required in order to simultaneously satisfy the requirements of mission effectiveness and pilot safety and comfort. Pilots, already overburdened, can expect additional demands with the advent of night vision devices, helmet mounted sighting and display systems, and anti-laser eye protection. An immense technical challenge exists to integrate these technologies into the helmet without placing the pilot at increased risk of neck injury in high G-maneuvers.

Neck injuries persist even with the lightest helmets now fielded. Definitive data which will enable the specification of the optimal helmet weight and configuration are not available. Nevertheless, it is recommended that 3 1/2 pounds represents a reasonable upper limit for safe helmet system weight (including mask) as long as the pilot's neck is the sole means of support for the helmet system. Additional systems should be added only with careful consideration to pilot safety within well characterized flight envelopes and emergency egress procedures. Maximum attention should be paid to developing and fielding the lightest helmet possible which optimizes the trade-offs between head protection, physiologic effects under acceleration and overall mission performance.



APS 22

Evaluation of the Effects of Visually Coupled Systems on the Human Response to Simulated Ejection Accelerations

Summary Report
July 1991

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Project Engineer
Escape and Impact Protection Branch
Biodynamics and Biocommunications Division
Crew Systems Directorate of the Armstrong Laboratory

Testing completed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Test Program managed by AL/CFP-HMST Program Office.

Atch 2

OVERVIEW AND OBJECTIVES

An experimental research effort was conducted to measure the effects of several prototype visually coupled systems (VCS) on the human head and neck response to a simulated ejection pulse. The effort was conducted in two phases with the first phase testing an advanced dynamic manikin's (ADAM) response with the various prototype VCS, and the second phase exploring volunteer human subject's responses with the various prototype systems.

The primary objective was to define the human head and neck dynamic response parameters for the development of head-mounted weight and center-of-gravity criteria. The criteria will be used to evaluate the effects present and future helmets and advanced helmet-mounted visually coupled systems have on ejection biodynamics. To do so, it was necessary to measure and analyze human and manikin head and neck responses to whole-body simulated ejection impact accelerations with various prototype helmet-mounted VCS. A secondary objective was to expand the present database of biodynamic responses for the refinement of mathematical models of human impact response. A third objective was to compare and correlate the ADAM responses to that of the human subjects.

BACKGROUND AND RELEVANCE

The mission profiles of some current military aircraft equipped with ejection seats are now being expanded for more demanding day and nighttime operations. To help overcome adverse flight conditions and improve pilot performance, the deployment of helmet-mounted visually coupled systems such as night vision devices and helmet mounted displays are being explored. During these demanding operations, the possibility exists for emergency escape by high-airspeed, low-altitude ejection. There has not yet been an incident requiring emergency escape by ejection while operating with helmet mounted systems; however, if the present systems were used during emergency escape, unacceptably high rates for major injuries and fatalities could occur. This would come from the increased mass and altered weight distribution that the systems add to the head, and their effect on the dynamic response of the ejectee's head and neck.

Minimal quantitative information is available regarding +Gz human neck tolerance with the addition of these external head mounted devices; moreover, there is also a lack of USAF criteria regarding maximum allowable head-supported weight and shifted center-of-gravity. Melvin (1979) reviewed mechanisms of injury and human cadaver tolerance levels. Settecerri, Privitzer, and Beecher (1987) studied the mass properties and inertial loading effects of head encumbering devices utilizing anthropomorphic manikin heads. Following recent studies in -Gx human dynamic responses (Muzzy, 1986), the Naval Biodynamic Laboratory subsequently proposed guidelines for safe human experimental exposure to impact acceleration (Naval Biodynamic Laboratory Impact Acceleration Guidelines, 1989). Limits (sled acceleration of 12.5 +Gz for 90 milliseconds with an end sled stroke velocity of 12 meters/second) were recommended for torso restrained, un-helmeted volunteers having the freely moving head and neck as the anatomical segments most at risk. However, little work has been done to quantify the human dynamic head and neck response following +Gz impact exposure simulating the ejection environment. This research effort was directed towards reducing any increased morbidity and mortality to ejected crewmembers from helmet-mounted visually coupled systems and other head encumbering devices.

APPROACH AND METHODS

The simulated ejection impulse environment was provided using a series of short-duration, +Gz impact accelerations using the AL/CFBE Vertical Deceleration Tower (See Figure 1 in Appendix 1). The tower is constructed of two vertical guide rails upon which a test carriage is positioned. The carriage is raised to a pre-determined height and then allowed to free-fall into a water reservoir. The height of the carriage and the shape of the piston (on the bottom of the carriage) that impacts the water, is what controls the pulse shape of the input acceleration. A generic seat was mounted on the VDT carriage assembly in an upright position so as to provide a +Gz input acceleration to the subject. Tests were conducted without a seat cushion on the flat seat pan of the generic seat. The seat back angle was 0° vertical, and the restraint harness was a standard USAF double shoulder strap and lap belt configuration. The headrest was in line with the seatback for the manikin tests but was 1 inch behind the seatback for the human subject tests. This headrest position allowed the subject to have eye's forward without head rotation, and to have there cervical vertebra aligned parallel with the seatback while wearing the prototype systems. Collected data included carriage acceleration and velocity, seat acceleration, ADAM neck and spine loads using Denton six-axis load cells, head and chest accelerations, and seat and restraint forces. For more detailed information on the test setup or the instrumentation system, please refer to Appendix 1.

It was decided that testing of the human subjects with the prototype helmet systems at a 10 G impact acceleration level with corresponding maximum velocity change of 30 feet/second, was acceptable and also within the guidelines as defined by the Crew Systems Directorate's Generic Impact Acceleration Protocol (GIAP). ADAM was subjected to impacts from 6 G to 20 G to provide a broader range of responses, and for comparison of the responses to current and previously collected human response data. The 10 G impact acceleration on the VDT is a simulation of the ACES II ejection because both produce an averge Dynamic Response Index (DRI), a spinal injury predictor, of approximately 12.5. The 15 G impact acceleration on the VDT is a simulation of a B-52 ejection profile with a DRI of approximately 19.

This research program tested both the prototype helmet systems and two baseline helmets for comparison. The baseline systems were the USAF HGU-26/P and the HGU-55/P flight helmets with a MBU-12/P mask. Three vendors each supplied two prototype VCS helmet systems. One system was a night vision only system, and the second was a night vision device and helmet mounted display combination. This made for a total of six prototype systems and eight overall helmets to be tested. The three vendors in alphabetical order are GEC Avionics, Honeywell, and Kaiser. Each system when discussed will be referred to the vendor by first letter only and as to type of system by NVG for night vision device helmet systems, and by HMD for the night vision device/helmet mounted display helmet systems.

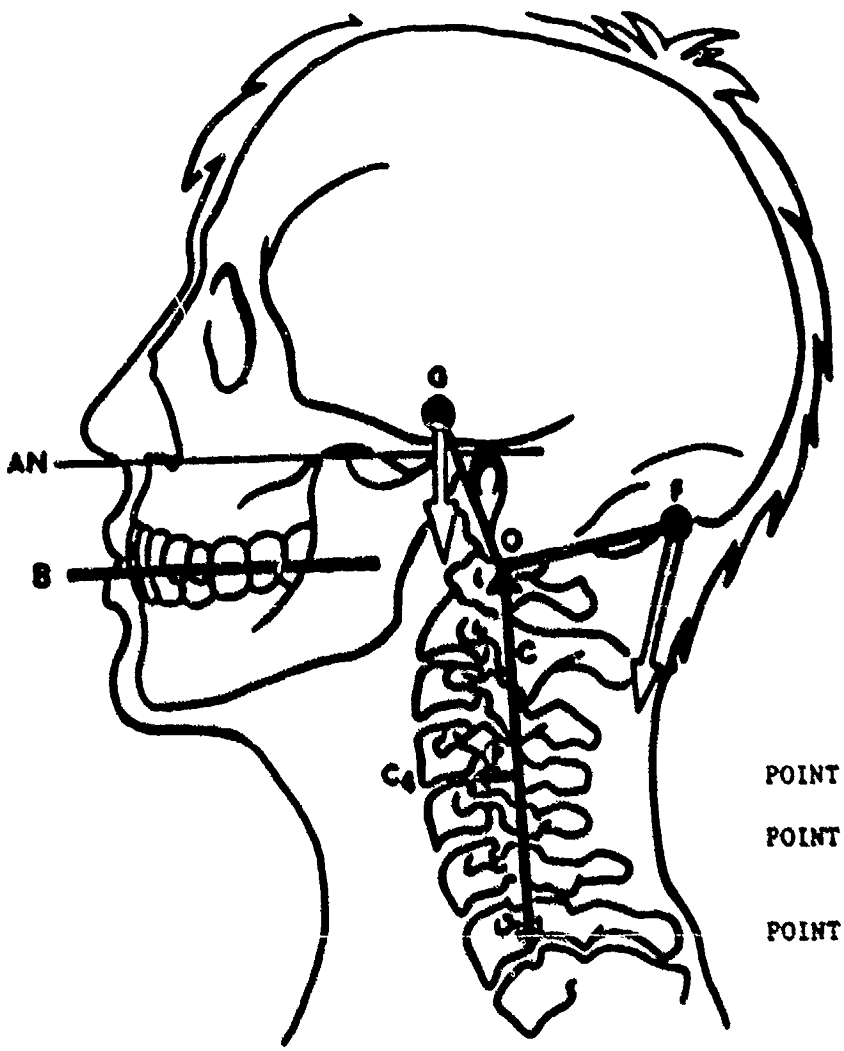
The experiment was conducted in two phases. In the first phase, ADAM was exposed to impact accelerations (6 G through 20 G) in a progressive order with each helmet (prototype and baseline). The manikin was exposed from between three to five times per impact level with each helmet. In the second phase, the human subjects were also exposed to all eight helmets but only at 10 G.

RESULTS

A comparative type analysis was used to analyze the effects of the prototype VCS on the human's biodynamic response during ejection. The comparison was between the I-NIGHTS helmets ADAM response as compared to both operational ejection scenario responses using baseline helmets and to neck strength as found in the literature. For the comparisons, the primary response parameters that were used were the z-axis compressive load at the occipital condyle, the x-axis shear load at the occipital condyle, and the torque or bending response at the occipital condyle. The occipital condyle is the cervical joint where the skull attaches to the first neck vertebrae (Figure 1).

To understand the potential problems that the prototype helmets could give a pilot beyond those of the baseline helmets, the inertial properties of the systems must first be collected and analyzed. Inertial properties includes weight, center-of-gravity (Cg), and moment of inertia or mass distribution. Table 1 shows the weight of each system, the system with a MBU-12/P mask, and the Cg of the system in combination with the large ADAM head and the mask. The Cg is shown with the ADAM head for relative comparison purposes and because of the large number of impact tests completed with the ADAM. The moment of inertia data is not shown because it is felt that the design of the prototypes is based on a baseline helmet platform, and the gross shape of the helmet will be limited by the headroom in the cockpit of the aircraft; therefore, the mass distributions will not be extraneous and the other inertial properties will be more limiting. It is clear from the inertial property data that the prototype systems are approximately 2 to 3.5 pounds heavier than the baseline helmets with a mask. It is also shown that the location of the optics of the visually coupled devices is forward of the baseline helmet/head combination by approximately 0.5 to 1.0 inches. From this data it is apparent why the effects of the increased weight and shifted center-of-gravity must be assessed before future VCS helmets can be flown.

Since the analysis of the data is of a comparative nature, this report will focus on the results of the manikin tests and there indications. The human test data, and its correlation with the manikin data, will be discussed in future reports; however, a few brief words shall be mentioned here. Human neck loading (z-axis compression, x-axis shear, and torque) was estimated using the measured linear and angular accelerations of the subject's heads. Preliminary analysis indicates that the Hybrid III neck found in the ADAM reasonably predicts the compressive and shear loading in the human neck. The torque measured by ADAM was on the average 50% less than that estimated



POINT O - OCCIPITAL CONDYLES

POINT G - CENTER OF GRAVITY OF HEAD

POINT F - NECK MUSCLES BALANCING FORWARD ROTATION OF HEAD

FIGURE 1. PHYSIOLOGY OF NECK LOADING

TABLE 1

VARIOUS HELMET/VISUALLY COUPLED SYSTEM MASS PROPERTIES

SYSTEM	WEIGHT (lb)	WEIGHT W/MASK (lb)	CENTER OF GRAVITY (in) X	Y	Z
LARGE HUMAN HEAD	9.70		0.00	0.00	1.22
LARGE ADAM HEAD	8.92		−0.27	−0.01	1.02
HGU−26/P	2.80	3.92	−0.26	0.05	0.82
HGU−55/P	2.43	3.55	−0.64	0.04	0.83
HGU−55/P + EAGLE EYE	3.96	5.08	−0.36	−0.04	0.70
I−NIGHTS G (NVG)	4.54	5.66	0.25	−0.03	1.09
I−NIGHTS G (HMD)	5.64	6.76	0.32	0.0	1.31
I−NIGHTS H (NVG)	5.16	6.28	0.13	0.06	0.90
I−NIGHTS H (HMD)	5.71	6.83	0.25	−0.08	0.69
I−NIGHTS K (NVG)	4.81	5.93	0.56	0.11	1.39
I−NIGHTS K (HMD)	5.84	6.96	0.41	0.03	1.39

for the human subjects. Further analysis will include continued correlation of the human data to ADAM, and correlation of both manikin and human data to the inertial property data. These correlations will be the first step in the development of USAF standards on maximum head mounted weight and Cg shift.

Current analysis of the ADAM data is shown in Figures 2 through 7. All ADAM data has an average standard deviation of approximately 5% of the response. Each figure is a bar graph showing the prototype helmets responses as compared to a baseline helmet response at each tested acceleration level. The first three figures (Figures 2-4) are of the prototype night vision device helmet systems and one of the baseline systems (HGU-55/P). It is quite apparent that each of the three biodynamic responses (compression, shear, torque) increases with the applied input acceleration for each helmet. It is also shown that at each acceleration level the prototype helmets have greater responses than the baseline helmet. It is interesting to note that above 10 G the heaviest helmet, the Honeywell NVG system, has a decreasing compressive neck load compared to the other helmets. This apparent anomaly can be explained by noticing that the Honeywell system has greater shear and torque values than the other helmets indicating that the Honeywell system is off-loading its inertial response from the z-axis into the x-axis and the torque around the y-axis.

The next three figures, Figures 5-7, are the ADAM results for the helmet mounted display systems and the HGU-55/P baseline helmet. Again the results are presented at each acceleration level for each of the three biodynamic parameters. As before the data increases with increasing input acceleration level for each biodynamic parameter. It is interesting to note that the heavier prototype systems (compared to baseline) generated higher compressive and shear loads but equal-to or less-than torque values, especially at the higher input accelerations.

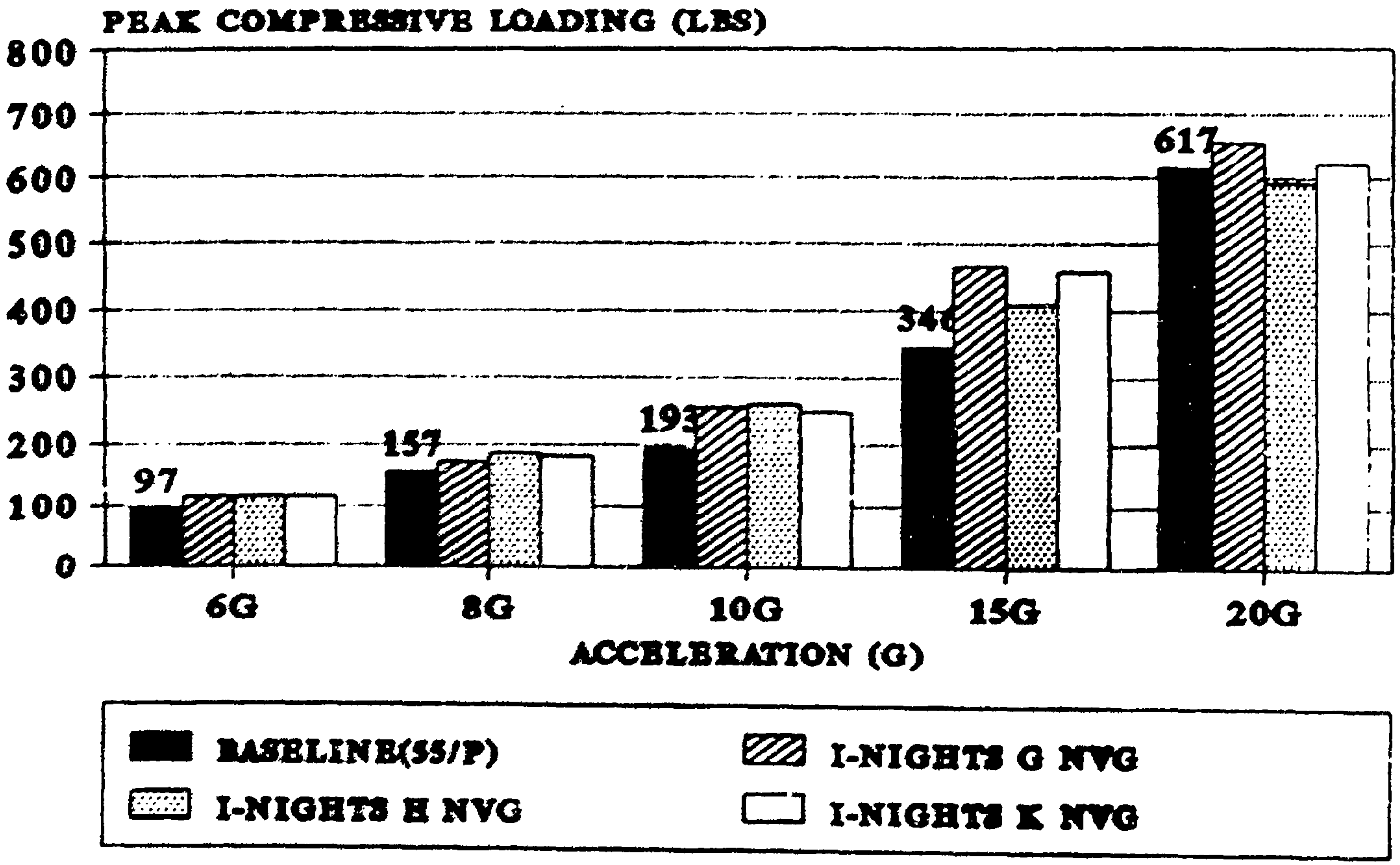
DISCUSSION

The concern about the potential for neck injury during ejection from an aircraft was addressed by an 1984 AGARD working group. Their findings indicated that non-ejection, high maneuvering environments and emergency ejection environments produced cervical fractures with current USAF helmets. The introduction of night vision devices, helmet mounted sighting and display systems, or a combination of both can be expected to increase the risk of cervical injury to the aircrew because of the increased weight and altered center-of-gravity. However, there exists very little information in the literature defining the maximum allowable mass on the head or maximum allowable shift in the combined head/helmet center-of-gravity in order to reduce the risk of neck injury.

There are no quantitative methods for prediction of cervical vertebral fracture risk similar to that for thoracic-lumbar vertebrae by calculating the Dynamic Response Index (DRI) for proposed test conditions (Brinkley & Shaffer, 1971). Literature reviews and operational experience have shown that the lumbar and thoracic vertebrae are more likely to be fractured than the cervical vertebrae during +Gz acceleration during ejection from aircraft (Ewing, 1972; Raddin et al, 1980). He makes no attempt to address head supported mass or actual aircraft mishap statistics. An occurrence of end-plate fractures of T-4 and T-5 at +10 Gz with a standard

I-NIGHTS HEAD/NECK LOADS

Z-AXIS NECK LOAD vs IMPACT ACCELERATION

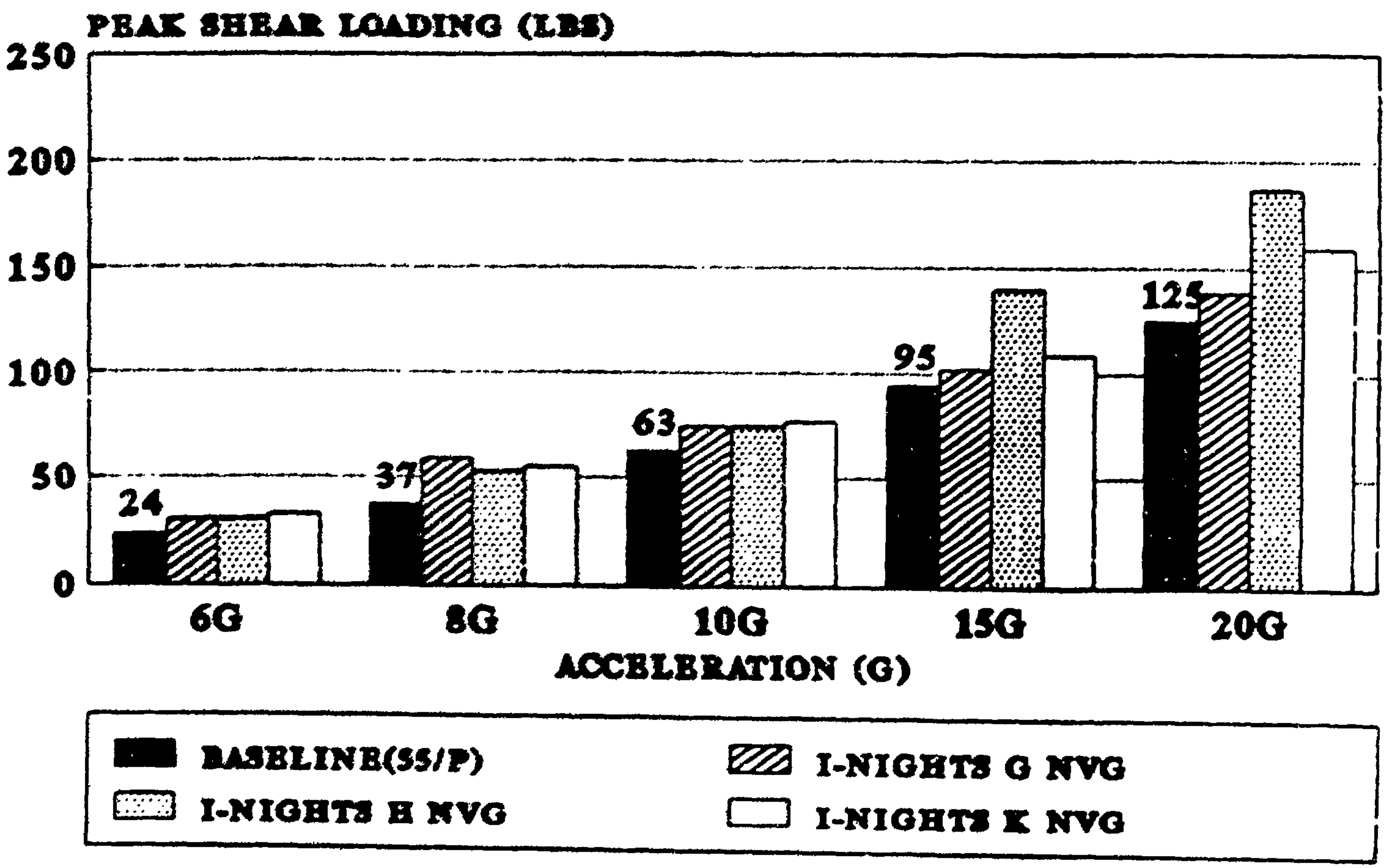


SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

FIGURE 2

I-NIGHTS HEAD/NECK LOADS

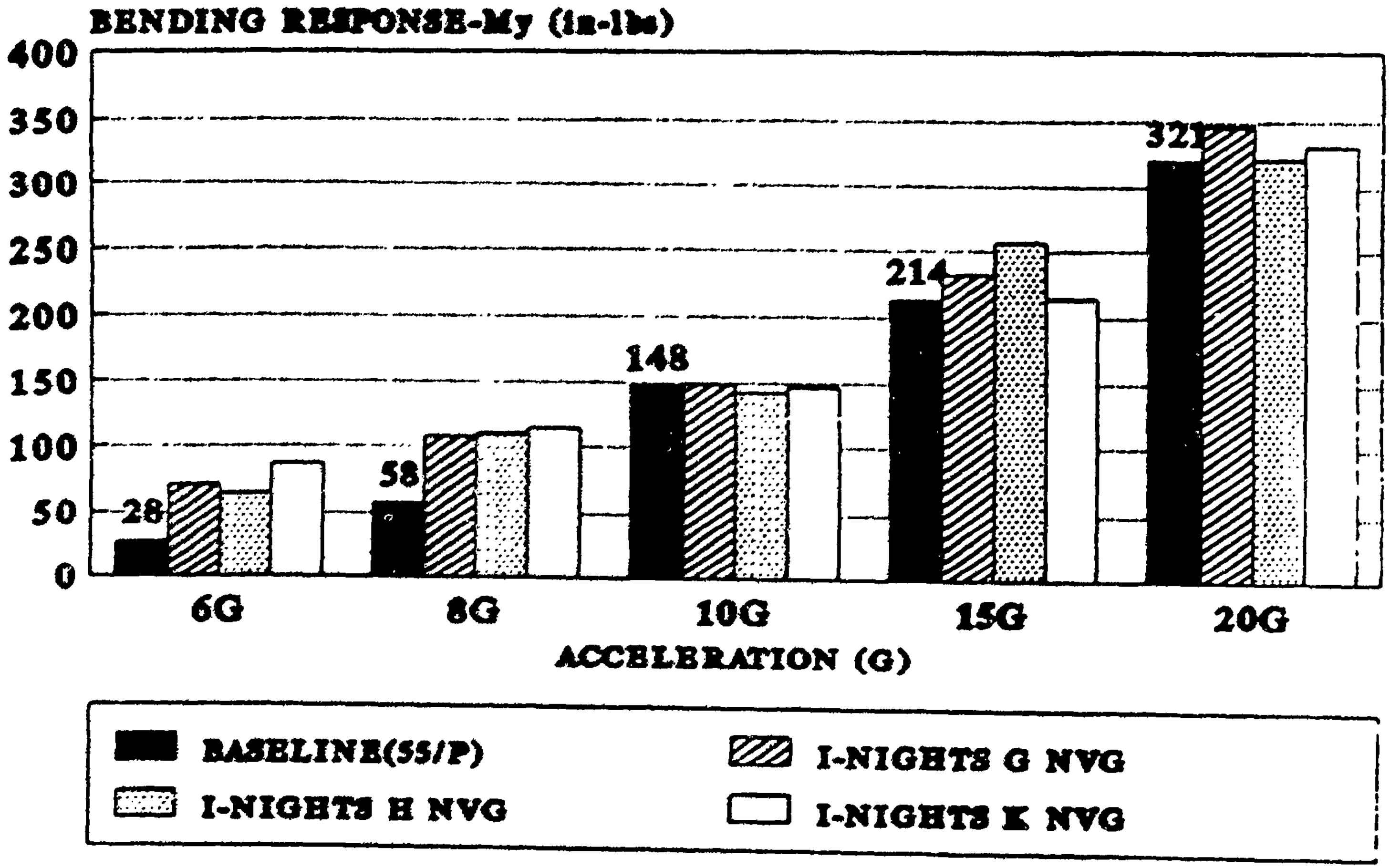
X-AXIS NECK LOAD vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

FIGURE 3

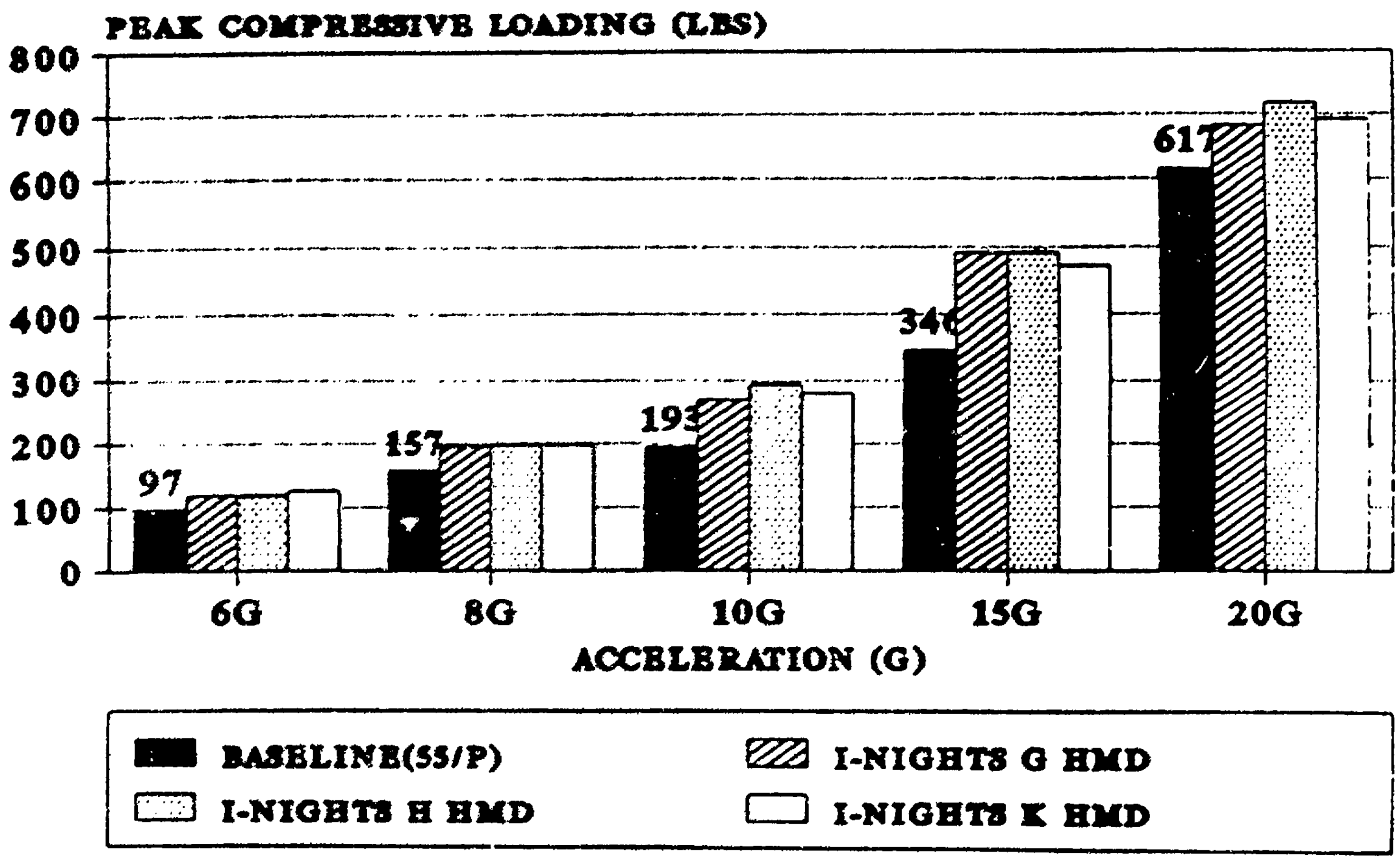
I-NIGHTS HEAD/NECK LOADS
BENDING RESPONSE vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

FIGURE 4

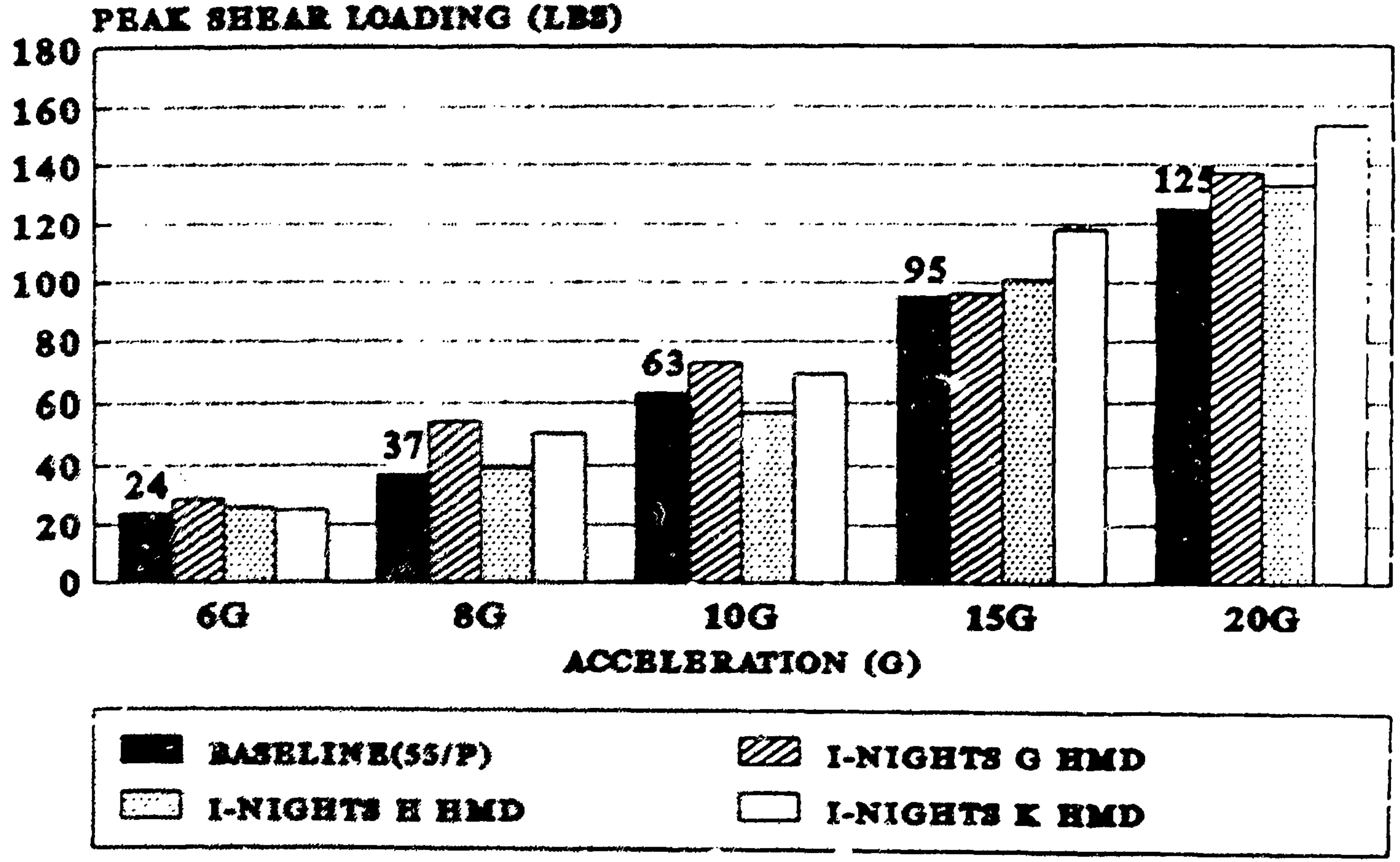
I-NIGHTS HEAD/NECK LOADS
Z-AXIS NECK LOAD vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK
FIGURE 5

I-NIGHTS HEAD/NECK LOADS

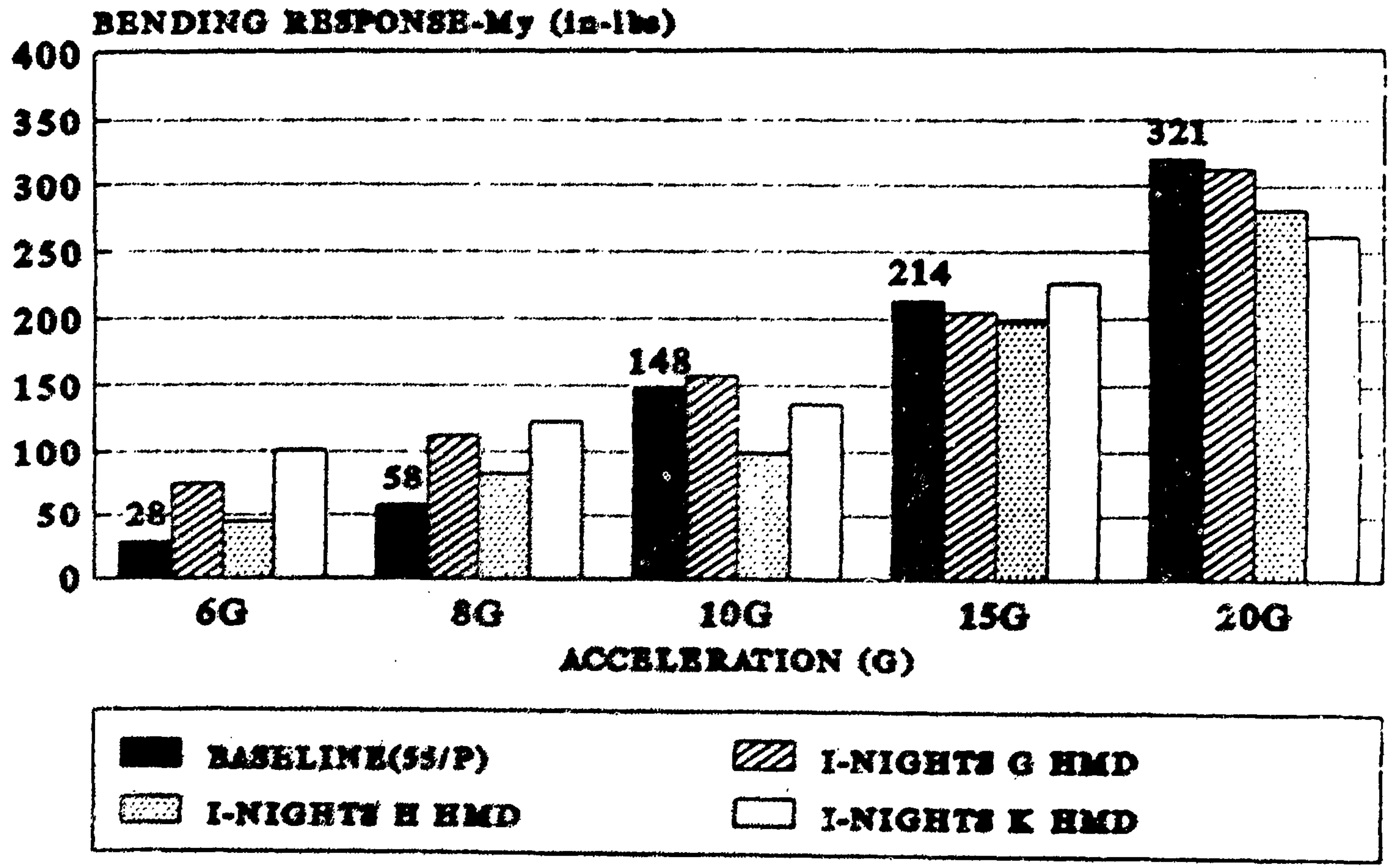
X-AXIS NECK LOAD vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

FIGURE 6

I-NIGHTS HEAD/NECK LOADS
BENDING RESPONSE vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

FIGURE 7

USAF helmet (HGU-26/P) has been reported (Orzech and Perry, 1988), but this was due to improper body positioning just prior to impact.

Bonner (1969, 1971) and Lehman (1973) reviewed USAF ejections from 1963-1967 and 1968-1972 respectively, focusing on helmets and head protection. In general, helmets which remained on during ejection reduced head injury rates. Bonner reported that 16.6% of helmets were lost. Only Lehman singled out cervical injury, which he reported as 21.2% (11/52) of injuries with the helmet intact and 14.6% (6/41) with helmet lost/failed. His data set included a total of 681 helmets, so the injury rates above are really 1.6 and 0.8% respectively. The type of cervical injury was not further deliniated.

U.S. Naval operational experience from 1949 to 1981 suggests a multitude of "ejection associated" factors (pre-ejection aircraft maneuver, poor positioning of the body, ejection catapult forces too high, windblast acting upon the ejectee's helmet, post-separation collisions of man and seat, parachute opening shock, ground contact, and rescue attempts) have resulted in an overall rate of approximately 7% for moderate "ejection associated" neck injuries and approximately 1% for severe neck injuries (Guill, 1983).

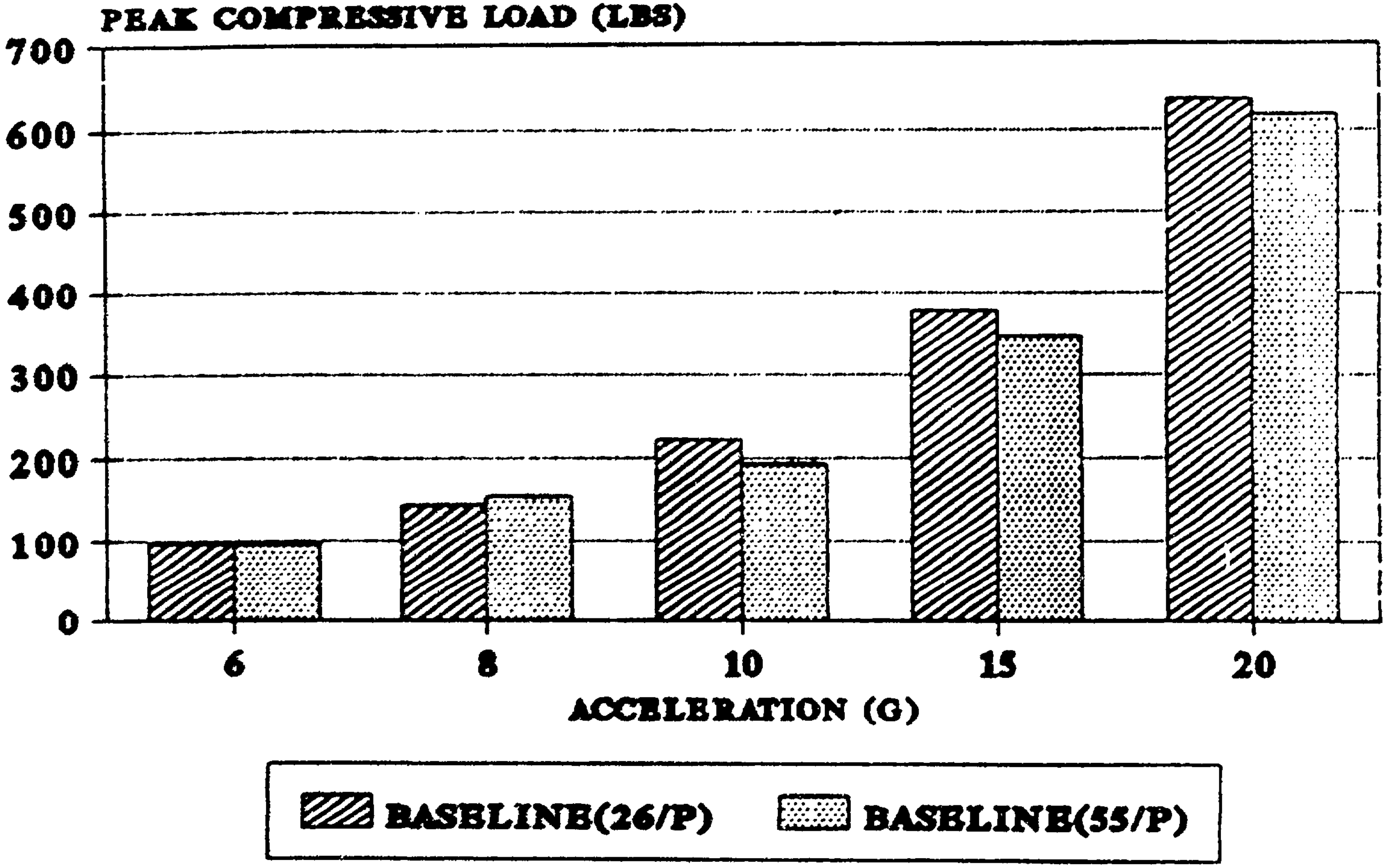
In a review of USAF aircraft accident data from 1978 to 1988 (Taylor, 1990), analysis focused primarily on head and neck injuries during ejection where the aircrew-member was known to be wearing either HGU-26/P or HGU-55/P flight helmets. The accidents which involved injury to the cervical spine showed approximately a 4% chance of occurrence, with about half of the injuries being fatal. If the data is sorted by ejection seat type (ACES II and B-52, Ballistic), it shows that there were no fatalities or major (fractures, dislocations, or transections) injuries to the cervical spine attributable solely to ejection force.

There is also very limited data in the literature indicating the strength and tolerance of the human neck in a dynamic environment. Estimates have been made using analytical models, operational accident data, and experimental impact data using human subjects and cadavers. In a pioneering study, Mertz and Patrick subjected human volunteer subjects to static and dynamic environments producing non-injurious head and neck responses. Cadavers were used to extend the analysis into the injury region. Based on testing in the -Gx direction, the following injury threshold values (maximum responses without producing ligament or bone damage at the occipital condyle) were estimated for the neck in flexion: (1) Moment (My) of approximately 1700 in-lbs, (2) Shear load of approximately 450 lbs, and (3) Compression load of approximately 400 lbs.

To determine the safety of the prototype I-NIGHTS helmets in an ejection, the limited injury and tolerance data requires a relative comparison analysis. The two different ejection profiles of main interest were the ACES II and the B-52 ejection seat profiles. The relative comparison for the prototype helmet systems in an ACES II ejection environment will be against the biodynamic data generated by the HGU-26/P baseline helmet in a B-52 ejection environment. The HGU-26/P helmet data can be found in Figures 8 through 10 along with the HGU-55/P baseline helmet. As shown, there is little difference between the two baseline helmets except at the lower G levels for shear and torque loading where the greater x-axis CG shift of the 26/P helmet takes effect. With a peak compressive loading of

I-NIGHTS HEAD/NECK LOADS

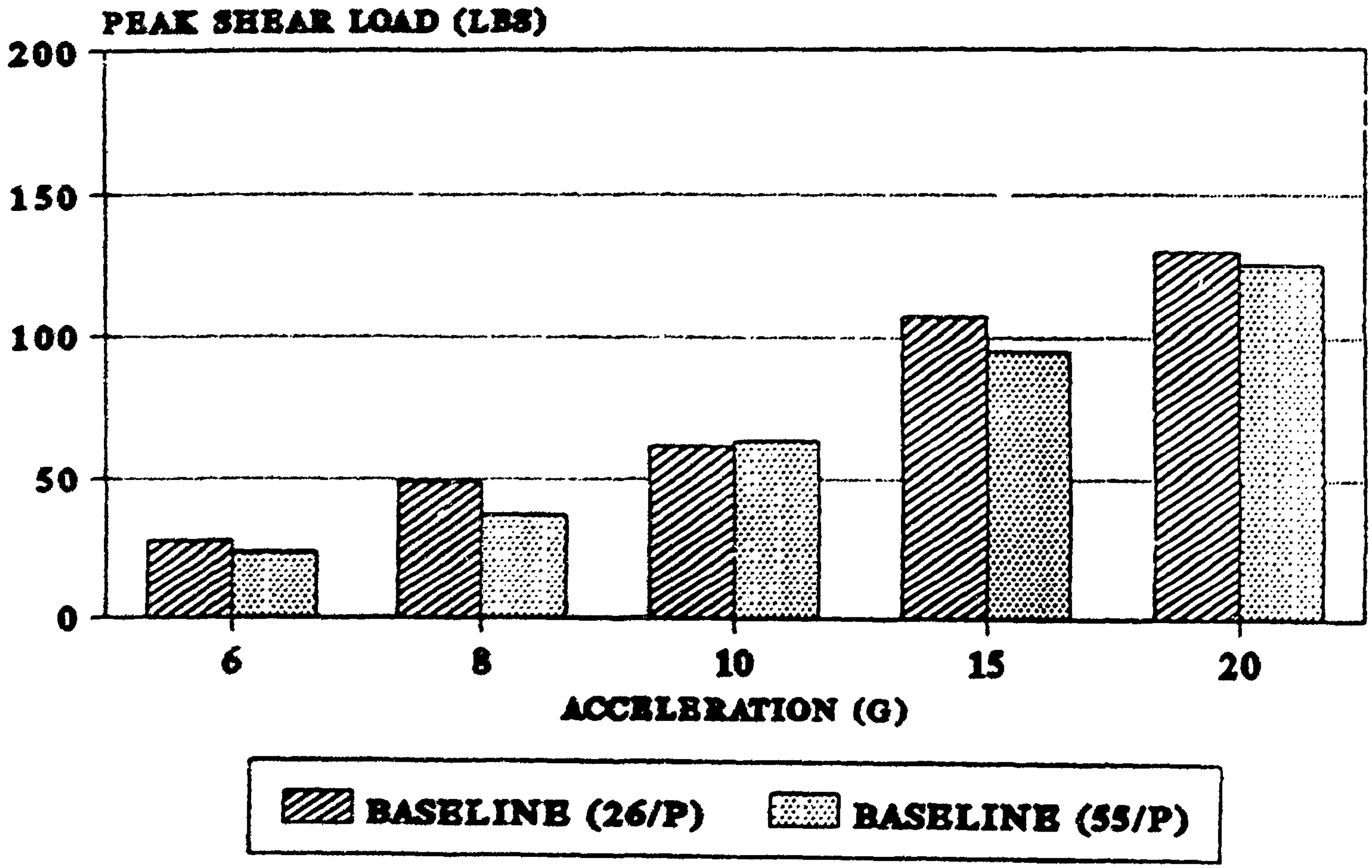
Z-AXIS NECK LOAD vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

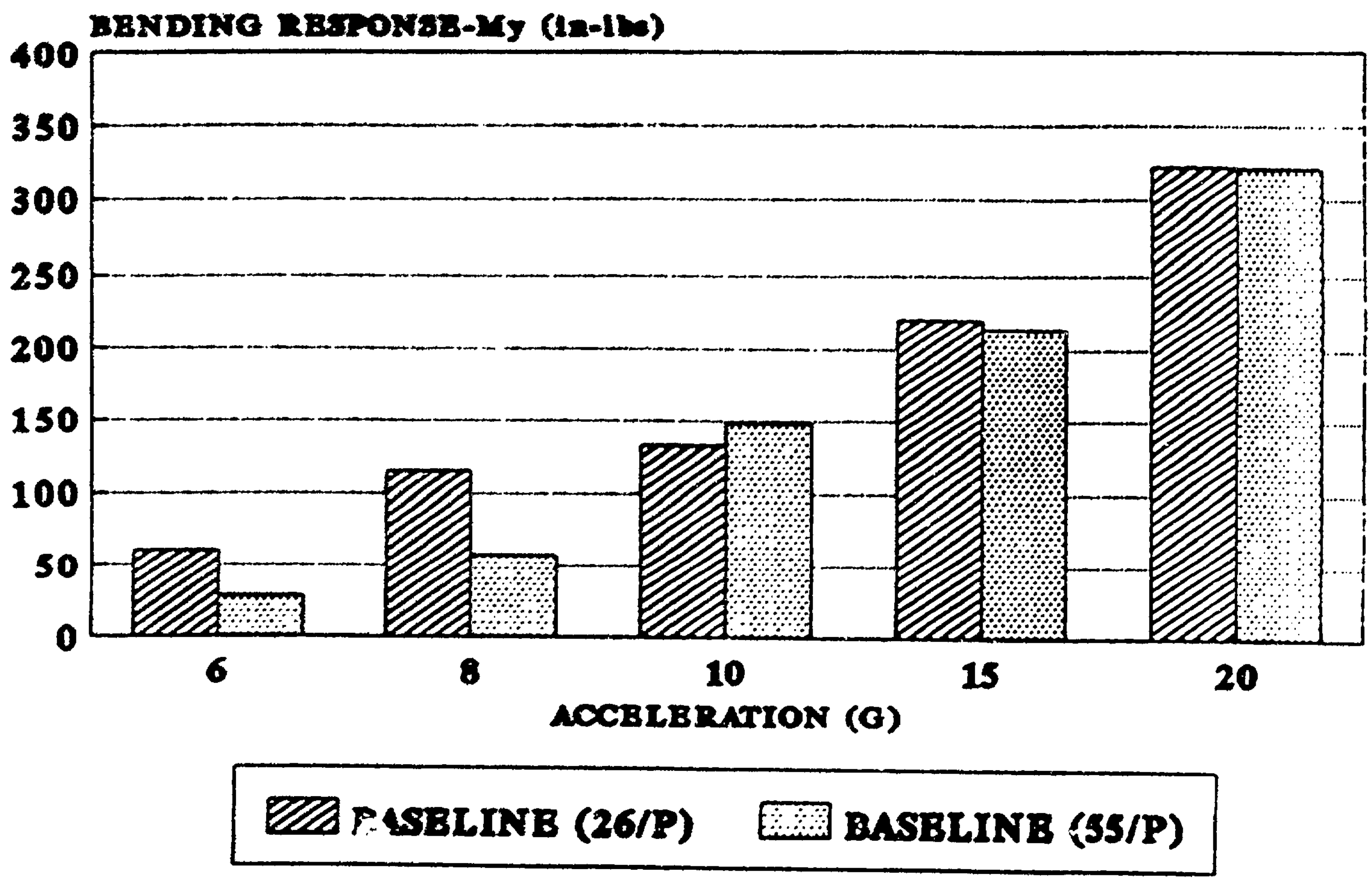
FIGURE 8

I-NIGHTS HEAD/NECK LOADS
X-AXIS NECK LOAD vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK
FIGURE 9

I-NIGHTS HEAD/NECK LOADS
BENDING RESPONSE vs IMPACT ACCELERATION



SYSTEMS TESTED WITH MBU-12/P OXYGEN MASK

FIGURE 10

approximately 380 pounds at 15 G, the 26/P helmet is greater than either prototype (night vision or helmet display) helmet system at the 10 G impact level. This indicates that the prototype systems could potentially generate no greater risk of compression injury than that produced by the 26/P baseline helmet. The same conclusion can also be reached for the shear and torque loading.

The second relative comparison analysis is for the B-52 ejection. At 15 G, all the prototype systems generate biodynamic responses greater than the 26/P baseline helmet; therefore, the comparison was then made to the injury threshold values determined by Mertz and Patrick. This comparison is conditional and is based on the assumption that the ADAM neck responses are representative of human responses under the same biodynamic conditions. This is currently being investigated and for now based on limited data, it will be assumed that the ADAM neck did an adequate job of mimicking the human neck response. Under this assumption, the prototype helmets (night vision and helmet display) were well below the shear and torque thresholds, but exceeded the compression neck load threshold value of 400 pounds. At this point, the analysis dictates that none of the prototype helmets are safe for a B-52 ejection. However, recent data on a 6.2 pound Swedish (Risk Assessment Working Group, 1990) flight helmet indicates a comparable fatal and major neck injuries to the USAF baseline (55/P and 26/P) helmets, but a 25% rate of minor neck injuries (soft tissue soreness, neck strains). The Swedish ejection environment averages DRI values of approximately 21, greater than the B-52. Refer to Figure 11 for a break down of these statistics. If these injury rates are considered acceptable, then the night vision device prototype helmet systems (because of similar weight) in a B-52 ejection could be considered to have no greater risk than the Swedish helmet.

CONCLUSIONS

The I-NIGHTS prototype helmet systems (all) will generate neck loads in an ACES II ejection, that are potentially no greater risk than the neck loads generated by a HGU-26/P flight helmet in a B-52 ejection environment. The I-NIGHTS prototype helmet systems (all) will generate neck loads in a B-52 ejection environment, that are potentially a greater risk than the neck loads generated by a HGU-26/P flight helmet in the same environment. The I-NIGHTS prototype helmet systems (night vision device only) will generate neck loads in a B-52 ejection that are potentially no greater risk than the 6.2 lb Swedish helmet.

It must be stated that these results are based on the responses of a manikin that has not been fully validated to simulate human responses; however, it is the best method available to test prototype equipment or safety systems before controlled human testing is conducted. As mentioned previously, data are currently being analyzed to correlate manikin and human responses with various helmet systems as well as to correlate the helmet inertial properties with the human and manikin biodynamic responses.

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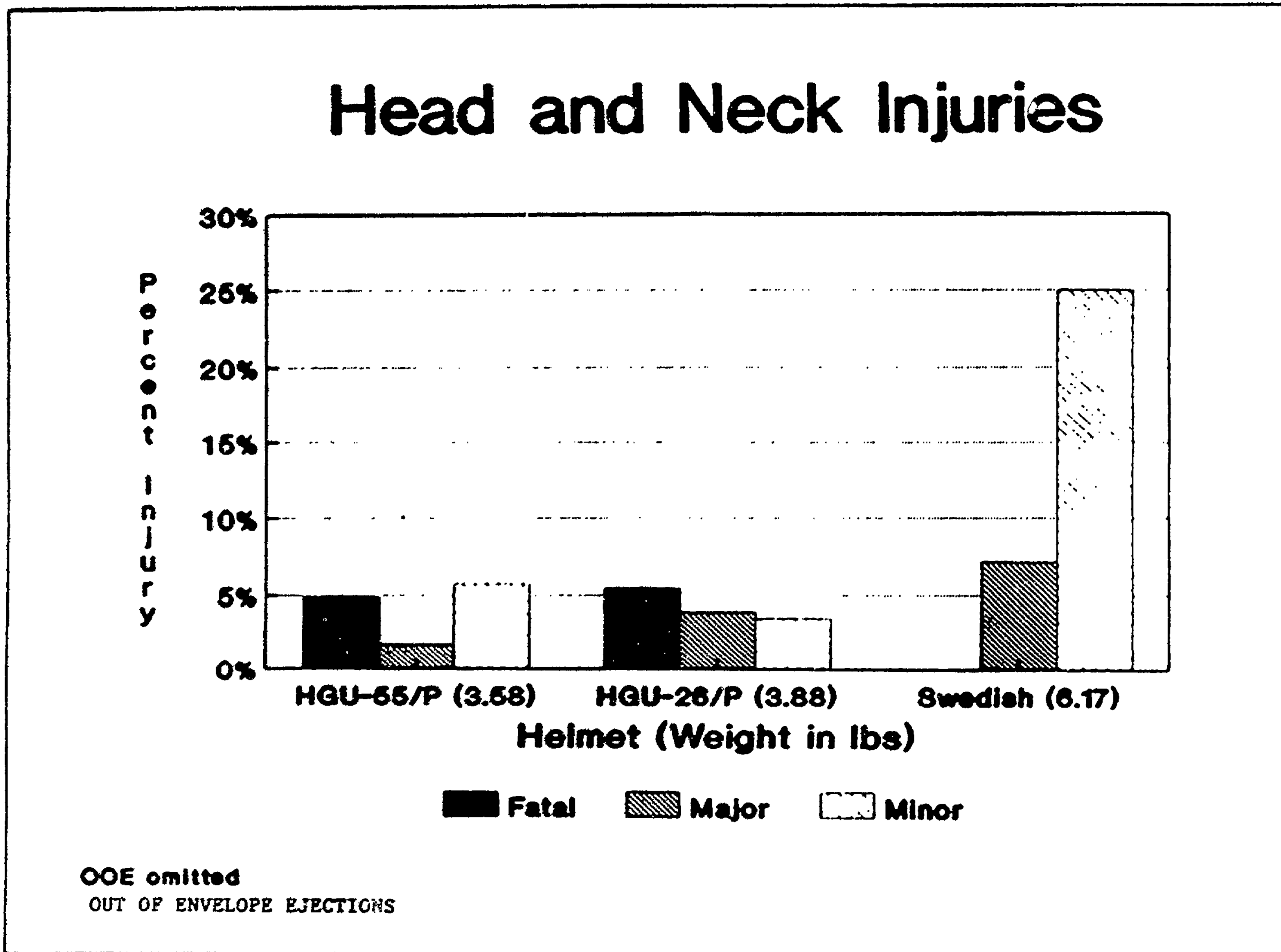
Head and Neck Injuries
30%
25%
20%
15%
10%
5%
0%
Percent Injury
HGU-55/P (3.58)
HGU-26/P (3.88)
Swedish (6.17)
Helmet (Weight in lbs)
Fatal
Major
Minor
OOE omitted
OUT OF ENVELOPE EJECTIONS

FIGURE 11

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APPENDIX J

WINDBLAST

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APPENDIX J: WINDBLAST

1. INTRODUCTION

Aircrew members ejecting from aircraft encounter a sudden, high speed blast of air as they emerge from the cockpit and enter the slip stream. A helmet-mounted system must withstand the blast and remain structurally intact. The helmet system must not create injurious forces for the head and neck. Additionally, with the ACES II ejection seat, proper parachute deployment depends on an unobstructed airflow to the two pitot sensors located on either side of the seat's headbox. Therefore, the helmet system must not disrupt the flow of air to the pitots. This report describes the windblast evaluation of three helmet-mounted systems. The three helmet systems were designed and built for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office. The testing was accomplished at Dayton T Brown Inc. facilities at Bohemia, New York by the Biomechanical Protection Branch, Biodynamics, and Biocommunications Division, Armstrong Laboratory, Wright-Patterson AFB, Ohio.

2. APPROACH

The structural integrity, head/neck loads, and air flow were measured by having an instrumented manikin wearing an I-NIGHTS helmet while strapped into an ACES II ejection seat. The seat and manikin were subjected to windblasts simulating ejections at 350, 450, 550 and 600 knots. The seatback angle was set at 17° and 30° to simulate F-15 and F-16 ejections.

3. OBJECTIVE

The objective of the windblast testing was to verify the helmet's structural integrity, measure the head/neck forces experienced by the manikin, and to verify that the helmet's shape did not disrupt the flow of air to the seat mounted pitot sensors.

TEST PLAN

TITLE: I-NIGHTS WINDBLAST TESTS

ACES II COMPATIBILITY/STRUCTURAL INTEGRITY

TASK: 325702

PREPARED BY: Laurence Hofferker DATE: 29 Aug 90
AAMRL/BBP

APPROVED BY: Francis L. Knox DATE: 29 Aug 90
AAMRL/BBP

APPROVED BY: James W. Brinkley DATE: 30 Aug 1990
AAMRL/BB

APPROVED BY: [signature] DATE: 30 Aug 90
HSD/YAH-HST

CREW PROTECTION BRANCH
BIODYNAMICS AND BIOENGINEERING DIVISION
HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

1.0 SCOPE

1.1 Scope of the Plan

This plan describes the experimental design, methods and procedures, test equipment, data processing and documentation requirements for an experiment to evaluate potential interference between I-NIGHTS helmets and the seat mounted pitot tubes on the ACES II ejection seat, evaluate head and neck aerodynamic loading, and evaluate the air flow in the headbox region with pressure measuring equipment. The responsibilities of contractor personnel and participating branch personnel are described.

1.2 Synopsis of Effort

The purpose of this experimental effort is to provide data for the evaluation of different helmet mounted displays using pressure and load measuring instrumentation. Measurements will be accomplished for the baseline helmet as well as three helmet mounted device (HMD) configurations.

2.0 SPONSOR

These tests are funded under Project 3257, Task 02. The principal investigator is Mr Lawrence J. Specker. The associate investigator is 2Lt John Tallarovic.

3.0 RESEARCH REQUIREMENT

3.1 Purpose and Relevancy

Emergency escape by crews wearing helmets equipped with night vision goggles and visual displays may cause head and neck injury and/or cause the performance of the escape system to be degraded by modifying the air pressure sensed by the pitot tubes mounted near the headrest. This test plan specifically addresses SAC Statement of Operational Need 307-87 and the TAC F-16 SORD 312-88-1-A. Head and neck aerodynamic loads and pressure surveys to the sides of the helmeted head will be provided to evaluate the potential for crew injury. The pressure measuring rake assemblies will be evaluated for utility in measuring the airflow intensity surrounding the upper portion of an ejection seat headbox near the ejection seat's pitot tubes. Several helmet configurations will be used in the study. This information is important in the development of windblast protection criteria and the design of head mounted crew equipment. The data collected during this test program will also be used in the development of advanced escape and crash protection systems.

3.2 Critical Issues

The critical issues that will be addressed by this test program and subsequent analytical efforts using the collected data are summarized as follows:

a. How do the different helmet configurations change the pressures measured by the ACES II pitots and headbox mounted rake assemblies?

b. How do the different helmet configurations change the head and neck loads measured on the manikin?

c. How do the pressure measurements from the deployable ACES II pitot tubes compare with the standard ACES II pitot measurements?

d. How well do the various helmet configurations withstand the windblast environment?

Secondary issues addressed by this program include:

a. How accurately do ACES II pitots measure pressure when compared to the high frequency response transducers mounted near the ACES II pitots?

b. How robust are the high frequency response transducers that are used in the pressure rake assemblies?

c. How well do windblast manikin head loads compare to previously collected low speed wind tunnel manikin head loads?

d. How well do full-scale head and neck loads compare with 1/2-scale model data for similar configurations?

e. How do the full-scale head and neck aerodynamic loads vary as a function of pitch angle.

f. How do the pressures measured with the rake assembly vary as a function of Q (=1/2 x density x velocity squared)?

g. How do the pressures measured with the rake assembly vary as a function of pitch angle?

4.0 TEST OBJECTIVES

4.1 Specific Objectives

The specific objectives of this research investigation are:

a. Determine the potential for ACES II pitot interference with various helmet configurations.

b. Measure the additional head and neck aerodynamic loading with different helmet designs and measure the pressures surrounding the ACES II ejection seat headbox during windblast testing with varying seat attitudes, airspeeds, and dynamic pressures.

c. Evaluate structural integrity of the HMD helmets during exposure to windblast.

4.2 Secondary Objectives

The secondary objectives of this experimental effort will be accomplished by subsequent analysis of the data that will be collected.

These objectives are:

a. To provide a data base that can be used to study the effects of head mounted configuration design changes.

b. To provide instrumentation design that can be used during wind-tunnel, windblast and track tests.

5.0 EXPERIMENTAL DESIGN

5.1 Experimental Hypotheses

The hypotheses being tested by this experiment are:

a. Each helmet prototype will cause greater aerodynamic forces and moments at the neck than the baseline helmet.

b. Each helmet prototype will cause a greater error in pressure measurement at the ACES II pitot tubes than the baseline helmet.

c. Pressure measurements from the deployable ACES II pitot tubes will be less affected by changes in airflow caused by the prototype helmets than the standard ACES II pitot measurements?

5.3 Test Schedule

The run schedule is summarized in Attachment 1.

6.0 EXPERIMENTAL METHODS

6.1 Windblast Facility

The windblast tests will be conducted at Dayton T. Brown Inc. in Bohemia, New York. The windblast facility is an outdoor test facility in which compressed air, stored in high pressure air cylinders, is expanded through a nozzle and directed at the test subject. The test air is provided by five horizontal rows, each with twenty cylinders of compressed air. The test section may be viewed from the control room. The facility can operate at a speed in excess of 600 KEAS. Basic controls for the air tanks and its auxiliaries are located in a room with remote controls provided for normal test operations.

6.2 Model Configurations

a. An F-16 configured ACES II ejection seat will be used in the test program. Attached to the ACES II seat for some of the configurations will be specially designed pressure transducer rake assemblies. A schematic of the left rake assembly is shown in Attachment 2.

b. The test subject (manikin) sample will consist of a 95th percentile manikin. The manikin will wear a flight suit, standard Air Force integrated parachute harness (PCU-15/P), oxygen mask (MBU-12/P), boots, and gloves. As a safety precaution, if possible all loose clothing and flight gear (such as the visor) will be taped down to prevent their separating from the manikin during the test. The manikin will be placed in the ACES II ejection seat and restrained to the seat at the parachute riser connectors and with the standard lap belt. A strap around the chest and seat will also be used. Nylon fasteners will be used at the elbows, hands, knees, and ankles to hold the manikin limbs in place. To insure that the head position remains the same throughout the entire test program, a neck brace will clamp the manikin's neck below the Denton balance and be bolted to the back of the seat headrest. In addition, the manikin's seated eye height will be measured before each test. The helmets will be positioned the first time by the manufacturer. After this initial fit, measurements will be made from the helmet to parts of the manikin or seat. On all subsequent tests, consistent helmet positioning will be provided by the use of the initial measurements. Helmet movement during the test will be monitored by comparing pretest and postest photos. The helmet and a fixed point on the seat will each be marked with fiducials to record their position.

6.3 Test Conditions

a. Initial Model Attitude

The model will be placed in front of the test nozzle on a test stand. The model pitch angle will be either 17.0 degrees or 34.0 degrees as measured by the rail angle of the seat with respect to the vertical, as shown in Attachment 3.

b. Windblast Conditions

Windblast test velocities are measured by a pressure rake located 18" downstream of the test nozzle. Data for the first tests will be collected at a core velocity of 375 KEAS. After these are completed, the configurations will be tested at core velocities of 450 KEAS, 550 KEAS, and 600 KEAS. Seat pitch angles (alpha) will be 17.0 and 34.0 degrees while sideslip angles (beta) will be 0.0 degrees for all tests.

7.0 DESCRIPTION OF TESTS

7.1 Safety

a. The windblast program will be conducted in compliance with Dayton T. Brown safety requirements.

b. These tests are not qualification tests for any of the systems being tested. The tests will determine problems with equipment compatability and structural integrity.

a. The risk category for this test program (overall risk) is defined by MIL-STD-882B as acceptable with management approval. The helmets will be windblast tested for structural integrity. Risk categories and hazard probabilities are listed in the table below.

EQUIPMENT DESCRIPTION	HAZARD	PROBABILITY
95 PERCENTILE MANIKIN	\$10,000 < III < \$100,000	D - remote
DENTON LOAD CELL	\$10,000 < III < \$100,000	D - remote
40 PRESSURE TRANSDUCERS	\$10,000 < III < \$100,000	C - occasional
HELMET CONFIGURATIONS	\$10,000 < III < \$100,000	C - occasional
OXYGEN MASK	0 < IV < \$10,000	A - frequent

b. As a safety precaution, Dayton T. Brown Inc. personnel will be responsible for performing a safety survey (inspect for loose debris, etc) of the windblast test area prior to each blast. The test manikin will be restrained to the ejection seat at the parachute harness fittings, with a standard lap belt, and with a belt around the chest and seat. In addition, the manikin's limbs will be fastened to the ejection seat and parachute harness at the arms and the legs with nylon fasteners.

7.2 Test Procedures

a. The conduct of the test will be the responsibility of an AAMRL/BBP test conductor and the project engineer from the Dayton T. Brown windblast facility. All facility operational procedures and checklists will be followed for the operation of the facility. The operation of the facility is the responsibility of contractor personnel. The AAMRL test conductor will direct the activities of all other personnel in the test area in accordance with a detailed checklist similar to that in Attachment 4. The test conductor will make a final check of the test area and equipment immediately prior to each test. Two pretest still photographs of the manikin/seat combination will document each test configuration.

b. Prior to each test, the facility will be checked for proper operating conditions and all personnel will be cleared from the test area. The test conductor will then give the facility project engineer clearance to start the test and operate the facility. After each test, two post-test photos will be taken of the test subject. Any test anomalies will be noted.

7.3 Emergency Procedures

The facility project engineer will secure the test area should an emergency occur. The test area is cleared prior to every test. Established contractor procedures will be followed.

7.4 List of Model Configurations

The model configurations will be tested in the order of presentation listed below. The anticipated run schedule is listed in Attachment 1.

a. Configuration 1 (tests 1 - 2) - ACES II ejection seat with pressure rake; 95th percentile manikin with slumped posture; 26P helmet.

b. Configuration 2 (tests 3 - 4) - ACES II ejection seat with deployable pitot tubes; 95th percentile manikin with slumped posture; 26P helmet.

c. Configuration 3 (tests 5 and 6) - same as configuration 1 with Honeywell HMD.

d. Configuration 4 (tests 7 and 8) - same as configuration 2 with Honeywell HMD.

e. Configuration 5 (tests 9 and 10) - same as configuration 1 with Kaiser HMD.

f. Configuration 6 (tests 11 and 12) - same as configuration 2 with Kaiser HMD.

g. Configuration 7 (tests 13 and 14) - same as configuration 1 with GEC HMD.

h. Configuration 8 (tests 15 and 16) - same as configuration 2 with GEC HMD.

i. Configurations 9 through 16 (tests 17 - 52) - same as configurations 1 through 8 except manikin has normal sitting height.

8.0 DATA ACQUISITION

8.1 Total Force and Moment Data:

During each test, head/neck load data will be collected using a Denton six degree-of-freedom load cell, supplied by the government. This load cell will collect the moments and loads about the head in all primary axes. After completion of a test, the final data stored in the data acquisition system (or disc pack) will be available for on-site plotting or additional analysis.

8.2 Pressure Measurements:

a. Static pressures will be measured at one location on the ACES II seat back. It will be located on the rear of the seat in order to measure base pressure. This pressure will be measured on all configurations.

b. Total pressure will be measured with two pressure rake arrays, each with 20 pressure transducers, mounted on the ejection seat headbox. These transducers will measure the pressures around the headbox and be used to evaluate pitot compatibility. The position of the rake arrays is shown in Attachment 5.

8.3 Photogrammetric Documentation:

a. Two pretest still photographs of the seat/subject will document each test configuration.

b. Two high speed cameras (400 frames/sec) will be used to provide a photographic record of each test.

c. Two postest still photographs of the seat/subject will document the condition of the test articles after each test.

d. A 1/2" VHS video tape of the tests will be taken to provide real time documentation of the tests.

9.0 DATA REDUCTION

9.1 Nomenclature and Symbols:

SYMBOL	DEFINITION
ALFMAN	Crewman angle of attack (positive nose up), deg
BETAM	Model angle of sideslip (positive nose left), deg
CA	Axial force coefficient, body axis (positive downstream) FA/QS
CAS	Axial-force area parameter, body axis, FA/Q, ft*2
CG	Center of gravity
CML	Rolling moment coefficient, body axis (positive clockwise looking upstream), ML/QSd
CMLV	Rolling-moment volume parameter, body axis, ML/Q, ft*3
CMM	Pitching-moment volume parameter, body axis (positive nose up), MM/QSd
CMMV	Pitching-moment volume parameter, body axis, MM/Q, ft*3
CMN	Yawing-moment coefficient, body axis (positive nose right), MN/QSd
CMNV	Yawing-moment volume parameter, body axis, MN/Q, ft*3
CN	Normal-force coefficient, body axis (positive up), FN/QS
CNS	Normal-force area parameter, body axis, FN/Q, ft*2
CPSB1	Static pressure coefficient, seat back reference, (PSSB1-P0)/Q
CP01-CPXX	Total pressure coefficients, (Ps-P0)/Q
CY	Side force coefficient, body axis (protective nose right), FY/QS
CYS	Side force area parameter, body axis, FY/Q, ft*2
d	Subject/seat reference length equivalent to the diameter of a circle with area equal to S, 35.07 in.
FA	Axial force, body axis (positive downstream), lb
FN	Normal force, body axis (positive up), lb
FY	Side force, body axis (positive nose right), lb
MACH,M	Freestream Mach number
ML	Rolling moment, (positive clockwise looking upstream), in-lb
MM	Pitching moment, (positive nose up), in-lb
MN	Yawing moment, (positive nose right), in-lb
MRC	Moment reference center
P0	Freestream static pressure, psia
PSSB1	Static pressure tap, seat back
PS01-PS0X	Total pressures, psfa
PTA1R	Total pressure, web "A", probe 1, right rake
PTA1L	Total pressure, web "A", probe 1, left rake
PTA2R	Total pressure, web "A", probe 2, right rake
PTA2L	Total pressure, web "A", probe 2, left rake

PTA3R   Total pressure, web "A", probe 3, right rake
rake
PTA3L   Total pressure, web "A", probe 3, left rake
PTB1R   Total pressure, web "B", probe 1, right rake
rake
PTB1L   Total pressure, web "B", probe 1, left rake
PTB2R   Total pressure, web "B", probe 2, right rake
rake
PTB2L   Total pressure, web "B", probe 2, left rake
PTB3R   Total pressure, web "B", probe 3, right rake
rake
PTB3L   Total pressure, web "B", probe 3, left rake

PTC1R   Total pressure, web "C", probe 1, right rake
PTC1L   Total pressure, web "C", probe 1, left rake
PTC2R   Total pressure, web "C", probe 2, right rake
PTC2L   Total pressure, web "C", probe 2, left rake
PTC3R   Total pressure, web "C", probe 3, right rake
PTC3L   Total pressure, web "C", probe 3, left rake

PTD1R   Total pressure, web "D", probe 1, right rake
PTD1L   Total pressure, web "D", probe 1, left rake
PTD2R   Total pressure, web "D", probe 2, right rake
PTD2L   Total pressure, web "D", probe 2, left rake
PTD3R   Total pressure, web "D", probe 3, right rake
PTD3L   Total pressure, web "D", probe 3, left rake

PTE1R   Total pressure, web "E", probe 1, right rake
PTE1L   Total pressure, web "E", probe 1, left rake
PTE2R   Total pressure, web "E", probe 2, right rake
PTE2L   Total pressure, web "E", probe 2, left rake
PTE3R   Total pressure, web "E", probe 3, right rake
PTE3L   Total pressure, web "E", probe 3, left rake
PTF1R   Total pressure, web "F", probe 1, right rake
PTF1L   Total pressure, web "F", probe 1, left rake
PTF2R   Total pressure, web "F", probe 2, right rake
PTF2L   Total pressure, web "F", probe 2, left rake
PTF3R   Total pressure, web "F", probe 3, right rake
PTF3L   Total pressure, web "F", probe 3, left rake

PTG1R   Total pressure, web "G", probe 1, right rake
PTG1L   Total pressure, web "G", probe 1, left rake
PTG2R   Total pressure, web "G", probe 2, right rake
PTG2L   Total pressure, web "G", probe 2, left rake

PT   Total pressure
QPSF   Freestream dynamic pressure, psf
RN/FT   Freestream Reynolds number per foot
RUN/PNT   Data run number and test point
S   Subject/seat reference area for 50th percentile equivalent to the projected frontal area of the seat and subject, 6.71 ft*2
SRP   Seat reference point
TEMP   Tunnel total temperature, deg F

VFPS   Freestream velocity, ft/sec
X,Y,Z   Coordinates in the body axis system

9.2 Subject/Seat:

The manikin force and moment data will be reduced to coefficient form in the body axis system. The measured forces will be divided by the dynamic pressure as measured at the rake 18" from the nozzle for each test.

9.3 Seat Base and Rake Pressures:

Seat base and rake pressures will be measured and presented in both engineering units of pounds per square inch absolute (psia) and as static and total pressure coefficients. To obtain the pressure coefficients, the measured pressure will be divided by the dynamic pressure as measured at the rake 18" from the nozzle.

10.0 DATA PRESENTATION

10.1 On-Line Tabulations:

Data obtained at each test point will be reduced as soon after the test point as possible. All the data within the run will be listed together. Each page and line of data will have the appropriate information to uniquely identify each data item. Among the information to be printed are:

a. Data run number (RUN)
b. Test identification
c. Time and date data were taken
d. Test conditions
   1. Test speed (KEAS)
   2. Static pressure (P0)
   3. Dynamic pressure (QPSF)
e. Subject/seat model attitude (ALFMAN, BETAM)

10.2 The variables listed above should be made available for plots during the test.

10.3 Data Tape:

All reduced data will be recorded on 5 1/4" or 3 1/2" magnetic disk. This will be done in an ASCII format. Two sets of data discs is required at the completion of the test. The data will not be deleted from the data acquisition system until the ASCII data on the disks have been verified.

10.4 Data Analysis:

a. Both measurements from the two seat mounted ACES II pitot tubes will be combined with the seat back static pressure. A determination will then be made as to what mode of operation the seat should have selected. This measurement will then be compared with the output signal of the environmental sensor to check for agreement.

b. The data from the 40 pressure transducers mounted on rake assemblies will be used to determine the extent of the wake region behind the helmet in the plane of the ACES II pitot tubes. The plot of the wake region will be compared to the mode selection switch to check that mode II was selected when the ACES II pitots were in the freestream.

c. The head/neck data will be used to compare the performance of each of the I-NIGHTS helmets to that of the baseline helmet. The head/neck data will also be compared with the pressure measurements from the rakes to investigate any relationship between the pressure measurements and head/neck loading.

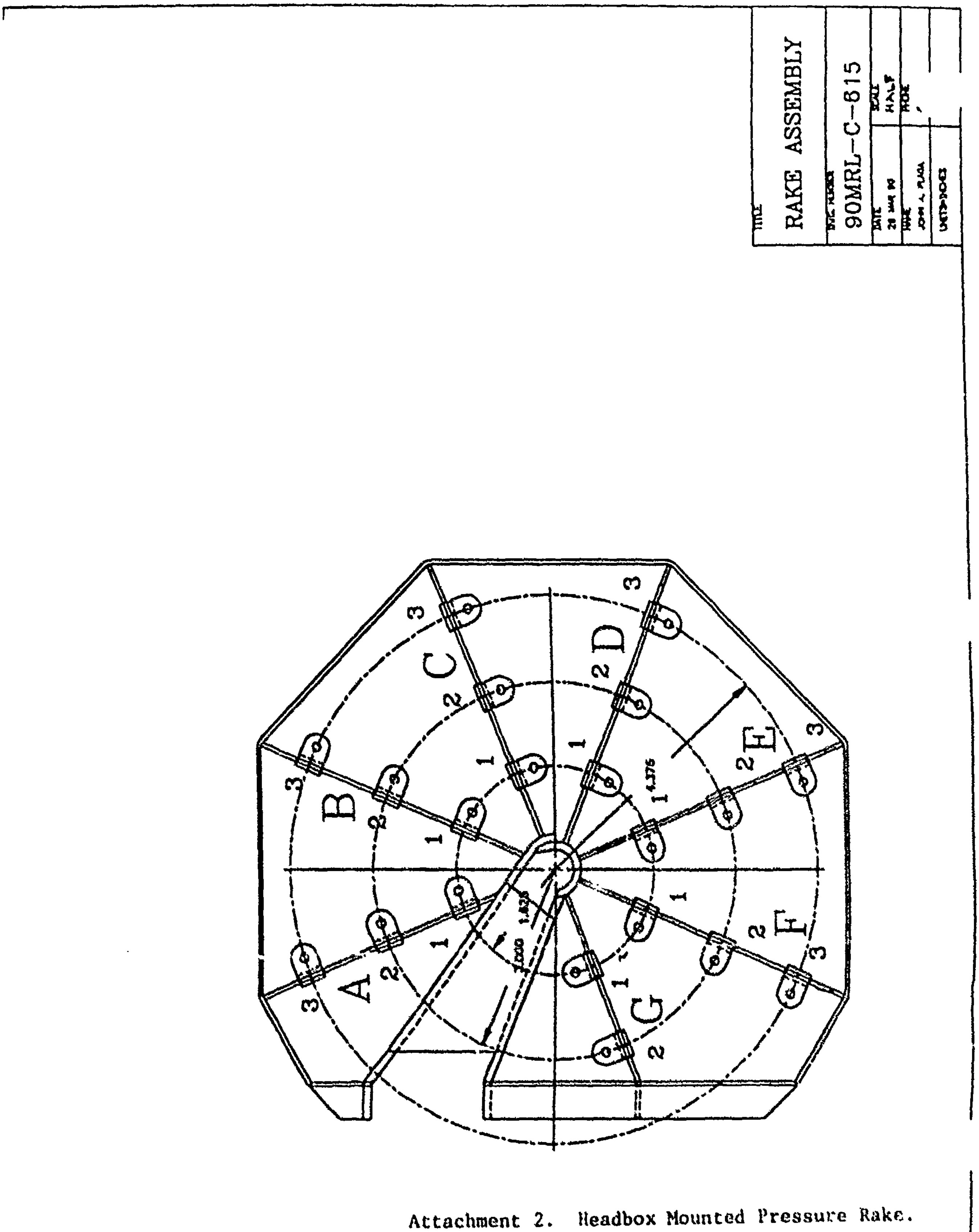
12. REFERENCES:

1. Specker, L. J. Low-Speed Wind Tunnel Evaluation of Pitot Rake Assemblies - Test Plan, 1990.

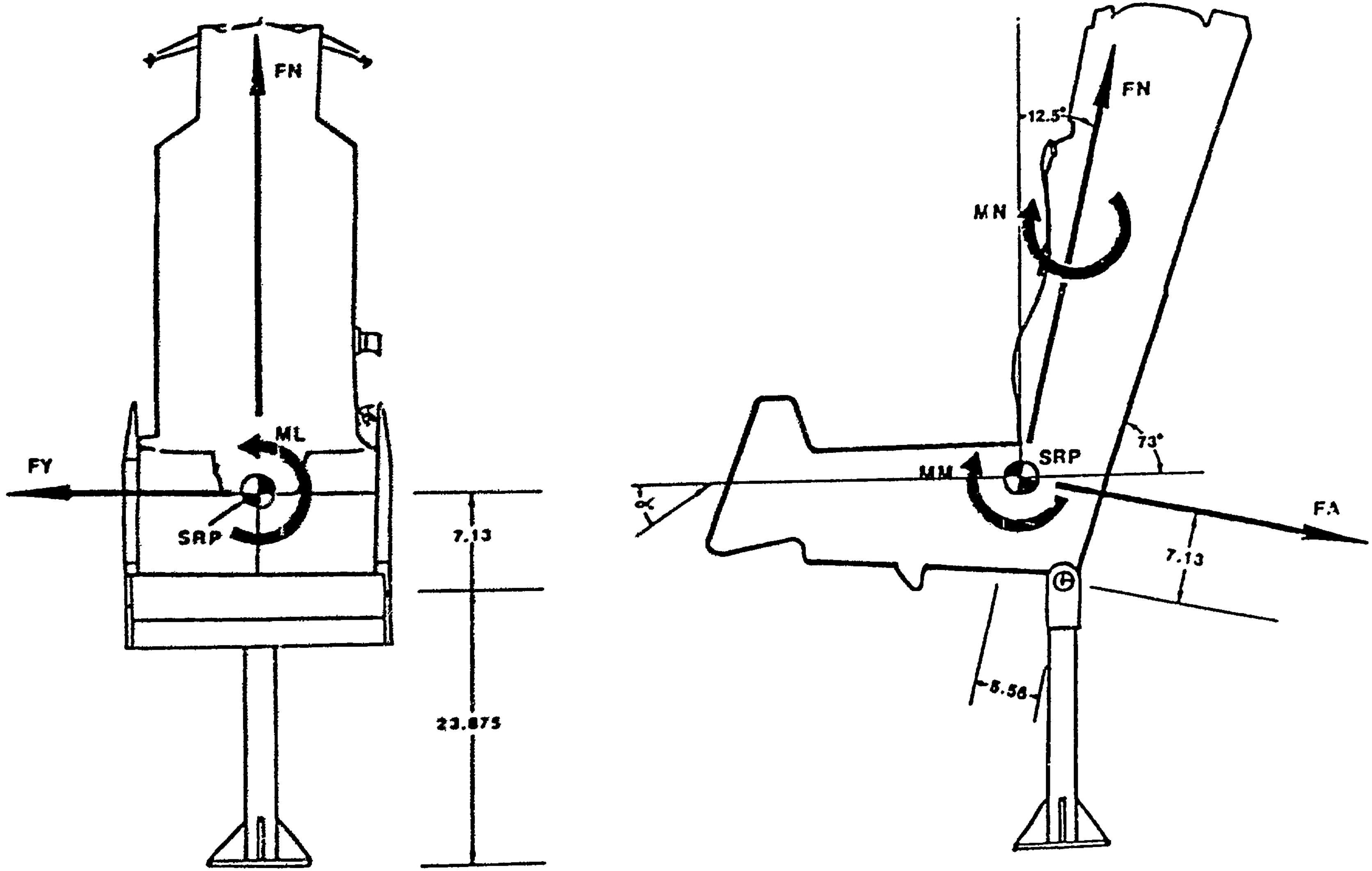
ATTACHMENT 1. RUN SCHEDULE

TEST	HEAD POSITION	HELMET TYPE	HEADBOX	SEAT ALPHA (DEGREES)	SPEED (KEAS)	MANIKIN SIZE
1	SLUMPED	HGU/26P	NORMAL	17	375	95%
2	SLUMPED	HGU/26P	NORMAL	34	375	95%
3	SLUMPED	HGU/26P	POP-OUT	17	375	95%
4	SLUMPED	HGU/26P	POP-OUT	34	375	95%
5	SLUMPED	HONEYWELL	NORMAL	17	375	95%
6	SLUMPED	HONEYWELL	NORMAL	34	375	95%
7	SLUMPED	HONEYWELL	POP-OUT	17	375	95%
8	SLUMPED	HONEYWELL	POP-OUT	34	375	95%
9	SLUMPED	KAISER	NORMAL	17	375	95%
10	SLUMPED	KAISER	NORMAL	34	375	95%
11	SLUMPED	KAISER	POP-OUT	17	375	95%
12	SLUMPED	KAISER	POP-OUT	34	375	95%
13	SLUMPED	GEC	NORMAL	17	375	95%
14	SLUMPED	GEC	NORMAL	34	375	95%
15	SLUMPED	GEC	POP-OUT	17	375	95%
16	SLUMPED	GEC	POP-OUT	34	375	95%
17	NORMAL	HGU/26P	NORMAL	17	375	95%
18	NORMAL	HGU/26P	NORMAL	34	375	95%
19	NORMAL	HGU/26P	POP-OUT	17	375	95%
20	NORMAL	HGU/26P	POP-OUT	34	375	95%
21	NORMAL	HONEYWELL	NORMAL	17	375	95%
22	NORMAL	HONEYWELL	NORMAL	34	375	95%
23	NORMAL	HONEYWELL	POP-OUT	17	375	95%
24	NORMAL	HONEYWELL	POP-OUT	34	375	95%
25	NORMAL	KAISER	NORMAL	17	375	95%
26	NORMAL	KAISER	NORMAL	34	375	95%
27	NORMAL	KAISER	POP-OUT	17	375	95%
28	NORMAL	KAISER	POP-OUT	34	375	95%
29	NORMAL	GEC	NORMAL	17	375	95%
30	NORMAL	GEC	NORMAL	34	375	95%
31	NORMAL	GEC	POP-OUT	17	375	95%
32	NORMAL	GEC	POP-OUT	34	375	95%
33	NORMAL	HGU/26P	NORMAL	17	450	95%
34	NORMAL	HGU/26P	NORMAL	34	450	95%
35	NORMAL	HGU/26P	NORMAL	17	550	95%
36	NORMAL	HGU/26P	NORMAL	34	550	95%
37	NORMAL	HGU/26P	NORMAL	34	600	95%
38	NORMAL	HONEYWELL	NORMAL	17	450	95%
39	NORMAL	HONEYWELL	NORMAL	34	450	95%
40	NORMAL	HONEYWELL	NORMAL	17	550	95%
41	NORMAL	HONEYWELL	NORMAL	34	550	95%
42	NORMAL	HONEYWELL	NORMAL	34	600	95%
43	NORMAL	KAISER	NORMAL	17	450	95%
44	NORMAL	KAISER	NORMAL	34	450	95%
45	NORMAL	KAISER	NORMAL	17	550	95%
46	NORMAL	KAISER	NORMAL	34	550	95%
47	NORMAL	KAISER	NORMAL	34	600	95%
48	NORMAL	GEC	NORMAL	17	450	95%

49	NORMAL	GEC	NORMAL	34	450	95%
50	NORMAL	GEC	NORMAL	17	550	95%
51	NORMAL	GEC	NORMAL	34	550	95%
52	NORMAL	GEC	NORMAL	34	600	95%



Attachment 2. Headbox Mounted Pressure Rake.



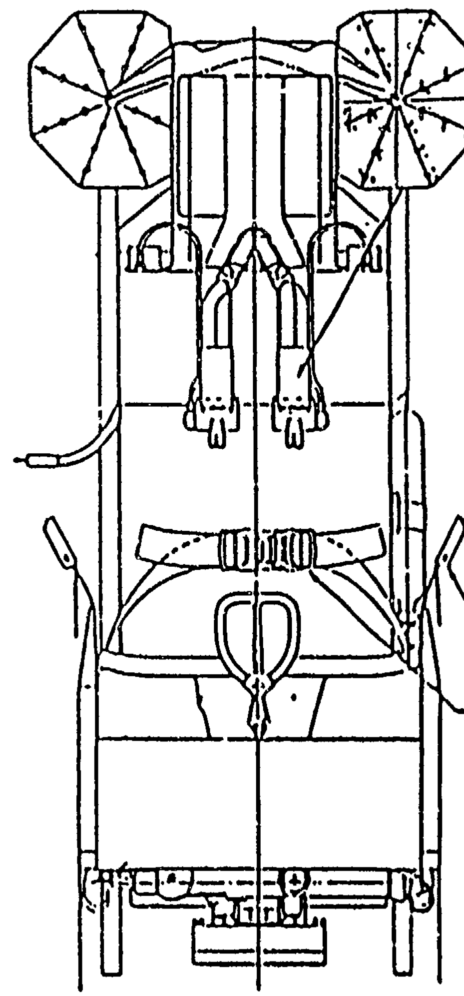
Attachment 3. Seat Body Axis Reference System.

ATTACHMENT 4. WIND BLAST TEST CONDUCTOR CHECKLIST

TEST PROGRAM: I-NIGHTS WINDBLAST TESTS

TEST NUMBER						
DATE						
VELOCITY (KEAS)						
CONFIGURATION						
PRE-TEST PHOTO						
INSPECT FOR DEBRIS						
CLEAR TEST SECTION						
INSTRUMENTATION READY						
FACILITY OPER. READY						
RECORD TIME						
CONDUCT TEST						
POST-TEST PHOTO						

Headbox Mounted Pressure Rakes



Attachment 5.

DEPARTMENT OF THE AIR FORCE
ARMSTRONG LABORATORY (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

REPLY TO ATTN OF: AL/CFBE

22 July 1991

SUBJECT: I-NIGHTS Final Windblast Test Results

TO: AL/CFA (HMST)

1. This letter outlines the results from windblast tests performed for the Helmet Mounted Systems Technology (HMST) Advanced Development Program Office (ADPO) by members of AL/CFBE. The tests were conducted from 4-25 September 1990 at the windblast facility at Dayton T. Brown Inc, Bohemia, NY. The objectives of the test program were to evaluate possible interference between the I-NIGHTS helmet mounted display (HMD) configurations and the ACES II ejection seat pitots, to measure head and neck loads due to aerodynamic loading, and to evaluate the structural integrity of the helmets.

2. This test program consisted of 52 individual windblast exposures divided into two phases. Phase I (Pitot Compatibility) was specifically designed to answer the windblast safety-of-flight issue of I-NIGHTS helmet compatibility with the ACES II ejection seat. The 32 Phase I tests were all conducted at a single test speed, 375 KEAS. In addition, helmet structural integrity and neck loading were investigated during Phase I. Phase II (Structural Integrity) was designed primarily to investigate the effects of higher speed windblasts on the safety-of-flight issues of I-NIGHTS helmet structural integrity and neck loading. Phase II consisted of 20 tests at airspeeds ranging from 450 KEAS to 600 KEAS.

3. This investigation involved the following variables: test helmet, configuration of headbox mounted pitot tubes, attitude of the ejection seat relative to the flow, position of the manikin's head, and windblast velocity.

a. Test Helmet: Four helmets were used in testing; a HGU-26/P baseline helmet and three I-NIGHTS helmets: Honeywell, GEC, and Kaiser. Of the I-NIGHTS helmet configurations, the NVG/HMD configuration had the most area projecting from the helmet. As a result, the NVG/HMD configurations were determined to have more potential for interference with the headbox mounted pitot tubes and subsequently used in this test program. Each of the four NVG/HMD helmets had eight Phase I and five Phase II tests for a total of thirteen tests.

b. Pitot Tubes: In Phase I, the four helmets were tested with the standard, fixed pitot tubes, and new deployable pitot tubes. The deployable pitot tubes measure air pressure at a location approximately 3.06 inches higher and 3.04 inches further out from the headbox centerline than the standard pitot tubes. Figure 1 shows the relative position of the standard and deployable pitot tubes. The deployable pitot tubes are designed to measure pressure outside any wake region caused by helmets or chest mounted survival gear. The pitot tubes were locked in the deployed position for all testing. In Phase II, the standard pitot tubes were used.

c. Seat Attitude: In Phase I and Phase II the helmets were tested with the test ejection seat at two seat angles (Alpha), 17 and 34 degrees. Figure 2 shows a 17 degree seat angle in detail. The seat angles for these tests were chosen to match the seat angles of aircraft expected to be used for flight tests with the I-NIGHTS helmets. In both Phase I and Phase II, the seat was aligned directly into the airflow and the sideslip angle (Beta) was zero degrees.

d. Head Position: During Phase I, two head positions were investigated, a normal upright position and a lower one called the slump position. The normal position was obtained by seating the test manikin on the seat pan and securing the manikin to the seat. The slumped position was obtained by removing the seat pan and seating the manikin lower so that the manikin's head was positioned 2 1/4" below the normal position. In both cases, the head of the manikin was centered in the headrest.

From human subject testing conducted on the ejection tower at NADC, the upward acceleration of the seat during ejection causes the crewmember's spine to compress approximately 1.75". The neck compression contributes 0.25" of slump, and there is 0.75" due to seat cushion compression. In addition, there is a 0.5" rise in the manikin due to windblast lift even though the manikin is secured by slump cables (1).

During phase II tests, with the focus on structural integrity and head loading, only the normal head position was tested.

e. Test Speed: The windblast speed for all tests in Phase I was 375 KEAS. The focus of Phase I was to measure the pressures at the pitot tubes and seat during a windblast exposure and determine, through analysis of the pressure data, if there was interference of the pitot tubes by the helmet configurations. The speed of the windblast exposures had to be great enough to produce sufficient pressure for a Mode 2 selection if no helmet interference was present. The crossover speed from Mode 1 to Mode 2 at sea level can occur anywhere from 265 KEAS to 320 KEAS, due to variability in the environmental sensor response. To provide sufficient pressure for Mode 2 selection when no helmet interference was present, the windblast velocity at the plane of the headbox mounted pitot tubes must be at least 320 KEAS.

The test velocity was measured approximately five feet before the headbox mounted pitot tubes at the main pressure rake. Through analysis, it was determined that the air flow decelerates 20 - 30 KEAS from the main pressure rake to the pitot tubes. Due to variability in test conditions, the windblast measured at the main rake was 375 KEAS to ensure at least 320 KEAS at the pitot tubes.

In Phase II, the windblast test speeds increased to test the structural integrity of the helmets and measure head forces and moments at high speeds. The speeds tested were: 450 KEAS, 550 KEAS, and 600 KEAS. The maximum test speed, 600 KEAS, corresponds to the maximum rating of the ACES II ejection seat.

f. Windblast Duration: The duration of the windblast exposure in Phase I was approximately 1 second. This is a sufficient length of time since the ACES II ejection seat locks into the mode of operation well before one second has elapsed after the initiation of the escape sequence.

The duration of the windblast exposure in Phase II was approximately 3 seconds. The structural integrity tests continued until air pressure in the reservoir tanks was depleted. The speed of the air during the windblast exposures was not constant, but decayed as the reservoir tanks emptied. Figure 3 shows a plot of the windblast pressure versus time.

3. Methods of Analysis: The three objectives of the test program were to evaluate possible interference between the I-NIGHTS helmet mounted display (HMD) configurations and the ACES II ejection seat pitots, to measure head and neck loads due to aerodynamic loading, and to evaluate the structural integrity of the helmets. The following describes the method of analysis for each of the objectives.

a. Pitot Interference: The criteria used for the evaluation of helmet interference with ACES II ejection seat pitot tubes were obtained from the Douglas Aircraft Company mode changeover envelope specification. ACES II pitot interference from the I-NIGHTS helmets was evaluated by comparing the length of time pressure conditions existed for the seat to make a Mode 2 selection to the mode changeover envelope specification. Figure 4 shows the mode changeover envelope for the ACES II ejection seat. As shown in Figure 4, there are several switch actuation lines to use for analysis. This is the result of variability in the operation of the environmental sensor under high accelerations or changing pressure conditions. This analysis was completed using two lines; the nominal switch actuation line crossing the abscissa at 4.75 inches mercury and a more conservative tolerance line to the right of the nominal line and crossing the abscissa at 5.20 inches mercury. The line to the right of the nominal switch actuation line completely envelops the region where the switch could be in either position. The line is more conservative because, for a given seat base pressure, a higher pitot pressure is required to obtain Mode 2 than with the nominal switch actuation line.

As the ACES II ejection seat emerges from the aircraft cockpit and enters the airflow, the two ACES II pitot tubes direct the total pressure of the airflow to the environmental sensor located behind the seat. The environmental sensor contains metallic bellows which expand and contract due to the total pressure from the ACES II pitot tubes and the base pressure measured behind the seat. During the mode 2 conditions, the environmental sensor sends an electrical signal to the recovery sequencer which charges a capacitor. The recovery sequencer receives signals from the environmental sensor for a 37 millisecond (ms) period, after which time the ejection mode is locked. The capacitor has a charge time of 12 +/- 4 ms. When the capacitor is completely charged, the recovery sequencer becomes locked into mode 2 operation. Since all capacitors have a tendency to decay with time, the analysis was conducted by examining if the environmental sensor showed at least 8 ms of continuous mode 2 conditions.

Since the test seat was equipped with two environmental sensors (one for each pitot tube), the analysis could have been done by only examining the position of the environmental sensor switches to check for Mode 2 conditions for at least 8 ms. However, if this method of analysis was used, the operation of the environmental sensor switch would have been included in the evaluation. To prevent including the operation of the environmental sensor in the evaluation of the helmets, the analysis was completed by examining the pressure inputs to the environmental sensor and using ejection seat operating specifications to determine the duration of mode 2 conditions.

Digital data from the pitot and seat base pressure channels filtered at 100 Hz were used to calculate which mode of operation the environmental sensor would indicate as per the Douglas Aircraft Company mode changeover envelope specification shown in Figure 4. Each pair of pitot and static pressure data points was independently used to determine if Mode 2 condition existed during each half millisecond (the digital sampling rate). A 37 ms time window was scrolled through the data to determine the maximum continuous mode 2 time which existed within the window. A helmet failed a given test if the pressures from either pitot tube and the seat base pressure port indicated less than 8 ms of continuous Mode 2 conditions. The program used to compare test data to the criteria is included in Appendix B. Figure 5 is a plot of the right pitot tube pressure during a 375 KEAS test with interference (test 8, fixed pitot) and without helmet interference (test 9, deployable pitot).

b. Head Loading: A modification was made to the 95th percentile VIP manikin neck to use a Denton model 1716 six degree-of-freedom load cell. A mounting bracket to ensure consistent head placement was secured around the manikin neck below the Denton load cell (figure 6). A bracket attached to the head rest was used for distinct placements of the neck brace for both the standard seated position and the slumped position 2-1/4" lower.

Head forces and moments were evaluated by comparison between the I-NIGHTS helmet configurations and the baseline helmet. The helmets were compared between tests with the same conditions. The conditions included the type of pitot tube on the headbox, the seat angle, the manikin's head position, and the test speed. The peak loads were taken from the 100 Hz digitally filtered data for each test.

c. Structural Integrity: The helmets were closely examined for any damage after each test. Any signs of damage were noted and repaired before the next test.

4. RESULTS:

a. Pitot Interference: Table 1 summarizes the maximum continuous time the environmental sensor would have indicated mode II for each pitot tube and for either pitot tube for the nominal and conservative analysis. Any time less than 8 msec for the left or right pitot would indicate a pitot compatibility failure. There were five pitot compatibility failures for the nominal analysis and seven failures for the conservative analysis. All pitot compatibility failures occurred with the normal, fixed pitot headbox. The failures are summarized below.

1. Test #3, slumped, fixed pitots, 34 degrees, Honeywell helmet failed both nominal and conservative analysis.

2. Tests #7 & 8, slumped, fixed pitots, 17 & 34 degrees, GEC helmet failed both nominal and conservative analysis.

3. Test #25, normal seated position, fixed pitots, 17 degrees, GEC helmet failed for conservative analysis.

4. Test #26, normal seated position, fixed pitots, 34 degrees, GEC helmet failed both nominal and conservative analysis.

5. Test #29, normal seated position, fixed pitots, 17 degrees, Honeywell helmet failed both nominal and conservative analysis.

6. Test #30, normal seated position, fixed pitots, 34 degrees, Honeywell helmet failed the conservative analysis.

b. Head Loading: Since criteria for head/neck injury are currently under development, a comparison of head loads was made between the HGU-26/P helmet and the I-NIGHTS helmets. In general, the I-NIGHTS helmets produced larger neck loads than the HGU-26/P helmet. An exception to this generalization can be seen in the higher side forces for the 34 degree 550 and 600 KEAS tests of the HGU-26/P. Test #50 (GEC helmet at 550 KEAS) showed an extremely large side force. This large force was caused by a structural failure of the helmet (see below). The maximum head lifting force, side force, and pitching moment (for tests with no structural failure) were all seen in test #47 involving the Kaiser helmet at a speed of 600 KEAS at a 34 degree seat angle. The head lifting force was 458 pounds whereas the HGU-26/P helmet showed a force of 290 pounds for the same test conditions. The maximum side force was 106 pounds, with the HGU-26/P helmet showing a side force of 91 pounds for the same test conditions. The maximum pitching moment was 1480 in*lbs compared to 1400 in*lbs for the HGU-26/P helmet.

c. Structural Integrity: Four of the tests resulted in structural failure of the helmet.

1. Test #37, HGU-26/P helmet, 600 KEAS. The left side of the visor broke off and was carried down range.

2. Test #40, Honeywell helmet, 550 KEAS. Both display module covers were damaged. The left cover completely broke off the helmet and was carried down range. The right cover broke in two pieces; the pieces were retained by the seat rake.

3. Test #41, Honeywell helmet, 550 KEAS. The left display module cover broke off the helmet and was carried down range.

4. Test #50, GEC helmet, 550 KEAS. The lower screw pulled through the right display module cover. Examination of the head/neck load data shows unusually large side force and large pitching and yawing moments

due to the structural failure. This area was repaired with epoxy. A larger washer was used on both sides to prevent a similar failure on future tests.

5. Conclusions/Recommendations:

a. Pitot Compatibility: Although five tests indicated pitot-compatibility failures for the nominal analysis and eight tests resulted in pitot compatibility failures for the conservative analysis, there were no failures on the tests which were conducted with the deployable pitot tubes. Therefore, any inflight testing should be conduced with the deployable pitot tube headbox on the ACES II seats.

b. Head/Neck Loading: While there are no defined injury level thresholds for neck injury, several suggested criteria exist. The HGU-53/P helmet chin strap has a specification to be able to withstand 250 pounds of lifting force. The CREST criteria for head lift is 300 pounds. The greatest disparity between the head/neck loads measured on the HGU-26/P helmet and the I-NIGHTS helmets was in the lifting force (figure 7). All three I-NIGHTS helmets exceeded 400 pounds of lift during the testing. The Kaiser helmet, the worst case, showed a 57 percent increase in lift. The CREST specification for side force, Fy, is 50 pounds. The Kaiser helmet was again the worst case (figure 8) showing 106 pounds, a 16 percent increase over the HGU-26/P. The largest head pitching moment (figure 9), a 5.7% increase over the HGU-26/P, was again seen on the Kaiser helmet. The 1480 in*lb pitching moment measured during a test of the Kaiser helmet is still below cadaver tests which showed no injuries with a 1700 in*lb pitching moment. In general, the head loads begin exceeding the preliminary injury criteria around speeds of 450 KEAS. Therefore, if the pilot has to eject while wearing an I-NIGHTS helmet, he should take appropriate measures to decrease airspeed if possible (which is standard procedure). Ejecting with any helmet over 450 KEAS has potential of injury not just to the neck, but also to the limbs and spine.

c. Structural Integrity: The structural failure which had the most serious potential for injury was test #50 of the GEC helmet at 550 KEAS, 17 degree angle of attack. The side force measured was 175 pounds and the pitching moment was 1500 in*lbs, which are much greater than any of the other tests. All helmets should be examined for potential of similar failures. The GEC and other helmets which may fail and cause injury should be reinforced prior to any inflight tests.

6. References:

1. ACES II Wind Blast Testing History, Requirements Rational & Set Up Procedures. Andries, Martin. September 1990.

John A. Plaga

JOHN A. PLAGA
Escape and Impact Protection Branch
Biodynamics & Biocommunications Division

TABLE 1

TEST	HELMET	HEAD POSITION	HEADBOX	SEAT ALPHA (DEGREES)	SPEED (KEAS)	Fx (LBS) MIN	Fx (LBS) MAX	Fy (LBS) MIN	Fy (LBS) MAX	Fz (LBS) MIN	Fz (LBS) MAX	Mx (FT LBS) MIN	Mx (FT LBS) MAX	My (FT LBS) MIN	My (FT LBS) MAX	Mz (FT LBS) MIN	Mz (FT LBS) MAX	NOMINAL LEFT	NOMINAL RIGHT	NOMINAL L OR R	CONSERVATIVE LEFT	CONSERVATIVE RIGHT	CONSERVATIVE L OR R
						NECK LOADS												MODE SWITCH TIME (msec)					
1	HGU/26P	SLUMPED	NORMAL	17	375	-16.40	151.7	-53.05	17.26	-4.02	115.0	-2.68	11.62	-36.00	2.859	-2.124	8.157	37	37	37	37	19	37
2	HGU/26P	SLUMPED	NORMAL	34	375	-18.41	167.1	-38.66	35.05	-1.29	105.2	-4.84	11.40	-41.95	2.368	-2.208	7.682	28	37	37	23	24	37
3	HONEYWELL	SLUMPED	NORMAL	34	375	-18.33	196.2	-43.55	42.05	-7.75	159.3	-4.81	10.49	-39.89	1.982	-4.803	8.119	6	9	12	2	7	7
4	HONEYWELL	SLUMPED	NORMAL	17	375	-13.29	205.0	-38.65	39.25	-4.32	125.3	-4.87	11.12	-50.79	1.633	-3.916	7.652	15	3	17	12	0	12
5	KAISER	SLUMPED	NORMAL	17	375	-23.75	201.7	-13.48	73.36	-5.13	122.2	-8.79	8.16	-73.79	3.825	-1.207	10.949	37	8	37	20	6	23
6	KAISER	SLUMPED	NORMAL	34	375	-18.24	244.6	-15.75	58.44	-3.68	168.9	-6.85	10.12	-87.43	2.368	-1.246	8.620	37	14	37	22	11	37
7	GZC	SLUMPED	NORMAL	34	375	-16.80	251.2	-12.37	48.25	-4.54	155.4	-4.29	10.26	-75.68	2.086	-1.791	8.152	7	0	7	6	0	6
8	GZC	SLUMPED	NORMAL	17	375	-34.43	202.3	-26.27	50.59	-5.10	132.7	-7.16	12.07	-59.01	8.406	-3.313	8.656	0	0	0	0	0	0
9	GZC	SLUMPED	DEPLOYABLE	17	375	-22.11	213.2	-18.26	58.22	-4.11	142.5	-6.81	9.60	-65.28	3.234	-2.934	9.225	27	9	27	20	7	20
10	GZC	SLUMPED	DEPLOYABLE	34	375	-20.26	239.7	-13.55	66.50	-3.42	156.8	-7.27	8.04	-75.70	2.214	-1.050	8.138	37	16	37	37	12	37
11	KAISER	SLUMPED	DEPLOYABLE	34	375	-26.14	286.2	-22.49	55.98	-10.24	177.7	-4.74	11.30	-99.39	3.809	-1.271	7.413	37	24	37	29	5	29
12	KAISER	SLUMPED	DEPLOYABLE	17	375	-23.68	243.9	-19.24	72.10	-4.76	134.6	-7.88	7.00	-86.29	4.287	-3.911	6.969	29	10	29	15	8	15
13	HONEYWELL	SLUMPED	DEPLOYABLE	17	375	-36.60	216.0	-42.47	45.51	-12.11	126.5	-5.35	12.24	-52.70	6.428	-4.891	11.937	31	6	32	28	4	28
14	HONEYWELL	SLUMPED	DEPLOYABLE	34	375	-23.67	193.1	-32.23	39.04	-7.53	168.6	-2.49	11.59	-49.37	3.506	-4.258	7.764	37	13	37	37	5	37
15	HGU/26P	SLUMPED	DEPLOYABLE	34	375	-24.35	125.9	-30.32	27.08	-8.57	101.2	-3.83	9.75	-28.69	3.585	-3.406	11.162	37	22	37	27	9	33
16	HGU/26P	SLUMPED	DEPLOYABLE	17	375	-20.95	164.9	-23.37	36.29	-6.54	141.6	-4.72	8.06	-42.57	3.469	-1.218	9.524	37	12	37	18	10	18
17	HGU/26P	NORMAL	DEPLOYABLE	17	375	-17.01	161.7	-33.70	37.02	-2.67	140.9	-5.82	8.29	-40.60	2.195	-2.812	11.151	37	9	37	37	7	37
18	HGU/26P	NORMAL	DEPLOYABLE	34	375	-17.01	101.6	-27.11	48.96	-2.18	107.1	-6.72	9.94	-25.20	2.984	-1.819	8.646	37	22	37	21	10	21
19	HONEYWELL	NORMAL	DEPLOYABLE	34	375	-29.62	184.8	-31.01	41.11	-6.45	160.0	-4.03	7.76	-45.72	5.204	-4.147	6.305	37	18	37	36	7	37
20	HONEYWELL	NORMAL	DEPLOYABLE	17	375	-15.95	226.7	-42.39	41.00	-4.97	134.0	-2.74	11.26	-57.93	1.628	-3.916	6.733	37	7	37	17	0	17
21	KAISER	NORMAL	DEPLOYABLE	17	375	-22.34	235.2	-17.64	87.42	-3.36	169.8	-7.75	8.90	-77.58	3.847	-1.644	11.978	37	13	37	37	10	37
22	KAISER	NORMAL	DEPLOYABLE	34	375	-24.12	217.1	-16.52	57.67	-3.35	182.7	-3.83	8.96	-81.01	6.092	-4.770	8.455	37	24	37	37	10	37
23	GZC	NORMAL	DEPLOYABLE	34	375	-29.97	169.9	-18.84	44.52	-3.03	202.3	-3.45	8.67	-62.47	5.084	-2.825	4.178	37	12	37	37	8	37
24	GZC	NORMAL	DEPLOYABLE	17	375	-22.14	152.8	-25.63	42.10	-3.06	189.6	-2.26	10.34	-48.78	3.777	-3.860	5.021	37	17	37	37	8	37
25	GZC	NORMAL	NORMAL	17	375	-26.23	170.8	-26.76	49.34	-3.08	185.4	-4.89	9.27	-54.98	3.581	-2.913	10.118	13	10	13	10	5	10
26	GZC	NORMAL	NORMAL	34	375	-30.51	162.5	-19.96	38.79	-4.49	165.1	-5.78	9.72	-59.47	5.351	-3.665	5.969	10	10	11	9	8	10
27	KAISER	NORMAL	NORMAL	34	375	-33.67	228.8	-28.19	63.26	-2.21	217.0	-10.07	11.88	-86.09	7.145	-3.322	5.047	14	17	37	13	8	14

TABLE 1 (Cont)

TEST	HELMET	HEAD POSITION	HEADBOX	SEAT ALPHA (DEGREES)	SPEED (KEAS)	NECK LOADS Fx (LBS) MIN	Fx (LBS) MAX	Fy (LBS) MIN	Fy (LBS) MAX	Fz (LBS) MIN	Fz (LBS) MAX	Mx (FT LBS) MIN	Mx (FT LBS) MAX	My (FT LBS) MIN	My (FT LBS) MAX	Mz (FT LBS) MIN	Mz (FT LBS) MAX	MODE SWITCH TIME (msec) NORMAL LEFT	NORMAL RIGHT	NORMAL L OR R	CONSERVATIVE LEFT	CONSERVATIVE RIGHT	CONSERVATIVE L OR R
28	KAISER	NORMAL	NORMAL	17	375	-24.47	200.8	-13.10	86.20	-2.97	180.3	-10.29	8.95	-78.50	3.530	-2.541	8.891	37	12	37	37	5	37
29	HONEYWELL	NORMAL	NORMAL	17	375	-20.83	252.3	-29.99	46.57	-5.39	203.7	-4.57	9.56	-78.17	2.616	-3.112	10.739	12	2	12	10	0	10
30	HONEYWELL	NORMAL	NORMAL	34	375	-28.46	181.7	-33.55	44.12	-6.99	145.1	-2.40	9.53	-39.94	3.560	-4.254	7.829	7	17	17	6	9	9
31	HGU/26P	NORMAL	NORMAL	34	375	-21.32	147.7	-27.45	30.22	-1.65	135.2	-4.66	10.20	-36.64	3.531	-1.896	7.862	7	37	37	4	21	21
32	HGU/26P	NORMAL	NORMAL	17	375	-19.23	154.0	-30.16	32.07	-3.63	143.2	-4.33	8.90	-33.08	3.508	-1.762	12.857	37	37	37	30	18	37
33	HGU/26P	NORMAL	NORMAL	17	450	-8.06	180.4	-18.82	46.56	-2.37	196.9	-6.55	12.35	-46.16	0.226	-4.080	12.623	37	37	37	37	37	37
34	HGU/26P	NORMAL	NORMAL	34	450	-4.73	102.4	-25.60	46.18	-1.98	191.2	-7.24	15.59	-47.65	4.137	-2.300	9.994	9	37	37	7	37	37
35	HGU/26P	NORMAL	NORMAL	34	550	-10.88	189.0	-19.31	97.49	-13.83	253.3	-16.39	15.48	-95.80	3.057	-0.8185	16.097	37	37	37	37	37	37
36	HGU/26P	NORMAL	NORMAL	17	550	-4.86	155.7	-45.12	84.91	-1.75	310.5	-15.10	16.60	-69.81	0.219	-5.797	16.359	37	37	37	37	37	37
37	HGU/26P	NORMAL	NORMAL	34	600	-9.24	180.5	-54.99	90.79	-2.17	289.7	-11.09	21.72	-97.11	5.076	-6.688	26.552	37	37	37	37	37	37
38	HONEYWELL	NORMAL	NORMAL	34	450	-6.72	171.3	-33.21	50.64	-2.00	240.7	-5.03	10.15	-75.26	0.215	-5.494	9.6978	33	24	37	12	15	37
39	HONEYWELL	NORMAL	NORMAL	17	450	-7.24	172.0	-55.22	32.27	-6.47	249.1	-3.35	15.88	-80.96	0.215	-5.081	9.9086	17	5	18	13	4	13
40	HONEYWELL	NORMAL	NORMAL	17	550	-5.32	203.7	-39.80	57.53	-1.60	371.9	-4.50	12.43	-92.92	0.187	-8.554	12.335	13	16	18	11	14	17
41	HONEYWELL	NORMAL	NORMAL	34	550	-6.86	164.5	-36.98	47.66	-4.99	408.7	-6.28	12.54	-82.55	5.593	-8.541	8.1134	37	35	37	37	18	37
42	HONEYWELL	NORMAL	NORMAL	34	600	-7.98	215.1	-55.48	62.20	-5.84	369.4	-6.79	15.68	-97.26	1.698	-9.245	11.198	37	37	37	37	37	37
43	KAISER	NORMAL	NORMAL	34	450	-4.27	114.6	-66.47	41.32	-1.65	261.1	-5.45	19.11	-76.77	0.178	-11.72	8.0302	19	37	37	17	37	37
44	KAISER	NORMAL	NORMAL	17	450	-7.19	141.7	-37.87	39.94	-0.78	284.2	-4.06	15.66	-97.19	0.152	-7.075	10.447	37	37	37	37	37	37
45	KAISER	NORMAL	NORMAL	17	550	-27.63	160.1	-12.55	83.04	-1.10	403.6	-9.83	5.05	-114.50	0.134	-3.754	11.812	37	37	37	37	37	37
46	KAISER	NORMAL	NORMAL	34	550	-8.61	174.8	-17.29	81.70	-4.93	372.7	-10.78	11.18	-99.77	1.439	-3.374	14.665	37	37	37	37	37	37
47	KAISER	NORMAL	NORMAL	34	600	-8.16	194.2	-6.32	106.00	-2.66	458.1	-14.18	7.80	-123.40	2.088	-3.977	15.774	37	37	37	37	37	37
48	GEC	NORMAL	NORMAL	34	450	-7.75	109.9	-10.97	54.77	-1.12	249.1	-5.84	11.67	-59.47	0.488	-0.539	9.7489	37	37	37	37	25	37
49	GEC	NORMAL	NORMAL	17	450	-11.95	120.2	-1.79	63.78	-0.88	289.8	-9.29	4.97	-72.73	0.077	-3.379	10.166	15	20	37	9	15	16
50	GEC	NORMAL	NORMAL	17	550	-11.89	195.2	-4.36	175.43	-1.03	413.4	-32.66	4.68	-125.10	0.048	-1.446	20.688	37	37	37	37	37	37
51	GEC	NORMAL	NORMAL	34	550	-5.55	175.1	-9.58	88.30	-0.76	371.2	-14.72	6.71	-93.98	3.066	-2.458	8.816	37	23	37	37	18	37
52	GEC	NORMAL	NORMAL	34	600	-12.39	218.2	-15.36	80.59	-10.78	449.5	-12.33	7.65	-116.70	4.137	-3.407	9.7822	37	37	37	37	37	37

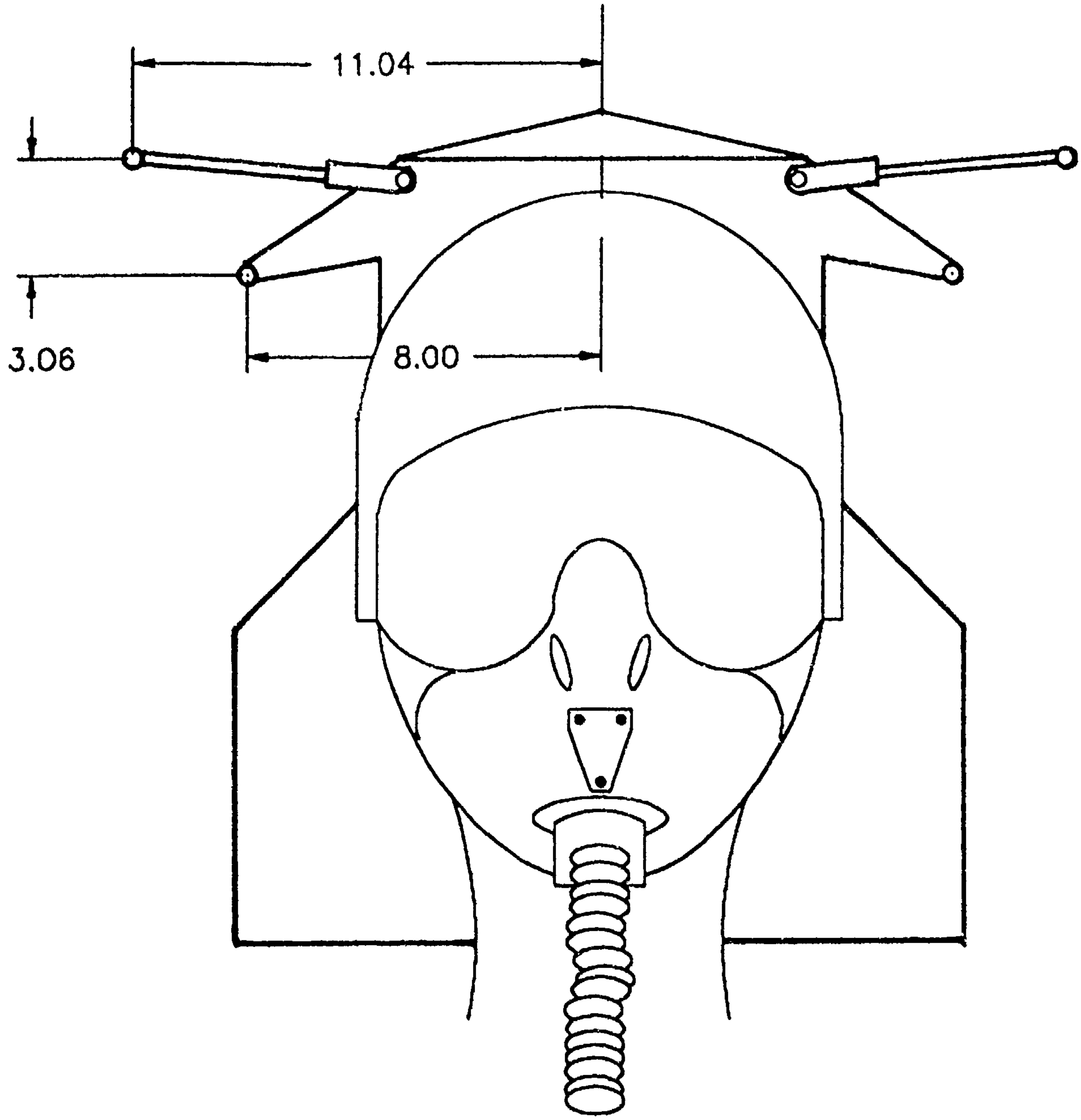


FIGURE 1
PITOT POSITONS

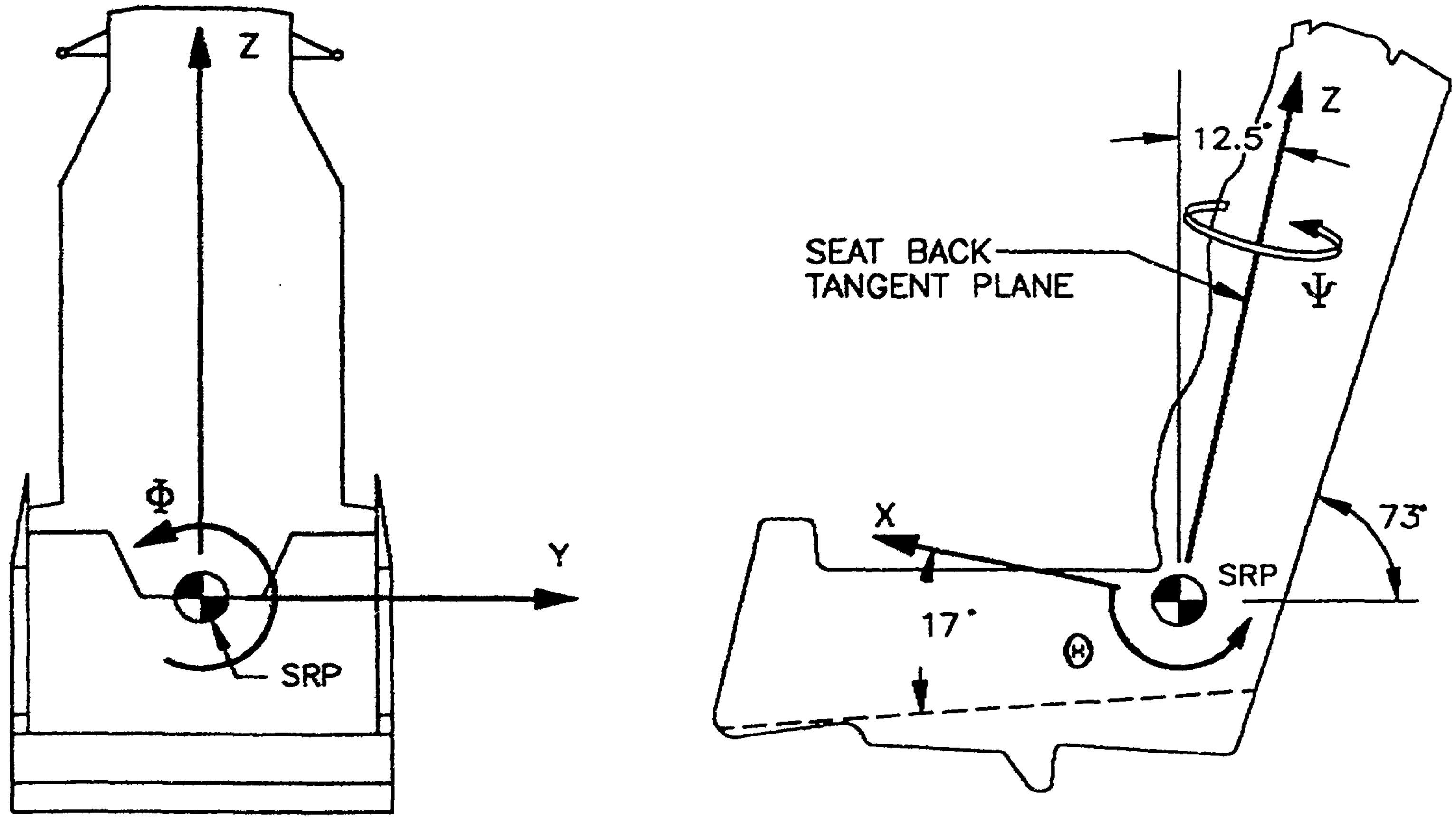


FIGURE 2
SEAT ATTITUDE

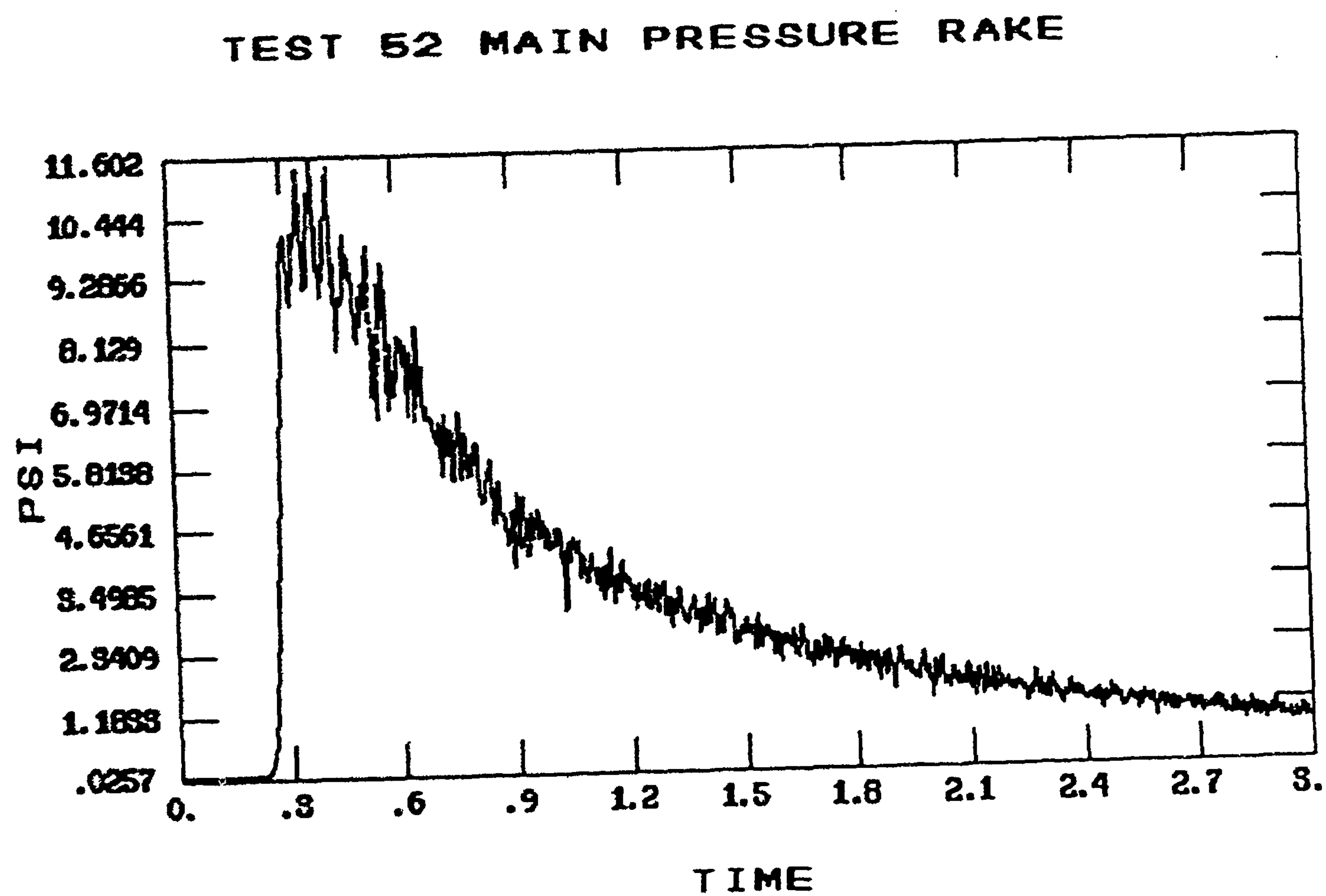
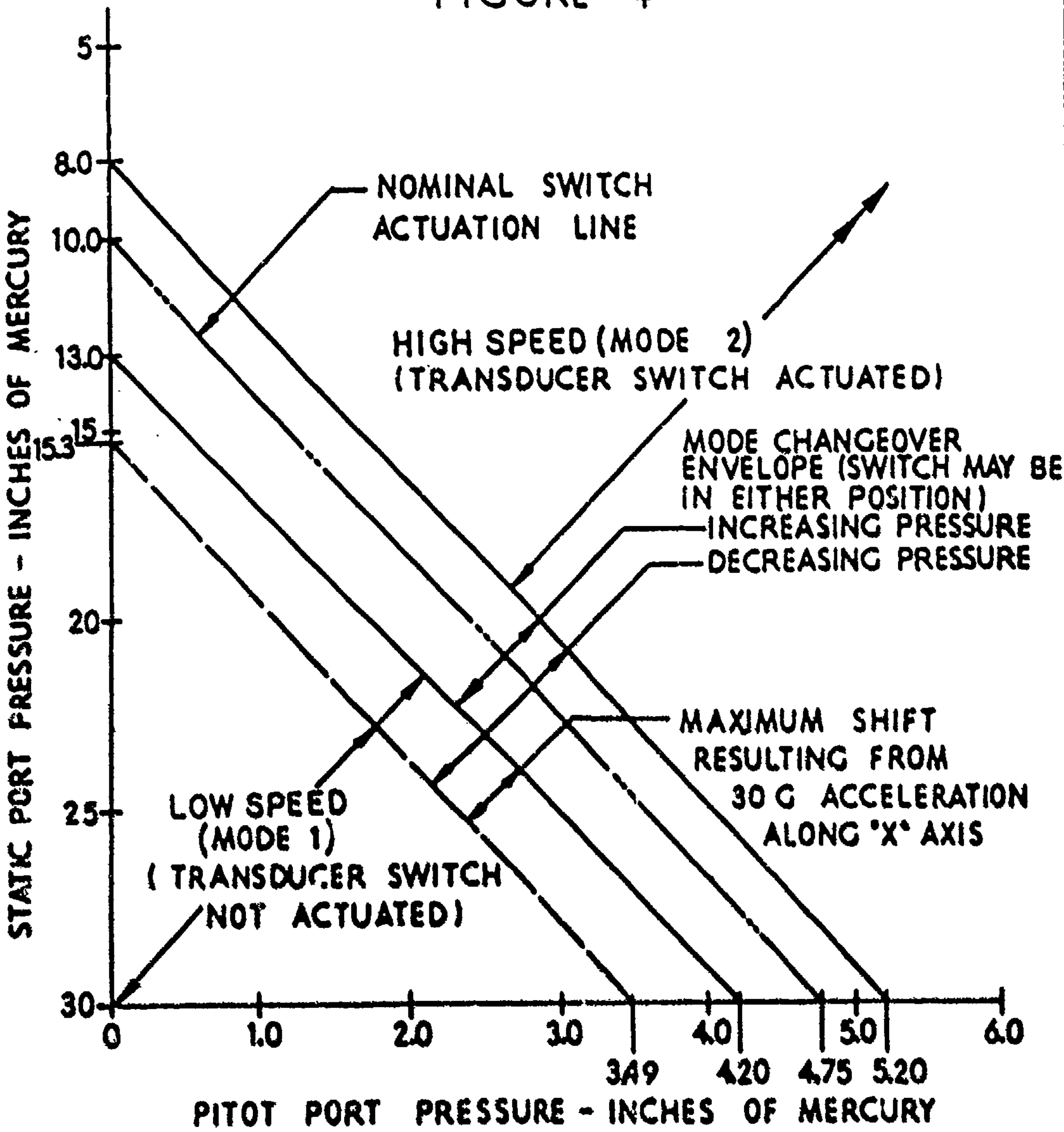


FIGURE 3
Windblast Pressure vs. Time

FORM XA60-13A2 (1-68)

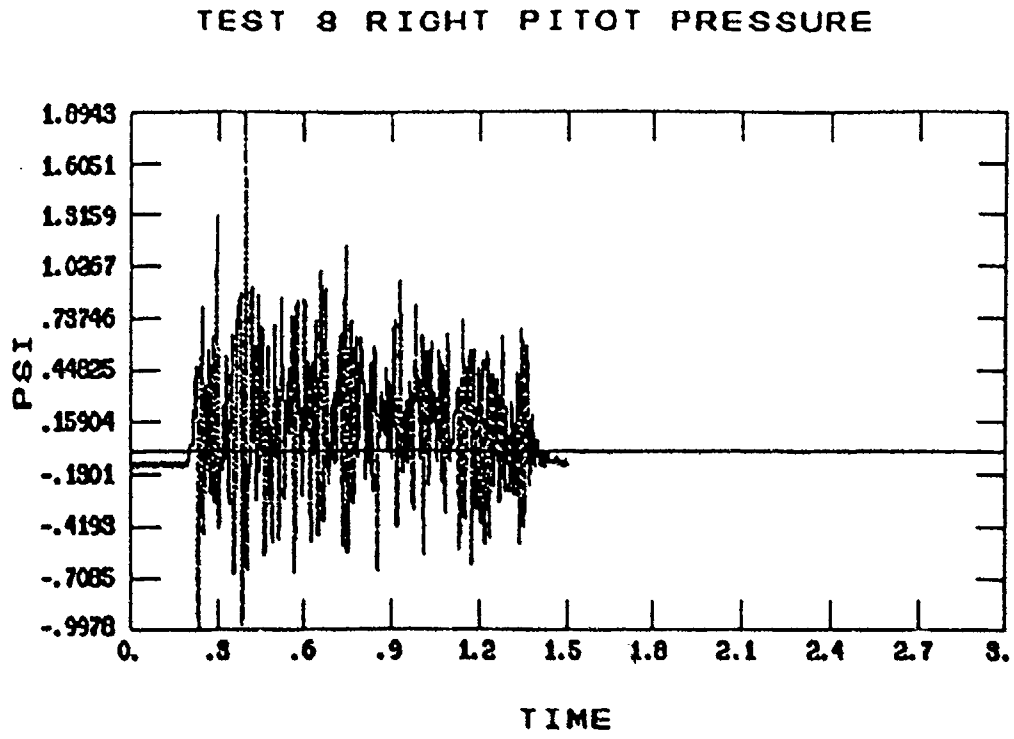
2.036 in Hg / PSI

FIGURE 4



PRESSURE TRANSDUCER OPERATION-
MODE CHANGEOVER ENVELOPE

DOUGLAS	SIZE A	CODE IDENT NO. 88277	A114310
			REV LTR 2 — SHEET 31


TEST 8 RIGHT PITOT PRESSURE
1.8943
1.6051
1.3159
1.0267
.73746
.44825
.15904
-.1301
-.4193
-.7085
-.9978
PSI
0.
.3
.6
.9
1.2
1.5
1.8
2.1
2.4
2.7
3.
TIME

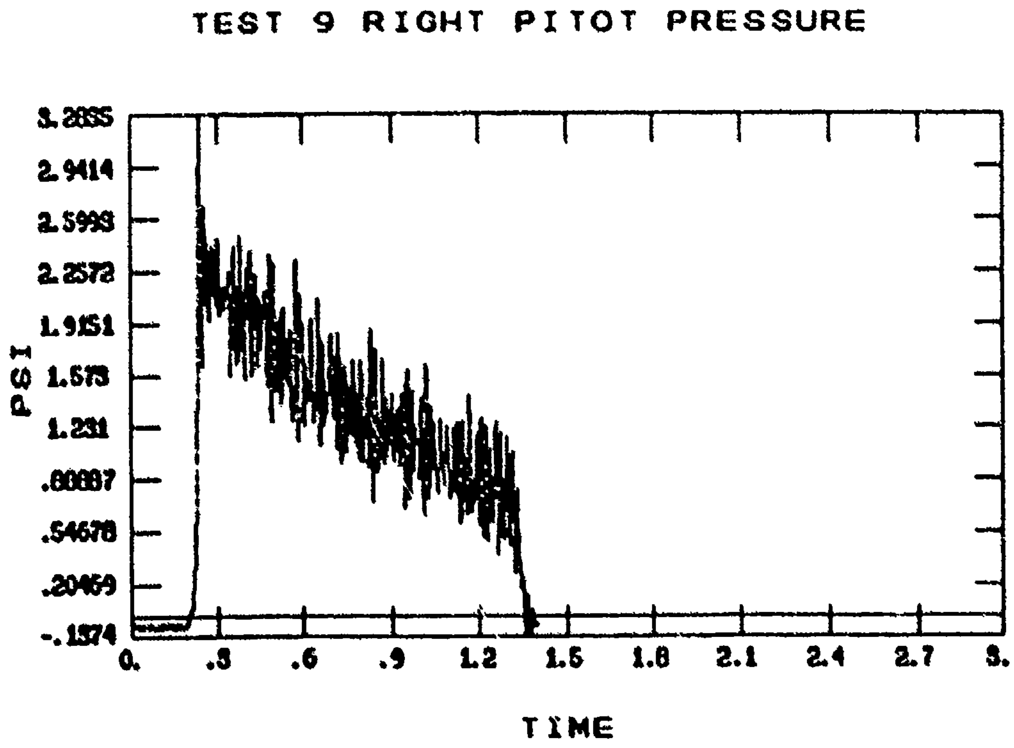

TEST 9 RIGHT PITOT PRESSURE
3.2835
2.9414
2.5993
2.2572
1.9151
1.573
1.231
.88887
.54678
.20469
-.1374
PSI
0.
.3
.6
.9
1.2
1.5
1.8
2.1
2.4
2.7
3.
TIME

FIGURE 5

FIGURE 6
NECK LOAD CELL

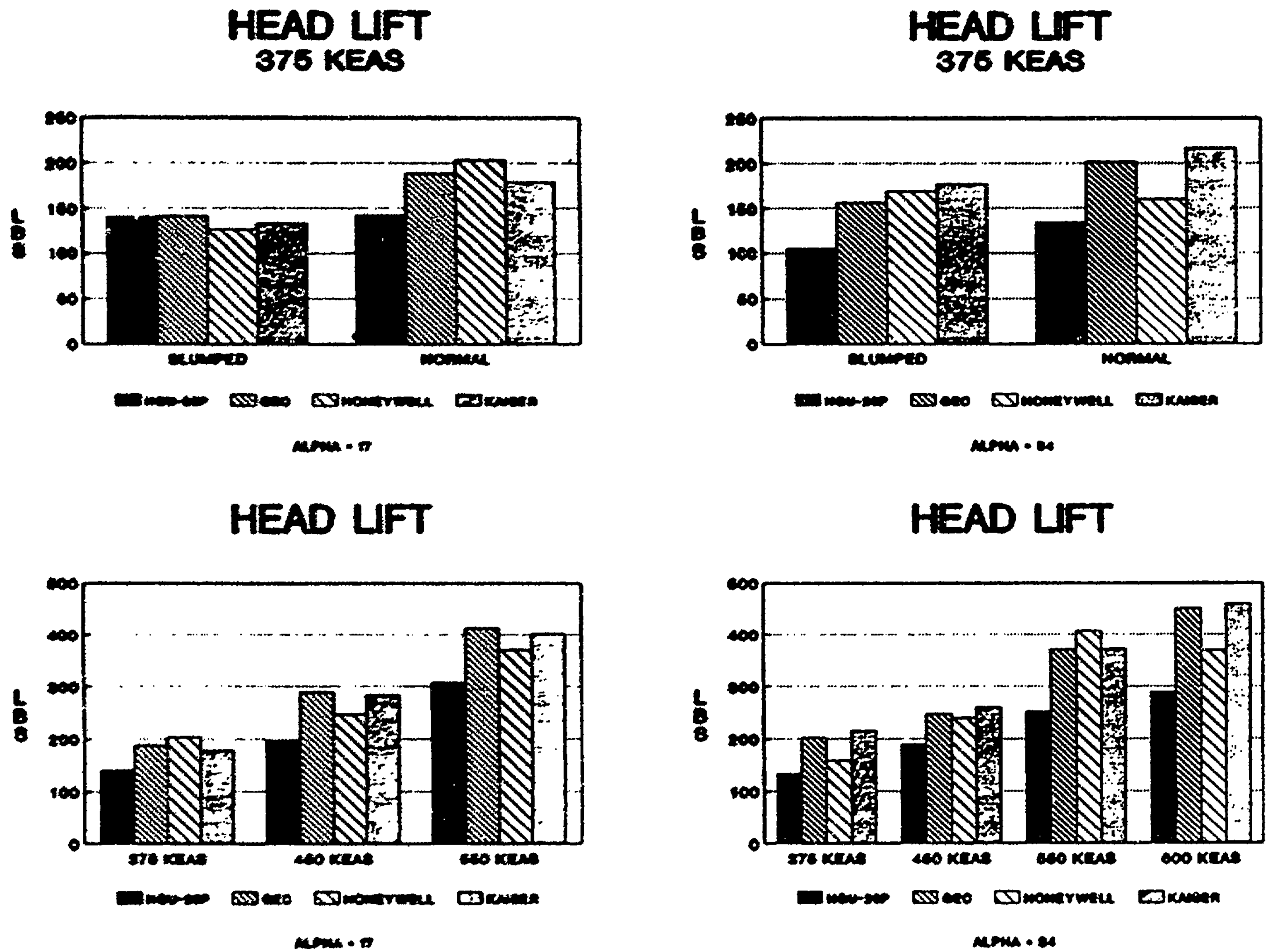

HEAD LIFT
375 KEAS
LBS
SLUMPED
NORMAL
GEC
HONEYWELL
KAISER
ALPHA = 17
HEAD LIFT
375 KEAS
LBS
SLUMPED
NORMAL
GEC
HONEYWELL
KAISER
ALPHA = 34
HEAD LIFT
LBS
375 KEAS
450 KEAS
550 KEAS
GEC
HONEYWELL
KAISER
ALPHA = 17
HEAD LIFT
LBS
375 KEAS
450 KEAS
550 KEAS
600 KEAS
GEC
HONEYWELL
KAISER
ALPHA = 34

FIGURE 7

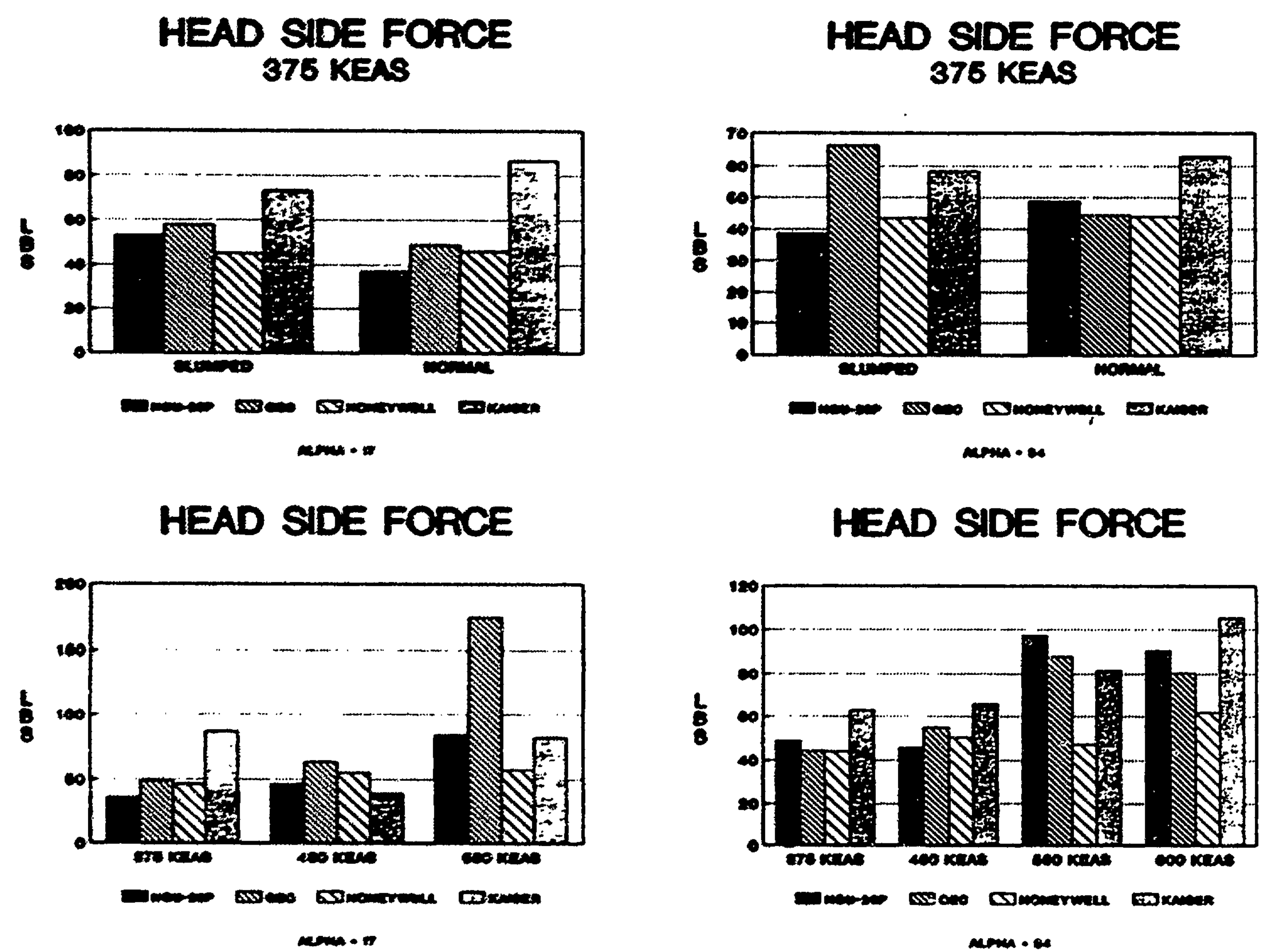

HEAD SIDE FORCE
375 KEAS
SLUMPED
NORMAL
HONEYWELL
KAISER
HEAD SIDE FORCE
375 KEAS
SLUMPED
NORMAL
HONEYWELL
KAISER
HEAD SIDE FORCE
HEAD SIDE FORCE

FIGURE 8

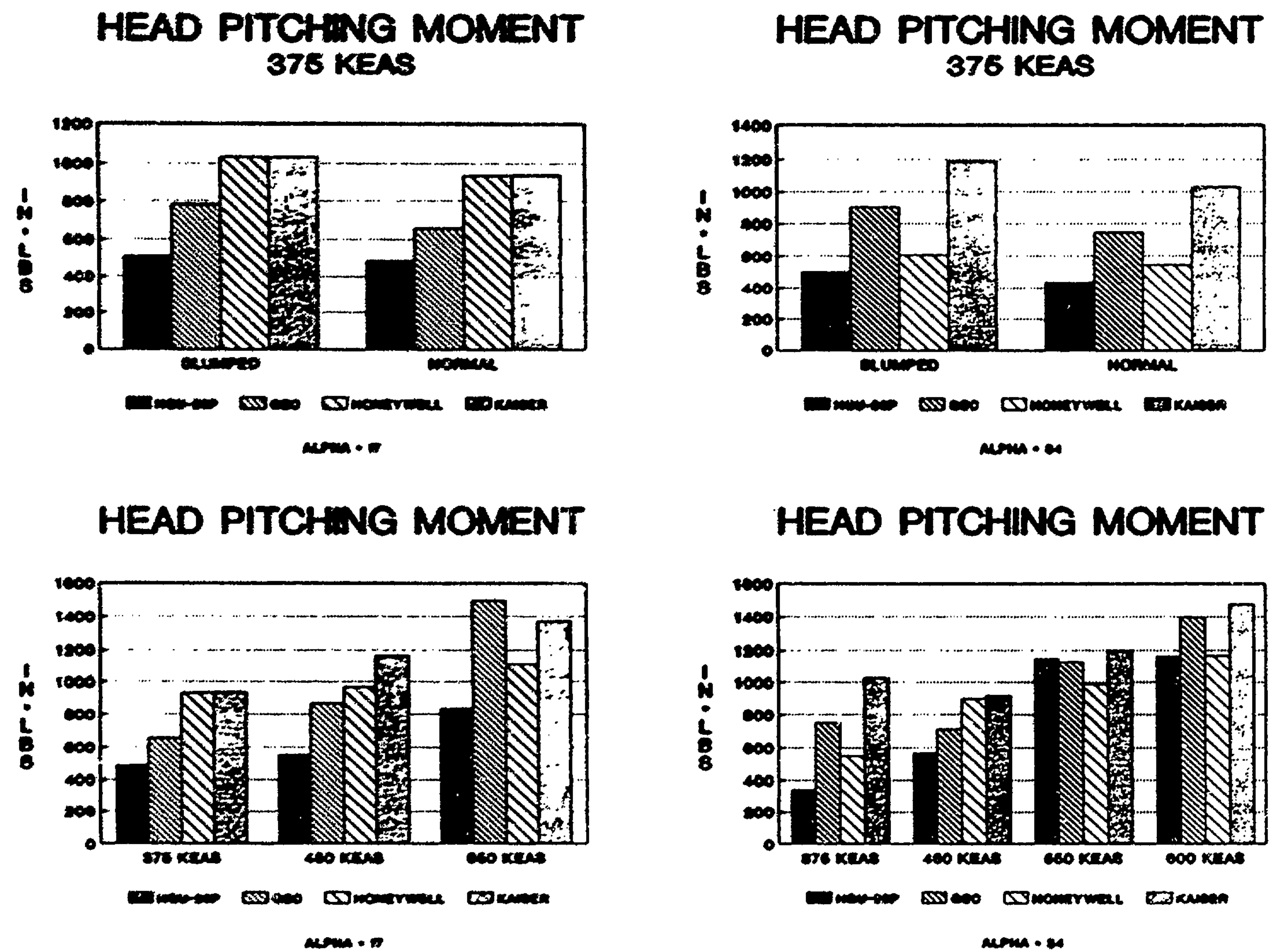

HEAD PITCHING MOMENT
375 KEAS
IN • LBS
SLUMPED
NORMAL
HONEYWELL
KAISER
HEAD PITCHING MOMENT
375 KEAS
IN • LBS
SLUMPED
NORMAL
HONEYWELL
KAISER
HEAD PITCHING MOMENT
IN • LBS
375 KEAS
480 KEAS
660 KEAS
HONEYWELL
KAISER
HEAD PITCHING MOMENT
IN • LBS
480 KEAS
660 KEAS
HONEYWELL
KAISER

FIGURE 9

APPENDIX K
MAN/SEAT SEPARATION

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APPENDIX K: MAN/SEAT SEPARATION

1. INTRODUCTION

Air crew members use ejection seats to separate themselves from a damaged aircraft or dangerous situation. After leaving the aircraft the crew member must safely separate from the seat to deploy the parachute. A crew member wearing a helmet-mounted display (HMD) along with it's support cabling must not interfere with the seat/man separation process. This report describes the evaluation of the seat/man separation process with three HMD systems. The three systems were designed and developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program for the Helmet-Mounted Systems Technology (HMST) Program Office (AL/CFA (HMST)). This evaluation was jointly conducted by HMST and the Naval Weapons Center, China Lake, California.

2. APPROACH

Seat/man separation was simulated by fitting an instrumented manikin with each of the three I-NIGHTS helmet systems. The helmet/manikin was then strapped into an ACES II ejection seat and then the seat was raised to a predetermined height. The seat was then allowed to drop. A cable attached to the parachute risors snubbed the manikin while the seat continued to fall away.

3. OBJECTIVE

The objective of seat/man separation testing was to verify that a crew member wearing an I-NIGHTS HMD could safely separate from an ACES II ejection seat. Additional objectives evaluated head/neck loads on the manikin; helmet/risor interference; HMD Optics/manikin eye relief; and HMD structural integrity, stability and retention.

TEST PLAN

INTERIM NIGHT INTEGRATED GOGGLE HEAD TRACKING SYSTEM

(I-NIGHTS)

TOWER DROP ACES II SEAT/MAN SEPARATION TESTS

31 January 1991

Prepared by:

Ron Gunderman (BSED)

COORDINATION:	DET 1 AL/BBP	[signature]	DATE:	11 MAR 91
COORDINATION:	NWC	Wendell L. Shaw	DATE:	28 Feb. 91
COORDINATION:	HSD/YAGO	[signature]	DATE:	9 FEB 91
APPROVED BY:	HSD/YAH-HMST	[signature]	DATE:	14 Mar 91

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INTERIM NIGHT INTEGRATED GOGGLE HEAD TRACKING SYSTEM
(I-NIGHTS)
TEST PLAN FOR TOWER DROP ACES II
SEAT/MAN SEPARATION TESTS
OF I-NIGHTS SYSTEMS

1.0 BACKGROUND

The Department of Defense has established the requirement for integrating night vision enhancement systems into the aircrewmans helmet assembly. Three candidate prototype helmet systems have been developed and are considered eligible for test and evaluation. NAVY ejection tower tests (using an SJU-5/A (F-18) ejection seat) have already been conducted to investigate the effects the helmet systems have on the pilot's head/neck response during emergency egress. NAVY tests have also been conducted at NWC to provide data on seat/man separation and parachute riser deployment.

2.0 PURPOSE

The purpose of this test plan is to define Air Force test conditions, test item configurations, and test methodology for conducting drop tests to determine the potential for the I-NIGHTS helmets to interfere with the deployment of the main parachute and riser assembly, and to measure and collect various loads and other electronic data as shown in attachment 1.

3.0 APPROACH

Three I-NIGHTS Helmet Systems will be tested in 2 configurations, NVG and HMD, to simulate F-16 and A-10 ejection profiles with focus on the riser deployment regime of the ejection sequence. The tests will be designed to study the interaction between the I-NIGHTS helmets and deploying riser assemblies. Data as shown in attachment 1 will be collected internally within the ADAM (Advanced Dynamic Anthropomorphic Mannequin) large mannequin and no telemetry will be required. Optical coverage will also be provided as shown in paragraph 6.2.

4.0 PROGRESS

The candidate helmets have been reviewed for configuration and fit checks have been conducted on a large ADAM instrumented mannequin which will be used for the instrumented tests. A small mannequin will be provided by NWC for the non-instrumented tests.

5.0 TEST METHODS

Conduct a series of 26 tests including 14 drop tests to assess interaction between the helmet and deploying riser assemblies during and after seat/man separation. These 14 tests will also measure head/neck loads and head/chest accelerations using a large (95th percentile) ADAM mannequin. Another 12 tests are planned using a small (5th percentile) NWC mannequin. The small mannequin tests will also focus on the interaction between the helmet and deploying riser assemblies, but no electronic data will be collected. Attachment 2 provides a matrix of the planned tests.

5.1 Test Description

5.1.1 Tests will be conducted at a dual tower site with winch controlled suspension cables connecting the towers. The test article will be prepared at ground level and hoisted to a height sufficient to apply a calculated load of approximately 1500 lbs per riser (3000 lbs for both riser assemblies) during the descent phase of the test article.

5.1.2 The test article consists of a test mannequin restrained in an ejection seat. A test site firing control circuit will signal the hoist cable to allow the seat/mannequin combination to free-fall. After descending a calculated distance, the mannequin will be snubbed from the ejection seat allowing the seat to continue descent until snubbed by a seat-saving restraint line connected between the seat and the mannequin harness.

Two different mannequins will be used for the various portions of the test. One large ADAM will be used to determine riser interference with a baseline HGU-55/P helmet and each of 3 vendor prototype systems using two different configurations (NVG only and HMD). Load and acceleration data (shown in attachment 1) will be collected internally within ADAM and no telemetry will be required. The second mannequin will be a small (5th percentile) mannequin provided by NWC which will be used to determine riser interference for small body profiles. No electronic data will be collected during the testing with the small mannequin. Both mannequins will undergo man/seat separation using two different seat configurations (vertical and 15° roll). The matrix in attachment 2 outlines the tests that are planned on each mannequin.

6.0 CRITICAL ISSUES

- Head/Neck Loads (Mass, Properties)
- Head/Neck Loads (Riser Deployment)
- Helmet/Riser Interference
- Eye Relief
- Structural Integrity
- Stability/Retention

7.0 DATA ACQUISITION

Data requirements consist of the following:

7.1 Electronic

7.1.1 Riser loads, head/neck loads, etc. (see attachment 1 for further information).

7.2 Optical

7.2.1 Movie Camera

16mm - 2 fixed positions at ground level
16mm - 1 camera mounted on mannequin

7.2.2 Video

1 position for general coverage and safety
1 position for ground level for test item coverage

7.2.3 Still Photography

8 X 10 pre- and post-test as required.

8.0 DATA DISTRIBUTION

All optical data recorded/retrieved by NWC will be released to the HSD/YAH-HMST office at Wright-Patterson Air Force Base (WPAFB).

The electronic data will be recorded internally in ADAM and downloaded after each test event using a Z-248 computer supplied by NWC. The data download will take approximately 15 minutes per test and will be completed by Systems Research Laboratory (SRL) personnel. All electronic data will be provided to the HSD/YAH-HMST office at WPAFB.

ADAM ELECTRONIC DATA CHANNEL REQUIREMENTS (16)

CHANNEL	PARAMETER	DYNAMIC RANGE (SENSOR CAPABILITY)	EXPECTED RANGE
4	Head X Accel	100 G	50 G
5	Head Y Accel	100 G	50 G
6	Head Z Accel	100 G	50 G
7	Head Angular Accel(R_y)	50000 rad/sec^2	2000 rad/sec^2
8	Chest X Accel	100 G	50 G
9	Chest Y Accel	100 G	50 G
10	Chest Z Accel	100 G	50 G
11	Chest Angular Accel(R_y)	50000 rad/sec^2	6000 rad/sec^2
12	*Neck Load X Force	2000 lbs	1000 lbs
13	*Neck Load Y Force	2000 lbs	1000 lbs
14	*Neck Load Z Force	3000 lbs	1500 lbs
15	*Neck Torque (M_x)	2500 in-lbs	1000 in-lbs
16	*Neck Torque (M_y)	2500 in-lbs	1000 in-lbs
17	*Neck Torque (Mz)	2500 in-lbs	1500 in-lbs
18	Riser Load (Left)	2000 lbs	+1500 lbs
19	Riser Load (Right)	2000 lbs	+1500 lbs

*This data provided from Denton 6-axis load cell.

<u>NOTE</u>: Frequency Range: ~~500~~HZ DC
200

Attachment 1

ACES II SEAT/MAN SEPARATION TEST MATRIX

ADAM MANNEQUIN (LARGE - 95TH PERCENTILE) - 14 TESTS

ACES II CONFIG	N/A	GEC	CONTRACTOR SYSTEM HON	KAI
Vertical	55-P	NVG (1G)	NVG (4H)	NVG (4K)
15° Roll	"		"	"
Vertical	N/R	HMD (4G)	HMD (4H)	HMD (4K)
15° Roll	N/R	"	"	"

NWC MANNEQUIN (SMALL - 5TH PERCENTILE) - 12 TESTS

ACES II CONFIG	N/A	GEC	CONTRACTOR SYSTEM HON	KAI
Vertical	55-P	HMD (4G or 1G)	NVG (4H)	NVG (4K)
15° Roll	"	"	"	"
Vertical	N/R	N/R	HMD (4H)	HMD (4H)
15° Roll	N/R	N/R	"	"

Attachment 2

NWC SEAT/MAN SEPARATION TESTS

RESPONSIBILITIES

6510TW

1. Insure proper F-16 chute deployment sequence is simulated @ NWC.

2. Observe portion of test, if able.

3. Provide data on 6510TW opening shock simulation capability for potential B-52 opening shock tests.

AAMRL/BBP

1. Review Test Plan and add information on:

   - Test Objectives
   - Instrumentation

2. Conduct Data Analysis on all data collected.

3. Provide test support equipment as shown on support equipment list.

HSD/YAG

1. On-scene support (CMSgt Smigiel) as escape system expert.

2. Provide test support equipment as shown on support equipment list.

SRL

1. Provide On-scene ADAM support.

2. Provide ADAM support equipment as shown on suppport equipment list.

Vendors

1. TBD

2. All notified - if they go I need SSN __________.

Attachment 3

NWC TEST SUPPORT EQUIPMENT LIST

Item	Quantity	Opr
Z-248 Computer/Printer/ Power Supply	1	NWC - (B/U YAGO)
Voltmeter	1	NWC
Voltage Standard	1	NWC (CAL Lab)
Soldering Iron	1	NWC
O-Scope	1	NWC
LPU-9D Life Preserver/ Surv. Vest	1	YAGO
G-Suit (Large)	1	YAGO
Large Flight Boots	1	YAGO
Ex-Large Flight Suit	1	YAGO
ADAM #12 (Large)	1	Holloman
ADAM I-NIGHTS Liners	3 (1 per vendor)	AAMRL/BBM
5% Hybrid III Liners	3 (1 per vendor)	AAMRL/BBM
*I-NIGHTS Helmets (HMD)	3 (4G,H,K)	HSD/YAH-HMST
" " (NVG)	3 (4H,K modified, 1G)	"
Large Harness/Riser Set	1	HSD/YAGO
Small Harness	1	BBP Loan (Lashley)
F-16 Frost Fittings	2	YAGO
Power Supply (ADAM)	1	SRL
W/ 100' Cable		
DRASS (ADAM)	1	SRL
Monitor (ADAM)-Hand Held	1	SRL
#4 ADAM-Load Cell #128	1	SRL

*NOTE: 4H,K will be modified on site to NVG configuration.

Attachment 4

NWC TEST SUPPORT EQUIPMENT LIST (CONTINUED)

Item	Quantity	Opr
Riser Load Cells	2 (10 avail)	NWC (B/U YAGO)
(Dog Bone)		
Linear Accelerometers	3	SRL
Angular Accelerometers	2 (Head, Chest)	YAH
(Range: $\pm$ 10,000 Radians/Sec^2)		B/U YAGO
(Size: 3/4" long, 1/2" Diameter)		(ARS Seat Pan)
55P Helmet/Liner/Mask	2 (L, S)	YAG
O_2 Mask	3	YAG
I-Nights Bayonets	3 Sets (1 ea)	YAH
SWARS (Seawater Activation Release System)	2	6510TW

NWC SEAT/MAN SEPARATION TEST

SCHEDULE OVERVIEW

(Based upon nominal test profile of 3 tests per day)

Preparation

3 days -	SRL Prep -	5 - 8 Feb
3 days -	NWC Prep -	6 - 9 Feb

Testing

ADAM	14 Tests	11 - 14 Feb
*SMALL	12 Tests	19 - 22 Feb

*Could extend til 8 Mar before 60 day down time for upgrade and maintenance.

Attachment 5

NWC SEAT/MAN SEPARATION TEST

CONTRACTOR EVENT CALENDAR

MON	TUE	WED	THU	FRI
11 Feb	12	13	14	15
55P	GEC-NVG	HON-NVG	KAI-NVG	Range Closed
55P	GEC-NVG	HON-NVG	KAI-NVG	
GEC	GEC-HMD	HON-HMD	KAI-HMD	
---		"	"	
18 Feb	19	20	21	22
Holiday	55P	GEC	HON	KAI
(Range	55P	HON	HON	KAI
Closed)	GEC	HON	KAI	KAI

Attachment 6

TEST REPORT

INTERIM NIGHT INTEGRATED GOGGLE HEAD TRACKING SYSTEM

(I-NIGHTS)

TOWER DROP ACES II SEAT/MAN SEPARATION TESTS

2 August 1991

Prepared by:

Ron Gunderman (BSED)

Helmet Mounted System Technology
Advanced Development Program Office
Office of Advanced Technology Integration Division
Crew Systems Directorate
Armstrong Laboratory
Human Systems Division
Wright-Patterson Air Force Base, Ohio 45433

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1.0 INTRODUCTION

The ACES II seat/man separation tests were conducted at the Naval Weapons Center at China Lake, CA. The formal test program was conducted during the period of 11 through 15 Feb 1991 at the Aerosystems Department drop test tower. Testing consisted of multiple drop tests with three candidate helmets (GEC, Kaiser, Honeywell) with multiple configurations for each helmet. Each configuration of helmet was drop tested in both the vertical seat position and fifteen degree (15°) left roll. Attachment 1 identifies the test conditions requested and controlled by on-site Air Force personnel. All tests were conducted using an ACES II ejection seat in conjunction with an Air Force furnished ADAM mannequin and a NAVWPNCEN furnished GARD mannequin as test subjects.

This report presents the results of the above tests as they relate to the following critical issues:

- Head/Neck Loads
- Helmet/Riser Interference
- Eye Relief
- Structural Integrity
- Stability/Retention

2.0 PROCEDURES

The test article consisted of a test mannequin restrained in an ACES II ejection seat. The test article was prepared at ground level and hoisted to a height sufficient to apply a calculated load of approximately 1500 lbs per riser (3000 lbs for both riser assemblies) during the descent phase of the test article.

A test site firing control circuit signaled a hoist cable to allow the seat/mannequin combination to free-fall. After descending a calculated distance, the mannequin was snubbed from the ejection seat allowing the seat to continue descent until snubbed by a seat-saving restraint line connected between the seat and the mannequin harness.

Two different mannequins were used for the various portions of the test. One large ADAM was used to determine riser interference with a baseline HGU-55/P helmet and each of 3 vendor prototype systems using two different configurations (NVG only and HMD). Load acceleration data (shown in attachment 2) was collected internally within ADAM. The second mannequin was a small (5th percentile) mannequin provided by NWC which was used to determine riser interference for small body profiles. No electronic data was collected during the testing with the small mannequin.

3.0 DATA ACQUISITION

All optical data was recorded with NAVWPNCEN furnished camera equipment. Two tri-pod mounted Fastex cameras and one photosonic 16mm camera were used for recording each test. The Fastex cameras were located one at ninety degrees (90°) to the left of the test subject and one directly in front of the test subject. Both were set to record at 2,000 frames per second. The photosonic camera was located on a specially designed bracket mounted to the chest of the mannequin viewing only the helmet/head area of the mannequin at a rate of 400 frames per second. In addition, one tri-pod mounted video recorder was positioned directly in front of the test subject. Pre and post-test still photography was provided by NAVWPNCEN for each test.

All electronic data was acquired using digital, solid state recording equipment. The data was collected internally within the ADAM mannequin and downloaded to the Data Retrieval and Storage System (DRASS) after each test event. Data analysis software was then used to upload the raw data from the DRASS and convert this data to engineering units.

Data analysis was accomplished by Ball Systems Engineering Division using criteria and advisory support provided by the Escape and Impact Protection Branch, Crew Systems Directorate. The guidelines used for safe human experimental exposure to impact acceleration are derived from tests conducted at the Naval Biodynamics Laboratory. Tension and Compression guidelines were derived from human cadaver experiments. The recommended tolerance levels for various other force components come from static tests on living human volunteers, and dynamics tests on human volunteers and human cadavers.

A summary of the guidelines (Baseline Thresholds) used for evaluating the results of the head/neck loads data collected on the ACES II seat/man separation tests follows. Note that the baseline threshold data below is based upon unconfirmed laboratory data.

PARAMETER	BASELINE THRESHOLD
Head Angular Accel (R_y)	1800 rad/sec^2
Neck Load X Force	437 lbs
Neck Load Y Force	437 lbs
Neck Load Z Force	
- Compression	400 lbs
- Tension	551 lbs
Neck Torque (M_y)	1701 in-lbs

4.0 TEST RESULTS

4.1 Head/Neck Loads Assessment

All of the I-NIGHTS helmets (GEC, Honeywell, Kaiser) experienced loads, torques and angular accelerations that were less than the established guidelines (i.e. reference data points). It is important to note that the combined riser loads achieved on these 21 tests varied between 2720 and 3920 lbs. Although these combined riser loads are representative of some of the loads that would be attained during actual parachute deployments they do not approach the peak riser loads that are possible in high speed/high altitude ejections. A summary of the data collected relating to the head/neck loads assessment follows. Each vendors' helmet (GEC, Honeywell, Kaiser) was compared to the HGU/55P helmet as a baseline. The 15 degree seat angle data is being used to represent the F-16 ejection profile. The vertical seat test data is similar to the 15 degree seat test data in all test configurations.

GEC HELMET COMPARISON

PARAMETER	*REFERENCE DATA POINT	HGU/55P	GEC (NVG)	GEC (HMD)
Head Angular Accel (Y)	1800 Rad/Sec^2	1435	1266	1435
Neck Load X	437 lbs	120	206	250
Neck Load Y	437 lbs	155	86	34
Neck Load Z	---	---	---	---
- Compression	400 lbs	26	26	26
- Tension	551 lbs	234	182	345
Neck Torque (My)	1701 in-lbs	107	258	295
Total Riser Load	N/A (lbs)	3533	3920	3231

*NOTE: Based upon unconfirmed laboratory data

KAISER HELMET COMPARISON

PARAMETER	*REFERENCE DATA POINT	HGU/55P	KAI (NVG)	KAI (HMD)
Head Angular Accel (Y)	1800 Rad/Sec^2	1435	1519	1350
Neck Load X	437 lbs	120	103	241
Neck Load Y	437 lbs	155	103	155
Neck Load Z	---	---	---	---
- Compression	400 lbs	26	130	52
- Tension	551 lbs	234	208	338
Neck Torque (My)	1701 in-lbs	107	373	301
Total Riser Load	N/A (lbs)	3533	3533	3188

*NOTE: Based upon unconfirmed laboratory data

HONEYWELL NVG HELMET COMPARISON

PARAMETER	*REFERENCE DATA POINT	HGU/55P	CURRENT	MODIFIED
Head Angular Accel (Y)	1800 Rad/Sec^2	1435	1266	1603
Neck Load X	437 lbs	120	241	275
Neck Load Y	437 lbs	155	121	103
Neck Load Z	---	---	---	---
- Compression	400 lbs	26	0	52
- Tension	551 lbs	234	234	338
Neck Torque (My)	1701 in-lbs	107	473	279
Total Riser Load	N/A (lbs)	3533	2844	3574

*NOTE: Based upon unconfirmed laboratory data

HONEYWELL HMD HELMET COMPARISON

PARAMETER	*REFERENCE DATA POINT	HGU/55P	CURRENT	MODIFIED
Head Angular Accel (Y)	1800 Rad/Sec^2	1435	1350	1350
Neck Load X	437 lbs	120	241	120
Neck Load Y	437 lbs	155	86	121
Neck Load Z	---	---	---	---
- Compression	400 lbs	26	0	52
- Tension	551 lbs	234	338	364
Neck Torque (My)	1701 in-lbs	107	86	215
Total Riser Load	N/A (lbs)	3533	1982	3662

*NOTE: Based upon unconfirmed laboratory data

ALL VENDORS NVG HELMET (15°/VERTICAL) COMPARISON

PARAMETER	*REFERENCE DATA POINT	GEC	HON	KAI
Head Angular Accel (Y)	1800 Rad/Sec^2	1266/1350	1266/1688	1519/1519
Neck Load X	437 lbs	206/86	241/223	103/103
Neck Load Y	437 lbs	86/51	241/223	103/103
Neck Load Z	---	---	---	---
- Compression	400 lbs	26/52	0/26	103/78
- Tension	551 lbs	182/338	234/390	208/234
Neck Torque (My)	1701 in-lbs	258/102	473/602	373/107
Total Riser Load	N/A (lbs)	3920/3619	2844/3532	3533/3532

*NOTE: Based upon unconfirmed laboratory data

4.2 Helmet/Riser Interference

The parachute deployment sequence that was simulated for this series of tests focused on the vertical and 15° off-vertical body positions only. No other random body positions were tested. The primary objective was to evaluate parachute riser interference with the various I-NIGHTS helmets (GEC, Honeywell, Kaiser). A secondary objective was to determine if a new Honeywell design for improved riser deployment was able to demonstrate less riser interference. The test results showed that the new Honeywell contour modifications for the NVG helmet resulted in less riser interference than the standard configuration Honeywell helmet. The test results for the Honeywell HMD contour modification also showed less riser interference. Each of the modified helmets, NVG and HMD, had acceptable head/neck loads that were less than the reference data point thresholds shown in section 4.1. Both the GEC and Kaiser baseline helmet tests showed that the riser interference was slightly more than with the HGU/55P baseline helmet but no unsafe conditions surfaced. All GARD mannequin (5th percentile) tests showed greater riser interference than with the 95th percentile ADAM mannequin tests. In conclusion, the NVG/HMD initial configuration GEC and Kaiser helmets and the modified Honeywell configuration helmets all show acceptable levels of riser interference in the vertical and 15° off-vertical parachute opening body positions. The original configuration Honeywell helmet shell is considered marginal. Ejection risk due to parachute deployment increases as body size (i.e. shoulder width) decreases since greater riser interference and damage to the helmets was observed during the 5th percentile tests than during the 95th percentile tests.

4.3 Eye Relief

Eye relief continues to be a concern with all vendor systems. Factors such as combiner positions (stowed or unstowed), body position, ejection speed/altitude, and the adequacy of helmet fit are some of the most important factors to consider. Combiner contact was observed on two of the I-NIGHTS systems, GEC and Honeywell. The GEC helmet showed a small amount of combiner contact was observed on the left side of the nose on one test. The GEC combiners are non-stowable. The Honeywell helmet showed a small amount of combiner contact on the left upper cheekbone area. The Honeywell combiners are stowable but that is not recommended due to the greater potential for riser interference in the stowed position. Finally, the Kaiser system did not show combiner contact during these tests but it is possible that combiner contact with the eye or eye socket area could occur in some ejection profiles. Recommend that the Kaiser combiners be stowed before ejection if time permits.

4.4 Structural Integrity, Stability and Retention

Some minor structural damage was observed on all helmet systems during testing. This was anticipated and it is not considered to present a safety problem with any of the helmets except the original configuration Honeywell helmet. In the case of the "unmodified" original Honeywell helmet it is possible that during riser deployment that the detachable optics modules could be damaged in such a way as to increase the probability of injury due to combiner contact with the eye and/or eye socket area. Structural integrity is not considered to be a major problem with the modified Honeywell helmet that has helmet contour design changes incorporated. In the area of stability and retention, no major problems were observed.

5.0 CONCLUSIONS/RECOMMENDATIONS

The head/neck loads for the I-NIGHTS helmets are acceptable when compared to the HGU/55P helmet within the scope of the test conditions used for these tests. However, exposure to combined riser loads greater than 3920 lbs and different random body positions may result in unacceptable loads. Further testing or modeling/simulation is needed to evaluate these profiles if required. In addition, since the data used as a "reference data point" has not been verified further research is needed to obtain validated injury threshold criteria.

Eye relief continues to be a concern with all vendor systems. Factors such as combiner position (stowed or unstowed), body position, ejection speed/altitude, and proper helmet fit are all variables that need to be considered. Recommend that a protective eyewear assessment be completed to determine the suitability, adequacy and impact of wearing various types of eye protection. Recommend that the Kaiser combiners be stowed before ejection if time permits.

Parachute riser interference is considered acceptable for the GEC and Kaiser helmets in both NVG and HMD configurations. The current Honeywell helmet is considered marginal in the NVG mode of operation and unacceptable in the HMD configuration. Recommend both Honeywell helmet configurations, NVG and HMD, be modified to include a new helmet contour shell which Honeywell has already designed. The modified helmets could also reduce the probability of injury due to eye relief by improving the structural integrity of the optics module.

I-NIGHTS TEST MATRIX

Test Date	Mannequin Identification	Helmet Configuration	Test Condition	Suspended Weight (lbs)
2-11-91	ADAM I	HGU-55/P	15 °	320±3
2-14-91	ADAM IR	HGU-55/P	15°	320±3
2-11-91	ADAM II	GEC/1G (NVG)	VERT	320±3
2-14-91	ADAM IIR	GEC/1G (NVG)	VERT	320±3
2-12-91	ADAM III	GEC/1G (NVG)	15°	320±3
2-12-91	ADAM IV	GEC/4G (HMD)	15°	320±3
2-12-91	ADAM V	4K-HMD	15°	320±3
2-13-91	ADAM VI	HON-X (NVG)	15°	320±3
2-13-91	ADAM VII	HON-4H (NVG)	15°	320±3
2-13-91	ADAM VIII	HON-X (HMD)	15°	320±3
2-13-91	ADAM IX	HON-X (NVG)	VERT	320±3
2-13-91	ADAM X	HON-4H (HMD)	15°	320±3
2-14-91	ADAM XI	KAI-4K (NVG)	15°	320±3
2-14-91	ADAM XII	KAI-4K (NVG)	VERT	320±3
2-12-91	GARD I	GEC/4G (HMD)	15°	320±3
2-14-91	GARD II	HON-X (NVG)	15°	320±3
2-14-91	GARD III	HON-X (HMD)	15°	320±3
2-15-91	GARD IV	KAI-4K (NVG)	15°	320±3
2-15-91	GARD V	HON-4H (NVG)	15°	320±3
2-15-91	GARD VI	KAI-4K (HMD)	15°	320±3
2-15-91	GARD VII	HGU-55/P	15°	320±3

ATCH 1

ADAM ELECTRONIC DATA CHANNEL REQUIREMENTS (16)

CHANNEL	PARAMETER	DYNAMIC RANGE (SENSOR CAPABILITY)	EXPECTED RANGE
4	Head X Accel	100 G	50 G
5	Head Y Accel	100 G	50 G
6	Head Z Accel	100 G	50 G
7	Head Angular Accel(R_y)	50000 rad/sec^2	2000 rad/sec^2
8	Chest X Accel	100 G	50 G
9	Chest Y Accel	100 G	50 G
10	Chest Z Accel	100 G	50 G
11	Chest Angular Accel(R_y)	50000 rad/sec^2	6000 rad/sec^2
12	*Neck Load X Force	2000 lbs	1000 lbs
13	*Neck Load Y Force	2000 lbs	1000 lbs
14	*Neck Load Z Force	3000 lbs	1500 lbs
15	*Neck Torque (M_x)	2500 in-lbs	1000 in-lbs
16	*Neck Torque (M_y)	2500 in-lbs	1000 in-lbs
17	*Neck Torque (Mz)	2500 in-lbs	1500 in-lbs
18	Riser Load (Left)	2000 lbs	+1500 lbs
19	Riser Load (Right)	2000 lbs	+1500 lbs

ATCH 2

APPENDIX L
PARACHUTE DEPLOYMENT

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APPENDIX L: PARACHUTE DEPLOYMENT

1. INTRODUCTION

Aircrew members, after ejecting from their aircraft, depend on parachutes to lower them safely to the ground. As the parachute deploys it literally yanks the crew member sending a force up to +25Gs through the body (opening shock). During opening shock the head and neck must support the added weight of a helmet-mounted display (HMD) without injury; the risors, which connect the crew member harness to the parachute, should not interfere with or damage the helmet; and the helmet must not shift causing the HMD optics to contact the face. This report describes the evaluation of parachute deployment effects on the head, neck and face while wearing an I-NIGHTS HMD. Three HMD designs were developed for the Interim-Night Integrated Goggle and Head Tracking System (I-NIGHTS) Program by the Helmet-Mounted Systems Technology (HMST) Program Office (AL/CFA (HMST)). The evaluation was jointly conducted by HMST and the 4950 Test Wing at Wright-Patterson Air Force Base, Ohio.

2. APPROACH

Parachute deployment effects were simulated by fitting an instrumented manikin with each I-NIGHTS helmet and a crew member parachute harness with risors. The manikin/helmet were dropped from a predetermined height. As the manikin fell the risors deployed past the helmet fully extending to provide opening shock forces. Clay in the manikin eye sockets documented any contact of the HMD optics and the drop was recorded on high speed camera. The opening shock forces were measured by accelerometers located about the manikin's head.

3. OBJECTIVE

The objective of parachute deployment testing is to determine the degree of risor interference with each of the I-NIGHTS helmets; explore the possibility of the HMD optics touching the face; and measure the opening shock forces on the head and neck.

TEST PLAN

INTERIM NIGHT INTEGRATED GOGGLE HEAD TRACKING SYSTEM

(I-NIGHTS)

B-52 EJECTION PARACHUTE DEPLOYMENT TESTS

26 April 1991

(First Revision)

Prepared by:

Ron Gunderman (BSED)

COORDINATION: DET 1 AL/BBP [signature] DATE: 31 May 91

COORDINATION: DET 1 AL/BBM [signature] DATE: 31 MAY 91

COORDINATION: ASD/ENECA [signature] DATE: 31 May 91

COORDINATION: 4950TW/AMX [signature] DATE: 31 May 91

APPROVED BY: AL/CFA (HMST) [signature] DATE: 3 Jun 91

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INTERIM NIGHT INTEGRATED GOGGLE HEAD TRACKING SYSTEM (I-NIGHTS) TEST PLAN FOR B-52 PARACHUTE DEPLOYMENT TESTS OF I-NIGHTS SYSTEMS

1.0 BACKGROUND

The Department of Defense has established the requirement for integrating night vision enhancement systems into the aircrewman's helmet assembly. Three candidate prototype helmet systems have been developed and are considered eligible for test and evaluation. Air Force vertical deceleration tower tests have already been conducted to investigate the effects the helmet systems have on the pilot's head/neck response during emergency egress. Tests have also been conducted at NWC (China Lake) to provide data on seat/man separation and parachute riser deployment for the ACES II seat aircraft.

2.0 PURPOSE

The purpose of this test plan is to define Air Force test conditions, test item configurations, and test methodology for conducting tests to determine the potential for the I-NIGHTS helmets to interfere with the deployment of the B-52 parachute and riser assembly, to determine eye relief, and to measure and collect various loads and other electronic data as shown in attachment 1.

3.0 APPROACH

Three I-NIGHTS Helmet Systems will be tested in the NVG configuration to simulate the B-52 riser deployment regime of the ejection sequence. One baseline helmet (HGU-55/P) will also be tested and compared with the I-NIGHTS test results. The tests will be designed to study the interaction between the I-NIGHTS helmets and deploying riser assemblies. Data as shown in attachment 1 will be collected internally within the ADAM (Advanced Dynamic Anthropomorphic Mannequin) large mannequin and no telemetry will be required. Optical coverage will also be provided as shown in paragraph 7.2.

4.0 PROGRESS

The candidate helmets have been reviewed for configuration and fit checks have been conducted on a large ADAM instrumented mannequin which will be used for the instrumented tests. Another mannequin will be provided for trial test runs to establish baseline riser loads and the adequacy of photographic coverage.

5.0 <u>TEST METHODS</u>

Conduct a series of tests to assess interaction between the helmet and deploying riser assemblies after B-52 seat/man separation. These tests will also measure head/neck loads and head/chest accelerations using a large (95th percentile) ADAM mannequin.

5.1 <u>Test Description</u>

5.1.1 Tests will be conducted using a crane with winch to hoist a release fixture with nylon webbing attached to the riser assembly. The ADAM test article will be prepared at ground level and hoisted to a height sufficient to apply a calculated load of approximately 3000 to 4000 lbs for both riser assemblies during the descent phase of the test article.

5.1.2 Nylon webbing straps will be used in lieu of the nylon suspension lines to suspend the ADAM from the crane. There are 4 parachute riser straps which normally run between the torso harness and the parachute suspension lines. There are 7 suspension lines connected to each riser strap, each suspension line is made of 550 lb nylon cord so the total load capability of each riser/suspension line group is 3850 lbs (550 lbs times 7 lines). In order to simplify the rigging of the test, each group of 7 suspension lines will be replaced with a length of nylon webbing of similar load capability (MIL-W-4088, type 8; 4000 lbs or type 21, 3600 lbs, depending on availability). A release fixture available from another test will be used to lift and release ADAM for the drop (see attachment 2). The release fixture has the capability for a simultaneous 4 point release. The 4 point release will allow ADAM to be dropped in numerous attitudes. Three (3) attitudes are planned, horizontal face down, horizontal face down with a 45 degree roll, and vertical (see attachment 2). A firing control circuit or another appropriate means will be used to allow the riser/mannequin combination to free-fall to simulate the proper riser deployment sequence.

5.1.3 This set up will include a strain link (strain gauges or load cells) to record riser loads. To simulate a typical snatch load a total riser load of 3000 to 4000 lbs is desired. Because of the nature of the Capewell type canopy release fittings (which connect the risers to the torso harness) the strain link will need to be installed where the MIL-W-4088 webbing straps mate with the spreader plate. Attachment 3 shows the details of the ADAM harness suspension set up in a post drop position. Current plans are to use the AMIT parachute riser links provided they are available (see attachment 4).

5.1.4 Two different mannequins will be used for the various portions of the test. Initially a GARD mannequin or similar non-instrumented mannequin will be used to establish the appropriateness of combined riser loads (3000 to 4000 lbs). Riser loads data will be collected on a strip chart recorder or downloaded to ADAM. Additionally, the adequacy of photo coverage will also be assessed during these trial runs. After the baseline trial tests have validated that the appropriate test conditions have been achieved, a large ADAM will be used to determine riser interference with a baseline HGU-55/P helmet and each of 3 vendor prototype systems using NVG configuration only. Load and acceleration data (shown in attachment 1) will be collected internally within ADAM and no telemetry will be required. The matrix in attachment 5 provides an overview of the tests planned.

6.0 CRITICAL ISSUES

- Head/Neck Loads (Riser Deployment)
- Helmet/Riser Interference
- Eye Relief
- Structural Integrity
- Stability/Retention

7.0 DATA ACQUISITION

Data requirements consist of the following:

7.1 Electronic

7.1.1 Riser loads, head/neck loads, etc. (see attachment 1 for further information).

7.2 Optical

7.2.1 Movie Camera (Color)

16mm - 1 fixed position at ground level (high speed)
16mm - 1 camera mounted on mannequin (photosonic I-P)

7.2.2 Video (Color)

1 for ground level test item coverage (documentation)

7.2.3 Still Photography (Color)

8 X 10 pre- and post-test as required (approximately 10 per test).

8.0 DATA DISTRIBUTION

All optical data recorded/retrieved by ASD/RMVTI (Tech Photo) will be released to the AL/CFA (HMST) office at Wright-Patterson Air Force Base (WPAFB).

The electronic data will be recorded internally in ADAM and downloaded after each test event using a Z-248 computer. The data download will take approximately 15 minutes per test and will be completed by Systems Research Laboratory (SRL) personnel. All electronic data will be provided to the AL/CFA (HMST) office at WPAFB.

ADAM ELECTRONIC DATA CHANNEL REQUIREMENTS

CHANNEL	PARAMETER	DYNAMIC RANGE (SENSOR CAPABILITY)	EXPECTED RANGE
4	Head X Accel	100 G	50 G
5	Head Y Accel	100 G	50 G
6	Head Z Accel	100 G	50 G
7	Head Angular Accel(R_y)	5000 rad/sec^2	2000 rad/sec^2
8	Chest X Accel	100 G	50 G
9	Chest Y Accel	100 G	50 G
10	Chest Z Accel	100 G	50 G
11	Chest Angular Accel(R_y)	5000 rad/sec^2	6000 rad/sec^2
12	*Neck Load X Force	2000 lbs	1000 lbs
13	*Neck Load Y Force	2000 lbs	1000 lbs
14	*Neck Load Z Force	3000 lbs	1500 lbs
15	*Neck Torque (M_x)	2500 in-lbs	1000 in-lbs
16	*Neck Torque (M_y)	2500 in-lbs	1000 in-lbs
17	*Neck Torque (M_z	2500 in-lbs	1500 in-lbs
18	Riser Load (Left)	2000 lbs	+1500 lbs
19	Riser Load (Right)	2000 lbs	+1500 lbs
TBD	Lumbar Load X Force	4000 lbs	TBD
TBD	Lumbar Load Y Force	4000 lbs	TBD
TBD	Lumbar Load Z Force	6000 lbs	TBD

*This data provided from Denton 6-axis load cell.

<u>NOTE</u>: Frequency Range: 200HZ DC

Attachment 1

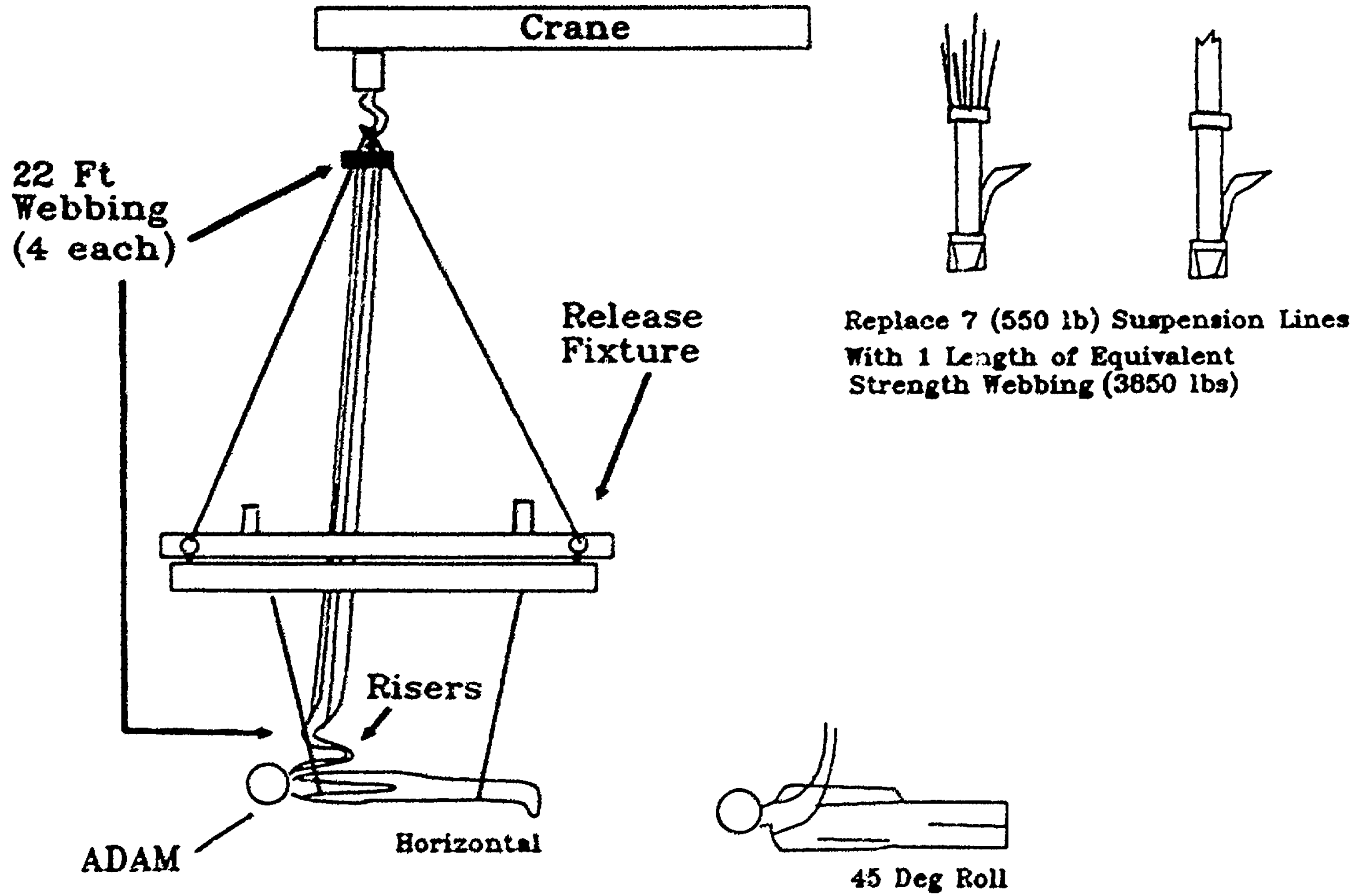


FIG 2. INIGHTS B-52 Static Drop Test Set Up

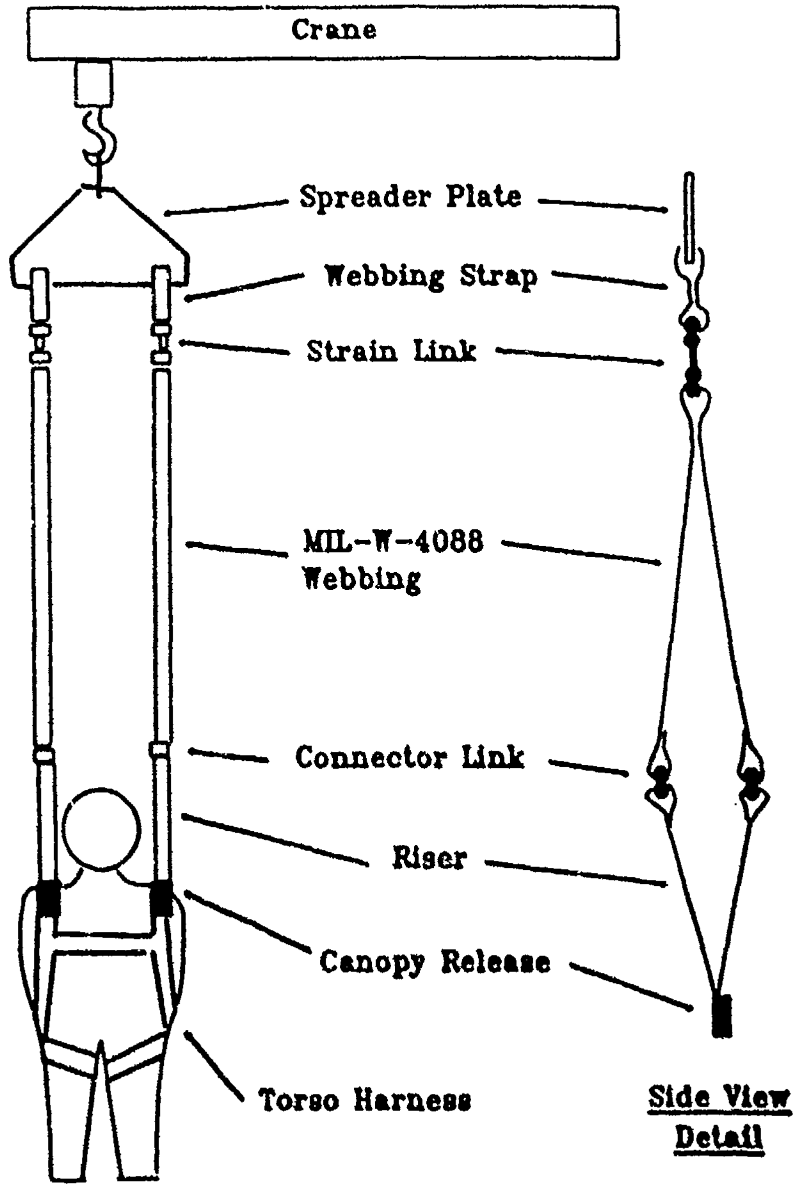
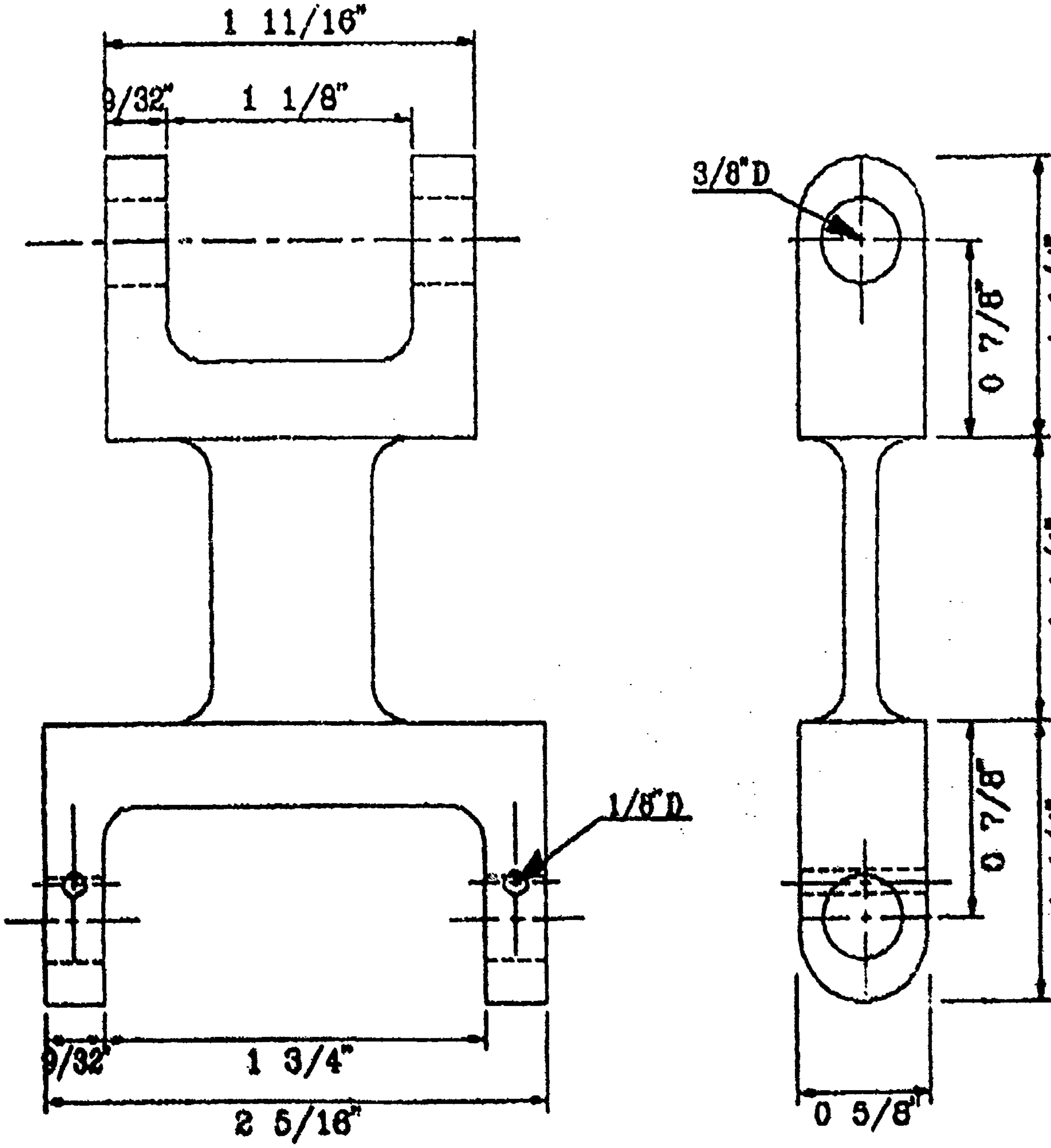


Fig 3. Detail of ADAM Suspension Set Up (Post Drop Position, Release Fixture Not Shown)

AMIT Parachute Riser Links



Attachment 4

B-52 PARACHUTE DEPLOYMENT TEST MATRIX

1. Pre-Test Validation Drops (GARD Mannequin)

Body Position	Helmet System (# Tests)
Horizontal	None (2)
45° Roll	None (2)
Vertical	None (2)
TOTAL TESTS:	= 6

2. Actual Test Drops (Instrumented ADAM)

Body Position	Helmet System (# Tests)			
Horizontal	HGU-55p	(3),	GEC, HON, KAI	(3 ea)
45° Roll	"	(1)	"	(1 ea)
Vertical	"	(2)	"	(2 ea)
Vertical (Cont.)			Modified HON	(2 ea)
TOTAL TESTS:				= 26

B-52 PARACHUTE DEPLOYMENT TESTS RESPONSIBILITIES

DET 1 AL/BBP

1. Review/coordinate on Test Plan.

2. Provide instrumentation recommendations and determine what data needs to be collected.

3. Identify baseline injury threshold criteria and/or guidelines for safety of flight evaluation.

4. Provide advisory support throughout the conduct of the test on a non-interference basis with other activities.

5. Provide test support equipment as shown on support equipment list (attachment 7).

DET 1 AL/BBM

1. Provide liaison to facilitate SRL contract support.

2. Provide advice on ADAM suitability and availability. (Note: Captain Badami of the CREST program office has authorized the use of one of his large ADAM mannequins located at Holloman AFB, NM.)

ASD/ENECA

1. Provide advice on engineering aspects relating to the parachute deployment tests.

2. Provide on-scene test support (Andrew Kididas) during the test period (approximately 5-7 days) as advisor/observer.

3. Provide test support equipment as shown on the support equipment list (attachment 7).

4950TW/AMX

1. Conduct test as described in this test plan and the program introduction document (PID).

2. Support test drops with personnel and equipment as needed.

3. Modify existing release fixture as needed to provide capability for simultaneous 4 point release of the lines holding the ADAM.

4. Provide test support equipment as shown on the support equipment list (attachment 7).

Attachment 6

SRL (Contractor Support)

1. Provide on-scene ADAM support including preparation, to data download and chart output for all data channels.

2. Provide ADAM support equipment as shown on support equipment list (attachment 7).

AL/CFA (HMST)

1. Coordinate test activities with 4950TW/AMX and other test participants.

2. Write Test Plan.

3. Analyze results based upon guidelines and assistance provided by DET 1 AL/BBP and ASD/ENECA.

4. Coordinate with ASD/RNVT (Tech Photo) for photographic requirements.

TEST SUPPORT EQUIPMENT LIST

Item	Quantity	Opr
Z-248 Computer/Printer/ Power Supply	1	4950TW/AMX (B/U YAGO)
Voltmeter	1	4950TW/AMX (B/U YAGO)
Voltage Standard	1	4950TW/AMX (B/U YAGO)
Soldering Iron	1	4950TW/AMX (B/U YAGO)
O-Scope	1	DET 1 AL/BBM (B/U: SRL)
B-52 Parachute Harness	1	ASD/ENECA
Large Flight Boots	1	DET 1 AL/BBP
Ex-Large Flight Suit	1	DET 1 AL/BBP
ADAM #12 (Large)	1	Holloman (YAGO Loan)
ADAM I-NIGHTS Liners	3 (1 per vendor)	DET 1 AL/BBM
HGU-55/P (Large)	1	DET 1 AL/BBP
I-NIGHTS Helmets (HMD)	3 (1G,H,K)	AL/CFA (HMST)
Riser Set	1	ASD/ENECA
Strain Gages (AMIT Riser Links)	2	DET 1 AL/BBP
Denton Load Cells		
- Head/Neck (Mod #1716)	1	DET 1 AL/BBM (B/U CREST)
- Lumbar (Mod #1914)	1	DET 1 AL/BBM (B/U CREST)
Power Supply (ADAM)	1	SRL
W/ 100' Cable		
DRASS (ADAM)	1	SRL
Monitor (ADAM) - Hand Held	1	SRL
#4 ADAM - Load Cell #128	1	SRL
GARD Manikin (Large)	1	Det 1 AL/BBP
Spreader Bar	1	NWC (China Lake)
Chest Camera Mount	1	NWC (China Lake)
Vest	1	ENECA
O_2 Mask	2	ENECA
O_2 Mask Clips (G, H, K)	1 ea	AL/CFA (HMST)
Hydraulic Fluid MIL-H-5606E	1 qt	4950TW/AMX

Attachment 7

SECTION 12

PARACHUTE DEPLOYMENT TESTS

B-52 PARACHUTE DEPLOYMENT TESTS OVERVIEW

- CRITICAL ISSUES
- KEY ELECTRONIC DATA COLLECTED
- COMPARISON OF ELECTRONIC DATA COLLECTED
  - GEC AVIONICS
  - HONEYWELL
  - KAISER
- PARACHUTE LOADS ASSESSMENT SUMMARY
- OVERALL TEST ASSESSMENT

B-52 PARACHUTE DEPLOYMENT TESTS CRITICAL ISSUES

- HEAD/NECK LOADS (RISER DEPLOYMENT)
- HELMET/RISER INTERFERENCE
- EYE RELIEF
- STRUCTURAL INTEGRITY
- STABILITY/RETENTION

O-1c1

B-52 PARACHUTE DEPLOYMENT TESTS KEY ELECTRONIC DATA COLLECTED

PARAMETER	REFERENCE DATA POINTS
*Head Angular Accel (R_y)	*2675 rad/sec^2
Neck Load X Force	437 lbs
Neck Load Y Force	437 lbs
Neck Load Z Force	
- Compression	400 lbs
- Tension	551 lbs
*Neck Torque (M_x)	*850 in-lbs
Neck Torque (M_y)	1701 in-lbs
Neck Torque (M_z)	TBD
Riser Load (Left)	1500 lbs (Target)
Riser Load (Right)	1500 lbs (Target)

*NOTE: These 2 data points are based upon human tests. The remaining data points are based upon unconfirmed laboratory data.

O-1d1

HORIZONTAL PARACHUTE DEPLOYMENT LOADS (BASED UPON AVERAGE OF THREE DROPS EACH)

HGU - 55/P - EXCEEDS NECK LOAD (TENSION) REFERENCE POINT BY 50 LBS

- REFERENCE DATA POINT: 551 LBS
- ACTUAL AVERAGE: 601 LBS

HGU - 55/P - EXCEEDS HEAD ANGULAR ACCELERATION REFERENCE POINT BY 847 LBS

- REFERENCE DATA POINT: 2675 LBS
- ACTUAL AVERAGE: 3522 LBS

GEC - ALL PARAMETERS PASS

HON - ALL PARAMETERS PASS

KAI - ALL PARAMETERS PASS

O-144

GEC HELMET RESULTS (VERTICAL DROP)

PARAMETER	*REFERENCE DATA POINT	HGU/55P (AVERAGE)	GEC (MAX)	GEC (MIN)
Head Angular Accel (Y)	2675 Rad/Sec^2	3694*	4037*	3178*
Neck Load X	437 lbs	39	77	250
Neck Load Y	437 lbs	195	171	134
Neck Load Z	----	----	----	----
- Compression	400 lbs	56	125	55
- Tension	551 lbs	575*	970*	928*
Neck Torque (My)	1701 in-lbs	115	186	125
Total Riser Load	N/A (lbs)	2899	3008	3002

*NOTE: These exceed reference data point

O-1f2

HONEYWELL HELMET RESULTS (VERTICAL DROP)

PARAMETER	*REFERENCE DATA POINT	HGU/55P (AVERAGE)	HON (MAX)	HON (MIN)
Head Angular Accel (Y)	2675 Rad/Sec^2	3694*	3866*	2749*
Neck Load X	437 lbs	39	154	146
Neck Load Y	437 lbs	195	238	228
Neck Load Z	----	----	----	----
- Compression	400 lbs	56	42	0
- Tension	551 lbs	575*	693*	555*
Neck Torque (My)	1701 in-lbs	115	301	293
Total Riser Load	N/A (lbs)	2899	3023	2908

***NOTE: These exceed reference data point**

O-1g2

KAISER HELMET RESULTS (VERTICAL DROP)

PARAMETER	*REFERENCE DATA POINT	HGU/55P (AVERAGE)	KAI (MAX)	KAI (MIN)
Head Angular Accel (Y)	2675 Rad/Sec^2	3694*	2234	1890
Neck Load X	437 lbs	39	86	52
Neck Load Y	437 lbs	195	219	143
Neck Load Z	----	----	----	----
- Compression	400 lbs	56	166	110
- Tension	551 lbs	575*	374	333
Neck Torque (My)	1701 in-lbs	115	178	151
Total Riser Load	N/A (lbs)	2899	3121	3059

*NOTE: These exceed reference data point

O-112

PARACHUTE LOADS ASSESSMENT SUMMARY

HORIZONTAL DROPS

AT THE LOWER RISER LOADS (APPROXIMATELY 2000 LBS) ALL SYSTEMS PASS EXCEPT THE BASELINE HELMET.

VERTICAL DROPS

AT THE HIGHER RISER LOADS (APPROXIMATELY 3000 LBS) THE KAISER HELMET PASSES ALL REFERENCE DATA POINTS. THE OTHER HELMETS FAIL ON TWO PARAMETERS (HEAD ANGULAR ACCELERATION AND TENSION NECK LOAD).

SUMMARY

THE BASELINE HELMET (HGU-55/P) APPEARS TO HAVE NO BETTER RESULTS THAN THE I-NIGHTS HELMETS IN THE AREA OF LOADS ASSESSMENT. CLEARLY EJECTION AT THE LOWEST POSSIBLE SPEEDS WOULD REDUCE HEAD/NECK LOADS.

OVERALL TEST ASSESSMENT

- HEAD/NECK LOADS - CRITERIA NEEDS TO BE VALIDATED. BEST TO COMPARE HGU-55/P WITH I-NIGHTS HELMETS.
- HELMET/RISER INTERFERENCE - RISERS DID PUSH THE HEAD FORWARD IN ALL CASES, BUT ONLY SNAGGED ON THE UNMODIFIED HONEYWELL HELMET.
- EYE RELIEF - CONTINUES TO BE A CONCERN WITH ALL VENDOR SYSTEMS. HOWEVER, SOME OF THE COMBINER CONTACT DID OCCUR AFTER THE 1st BOUNCE.
- STRUCTURAL INTEGRITY - ALL HELMETS SUSTAINED MINOR DAMAGE TO BOTH HELMET SHELL AND COMBINERS.
- STABILITY/RETENTION - EJECTION WITH OXYGEN MASK FASTENED TO THE HELMET IS STRONGLY RECOMMENDED.
- BODY SIZE - SMALLER BODY SIZE CONSIDERED HIGHEST RISK DUE TO GREATER PARACHUTE RISER INTERFERENCE.

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