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ADVANCED DEVELOPMENT INVESTIGATION AIRDROP CONTROLLED EXIT SYSTEM (ACES)

BY
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AAI CORPORATION
COCKEYSVILLE, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)												
<p>An advanced development investigation was made on the Airdrop Controlled Exit System (ACES). Ideally, the objective is to permit simultaneous extraction of multiple platform loads based upon the use of hydraulic motion damping between adjacent platforms. Through the study of preliminary data and motion picture films of early tests of simultaneous extraction techniques, certain key problems and their causes were identified. A mathematical model</p> <p style="text-align: right;">(Continued)</p>												

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20. **ABSTRACT (Continued)**

of the extraction and early descent phases of multiple platform groups was developed and programmed for computer analysis. With this new data, engineering drawings and prototype hardware were developed which could be used to modify existing modular platforms.

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AIRDROP CONTROLLED EXIT SYSTEM (ACES)
Advanced Development Investigation

I. INTRODUCTION

Standard procedure for airdropping a number of platform loads from a single cargo aircraft calls for a separate extraction for each cargo. The time lag between each extraction coupled with variations in parachute opening times, aerodynamic configuration, and wind conditions operating on each cargo independently can create large dispersions in the drop zone. Previous studies have been performed which investigated various methods for reducing the time for cargo extraction. Candidate methods included a concept for extracting and recovering groups of platform loads linked together as a flexible unit. This simultaneous extraction technique known as the "rapid extraction system" is an extremely attractive scheme because it eliminates the time delay and resultant dispersion between cargos caused by sequential individual extraction.

The purpose of this advanced development investigation was to conduct a program review, analytical studies, concept formulation and to prepare engineering drawings for a prototype system which would meet the Airdrop Controlled Exit System (ACES) goals. Ideally, this would be a system that would permit the simultaneous extraction of multiple platform loads.

The program began with a review of previous studies as well as data and films from tests of the "rapid extraction system" performed by the Air Force Flight Dynamics Laboratory. Several systems were examined which utilized simultaneous extraction. Some considered simultaneous extraction followed by subsequent separation and recovery of individual cargos. Others were based on the "rapid extraction system" and thus considered group extraction along with recovery of the group as a single unit. Where applicable, analyses of the various concepts were undertaken with computer models. Based on the computer analyses, a prototype system based on the "rapid extraction system" and utilizing a hydraulically damped linkage between platforms presents the best potential for eliminating the dispersion problem for cargo groups of three or less. Cargo groups of more than three could not be modeled within the scope of this contract and thus performance for large groups is a matter of speculation. However, airdropping linked groups of three cargos appears to be a very workable system and consolidating greater numbers of platform loads into groups of three would significantly reduce the overall dispersion.

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I. INTRODUCTION

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II. REVIEW OF GOALS AND REQUIREMENTS

In general, the system developed to meet the ACES requirements would have to satisfy standard military specifications, safety, reliability, serviceability, and human engineering criteria. In addition, the system should utilize as many standard airdrop parts and procedures as possible and require only a minimum of modification to standard hardware when necessary. A partial list of the primary performance and compatibility goals and requirements are as follows:

A. Performance Characteristics

The airdrop system shall be capable of airdropping supplies and equipment weighing up to the maximum allowable rigged platform load weights, in combat serviceable condition to ground combat units in tactical situations from standard and developmental USAF cargo aircraft under the following conditions:

- (1) At an altitude between 750 to 1500 feet (117.5 to 455.0 meters).
- (2) At speeds of 130 to 150 knots (67 to 77 m/sec) EAS.
- (3) In ground winds with velocities from 0 to 15 knots (7.7 m/sec).
- (4) A system reliability (delivery of a serviceable load) of 0.96 is desired as a goal
- (5) The system shall be capable of airdropping supplies and equipment as a single load configuration, or multiple tandem load configurations compatible with the length of the cargo compartment and allowable load weight of the aircraft. The maximum rigged weight of the single load or multiple tandem load configuration shall be 35,000 pounds. The system shall be suitable for use on nominal size drop zones prescribed without extensive ground preparation.
- (6) The system shall facilitate simple and rapid rigging and derigging of loads by troops and minimum use of materials handling equipment.
- (7) The vertical impact velocity shall not exceed a maximum of 28.5 ft/sec (8.6868 m/sec) on a drop zone 5000 ft (1524.0 meters) above sea level and at 100°F (37.8°C).

- (8) The system shall provide for maximum flexibility with respect to center of gravity limitations in positioning loads in aircraft.
- (9) The system shall require no major modifications of standard vehicles or equipment to be delivered and only such minor modifications as can be accomplished by using personnel without special equipment or tools.
- (10) The system shall be suitable for use during adverse weather and night and day operation.

B. Physical Characteristics

- (1) The quantity, weight, and size of system components shall cause minimum loss in cargo carrying capacity of the aircraft in any role.
- (2) The system components shall be designed for use in any of the various standard and developmental aircraft with a minimum adaptation of either the system or the aircraft.
- (3) Platform components shall be of modular construction to provide for the variable lengths required for efficient delivery of supplies and equipment and shall be compatible with the following airdrop platforms:
 - Type 5 Joint Service Platform
 - Metric Platform
 - Type II Modular Platform

(compatibility with the Type II Modular platform was not a strict requirement)
- (4) Parachute components shall be compatible with standard items to the maximum extent possible.
- (5) System components that are subject to an extraction force shall have a safety element to prevent danger to the aircraft in the event of extraction system failure.
- (6) The design of the system shall be such that no components need be retrieved into the aircraft after the airdrop of supplies and equipment.

- (7) The design of the system shall be such that visual inspection to confirm the proper connection of extraction and suspension lines/linkages for operational readiness is possible at any time prior to use.
- (8) The system shall consist of materials which are inexpensive, non-strategic, and non-critical.
- (9) No system component shall contact the aircraft skin before, during, or after it has completed its function.

III. BACKGROUND/APPROACH TO THE PROBLEM

The program began with a review of analytical studies and published test data related to ACES. Many methods can be used to reduce the dispersion of platform loads including various techniques for trajectory control and reduction of the extraction delay between individual cargos. A study done for the Army by MB Associates¹ revealed that a technique for extraction and recovery of groups of platforms linked as a flexible unit and known as the Rapid Extraction System (RES) had the best potential for eliminating, or greatly reducing, cargo dispersion in the drop zone. Other techniques such as combining several loads on one large platform, sequential extraction of several platforms with one extraction parachute, and variably reefed recovery parachutes provided some improvement in overall reduction of dispersion, but not as effectively as the RES.

Feasibility tests of the RES were conducted by the Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio². The tests were of a simplified system in which three interconnected platforms were extracted and recovered as a single unit. The test arrangement allowed the use of three 12-ft platforms in the 40-ft length of a C-130B aircraft.

In general, the technique for multiple-cargo group-extraction and recovery proved to be feasible. However, a major problem revealed by the tests concerned oscillations of the platform loads after they left the aircraft. Extreme rotation of the third platform (last to exit the aircraft) caused it to close on the middle platform and produced direct, violent impact of the cargos as shown in figure 1. In some cases during these tests (and others), the rotation and impact was so violent that the linkage between the platforms was broken. In one case, the third platform became entangled in the parachute suspension slings and caused a disoriented ground impact that would have destroyed conventional cargo loads.

At first, it appeared that the violent platform rotation and cargo impact was caused by the snatch force of the recovery parachutes on the third platform to exit. Several schemes were considered for modifying the suspension system so that the force from the suspension lines would be distributed

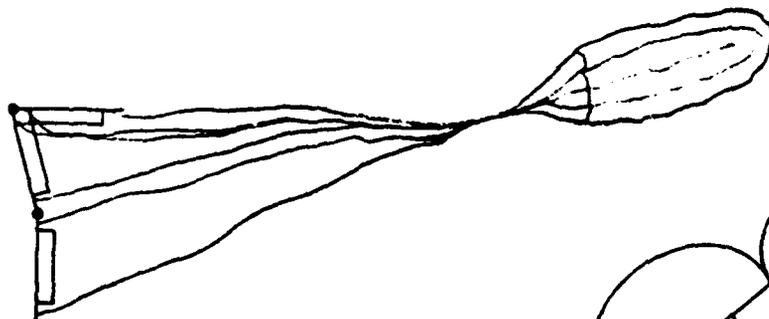
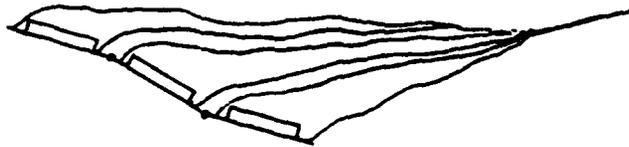
- ¹ G.L. Fritzler; "Airdrop Controlled Exit (ACE) System"; MB Associates; San Ramon, California; Tech Report 74-38-AD; July, 1973.
- ² J.E. Leger; "Feasibility Investigation of Multiple Platform Extraction and Recovery Technique for Airdrop Operations"; Air Force Flight Dynamics Laboratory, Air Force Systems Command; Wright-Patterson AFB, Ohio; Tech Memorandum AFFDL-TM-73-133-FER; November, 1973.



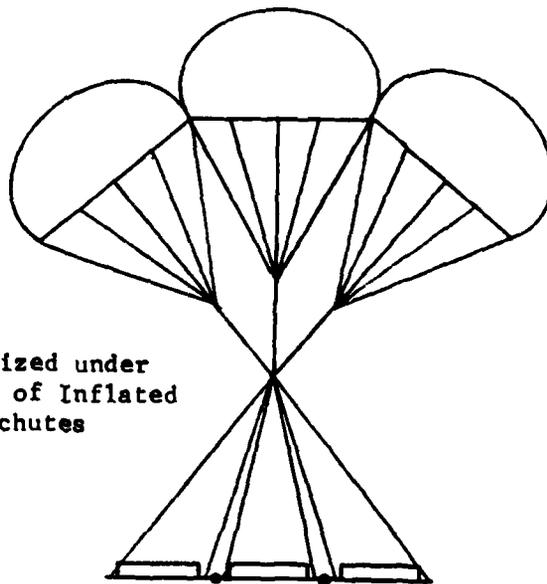
Extraction and Force Transfer



Deployment of Recovery Parachutes Begins



Flip-over and Impact of Cargos 2 and 3



System stabilized under the influence of inflated Recovery Parachutes

Figure 1

Typical Progression of RES Airdrop Without Inter-Platform Restraint

evenly, regardless of the platform orientation. However, closer study of test films revealed that the severe rotation occurred before the recovery slings actually became taut. Subsequent analysis showed that the primary causes of the violent rotation of the last platform to leave the aircraft were the increased tip off torque caused by the weight of the first cargos out hanging onto the last one, and the aerodynamic forces on the cargos after they entered the airstream.

The first cargo to leave the aircraft tips out under the influence of its own weight as in a conventional extraction procedure. The second platform in the "train" tips under the influence of its weight plus the weight of the first cargo acting as a dead weight attached to the edge. This increases the rotational velocity of the second cargo. However, the fact that the third cargo in the train is also attached to the opposite edge of the second cargo prevents the second cargo from rotating into the first. The third (or last) cargo to leave the aircraft tips under the influence of its own weight plus the effective weight of the first two cargos acting as a concentrated load on the unsupported edge. Thus, the rotational velocity of the last cargo is greatly increased and because its trailing edge is unrestrained, it is free to rotate about the link between it and the second cargo in a "crack-the-whip" manner. The problem is compounded when the platform group enters the airstream. Lift and drag forces on the platform are significant, and because one edge of both the first cargo and last cargo to leave the aircraft is unrestrained, the platforms are free to rotate about the middle cargo. The effect of aerodynamic forces on the last cargo superimposed with the accentuated tip off velocity creates a large angular velocity relative to the middle platform.

Although the initial violent rotation and impact of the cargos would be sufficient to cause extensive damage, the test films illustrated that the subsequent influence of the inflated recovery parachutes does a fine job of stabilizing the cargo group and results in a normal ground impact. For this reason it was felt that, if the initial post-tip-off rotation and impact could be averted or delayed by restraining the motion of the platforms, the RES concept would be an excellent system. Finding an effective restraint technique became the main thrust of the concept investigation phase of the program. It was essential that platform-group flexibility be maintained in the negative (tip off) direction to avoid interference problems with the aircraft during tip off. It was also necessary to find a technique that would provide sufficient retarding torque over a wide range of cargo weights and airdrop conditions. Early

government-tests, discussed above, included experimentation with rotational constraints such as "bending-bars" and "torsion-bars" used in the linkage between platforms. These techniques proved to be inadequate. They yielded and/or fractured allowing cargo impact. It was decided to consider hydraulics as an alternative because of its energy dissipation characteristics and its functional relationship to the relative velocity of the cargos.

In addition to concepts for reducing relative cargo rotation, several schemes were considered which employed group extraction with post-tip-off platform separation for individual recovery of the cargos. Where applicable, computer modeling was used for analysis of the concepts. A two-dimensional trajectory model was used for studying the group-extraction-separation techniques. A simple two-dimensional model was developed to examine the relative motion of the platforms for the RES. It must be noted here, and reemphasized elsewhere in this report, that the computer models used were not highly rigorous, exact simulations of the performance of either the group-extraction-separation or RES techniques. Thus they were not intended to be used as exact predictors of system trajectory performance, but as tools for assessing the relative performance of candidate techniques and for prototype design.

The analyses emphasized groups of three platforms or less. The primary reason for this is that there was some test data available for three-cargo RES configurations with which the simplified computer model could be verified. There were no data available concerning the performance of four-cargo groups and thus the validity of extrapolating the simplified model could not be checked. In addition, the length of aircraft cargo compartments limited the majority of feasible platform groups to two or three. Consideration of eight-foot long platforms was eliminated from study as per government instructions and groups of greater than three 12-ft platforms are not feasible for the C-130 aircraft. Groups of four 16-ft platforms and five 12-ft platforms are possible in the C-141, but it was felt that development and verification of a math model of sufficient sophistication to predict the performance of large groups could not be performed within the scope of this contract.

The following sections describe the techniques considered to satisfy the ACES requirements and the results of the analyses. A more detailed description of the math model and results for the recommended configuration is given in Sections IV.A. and IV.B.

IV. TECHNICAL DISCUSSION

A. Group Extraction/Individual Recovery

1. Assumptions

Several concepts were explored for a controlled exit scheme in which platform cargos would be extracted as a single unit, but subsequently separated for individual recovery. Two basic approaches for separation were considered possible. The platforms could either be separated simultaneously shortly after tip-off of the last cargo, or the platforms could be separated sequentially. Likewise, the recovery parachutes for each platform could either be deployed and inflated simultaneously or sequenced to avoid interference problems during inflation. Several concepts were eliminated after a cursory examination because of obvious major problems. For example, it was assumed that simultaneous separation with immediate full deployment and inflation of the main recovery parachutes would not be practical because of the possibility of interference created when parachutes for several different platforms inflated in very close proximity as the platforms fell virtually uncontrolled along the same trajectory. However, two techniques for simultaneous separation with delayed/sequenced inflation of the recovery parachutes were studied. Similarly, it was assumed that delayed/sequenced inflation should progress from the aft-most cargo to the foremost (from first to leave aircraft to last). Separating the foremost cargo first and inflating its parachutes presents the danger of following cargos crashing through the inflated parachutes and cargo unless inflation times and trajectories could be planned and controlled very accurately. Sequentially separating the aft-most cargo does not present this problem.

Concepts were evaluated by using a two dimensional trajectory computer program plus manual calculations to determine the performance for each platform/cargo. These were subsequently superimposed and combined graphically to determine the overall performance of the group. Parachute data such as inflation times were "ideal" values calculated with equations in "Performance of and Design Criteria for Deployable Aerodynamic Decelerators".³ Performance of the various concepts was evaluated for one set of representative cargo weight/platform length data for comparative purposes. Thus, the results reflect ideal nominal values. No attempt was made to perform a detailed sensitivity analysis although limiting values based on variation in parachute inflation times were considered. Nevertheless, the results indicate the relative merit of the concepts from the standpoint of cargo separation.

³ "Performance of and Design Criteria For Deployable Aerodynamic Decelerators"; Air Force Flight Dynamics Laboratory, Air Force Systems Command; Wright-Patterson AFB, Ohio; Tech Report No. ASD-TR-61-579; December, 1963.

Many of the conditions which would be encountered during actual airdrop conditions could not be considered in the idealized evaluation. These conditions could present severe problems when trying to separate groups of platform cargos for individual recovery. They are presented here so that they can be considered when reading the discussions of various concepts.

(a) Platform cargos are basically unstable configurations as shown by government tests and contractor wind tunnel tests under contract number DAAK60-77-C-0073.⁴ During the transition period when parachutes are being deployed, the cargos are falling uncontrolled. If cargos are in very close proximity, slight variations in aerodynamic properties, angular momentum, etc., could cause interference and collisions.

(b) Problems created by group extraction such as excessive rotation of the last cargo out of the aircraft illustrated by test data for group extraction/group recovery techniques could still be significant even if cargos are separated after tip-off. If the connection between cargos is maintained for several seconds after tip-off, the behavior of the cargo group would be basically the same as that for the RES group recovery scheme during parachute deployment. That is, the problem of rotation and collision of the last cargo would still be present. If the cargos are separated immediately after tip-off, the angular momentum and aerodynamic forces associated with the last cargo could still cause it to collide with other units.

(c) The effects of winds on cargos with various size parachutes or parachutes at various stages of inflation could serve to either increase or decrease spread between cargos separated and recovered individually.

(d) Timing devices or altitude sensing devices used in sequenced separation schemes cannot be expected to be exact. Allowing for variations in these devices would necessitate providing a safety factor in the drop height above ground to guarantee complete separation and recovery parachute inflation. Use of lanyards for positive initiation of sequenced events would help solve this problem.

(e) The variation in parachute inflation times from one airdrop operation to the next as well as variation among cargos of the group can have a significant effect on the spread of cargos within a group. This is particularly true if sequence events are keyed to specific parachute inflation criteria.

⁴ A.L. Farinacci and W.L. Black; "Exploratory Development of a High Level Airdrop System for Platform-Mounted Cargos"; AAI Corporation, Cockeysville, MD; Contract No. DAAK60-77-C-0073; February, 1980.

analysis:

The following assumptions were used in performing the

- A group of three 6000-lb (2724 kg) cargos of 12-ft platforms was used as a representative configuration for comparative purposes.
- The main recovery parachute configuration for each cargo was assumed to be two G-11A flat circular canopies.
- The initial indicated airspeed of the cargo group at tip-off was 200 fps (61 m/sec).
- The average separation velocity between the extraction velocity and cargo during deployment of the mains was 175 fps (53 m/sec).
- The length of the main suspension lines were 100 ft (30.4 m) and the deflated parachute radius was 50 ft (15.2 m) resulting in a deployment separation distance of 150 (46 m) ft.
- Theoretical filling time for the mains was calculated according to the equation:

$$t_f = \frac{2 D_o}{3\pi V_s (9/70 - C/3)}$$

Where:

D_o = nominal canopy diameter

V_s = velocity at beginning of inflation

C = effective porosity value (assumed value = .06)

Ref: "Performance of and Design Criteria For Deployable Aerodynamic Decelerators" ASD-TR-61-579 (page 163, reference 3)

Substituting, the minimum theoretical inflation time for the 100 ft. diameter parachute at $V_s = 200$ fps (61 m/sec) is:

$$t_f = \frac{2(100)}{3\pi(200) (9/70) - .06/3} = 0.977 \text{ sec} \approx \text{sec}$$

In practice, the filling time could be much longer. The maximum filling time considered in this analysis was based on the ratio of observed actual filling times to theoretical filling times for geometrically porous parachutes presented in ASD-TR-61-579, page 163. It was assumed that the same ratio would apply for solid cloth parachutes. The maximum filling time for an unreefed G1A was considered to be

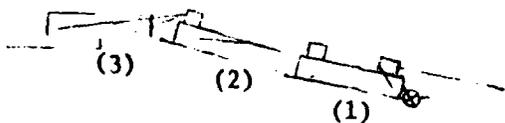
$$t_{fm} = 3.75 (1.0) = 3.75 \text{ sec}$$

- The relationship between the ratio of instantaneous parachute diameter to nominal diameter (D/D_0) and the ratio of time to filling time (t/t_f) was as presented in ASD-TR-61-579, page 151.

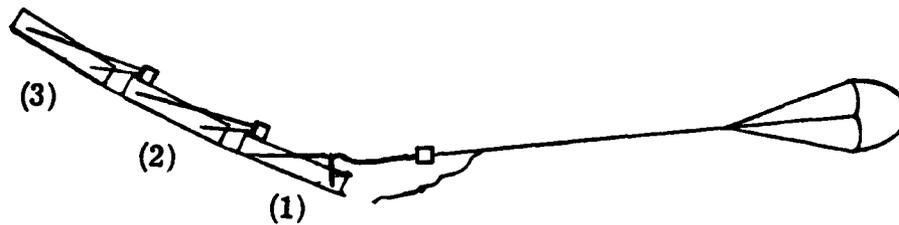
2. Group Extraction/Sequential Separation (First Out/First Inflated):

The following sequence of events illustrates this concept.

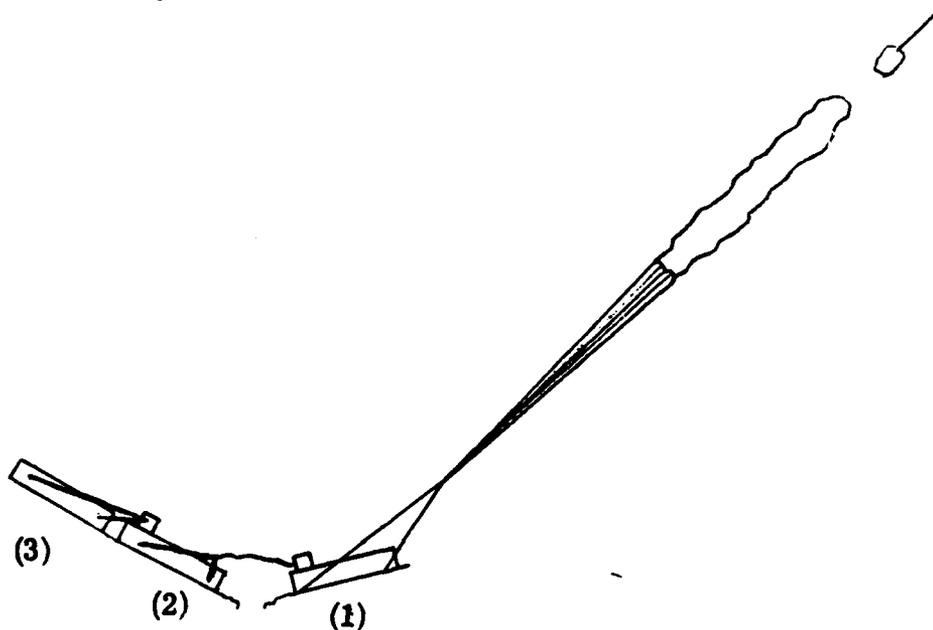
(a) Cargos are extracted as a group. The recovery parachutes for cargo (3) are rigged on cargo (2). The recovery parachutes for both cargo (2) and cargo (1) are rigged on cargo (1). The cargos are either directly connected with cables, or load-bearing platforms are connected with cables or releasable latch mechanisms. If cables are used, they may be equipped with explosively actuated cable cutters or a mechanical latch/release mechanism. The mechanisms for initiating the cable cutters or releasing the latch are the main recovery parachute recovery slings. The slings are tied to the platform with break cords so that they cannot extend until the main recovery parachutes for the relevant cargo are fully deployed and start to inflate. Full extension of the main suspension slings could either pull an auxiliary line connected to a latch-release/shear-pin, actuate a mechanical firing pin mechanism, or generate a current through an electro-mechanical firing device to initiate a squib in a cable cutter. The extraction parachute is connected to the cargo/platform group through a 35K load transfer device.



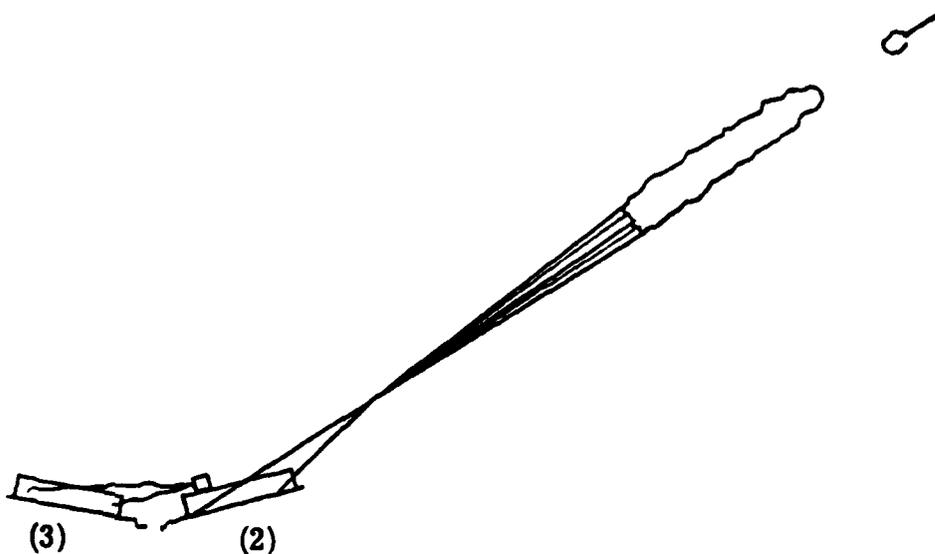
(b) As soon as the last cargo tips out of the aircraft, extraction parachute load is transferred to the recovery parachute bags to begin deployment. Recalling assumptions (d) and (e), the average separation velocity during the 150 ft (46m) line and parachute extension is 175 fps (52 m/sec) yielding a deployment time for the cargo (1) recovery parachutes of 0.86 sec.



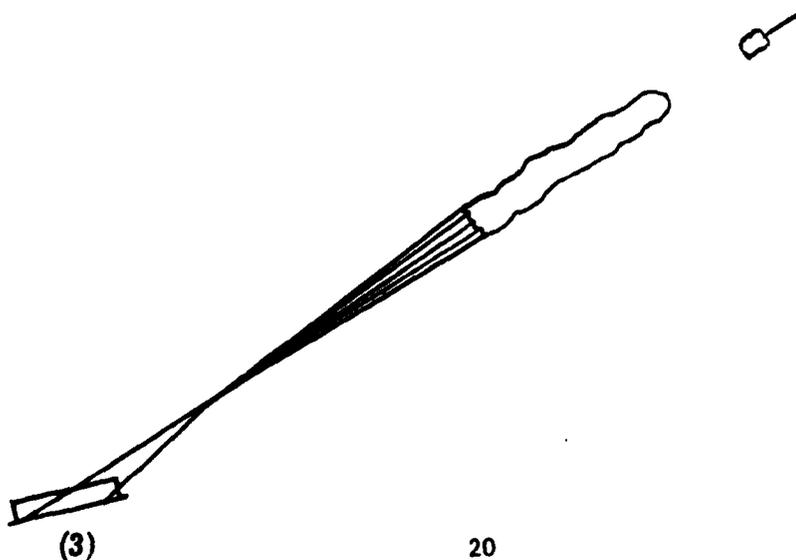
(c) As soon as the cargo (1) parachutes start to inflate, cargo (1) is released from cargo (2) and begins to separate; extending the cargo (2) recovery parachutes. The separation time depends on the rate at which the cargo (1) recovery parachutes inflate. If a one-second inflation time is used, the separation time is 1.25 sec. If a 3.75-second inflation time is considered, the separation time is 2.45 sec.



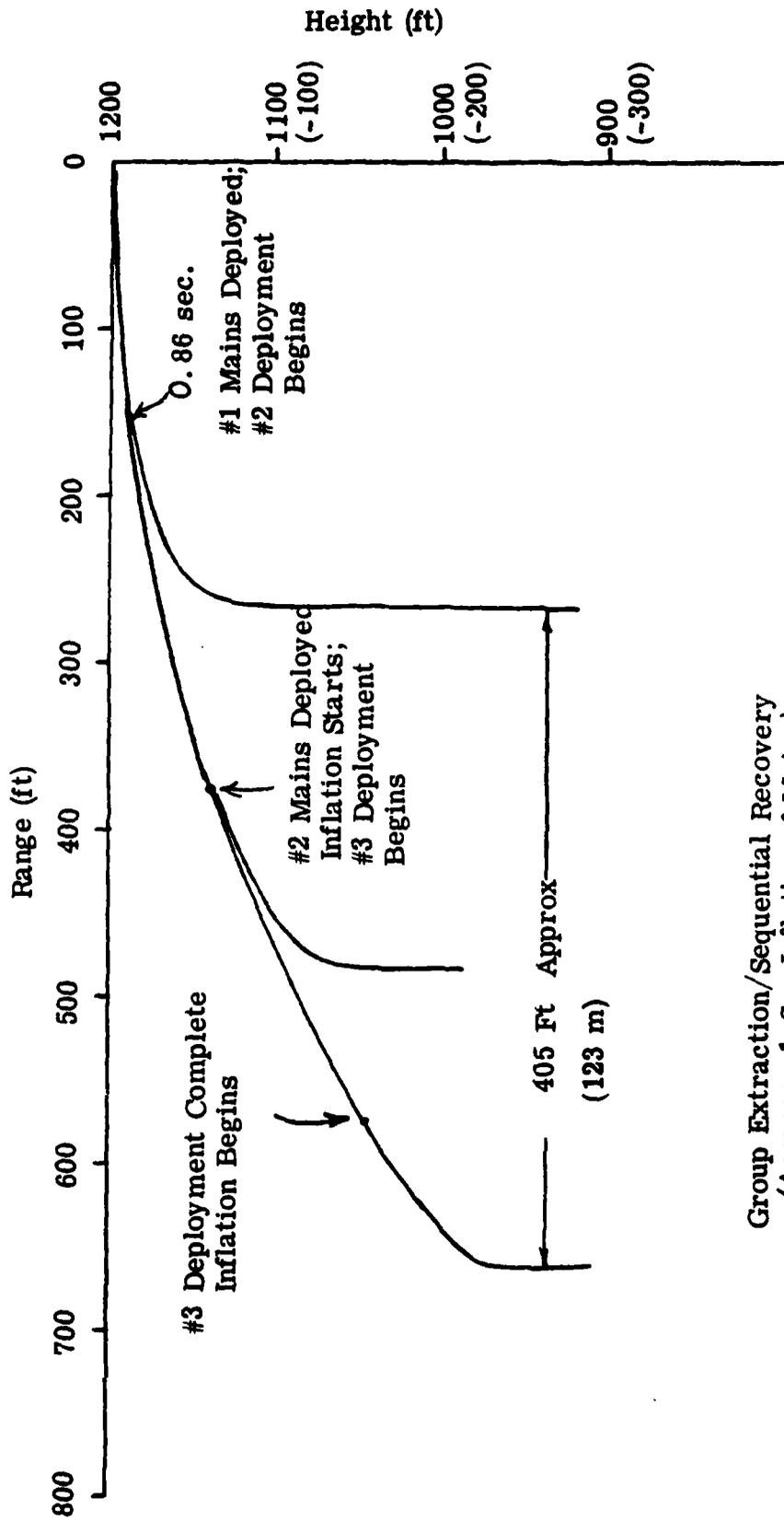
(d) When the cargo (2) recovery parachutes begin to inflate, cargo (2) is released from cargo (3) recovery parachutes in the process. Again, the separation time depends on the inflation time of the cargo (2) parachutes. The velocities are such that the separation times for cargos (2) and (3) are very close to the separation times for cargo (1) and the (2)-(3) group and so the times were assumed to be the same. Separation time is 1.25-seconds for one-second inflation and 2.45 seconds for 3.75-second inflation.



(e) When separation of cargo (2) and cargo (3) is complete, the recovery parachutes inflate. The composite trajectory for one-second inflation times and 3.75-second inflation times are shown in Figures 2 and 3. Note the difference in scale. The total separation distance considering one-second inflation (the theoretical minimum) is approximately 405 ft (123 m). The total spread for 3.75-second inflation time is 730 ft (223 m). Allowing for a 3.75-second inflation time for each cargo, the minimum vertical distance required for inflation of the 3-cargo group is about 750 ft (229 m).

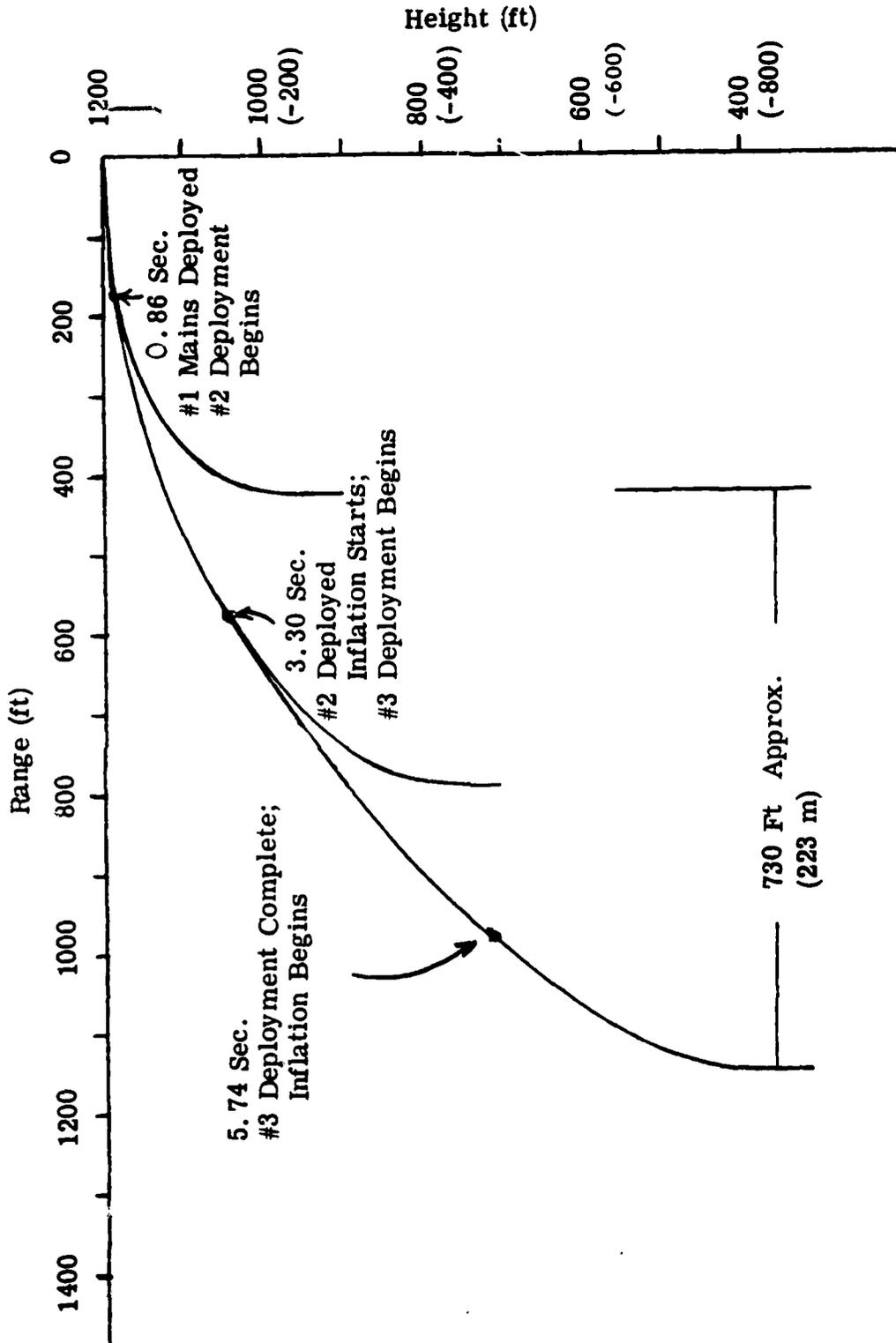


It must be noted that some of the problems inherent to group extraction such as rotation of the last cargo into the preceding cargos would be present in this scheme. If some restraint method were necessary to prevent cargo (3) from rotating and crashing into cargo (2), then there would be no reason to separate the cargos. They could be recovered as a connected group. Therefore, the group extraction/sequential separation scheme appears to have only limited merit.



Group Extraction/Sequential Recovery
(Assumes 1-Sec Inflation of Mains)

Figure 2



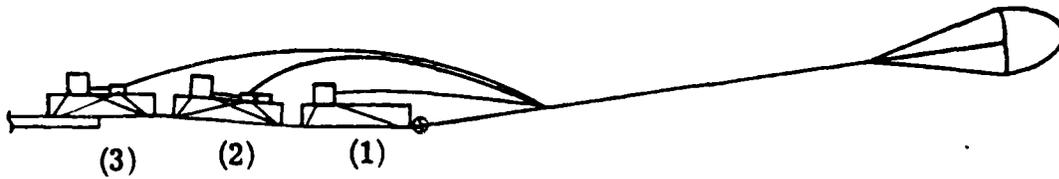
Group Extraction/Sequential Recovery
 (Assumes 3.75 Sec. Inflation of Mains)

Figure 3

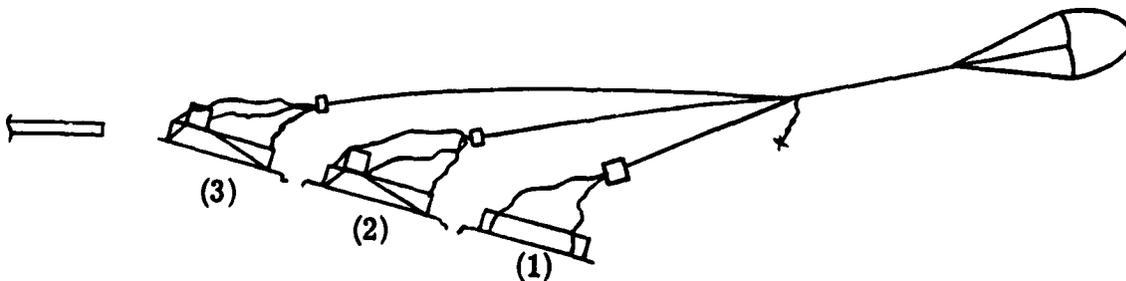
3. Simultaneous Separation/Two-Stage Recovery

This technique makes use of small diameter pilot parachutes during simultaneous separation to maintain cargo stability while avoiding potential interference problems of fully inflated recovery parachutes:

(a) Cargos are extracted as a group. They are connected as described in Section IV.A.2. Recovery parachutes are rigged on their respective cargos. In addition to the recovery parachutes, cargos (2) and (3) are equipped with 22-ft diameter ringslot pilot parachutes; one on cargo (3), two on cargo (2). The smaller diameter pilot parachutes are necessary to stabilize the cargos between the time that the platforms are disconnected and enough separation develops to deploy and inflate the main recovery parachutes. Deployment lines for cargo (2) and (3) pilot parachutes as well as cargo (1) main parachutes are connected to the extraction line.

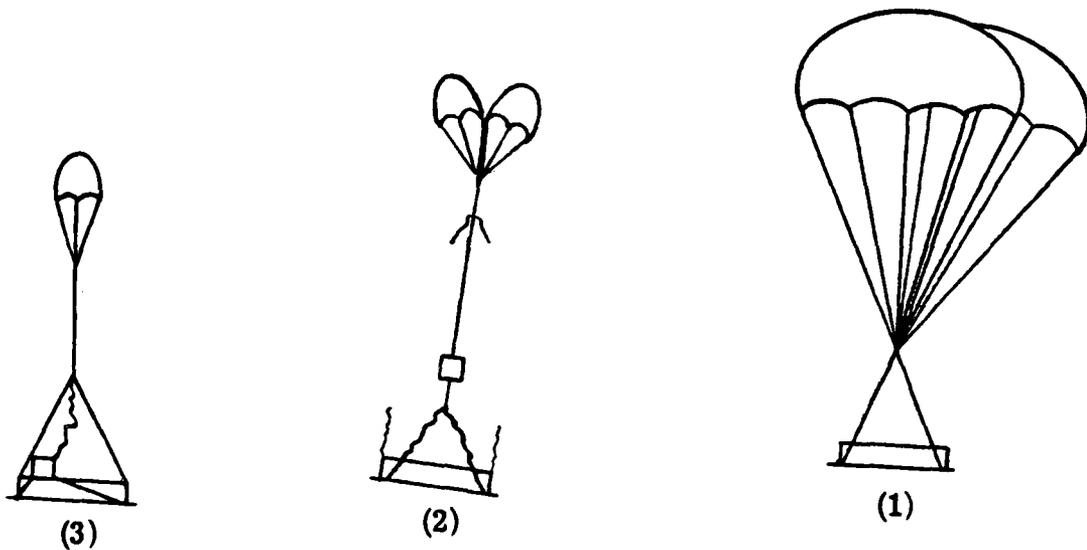


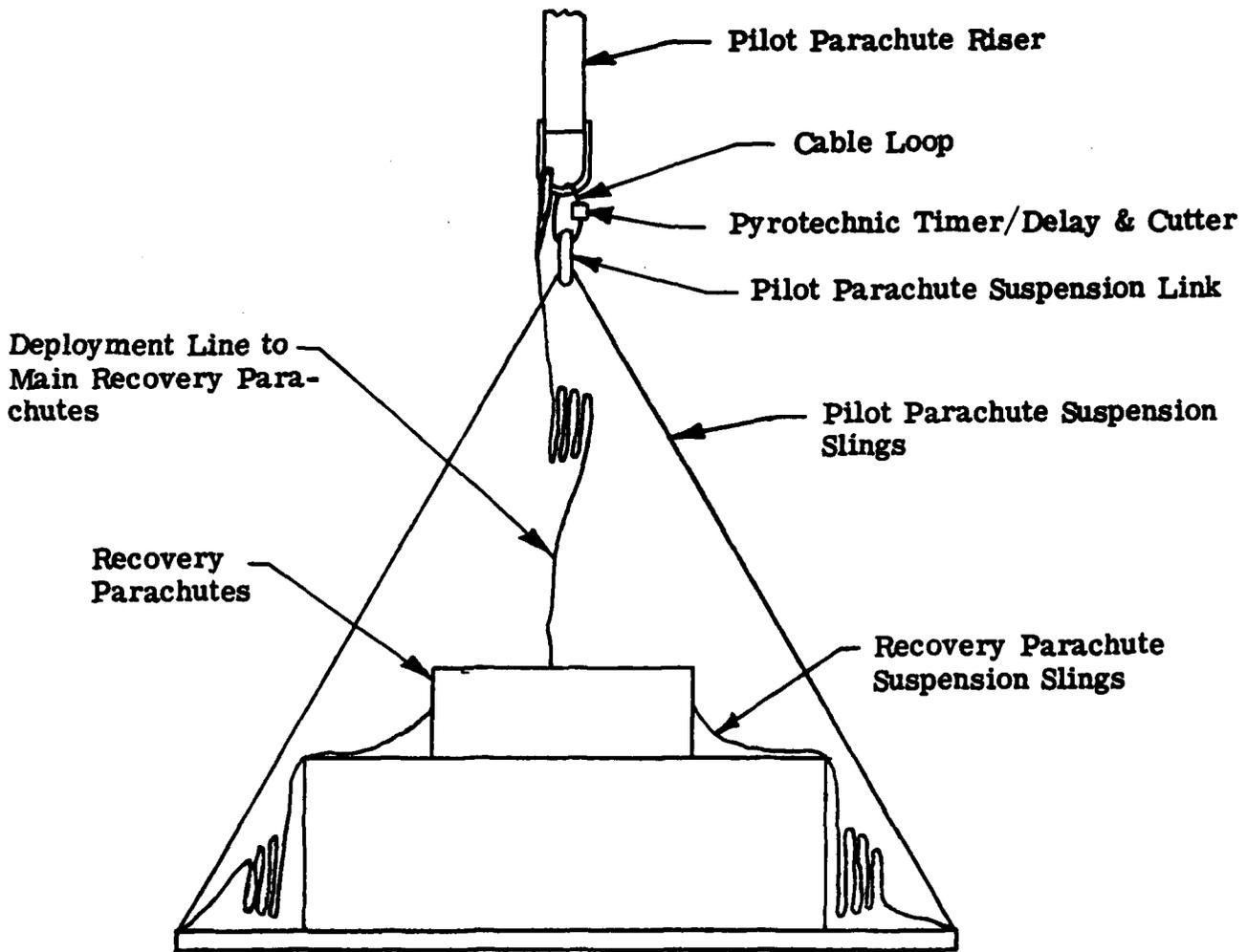
(b) After tipoff of the last platform, the platforms are disconnected and extraction force is transferred to deploy the pilot parachutes for cargos (2) and (3) and the recovery parachutes for cargo (1). The suspension lines and risers for the pilot parachutes must be sized so that deployment for all parachutes occurs simultaneously. Deployment time is 0.86 seconds. From information in ASD-TR-51-579 cited earlier, the filling time for the pilot parachutes may vary from 0.66-2.48 seconds.



The pilot parachutes are suspended from the same cargo suspension points as the main recovery parachutes. The pilot parachute suspension slings are connected to the riser through a cable loop equipped with a ballistic cutter and delay. This arrangement is illustrated in Figure 4.

(c) Cargo (2) and cargo (3) fall under the influence of the pilot parachutes until enough separation is developed to allow deployment of the mains. It is assumed that one second after the pilot parachute for cargo (2) is inflated, the timer activates the cutter in the cable loop to the pilot parachute riser, allowing the main recovery parachutes to deploy and inflate.

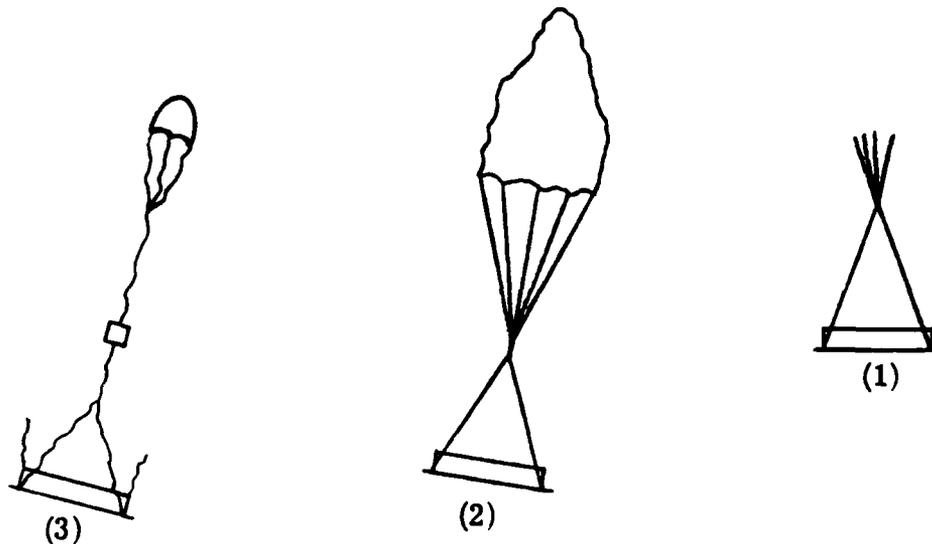




Attachment of Pilot Parachute

Figure 4

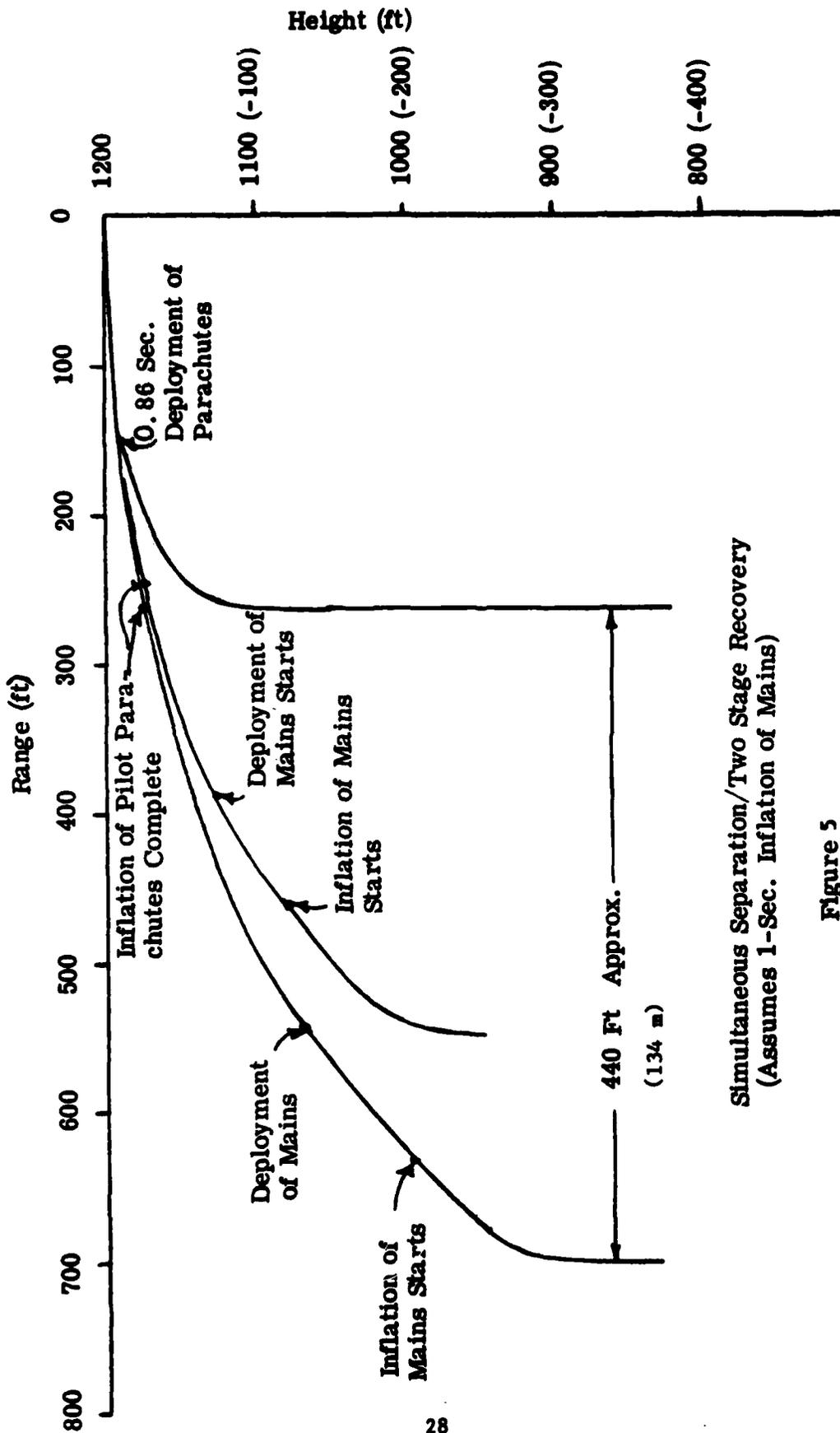
(d) Two seconds after the cargo (3) pilot parachute is inflated, the cable loop is cut and the main recovery parachutes are deployed.



The composite trajectory for a three cargo system assuming the minimum inflation time for the pilot parachutes (0.66 sec.) and the main recovery parachutes (1.0 sec.) is shown in Figure 5. The minimum spread possible is on the order of 440 ft (134 m). Longer inflation times for the parachutes would increase the spread. The use of timers in the system adds variability in the deployment sequence that would affect dispersion. In the time range of 2 to 4 seconds after tip-off (where second stage sequencing takes place), the spread would increase about 100 ft (30.5m) for a one-second increase in delay for cargo (2) sequencing and 120 ft (37 m) for cargo (3).

4. Simultaneous Separation/Delayed Disreef Recovery

This scheme is very similar to the two stage system previously discussed except reefed main recovery parachutes are used to stabilize cargos during separation rather than pilot parachutes. The advantage is that it eliminates the need for a second "free fall" condition during the deployment of the mains by the pilot parachutes.



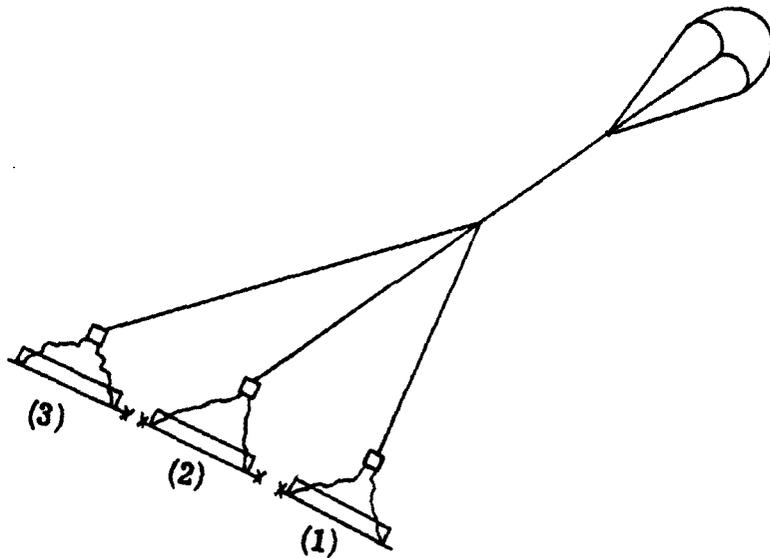
Simultaneous Separation/Two Stage Recovery
(Assumes 1-Sec. Inflation of Mains)

Figure 5

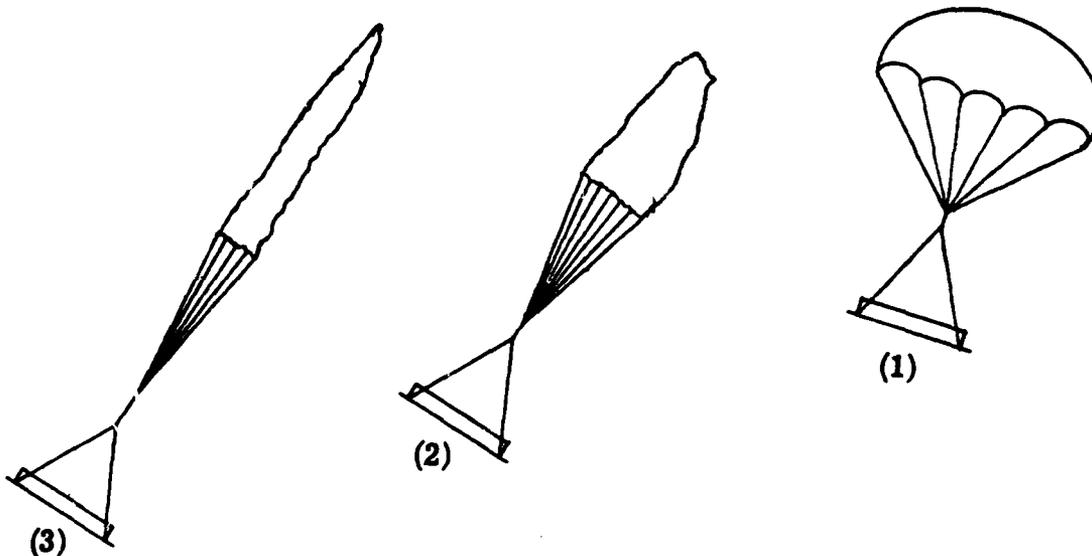
(a) Cargos are extracted as a group. Recovery parachutes are rigged on their respective cargos. Deployment lines for each recovery parachute are connected to the extraction line.

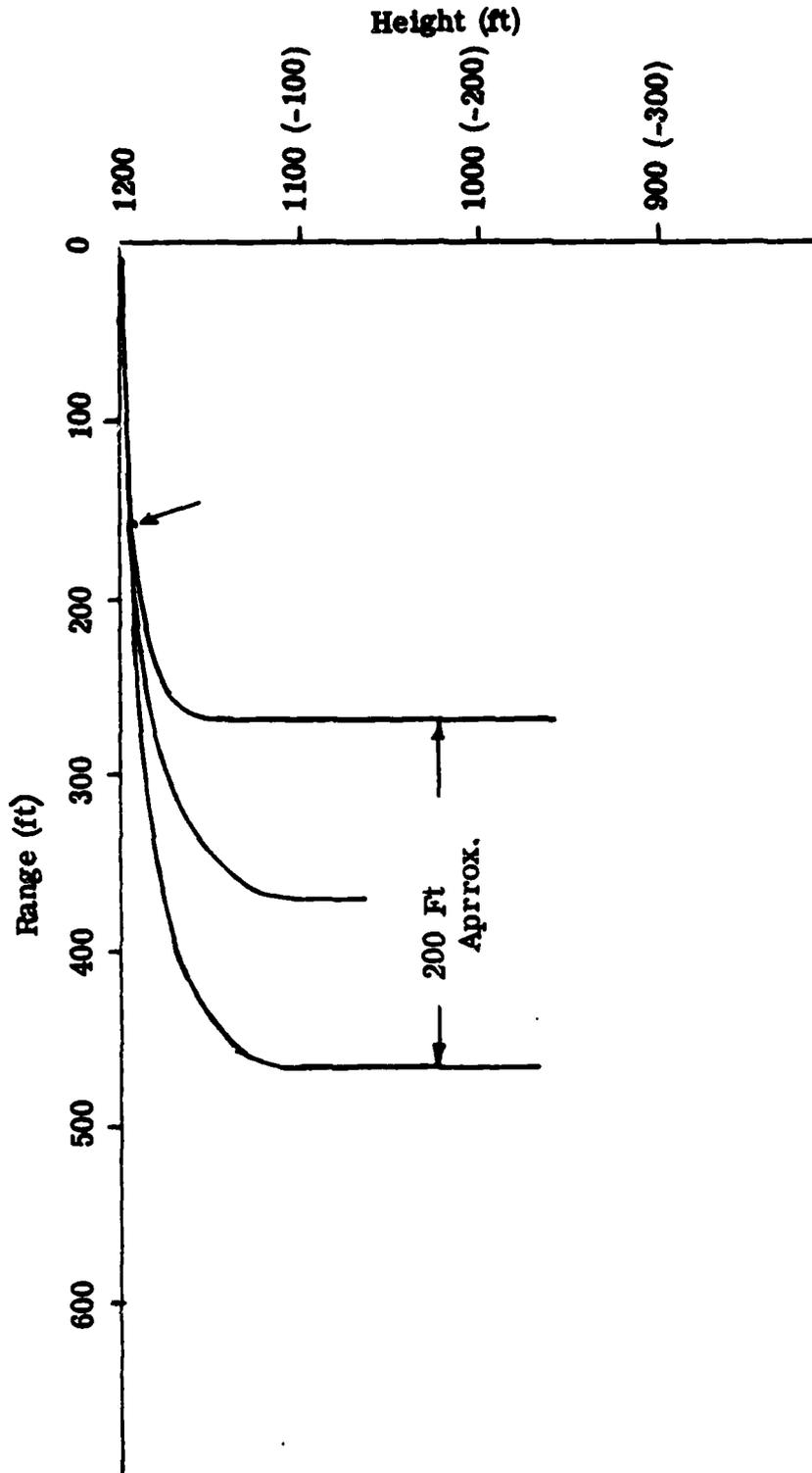


(b) As soon as the last cargo tips out of the aircraft, the cargos are disconnected and extraction load is transferred to the deployment lines of the main recovery parachutes.



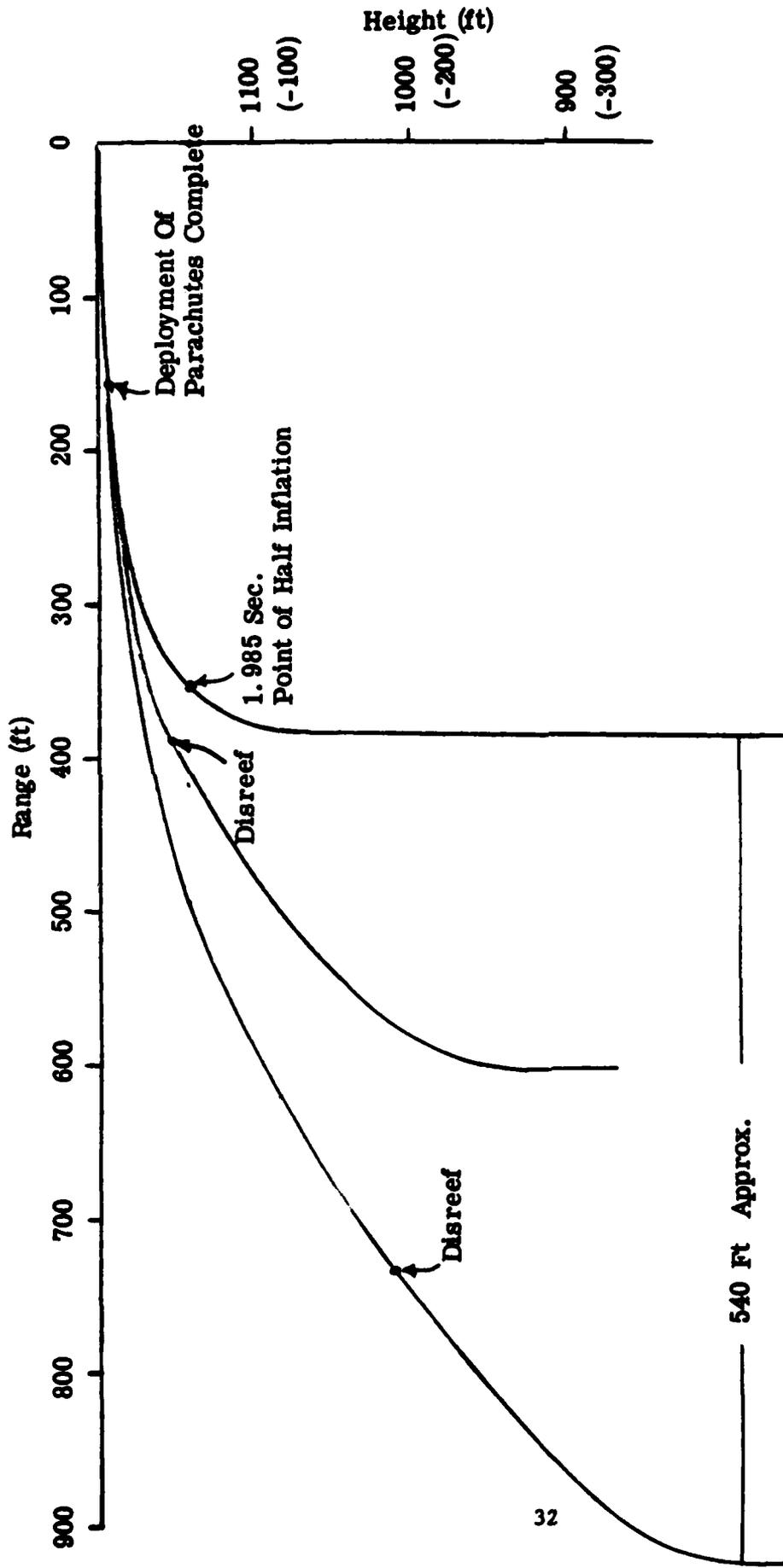
(c) Deployment of all of the parachutes occurs simultaneously after 0.86 sec. However, the cargo (2) recovery parachutes are reefed to a 16-ft diameter and cargo (3) parachutes are reefed to an 8-ft diameter. The reefing lines contain ballistic cutters and pyrotechnic delays that are armed when the suspension lines are fully deployed. Cargo (1) parachutes are allowed to inflate immediately. At a time keyed to approximately the half inflation condition of cargo (1), the timer in cargo (2) initiates the reefing line cutter and allows cargo (2) recovery parachutes to inflate. At a time corresponding to about half inflation of cargo (2), the reefing line in cargo (3) recovery parachutes is cut allowing full inflation. If a one-second inflation time is assumed for the recovery parachutes, the pyrotechnic delay for cargo (2) is 0.5 sec. after full deployment and the delay for cargo (3) is one second. If an inflation time of 3.75 seconds is used, the delay for cargo (2) is 1.875 sec. after full deployment and 3.75 sec. for cargo (3). The composite trajectories for these two conditions are shown in Figures 6 and 7. The absolute minimum spread when considering one-second inflation is about 200 ft. The minimum for 3.75-second inflation is about 540 ft. Both are also subject to variations in reefing, line-cutter timer delay as well as other variables.





Simultaneous Separation/Delayed Disreef
 (Assumes 1-Sec. Inflation of Mains)

Figure 6



Simultaneous Separation/Delayed Disreef
(Assumes 3.75 Sec. Inflation of Mains)

Figure 7

B. Group Extraction/Group Recovery; Rapid Extraction System

1. General

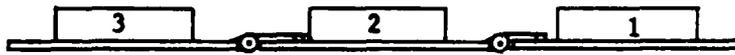
Although the group extraction/group recovery rapid extraction system has the greatest potential for eliminating cargo dispersion, it has the problem of severe cargo oscillations and possible cargo impact within the tandem group. For the system to be operational, the violent rotation between cargos must be prevented or attenuated. An attempt was made toward this end in one series of tests conducted by the Air Force⁵. Groups of three 6000-lb (2724-kg) cargos on 12-ft platforms were linked in tandem for the tests. A torsion tube was used in the linkage to provide resistance to cargo rotation in the positive (cargo collision) direction. Cargos were allowed to rotate freely in the negative direction to avoid any problems during tip-off. Torque could be transmitted only for positive relative angles, i.e., after the cargos passed the vertical or "straight line" configuration. This is illustrated schematically in Figure 8.

The largest torque tube used in the Air Force tests was designed to provide 10,000 ft-lb (13600 N-m) of torque at a 20-degree rotation. Unfortunately, the system failed catastrophically. The third cargo (last to leave the aircraft) rotated approximately 100 degrees positively around the middle platform. In the process, the torque tube was permanently twisted 50 to 60 degrees, the main tube section was warped, most of the mounting pins for the torque tubes were sheared, and there was still enough residual relative rotational velocity to cause a violent impact to the cargos.

The fact that the platforms were free to rotate in both directions for negative relative angles and that no restraining torque was provided until the platforms rotated past the neutral position is the key to why the early tests of the torque tube failed catastrophically. With no restraint provided during the time from which the last cargo tips out of aircraft until it reaches a neutral angle with respect to the middle cargo, the aerodynamic forces on the platforms can add to the rotation induced during tip-off to create a large relative angular velocity between the third and middle cargo. The kinetic energy carried by the third cargo under these conditions becomes quite large.

⁵ P.J. O'Brien; "Evaluation Tests of the Type V Airdrop Platform and Associated Hardware"; Directorate of Crew and AGE Engineering, Air Force Systems Command; Wright-Patterson AFB, Ohio; Tech Memorandum ENCM-TM-75-3; July, 1975.

Direction of Extraction



Neutral Position

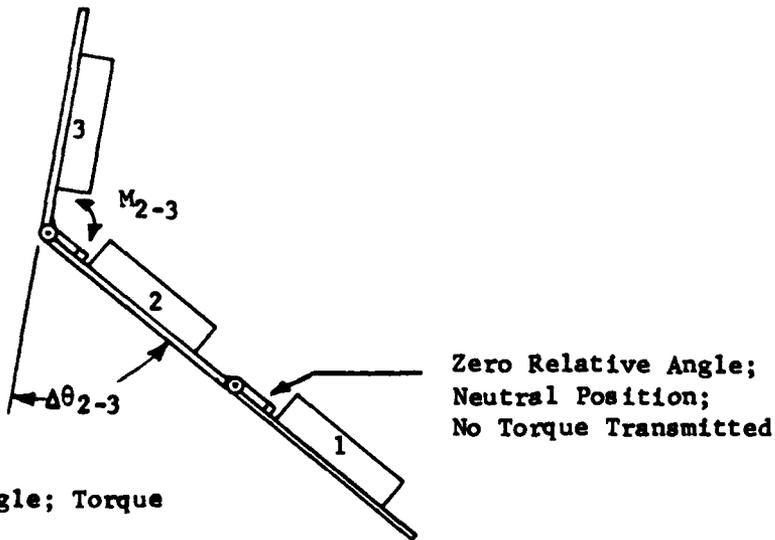
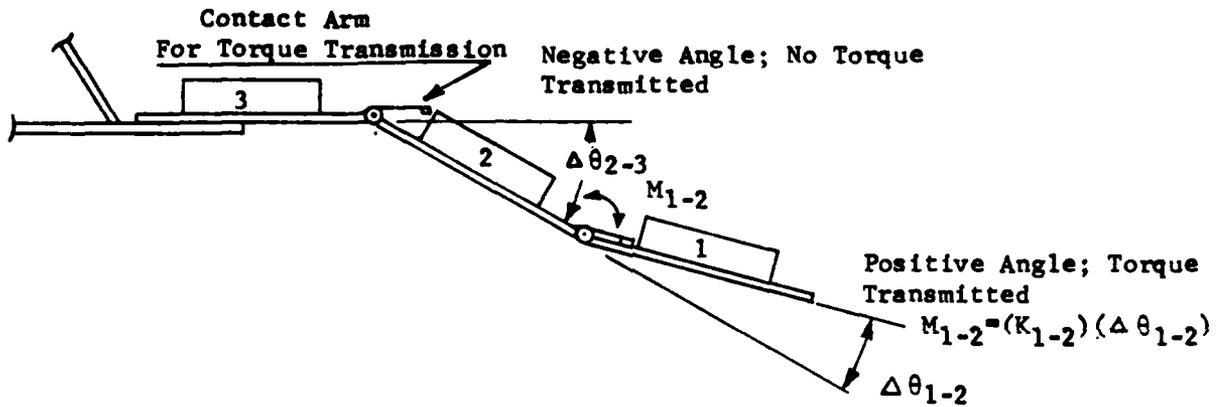


Figure 8

Schematic Effect of Torsion Bar Rotational Restraint

For example, the elastic and permanent plastic deformation in the torque tubes used in the Air Force tests indicate that the work done in deforming the torque tube was approximately 10,450 ft-lb (14212 N-m), found as follows:

$$E_D = 1/2 T_E \theta_E + T_P \theta_P$$

where

- E_D = energy of deformation (ft-lb)
- T_E = maximum torque provided in the elastic range (ft-lb)
- θ_E = elastic angular deflection (radians)
- T_P = yield torque (ft-lb)
- θ_P = plastic angular deflection (radians)

Assuming that the 20 degree (0.35-radian) design angle specified for the torque tube was the elastic limit, the energy absorbed considering a 50 degree (0.87-radian) permanent deformation was;

$$\begin{aligned} E_D &= 1/2(10000)(0.35)+(10000)(0.87) \\ &= 10450 \text{ ft-lb (14212 N-m)} \end{aligned}$$

Added to this must be the energy used to shear the mounting pins and to warp the tube laterally plus the residual energy of cargo impact. A computer simulation run by AAI to match the 6000 lb-cargo test conditions indicated that the kinetic energy of the third cargo with respect to the middle cargo was on the order of 13,000 ft-lb (17680 N-m); about 25% more than was absorbed by the torque tube deformations. It must be noted that this value is for the kinetic energy at the point of contact for the beginning of torque-tube influence and does not include the continuing driving force from the aerodynamic loads on the platforms. Aerodynamic loads alone are quite significant. At an airspeed of 150 knots, the approximate speed of the aircraft when the cargos enter the airstream, the aerodynamic loads can be nearly 14,000 lb (62305 N) on a 20-ft platform.

Thus, it became apparent during the early stages of the concept development phase of the program that any technique used to restrain the platforms would have to prevent large positive relative-angular-velocities from ever accumulating. Keeping relative angular velocities small would reduce the kinetic energy in the system, allowing the design of the restraint system hardware to be keyed to the "quasi-static" aerodynamic loads. Even the aerodynamic loads alone are capable of inducing bending moments on the order of 150,000 ft-lb (204,000 N-m) for 20-ft platforms and necessitate significant reinforcement of the platform structure.

2. Restraint Systems; Design Factors

When generating concepts for a system to restrain the relative positive rotation and prevent cargo impact within tandem platform groups, there were many design constraints as well as required and desired features. Some of these parameters are discussed below.

(a) The system must prevent cargo impact. Early layout-design work considering 6-ft - high cargo ends approximately 3-ft apart on adjacent platforms showed that positive rotations had to be limited to relative angles of less than 30 degrees. Shorter linkages or higher cargo ends would require smaller positive rotations. Limiting the positive angle of rotation between adjacent cargos to angles significantly less than 30 degrees was considered desirable as long as it did not greatly increase bending loads.

(b) Resultant negative relative rotations created during tip-off, aerodynamic loading on platforms, and angular velocities induced during tip-off are a function of cargo weights; C.G. locations; mass moments-of-inertia; aircraft speed at extraction; aerodynamic characteristics of the cargos; platform lengths; the relative positions of different weight and length platforms within the tandem group; the weight, moment-of-inertia, and length disparity between adjacent cargos; point of extraction parachute load transfer; and other possibly unpredictable factors. Because of these variables, the restraint system must be adaptable and as self-regulating as possible to perform properly (prevent cargo impact) under a tremendous variety of conditions.

(c) The system should be as simple as possible and require a minimum of special mechanical devices and post-tip-off events. In other words, the system should avoid stored energy devices or timed latching and un-locking mechanisms, particularly if failure to operate or accidental pre-activation could be detrimental to the success of the operation or the safety of the aircraft crew.

(d) Because of the differences in cargo load-bearing characteristics, it must be assumed that all bending moments created by a rotational restraint system must be borne by the platform structure alone. It is recognized that some cargos such as vehicles and structural equipment are relatively stiff and could provide significant bending strength to the platforms. On the other hand, supply loads made up of individual boxes of rations, ammunition etc., could not be depended upon to carry bending.

(e) A restraint system that functioned as an energy dissipator would be preferred over an energy absorbing/storing system. A system which merely stored energy, such as a torsion-bar, spring, etc., could create high rebound velocities and actually add to the cargo oscillation problems rather than help to solve them.

3. Rotational Restraint Concepts

Several basic concepts were considered for providing restraint to cargo rotation. In general, these included constant force energy dissipators, mechanical locking devices, torsion springs, and hydraulics. Some of the types of restraint systems are discussed below briefly.

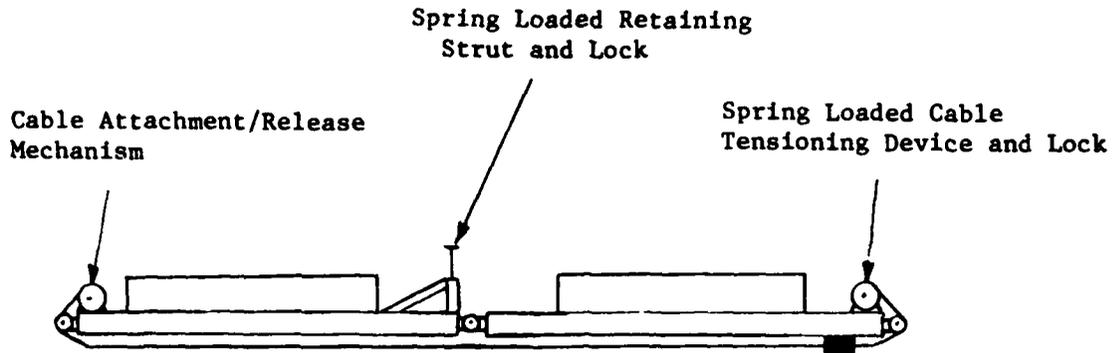
a. Constant Force Energy Dissipators

Constant force energy dissipators such as disk brakes and techniques such as forcing a rod through a smaller diameter tube were rejected because of the wide variance of stopping forces that would be required for different combinations of platform size, cargo weights, extraction conditions, etc. The stopping force would have to be specially tailored to virtually every possible combination of cargos. In addition, since there is a large force present in one direction to actuate a constant force energy dissipator and virtually none in the other, a reasonably sophisticated release device would be needed to allow the group of tandem cargos to return to the neutral position. Also, the device is limited to developing a relatively constant force whereas the driving force acting to rotate the cargos is not necessarily constant. Thus if the resistance force were set too low, there would be a good possibility of overriding that preset force and reaching the point of cargo collision.

b. Mechanical Locking Devices

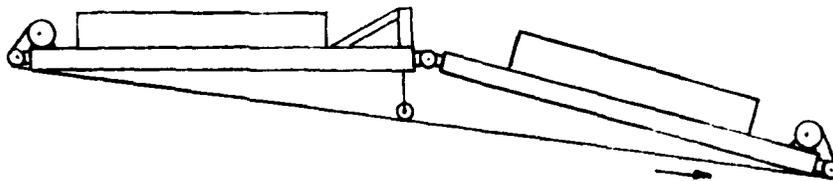
Earlier it was mentioned that during the extraction phase of the rapid extraction system, the relative angle between adjacent cargos changes from negative to positive as extraction progresses. The essence of a mechanical locking device is to fix the relative position of adjacent cargos at the instant of transition between negative to positive angle. At this point, the relative angular velocity is zero which makes the relative kinetic energy zero and the loads in the platform structure are basically limited to aerodynamic forces. The locked group must be unlocked when the main recovery parachutes inflate enough to control the group.

One type of such a locking device using a tensioning cable is illustrated schematically for a two cargo group in Figure 9. The system would be virtually the same for larger cargo groups with a cable device used for each adjacent set of platforms. The system consists of two cables, tensioning devices which automatically reel in cable slack, and spring loaded retaining rods. The cables run under the platforms along both sides so that they ride in the space between the rollers in the dual rail system. There is a spring-loaded-cable tensioning device and a spring-loaded retaining strut for each cable.



Cables under platform ride in free space between dual rail rollers

STORED CONFIGURATION



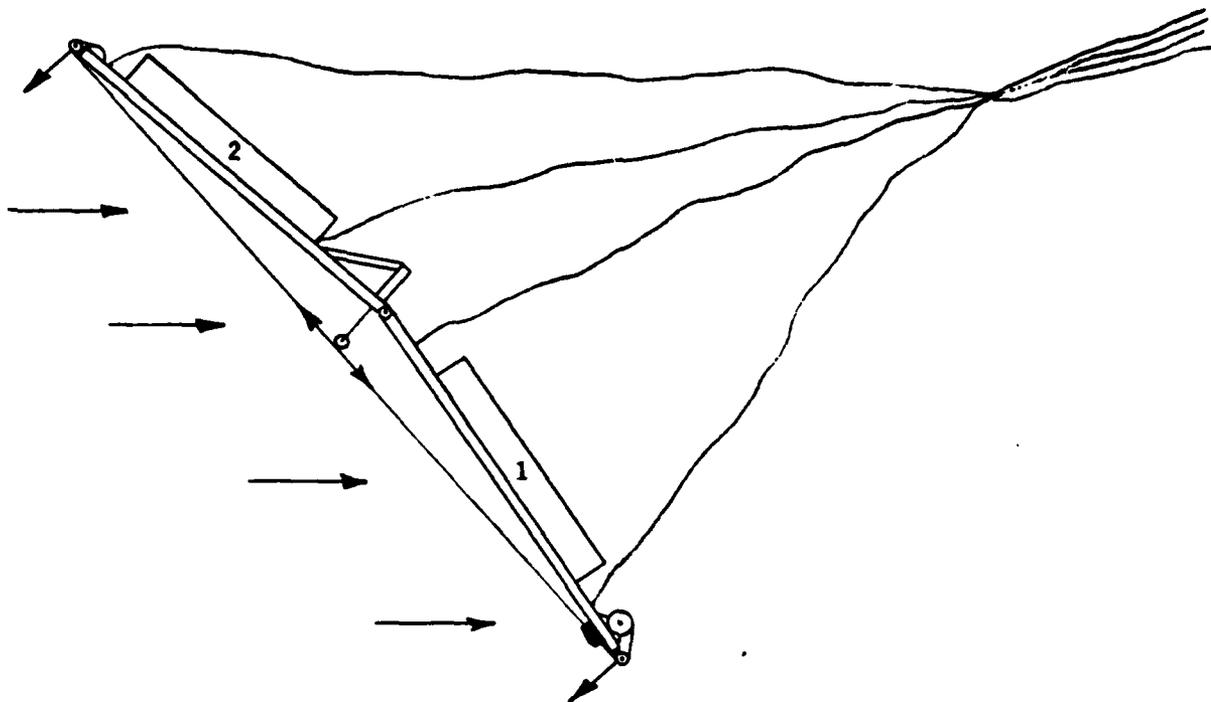
EXTRACTION CONFIGURATION

As platforms exit and negative angle develops, the slack in the cables is automatically withdrawn by the tensioning device and continuously locked in place. The spring loaded retaining strut descends and locks in place.

Figure 9 (pg. 1 of 2)

Schematic of Cable Mechanical Locking Device

(continued)



TRANSITION CONFIGURATION

During the time that the main recovery parachutes are deploying, the rotation of the platforms is arrested. The aerodynamic forces and inertial forces of the cargo react to place the cable in tension and the platforms in compression. When the main recovery parachutes are nearly inflated, the cables and retaining devices must be unlocked so that the platforms can return to the neutral position.

Figure 9 (pg. 2 of 2)

As extraction progresses and the platforms take a negative relative angle, the spring loaded cable tensioning device and retaining strut continually take up the slack in the cable and lock it into place with ratchet-type devices. When the transition point is reached and the relative angular velocity changes from negative to positive, the locked cable prevents motion in the positive direction. The aerodynamic loads working against the momentum of the cargos places the cable in tension and the platforms in compression. After the main recovery parachutes are inflated enough to control the motion of the cargos, the cables are released and the retaining rods retracted.

The tension in the cables and the compression in the platforms depends on the size of the platforms and the magnitude of the negative angle. Shallower angles produce higher cable tensions. One of the worst cases encountered of the computer simulations mode was for a three cargo group in which two light, small cargos on 12-ft platforms were followed on extraction by a heavy load on a 20-ft platform. The maximum negative angle was only about 7.5 degrees. Under these conditions the total tension load could be approximately 65000 lb (289,300 N). However, this load could be carried by three 7/16-in. diameter cables on either side of the platforms.

There are several very desirable features of this system. The relative motion between cargos is prevented at an instant when the relative angular velocity is zero, and so dissipation of kinetic energy is not a problem. Also, the primary loads which must be borne by the platforms are those of compression which they can take with little or no reinforcement. However, the mechanical design problems created by the tensioning, locking, and unlocking mechanisms are significant particularly when considering that if one of the devices jams or fails to function properly the load would probably be damaged. The concept was rejected on the grounds of mechanical complexity.

c. Torsion Bars

The undesirable features of torsion bars as a restraint device were touched upon in section IV.B.1. concerning Air Force feasibility tests. One of the major drawbacks of the concept is that it is an energy storage system rather than an energy dissipation system. Another drawback is that the system, as used in the Air Force feasibility tests, provided no resistance to rotation until the relative angle between adjacent platforms became positive, giving rise to the accumulation of large amounts of kinetic energy. The magnitude of the kinetic energy accumulation becomes enormous as platform size and cargo weight increase.

For example, computer simulations indicate that a 12,000-lb (5448 kg) cargo on a 16-ft platform assumed to be the last cargo extracted in a three-cargo group, could have a kinetic energy of nearly 84,000 ft-lb (114240 N-m) with respect to the middle platform at the instant the neutral position is passed. If all of this energy were to be absorbed elastically with a torsion bar within a 30° angular deflection, the peak torque developed at maximum deflection would have to be

$$\begin{aligned}
 T &= \frac{2 E_d}{\theta} \\
 &= \frac{2 (84,000)}{0.524} \\
 &= 320,900 \text{ ft-lb (436,424 N-m)}
 \end{aligned}$$

If two torsion bars extending the width of the platform were used in parallel, each supplying 160,450 ft-lb at 30°, the polar moment of inertia would have to be,

$$J = \frac{(T)(L)}{(G)(\theta)}$$

where:

J = polar moment of inertia (in⁴)
 T = torque at θ (in-lb)
 L = length of bar (in)
 G = shear modulus of material
 = 12 x 10⁶ psi for steel
 θ = twist (radians)

Substituting for a 9-ft wide platform

$$\begin{aligned}
 J &= \frac{(160,450)(12)(9)(12)}{(12 \times 10^6)(0.524)} \\
 &= 33.07 \text{ in}^4 (1376 \text{ cm}^4)
 \end{aligned}$$

The smallest bar that could provide this polar moment of inertia has a radius of

$$\begin{aligned}
 r &= \frac{2 J}{\pi}^{\frac{1}{2}} \\
 &= \frac{(2)(33.07)}{\pi}^{\frac{1}{2}} \\
 &= 2.14 \text{ in (5.44 cm)}
 \end{aligned}$$

The max shear stress in the outer fibers of each bar would be

$$\begin{aligned} S_{SM} &= \frac{(T)(r)}{J} \\ &= \frac{(160450)(12)(2.14)}{33.07} \\ &= 124,600 \text{ psi (859 MPa)} \end{aligned}$$

This shear stress level could only be achieved with some heat treated, high-strength steel alloy, perhaps even a nickel maraging steel. The cost would be prohibitive and the weight of the two bars alone (not counting mounting structure and reinforcement to the platform) would be;

$$\begin{aligned} W &= 2 (\pi)(r^2)(L)(\rho) \\ &= 2 (\pi)(2.14)^2(9)(12)(0.283) \\ &= 880 \text{ lb (399 kg)} \end{aligned}$$

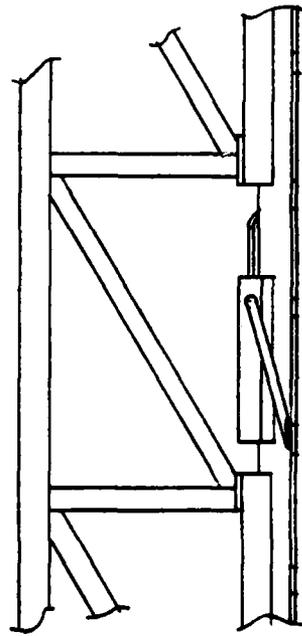
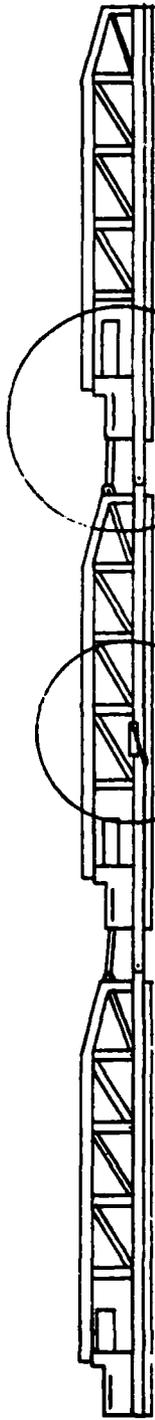
d. Hydraulic Damping

It was recognized early in the concept development phase of the program that the use of hydraulics to retard or damp the relative rotation of cargos within a tandem group has a number of advantages. The retarding forces generated by a hydraulic system are variable and somewhat self-adjusting. That is, large forces or high velocities applied as inputs to the system generate higher resistance than low forces or low velocities. The resistance to motion in opposite directions can be controlled easily by the use of a check valve and different effective orifice areas for the opposite directions. This feature can be used to allow nearly unrestrained motion in the negative direction during tip-off and a virtually locked condition for rotations in the positive direction. Use of a very large orifice for negative rotation allows very free motion, but a very small orifice for positive rotation greatly reduces any velocity accumulation. The advantage of this type of arrangement is that the system is never truly "locked" and so no special operation is needed to "unlock" the system after the recovery parachutes are inflated. Under the influence of the recovery parachutes, the tandem platforms will return automatically, although slowly, to the neutral configuration.

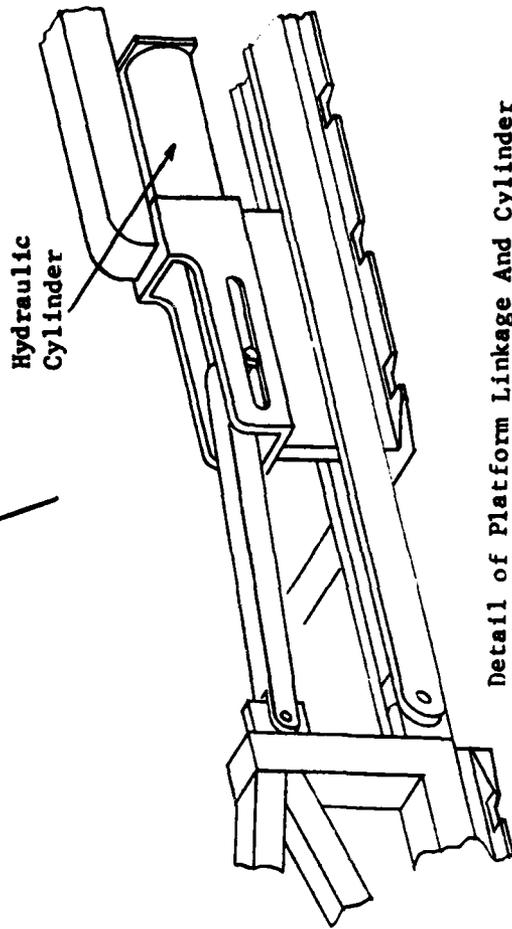
The basic arrangement for employing hydraulic damping is shown in figure 10. . Hydraulic cylinders are mounted over the rails on each side of one platform, and connecting rods for the pistons are attached to the adjacent platform. The cylinders and connecting rods are attached to truss-work reinforcement rails that bolt to the existing platform side rails. The large reinforcement rails are necessary because, as with any rotation restraint technique that could be employed at the platform linkage, very large bending moments are needed to resist the aerodynamic and/or inertial forces tending to rotate the platforms about linked edges. Computer simulations indicate that these bending moments are in excess of 100,000 ft-lb (136,000 N-m) for 16 and 20-ft platforms. The construction and configuration of the reinforcement trusses will be discussed in more detail in section IV.C.3. .

In the neutral, or stowed configuration, the pistons are at mid-stroke. As each platform successively tips out of the aircraft, it creates a negative angle with the platform following it. A large effective orifice for this direction of motion allows the negative angle to increase and the piston is drawn back in the cylinder. When the relative angle between adjacent platforms starts to go positive, the forward motion of the piston closes a check valve and begins forcing hydraulic fluid through a small orifice area.

3-Cargo Tandem Group



Detail of Mounting For 35-K Release Mechanism



Hydraulic Cylinder
Detail of Platform Linkage And Cylinder Mounting

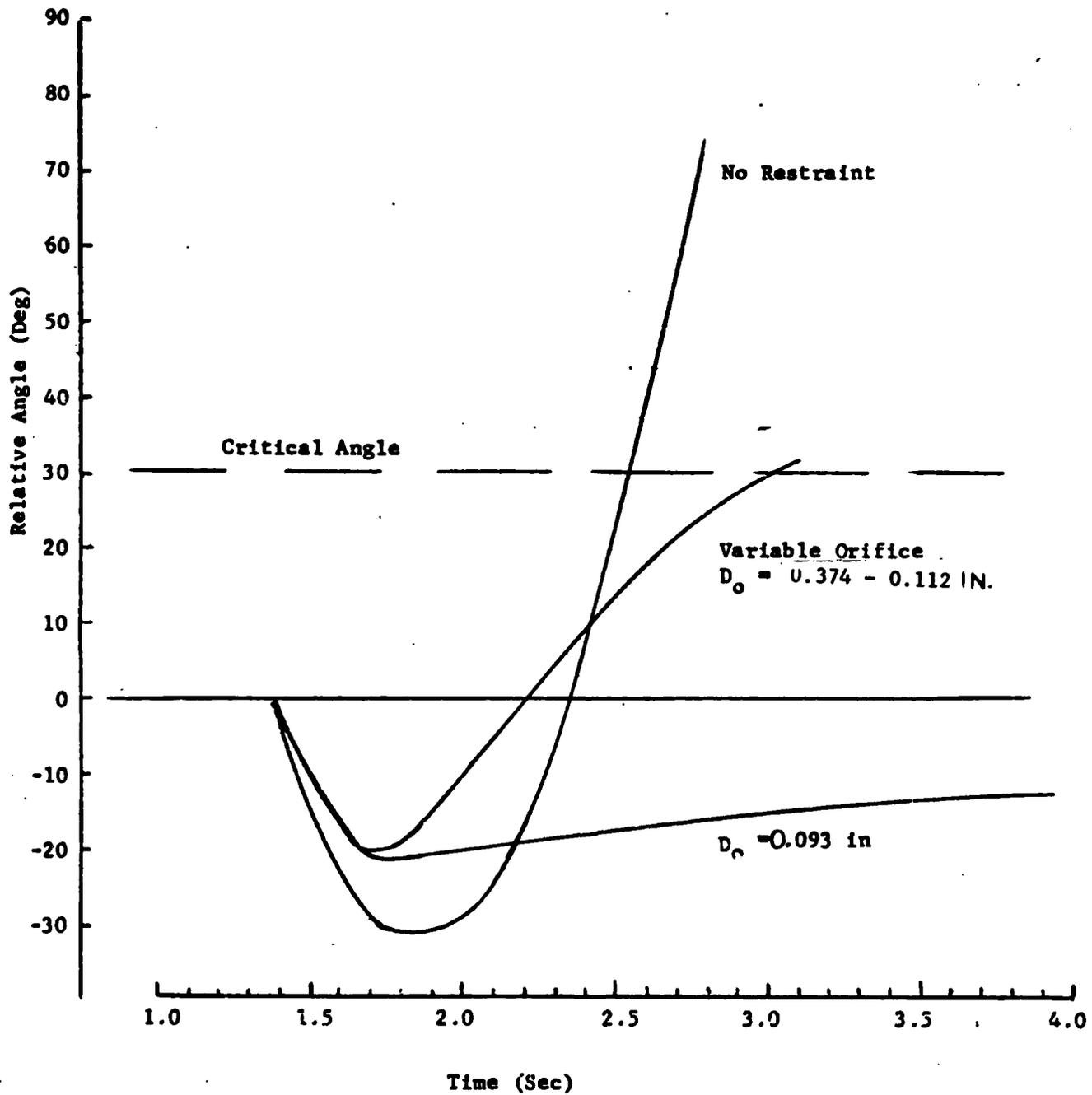
Group-Extraction/Group Recovery; RES With Hydraulic Damping

Figure 10

Two approaches to the use of hydraulics were considered: (1) cylinders with a constant orifice area, (2) cylinders with an orifice area that steadily decreases as a function of stroke, as in a standard shock absorber. The decreasing orifice technique gives a flatter "force-time" relationship because it allows a higher velocity early in the stroke. This technique is excellent for stopping bodies already in motion. However, in the case of damping adjacent platform motion, the initial relative angular velocity at the transition point is zero and it is not wise to use a large orifice and allow velocity to accumulate unnecessarily.

The best way to appreciate the benefits of a hydraulically damped group of linked tandem platforms is to understand that the natural motions created by aerodynamic and inertial forces are never completely prevented, but are greatly retarded so that the main recovery parachutes have time to inflate. This can be seen in figure 11 which is an example of computer simulation results for a hypothetical case of three 12,000-lb cargos on 16-ft platforms extracted in tandem. The plot shows the relationship of the relative angle between the middle platform and the third (last) platform extracted as a function of time for: (1) a condition where no rotational restraint is used, (2) hydraulic cylinders with a decreasing orifice area are used for restraint and (3) hydraulic cylinders with a constant small orifice area are used. It can be seen that if no restraint is used, the third cargo rotates beyond the 30° critical impact angle very rapidly. The decreasing orifice area cylinders slow the rotation considerably, but too much rotational velocity is allowed to accumulate and the critical rotation is reached in a relatively short time. On the other hand, the single small orifice system greatly slows the rotation giving the main recovery parachutes time to deploy and inflate.

After preliminary study, it was felt that use of hydraulic damping would be the most efficient way to prevent large relative rotation and cargo collision. Various combinations of cargo weight, platform length, orifice size, extraction force and force transfer time were analyzed with a computer simulation. A discussion of the computer model, results of some of the analyses, and a description of the recommended system are presented in the following section.



Comparative Time Delay For Types of Hydraulic Restraint
Figure 11

C. Recommended System; RES with Hydraulic Buffer

1. Math Model and Computer Analysis

The paragraphs to follow present the mathematical analysis used to simulate the RES group airdrop configurations. The topics of discussion are concerned with three-cargo configurations; two-cargo configurations are treated as simplified versions of the three-cargo configuration model. The analysis is a two-dimensional study incorporating the interaction of the cargos, the parachute and the aircraft ramp. The parameters of interest are the pitch angles of the individual cargos and, as such, a full trajectory analysis was not developed.

As developed, six performance phases have been accounted for. All three cargos experience a phase called "tip-off" and cargos #2 and #3 experience a phase called "impending tip-off". The sixth phase is the free-fall of all three cargos. Impending tip-off is defined as being the time from which the aft edge of the cargo is at the ramp edge until the time that the sum of the moments on the cargo cause rotation. Until that time, the cargo is in full contact with the ramp.

As indicated earlier, this analysis is not a true dynamic treatment of the problem. As such, certain liberties have been taken with the application of forces and moments. Also, the inertial coordinate system is assumed fixed in space at the aircraft ramp edge. Theoretically, then, the cargo configuration is initially at rest and motion is imposed by the drag force exerted on the parachute. This force is computed as being $\frac{\rho}{2} C_D A V^2$ where V is the aircraft velocity. The forces acting on each body are its own weight, lift and drag, and the horizontal and vertical forces acting on the ends of the cargo. Generally, these forces consist of the weight of the adjacent cargos, the parachute force and, during extraction, a horizontal inertial force due to the acceleration of the system. Also, restoring moments are applied to the cargo platform ends consistent with the restoring mechanism. The analytical treatment of the restoring moment is given at the end of this section.

The basic assumptions used for this analysis are as follows:

- 1) Lift and drag coefficients are known and are functions of angle of attack.
- 2) Air density is constant throughout the simulation.
- 3) Lift and drag forces are imposed only after the cargo is completely outside the cargo hold.

- 4) During extraction the horizontal acceleration is assumed constant, consistent with the orientation of the parachute line.
- 5) Lift and drag act through the cargo C.G.
- 6) The principal axes are aligned with the cargo C.G.

Listed below is a description of the analysis for each phase of the simulation. At the end of this section the method by which the restoring moment mechanism is simulated is described. The nomenclature used for the analysis is as follows:

- \ddot{x}_s = horizontal acceleration of the cargo system
- L = length of parachute line
- ϕ = angle the parachute line makes with the horizontal
- F = force in parachute line
- θ_i = pitch angle of i^{th} cargo
- m_i = mass of i^{th} cargo
- W_i = weight of i^{th} cargo
- I_i = moment of inertia of the i^{th} cargo (pitch plane)
- A_i = distance measurement for the i^{th} cargo (see Figures 12-17)
- B_i = distance measurement for the i^{th} cargo (see Figures 12-17)
- C_i = distance measurement for the i^{th} cargo (see Figures 12-17)
- d_2, d_4, d_5 = distance measurements (see Figures 12-17)
- G_i = length of i^{th} cargo
- $F_{A_{V_i}}, F_{A_{H_i}}$ = vertical and horizontal components of lift and drag for i^{th} cargo
- N_i, T_i = normal and tangential components of lift and drag for i^{th} cargo
- Q_i = horizontal force acting on i^{th} cargo during extraction and tip-off
- R_i = vertical force acting on i^{th} cargo during extraction and tip-off

Phase I - Tip-Off, Cargo #1

The physical conditions encountered during Phase I are shown in Figure 12. The origin of the x-y coordinate system coincides with the ramp edge. From the figure the following geometrical relationships may be obtained:

$$y = \frac{1}{\cos\theta} (a_1 + x \sin\theta_1)$$

$$l = (x \cos\theta_1 + y \sin\theta_1) + b_1$$

$$r = (x^2 + y^2)^{\frac{1}{2}}$$

Defining $\Phi_1 = -\theta_1$, the angle that the parachute line makes with the horizontal is given by

$$\psi = \sin^{-1} \frac{l \sin\Phi_1}{L}$$

Then, the acceleration of the system may be computed from

$$\ddot{x}_s = \frac{F \cos\psi}{m_1 + m_2 + m_3}$$

where

$$F = \frac{\rho}{2} C_D A V^2$$

Next, the forces Q_1 and R_1 may be computed from

$$Q_1 = \ddot{x}_s (m_2 + m_3)$$

and

$$R_1 = \frac{W_2}{1 + b_2/c_2}$$

Having defined all the forces acting on the cargo the angular acceleration of the cargo is found by summing moments about the ramp edge as follows:

$$(I_1 + m_1 r^2) \ddot{\theta}_1 = F l (\cos\psi \sin\Phi_1 + \sin\psi \cos\Phi_1) + (G_1 - l) (Q_1 \sin\Phi_1 + R_1 \cos\Phi_1) - W_1 x + M_1$$

where M_1 is the restoring moment.

This phase ends when $l \geq G_1$.

Phase II - Impending Tip-Off, Cargo #2

The physical conditions encountered during this phase are shown in Figure 13. From the Figure the following geometrical relationships are obtained:

$$\psi = \sin^{-1} \frac{G_1 \sin \Phi_1}{L}$$

$$d_2 = (a_1^2 + c_1^2)^{\frac{1}{2}}$$

where

$$\Phi_1 = -\theta_1$$

The acceleration of the system is given by

$$x_s = \frac{F \cos \psi}{m_1 + m_2 + m_3}$$

Next, the lift and drag forces on cargo #1 may be determined from the standard equations $\frac{\rho}{2} C_D AV^2$ and $\frac{\rho}{2} C_L AV^2$. The velocity, V, of the cargo

is determined by summing the horizontal velocity of the cargo (the aircraft speed) and the tangential velocity of rotation of the cargo.

The forces are then summed and resolved into horizontal and vertical components at the cargo C.G. Designating these components as F_{A_H} and F_{A_V}

for horizontal and vertical respectively, the rotation of cargo #1 may be determined from summing moments about point A. Therefore,

$$(I_1 + m_1 d_2^2) \ddot{\theta}_1 = FG_1 (\cos \psi \sin \Phi_1 + \sin \psi \cos \Phi_1) - W_1 (C_1 \cos \theta_1 - a_1 \sin \theta_1) + F_{A_V} (C_1 \cos \theta_1 - a_1 \sin \theta_1) - F_{A_H} (C_1 \sin \theta_1 + a_1 \cos \theta_1) + M_1$$

The moment acting on cargo #2 is determined by summing moments at the ramp edge. Here, the lift and drag on cargo #1 are applied at the aft end of cargo #2. The force R_2 is computed from

$$R_2 = \frac{W_3}{1 + b_3/c_3}$$

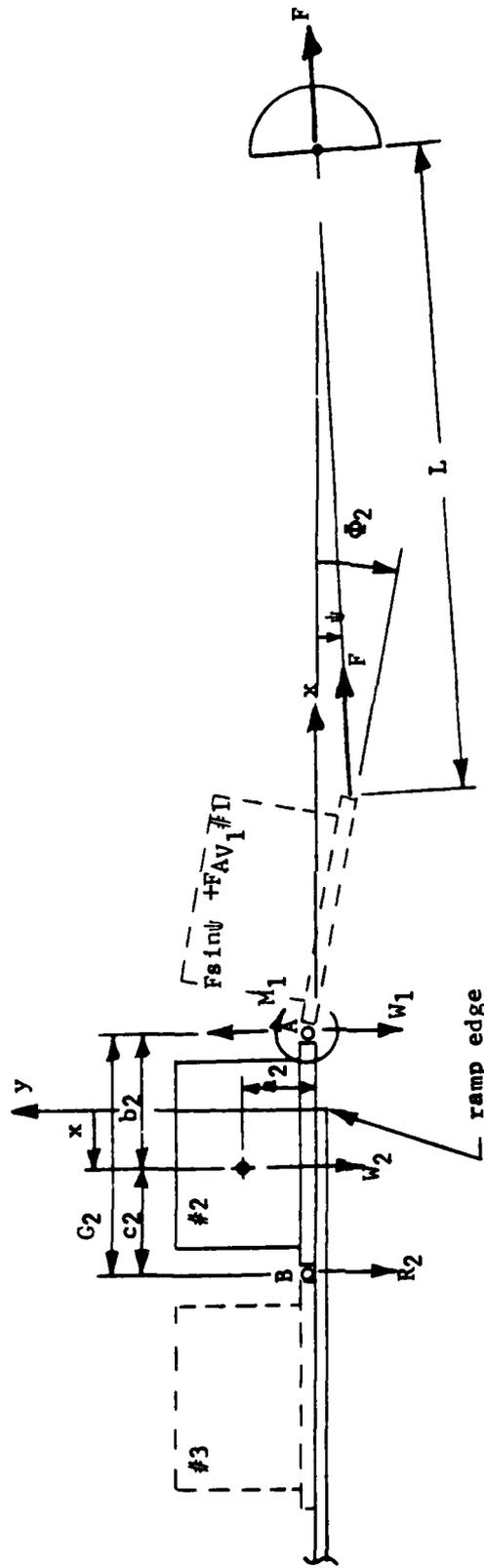


Figure 13 - Phase II Configuration; Math Model

Then

$$\Sigma M_{\text{ramp edge}} = R_2(c_2 - x) - W_2 x - (b_2 + x)(W_1 - F \sin \psi + F_{AV_1}) - M_1$$

This phase ends when $\Sigma M \leq 0$.

Phase III, Tip-Off of Cargo #2

The physical conditions encountered during Phase III are shown in Figure 14. From the figure, the following geometrical relationships may be obtained:

$$y = \frac{1}{\cos \theta_2} (a_2 + x \sin \theta_2)$$

$$l = (x \cos \theta_2 + y) \sin \theta_2 + b_2$$

$$r = (x^2 + y^2)^{\frac{1}{2}}$$

Defining $\Phi_1 = \theta_1$ and $\Phi_2 = -\theta_2$, ψ is found from

$$\psi = \sin^{-1} \left(\frac{l \sin \Phi_1 + G_1 \sin \Phi_1}{L} \right)$$

The acceleration of the system is computed from

$$\ddot{x}_s = \frac{F \cos \psi}{m_1 + m_2 + m_3}$$

The rotational motion of cargo #1 is computed as in Phase II; therefore

$$(I_1 + m_1 d_2^2) \ddot{\theta}_1 = F G_1 (\cos \psi \sin \Phi_1 + \sin \psi \cos \Phi_1) - W_1 (c_1 \cos \theta_1 - a_1 \sin \theta_1) + F_{AV_1} (c_1 \cos \theta_1 - a_1 \sin \theta_1) - F_{AH_1} (c_1 \sin \theta_1 + a_1 \cos \theta_1) + M_1$$

Next, the forces Q_2 and R_2 are found from

$$Q_2 = m_3 \ddot{x}_s$$

and

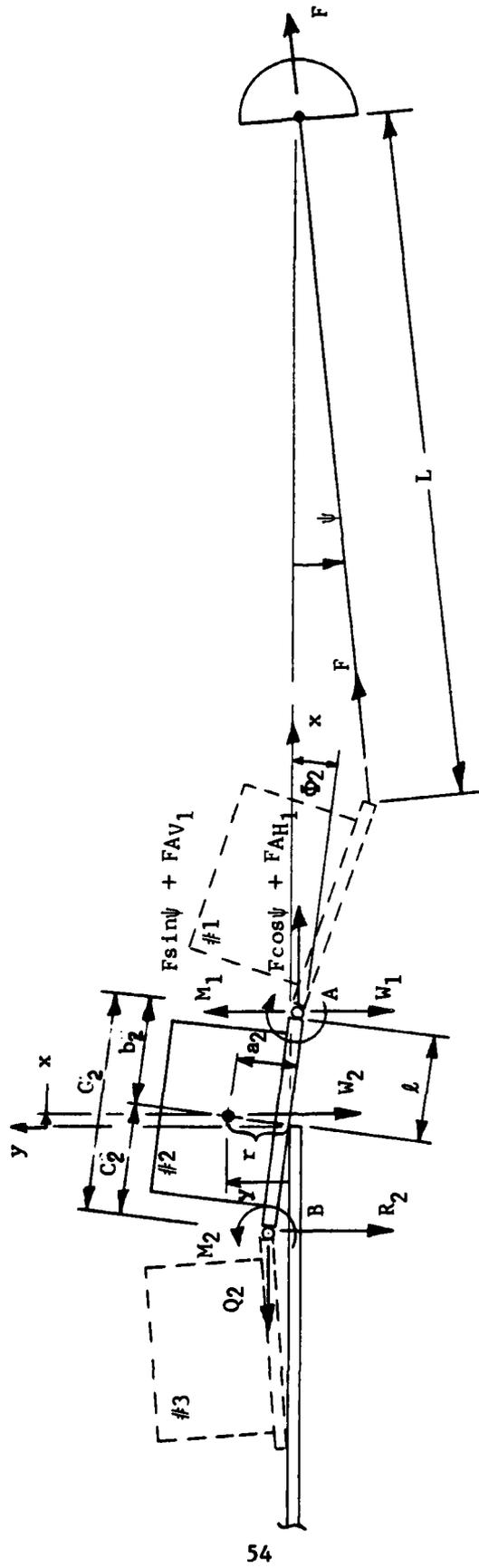


Figure 14 - Phase III Configuration; Math Model

$$R_2 = \frac{W_3}{1 + b_3/c_3}$$

Finally, the rotational motion of cargo #2 is found by summing moments about the ramp edge as follows;

$$\begin{aligned} (I_2 + m_2 r^2) \ddot{\theta}_2 = & F l (\cos \psi \sin \phi_2 + \sin \psi \cos \phi_2) + m_1 \ddot{x}_s l \sin \phi_2 \\ & - W_1 l \cos \phi_2 + (G_2 - l) (Q_2 \sin \phi_2 + R_2 \cos \phi_2) - W_2 x \\ & + F_{AV} l \cos \phi_2 + F_{AH} l \sin \phi_2 - M_1 + M_2 \end{aligned}$$

The forces F_{AV} and F_{AH} are the vertical and horizontal components of the the lift and drag forces on cargo #1 and M_1 and M_2 are the restoring moments. This phase ends when $l \geq G_2$.

Phase IV - Impending Tip-Off Cargo #3

The physical conditions encountered during Phase IV are shown in Figure 15. From the figure, the following geometrical relationships are obtained:

$$\begin{aligned} \psi &= \sin^{-1} \left(\frac{G_2 \sin \phi_2 + G_1 \sin \phi_1}{L} \right) \\ d_2 &= (a_1^2 + c_1^2)^{1/2} \\ d_4 &= (a_2^2 + c_2^2)^{1/2} \end{aligned}$$

The acceleration of the system is computed from:

$$\ddot{x}_s = \frac{F \cos \psi}{m_1 + m_2 + m_3}$$

The rotational motion of cargo #1 is found as before:

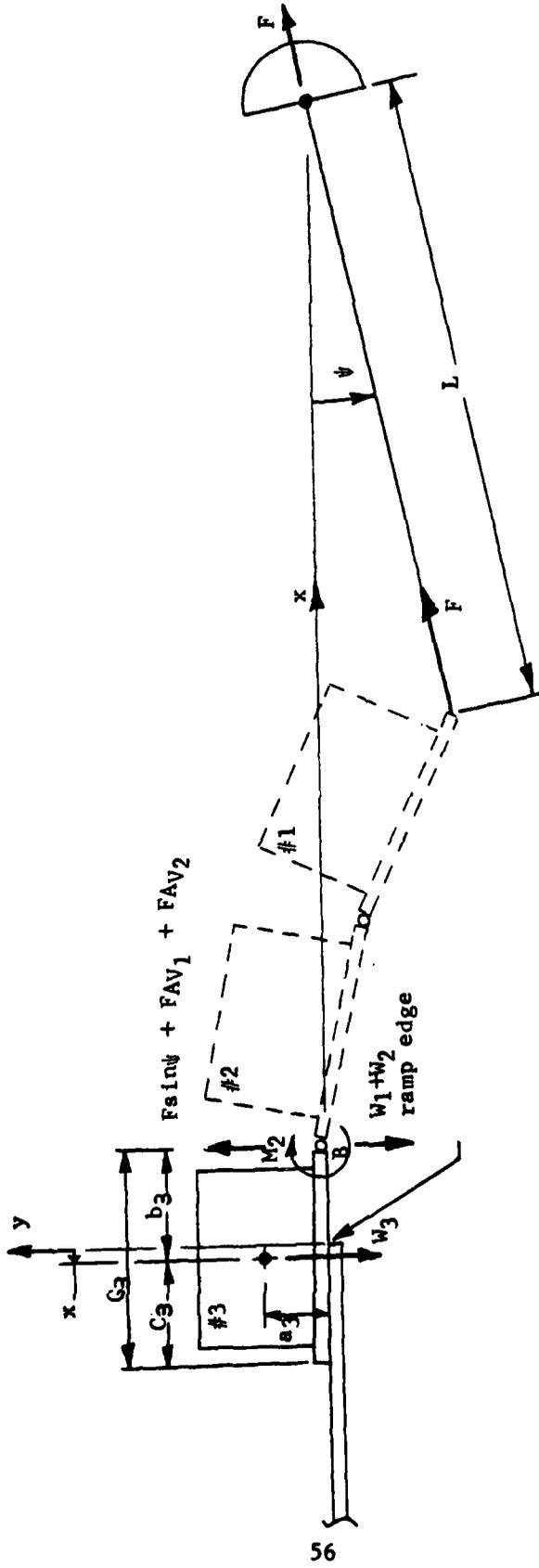


Figure 15 - Phase IV Configuration; Math Model

$$(I_1 + m_1 d_2^2) \ddot{\theta}_1 = FG_1 (\cos\psi \sin\Phi_1 + \sin\psi \cos\Phi_1) - W_1 (c_1 \cos\theta_1 - a_1 \sin\theta_1) \\ + F_{A_{V_1}} (c_1 \cos\theta_1 - a_1 \sin\theta_1) - F_{A_{H_1}} (c_1 \sin\theta_1 + a_1 \cos\theta_1) + M_1$$

Summing moments about point B₁ the rotational acceleration of cargo #2 is given by:

$$(I_2 + m_2 d_4^2) \ddot{\theta}_2 = FG_2 (\cos\psi \sin\Phi_2 + \sin\psi \cos\Phi_2) + m_1 \ddot{x}_s G_2 \sin\Phi_2 - W_2 (c_2 \cos\theta_2 - a_2 \sin\theta_2) \\ - W_1 G_2 \cos\Phi_2 + F_{A_{H_1}} G_2 \sin\Phi_2 + F_{A_{V_1}} G_2 \cos\Phi_2 \\ + F_{A_{V_2}} (c_2 \cos\theta_2 - a_2 \sin\theta_2) - F_{A_{H_2}} (c_2 \sin\theta_2 + a_2 \cos\theta_2) - M_1 + M_2$$

The moment acting on cargo #3 is determined by summing moments at the ramp edge. Here, the lift and drag on cargos #1 and #2 are applied at the aft end of cargo #3. Then

$$\sum M_{\text{ramp edge}} = W_3 x - (W_1 + W_2 - F \sin\psi + F_{A_{V_1}} + F_{A_{V_2}}) (b_3 + x) - M_2$$

This phase ends when $\sum M \leq 0$

Phase V - Tip-Off, Cargo #3

The physical conditions encountered during this phase are shown in Figure 16. From the figure, the following geometrical relationships are obtained:

$$y = \frac{1}{\cos\theta_3} (a_3 + x \sin\theta_3)$$

$$l = (x \cos\theta_3 + y \sin\theta_3) + b_3$$

$$r = (x^2 + y^2)^{\frac{1}{2}}$$

Defining $\Phi_1 = -\theta_1$, $\Phi_2 = -\theta_2$ and $\Phi_3 = -\theta_3$ the angle ψ is found from

$$\psi = \sin^{-1} \left(\frac{l \sin \Phi_3 + G_2 \sin \Phi_2 + G_1 \sin \Phi_1}{L} \right)$$

Then, the acceleration of the system is found from

$$\ddot{x}_s = \frac{F \cos \psi}{m_1 + m_2 + m_3}$$

The rotational acceleration of cargos #1 and #2 is computed as before; therefore:

$$\begin{aligned} (I_1 + m_1 d_2^2) \ddot{\theta}_1 &= FG_1 (\cos \psi \sin \Phi_1 + \sin \psi \cos \Phi_1) - W_1 (c_1 \cos \theta_1 - a_1 \sin \theta_1) \\ &\quad + F_{A_{V_1}} (c_1 \cos \theta_1 - a_1 \sin \theta_1) - F_{A_{H_1}} (c_1 \sin \theta_1 + a_1 \cos \theta_1) + M_1 \end{aligned}$$

and

$$\begin{aligned} (I_2 + m_2 d_4^2) \ddot{\theta}_2 &= FG_2 (\cos \psi \sin \Phi_2 + \sin \psi \cos \Phi_2) + m_1 \ddot{x}_s G_2 \sin \Phi_2 - W_2 (c_2 \cos \theta_2 - a_2 \sin \theta_2) \\ &\quad - W_1 G_2 \cos \Phi_2 + F_{A_{H_1}} G_2 \sin \Phi_2 + F_{A_{V_1}} G_2 \cos \Phi_2 - M_1 + M_2 \\ &\quad + F_{A_{V_2}} (c_2 \cos \theta_2 - a_2 \sin \theta_2) - F_{A_{H_2}} (c_2 \sin \theta_2 + a_2 \cos \theta_2) \end{aligned}$$

Finally, the rotational acceleration of cargo #3 is found by summing moments about the ramp edge.

$$\begin{aligned} (I_3 + m_3 r^2) \ddot{\theta}_3 &= Fl (\cos \psi \sin \Phi_3 + \sin \psi \cos \Phi_3) + (m_1 + m_2) \ddot{x}_s l \sin \psi - W_3 x \\ &\quad - (W_1 + W_2) l \cos \Phi_3 + l [(F_{A_{V_1}} + F_{A_{V_2}}) \sin \Phi_3 + (F_{A_{H_1}} + F_{A_{H_2}}) \cos \Phi_3] - M_2 \end{aligned}$$

Phase VI, Free Fall

The physical conditions encountered in this phase are shown in Figure 17. At this point in time the extraction parachute is assumed to be released and the motion of the three body system is influenced only by its own weight and the aerodynamic forces imposed on the system. Further, it is assumed that the individual cargo weights do not influence the rotational motion of the system. The angular accelerations are computed by summing moments at the connection points between cargos. For cargo #1, this point is point A. For cargos #2 and #3 this point is point B. During this phase, the aerodynamic forces are resolved into components normal and tangent to the longitudinal axes of the cargos. This being the case, the three rotational acceleration equations used for this phase are as follows:

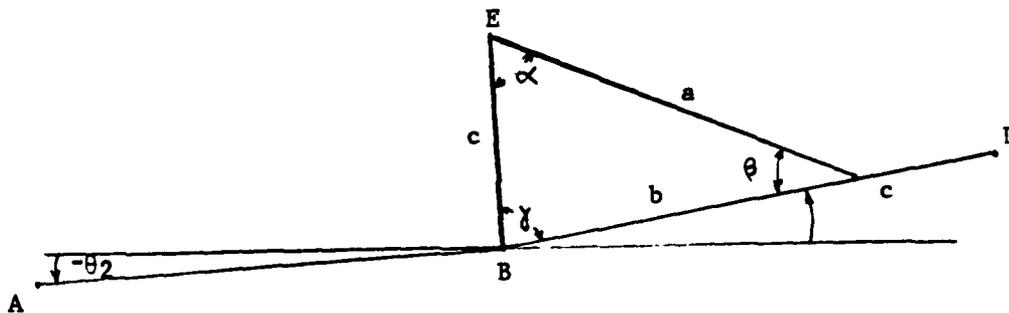
$$(I_1 + m_1 d_2^2) \ddot{\theta}_1 = N_1 c_1 - T_1 a_1 + M_1$$

$$(I_2 + m_2 d_4^2) \ddot{\theta}_2 = N_2 c_2 - T_2 a_2 + N_1 c_2 - M_1 + M_2$$

$$(I_3 + m_3 d_5^2) \ddot{\theta}_3 = -N_3 b_3 - T_3 a_3 - M_2$$

Restoring Moment Mechanism

The proposed piston system restoring mechanism can be graphically represented by the following sketch:



The lines AB and BCD represent the base of cargos #2 and #1, respectively. Line CE represents the piston and line BE represents the fixed support on cargo #2. The problem here is one of determining the motion of the rod in the piston and, having that information, determining the oil pressure in the cylinder. Subsequently, the forces at points E and C can be determined and then, the moments acting on the cargos can be found.

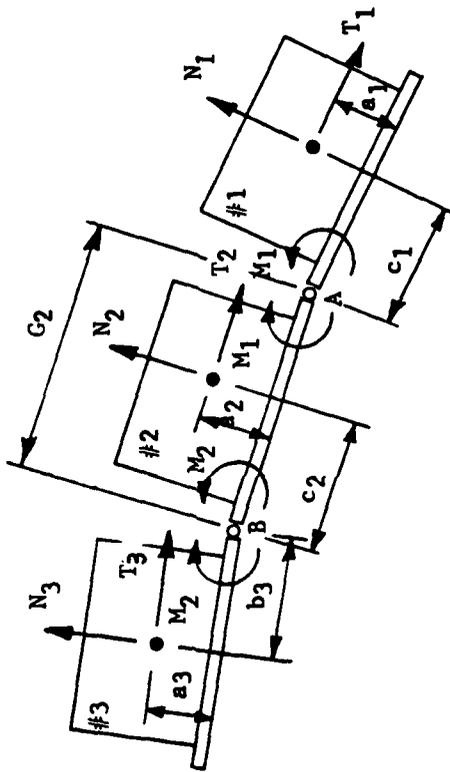


Figure 17 - Phase VI Configuration; Math Model

Because line CE represents the piston and rod it is first necessary to determine the rate of change of the length a. from the law of cosines :

$$a^2 = b^2 + c^2 - 2bc \cos \gamma$$

where $\gamma = \frac{\pi}{2} (\theta_1 - \theta_2)$

Differentiating with respect to time we have

$$2a \dot{a} = (bc \dot{\gamma}) \sin \gamma$$

or

$$\dot{a} = \frac{(bc \dot{\gamma}) \sin \gamma}{\sqrt{b^2 + c^2 - 2bc \cos \gamma}}$$

where

$$\dot{\gamma} = \dot{\theta}_2 - \dot{\theta}_1$$

Also,

$$\dot{a} = \frac{KA_o}{A_p} \sqrt{F/A_p}$$

where

$$K = c \sqrt{\frac{2}{P}}$$

and

- c = discharge coefficient
- ρ = fluid density
- F = force in piston rod
- A_o = orifice area
- A_p = piston area

Then

$$\frac{KA_o}{A_p} \sqrt{\frac{F}{A_p}} = \frac{(bc \dot{\gamma}) \sin \gamma}{\sqrt{b^2 + c^2 - 2bc \cos \gamma}}$$

The moments exerted on cargos #1 and #2 are, respectively,

$$M_{R_1} = (Fb) \sin \beta$$

and

$$M_{R_2} = (Fc) \sin \alpha$$

where the sign of the moment is dependent on the relative motion of the cargos (i.e., opening or closing).

2. Analyses and Results

a. Relevant Variables

The simplified mathematical model was used to compare the effects on performance of the following variables:

- 1) Orifice size; the effective orifice area, and/or the rate of change of orifice area in the case of shock absorbers, affects the rate of fluid flow and pressure in the cylinder. These control the relative velocity of adjacent platforms and the torque transmitted through the platform linkage.
- 2) Cargo weight; the weight of the cargo and its mass moment of inertia affect the angular velocity induced by gravity at tip-off and the rate of velocity reduction imposed by moments generated through the hydraulic damping linkage.
- 3) Platform lengths; the size of the platforms is an important factor controlling the magnitude of the aerodynamic forces acting on the system.
- 4) Time of force transfer; the length of time that the extraction parachute acts on the cargo group affects the speed of extraction and thus affects the orientation of the cargos and relative angular velocities between cargos during and shortly after tip-off. The force transfer point was expressed in terms of the instant when a specified point in the tandem cargo group passed the ramp edge.
- 5) Arrangement of various combinations of cargo weights and platform lengths; the weights of the cargos which exit the aircraft first and "hang" onto the cargo in the process of tipping off affect the tip-off velocity induced in each successive cargo to exit.
- 6) Effective hydraulic piston area; the effective piston area largely determines the pressure developed in the cylinder which is needed to damp relative platform rotations. There are state-of-the-art limitations related to the maximum pressure which can be contained by cylinder seals and structure.

b. Assumptions

Assumptions made during the analysis included the following:

- 1) The maximum operational airdrop load was assumed to be 35,000 lb. (15890 kg). However, several cases with total weights above this value were also considered to gain some insight to the possible effects to system performance in the event the load limit is increased for future airdrop operations.
- 2) Platform cargos were assumed to have lift and drag properties of flat plates. Initially some comparative computer simulations were done using aerodynamic properties for various cargos determined by AAI through wind tunnel testing under contract DAAK60-77-C-0073 which was being done concurrently with the ACES program. It was found that the aerodynamic coefficients for the actual cargos closely approximated those for flat plates for positive angles of attack greater than about 6 degrees, and that the overall performance of the system was relatively insensitive to the difference between "wind tunnel model" aerodynamic coefficients and "flat plate" coefficients. In addition, the wind tunnel coefficients were appropriate for individual cargos in the airstream and not for linked tandem cargo groups. In "control simulations" intended to match the results of early Air Force feasibility tests of tandem cargos, the "flat-plate" assumption gave reasonably good agreement and so it was decided to maintain this assumption throughout the analyses.
- 3) The c.g. of the cargo was assumed to be at the geometric center of the cargo and over the mid-point of the platform. Cargos were considered to be rectangular parallelepipeds ranging in height from: 3 to 4 ft (0.914 to 1.22 m). They were assumed to be mounted on top of a 1-ft (0.305 m) thick layer of paper honeycomb.
- 4) The extraction force for all simulations was assumed to be 1.25 G and the aircraft speed during extraction was assumed to be 130 KIAS.
- 5) The discharge coefficient for the effective hydraulic cylinder orifice area was assumed to be 0.6.
- 6) The density of the hydraulic fluid was assumed to be 1.746 slug/ft³.

- 7) The characteristics of the cylinders mounted between platforms 1 and 2 were the same as for the cylinders between platforms 2 and 3.

c. Relevant Outputs

The results of the analysis that were of prime concern were:

- 1) The relative angles between adjacent platforms as a function of time.
- 2) The relative angular velocity of adjacent cargos as a function of time.
- 3) The angle of each platform with respect to the horizontal.
- 4) The torque developed between adjacent cargos by the hydraulic cylinders as a function of time.
- 5) The force developed by the cylinder. The peak pressure had to be kept below 5,000 psi (34.5 MPa).
- 6) The "lock-up" angles, i.e., the relative angles between adjacent cargos at the instant the relative angular velocity changes from negative to positive.

d. General Results

Because of the tremendous number of possible combinations of cargo weight and platform length, it was impossible to simulate every configuration that could conceivably be encountered in the field. A variety of configurations were considered which were felt to be representative of realistic conditions, so that insight could be gained regarding basic trends and possible worse-case conditions. Some of the key simulation results are summarized in Table 1. (Recall that the cargos are numbered in the order that they are extracted, i.e., cargo #1 is the first to leave the aircraft.) Using the computer output, it was also possible to observe the general space-time behavior of the cargo groups. For example, figures 18, 19, and 20 show the relative orientation of a tandem group of three 6000-lb cargos on 12-ft platforms for various damping orifice sizes. This type of plot was helpful in visualizing the qualitative behavior of the platforms. Another type of presentation that was helpful in comparing the relative performance of various configurations is illustrated in figures 21 through 27. These show the relative angle between the critical two platforms as a function of time for various orifice sizes. In all but a few cases, the critical platform pair was the last two to leave the aircraft.

Early in the analysis phase, simulations were limited to groups of equal weight cargos on equal length platforms. Orifice sizes and load transfer points were varied to determine the effects on peak torques between platforms and the rate of relative rotation. In addition to the equal weight configurations, several configurations of mixed cargo weights and platform lengths were considered. The mixed cargo configurations were intended to demonstrate the behavior of groups containing a large disparity of cargo weights and platform lengths. During the later stages of the analysis phase, the cylinder stroke, connecting rod diameter and mounting structure were modified to meet other design restrictions. The net effect was to work the cylinders at higher pressures for a given torque level.

From the results of the computer analysis performed, many general conclusions can be drawn regarding the performance and design characteristics of the system. Some of these are discussed below.

1) The peak torque developed between cargos is a complex relationship between the inertial forces and aerodynamic forces. In most cases, the largest torque is developed between the second and third cargos to leave the aircraft. The time at which the peak torque occurs is a function of many variables such as the angle at which the cargos enter the airstream, the size of the damping orifice, the cargo weights, and the platform lengths. In some cases the peak torque between cargos 2 and 3 occurs at tip-off of cargo 3. This is particularly true when considering heavier cargos.

Table 1

PARTIAL SUMMARY OF PERTINENT COMPUTATIONS

Config. No.	Tandem Load Properties									Restrictive Orifice Diameter (In)	Force Transf. Point
	Cargo #1			Cargo #2			Cargo #3				
	Wgt (Lb)	Icg (Slug-Ft ²)	Plat. Len. (Ft)	Wgt (Lb)	Icg (Slug-Ft ²)	Plat. Len. (Ft)	Wgt (Lb)	Icg (Slug-Ft ²)	Plat. Len. (Ft)		
1	6,000	1,135	12	6,000	1,135	12	6,000	1,135	12	.50	Midpoint
2	"	"	"	"	"	"	"	"	"	.375	"
3	"	"	"	"	"	"	"	"	"	.25	"
4	9,000	1,700	12	9,000	1,700	12	9,000	1,700	12	No Restraint	"
5	"	"	"	"	"	"	"	"	"	.375	"
6	"	"	"	"	"	"	"	"	"	.25	"
7	"	"	"	"	"	"	"	"	"	.125	"
8	"	"	"	"	"	"	"	"	"	.25	End #2
9	"	"	"	"	"	"	"	"	"	"	Midpoint
10	"	"	"	"	"	"	"	"	"	"	End #2
11	15,000	2,834	12	15,000	2,834	12	15,000	2,834	12	"	Midpoint
12	"	"	"	"	"	"	"	"	"	.125	"
13	12,000	7,500	16	12,000	7,500	16	12,000	7,500	16	No Restraint	"
14	"	"	"	"	"	"	"	"	"	.125	"
15	"	"	"	"	"	"	"	"	"	.093	"
16	"	"	"	"	"	"	"	"	"	(.374-.112)vari.	"
17	18,000	11,225	20	18,000	11,225	20	-	-	-	(.374-.112)vari.	"
18	"	"	"	"	"	"	"	"	"	.125	"
19	Mixed Cargo 3,000	Configurations 567	12	6,000	1,135	12	9,000	1,700	12	No Restraint	Midpoint
20	"	"	"	"	"	"	"	"	"	.25	"
21	9,000	1,700	12	6,000	1,135	12	3,000	567	12	No Restraint	"
22	"	"	"	"	"	"	"	"	"	.25	"
23	6,000	1,135	12	15,000	2,834	12	6,000	1,135	12	No Restraint	"
24	"	"	"	"	"	"	"	"	"	.25	"
*25	6,500	4,000	20	14,000	4,225	12	14,000	4,250	12	.125	"
*26	27,000	16,840	20	4,000	1,200	12	4,000	1,200	12	"	"
*27	14,000	4,250	12	6,500	4,000	20	14,000	4,250	12	"	"
*28	4,000	1,200	12	27,000	16,840	20	4,000	1,200	12	"	"
*29	14,000	4,250	"	14,000	4,250	12	6,500	4,000	20	"	"
*30	4,000	1,200	"	4,000	1,200	12	27,000	16,840	20	"	"
*31	28,500	17,775	20	6,500	2,000	12					
*32	6,500	2,000	20	28,500	17,775	20					
*33	6,500	4,000	20	4,000	1,200	12	4,000	1,200	12	"	"
*34	4,000	1,200	12	6,500	4,000	20	4,000	1,200	12	"	"
*35	4,000	1,200	12	4,000	1,200	12	6,500	4,000	20	"	"

*Modified cylinder size and mounting arrangement

Table 1

PERTINENT COMPUTER SIMULATIONS

Relative Force Order	Force Transfer Point	Resultant Data for Platforms 1 and 2				Resultant Data for Platforms 2 and 3			
		Peak Torque (Ft-Lb)	Max. Cyl. Pressure (Psi)	Rel. Angle At 3 Sec (DEG)	Rel Angular Velocity-3sec (DEG/Sec)	Peak Torque (Ft-Lb)	Max. Cyl. Pressure (Psi)	Rel Angle At 3 Sec (DEG)	Rel Angular Velocity-3 sec (DEG/Sec)
50	Midpoint #2	-18,488	348	-3.5	11.7	-52,010	1,000	61.1	-63.3
375	"	-24,729	477	-1.3	-3.5	-50,782	1,034	28.4	-28.6
25	"	-31,103	607	-5.9	-2.5	-50,357	1,063	4.3	-14.7
Constraint	"	-	-	17.6	73.1	-	-	>90.0	-285.5
375	"	-33,628	647	19.0	-7.7	-57,552	1,168	46.8	-42.7
25	"	-44,471	886	6.3	-3.4	-57,035	1,362	12.9	-14.4
125	"	-49,160	988	-11.1	-2.1	-54,587	1,238	-10.2	-5.5
25	End #2	-51,453	1,024	4.7	-2.5	-78,099	1,699	21.4	-18.1
"	Midpoint #3	-52,769	1,048	4.7	2.4	-94,583	1,979	24.3	-19.4
"	End #3	-52,769	1,048	7.5	2.3	-103,000	2,176	17.8	-13.4
"	Midpoint #2	-75,343	1,482	15.9	9.6	-105,000	2,525	7.0	28.0
125	"	-88,170	1,772	-3.0	-3.9	-163,006	3,876	-14.9	18.1
Constraint	"	-	-	10.0	74.0	-	-	>90.0	232.0
125	"	-86,748	1,744	-7.8	6.7	-99,233	2,383	-10.4	-8.7
993	"	-88,690	1,786	-10.8	8.5	-135,518	3,231	-15.2	-5.1
2)vari.	"	-59,961	1,134	7.7	-7.9	-123,457	2,352	22.6	-10.8
2)vari.	"	-115,041	2,151	27.0(est)-5.5(est)					
125		-190,545	3,607	7.02	-6.7				
Constraint	Midpoint #2	-	-	16.0 (t=2.2)	-	-	-	> 90 (t=2.2)	Gross Impact
25	"	-13,497	261	9.1	-2.75	-62,795	1,270	20.9	-15.5
Constraint	"	-	-	71.0 (t=1.9)	-	-	-	>90 (t=1.9)	Gross Impact
25	"	-57,305	1,131	-90.4	107.0	-55,273	1,344	9.1	-16.4
Constraint	"	-	-	11.0 (t=1.8)	-	-	-	> 90 (t=1.8)	Gross Impact
25	"	-46,587	907	13.4	-9.5	>-100,000	2,422	23.4	-15.1
125	"	-71,956	2,365	-4.8	7.5	-93,545	3,211	14.9	-9.8
"	"	-272,597	>6,000	-90 (t=2.3)	Beyond neg. Limit	-224,787	>6,000	-2.8	-
"	"	-108,026	3,681	-90 (t=2.8)	Beyond neg. Limit	-75,000	4,725	-33.9	-
"	"	-18,431	632	1.4	-8.1	-253,470	>6,000	12.1	-9.7
"	"	-120,600	3,896	Group Rolled Beyond Model Limits		-192,775	>6,000		
"	"	-23,332	815	-18.3	-10.4	-94,716	2,997	-10.1	-19.8
"	"	-289,956	>6,000	16.0	-9.9				
"	"	-28,566	915	9.0	-9.6				
"	"	-54,382	1,813	-90.5(t=2.4)	258.0	-87,923	3,069	-1.3	-16.4
"	"	-6,040	205	-4.8	1.8	-36,490	1,349	-1.9	9.2
"	"	-16,503	559	-12.0	-8.4	-74,955	2,991	-10.0	-18.2

12

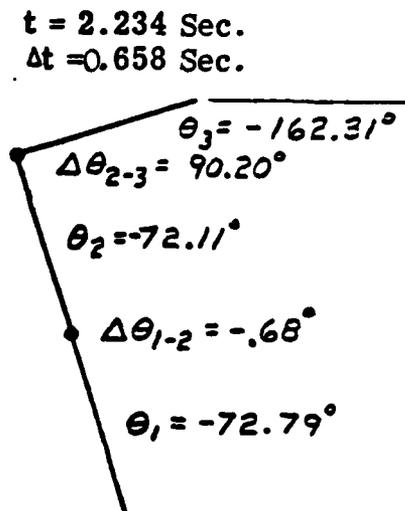
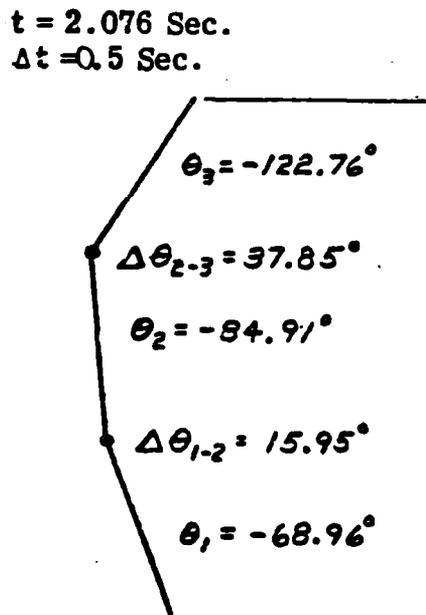
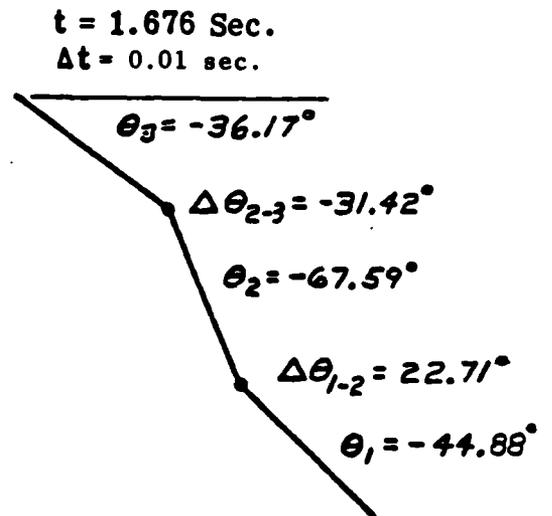
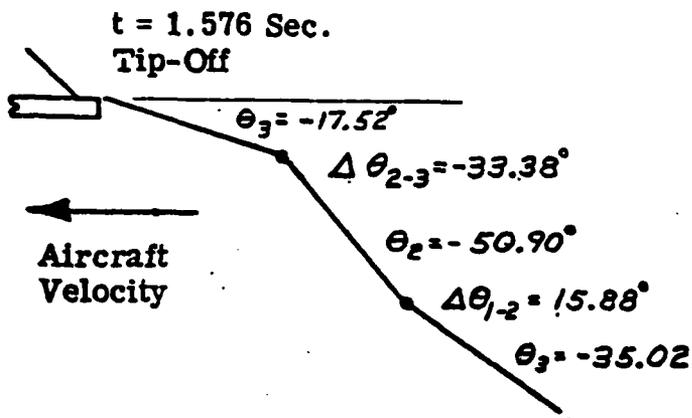
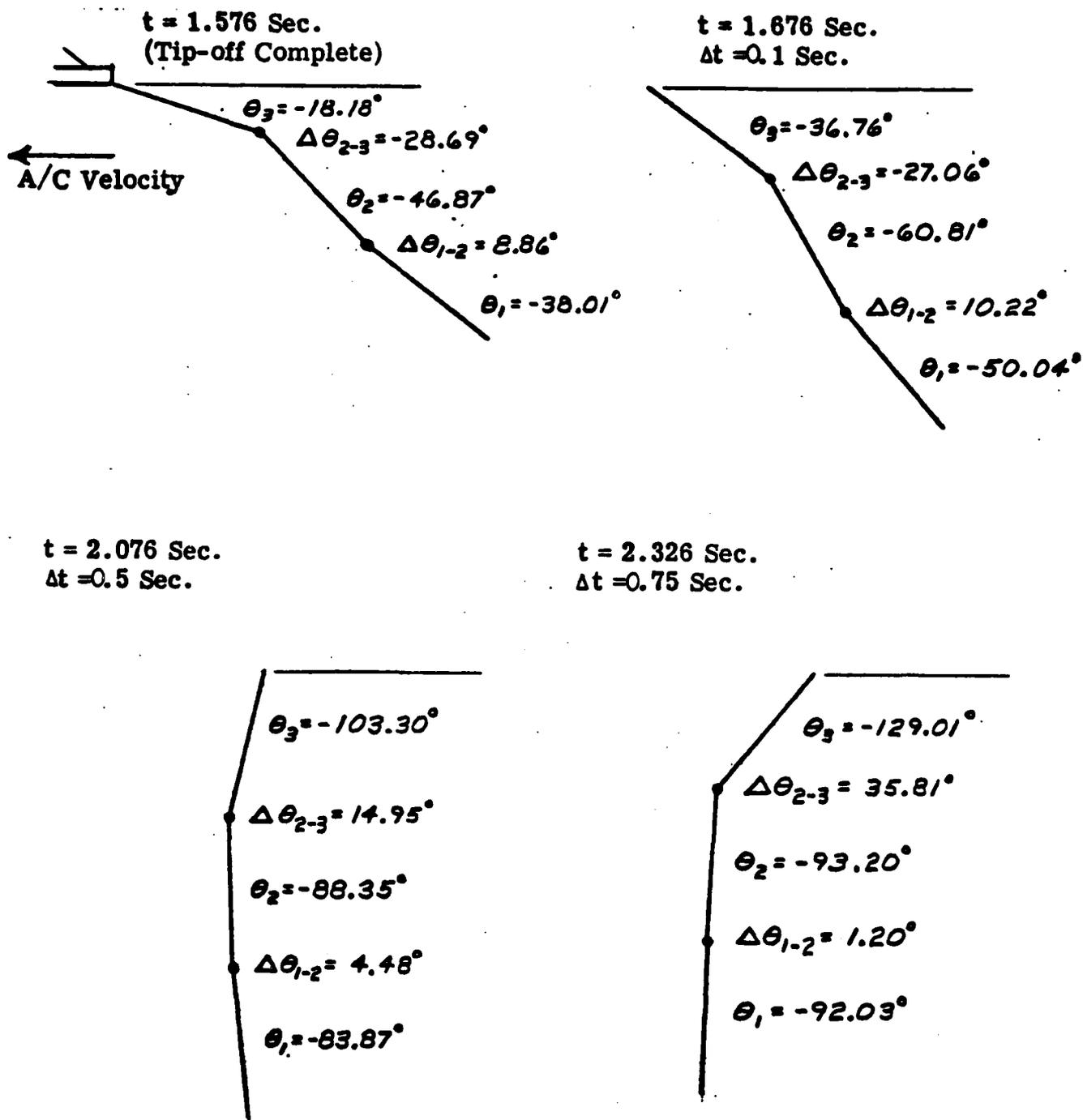


Figure 18 Orientation of Cargo Group After Tip-Off;
"Simplified Model"

(6000 lb cargos, 1.25 g extraction force, extraction force released at midpoint of cargo #2, no rotational restraint)



**Figure 19 Orientation of Cargo Group after Tip-Off
Simplified Model**

(Three 6000 lb cargos; extraction force = 1.25 G;
extraction released midway through cargo #2;
piston dia = 5 in.; primary orifice dia = 0.5 in.)

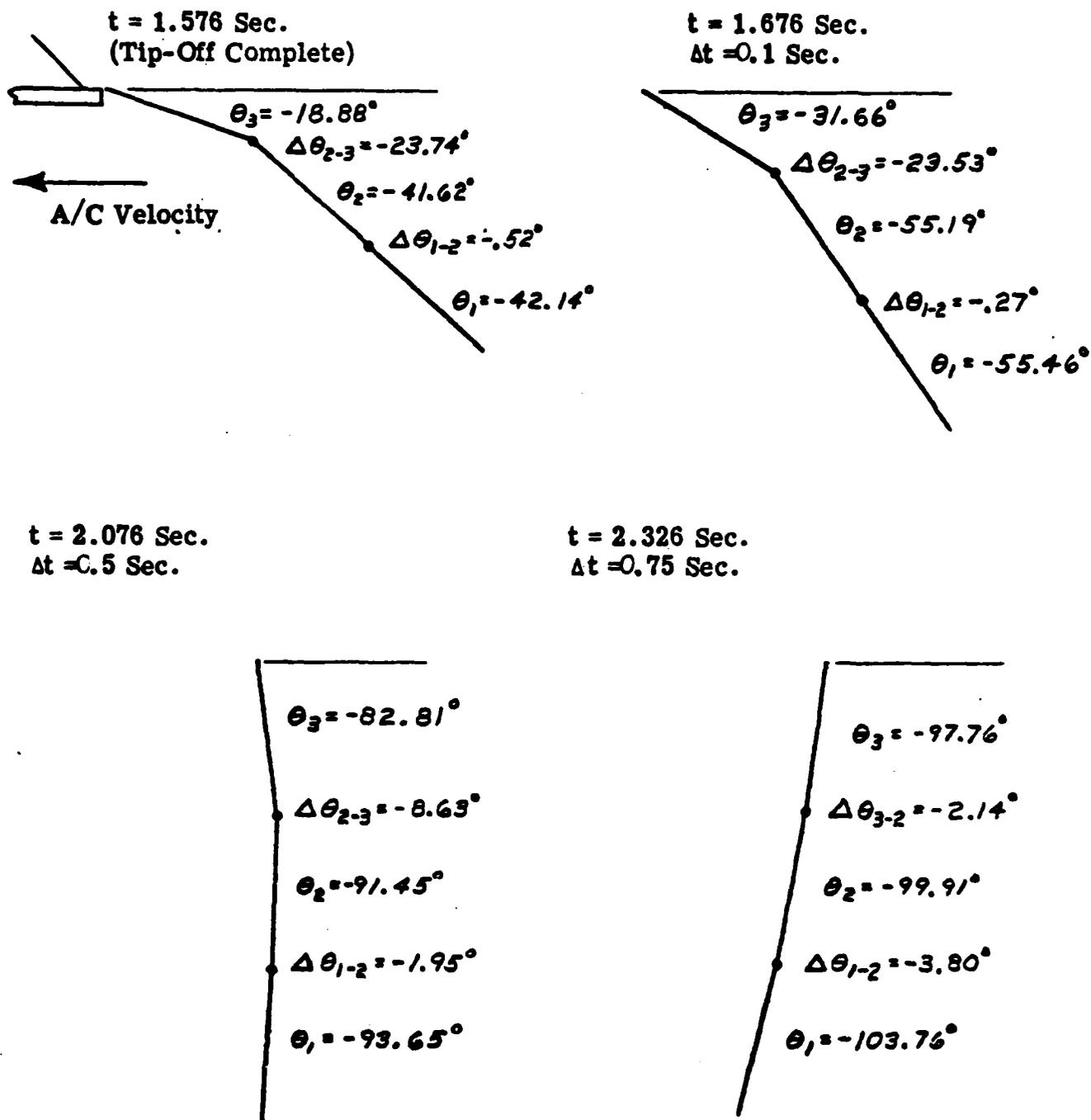


Figure 20 Orientation of Cargo Group After Tip-Off Simplified Model

(Three 6000 lb cargos; extraction force = 1.25 G;
 extraction force released midway through cargo #2;
 piston dia = 5 in.; primary orifice dia = 0.25 in.)

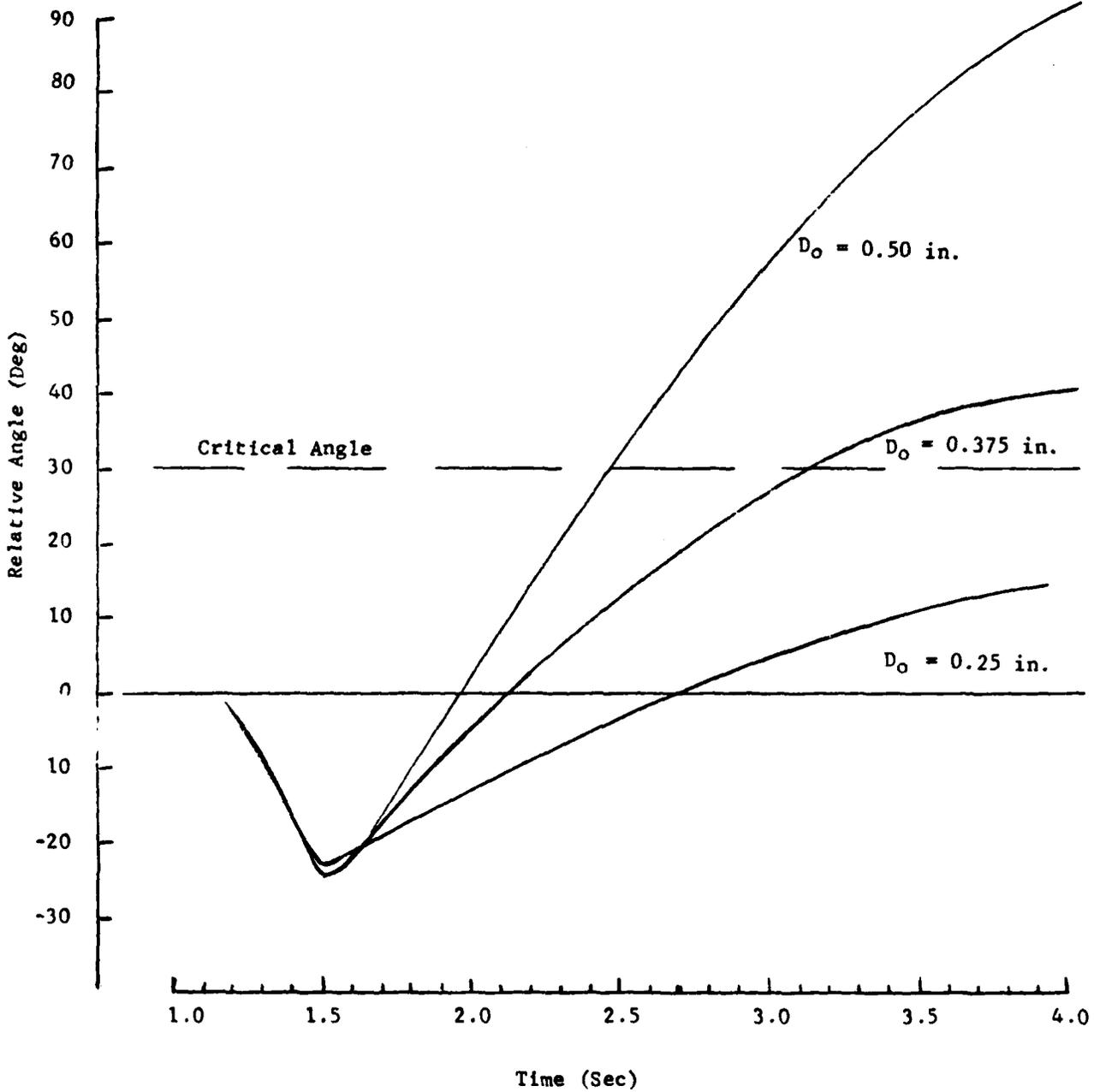


Figure 21
 Relative Angle Between Cargo 2 and 3 vs time; Three
 6000-lb cargos on 12-ft platforms; single
 constant orifice

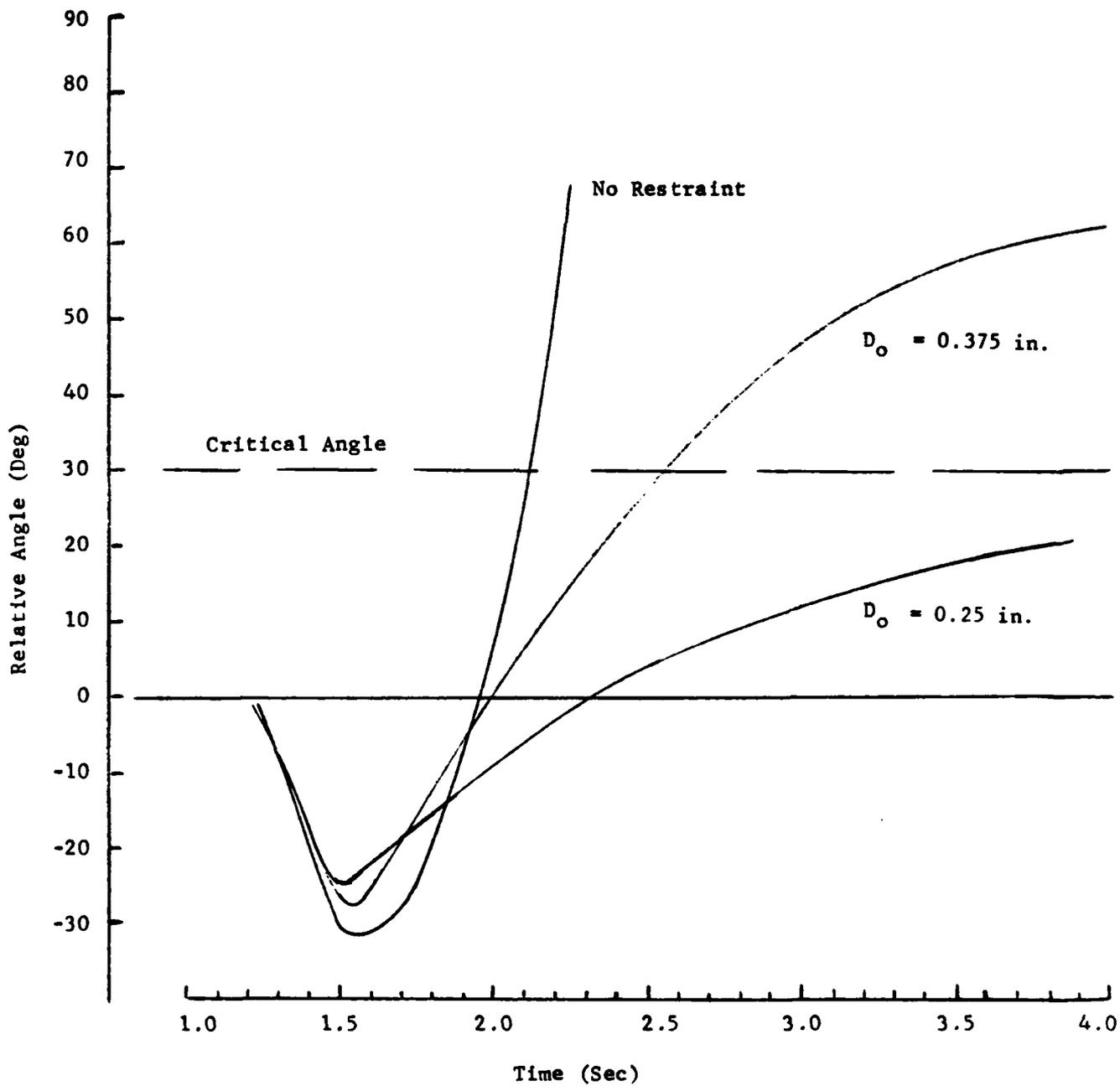


Figure 22
 Relative Angle Between Cargo 2 and 3 vs Time; Three
 9000-lb cargos on 12-ft platforms single
 constant orifice

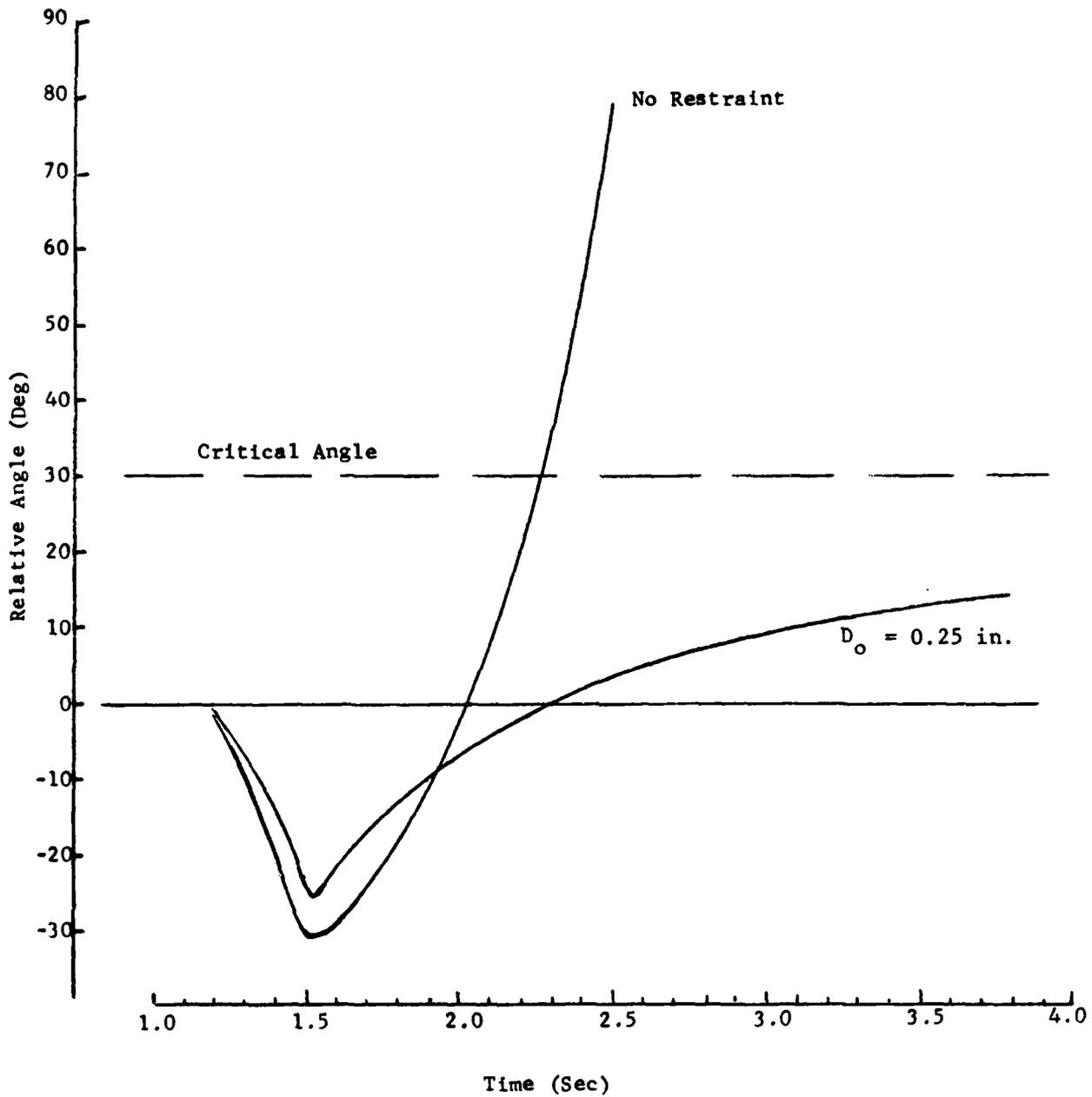


Figure 23
 Relative Angle Between Cargos 2 and 3 vs Time; Three
 15,000-lb cargos on 12-ft platforms; single
 constant orifice

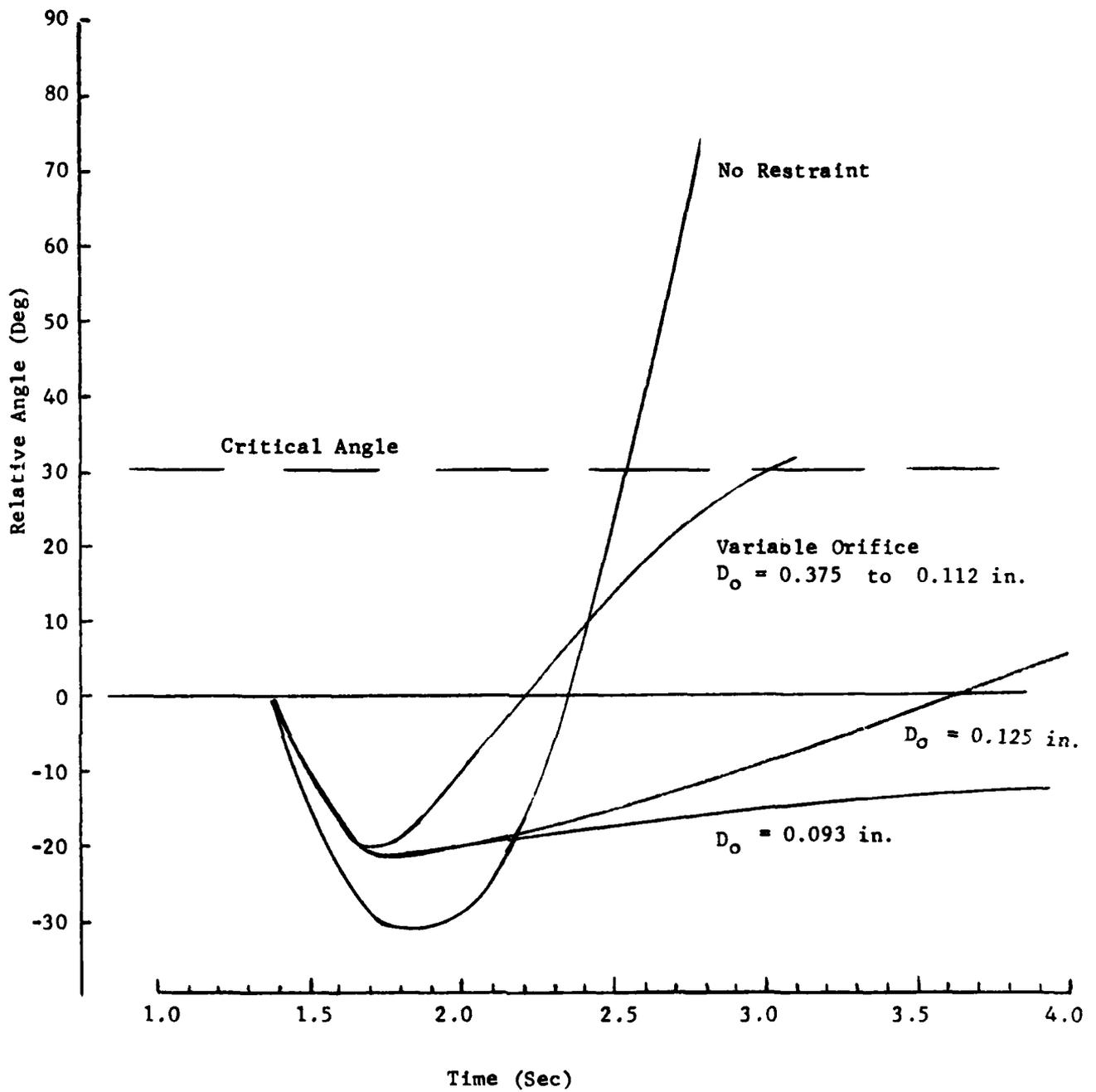


Figure 24
 Relative Angle Between Cargos 2 and 3 vs Time; Three
 12,000-lb cargos on 16-ft platforms

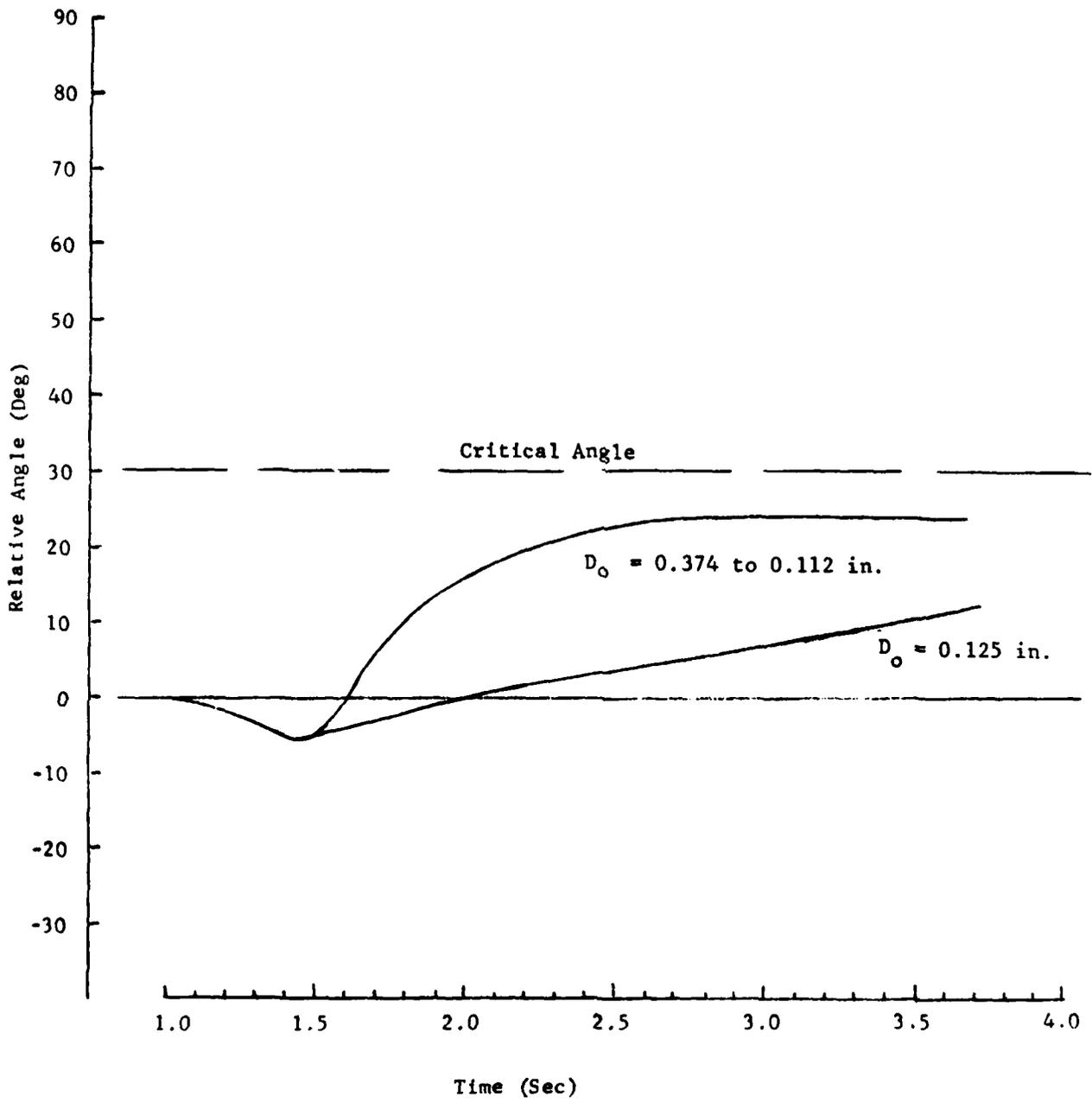


Figure 25
 Relative Angle Between Cargos 1 and 2 vs Time; Two
 18,000-lb cargos on 20-ft platforms; variable
 orifice

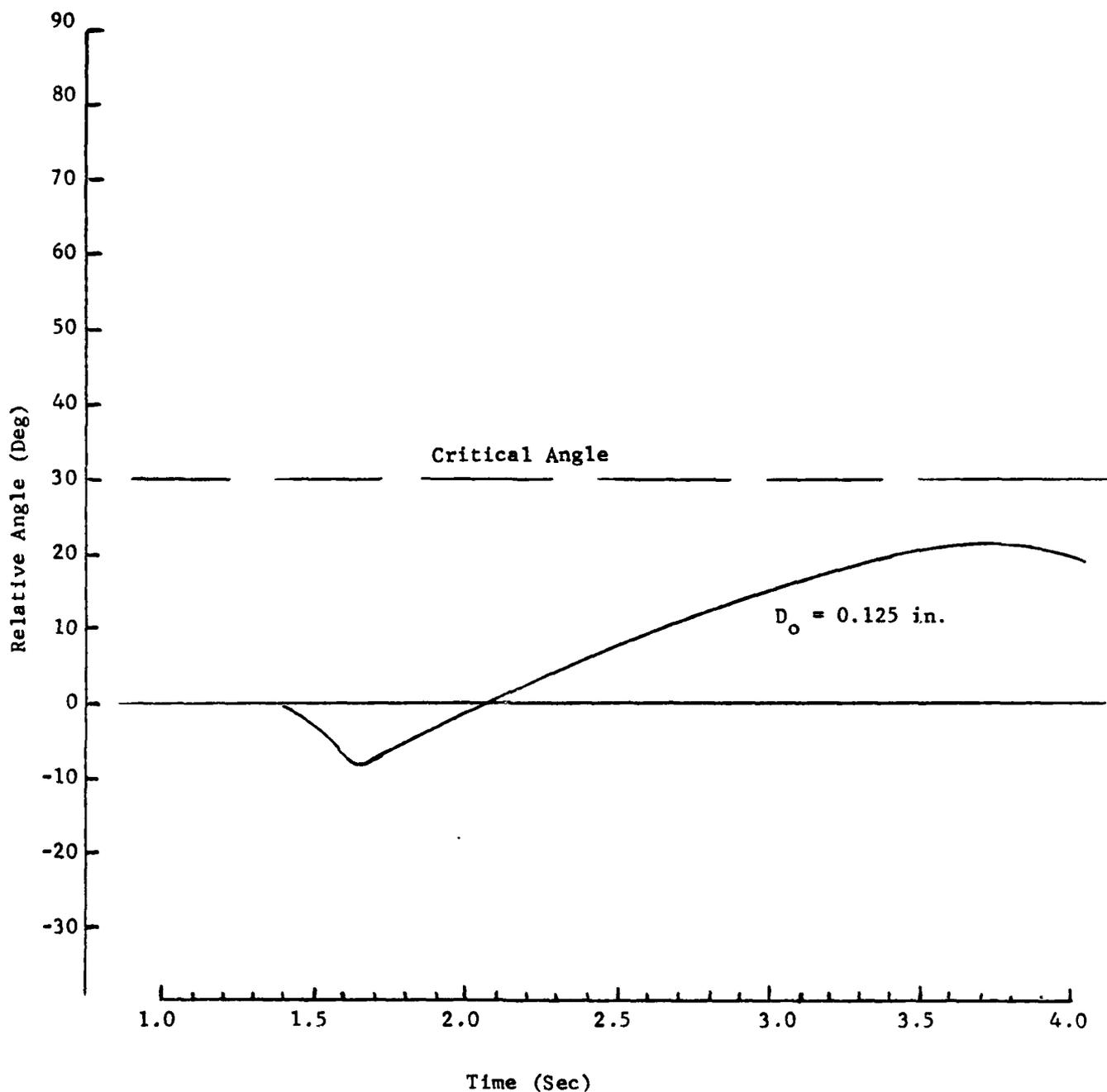


Figure 26
Relative Angle Between Cargos 2 and 3 vs Time;
mixed weights and lengths

Cargo 1 = 6,500 lb	Platform 1 = 20 ft
Cargo 2 = 14,000 lb	Platform 2 = 12 ft
Cargo 3 = 14,000 lb	Platform 3 = 12 ft

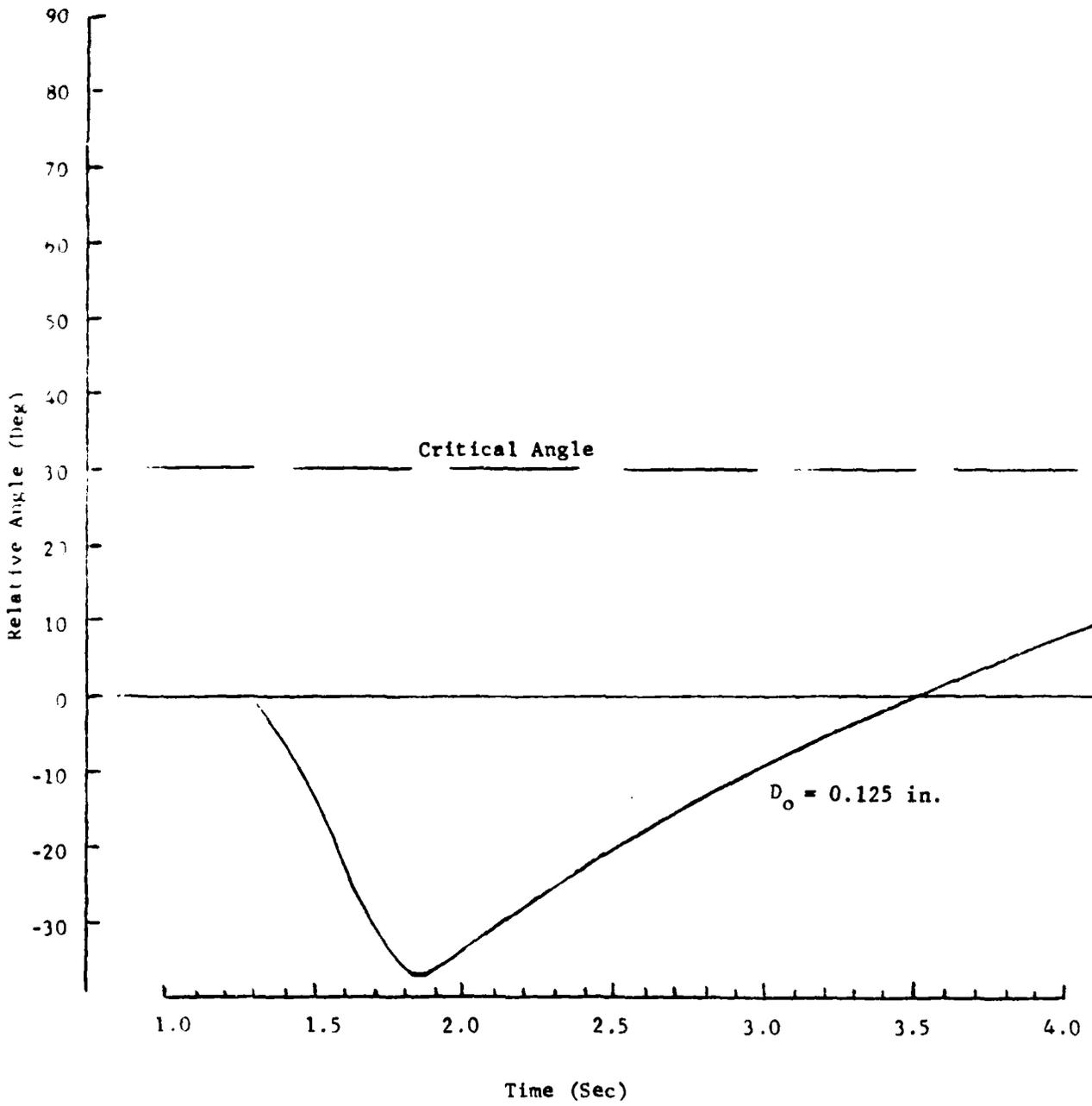


Figure 27
Relative Angle Between Cargos 2 and 3 vs Time;
mixed weights and lengths

Cargo 1 = 4,000 lb	Platform 1 = 12 ft
Cargo 2 = 4,000 lb	Platform 2 = 12 ft
Cargo 3 = 27,000 lb	Platform 3 = 20 ft

$D_o = 0.125 \text{ in.}$

2) Decreasing the orifice size tends to increase the torque developed between cargos 1 and 2 in a three-cargo group, but does not greatly alter the peak moment between 2 and 3. Decreasing the orifice size tends to cause the peak torque to occur sooner after tip-off. Because of the geometry of the cylinder mounting and linkage, peak cylinder pressure and peak torque do not necessarily occur simultaneously.

3) Postponing the point of force transfer tends to increase the relative torque between adjacent cargos; to increase the angle and angular velocity between cargos 1 and 2; and to decrease the angle and angular velocity between cargos 2 and 3.

4) Decreasing orifice size generally reduces relative angle and angular velocity between cargos 2 and 3. In some cases, decreasing the orifice size actually tends to decrease the peak torque between cargos 2 and 3. It is felt that this is because the relative velocity between cargos is kept to a minimum.

5) When mixing different weights and lengths of cargo, it is mandatory that lighter cargos be extracted first. This can be seen very readily when examining cases 25 through 26 in table 1. Configurations 25 and 30 are the only three-cargo groups of 35,000 lb total weight that are satisfactory from the standpoint of peak torque, relative angle, and cylinder pressure. These configurations are arranged so that the heaviest cargo is loaded foremost in the aircraft and extracted last.

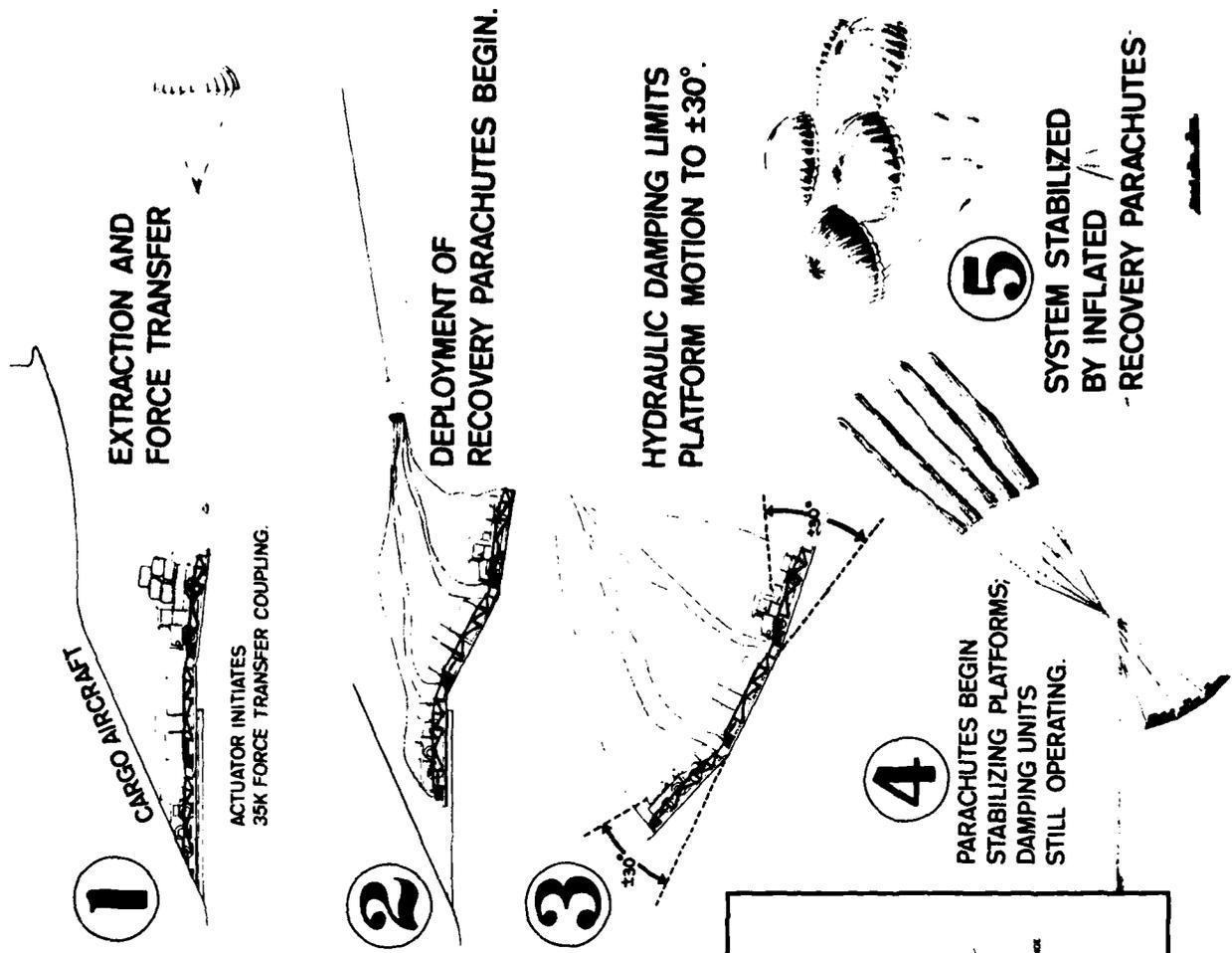
3. Prototype Design

Based on the performance results indicated by the computer model, the recommended system is based on the group-extraction/group recovery RES with hydraulic damping at the platform connecting links. The greatest advantage of this system is that it allows groups of cargos to be recovered with no dispersion and virtually no danger of cargo collision during extraction and inflation of the main recovery parachutes. The system described in this section is designed to be used with the standard Metric modular platform. When designing the system, it was recognized that the configuration recommended for this phase of development may not be optimum. In fact, it is believed that the design is somewhat conservative. However, because of the lack of measured test data and the possibility of high bending loads as indicated by the computer model, a conservative approach is encouraged for purposes of initial flight testing. The recommended concept is illustrated in figures 28 and 29. Drawings for the recommended system are included as an appendix.

The cylinders in the prototype system have a 5-in. (12.7 cm) bore and 12-in. (30.48 cm) stroke. The connecting rod is 2 in (5.08 cm) in diameter. The proposed hydraulic technique calls for a closed system in which hydraulic fluid is forced from one side of the piston to the other. An orifice diameter of 0.75 in. (1.91 cm) is used for flow corresponding to negative relative angular velocities. This large diameter creates a minimum of resistance. Based on computer analyses the effective constant orifice diameter corresponding to positive relative angular velocities should be in the range of 0.0937 to 0.156 in. (0.238 to 0.396 cm). Because of the number of variables which can affect the overall performance of the system, the exact orifice sizes must be determined by both laboratory and flight tests. It is hoped that a single orifice area can be used to cover a wide enough range of cargo weights and platform sizes so that adjustments in the field will not be necessary once the system is fully operational.

The reinforcement trusses are made of tubular steel and aluminum, welded together and bolted to the existing platform rails. The overall height of the reinforcement trusses is 25 in (63.5 cm). The top member is a 3-in. x 4-in. x 1/4-in. (7.62-cm x 10.16-cm x 0.635-cm) rectangular tube of ASTM A-500 steel. Truss members are 2-in. x 2-in. x 1/8-in. (5.08-cm x 5.08-cm x 0.3175-cm) ASTM A-500 steel tubes and the bottom member is a 5-in. x 3/4-in. (7.62-cm x 1.905-cm) 2024-54 aluminum plate. The thickness of the bottom plate is reduced locally and holes are drilled through at 5 in (12.7 cm) centers to accept the tiedown clevises. Some minor re-routing of tiedown straps may be necessary because attachments must be made to the lower plate of the truss rather than to the platform rail. The size and configuration of the trusses are necessary to withstand the large anticipated bending moments imparted to the platforms. Computer analyses indicate that bending moments of over 100,000 ft-lb (135,500 N-m) can be encountered. The reinforcement trusses are designed to carry

ACES AIRDROP CONTROLLED EXIT SYSTEM



CARGO AIRCRAFT

ACTUATOR INITIATES 35K FORCE TRANSFER COUPLING.

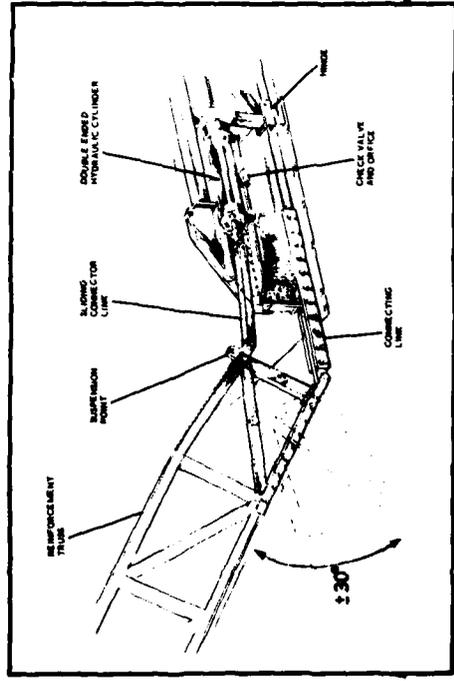
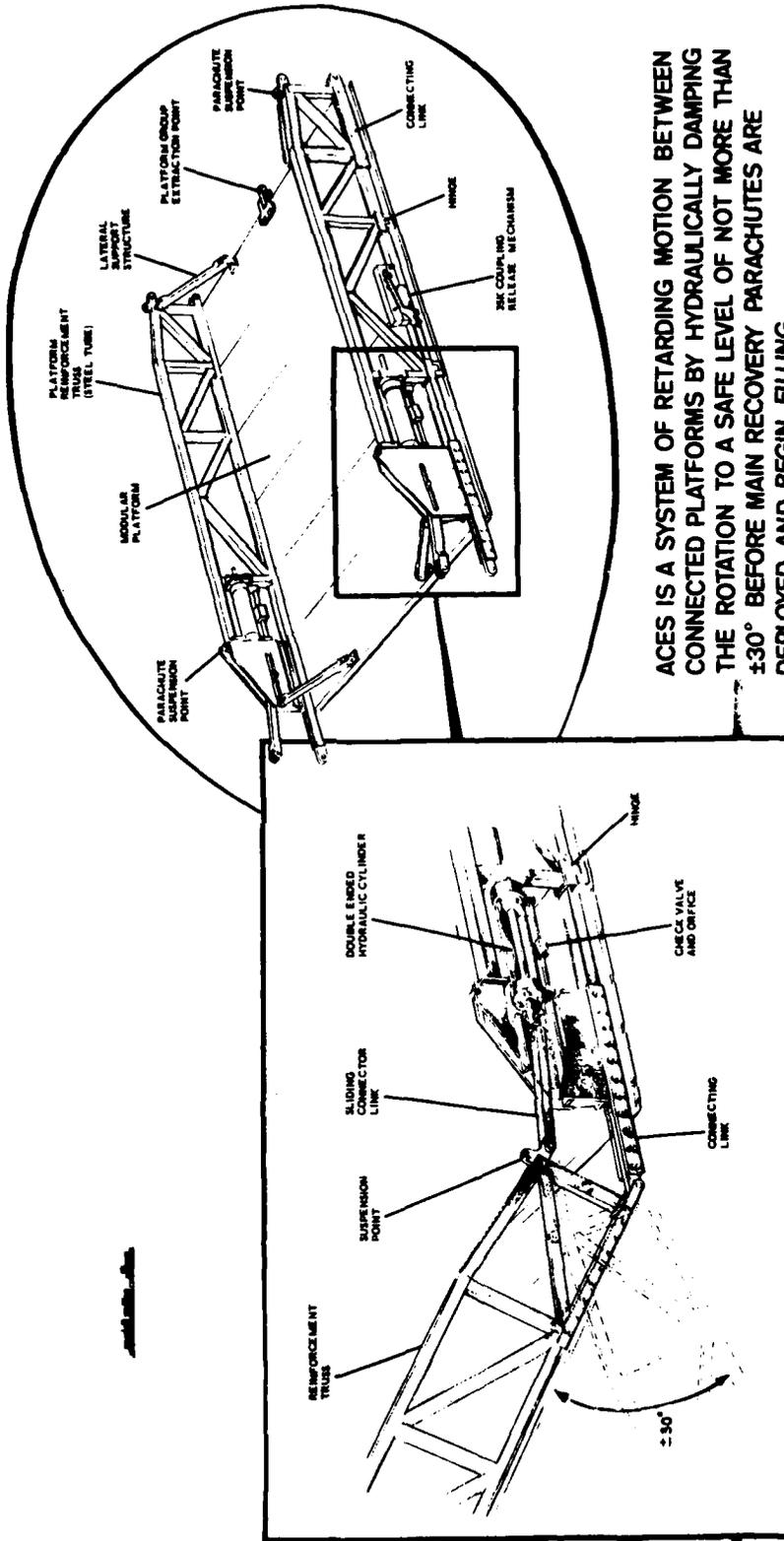


Figure 28
ACES Operational Concept



ACES

AIRDROP CONTROLLED EXIT SYSTEM



ACES IS A SYSTEM OF RETARDING MOTION BETWEEN CONNECTED PLATFORMS BY HYDRAULICALLY DAMPING THE ROTATION TO A SAFE LEVEL OF NOT MORE THAN $\pm 30^\circ$ BEFORE MAIN RECOVERY PARACHUTES ARE DEPLOYED AND BEGIN FILLING.

Figure 29
ACES Rotation Control Concept

64,000 ft-lb (86720 N-m) each with a safety factor of 1.5 to yield. The cross-section characteristics of the truss configuration provide stability against buckling for unsupported lengths of up to 16 ft (4.88 m). Lengths greater than this will require intermediate lateral supports attached to the platform or local reinforcement of the upper truss member.

Extraction of tandem platform groups is accomplished through the platforms rather than directly through the cargos. The last platform section of the group is modified to provide attachment of the standard 35-K force transfer coupling. Provision is made in the reinforcement trusses to allow the release actuation mechanism for the 35-K coupling to be mounted on the existing platform rails. For two-cargo groups, the release mechanism is mounted at the middle of the second platform to leave the aircraft. For three-cargo groups the release mechanism is mounted midway on the middle platform. This arrangement requires a release cable length beyond the maximum standard length for standard airdrop inventory. The extra length cable can be provided from the manufacturer and it is felt that the extra length will not cause any difficulty in actuating the force transfer coupling. This can be verified with laboratory tests before flight testing.

The weight of the complete system for a 12-ft platform is approximately 1100 lb (498 kg). This includes the cylinders, linkage, mounting structure and reinforcement trusses. Each reinforcement truss weighs 20.6 lb/ft (30.61 kg/m) not counting cylinder mounting structure. To reduce the number of different items for inventory, it is anticipated that the same cylinders and mounting structure will be used for all platform lengths. Thus, the system weight for a 20-ft platform is only 320 lb (145.2 kg) heavier than for a 12-ft platform.

Because of the restrictions to exterior width imposed by the aircraft, the volume occupied by the cylinders and reinforcement trusses subtract from available cargo area on the platform. Therein lies the most significant problem with the recommended system. The current design allows a free width of 97 inches (246 cm) between the hydraulic cylinders and 100.9 inches (277 cm) between the inside surfaces of the upper members of the trusses. These width restrictions imposed by cylinders and trusses eliminate at least five cargos from use with the system. However, it is felt that this is not an unreasonable sacrifice when traded off against the tremendous capability provided by being able to eliminate dispersion for most groups of up to three cargo loads. Also, it is anticipated that flight tests will reveal that the size of the reinforcement trusses may be reduced. In addition there are other components of the system that might be optimized, given that large scale procurement is justified. For example, the hydraulic cylinders recommended for advanced development tests are readily-available commercial-grade items. Hydraulic pressures for these items must be maintained below 5000 psi (34.48 MPa). If flight tests show that moments transmitted through the linked platforms are

significantly lower than those indicated by computer simulations, or if a cylinder could be designed to operate at pressures of much greater than 5000 psi, the diameters of the cylinders could be reduced and more cargo area would be available on the platform.

To facilitate rigging and de-rigging, the reinforcement trusses and cylinder mounting structure are hinged just above the normal platform rails. The removal of several bolts on each side of the platform allows the reinforcement trusses to be rotated downward and out of the way. This allows cargos to be placed on the platform and almost completely rigged without interference from the trusses. The trusses must be rotated upward and bolted in place for just the last fore and aft tiedowns. Field de-rigging is made relatively simple by rotating the trusses away from the platform. Removal of the trusses allows easy access to the tiedowns and allows cargos to be dragged or driven off the platforms.

V. CONCLUSIONS AND RECOMMENDATIONS

Computer simulation analysis of the Rapid Extraction System (RES) with hydraulic damping applied through the platform linkage shows that extraction and recovery of tandem cargo groups is feasible, and is the most desirable ACES concept. Motion damping and retardation of inter-platform rotation provided by hydraulic cylinders at the platform joints prevent cargo collision while the main recovery parachutes open and stabilize the cargo group.

The advantages of extracting and recovering groups of cargos intact are tremendous. However, the analysis indicates that there is a price to pay in the form of extra weight as well as some loss of storage area on the platforms caused by the hydraulic cylinder mounting apparatus and structure needed to reinforce the platforms against potentially large bending moments transmitted through the linkage. Because of the assumptions made in the simplified computer model, it is felt that the bending moments indicated by the simulations are overstated, and that tests will show that the size and weight of the reinforcement structure can be reduced considerably. Nonetheless, a conservative approach is suggested for early tests, and the prototype system recommended is designed to carry the high loads indicated by the computer simulations.

A two-stage test program is recommended to prove the capability of the system. Laboratory tests which apply loads indicated by the computer analysis would be used to measure stresses in the platform structure as well as to record dynamic performance of the hydraulic cylinders. These laboratory tests would verify the load-bearing capability of the platform structure, and would aid in the selection of proper cylinder orifice sizes needed to provide the desired displacement-time history. The laboratory tests would be followed by actual airdrop tests in which the platforms were instrumented to measure loads and stresses created in the true airdrop environment. Film coverage would also verify platform rotation-time performance indicated by the computer simulations. Based on the data provided by the instrumented airdrop tests, the platform linkage and reinforcement structure could be optimized from the standpoint of size, weight, configuration, and operational simplicity.

For early testing purposes, it is recommended that cargo groups be limited to two or three platforms. Computer simulations indicate that groups of up to three 16-ft platforms or two 20-ft platforms create loads that are within the load-carrying capability of the platform reinforcement structure. Groups of three 20-ft platforms could create bending moments beyond the strength of the structure. It is suggested that initial tests be done with various weight cargos on 12-ft platforms in order to gather data which can be used for comparison to computer simulation results.

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- 3 "Performance of and Design Criteria For Deployable Aerodynamic Decelerators"; Air Force Flight Dynamics Laboratory, Air Force Systems Command; Wright-Patterson AFB, Ohio; Tech Report No. ASD-TR-61-579; December, 1963.
- 4 A.L. Farinacci and W.L. Black; "Exploratory Development of a High Level Airdrop System for Platform-Mounted Cargos"; AAI Corporation, Cockeysville, MD; Contract No. DAAK60-77-C-0073; February, 1980.
- 5 P.J. O'Brien; "Evaluation Tests of the Type V Airdrop Platform and Associated Hardware"; Directorate of Crew and AGE Engineering, Air Force Systems Command; Wright-Patterson AFB, Ohio; Tech Memorandum ENCM-TM-75-3; July, 1975.

APPENDIX

Drawings of Recommended ACES Cargo Airdrop Systems

(NOTE)

The following are contractor drawings presented to U.S. Army NLABS for approval and initial system assembly. Because of subsequent test and evaluation, they may not be the latest edition. Questions concerning the latest revision should be directed U.S. Army Natick Research and Development Laboratories, Natick, MA.

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NO.	DATE	APPROVED

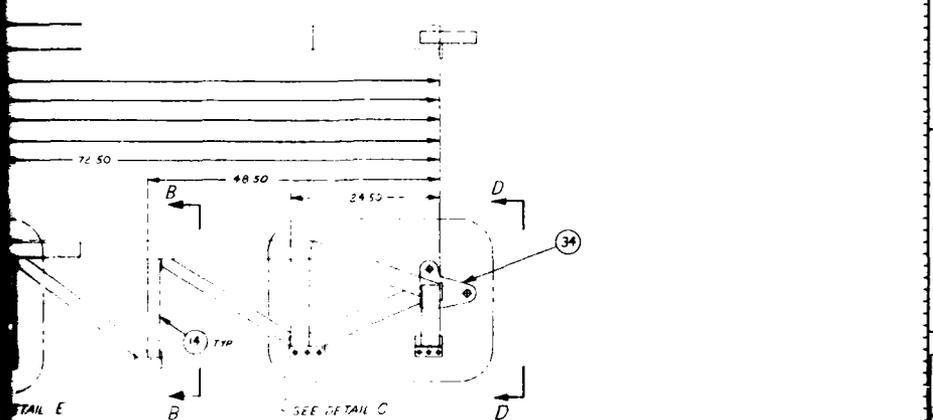
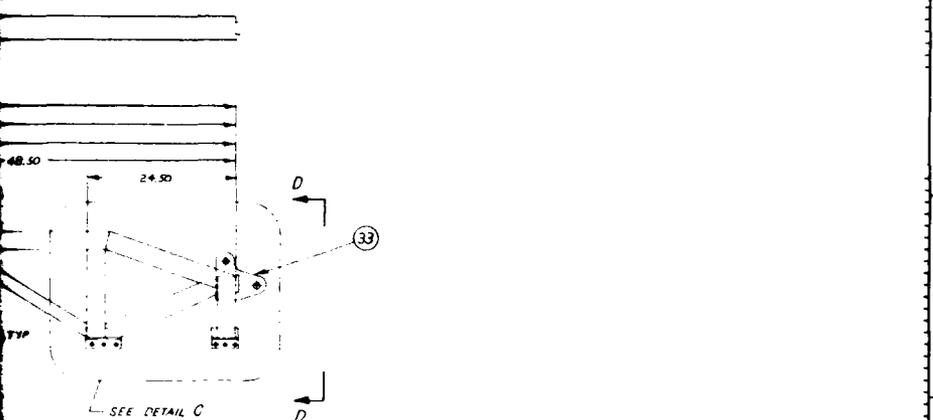
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31	PLATE OR BAR
32	PLATE OR BAR
33	PLATE OR BAR
34	PLATE OR BAR
35	PLATE OR BAR
36	PLATE OR BAR
37	PLATE OR BAR
38	PLATE OR BAR
39	PLATE OR BAR
40	PLATE OR BAR
41	PLATE OR BAR
42	PLATE OR BAR
43	PLATE OR BAR
44	PLATE OR BAR
45	PLATE OR BAR
46	PLATE OR BAR
47	PLATE OR BAR
48	PLATE OR BAR
49	PLATE OR BAR
50	PLATE OR BAR

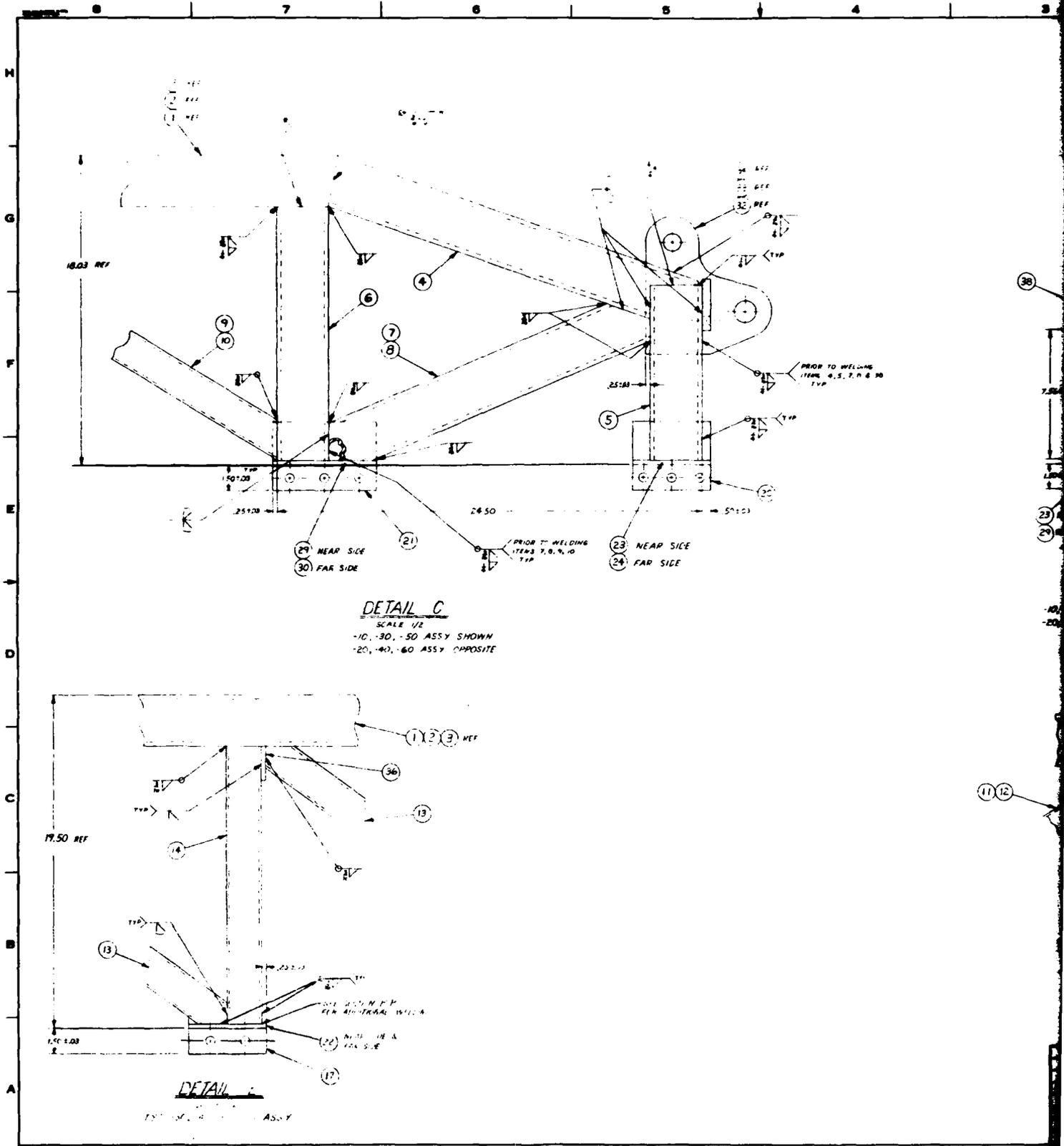
Copy available to DTIC does not permit fully legible reproduction

REVISIONS			
ZONE	DATE	DESCRIPTION	APPROVED

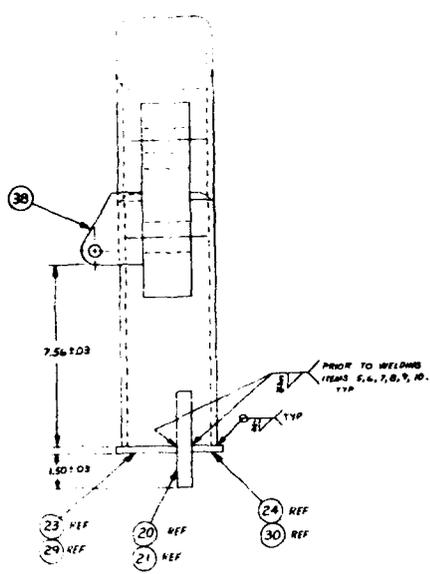


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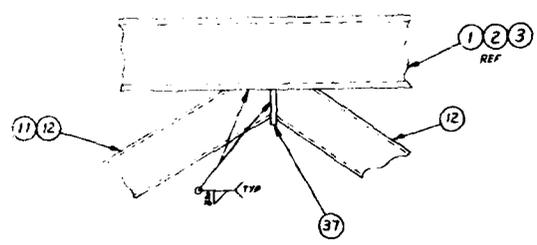
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	GW 382107 BALTIMORE, MD.	TRUSS
TOLERANCE FRACTIONS: ± .005 DECIMALS: ± .005 ANGLES: ± .010 HOLE POSITION: ± .010 HOLE SIZE: ± .005	97384	56947-40001
MATERIAL: 100% ANILIN STEEL	97384	56947-40001
TEMP: -50.00	97384	56947-40001
NEXT ASSY:	97384	56947-40001
USED ON:	97384	56947-40001
APPLICATION:	97384	56947-40001



REV	DATE	DESCRIPTION	BY	APP'D



VIEW D-D
SCALE 1/2
-10, 30, 50 ASSY SHOWN
-20, 40, 60 ASSY OPPOSITE



DETAIL F
SCALE 1/2

REV	DATE	DESCRIPTION	BY	APP'D

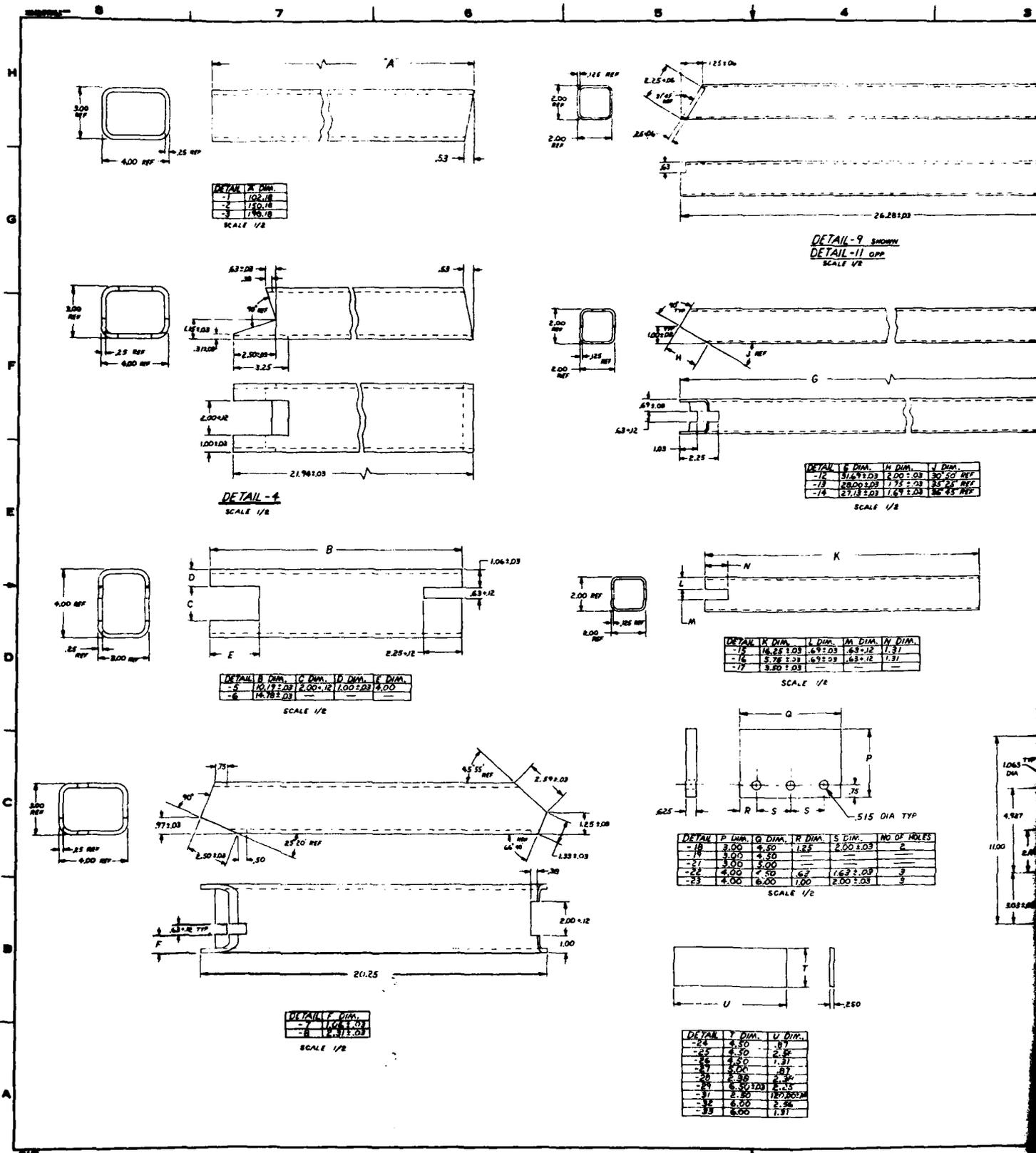
REV	DATE	DESCRIPTION	BY	APP'D

UNLESS OTHERWISE SPECIFIED FINISHES ARE AS SHOWN TOLERANCE DIMENSIONS & ANGLES FRACTIONS $\frac{1}{16}$ TO $\frac{3}{16}$ ± 0.005 DECIMALS $\frac{1}{16}$ TO $\frac{3}{16}$ ± 0.005 MATERIAL: LOW CARBON STEEL	PART NUMBER 9738A	MANUFACTURER'S NO. 56947-40001	QUANTITY 1	UNIT EACH
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1 2



DETAIL	K DIM.
-1	1.02 ±.03
-2	1.50 ±.03
-3	1.98 ±.03

SCALE 1/2

DETAIL-9 SHOWN
DETAIL-11 OPP
SCALE 1/2

DETAIL-4
SCALE 1/2

DETAIL	K DIM.	W DIM.	L DIM.
-12	31.67 ±.03	2.00 ±.03	50.50 REF
-13	28.00 ±.03	1.75 ±.03	55.50 REF
-14	27.73 ±.03	1.69 ±.03	56.95 REF

SCALE 1/2

DETAIL	B DIM.	C DIM.	D DIM.	E DIM.
-5	10.75 ±.03	2.00 ±.12	1.00 ±.03	4.00
-6	14.75 ±.03	—	—	—

SCALE 1/2

DETAIL	K DIM.	L DIM.	M DIM.	N DIM.
-15	18.25 ±.03	6.9 ±.03	6.3 ±.12	1.31
-16	5.78 ±.03	6.9 ±.03	6.3 ±.12	1.31
-17	3.50 ±.03	—	—	—

SCALE 1/2

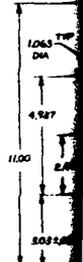
DETAIL	P DIM.	Q DIM.	R DIM.	S DIM.	NO OF HOLES
-18	3.00	4.50	1.52	2.00 ±.03	2
-19	3.00	4.50	—	—	—
-20	4.00	7.00	.52	1.63 ±.03	3
-21	4.00	6.00	1.00	2.00 ±.03	3

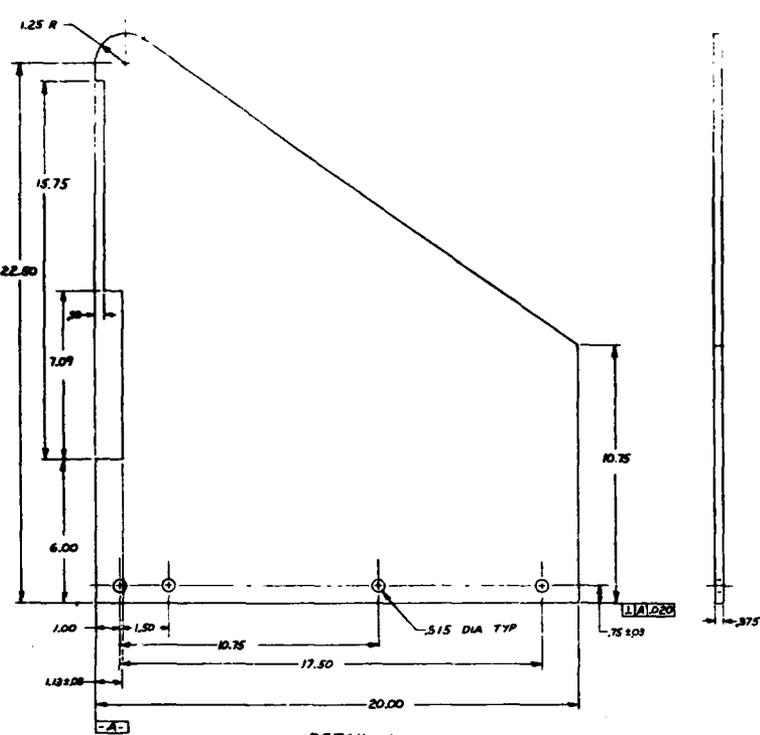
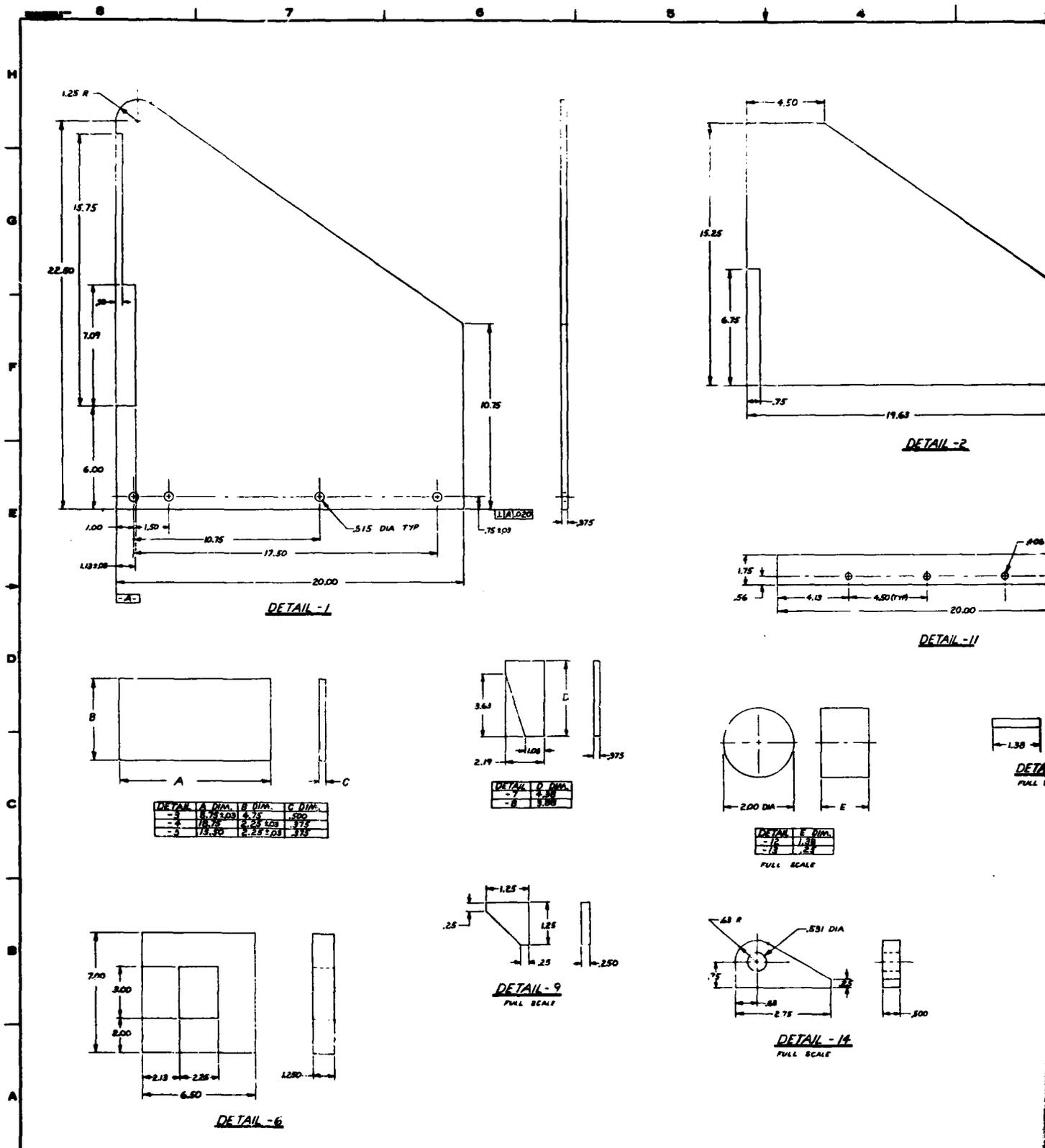
SCALE 1/2

DETAIL	F DIM.
-7	1.68 ±.03
-8	2.31 ±.03

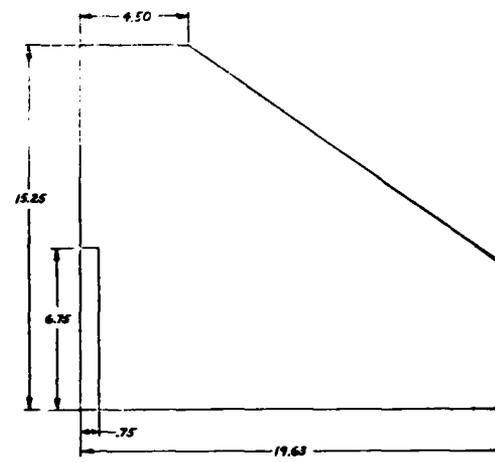
SCALE 1/2

DETAIL	T DIM.	U DIM.
-22	4.50	.87
-23	4.50	2.37
-24	4.50	1.87
-25	2.38	2.37
-26	4.50 ±.03	2.37
-27	2.38	1.87
-28	6.00	2.38
-29	6.00	1.87





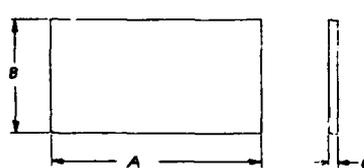
DETAIL - 1



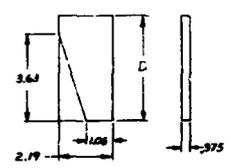
DETAIL - 2



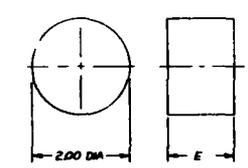
DETAIL - 11



DETAIL	A DIM.	B DIM.	C DIM.
- 3	6.75 ± .03	4.75	.000
- 2	10.75	4.25 ± .03	.975
- 1	15.50	4.25 ± .03	.375



DETAIL	D DIM.
- 4	3.63
- 3	3.86

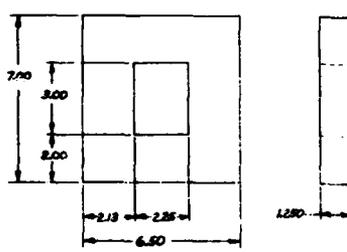


DETAIL	E DIM.
- 5	1.38
- 3	.54

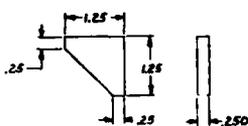
FULL SCALE



DETAIL - 6

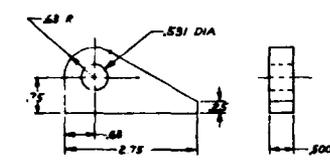


DETAIL - 6



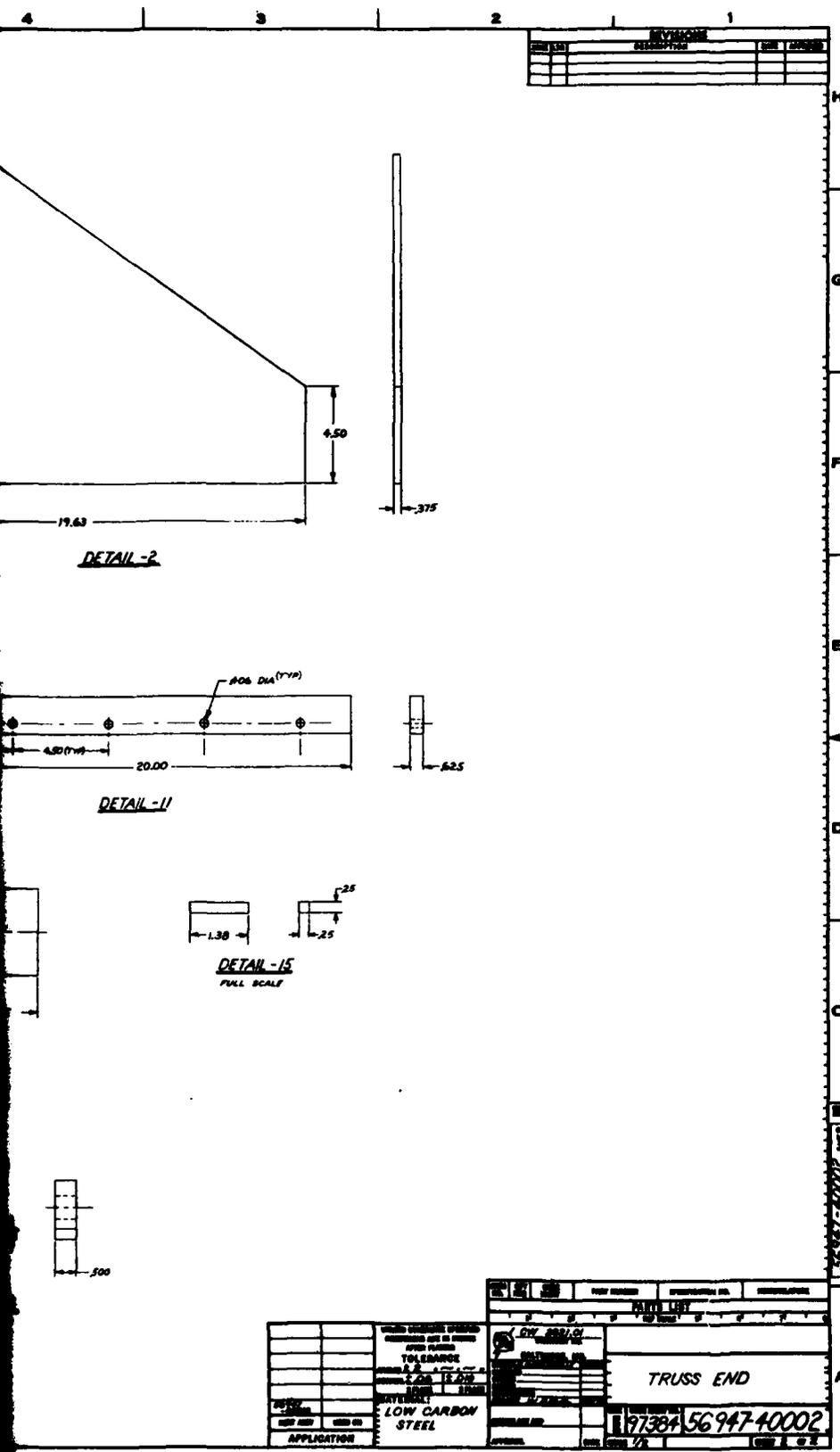
DETAIL - 9

FULL SCALE



DETAIL - 14

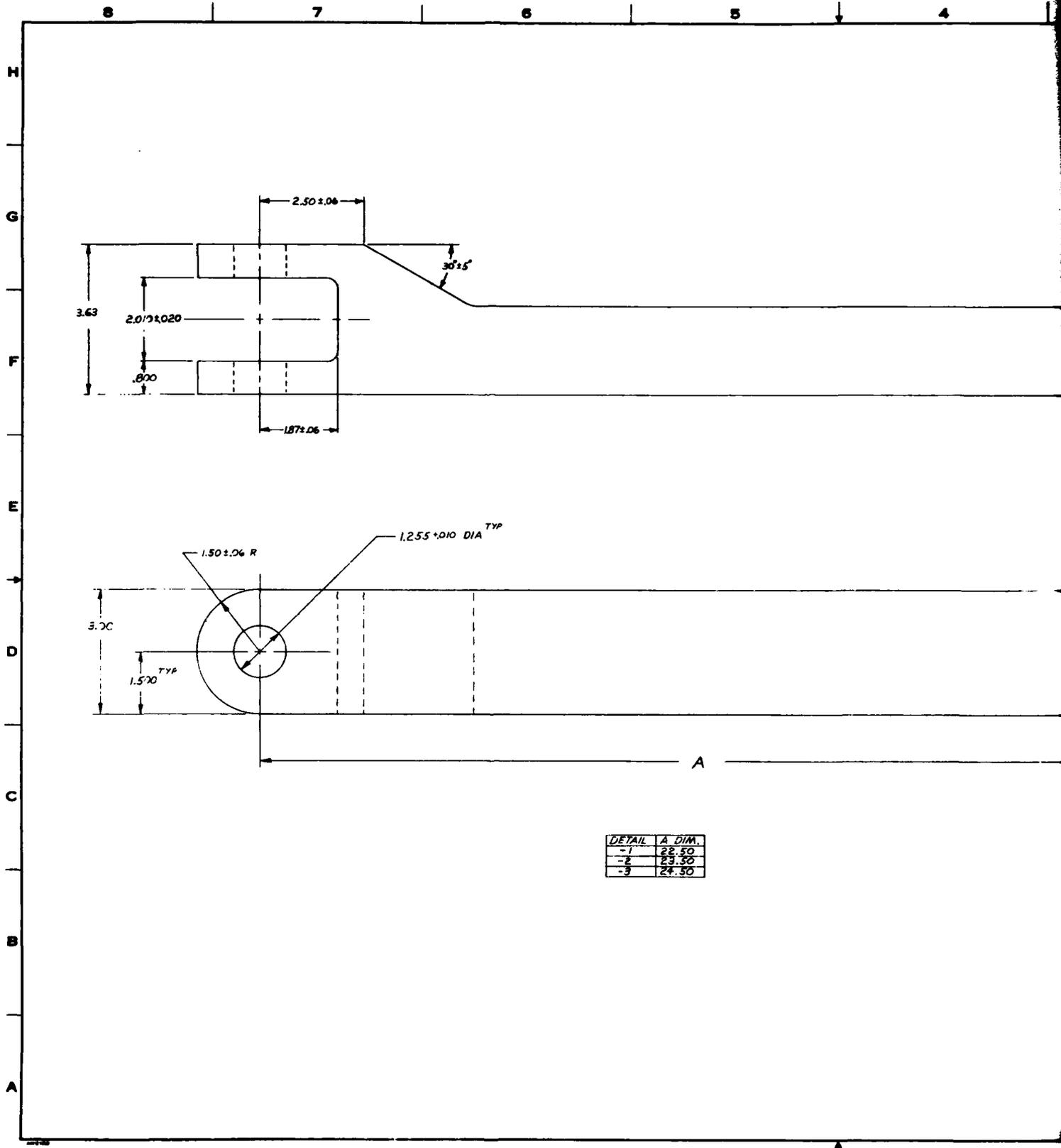
FULL SCALE



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TITLE LIST TRUSS END	
197381 56947-40002	TRUSS END
MATERIAL: LOW CARBON STEEL	APPLICATION:

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DETAIL	A DIM.
-1	22.50
-2	23.50
-3	24.50

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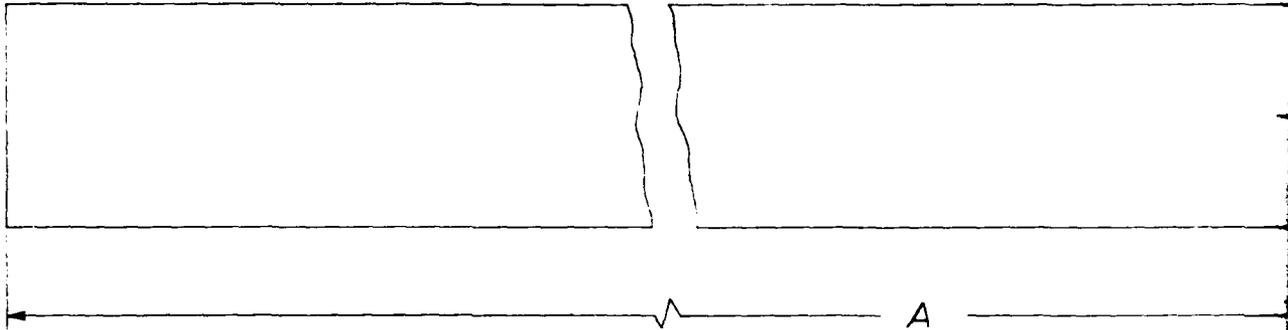
4

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NOTES:

1. BREAK SHARP EDGES .015 R APPROX.

DETAIL	A DIM.
-1	30.00 ± .06
-2	31.00 ± .06
-3	32.00 ± .06

5/8

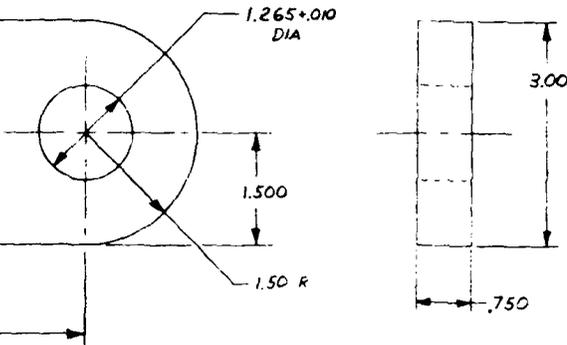
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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



DETAIL	A DIM.
-1	30.00 ± .06
-2	31.00 ± .06
-3	32.00 ± .06

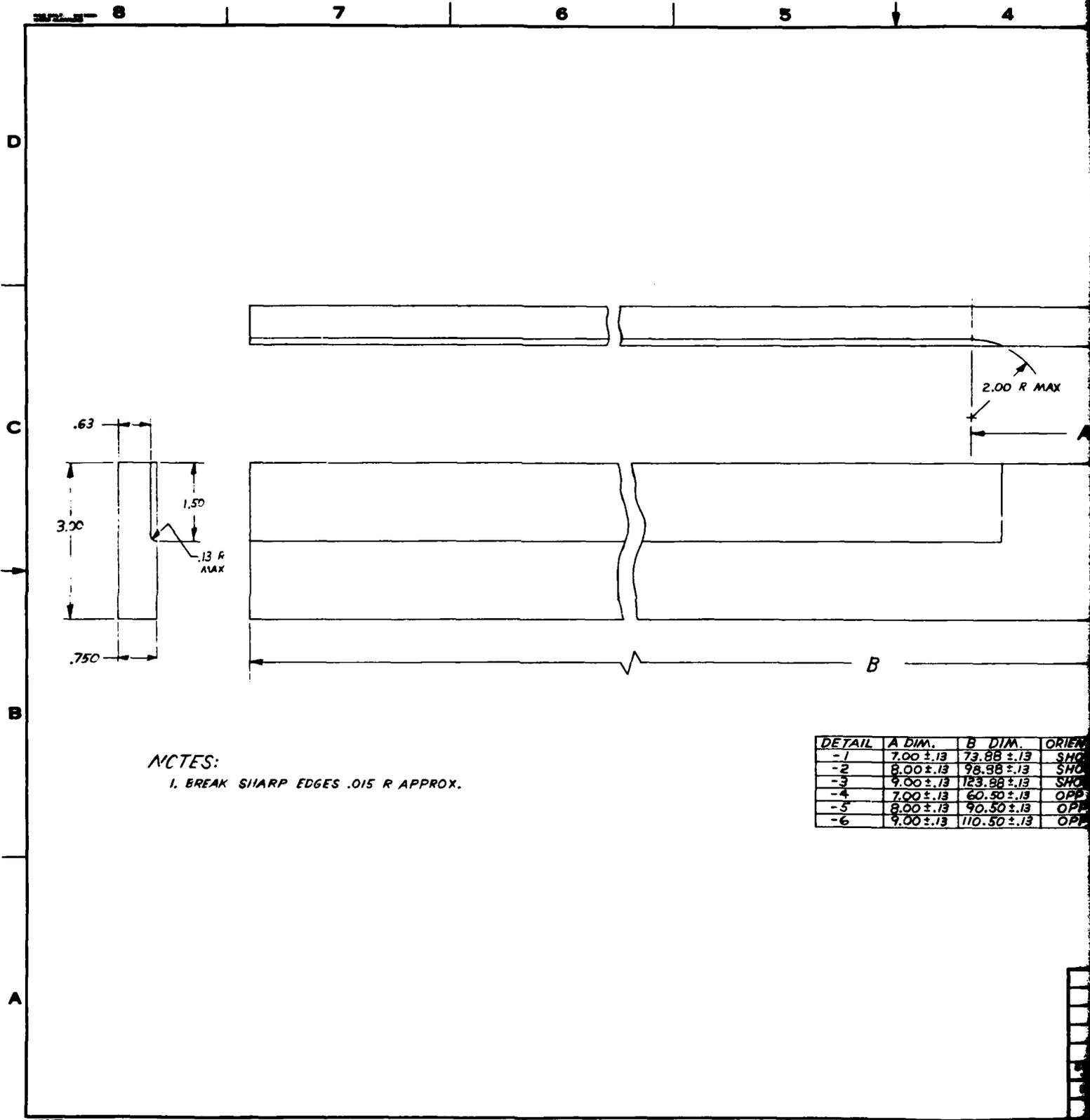
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56947-40005

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
-3			20 FT PLATF		LINK
-2			16 FT PLATF		LINK
-1			12 FT PLATF		LINK

PARTS LIST							
1	2	3	4	5	6	7	8
REF SCALE							

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING		CW 3821.01 COUNTRY NO.		BALTIMORE, MD.		LINK	
TOLERANCE		DRAWN <i>R. GUINZVALLI</i>		CHECKED			
ANGLES 2		DESIGN		STRESS			
DECIMAL ±.03 ±.010		ENGINEERING		PROJECT <i>W. Mack</i>			
2 PLACE 3 PLACE		MATERIAL:		SIZE		CODE IDENT NO.	
56947-40018		ALUM BAR,		D 97384		56947-40005	
NEXT ASSY USED ON		2024-T4,		APPROVAL		DATE	
APPLICATION		QQ-A-225/6		SCALE 1/1		SHEET 1 OF 1	

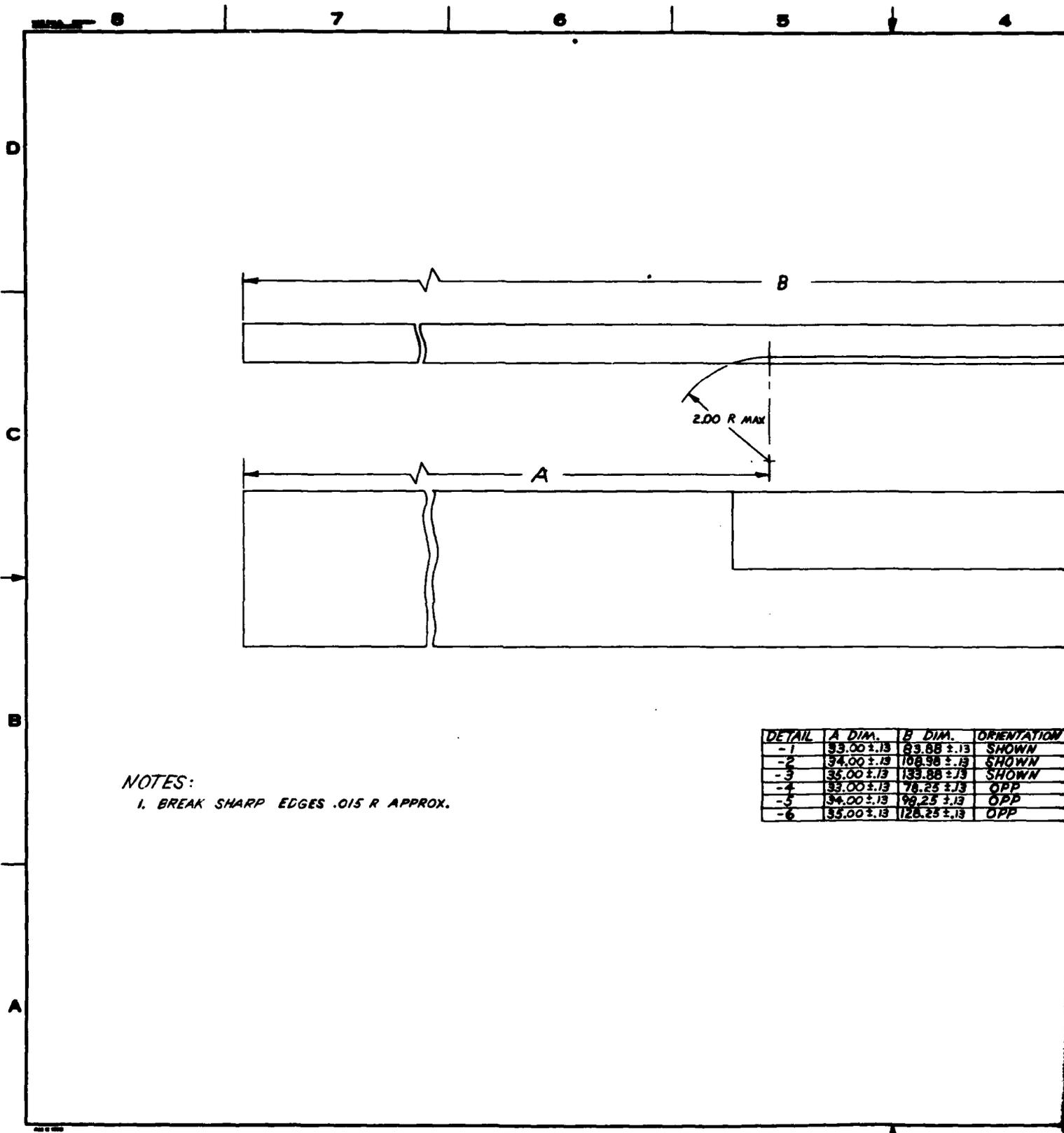
12



NOTES:

1. BREAK SHARP EDGES .015 R APPROX.

DETAIL	A DIM.	B DIM.	ORIENT
-1	7.00 ±.13	73.88 ±.13	SHO
-2	8.00 ±.13	98.98 ±.13	SHO
-3	9.00 ±.13	123.88 ±.13	SHO
-4	7.00 ±.13	60.50 ±.13	OPP
-5	8.00 ±.13	90.50 ±.13	OPP
-6	9.00 ±.13	110.50 ±.13	OPP



NOTES:
 1. BREAK SHARP EDGES .015 R APPROX.

DETAIL	A DIM.	B DIM.	ORIENTATION
-1	93.00 ±.13	83.88 ±.13	SHOWN
-2	94.00 ±.13	108.98 ±.13	SHOWN
-3	95.00 ±.13	133.88 ±.13	SHOWN
-4	93.00 ±.13	78.23 ±.13	OPP
-5	94.00 ±.13	99.23 ±.13	OPP
-6	95.00 ±.13	126.23 ±.13	OPP

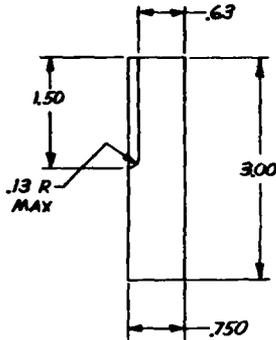
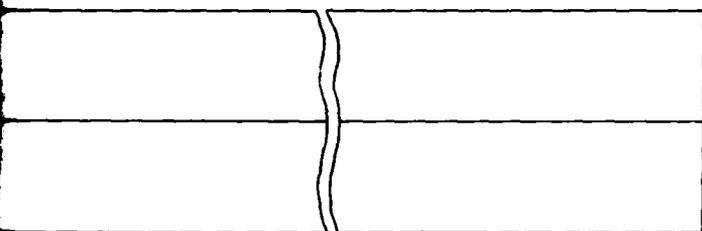
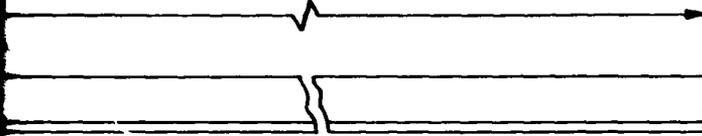
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REVISIONS			
DATE	BY	DESCRIPTION	APPROVED



DIM.	ORIENTATION
13.88 ± .13	SHOWN
26.98 ± .13	SHOWN
13.88 ± .13	SHOWN
18.25 ± .13	OPP
18.25 ± .13	OPP
18.25 ± .13	OPP

-6	20 FT PLATF	SIDE RAIL FWD
-5	16 FT PLATF	
-4	12 FT PLATF	
-3	20 FT PLATF	
-2	16 FT PLATF	
-1	12 FT PLATF	SIDE RAIL FWD

QTY	QTY REQ	QTY ON HAND	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
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PARTS LIST

ORDER ORIGINATOR'S OFFICE ORDERING AGENCY OR DIVISION APPROV PLANNING TOLERANCE DIMENSIONS ± .003 ± .010 SURFACE FINISH MATERIAL: ALUM BAR, 2024-T4, QQ-A-225/6		CW 3821.01 BALTIMORE, MD. DRAWN BY: [Signature] CHECKED BY: [Signature] APPROVED BY: [Signature]	SIDE RAIL, FWD
PART NO. 56947-4000 QTY ON HAND QTY ON ORDER	APPLICATION	DATE SCALE 1/1	SHEET 1 OF 1

56947-4000Y

1 2

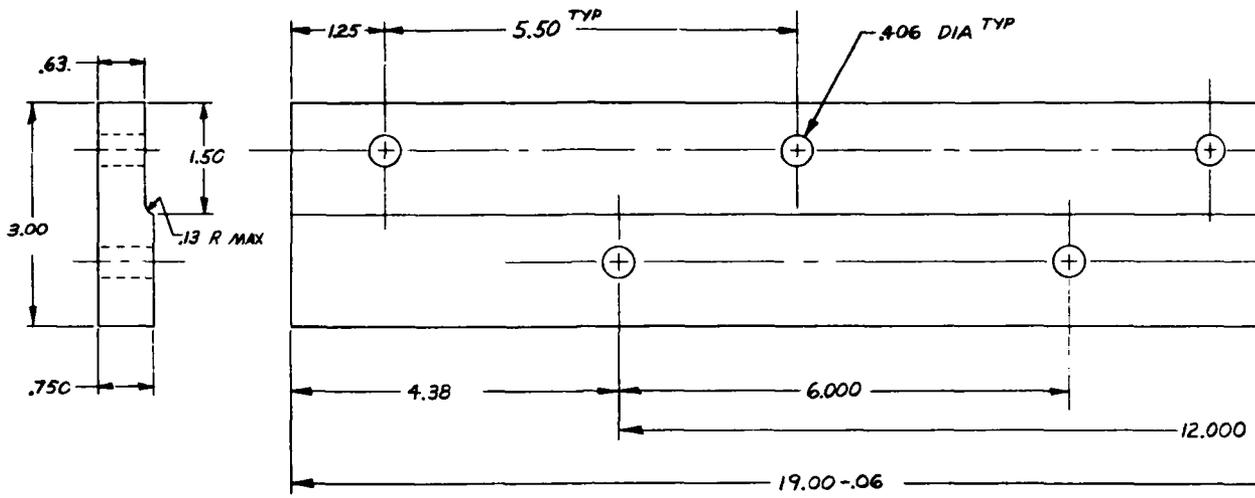
8 7 6 5 4

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NOTES:

1. BREAK SHARP EDGES .015 R APPROX.

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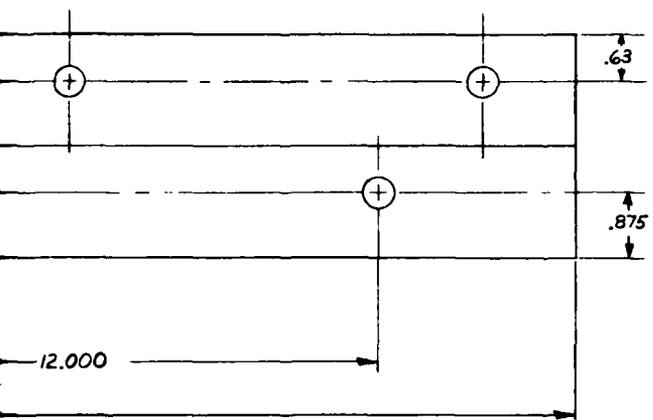
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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE APPROVED

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56947-40008



ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
PARTS LIST					
REF SCALE: 1 2 3 4 5 6 7 8					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING			CONTRACT NO. CW 9821.01 BALTIMORE, MD. DRAWN K. GUNTER / W. J. ...		
TOLERANCE			CHECKED _____ STRESS _____ DESIGN _____ DIMENSIONS _____		
ANGLES ± 2° DECIMAL 2 PLACE 3 PLACE MATERIAL: ALUM BAR, 2024-T4, QQ-A-225/6			SIZE CODE IDENT NO. D 97384 56947-40008 APPROVAL _____ DATE _____ SCALE 1/1 SHEET 1 of 1		
56947-40008 NEXT ASSY USED ON APPLICATION			RAIL, FILLER		

12

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

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56947-40009

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			-3	20 FT PLATF	BAR
			-2	16 FT PLATF	BAR
			-1	12 FT PLATF	BAR

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
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PARTS LIST							
1	2	3	4	5	6	7	8

CW 3821.01
CONTRACT NO.
BALTIMORE, MD.
DRAWN BY: QUINCY VALLEY 5-578
CHECKED: _____
DESIGN: _____
SUPERVISOR: _____
PROJECT: W/AVACK 2/6/78

BAR

APPROVAL: _____ DATE: _____
SCALE: 1/2 SHEET 1 OF 1

SIZE: C CODE IDENT NO. 97384 56947-40009

2

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES:

1. BREAK SHARP EDGES .015 R APPROX.

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56947-40010

			-2		PLATE
			-1		PLATE

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
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PARTS LIST							
1	2	3	4	5	6	7	8
			REF SCALE				

CW 3821.01
CONTRACT NO.

BALTIMORE, MD.

DRAWN BY: *W. GURTY/ALL S-K-70*
CHECKED:
DESIGN:
ENGINEERING:
PROJECT: *W. GURTY*

DESIGN ACT APP:

SIZE: **C** CODE IDENT NO. **97384** **56947-40010**

APPROVAL: DATE: SCALE: **1/1** SHEET **1** OF **1**

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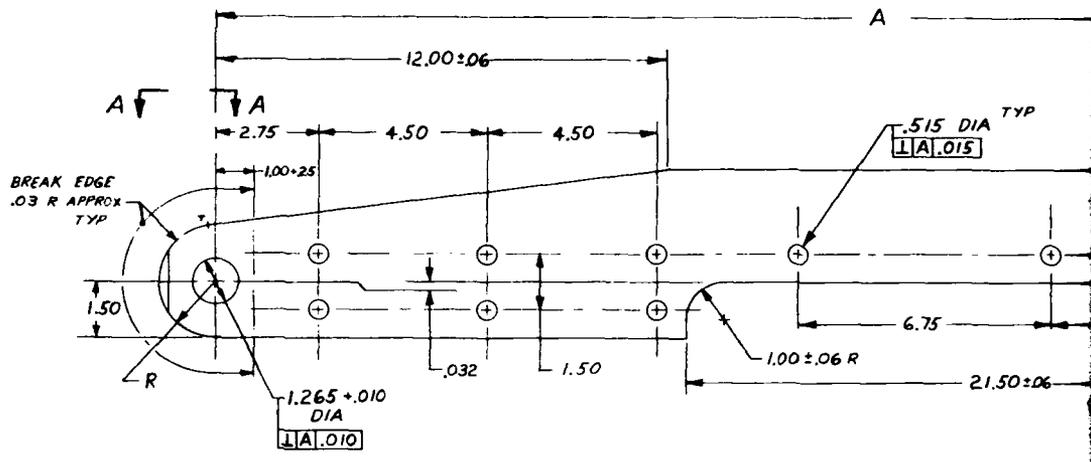
8 7 6 5 4

D

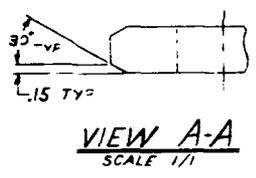
C

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A



DETAIL	A DIM.
-1	34.00 ± .06
-2	35.00 ± .06
-3	36.00 ± .06



- NOTES:**
- BREAK SHARP EDGES .015 R APPROX.
 - FINISH NO. 4.4 + 5.2 + 20.8 OF MIL-STD-171C (MR),
OLIVE DRAB NO. 2+087 OF FED-STD-595.
MASK HOLE PRIOR TO PAINTING

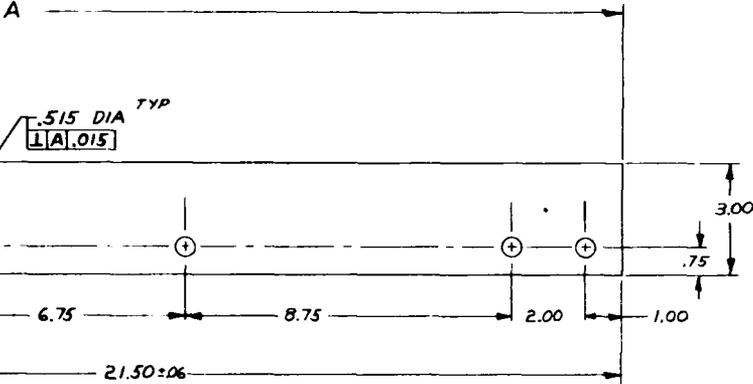
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REVISIONS				
CDME	LTR	DESCRIPTION	DATE	APPROVED



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0 ± .06
0 ± .06
0 ± .06

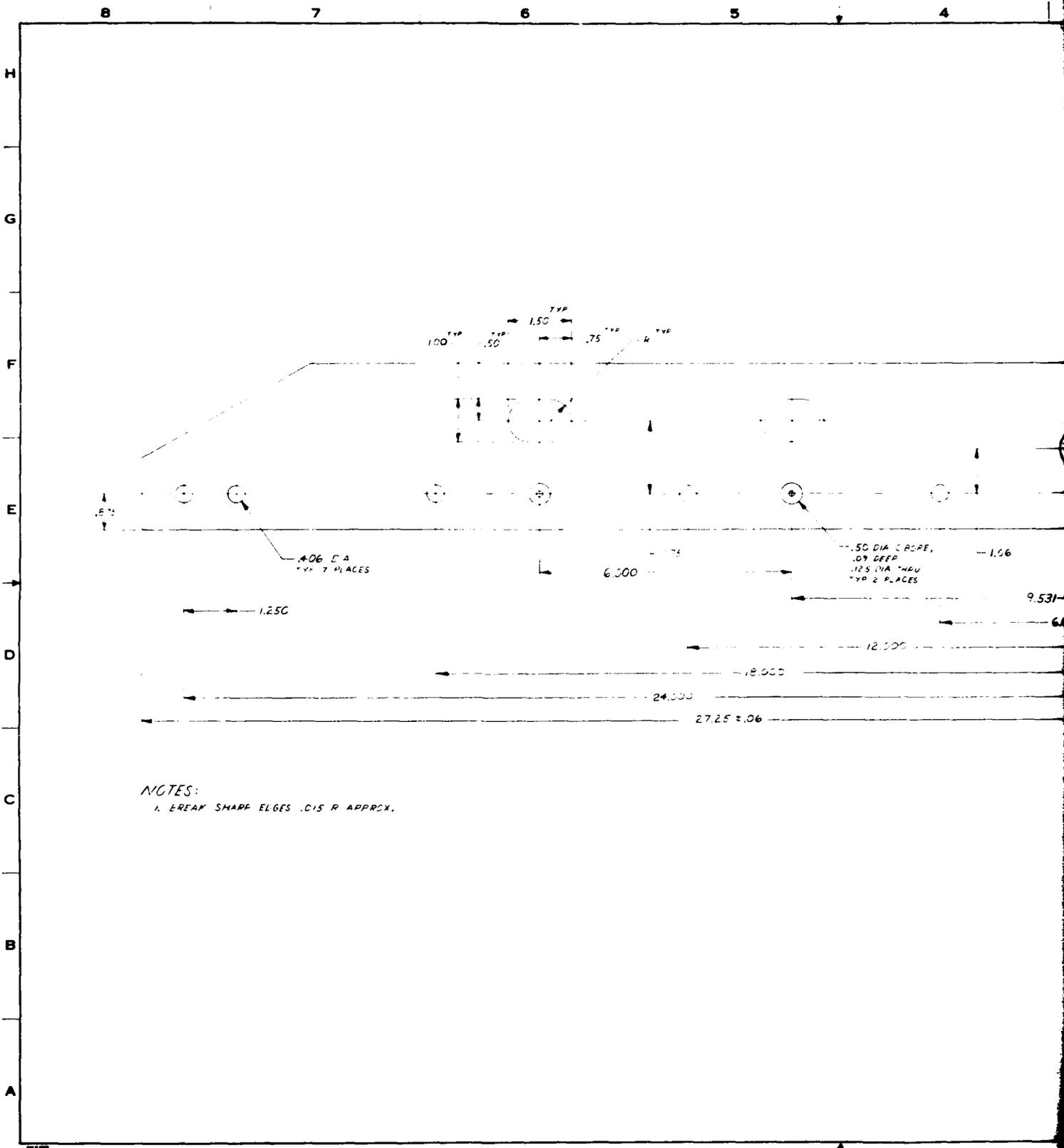
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56947-40011

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
-3			20 FT PLATF		RAIL
-2			16 FT PLATF		RAIL
-1			12 FT PLATF		RAIL

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING TOLERANCE FINISH ± .03 ± .010 DECIMAL 3 PLACE 3 PLACE		CW 3821.01 CONTRACT NO. BALTIMORE, MD. DRAWN R. GUNZVILLE CHECKED STRESS DESIGN ENGINEERING PROJECT W. Mack	RAIL, EXTENSION
56947-40011 NEXT ARMY USED ON	MATERIAL: 4140 STEEL, H.T. TO 140,000 PSI TENSILE, Rc 30-34	SIZE D CODE IDENT NO. 97384 56947-40011	APPROVAL DATE SCALE 1/2 SHEET 1 OF 1

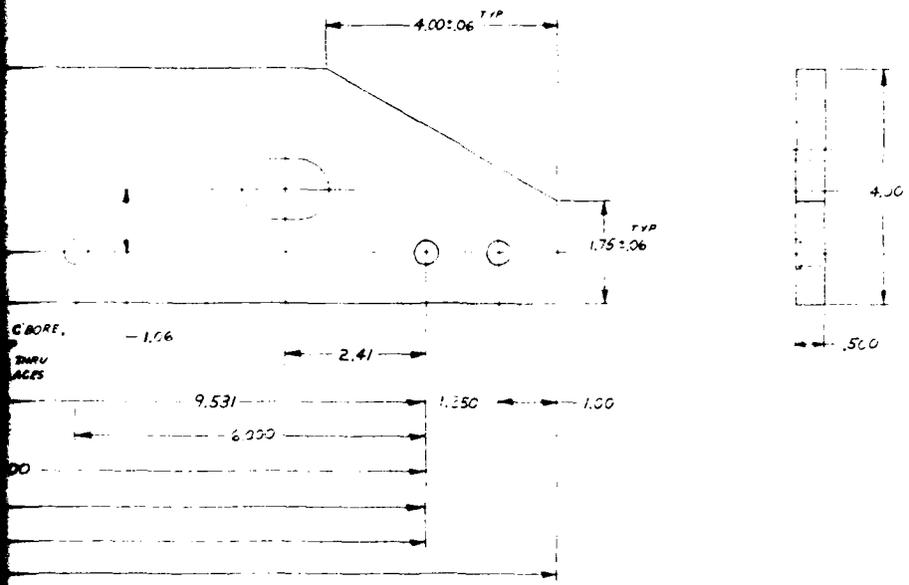
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NOTES:
 1. BREAK SHARP EDGES .015 R APPROX.

4 3 2 1

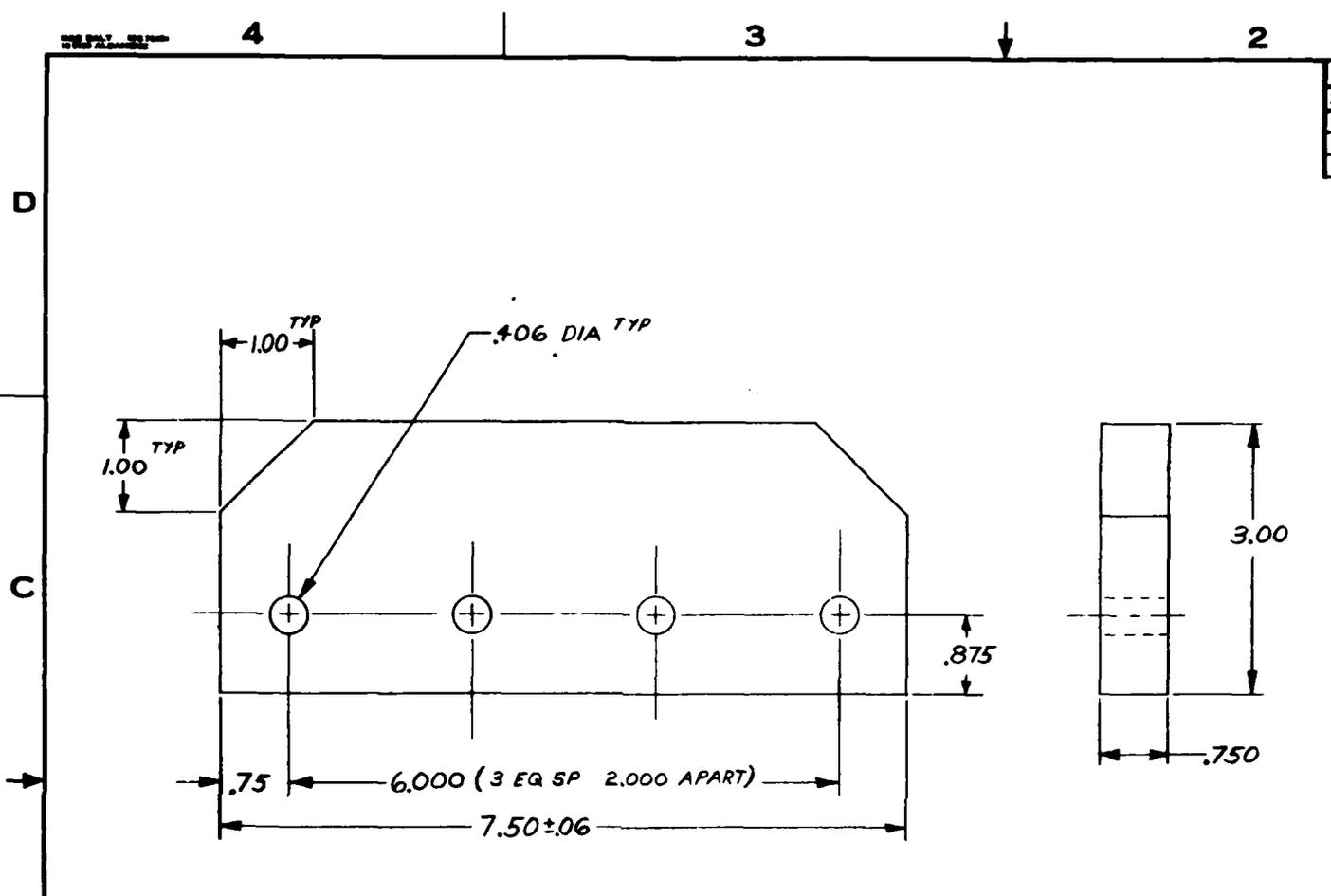
REVISIONS			
ZONE	LTR	DESCRIPTION	DATE APPROVED



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56947-40012

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
PARTS LIST					
REF SCALE 1 2 3 4 5 6					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING					
TOLERANCE					
ANGLES ± .2					
DECIMALS ± .03 ± .010					
FRACTIONS 2 PLACE 2 PLACE					
MATERIAL: ALUM BAR, 2024-T4, QQ-A-225/6					
DRAWN BY: <i>[Signature]</i>			CONTRACT NO. CW 3821.01		
CHECKED BY: <i>[Signature]</i>			BALTIMORE, MD.		
DESIGN BY: <i>[Signature]</i>			SPLICE PLATE		
ENGINEERING			DATE: 10/78		
DESIGN ACT APP			SITE CODE IDENT NO. 97384		
APPROVAL			DATE SCALE 1/1		
APPLICATION			SHEET 1 OF 1		

2



NOTES:

1. BREAK SHARP EDGES .015 R APPROX.

ITEM NO.	QTY REQ	CODE IDENT
	1	
CW 3821 CONTINUED BALTIMORE DRAWN <i>R. G. QUINZ</i> CHECKED _____ STRESS _____ DESIGN _____ ENGINEERING PROJECT <i>W. B. ...</i> DESIGN ACT APP _____ APPROVAL _____		

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING	
TOLERANCE	
ANGLES	± 2
DECIMAL	± .03 ± .010
	2 PLACE 3 PLACE
MATERIAL:	
ALUM BAR, 2024-T4, GQ-A-225/6	
NEXT ASSY	USED ON
APPLICATION	

2

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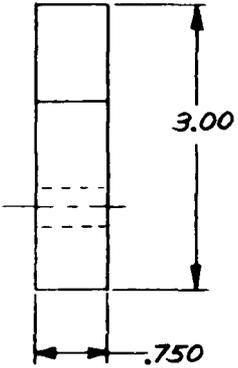
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

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56947-40013



ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
PARTS LIST					
1	2	3	4	5	6
REF SCALE					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING TOLERANCE ± .02 ± .03 ± .010 2 PLACE 3 PLACE		CW 3821.01 CONTRACT NO. BALTIMORE, MD. DRAWN <i>R. GUINZALE</i> 9-178 CHECKED STRESS DESIGN ENGINEERING PROJECT <i>W. Beck</i> 8/6/78		SPLICE PLATE	
SERIAL: ALUM BAR, 2024-T4, QQ-A-225/6		DESIGN ACT APP	APPROVAL	DATE	SIZE CODE IDENT NO. 97384 56947-40013
SCALE 1/1			SHEET 1 OF 1		

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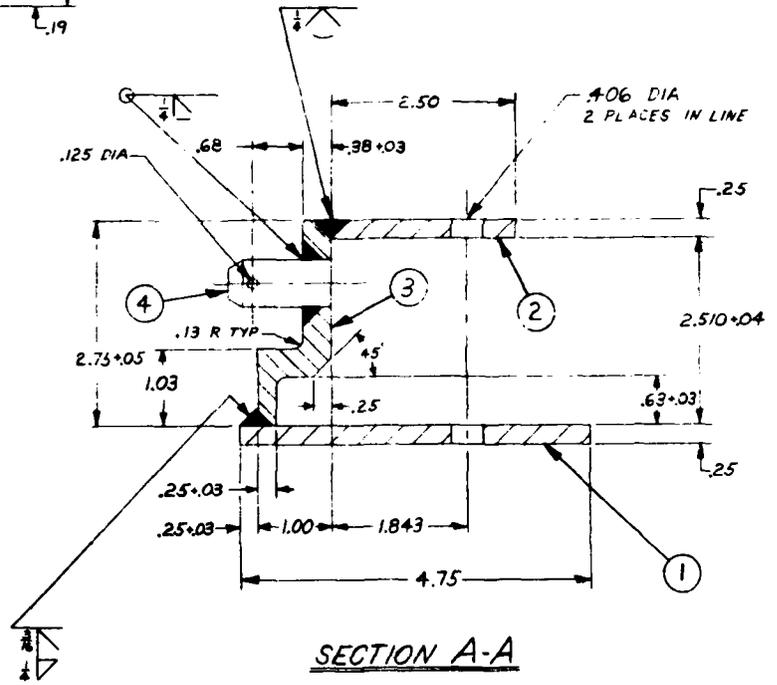
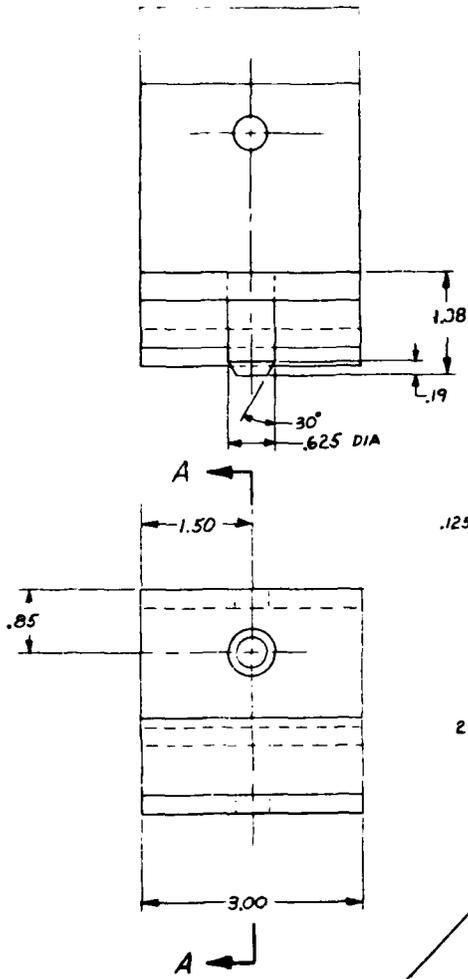
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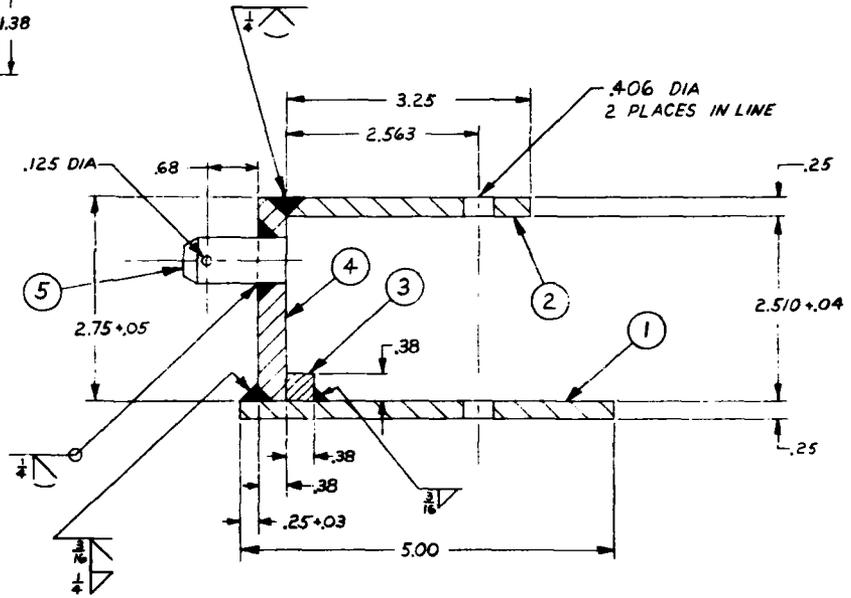
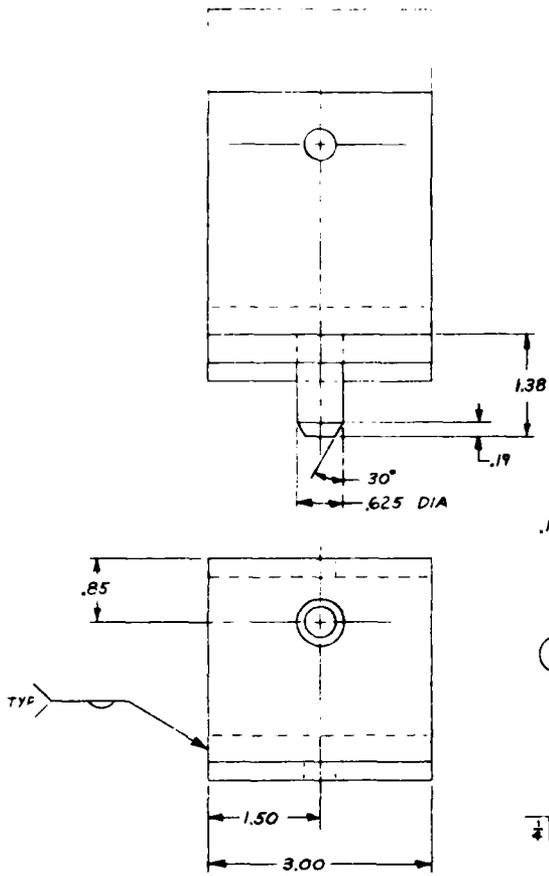
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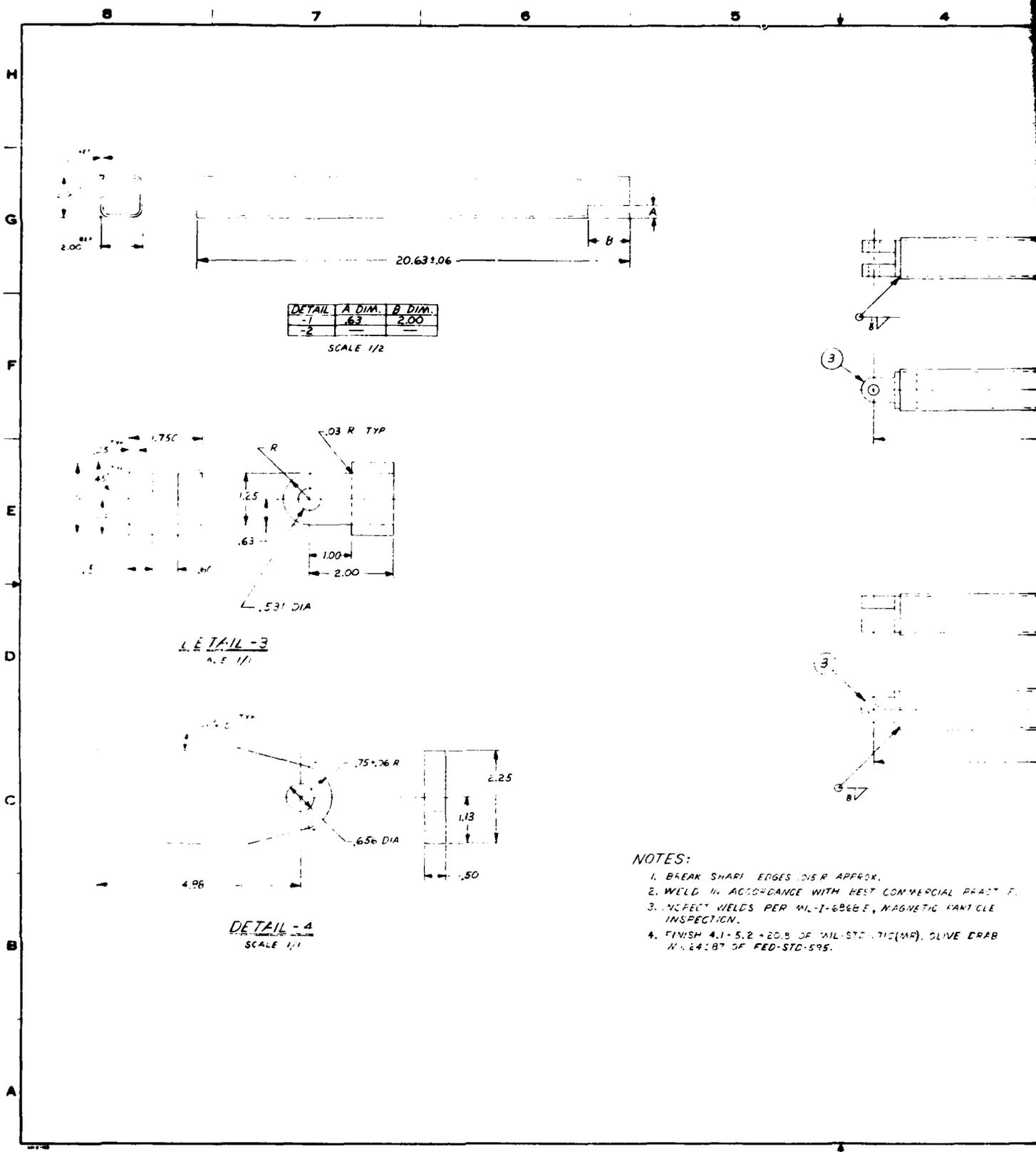
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DETAIL	A DIM.	B DIM.
-1	.63	2.00
-2	—	—

SCALE 1/2

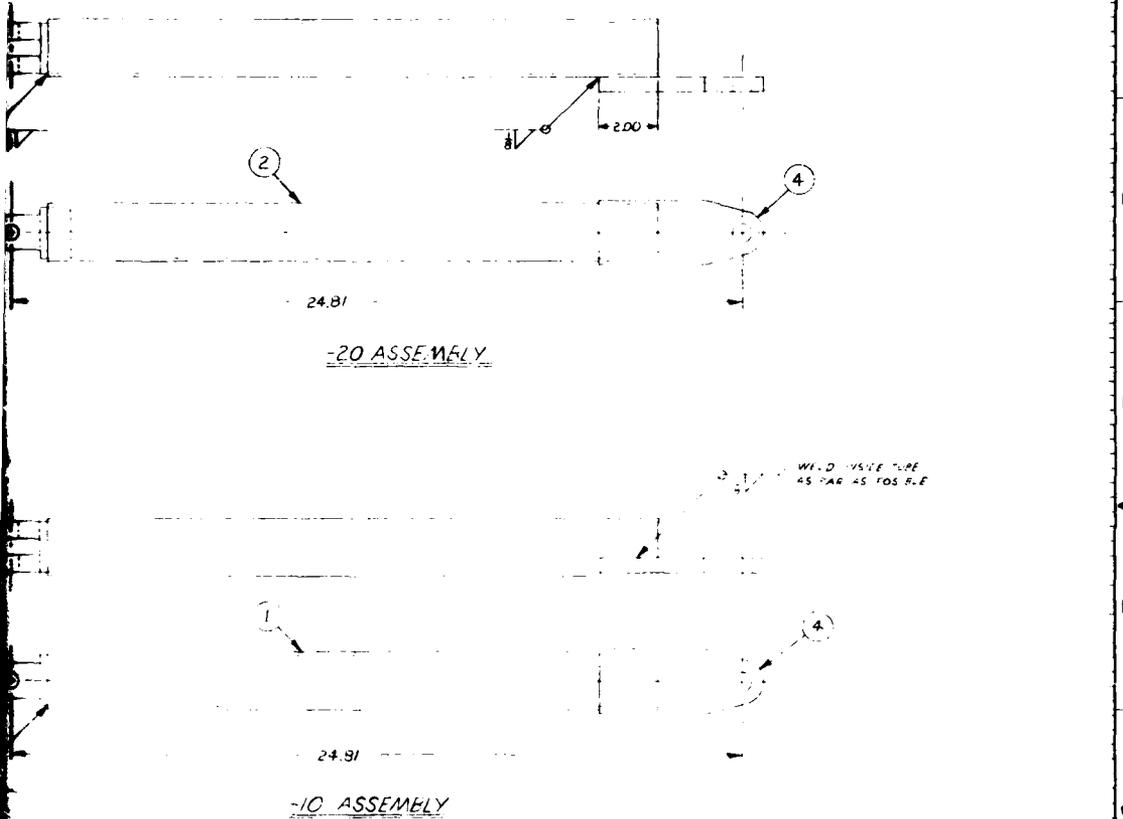
DETAIL - 3
SCALE 1/1

DETAIL - 4
SCALE 1/1

NOTES:

1. BREAK SHARP EDGES .015 R APPROX.
2. WELD IN ACCORDANCE WITH BEST COMMERCIAL PRACTICE.
3. INSPECT WELDS PER MIL-I-6066E, MAGNETIC PARTICLE INSPECTION.
4. FINISH 4.1-5.2 ± 20.5 OF MIL-STD-113C(MR), OLIVE DRAB MIL-C-48187 OF FED-STD-595.

REVISIONS			
DATE	DESCRIPTION	DATE	APPROVED



COMMERCIAL BRASS
MAGNETIC PARTICLE
TESTING (M) OLIVE DRAB

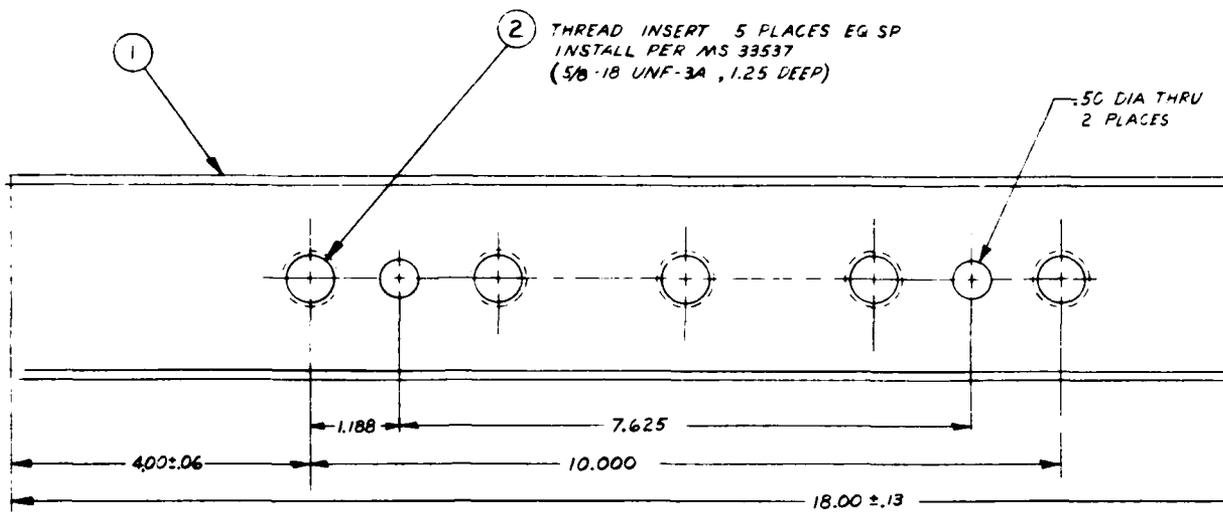
QTY	REQ	ITEM NO.	CODE IDENT	PART NUMBER	SPECIFICATION NO.	SYMBOL & FIGURE
1	1	4		4	10-2-1-304	201
1	1	3		3	10-2-1-304	201
1	1	2		2	10-2-1-304	201
1	1	1		1	10-2-1-304	201

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING		CW 342121 CONTRACT NO.	
TOLERANCE DIMENSIONS: 2 DECIMAL: 3 PLACES ANGLES: 10 TYPICAL: 10		BALTIMORE, MD. CHECKED BY: [Signature] STRESS DESIGN ENGINEERING PROJECT 10-2-1-304	
MATERIAL: LOW CARBON STEEL		STRUT LATERAL RESTRAINT	
NEXT ASSY: 56447-40016 USED ON:	DESIGN ACT APP:	SIZE CODE IDENT NO: F 77384 56447-40016	REF SCALE: 1:1 SHEET 1 OF 1
APPLICATION:	APPROVAL:	DATE:	SCALE: VCTFD

12

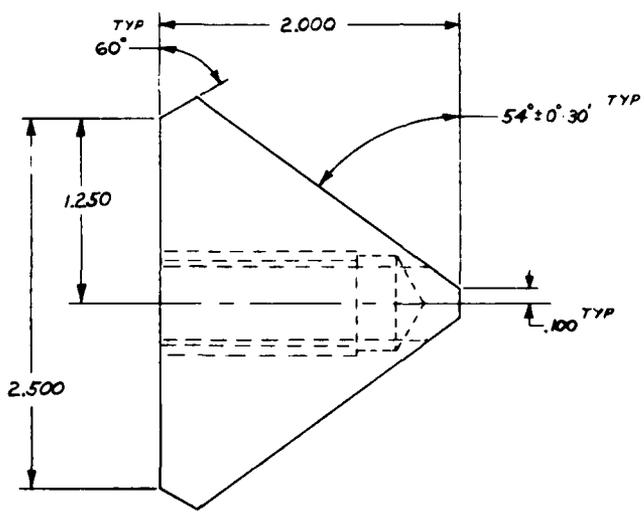
8 7 6 5 4

D



-10 ASSEMBLY
SCALE 1/1

B



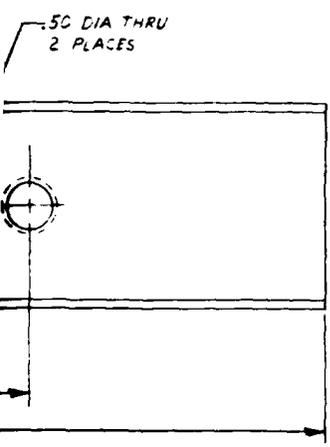
NOTE
1. BREAK SHARP EDGES .015

VIEW A-A
SCALE 2/1

A

4 3 2 1

REVISIONS			
EDM LTR	DESCRIPTION	DATE	APPROVED



A

A

D
C
B
56947-40017

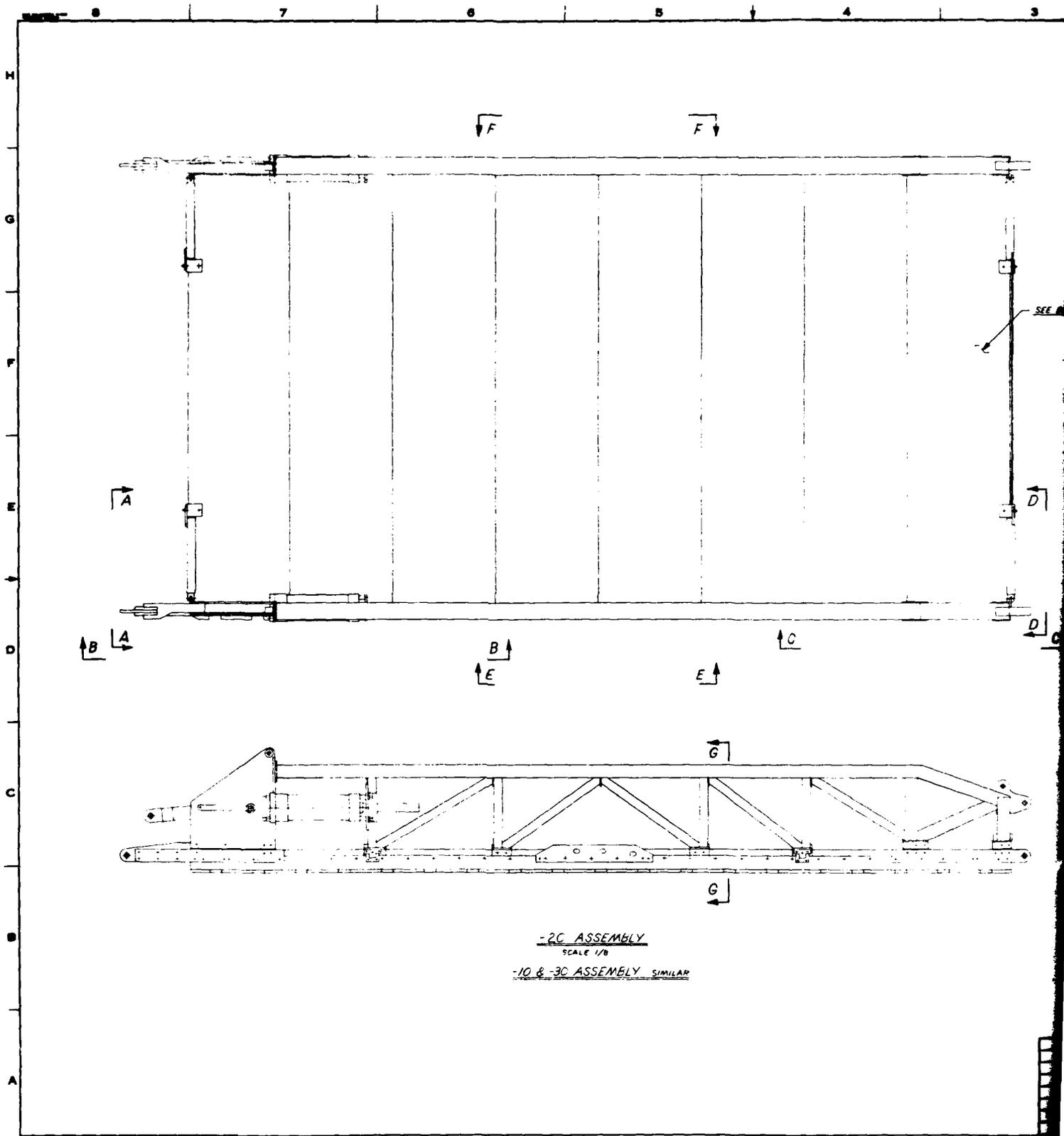
BREAK SHARP EDGES .015 R APPROX.

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
2	5		MS 21209-F1020		INSERT
1	1		-1		BAR
			-10		ASSEMBLY

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING			REINFORCEMENT BAR
TOLERANCE ANGLES ± 2° DECIMAL 3 PLACE 3 PLACE FRACTIONS 1/16 1/32			
MATERIAL:		DRAWN <i>E. QUINN VALLERIE</i> CHECKED _____ DESIGNED _____ DIMENSIONS _____ PROJECT <i>UJMAK</i>	REINFORCEMENT BAR
ALUM BAR 2024-T4, QQ-A-225/6		DRAWN ACT APP _____ APPROVAL _____ DATE _____	
56947-40017 NEXT ASSY _____ USED ON _____	APPLICATION _____	CODE IDENT NO. D 97384 56947-40017 SCALE NOTED _____ SHEET 1 OF 1	

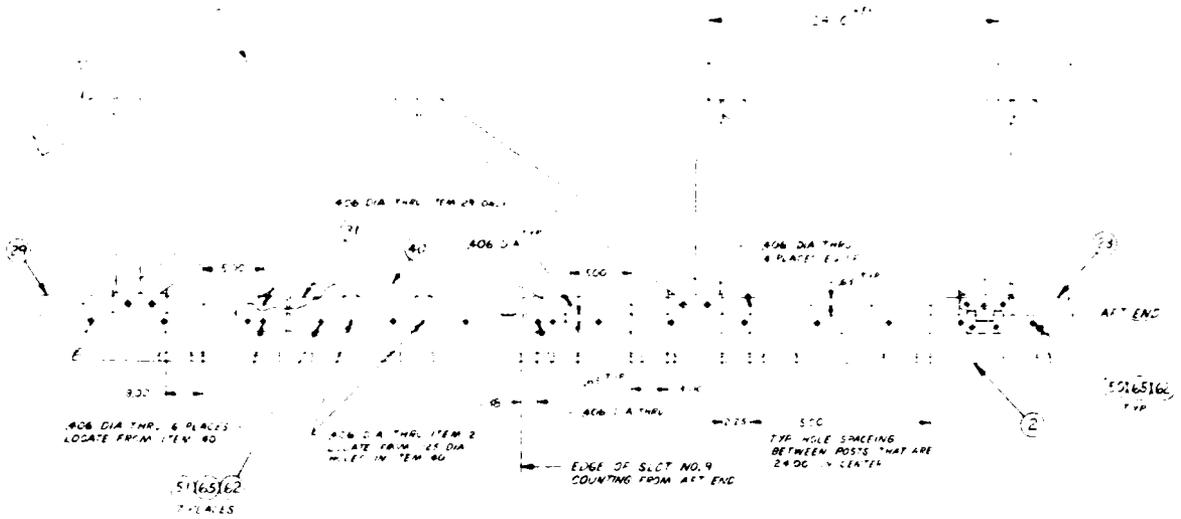
2



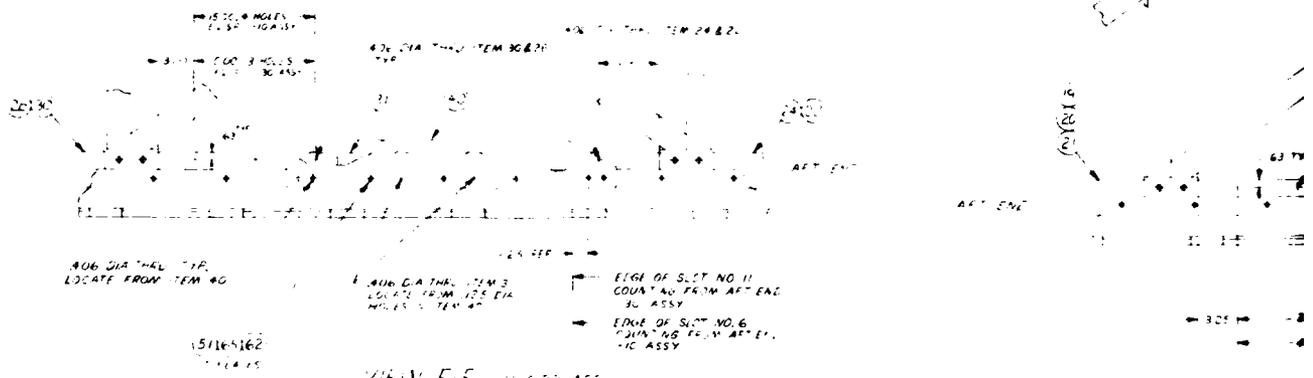
-2C ASSEMBLY
 SCALE 1/8
 -10 & -30 ASSEMBLY SIMILAR

8 7 6 5 4 3

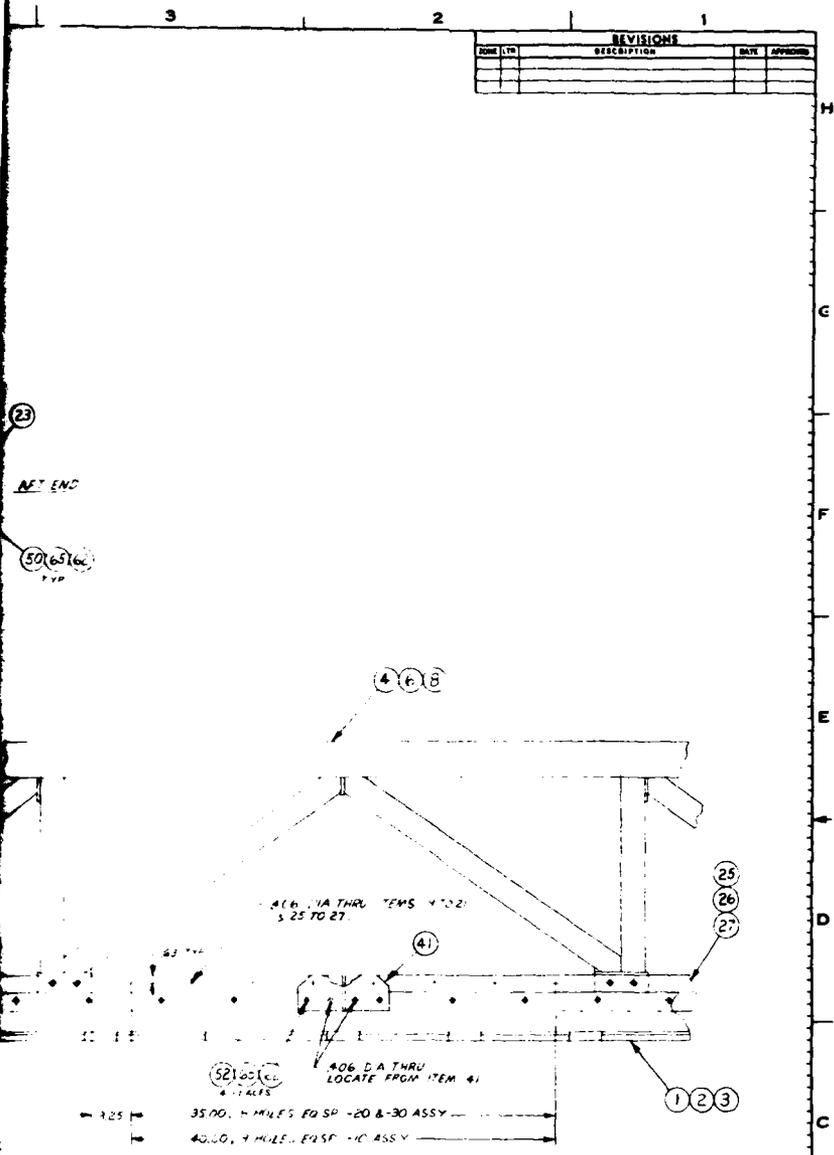
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VIEW E-E - 20 ASSY
SCALE 1/4



VIEW E-E - 30 ASSY
SCALE 1/4



VIEW F-F
SCALE 1/4

REVISIONS			
NO.	DATE	DESCRIPTION	BY

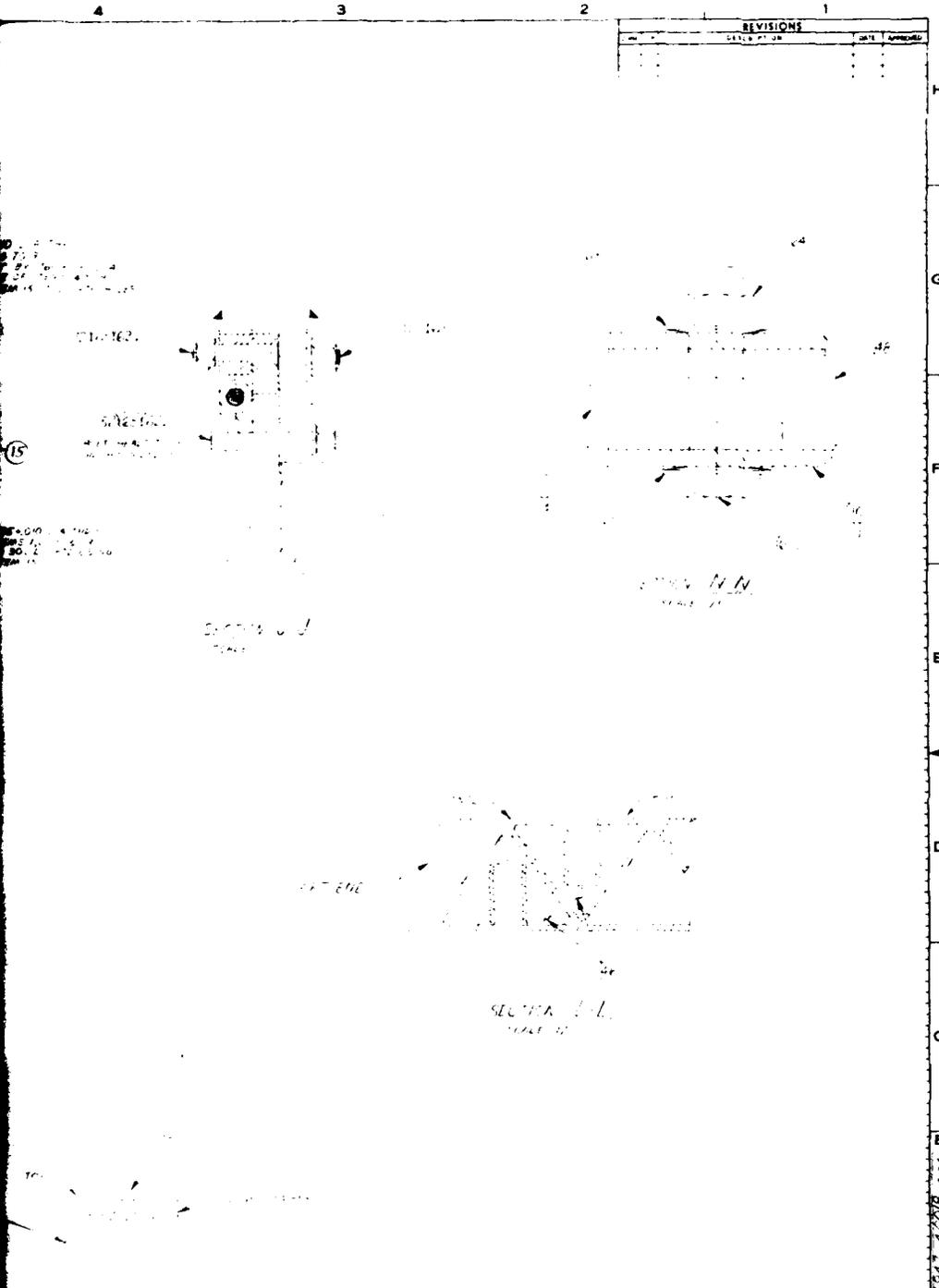
23
NET END
506916

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B
56947-40018 - SH. 3

ITEM NO.	QTY REQ.	CODE	PART NUMBER	SPECIFICATION NO.	REVISION/DATE
PARTS LIST					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND DECIMALS					
TOLERANCE					
FINISH: 1/8" 1/16" 1/32"					
MATERIAL:					
DATE	BY	APPROVED	DATE	SCALE	SHEET 3 OF 4

ACES PLATFORM ASSEMBLY
97364 56947-40018

2



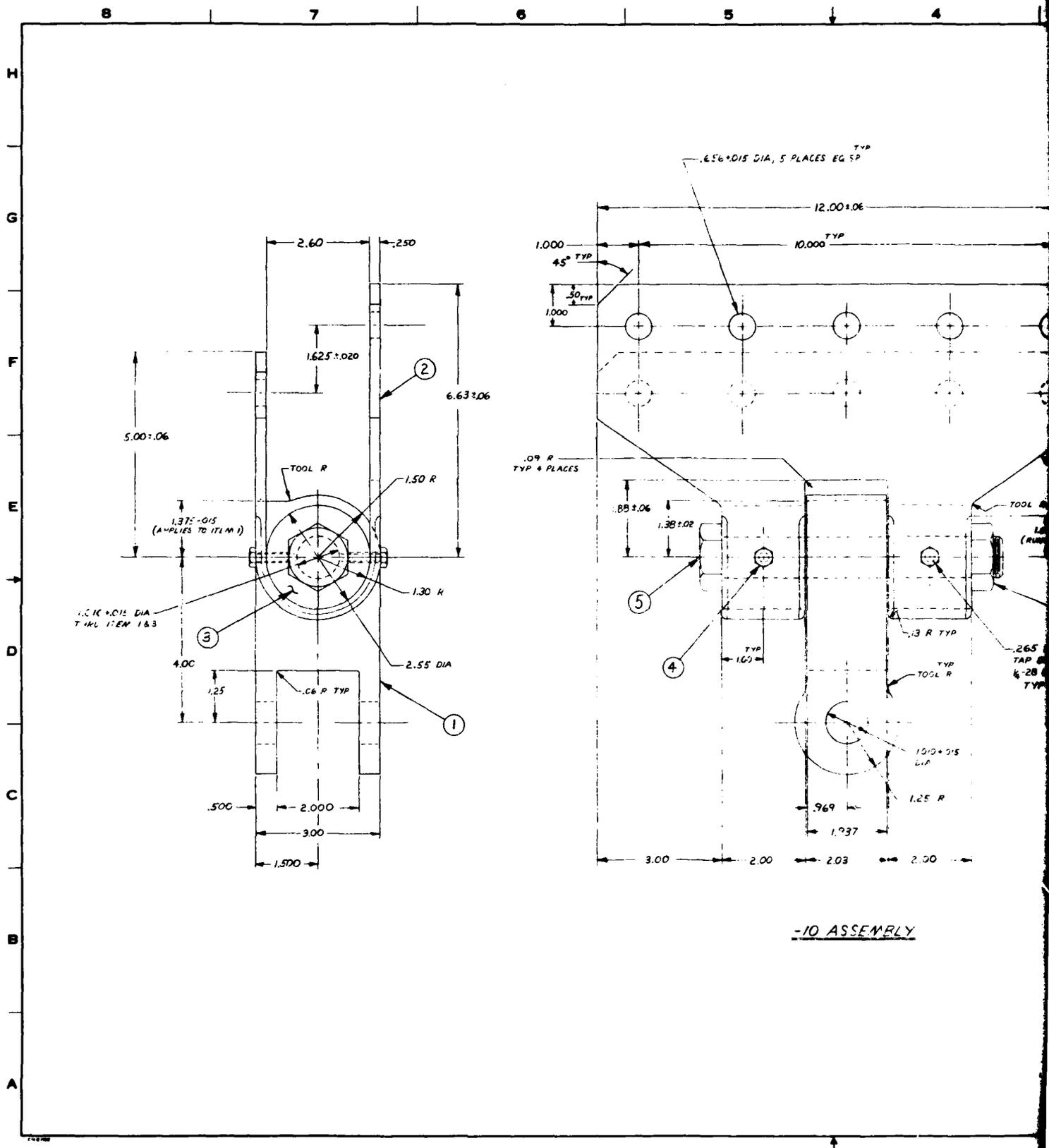
REVISIONS			
NO.	DESCRIPTION	DATE	APPROVED

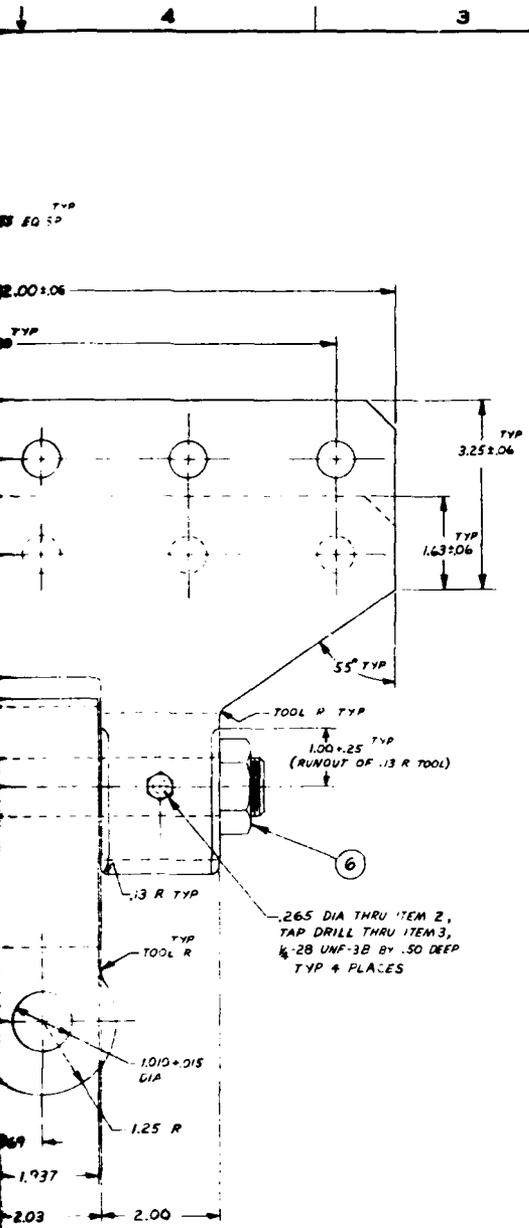
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ITEM NO.	370	CODE		PART NUMBER		SPECIFICATION NO.		MANUFACTURE									
PARTS LIST																	
BY SCALE																	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES																	
APPLY FINISH																	
TOLERANCE																	
ANGLES																	
FIT																	
MATERIAL																	
NEXT DRAWING																	
APPLICATION																	
<table border="1"> <tr> <td>DESIGNER</td> <td>DATE</td> <td>SCALE</td> <td>SHEET</td> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </table>										DESIGNER	DATE	SCALE	SHEET				
DESIGNER	DATE	SCALE	SHEET														

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2





REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES:

- BREAK SHARP EDGES .125 R APPROX.
- MATERIAL
 - 1 STEEL, 4130, MIL-S-4759, H.T. TO 125,000 PSI TENSILE.
 - 2 STEEL, 4130, MIL-S-3729, CONG A, H.T. TO 130,000 PSI TENSILE.
 - 3 ALUM BAR, 2024-T4, 3Q-A-225/6
- FINISH PER MIL-STD-170C(AR)
 - 1&-2 FINISH NO. 1.1.2.2 +20.1, OLIVE BAR NO 2+057 OF FED-STD-545.
 - 3 FINISH NO. 7.1.1-20.8

ASSEMBLY

6	1	MS21083N16	WLT
5	1	AN7-54 A	PLT
4	4	AN4-5A	PLT
3	2	-3	SPACER
2	1	-2	PLATE
1	1	-1	SEMI-UNIT
		-0	ASSEMBLY

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO	NOMENCLATURE
----------	---------	------------	-------------	------------------	--------------

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		CW 9821.01		CONTRACT NO.	
AFTER PLATING		BALTIMORE, MD.		35 K PLATFORM	
TOLERANCE		CHECKED		EXTRACTION COUPLING	
ANGLES 2.0		STRONG		FOR METRIC PLATFORM	
DECIMAL 3.03		DESIGN		97384 56947-40019	
1 PLACE 1.010		ENGINEERING		DATE	
3 PLACE		PROJECT 44-24262		SCALE 1/1	
MATERIAL:		SEE NOTE 2		SHEET 1 OF 1	
NEXT ASSY	USED ON	DESIGN ACT APP	DATE	APPROVAL	
APPLICATION		DATE		SCALE 1/1	

5

4

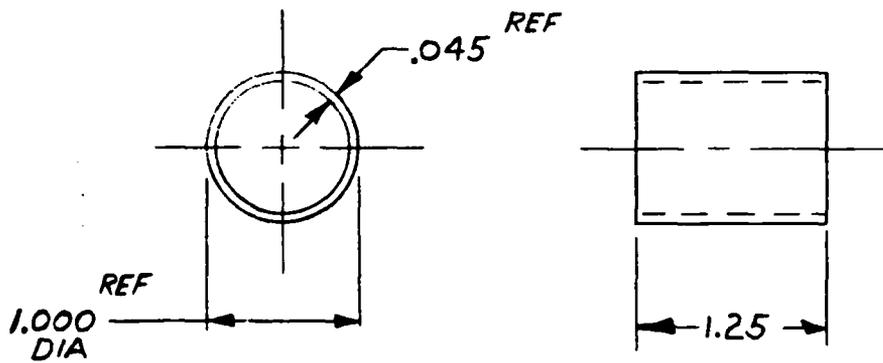
3

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NO
1.
2.

56947-40018	
NEXT ASSY	USED ON
APPLICATION	

11
DIMENSIONS A
IN INCHES AFT
PLATING. TO
ANG ± 2° ~
DEC ± .03 ± .0
2 PLACE 3 PL
MATERIAL
TUBING, STEEL
LOW CARBON

3	2	1		
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

D

C

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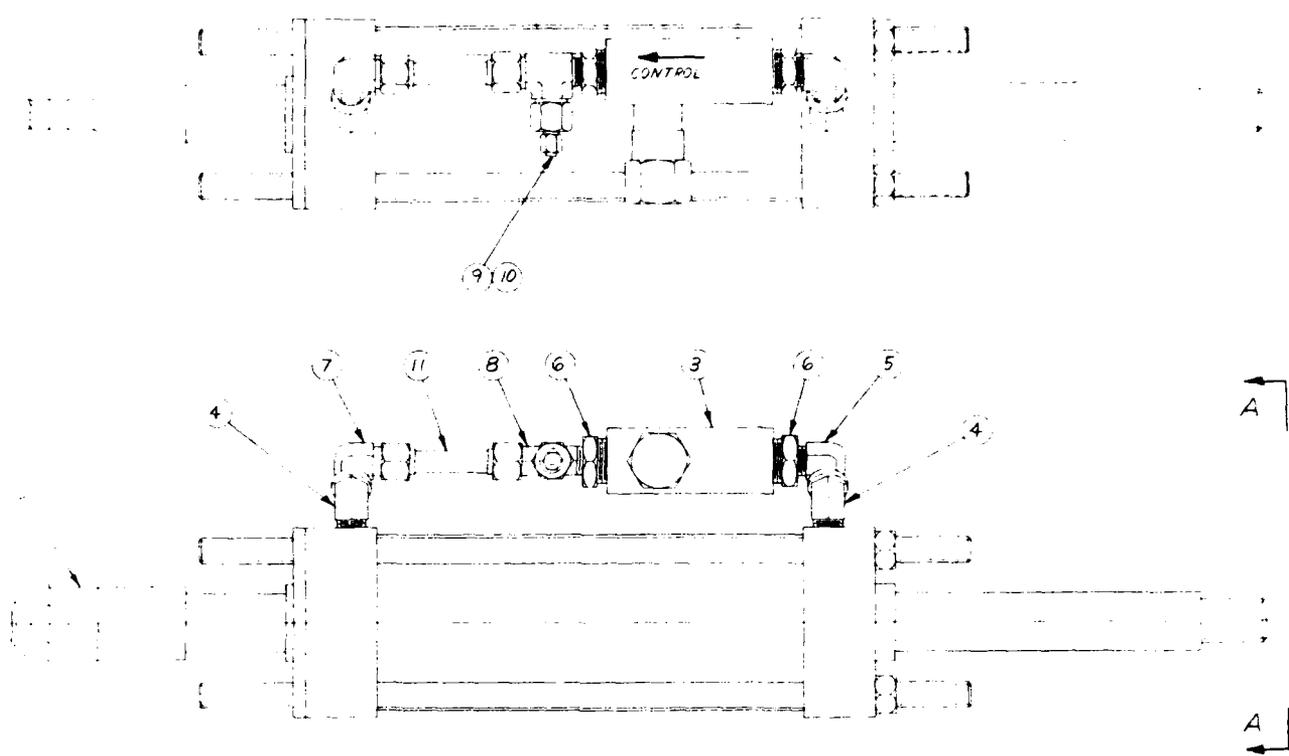
NOTES:

1. BREAK SHARP EDGES.
2. CADMIUM PLATE PER MIL-STD-171C (MR) FINISH NO. 1.1.2.2.

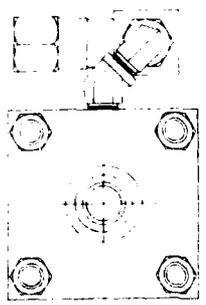
1	2	3	REF	SCALE	5	6	7	8	
DIMENSIONS ARE IN INCHES AFTER PLATING. TOL:		CW 3821.01 CONTRACT NO.		SLEEVE					
ANG ± 2° ~ ~ ~		COCKEYSVILLE, MD. DWN R.M.Q. 10-4-78							
DEC ± .03 ± .010		CHKD PROJ W Black w/6/78		SIZE	CODE IDENT	56947-40020			
2 PLACE 3 PLACE		APP		B	NO 97384	SHEET 1 OF 1			
MATERIAL: TUBING, STEEL, LOW CARBON		APP		SCALE 1/1					

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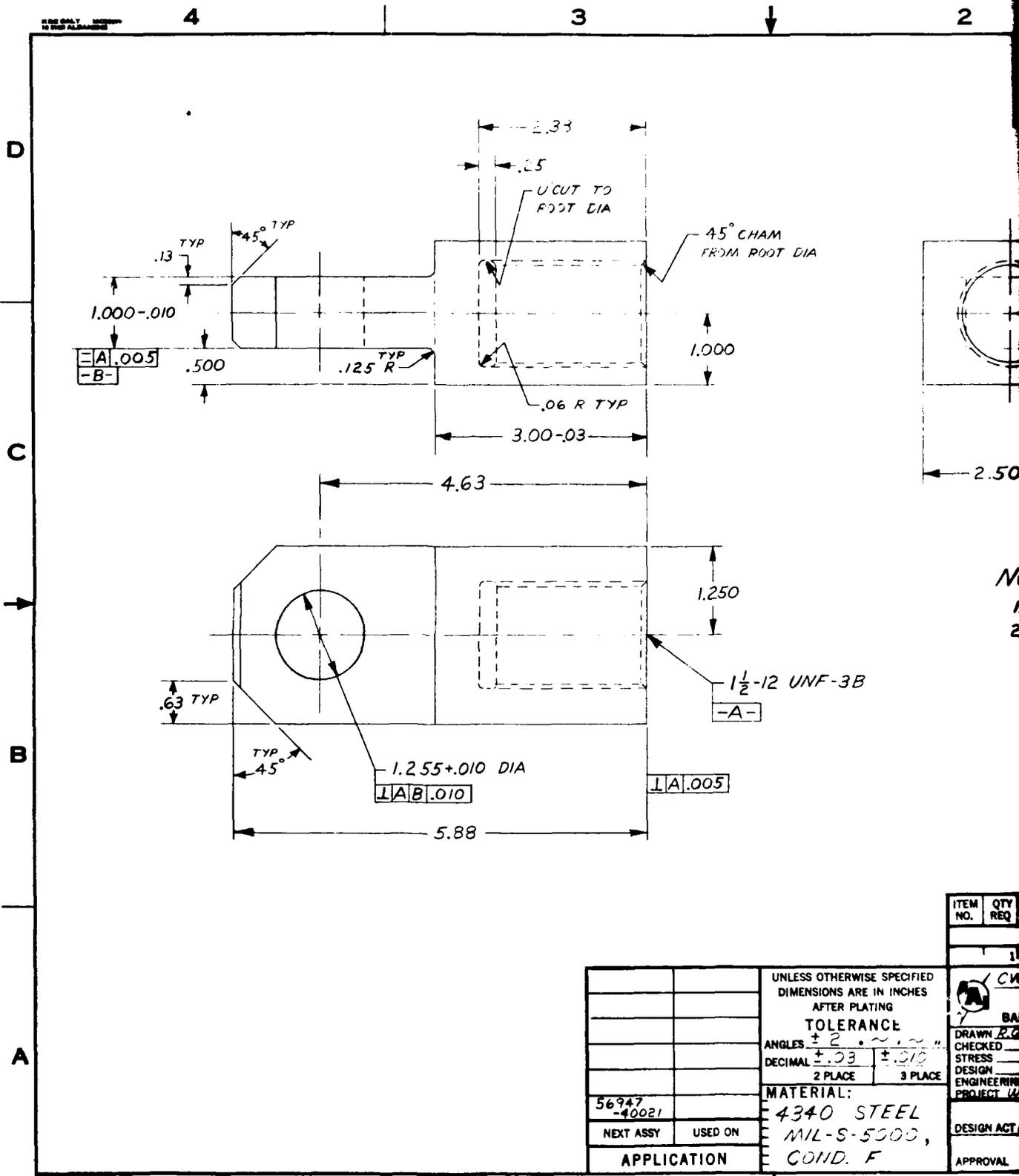


-10 ASSEMBLY



VIEW A-A
 -10 ASSY, VIEW SHOWN
 -20 ASSY, VIEW OPPOSITE

SEE ONLY MEMPH
IN THE ALIGNED



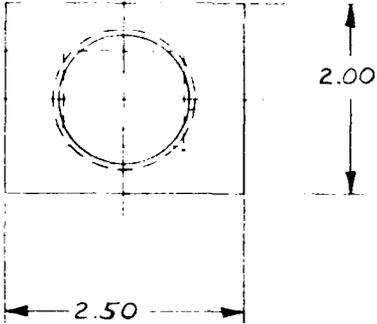
NO
1
2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING		ITEM NO.	QTY REQ
TOLERANCE		11	
ANGLES ± 2		CW	
DECIMAL $\pm .03$ $\pm .010$		BAS	
2 PLACE 3 PLACE		DRAWN R.C.	
MATERIAL:		CHECKED	
4340 STEEL		STRESS	
MIL-S-5000,		DESIGN	
COND. F		ENGINEERING	
APPLICATION		PROJECT (U)	
NEXT ASSY USED ON		DESIGN ACT	
56947 -40021		APPROVAL	

APR 6 1958

2

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



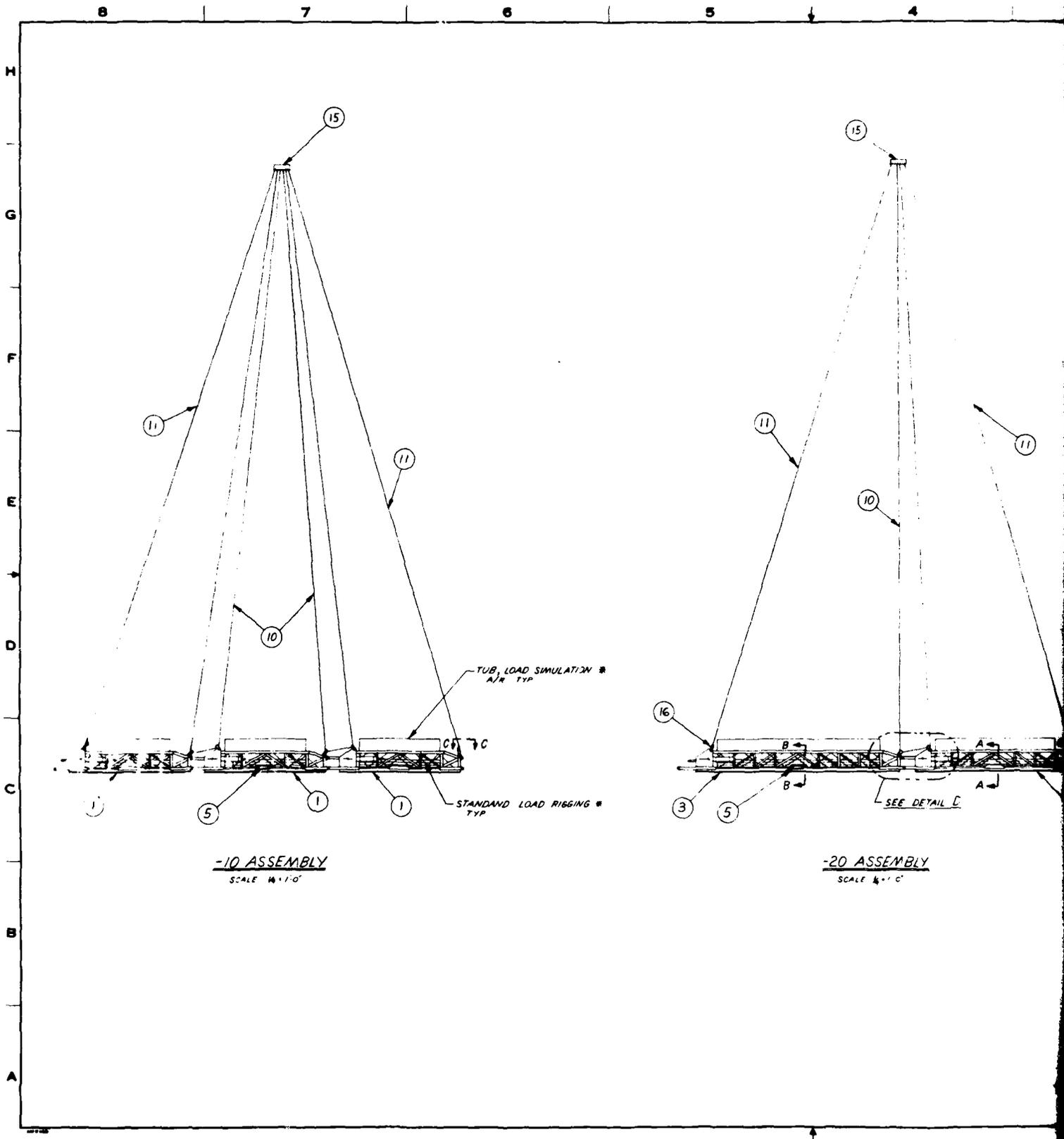
NOTES:

1. BREAK SHARP EDGES .015 R APPROX.
2. CADMIUM PLATE PER MIL-STD-171C(MR) FINISH NO. 1.1.2.2.

UNF-3B

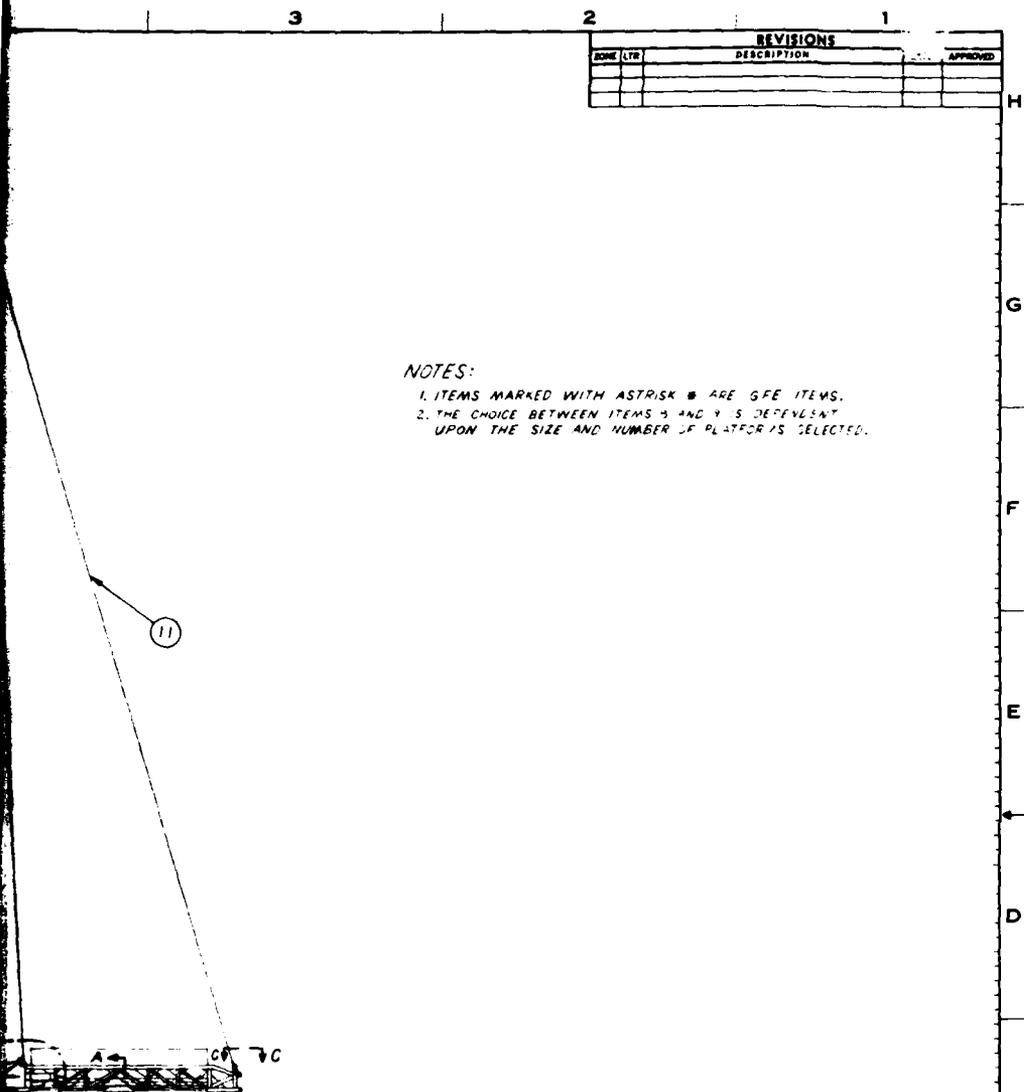
D
C
B
56947-40022

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
PARTS LIST					
1	2	3	4	5	6
REF SCALE 1 5 6 7 8					
CONTRACT NO. CW 3821.01 BALTIMORE, MD. DRAWN R. QUINTAVALLE 10-578		COUPLING			
CHECKED STRESS DESIGN ENGINEERING PROJECT <i>W. Stach</i> 10/6/78					
DESIGN ACT APP APPROVAL		DATE	SIZE C	CODE IDENT NO. 97384	56947-40022
SCALE 1/1		SHEET 1 OF 1		SERIAL: 340 STEEL MIL-S-5000, COND. F	



-10 ASSEMBLY
SCALE 1/4" = 1'-0"

-20 ASSEMBLY
SCALE 1/4" = 1'-0"



REVISIONS		
DATE	DESCRIPTION	APPROVED

NOTES:
 1. ITEMS MARKED WITH ASTRISK * ARE GFE ITEMS.
 2. THE CHOICE BETWEEN ITEMS 3 AND 4 IS DEPENDENT UPON THE SIZE AND NUMBER OF PLATFORMS SELECTED.

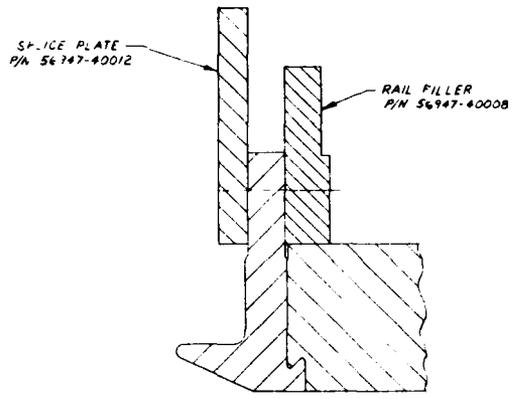
ITEM NO.	QTY REQ	CODE	IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
* 8	12	6		MS 27-337-6		CLEVIS
* 1	1	15		MS 27-337-6		24.5" DCL ORLG
1	1	14		MS 27-337-6		VULT
1	1	13		AN 7-41A	1 x 4 1/8"	2 1/2" DIA. HOLE
1/2	10	12		MS 353-2-42	2 x 1/2"	2 1/2" DIA. HOLE
* 4	4	11	81337	88F 217-30		2 1/2" DIA. HOLE
* 2	4	10		88F 217-41		LIVE SUPPORT
* 1	1	9		11-1-26-6	SEE NOTE 2	2 1/2" DIA. HOLE
* 1	1	8		11-1-26-5	SEE NOTE 2	2 1/2" DIA. HOLE
* 1	1	7		11-1-715		2 1/2" DIA. HOLE
* 1	1	6		11-1-725		2 1/2" DIA. HOLE
1	1	5	81337	11-1-737		2 1/2" DIA. HOLE
1	1	4	97384	56-47-40019-0		36" CABLE ASSEMBLY
A/R	A/R	3		-40019-30		2 1/2" DIA. HOLE
A/R	A/R	2		-40019-20		2 1/2" DIA. HOLE
A/R	A/R	1		56-47-40019-0		2 1/2" DIA. HOLE
						2 PLATE DIA.
						3 PLATE DIA.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		CW 3921.21	
AFTER PLATING		CONTRACT NO.	
TOLERANCE		BALTIMORE, MD.	
ANGLES	DECIMAL	CHECKED BY: J. J. ZWILLER	
3 PLACE	3 PLACE	STRESS	
MATERIAL:		DESIGNED BY: J. J. ZWILLER	
NEXT REV.	USED ON	DATE: 11-1-73	
APPLICATION		APPROVAL: [Signature]	

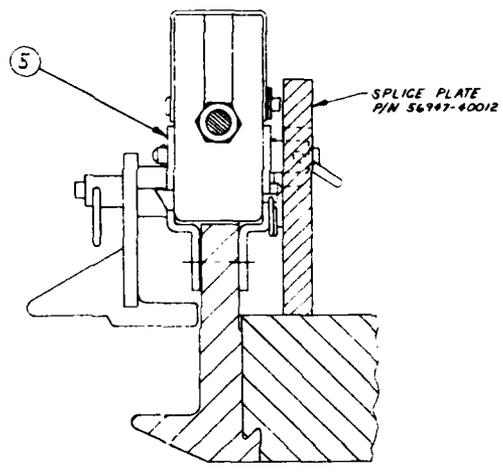
PARTS LIST	
REV	CODE
1	97384
2	56147-40023

8 7 6 5 4

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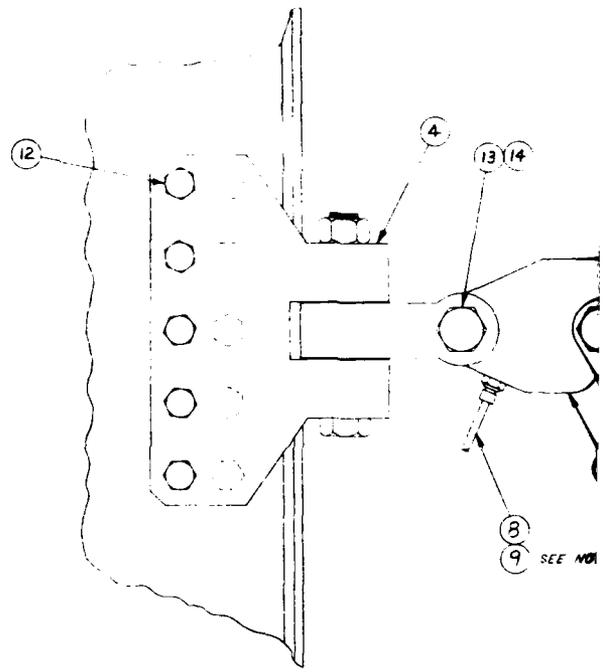
SECTION A-A
SCALE 1/1



SECTION B-B
SCALE 1/1

35 K EFTC ACTUATOR INSTALLED ON RAIL

REMOVE THE RAIL FILLER P/N 56947-40008 AND THE 2 NUTS AND BOLTS THAT HOLD IT IN PLACE. RELOCATE THE SP-LICE PLATE P/N 56947-40012 TO THE INSIDE OF THE RAIL.

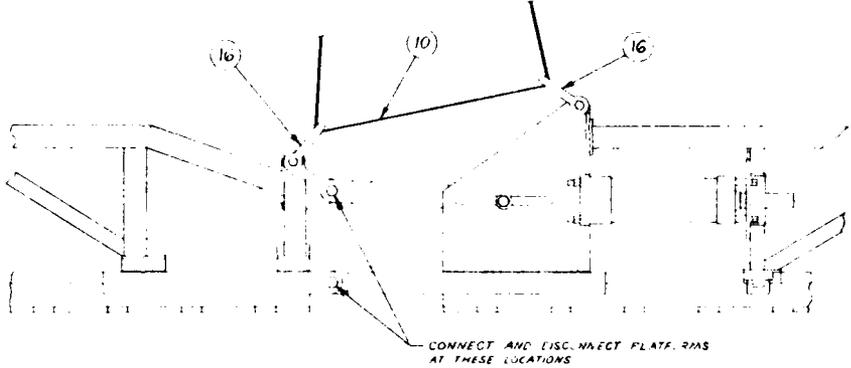


VIEW C-C
SCALE 1/2

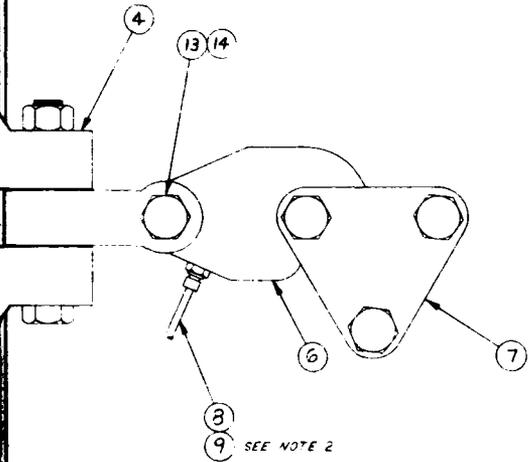
35 K EFTC INSTALLED ON AFT P. PLATFORM

4 3 2 1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



DETAIL D
SCALE 1/8
TYP. CONNECTION BETWEEN PLATFORMS.



FT PLATFORM

56787-4023

ITEM NO.	QTY REQ	CODE IDENT	PART NUMBER	SPECIFICATION NO.	NOMENCLATURE
PARTS LIST					
REF SCALE: 1" = 1'-0"					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AFTER PLATING			CW 3821.31 CONTRACT NO. BALTIMORE, MD. DRAWN BY: 2022/2/16/12/23 CHECKED BY: DESIGN BY: ENGINEERING BY: PROJECT: 56787-4023		
TOLERANCE ANGLES: DECIMAL: MATERIAL: 2 PLACE 3 PLACE			RIGGING ASSEMBLY, ACES		
NEXT ASSY: USED ON: APPLICATION: APPROVAL: DATE: SCALE: NOTED			SITE CODE IDENT NO. 97384 56947-40023 SHEET 2 OF 2		

1 2

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