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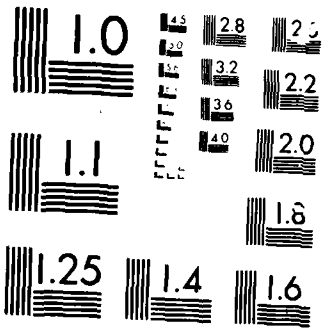

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CONCEPTUAL STUDY OF THE LB/TS INSTRUMENTATION, DATA ACQUISITION AND FACILITY CONTROLS SYSTEM

Sverdrup Technology, Inc.
P.O. Box 884
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Technical Report

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Impulse Facilities; Data Acquisition Systems; Blast Waves; Physical/Intrusive Sensors; Instrumentation; Thermal Radiation Simulators

19 ABSTRACT (Continue on reverse if necessary and identify by block number)
A conceptual study of a comprehensive instrumentation, data acquisition and control system supporting the Large Blast/Thermal Simulation Facility (LB/TS) addressing physical sensors; optical sensors, data acquisition, reduction, and display; facility controls; calibration systems; software, interface hardware; and associated equipment is described. Physical sensors for measurement of pressure, temperature, heat flux, strain, displacement, and acceleration are discussed. Over ten candidate optical/non-intrusive measurement systems are evaluated for temperature, displacement, flow velocity, and other measurements.

Three basic data acquisition systems—a conventional digital system, an analog tape system and a hybrid analog/digital system—are evaluated to acquire process data from over 100 blast wave, flow field, thermal radiation simulator (TRS), and target response sensors. A system for monitoring of the facility status and control of the facility operation is also described. The complete sensor, data acquisition, and control system as developed in this study will be state-of-the-art in FY87 and provide for robust, durable operation in the

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18. SUBJECT TERMS (Continued)

Optical/Non-Intrusive Measurement Systems

19. ABSTRACT (Continued)

high-enthalpy, impulse environment of the LB/TS.

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SECTION 1
INTRODUCTION

A large facility capable of simulating the combined thermal and blast effects of tactical nuclear and other explosions is being evaluated by the Defense Nuclear Agency. The Large Blast/Thermal Simulator Facility (LB/TS) is a shock tunnel facility consisting of large, high-pressure drivers; fast-acting diaphragms or valves; a long, large, noncircular cross-section driven tube; an active rarefaction wave eliminator; and a number of thermal radiation simulators (TRS). High-enthalpy, high-pressure impulsive flows, with significant transients of a few microseconds rise time, important measurement phenomena occurring over microseconds, and an overall operating period of only a few seconds are generated. Operating parameters in the facility such as driver pressure, driver length, driver/driven area ratio and driver temperature are varied over a wide range to simulate important features of tactical nuclear blast waves, thermal radiation, and target response. Variable yield explosions and target response at various distances from the point of explosion can be simulated. A qualitative wave diagram of the flow field variations with time through the LB/TS is shown below in Figure 1.

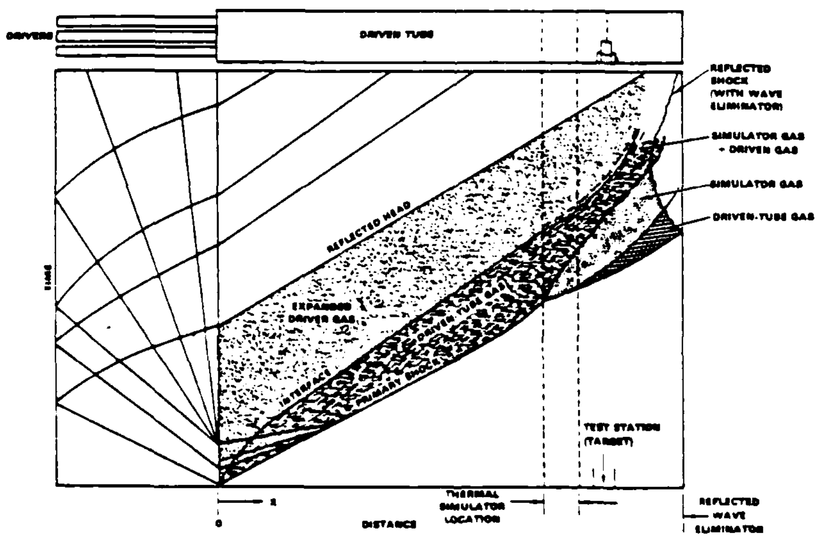


Figure 1. Qualitative wave diagram of facility flow field.

The instrumentation systems supporting the operation of this facility must be capable of providing measurements which:

- characterize all important parameters of the flow and TRS such as static pressure, dynamic pressure, velocity, static and total temperature, radiant energy, total heat flux, and enthalpy
- characterize important aspects of target response such as pressure distribution; temperature distribution; heat flux; component loading, strain, and deflection; component and whole body acceleration, vibration, and motion
- are resolved in time with response sufficient to characterize all essential changes within the period of important flow variations
- are operable under harsh thermal and blast conditions in a non-laboratory environment with reliable, traceable calibration and reference standards

It is vital that innovative approaches to data acquisition be evaluated in developing a facility plan to incorporate all of the rapid advances which are occurring in both optical and physical sensors and data acquisition/processing systems. The LB/TS, though unique, can adapt a number of these current developments to produce a high-enthalpy impulse facility instrumentation system which is superior to any presently available. The instrumentation and facility control concept plan which is developed must also be sufficiently versatile for research, development, and routine proof testing of a wide variety of military targets.

The first task of the project involved the survey of possible physical sensors, optical sensors, and data acquisition and control systems and assessment of current availability of equipment and components which meet the LB/TS measurement requirements. The candidate requirements are listed in Table 1 and involve:

- pressure, temperature, displacement, and other measurements needed for control and status monitoring of the facility and its operating subsystems
- pressure, temperature, heat flux, and other measurements of the blast wave, flow field, and TRS
- pressure, temperature, heat flux, strain, displacement, and acceleration of the target itself

Actual measurement requirements for the system must be finalized after ongoing facility configuration studies are completed.

Table 1. Candidate LB/TS measurements required for target data acquisition and facility control.

1. Measurements for Facility Control and Status/Performance Monitoring

   1.1 Pressure

   - Charge Pressure in each Driver Tube
   - Pressure in Nitrogen Drivers associated with TRS
   - TRS Liquid Oxygen Supply Pressures
   - Atmospheric Reference Pressure
   - Miscellaneous Pressures in other Subsystems

   1.2 Temperature

   - Gas Temperature in Driver Tubes
   - TRS Liquid Oxygen Supply
   - TRS Pilots
   - Gas Temperature in the TRS Vent System
   - Miscellaneous Temperature in other Subsystems

   1.3 Displacement Measurements

   - TRS Vent Positions (sliding door)
   - Rarefaction Wave Eliminator (RWE) Vane Positions
   - TRS Valve Positions; LOX, AL, N_2 Solenoid and Control Valve Positions

   1.4 Air Compressor System Control

   - Valve Positions
   - Pressure Control
   - Compressor Status Monitors

2. Measurement of Blast Wave and Flow Parameters

   2.1 Pressure Instrumentation

   - Wall Pressures for Signature and Arrival Time Determination
   - Strain Gage and Piezioelectric Pressure Transducers for Diffraction Period
   - Strain Gage Pressure Transducers for Drag Phase
   - Differential Pressure Probes
   - Stagnation Pressure Probe

   2.2 Flow Velocity Instrumentation

   - Laser Doppler Velocimeter (During Drag Phase)

   2.3 Density, Inferred Density, Enthalpy, Other

   - Stagnation Heat Flux
   - Shadowgraph

Table 1. Candidate LB/TS measurements required for target data acquisition and facility control. (Concluded)

2.4 Temperature (to be used during thermal pulse also)

- Aspirating Thermocouples for Stagnation and/or Static Temperature
- Film Thermocouples

3. Measurement of the Input Thermal Pulse (associated with the TRS)

- Flux Meters (Calorimeter, Coaxial Gages, etc.)
- Optical Pyrometer, Two Color, Reference Measurement for each TRS

4. Measurement of Target Response

4.1 Pressure Distribution on Target

4.2 Structural Strain and Displacement Measurements

4.2.1 Strain Gages

4.2.2 Displacement Gages

- Mechanical - Potentiometer
- Electrical - Eddy Current

4.2.3 Optical Displacement

- Pulsed X-Ray
- *Floroscopic* X-Ray
- Moire
- OPTRON Displacement Follower

4.2.4 Accelerometers

4.3 Skin Temperature, Surface Heat Flux

- Thermocouples, Backside
- Surface Heat Flux; Surface Temperature or Others
- Optical Pyrometers; Multiple Points or Surface Distribution

4.4 Rigid Body Motion (Primary Drag Phase)

- High-Speed Photography
- Inertial Acceleration Measurements
- X-Ray

Each of the measurement requirements involving physical sensors are addressed in Section 3. A specific list of the ten primary optical/non-intrusive measurements which are discussed in Section 4 is given in Table 2. The parameters to be measured, anticipated level of each parameter, and time response required are noted.

Additional systems which permit data acquisition, facility control, facility monitoring, data reduction, data display, and data archival, and which facilitate overall LB/TS operation are listed in Table 3. The data acquisition subsystem (Item 1, Table 3) is discussed in Section 5 of this report and the facility control subsystem is discussed in Section 6. In completing this survey, the number of channels and minimum sample rate for each channel for the four measurement categories were established as shown in Table 4. The number of channels and sample rates shown do not represent requirements for the LB/TS but rather define a baseline system against which comparative evaluations are made. These form the basis for evaluating digital, analog, and hybrid analog-digital data acquisition and control systems.

In completing the sensor and data acquisition system survey, a nominal time line for the operation of the LB/TS was developed as shown in Figure 2. The measurements and control events required to pressurize the drivers would be followed by a short sequence to ignite the five (nominal) TRS. Burn time of the TRS will be variable over a period from about one to five seconds to produce the radiant heat flux and fluence of the blast being simulated. After termination of the TRS burn, a variable delay period of one to three seconds (nominal) would precede rupture of the diaphragms to initiate blast flow. The delay period would simulate variable distance from ground zero. About one-half second after rup'ure of the diaphragms, the blast wave will impinge on the target with a short diffraction period (approximately 10 msec in duration, dependent on target size) in which the blast wave passes over the target followed by a longer drag phase of up to 2 seconds in duration. Data acquisition periods are shown in the lower portion of Figure 2.

Table 2. Requirements for optical measurement systems.

OPTICAL SENSOR TYPE	PARAMETER	LEVELS*	FIELD OF VIEW*	TIME RESPONSE*	COMMENTS
THERMOVISION	TARGET SURF. TEMP. DISTRIBUTION	AMBIENT — 2000° K	10 X 12 ft (3 X 4 m)	1000/sec	5° K RESOLUTION @ 500° K
OPTICAL PYROMETER	TARGET SURF. TEMP. (5 POINTS)	AMBIENT — 2000° K	5 POINTS SPACED OVER 15 X 15 ft (5 X 5 m)	≥1000/sec	MEASURE APPARENT SURF. TEMP. ±1%
TWO-COLOR OPTICAL PYROMETER	TRS TEMP. (5 POINTS)	2000-3500° K EQUIVALENT B. B. SOURCE	5 POINTS SPACED OVER 5 X 15 ft (1 X 5 m)	1000/sec	RUN TO RUN REF. MEASUREMENT ON TRS
PULSED X-RAY	TARGET DISPLACEMENT	DISPLACEMENTS UP TO 50 cm	UP TO 3 X 3 m; 50 X 50 cm ACCEPTABLE	10-100/sec	≤1 μ SEC. EXPOSURE INTERVAL
FLUOROSCOPE X-RAY	TARGET DISPLACEMENT	DISPLACEMENTS UP TO 50 cm	UP TO 3 X 3 m; 50 X 50 cm ACCEPTABLE	1000/sec	
TWO-AXIS LASER VELOCIMETER	FLOW VELOCITY	20 TO 2000 FPS (6 TO 600 *m/sec*)	10 X 10 ft (3 X 3 m)	TBD	TIME HISTORY OF VELOCITY AHEAD OF TARGET, TO ± 1%
HIGH-SPEED CAMERA SYSTEM HIGH-SPEED VIDEO SYSTEM	TARGET MOTION/ CONDITION	DISPLACEMENT ~ 1 TO 50 cm MOTION ~ 50 cm TO 5 m	25 X 25 cm CLOSEUP 5 X 5 m OVERALL	200-2000/sec 1000/sec	ALSO USED FOR STUDY OF GENERAL CONDITION OF TARGET WITH TIME, COLOR HELPFUL
SHADOWGRAPH	SHOCK SHAPE	N/A	3 X 3 m DESIRED; 1 X 1 m ACCEPTABLE	10,000/sec	WOULD LIKE TO SEE PROCESS OF SHOCK PASSAGE OVER TARGET
MOIRE FRINGE	TARGET DISPLACEMENT	UP TO 50 cm	3 X 4 m DESIRED; 1 X 1 m ACCEPTABLE	≥1000/sec	
CIRCULAR VARIABLE FILTER RADIOMETER	TRS RADIANT OUTPUT	UP TO 3500°K	0.5 BY 1m	.1 sec	SERVES AS FACILITY SPECTROMETER AND TOTAL RADIOMETER
OPTRON FOLLOWER	TARGET DISPLACEMENT	UP TO 10 cm	10 cm by 10 cm	10,000/sec	

*VALUES SELECTED AS BASIS FOR SURVEY AND EVALUATION OF SYSTEMS ONLY.

Table 3. LB/TS data, control, and monitor system.

1. Data Acquisition System

   - High-Speed Analog Tape
   - High-Speed Digital Recorders
   - Signal Conditioning

2. Data Reduction Data Display, and Data Archival System

   - Data Reduction Minicomputer
   - Plotters
   - Disc Storage
   - Printers
   - Graphics Terminals
   - Digital Photo Image Analyzer

3. Facility Control Minicomputer System

   - Status Monitoring
   - Interlocks
   - Sequencing
   - Open-Loop Control
   - Closed-Loop Control

4. Experimental and Safety Observation Equipment

   - Video Cameras
   - Acoustic Monitors/Recorders

Table 4. Data acquisition system survey constraints.
(Values selected as basis for system evaluation only)

MEASUREMENT CATEGORY	NUMBER OF CHANNELS MAXIMUM	MEDIUM	MINIMUM	MINIMUM SAMPLE RATE, KHz
1.0 FACILITY MEASUREMENTS				
DRIVER PRESSURES	10	10	10	1
TRS NITROGEN PRESSURES	5	5	2	↓
TRS LOx SUPPLY PRESSURES	5	5	2	↓
ATMOSPHERIC REFERENCE	1	1	1	↓
DRIVER GAS TEMPERATURE (TC)	21	14	10	↓
GAS SUPPLY TEMPERATURE (TC)	5	5	5	↓
PILOT TEMPERATURE (TC)	5	5	5	↓
VENT GAS TEMPERATURE (TC)	5	5	5	↓
VENT POSITION	5	5	5	↓
RWE POSITION	3	3	3	↓
VALVE POSITIONS	15	15	10	↓
MISCELLANEOUS	20	12	12	↓
SUBTOTAL	100	85	70	
2.0 FLOW ENVIRONMENT MEASUREMENTS				
WALL PRESSURES	20	15	10	50
DIFFRACTION PHASE PRESSURE (FAST RESP.)	5	5	3	250
DRAG PHASE PRESSURES (MODERATE RESP.)	5	3	3	20
DIFFERENTIAL PRESSURE PROBES	5	5	3	250
STAGNATION PRESSURE PROBES	2	2	2	250
STAGNATION HEAT FLUX (TC)	3	3	3	20
FLOW TEMPERATURE (TC)	5	3	3	20
SUBTOTAL	45	37	27	
3.0 THERMAL INPUT MEASUREMENTS				
HEAT FLUX GAGES (TC)	5	5	5	1
THERMOCOUPLES	10	10	10	1
RADIANT HEAT FLUX GAGES	10	10	8	20
OTHER (OPTICAL PYROMETER)	5	5	5	1
SUBTOTAL	30	30	28	
4.0 TARGET RESPONSE MEASUREMENTS				
PRESSURE DISTRIBUTION	30	15	10	50
STRUCTURAL STRAIN	30	15	10	50
DISPLACEMENT GAGES	10	5	5	50
THERMOCOUPLES, BACKSIDE	20	10	10	1
THERMOCOUPLES, SURFACE	20	15	8	20
ACCELEROMETERS	10	5	5	50
OTHER (OPTICAL PYROMETERS)	15	10	10	1
SUBTOTAL	135	75	58	
SYSTEM TOTALS	310	227	183	

SYSTEM TOTALS BY SAMPLE RATE:

SAMPLE RATE	SYSTEM MAXIMUM	MEDIUM	MINIMUM
1000/sec	155	125	110
20,000/sec	43	34	25
*50,000	100	56	40
250,000	12	12	8
TOTALS	310	227	183

*50,000 IS MINIMUM ACCEPTABLE; 250,000 IS DESIRABLE. IT IS ALSO DESIRABLE FOR ALL HIGH SPEED CHANNELS (20-250 KHz) TO BE OF SAME SAMPLE RATE.

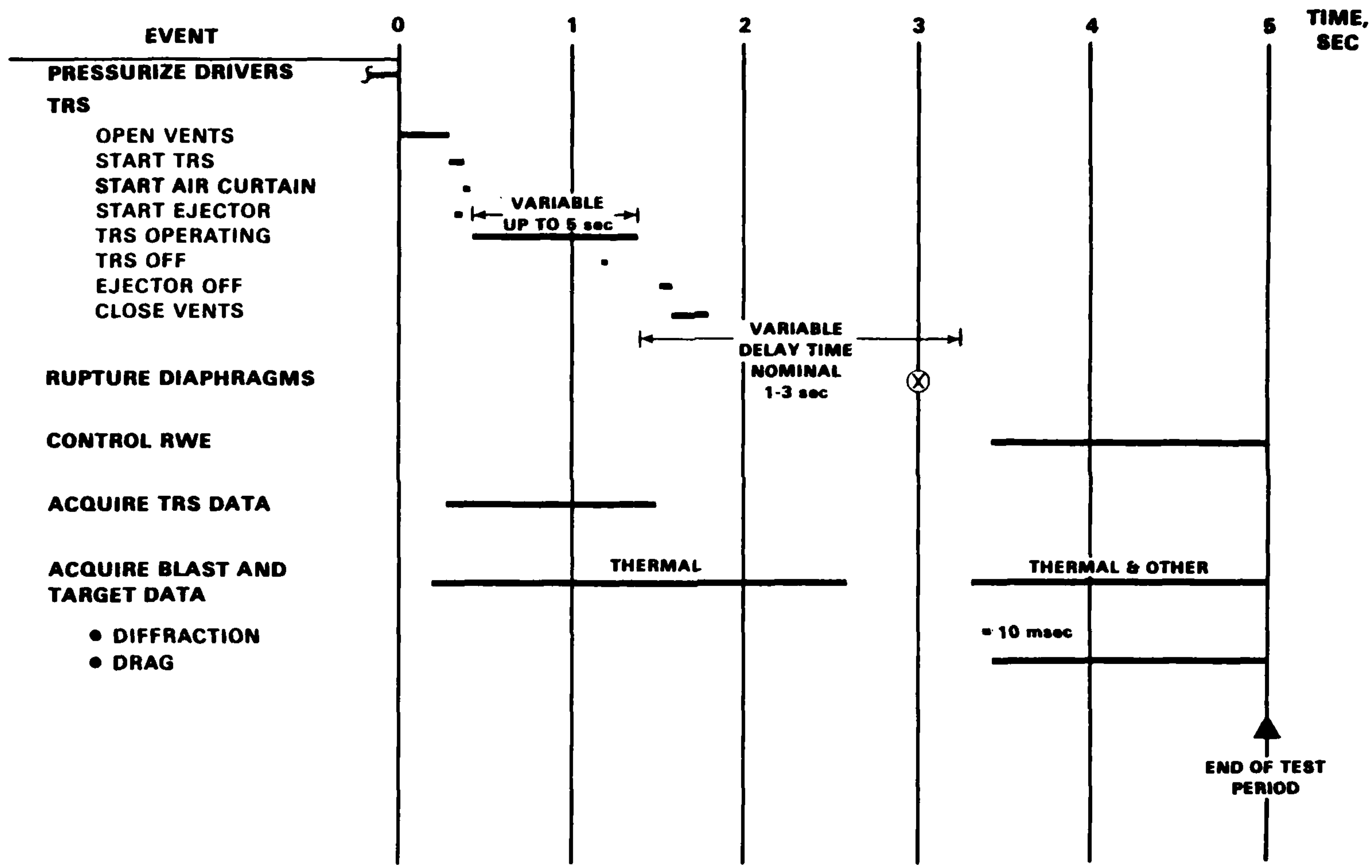


Figure 2. Nominal time line LB/TS.

The final task of the project involved the selection of a configuration for the sensor, data acquisition, and control (SDAC) system which best meets the unique requirements of the LB/TS. This comprehensive system, including functional block diagrams, is discussed in Section 7.

SECTION 2
CHARACTERIZATION OF LB/TS FLOW AND THERMAL ENVIRONMENT

2.1 DESCRIPTION AND PERFORMANCE RANGE OF THE LB/TS FACILITY.

The LB/TS facility is a shock tube configuration consisting of a series of from seven or more drivers whose gas is expanded into a driven tube. The test region is near the end of the driven tube. At the writing of this report the overall geometry of the LB/TS had not been completely specified. For purposes of this study however, a nominal configuration will be identified whose characteristics will ultimately define nominal aerodynamic and thermal environmental parameters.

The LB/TS consists of a driver section as described in the preceding paragraph, a diaphragm or fast-acting valve section which separates the driver gas from the driven tube gas. Upon initiation of the valves or rupture of the diaphragm, the high-pressure driver gas expands through an opening into conical diffusers and into the driven tube. Half-angle of the diffusers is approximately 16 degrees, Reference 2.1. The primary shock wave moves down the driven tube followed by a high-pressure region of expanding and interacting driver gases. For the purposes of this study it will be assumed that the driven tube is nominally 300 meters or 1,000 feet in length with a cross-sectional area of nominally $165m^2$. At the end of the driven tube is an active rarefraction wave eliminator (RWE) to tailor the reflected wave so that an accurate simulation of the blast wave structure may be maintained in the test region.

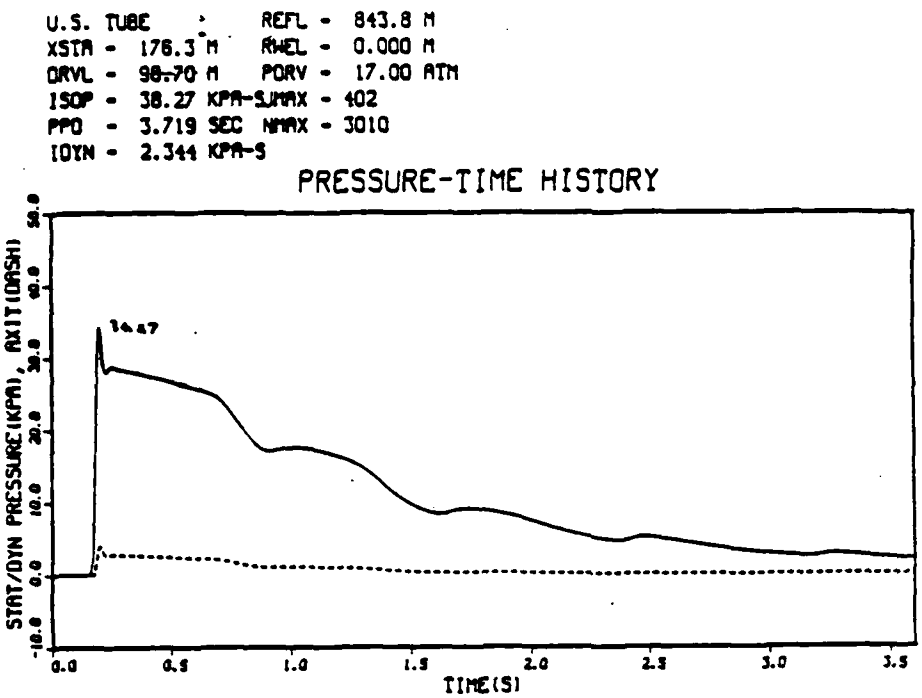
In order to simulate the thermal environment of a high-yield blast, a thermal radiation source (TRS) is located just upstream of the test region. The thermal radiation source consists of five or more flames normal to the driven tube axis. These flames use LOX and aluminum powder to create a high-temperature, radiant, optically dense medium.

Nominal performance design conditions have been identified for the LB/TS characterizing both the aerodynamic and the thermal radiation environment. Driver pressures and driven/driver tube geometries must be structured so that shock overpressures are maintained at a maximum of nominally 240 kPa or 35 psi. To achieve this condition approximately a 150-bar driver pressure is required with the driven tube operating at atmospheric conditions. A typical pressure trace is shown in Figure 3 which represents calculations made by U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, for a typical U.S. LB/TS. This pressure history includes a RWE to tailor reflections from the tube end and maintain the pressure decay behind the shock as a function of time. The form of this calculated pressure versus time curve is representative of the conditions expected in the LB/TS at the desired operating conditions. In addition, driver gas temperature may be increased to provide better matching of desired wave structures.

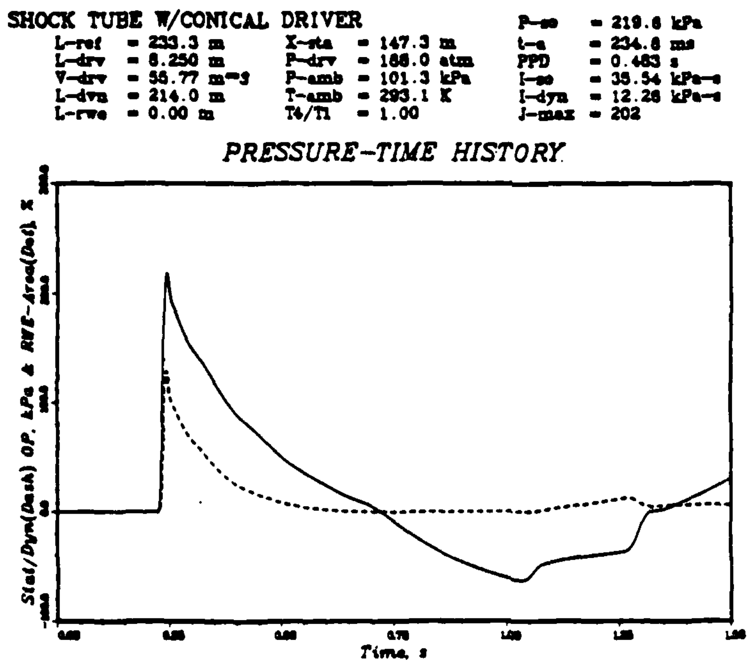
The TRS as described earlier is designed to produce a source flux of nominally 100 calories per centimeter squared per second with a fluence ranging from 100 to 500 calories per centimeter squared. The color temperature of the LOX flame is estimated to be nominally 3000 degrees Kelvin. Data from a recent TRS test is shown in Figure 4 which is a working model of the full TRS system. As can be seen, the flux is nonstationary in time. Gas from the TRS during the burn is drawn off at the top of the test section to eliminate the burnt gas residues from the test region so that the aerodynamic blast wave is not contaminated. The TRS, in a normal sequence of events, will be ignited before the aerodynamic blast front has reached the test region within the driven tube as shown in the bar chart in Figure 2.

2.2 DEFINITION OF AERODYNAMIC AND THERMAL DATA RANGES.

In order to define the aerodynamic range of the LB/TS, some sample calculations were made using a Sverdrup shock tube code. A brief writeup of the shock tube code is given in the following paragraphs. The area distribution utilized in the sample calculation is shown in Figure 5 where it was assumed that no rarefraction wave eliminator was present (driven tube very long). All lengths referred to in the following figures are normalized by the driven tube length with areas normalized by the test section area of 165 meters squared. Sample calculations were based on an instantaneous diaphragm break with equal driver and driven tube gas temperatures.



(A) LOW-PRESSURE CASE



(B) HIGH-OVERPRESSURE CASE

Figure 3. Sample pressure-time history calculation for the LB/TS.

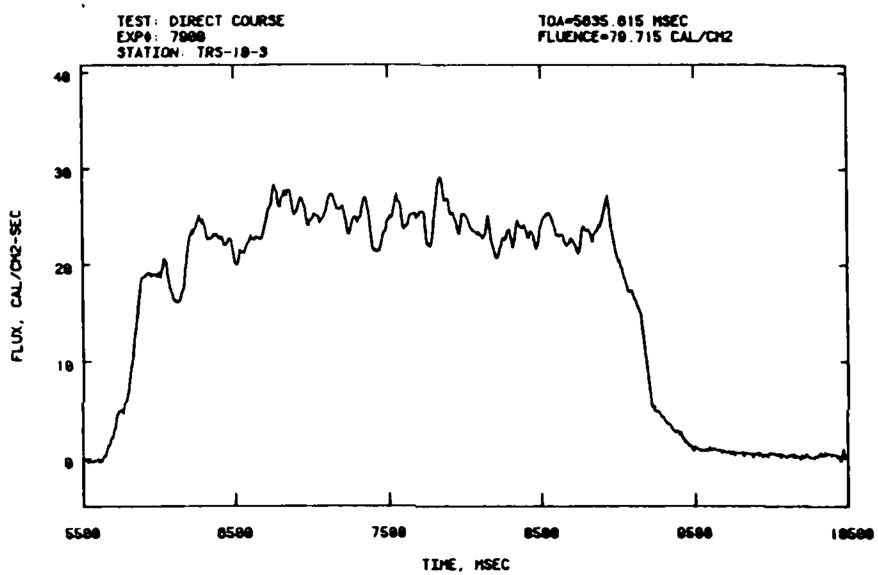


Figure 4. Typical TRS heat flux time history.

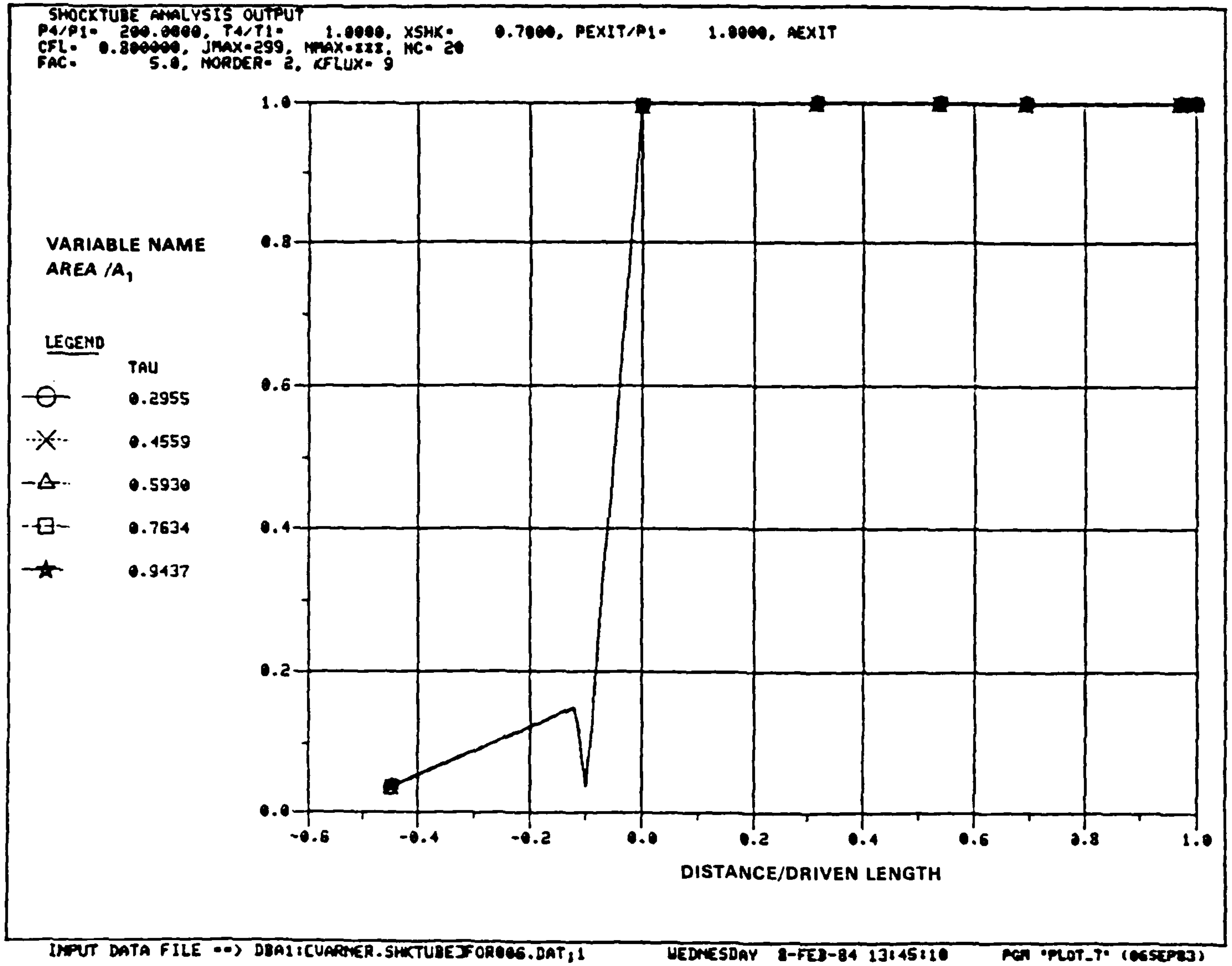


Figure 5. Assumed LB/TS area variation.

The numerical solution algorithm utilized in the present shock tube code is based on flux splitting the governing one-dimensional equations written in partial differential form. The application of this technique, which will be described in the following paragraphs, is an outgrowth of the MacCormack explicit/implicit approach described in References 2.2 and 2.3.

Over the past 15 years considerable progress has been made in the development of implicit and explicit solution algorithms to accurately define hyperbolic flow fields where large perturbations of the flow are present. Early transient studies utilized the explicit algorithm to track transient flows. The MacCormack explicit algorithm is a two-step predictor/corrector technique. The flowfield solution is updated after each predictor and corrector step utilizing grid sweeps in alternate directions. The result of this approach is that second-order accuracy is achieved while using only first-order spatial differencing and first-order Taylor series expansions in time. This explicit method, as in all explicit methods, contains a stability restriction which restricts the size of the allowable time step as constrained by the Courant-Fredrichs-Lewy (CFL) criteria. This allowable maximum step is governed by the grid density, local flow velocity, and local speed of sound.

The MacCormack implicit technique is a two-step extension of the 1969 predictor/corrector explicit technique. Utilizing the implicit technique, CFL's greater than one can be routinely exercised over part or all of the grid. The implicit technique utilizes as its basis the explicit solution of the governing equations based on the explicit algorithm of MacCormack. The second stage of the implicit technique removes the CFL stability criteria by numerically transforming the governing equations into an equivalent implicit form which, in general, requires a bidiagonal solution scheme. This new implicit technique has found wide application in a variety of aerodynamic flows.

In spite of the algorithm speed and simplicity of the implicit technique, errors exist when tracking shocks which occur in shock tube transients. For moving shocks which are not centered in a grid cell, "solution noise" can result in the vicinity of the shock due to the flux imbalances across the shock. When the grid is properly aligned, the solution oscillations on either side of the shock can be essentially eliminated.

In order to accurately track flows where moving shocks are present, a shock fitting technique with an adaptive grid algorithm can be implemented. The present solution algorithm does not, however, apply the adaptive grid approach. A split characteristics formulation is utilized in order to accurately and realistically account for the passage of flux information into and out of the shock, depending upon the sign of the eigenvalues in the vicinity of the shock front. This new technique is an extension of the MacCormack implicit/explicit concepts as presented and draws on the split characteristics concepts as given in Reference 2.4. No explicit dissipation is required in the formulation. The six steps given below briefly describe the application of the numerical solution algorithm as utilized in the shock tube code.

1. The system of governing equations written in weak conservation law form, is converted to a characteristics form by diagonalizing the flux vector.
2. The governing equations in characteristics form are separated corresponding to the sign of the eigenvalues or characteristic directions.
3. Both the flux vector and source terms are split utilizing the eigenvectors.
4. The delta formulation of the solution variables is developed from the split governing equations.
5. A two-step Runga Kutta calculation procedure is implemented to calculate the new time level solutions where the predictor and corrector steps are applied in a manner similar to the 1969 MacCormack algorithm.
6. Compatible split characteristic boundary conditions are applied at inflow and outflow boundaries where the right-hand side of the constraint equations corresponds to linear combinations of the solution variables in delta form. The sign of the eigenvalues at the inflow or outflow boundary determines the equations that are to be replaced in the constraint system.

The advantage of this new technique over other previous techniques is that it can resolve transient shocks accurately without an adaptive grid algorithm. In addition, it is computationally efficient compared to split flux schemes (for example) since, in its present form, it does not require a tridiagonal solution algorithm.

The summary calculations as given in Figures 6 through 12 describe the flow variable behavior as a function of time after diaphragm rupture at one station within the driven tube--at a point seventy percent of the driven tube length from the diaphragm. Figure 6 gives the static pressure distribution history normalized by the driven tube pressure P1. As can be seen the pressure rises rapidly as the shock passes the plotted X location. Once the shock passes the station of interest, the pressure field decays gradually and then very rapidly due to the interaction of the expanded driver gas. The driver to driven tube pressure ratio used for these calculations is 200.

The stagnation pressure normalized by the driven tube pressure is shown in Figure 7 and indicates a level of approximately 17 is reached in the early time evolution of the flow for the driver tube/driven tube pressure ratio of 200 as stated earlier. For a driver to driven tube pressure ratio of 200, the stagnation pressure ratio approaches values as high as 40 late in the wave evolution process.

Total and static temperature ratios normalized by the driven tube temperature are shown in Figures 8 and 9. These two figures show nominally the same rise times as shown in the pressure traces given in Figures 6 and 7. Static and total temperatures peak at 1.5 and 1.8 for this driver to driven tube pressure ratio of 200, respectively. The decay of the total temperature and static temperature following the peak rise is similar to the pressure decay as presented in Figures 6 and 7. Flow velocity, as normalized by the driven tube speed of sound, given in Figure 10 shows a level of approximately 1.2 immediately behind the shock and rising to a level of 1.7 at a later time.

The thermal environment of the LB/TS consists, as described in the preceding paragraphs, of two parts. The first part occurring in the time sequence is the thermal radiation source environment which is nominally on for 1 to 5 seconds early in the test. This is followed by a nominal two-second duration of time in the test where neither the

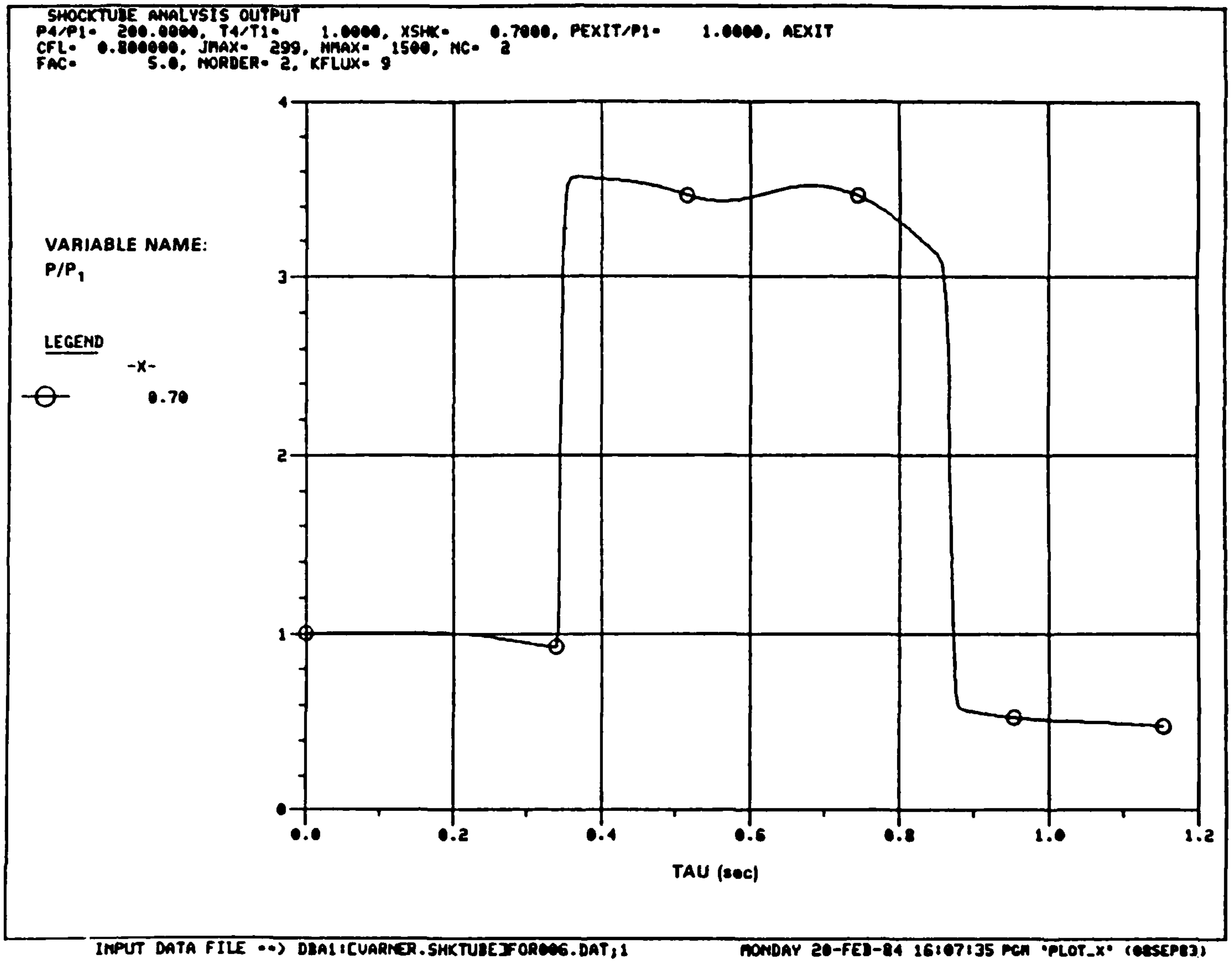


Figure 6. Normalized static pressure in the driven tube.

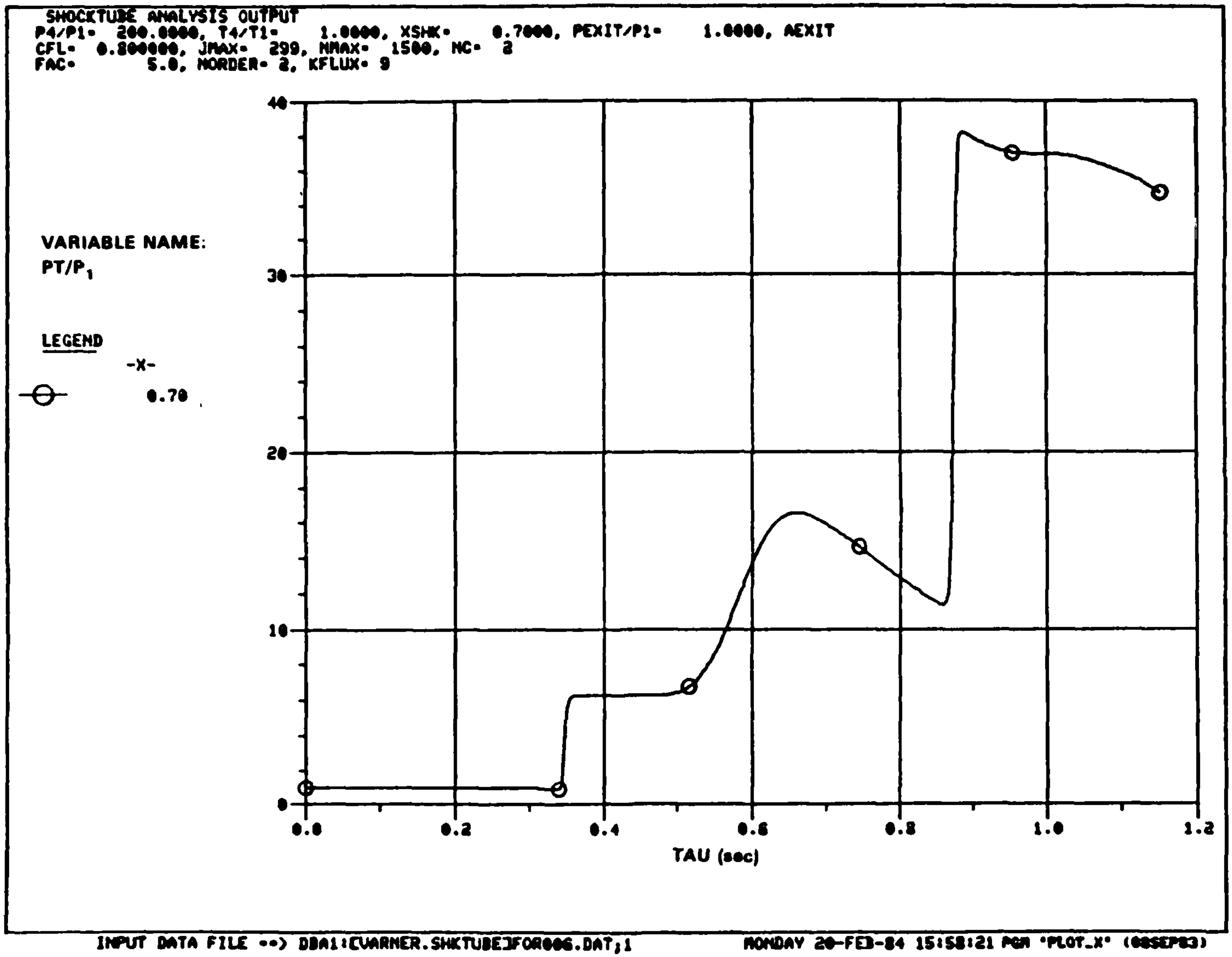


Figure 7. Normalized total pressure in the driven tube.

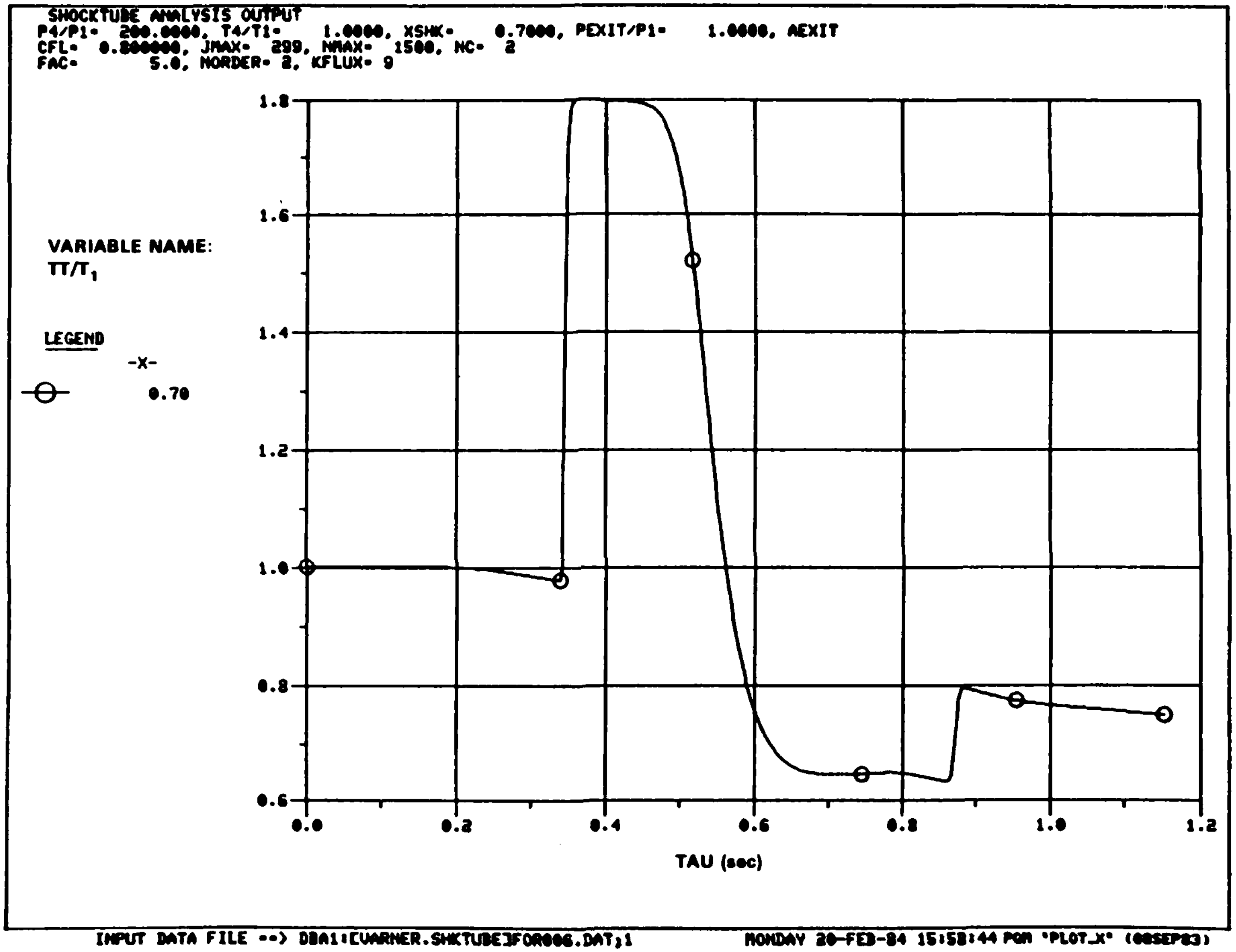


Figure 8. Normalized total temperature in the driven tube.

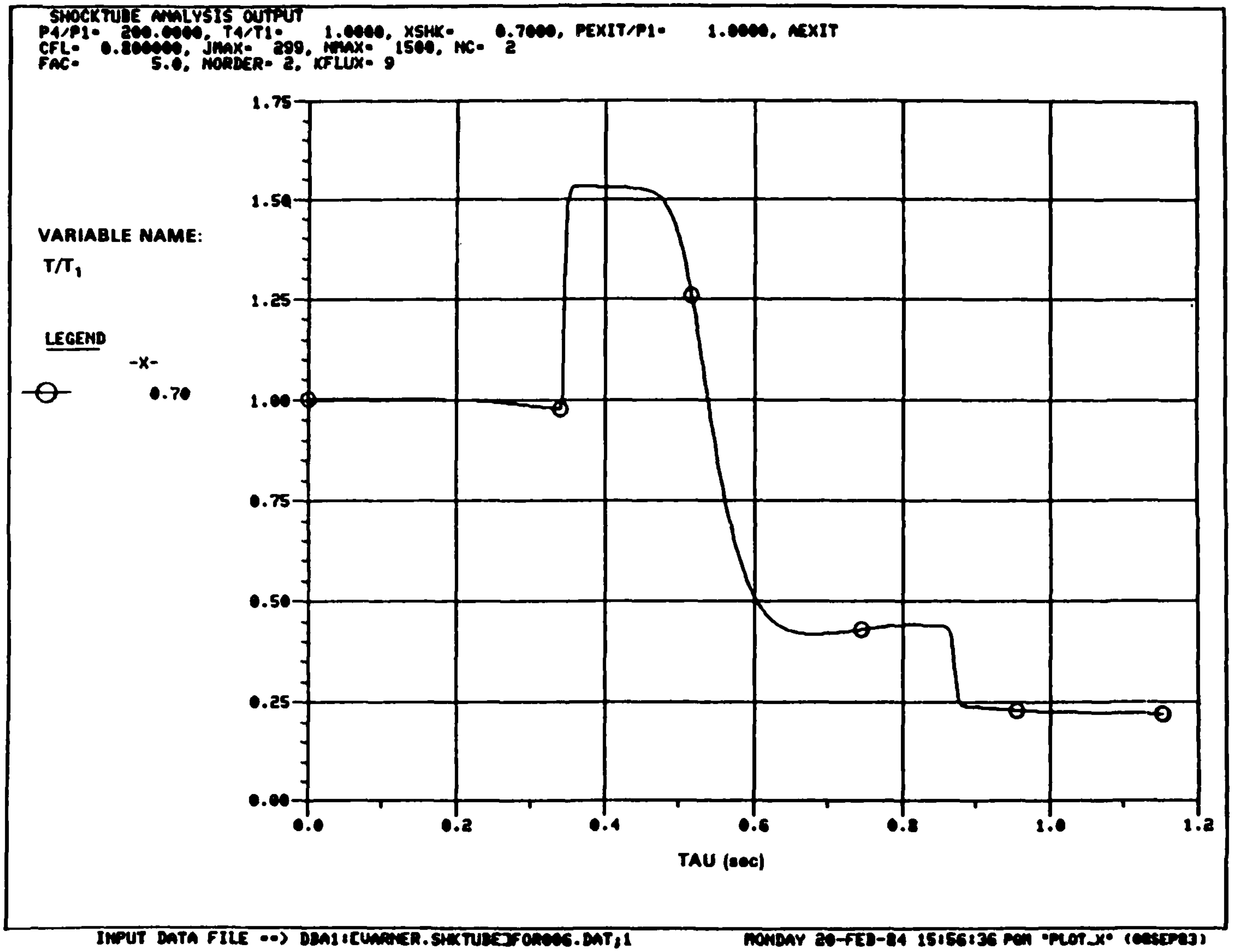


Figure 9. Normalized static temperature in the driven tube.

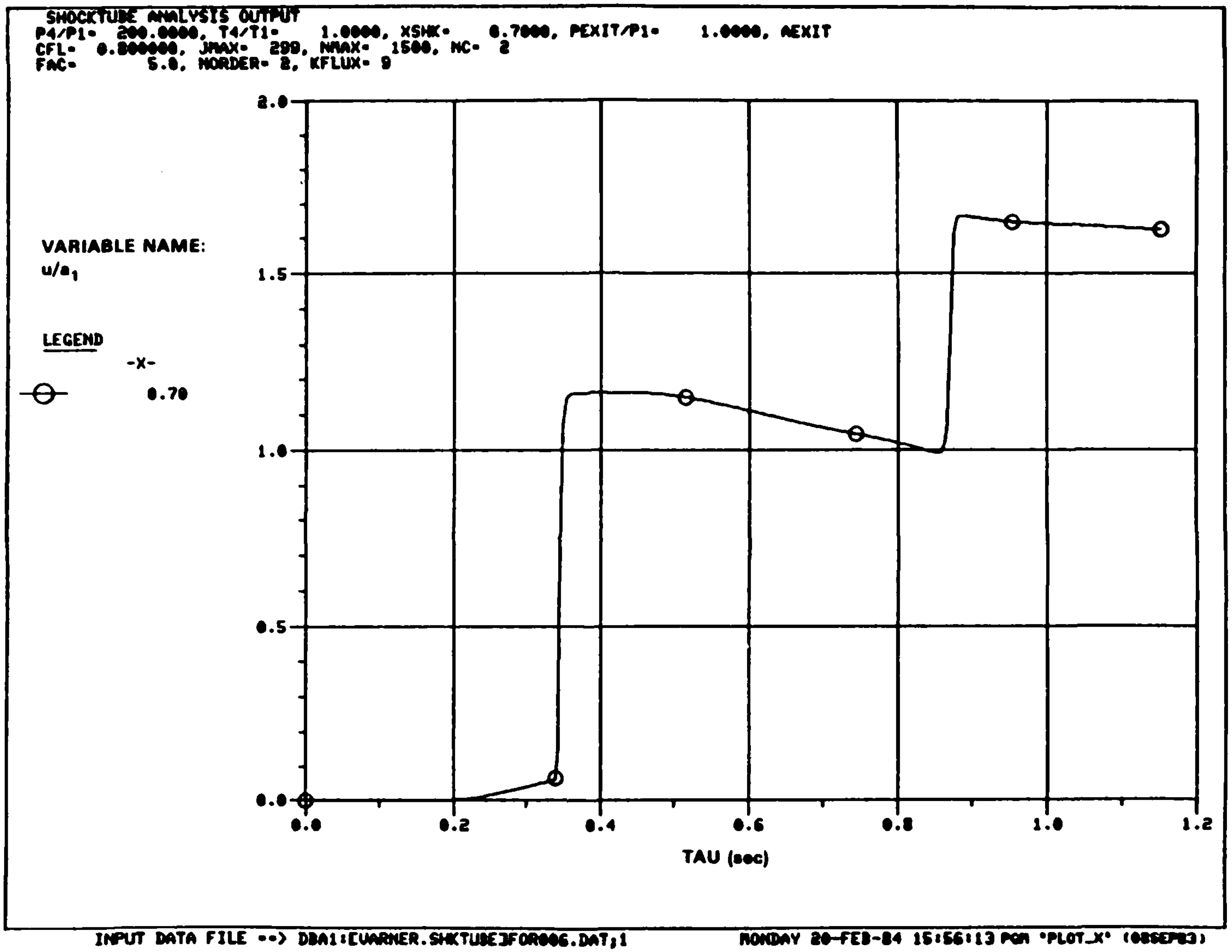


Figure 10. Normalized gas velocity in the driven tube.

aerodynamic or thermal radiation source fields are on. Following this delay time the blast wave and associated aerodynamic response takes place.

Sample calculations were made using the aerodynamic calculations as indicated in Figures 6 through 10 to define the heating levels in the test region due to aerodynamic sources only. Heat transfer calculations were based on flat plate heating and on stagnation point heating on a sphere where length scales for heating calculations were assumed to be equal to 0.3 meter. In addition, the calculations assume that the wall temperature of both the plate and the sphere were maintained at the initial driven tube temperature T1.

Graphical results are presented in Figures 11 and 12 for the flat plate and stagnation heating environment as a function of time for the two selected stations within the driven tube. As can be seen, for a driver to driven tube pressure ratio of 200, flat plate heating levels approach 8 cal per cm squared per second immediately behind the shock. Heating levels approach 3 cal per cm squared per second behind the shock for the stagnation point heat transfer. Rise times associated with the aerodynamic heat flux are on the same order as the passage of the shock front. For temperature rises or decreases caused by aerodynamic heating as described in Figures 11 and 12, test article thermal rise times will be dependent upon the configuration and can result in transient surface and through thickness temperatures which scale on the order of milliseconds to tenths of seconds.

The thermal radiation source environment as described earlier provides a color temperature of nominally 3000 degrees Kelvin and is a radiation source as it influences the test article. At this color temperature, radiation heating due to the TRS can reach as high as 100 cal per cm squared per second for a duration of from 1 to 5 seconds as indicated in Figure 4. This high heating level coupled with temperature variations in the thermal mass and geometry of the test article can result in surface and through thickness temperature variations of a few degrees Kelvin to surface temperature increases on the order of 1000 Kelvin with rise times in the millisecond range.

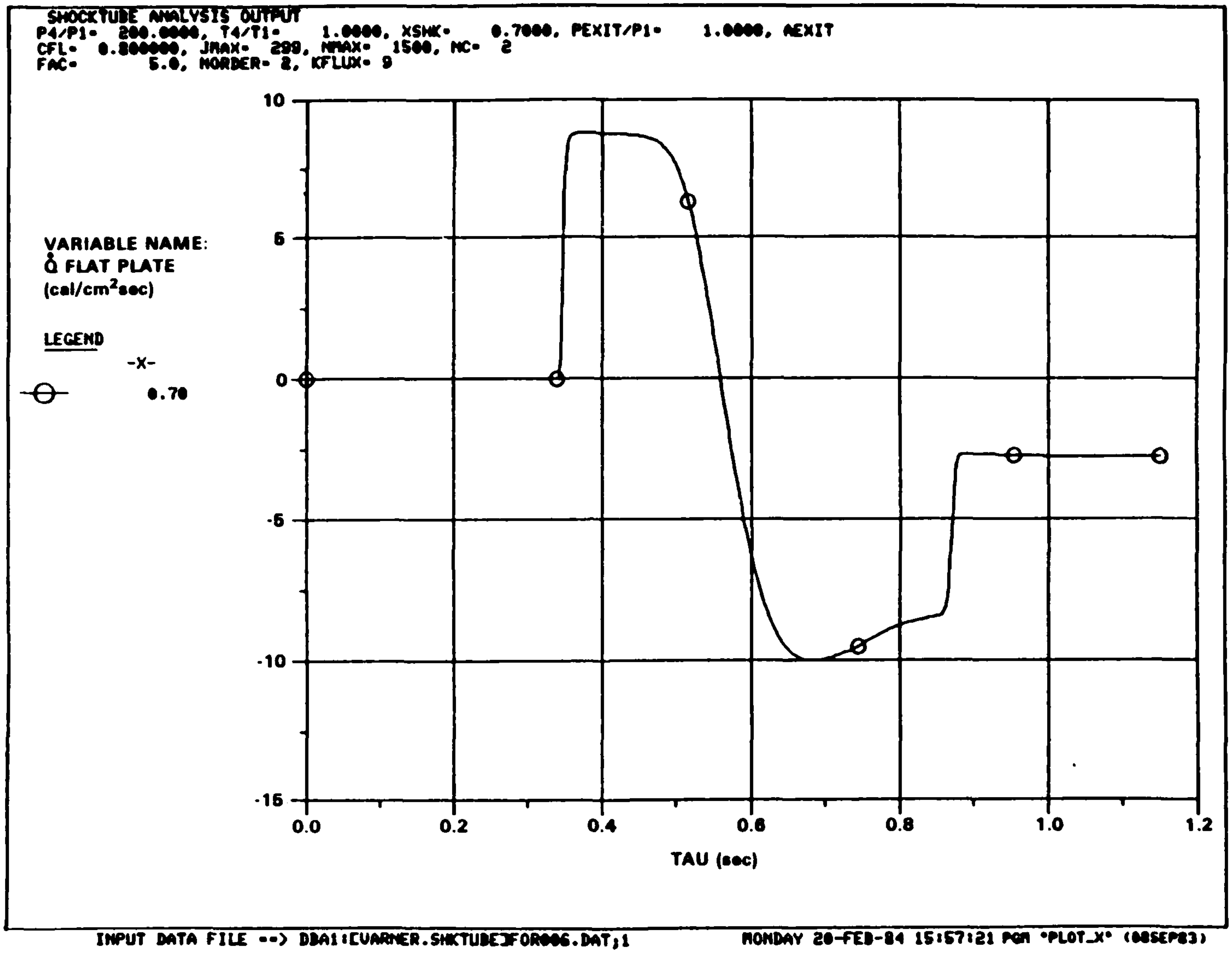


Figure 11. Flat plate heat flux for turbulent flow on a 0.3 meter flat plate.

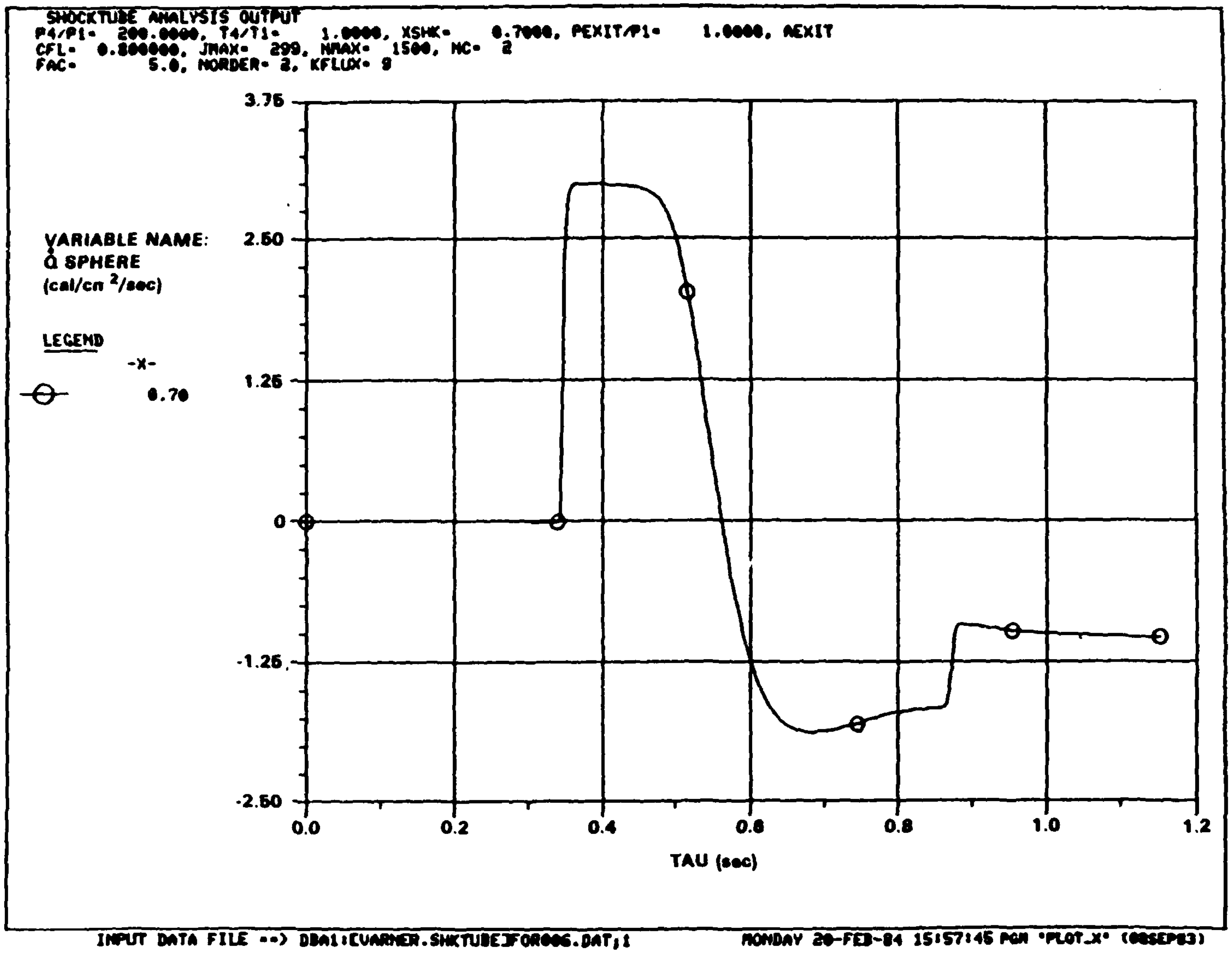


Figure 12. Stagnation heat flux on a 0.3 meter diameter sphere.

As a result of the high aerodynamic transient loading on the test article due to the passage of the blast front, significant displacement, velocity, and accelerations of the test article can take place. Measurement requirements on the test article can be as variable as the definition of the vibration environment of a stiff member to the definition of the displacement of the entire test article as a solid body. This provides for a wide spectrum of acceleration and displacement ranges for the test article dependent upon the type of measurement desired. For a high stiffness member where the vibration environment is desired, displacements on the order of ten thousandths to tenths of an inch and acceleration loads of thousands of g's are possible. For high mass/large configurations, such as armored vehicles, displacements can range from hundredths of an inch to feet with commensurate low accelerations on the order of 1g.

Table 5 provides a summary of the LB/TS test data characterization as described in preceding paragraphs. Data found in this table is a merging of results obtained from the sample calculation and from BRL design information for the LB/TS. It is to be emphasized that the magnitude and rise time ranges as given for each one of the data types are by no means the minimum or maximum ranges anticipated but are intended to represent the nominal extent of the ranges to be expected during typical LB/TS operation. In using this table it is also emphasized that the aerodynamic environment occurs at a different time during the test evolution than the thermal or TRS environment as shown graphically in Figure 2. Thus, in a temperature measurement system that must measure both the thermal and aerodynamic temperature environment, one must consider the temperature range given for both aerodynamic data and the thermal data both separately and collectively. In addition it is to be noted that the heat flux estimates provided in this table, for aerodynamic heating, are based on turbulent flow on a flat plate and for stagnation heating on a sphere nominally one foot in diameter. The displacement, velocity, and acceleration values given in the table are characteristic of the test article as influenced by aerodynamic loads. Since strains and stresses are a function of the precise geometry of the test article no attempt was made to estimate or bracket the range of this data type.

Table 5. LB/TS test data characterization.

DATA TYPE	MAGNITUDE NOMINAL RANGE		RISE TIME (sec) NOMINAL RANGE		COMMENTS	NOTES
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM		
AERODYNAMIC						1
					SHOCK TUBE GENERATED ONLY (1 TO 3 SEC. NOMINAL DURATION)	
PRESSURES (atm) TOTAL	1	200	.01	1.0	DRIVER TUBE	
	1	40	.00001	.01	TEST REGION	
STATIC	1	200	.01	1.0	DRIVER	
	1	4	.00001	.01	TEST REGION	
TEMPERATURE TOTAL, STATIC	200°K	600°K	.1	1.0	DRIVER TUBE (MODERATE HEATING OF DRIVER GAS)	
TOTAL, STATIC	200°K	600°K	.001	.01	DRIVEN TUBE, TEST REGION	
DISPLACEMENT (cm)	.0025	.25	0.000025	.0025	VIBRATION ENVIRONMENT	
	.25	100	.025	.25	SOLID BODY MOTION	
VELOCITY (m/sec)	0	500	0.00001	0.1	GAS ONLY	
ACCELERATION (g's)	1	1500	.00001	0.1	RANGE DEFINES SOLID BODY MOTION TO STIFF MEMBER VIBRATION	
HEAT FLUX (cal/cm^2/sec)	0	10	.001	.1	RANGE DERIVED FOR PLATE AT .3M OR .3M DIAMETER SPHERE, TURBULENT FLOW, 300°K WALL TEMPERATURE	
THERMAL						2
					TRS GENERATED ONLY (1 TO 10 sec. NOMINAL DURATION)	
TEMPERATURE	0	3500°K	.001	.1	TRS	
	0	1000°K	.001	.1	TEST ARTICLE	
HEAT FLUX (cal/cm^2/sec)	0	100	.001	.1	TEST ARTICLE, 500 cal/cm^2 FLUENCE	

1. AERODYNAMIC DATA OCCURS NOMINALLY 2 SECONDS AFTER TRS ENVIRONMENT HAS BEEN COMPLETED (SEE FIGURE 1-2 FOR REFERENCE)

2. THERMAL DATA OCCURS AT THE INITIAL PART OF THE TEST DATA ENVELOPE PERIOD (SEE FIGURE 1-2 FOR REFERENCE)

SECTION 3
SURVEY OF PHYSICAL/INTRUSIVE SENSORS

A survey of sensors which are normally categorized as intrusive (physically having some point of contact on the measurement surface) is presented in this section. Our survey includes selected specifications as provided by manufacturers' catalogs (Appendix A) and a bibliography (Appendix B) of recent instrumentation developments which are either directly applicable or related to the LB/TS type environment.

3.1 PRESSURE MEASUREMENTS.

Numerous pressure sensors will be required to take facility measurements, monitor the blast wave and flow environment, and measure target response (Table 1). Facility measurements will include driver pressure, TRS nitrogen pressure, TRS LOX supply pressure, atmospheric reference pressure, and others. Blast wave and flow measurement pressures will include driven tube wall pressure distribution, diffraction, drag phase pressures using flow field probes, and target response during the drag phase. Both piezoelectric and strain gage transducers are frequently used in blast simulation experiments.

The piezoelectric effect is an effect whereby strains in certain types of crystals of insulating materials lead to a separation of charge (i.e., positive on one face, negative on another). The effect may be inverted; in that application, a charge will cause a strain. Over a range of strains due to forces, the charge is proportional to the strain which is the basis for pressure transducers based on the piezoelectric effect. Since charge tends to be neutralized by the surroundings, transducers based on this effect are primarily useful in dynamic or transient systems such as characterized by the LB/TS environment.

Where slightly slower response can be tolerated, strain gage or capacitive and inductive transducers may be specified. The resistance (strain) of a wire is dependent on its length and cross-sectional area, so that when a wire is stretched, its resistance changes due to increase in length and decrease in area. However, there is an additional effect on the resistivity of the material itself. The resistivity, as opposed to the resistance, is a function of strain also, so that the change of resistance per unit elongation is often different from what one would expect on the basis of elongation alone.

The wire may be attached firmly to a surface undergoing change in length, such as a diaphragm being deflected by pressure, in which case it is referred to as a **bonded** strain-gage. In other designs, the diaphragm displacement may be transmitted by a mechanical linkage so as to stretch wires which are attached only at the ends, in which case the device is referred to as an **unbonded** strain-gage. Rise time and frequency response are slower for these designs. In any case, the change in resistance must be measured and related to the pressure.

In capacitive and inductive transducers, the change of the distance between a fixed electrode and a movable electrode (such as a diaphragm) may be used to produce a measurable change in capacitance. In addition, by changing the distance between a coil and an iron diaphragm, the inductance of the coil may be changed. Either of these effects may be sensed electrically, and related to pressure.

3.1.1 Nature of Required Pressure Measurements.

Table 4 identifies a minimum requirement for 15 facility pressure measurements, 21 blast wave and flow measurements, and 10 target response pressure sensors. Table 6 details general specifications for pressure requirements. The table identifies an extremely wide range of pressure sensor requirements. Rise time and frequency response for facility control sensors are less severe than other pressure measurements but the maximum pressure level required is much higher. Strain gage transducers will be suitable for facility control while piezoelectric or fast-response silicon diaphragm gages must be employed for the remainder. Several static and total pressure sensors suitable for use in the LB/TS are given in Appendix A for mounting in the tunnel wall, reference bodies in the test section, or special probes.

Table 6. Pressure sensor requirements and specifications.

Requirements	Facility Monitor and Control	Blast Wave and Flow Measurements	Target Response
Range	Driver Pressure, 10,000-24,000 kPa TRS N , 7000-14,000 kPa LOX, 10 to 700 kPa Atm. reference, 100 kPa	Wall Static Pressure, 200-350 kPa Diffraction Static, 200-350 kPa Drag Static, 200-350 kPa Differential probes, 40-60 kPa Stagnation probes, 200-1000 kPa	100-350 kPa
Frequency	1 kHz	Wall Pressure, 50 kHz Diffraction, 250 kHz Drag, 20 kHz Differential, 250 kHz Stagnation, 250 kHz	50 kHz

Blast wave and/or shock tunnel flow calibration is dependent on accurate measurement of static and total pressure and their difference. Absolute measurement of both static and total pressure involves potential errors since the absolute level of each may be considerably different. Numerous designs for differential probes have been produced by shock tube and blast simulator engineers. Figure 13 reproduces one such probe (Reference 3.1) used at the BRL. It is a modification of an original BRL design to utilize standard Kulite pressure sensing elements (the XCW-190 series), which were suitable for adaption to make a differential pressure gage. The outer configuration is that of a long cylindrical rod oriented parallel to the expected direction of air flow. A single pressure-sensing diaphragm is placed within the rod about one rod diameter from the nose. Stagnation overpressure is developed on one side of the diaphragm from the input port in the nose of the rod. The static overpressure is developed on the rear of the diaphragm by a connection of the internal volume at the rear of the diaphragm to static pressure inlet ports that are two rod diameters to the rear of the nose. These ports are 12 cylindrical holes drilled perpendicular to the axis of the rod and spaced uniformly around its circumference. A metal screen with holes is placed immediately in front of the diaphragm to protect it from direct impact by particles in the air stream. The diaphragm is of silicon and contains an active Wheatstone bridge. It is coated on both sides with an RTV compound to minimize heat conduction effects during the test period.

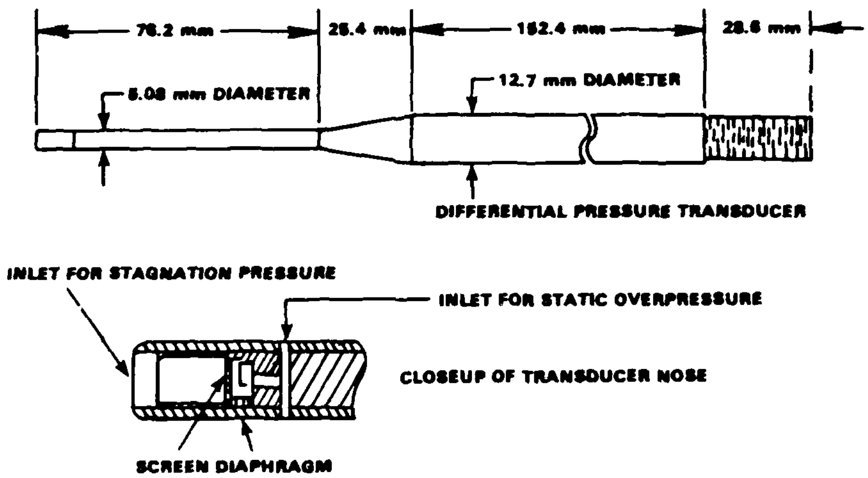


Figure 13. Configuration of the differential pressure gage for blast wave measurements.

Differential pressure gages with peak ranges of 6.9 kPa (1 psi), 13.8 kPa (2 psi), and 34.5 kPa (5 psi) have been tested to a limited extent in a shock tube at BRL. The gages were exposed to step shocks generated in the 0.56-meter diameter shock tube, and the signals were recorded using an 80-kHz magnetic tape recording system and a frequency response of about 20-kHz (flat) was measured.

Conventional stagnation probes consisting of single, open-ended tubes with protective filters are used for total pressure measurements when high-frequency response is not required. Surface-mounted sensors such as Kulite gages can measure local total or static pressures and discriminate flow oscillations at frequencies up to 200 kHz (flat response) in the LB/TS pressure range.

Direct use of pressure sensors and development of pressure probes and other devices using pressure sensors in environments such as produced by the LB/TS facility are extremely difficult if productivity and reliability are of prime importance. The use of screens and baffles to prevent particle impact will always degrade sensor frequency performance. The simple expedient of placing a plastic insulative coating over a diaphragm will serve to increase sensor life and delay temperature effects at the cost of lower frequency response. Corrections to the data for gage or probe acceleration during the blast, temperature rise in the sensing element due to high heat transfer from the TRS and flow, errors induced by inadequate mounting, and degraded response time in a given test situation requires continuous close attention in the application of seemingly attractive commercial sensors. Techniques for minimizing these effects or making corrections to data have been developed at BRL and other impulse facilities to permit reliable use of the commercial pressure sensors.

3.1.2 Sources of Pressure Sensors.

There are numerous manufacturers of high-quality pressure transducers in the U.S. The industry is quite competitive and innovative and specialized development for measurement of transient pressures in extreme environments has been accomplished by numerous firms to meet requirements of the government and industry. The following companies routinely manufacture pressure sensors which would be candidates for the LB/TS facility.

- Celesco Transducer Products, Inc.
  7800 Deering Avenue
  Canoga Park, CA 91304

- Kistler Instrumentation Corp.
  75 John Glen Drive
  Amherst, NY 14120

- Entran Devices, Inc.
  10 Washington Avenue
  Fairfield, NJ 07006

- Endevco
  Rancho Viejo Road
  San Juan Capistrano, CA 92675

- PCB Piezotronics, Inc.
  3425 Walden Avenue
  Depew, NY 14043

- Sensotec
  1200 Chesapeake Avenue
  Columbus, OH 43212

- Kulite Semiconductor Products
  1039 Hoyt Avenue
  Ridgefield, NJ 07657

- Setra Systems, Inc.
  45 Nagog Park
  Acton, MA 01720

- BBN Instruments
  50 Moulton Street
  Cambridge, MA 02138

- Kaman Instrumentation Corporation
  1500 Garden of the Gods Road
  Colorado Springs, CO 80933

- Transamerica Delava (CEC)
  360 Sierra Madre Villa
  Pasadena, CA 91109

- MKS Instruments, Inc.
  34 Third Avenue
  Burlington, MA 01803

Although the above list by no means identifies all pressure transducer manufacturers* it does represent the majority of those who compete for development contracts when advanced test facilities are constructed by the government. Since specific performance criteria are not established, it is beyond the scope of the present study to recommend one particular manufacturer for each specific measurement in the LB/TS facility. Any one of the above cited manufacturers could produce systems capable of measuring pressures during both the diffraction and drag phase of operation. However, a few specifications and operating characteristic descriptions have been extracted from technical catalogues and are included in Appendix A to demonstrate available sensors and unique designs related to the LB/TS environment. The appendix is divided into separate sections for pressure, heat flux, etc.

A brief open-literature search was conducted to evaluate the extent of development work being accomplished for pressure measurement systems which would have direct applicability to the LB/TS facility. The bibliography contains descriptive abstract listings of 14 such papers by personnel at agencies and facilities such as Aberdeen Proving Grounds, Sandia Laboratories, Air Force Weapons Laboratory, Defense Nuclear Agency, Los Alamos Scientific Laboratories, NASA, and foreign sources. Most of these reports deal with evaluation of specific pressure sensors in field blast conditions. Their recommendations are normally unique to their specific testing situation but can serve as general guides for selection of future sensor procurements.

3.2 TEMPERATURE AND HEAT FLUX MEASUREMENTS.

3.2.1 Temperature.

Direct thermocouple measurements will be the most common temperature sensor utilized in the LB/TS. A comparison chart (Table 7) of various temperature sensors (RTD, thermistor, thermocouples, semiconductors) prepared by Hy-Cal Engineering follows on the next page.

*The 1983-84 ISA Directory lists 98 companies under the heading - Pressure Transducers, Electronic

Table 7. Comparison chart of various temperature sensors. (Prepared by HY-CAL Engineering)

EVALUATION CRITERIA	PLATINUM RTD 100Ω wire wound and thin film	PLATINUM RTD ⓄULTRA-7™ 1000Ω thin film	NICKEL RTD 1000Ω wire wound	BALCO RTD 2000Ω wire wound	THERMISTOR	THERMO-COUPLE	SEMI-CONDUCTOR DEVICES
Cost - OEM Quantity	HIGH	LOW ★	MEDIUM	MEDIUM	LOW ★	LOW ★	LOW ★
Temperature Range	WIDE —400°F to +1200°F ★	WIDE —320°F to +1000°F ★	MEDIUM —350°F to +600°F	SHORT —100°F to +400°F	SHORT to MEDIUM —100°F to +500°F	VERY WIDE —450°F to +4200°F ★★	SHORT —57°F to +257°F
Interchangeability	EXCELLENT ★★	EXCELLENT ★★	FAIR	FAIR	POOR to FAIR	GOOD ★	FAIR
Long Term Stability	GOOD ★	GOOD ★	FAIR	FAIR	POOR	POOR to FAIR	GOOD to FAIR
Accuracy	HIGH ★	HIGH ★	MEDIUM	LOW	MEDIUM	MEDIUM	MEDIUM
Repeatability	EXCELLENT ★★	EXCELLENT ★★	GOOD ★	FAIR	FAIR to GOOD	POOR to FAIR	GOOD ★
Sensitivity (output)	MEDIUM	HIGH ★	HIGH ★	VERY HIGH ★★	VERY HIGH ★★	LOW	HIGH ★
Response	MEDIUM	MEDIUM to FAST ★	MEDIUM	MEDIUM	MEDIUM to FAST ★	MEDIUM to FAST ★	MEDIUM to FAST ★
Linearity	GOOD ★	GOOD ★	FAIR	FAIR	POOR	FAIR	GOOD ★
Self Heating	VERY LOW to LOW ★	MEDIUM	MEDIUM	MEDIUM	HIGH	N/A	VERY LOW to LOW ★
Point (end) Sensitive	FAIR	GOOD ★	POOR	POOR	GOOD ★	EXCELLENT ★★	GOOD ★
Lead Effect	MEDIUM	LOW ★	LOW ★	LOW ★	VERY LOW ★★	HIGH	LOW ★
Physical Size/Packaging	MEDIUM to SMALL	SMALL to LARGE ★	LARGE	LARGE	SMALL to MEDIUM ★	SMALL to LARGE ★	SMALL to MEDIUM ★

★★ Best Rating
★ Good Rating

Figure 14 represents output versus temperature in °F for various thermocouple materials. Choice of thermocouple material is based on considerations other than temperature level. Direct temperature measurements will be required for measurement of driver gas, LOX supply, pilot, and vent gas temperatures. For blast wave and flow monitoring, the temperature of the flow can be measured with shielded and vented thermocouple probes. Both backface and frontface temperatures on the target can be obtained with simple thermocouples, RTD's, or thermistors. Table 4 identifies 24 facility temperature measurements, 6 blast wave and flow measurements, 10 thermal input temperatures, and 18 target response thermocouples for a total of 58 temperature sensors as a minimum requirement. Table 8 summarizes the various temperature sensor requirements.

Platinum-rhodium/platinum thermocouples provide the best combination of resistance to corrosion and high-temperature capability. Although temperature to 3000°F (1921°K) can be measured with such thermocouples, the surfaces should be coated to minimize surface catalytic effects. Tungsten-tungsten rhenium thermocouples provide a capability to measure temperatures up to 5000°F (3032°K), but this material has a poorer oxidation resistance. The development of thermocouples and probes, specifically RTD and thin-film devices, by commercial firms is extensive. The selection of a specific thermocouple sensor from literally hundreds on the market is beyond the scope of the present study.

The following comments are related to one device (a total temperature probe, Figure 15) designed to overcome many of the problems associated with flow temperature measurement with thermocouple devices (Reference 3.3). Since at high velocities the free stream static temperature cannot readily be measured, one resorts to measuring the total gas temperature. This requires a probe with a stagnation chamber wherein the gas can be brought adiabatically to a low velocity. If the process is perfectly adiabatic, the recovery temperature, T_r, equals the total temperature, T_o, from which T_∞ can be calculated

$$T_\infty = T_o - \frac{V^2}{2\,c_p}$$

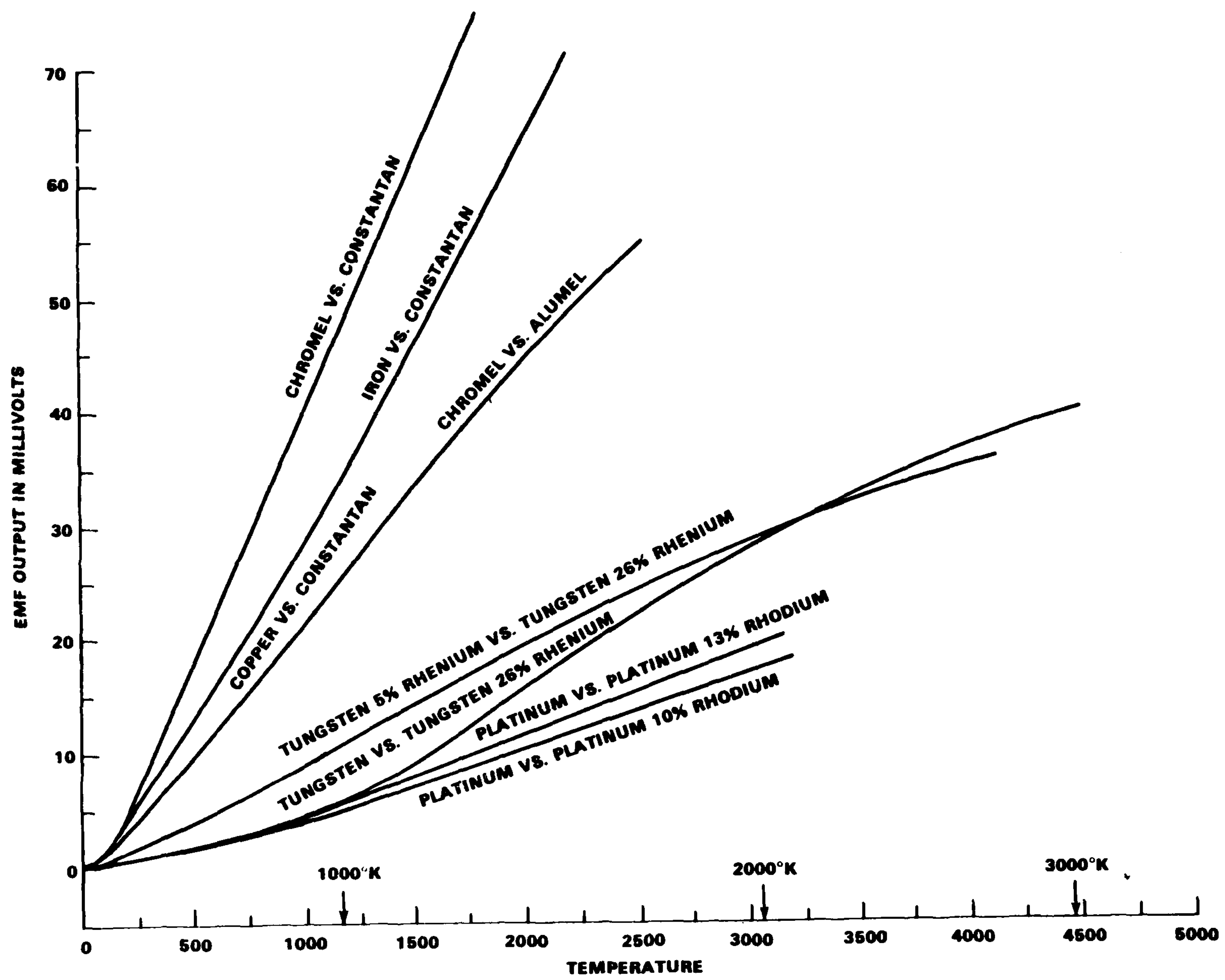
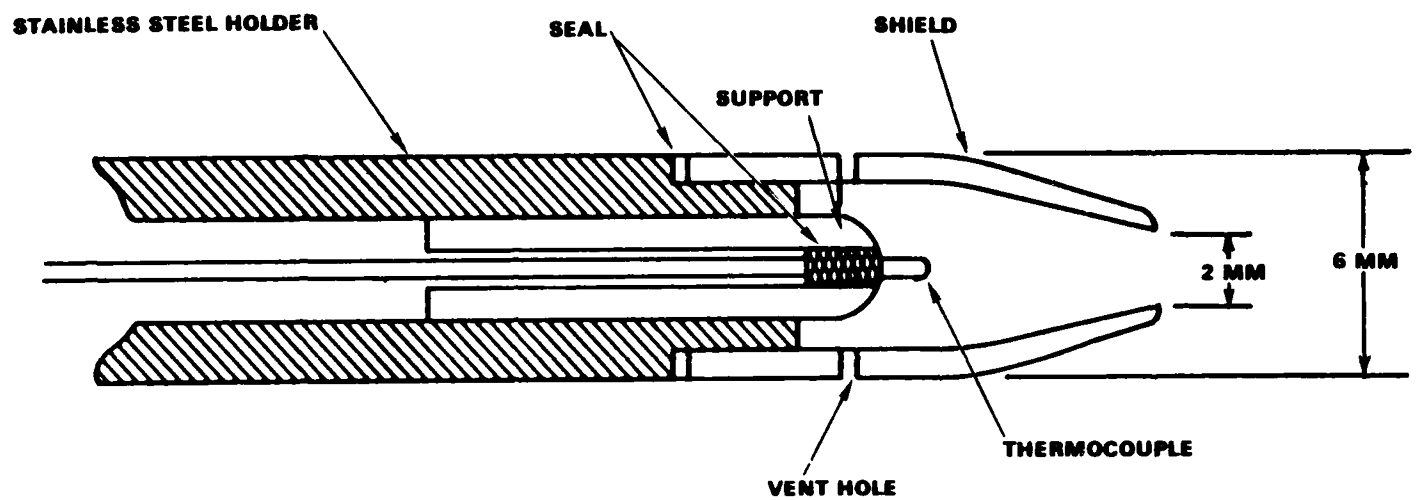


Figure 14. Thermocouple output vs. temperature.

Table 8. Temperature sensor requirements and specifications.

Requirements	Facility Monitor and Control	Blast Wave and Flow Measurements	Target Response
Range	Driver Gas, 600°K LOX Supply, Crygenic Vent Gas, 2000°K	Shielded Probe, 600°K	Backside, 400°K Frontside, 800°K
Types	Platinum RTD and High-Temperature TC'S	High-Temperature TC'S	Platinum RTD and High-Temperature TC'S
Response	0.1 sec	.001 sec	0.001 on surface 0.01 on backside



THERMOCOUPLE SUPPORT AND SHIELD MADE OF SILICA WITH
ALL EXPOSED SURFACES PLATINUM COATED:
THERMOCOUPLE: IRON-CONSTANTAN, 0.25 MM DIAMETER,
FIBERGLASS INSULATED;
TWO VENT HOLES.

Figure 15. Design of stagnation temperature probe.

In practice, however, the gas cannot be brought to rest adiabatically. Frictional heating and dissipation by conduction in the boundary layer make it impossible to recover all the kinetic energy of the flowing gas. Moreover, as already noted, if the gas flows too slowly over the probe, conduction and radiation losses become excessive. Therefore, in any viscous fluid some recovery error must be tolerated and a compromise between this recovery error and the radiation-conduction error must be made. The important consideration is that the error remains essentially constant throughout all flow conditions. Many of the earlier high-velocity temperature probes were merely bare thermocouples positioned in the flow.

Due to the difficulties of measuring the recovery factor, r, and the unknown influence of parameters such as surface roughness, junction formation, etc., it is not likely that values of r for an uncalibrated probe can be more reliable than ±10%. This uncertainty in the recovery factor becomes of little consequence, however, if the velocity over the thermocouple junction is reduced to a low value. The simplest device for this purpose is a straight tube with vent holes. Specific probe designs are necessary for particular flow environments to minimize the cumulative errors attributable to radiation, velocity, and conduction. Varner performed an analysis of corrections necessary to such probes and concluded that the error analysis must include the developing thermal layer within the tube (Reference 3.4). Before such devices are designed for the LB/TS environment, an in-depth error analysis should be performed to evaluate probe effectiveness.

Target thermal response will be made, in part, by front and backside bare thermocouple sensors. Measurements using wall thermocouples require that the junction size be small to increase response. Also, any material near the junction must be similar to the wall in order to minimize the effect of local differences in thermal properties (Reference 3.5).

There are many manufacturers of thermocouple devices in the United States.* Three of the best known firms are:

*The **1983-84 ISA Directory** lists 146 manufacturers under the heading - Temperature Sensors, Thermocouples, and Accessories

Hy-Cal Engineering
9650 Telstar Avenue
El Monte, CA 91731

Nanmac Corporation
9-11 Mayhem Street
Framingham Centre, MA 01701

Omega Engineering
Box 4047
Stamford, CT 06907

Any of these manufacturers could design specific thermocouple sensor packages to meet LB/TS criteria. The bibliography (Appendix B) contains 15 abstracts for development of thermocouple sensors in environments such as the LB/TS. Transient errors, oxidation effects, calibration, and development of analytic codes to infer heat transfer rate and correct for thermocouple errors are included.

3.2.2 Heat Flux.

Intrusive devices for surface heat flux (calorimeters) can be used for a variety of purposes in the LB/TS facility. By innovative design, gas temperatures, flow enthalpy, and velocity can be inferred from calorimeter devices. These would be useful for both facility measurements, blast wave and flow measurements, and target measurements. Thermal input from radiation source can be directly measured by calorimeters sensitive to radiant energy. Target radiant and convective energy can also be directly measured with on-board devices. Direct measurement heat flux sensors have been widely developed for unique test facilities.

A coax thermocouple heat flux sensor (Figure 16) has advantages over other devices including operational durability, time response, calibration stability, miniature size, and the ability to contour the gage exactly to the surface of the instrumented component. Co-axial surface thermocouples can be employed for measurements over a heat-transfer-rate range of 1 to 135 cal/cm^2 sec. (3-500 Btu/ft^2 sec.). Preamplification units can extend the heat-transfer-rate level to 0.3 cal/cm^2 sec. The cylindrical thermocouple assemblies are small, typically 0.16 to 0.32 cm O.D. and approximately 0.36 to 1.0 cm long.

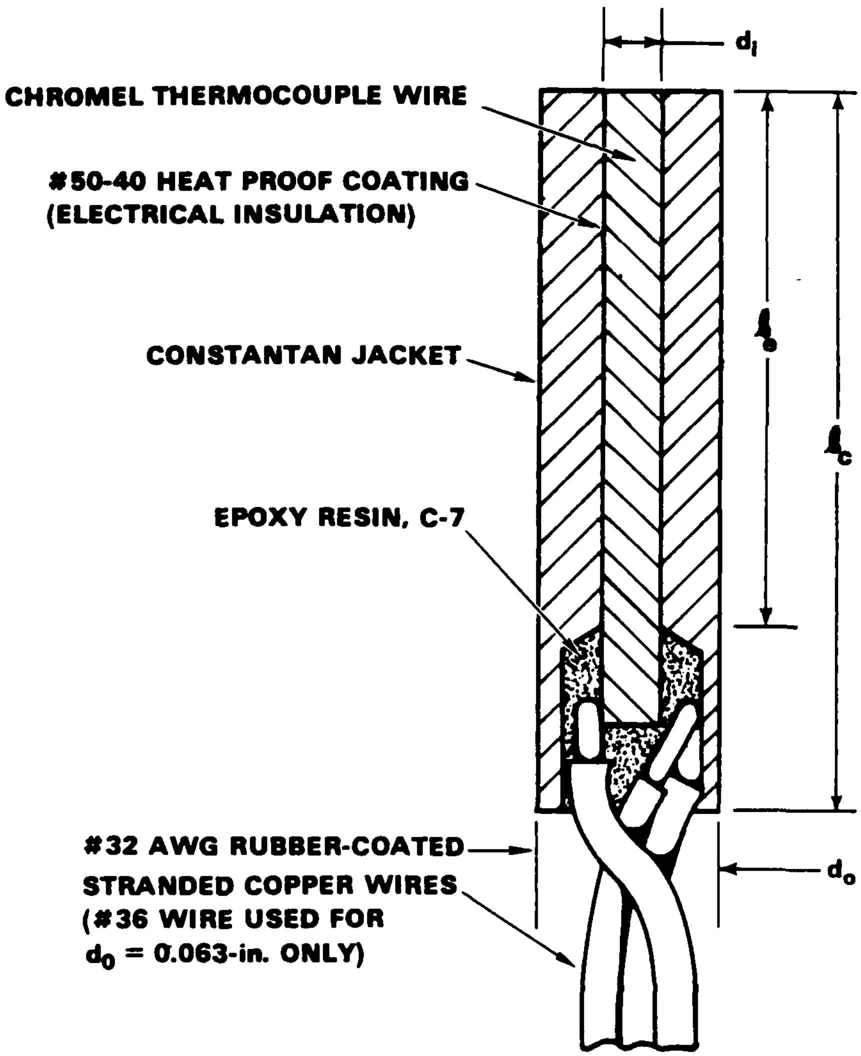


Figure 16. Chromel - Constantan coaxial surface thermocouple.

Experimental calibration of co-axial surface thermocouples is performed in the laboratory by a transient heat flux calibration technique. A known and constant heat flux from an air-acetylene flame or radiant light source is applied to the sensing surface of the co-axial thermocouple for a time period not exceeding the effective test time, and a timewise output data record is obtained. This experimental procedure permits the evaluation of a co-axial thermocouple calibration factor which has been found to agree with the theoretical heat flux sensitivity within ±5 percent when the gage is properly constructed. This experimental procedure is repeated at different heat flux levels. Since the co-axial thermocouple assembly is comprised of thermoelectric grade materials, the unit maintains the inherent excellent calibration stability characteristics of bi-metal thermocouples.

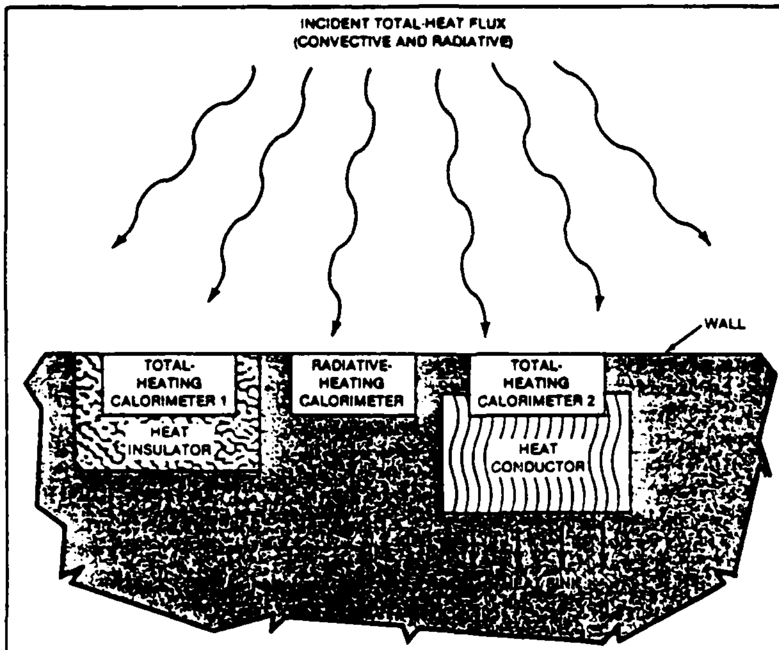
Vent temperature and flow temperature can be inferred from measurement of radiation and convective energy. The device (Reference 3.2) shown in Figure 17 was developed for rocket motor and jet engine exhaust temperature measurement. By keeping the device on a wall component, the intrusive characteristic can be minimized. Similar techniques can measure the thermal output of the TRS by placing an array of sensors at various distances from the radiation source.

Flow enthalpy and flow velocity can be inferred from calorimeter gage measurements on blunt cylinders with the aid of Fay-Riddell analytic solutions (Reference 3.10). Difficulties in obtaining precise flow enthalpy and velocity result from three unknowns: gas composition, flow field pressure distribution, and empirical assumptions contained in the analytic models. For the flow environment of the LB/TS, these are not large unknowns.

Target response to radiation and convective heating during the thermal simulator pulse and diffraction period can be measured by fast-response Gardon gages, RT gages, co-ax gages, or Schmidt-Boelter gages. Requirements for durability and calibration traceability suggest use of co-ax or Schmidt-Boelter gages in lieu of Gardon or R-T gages for the LB/TS application based on experience in similar impulse test facilities.

Table 9. Heat flux sensor requirements.

Requirements	TRS Output	Blast Wave and Flow Measurements	Target Response
Range	5-100 cal/cm² sec	2-10 cal/cm² sec	0-10 cal/cm² sec
Type	Co-ax	Co-ax or Gardon	Thin skin TC Co-ax Schmidt-Boelter
Pressure	0.1 sec	0.001 sec	0.01 sec



HEAT-FLUX EQUATIONS:

$$q_1 = h(T_G - T_{W1}) + q_R$$
$$q_2 = h(T_G - T_{W2}) + q_R$$

WHERE:

q_1, q_2 = HEAT-FLUX MEASUREMENTS FROM TOTAL-HEAT CALORIMETERS

q_R = RADIATIVE HEAT FLUX

T_{W1}, T_{W2} = WALL-SURFACE TEMPERATURES

T_G = GAS TEMPERATURE

THEN:

$$T_G = \frac{(q_1 - q_R)T_{W2} - (q_2 - q_R)T_{W1}}{(q_1 - q_R) - (q_2 - q_R)}$$

Figure 17. Concept developed by Rockwell International for gas temperature measurement. (Reference 3.2)

Table 9 summarizes heat flux sensor requirements for the LB/TS. Sensor durability is the primary problem in field situations and, in the case of the LB/TS environment, will almost certainly dictate sensor selection even at the expense of response and range requirements. The primary operational problems involve gage attachment in the blast environment, electrical lead attachment and survival, and in-place calibration. Gages which minimize in-place calibration requirements--which have highly stable output or sensitivity easily traceable to laboratory calibrations--are to be favored.

An excellent review of methods for obtaining point measurements of heat transfer rate on test articles in high-performance facilities has been written by Trimmer, et al. (Reference 3.11). Thin-skin thermocouple measurements, R-T gages, Gardon gages, and co-ax thermocouple gages are all reviewed with their individual advantages and disadvantages discussed. In addition, non-discrete techniques such as temperature-sensitive coatings are reviewed. Where slow response below values cited in Table 9 can be tolerated (0.5-1.0 sec), a Schmidt-Boelter gage (Reference 3.9) will have strong advantages over co-ax, R-T, or Gardon sensors.

At present, two government-supported labs are developing gages for combustion chamber, aerodynamic, and aircraft propulsion system applications (References 3.4 through 3.8):

Calspan Advanced Technology
Buffalo, NY, and Arnold AFS, TN
14225 and 37389

United Technology Corporation
Power Sector
Commercial Products Division
East Hartford, CT

Commercial sensors are developed and sold by:

Thermogage, Inc.
330 Allegany Street
Frostburg, MD 21532

Medtherm Corporation
Post Office Box 412
Huntsville, AL 35804

Hy-Cal Engineering
9650 Telstar Avenue
El Monte, CA 91731

These firms and laboratories are fully capable of developing specific sensor packages for the LB/TS environment.

The bibliography (Appendix B) contains abstracts of nine recent development efforts in the heat flux measurement area.

3.3 STRUCTURAL STRAIN, DISPLACEMENT, AND ACCELERATION SENSORS.

On-board intrusive devices to measure structural strain, displacement, and acceleration will include strain gage balances, accelerometers, and linear potentiometers. In addition, shear displacement and seismometer devices have also been developed as noted in abstracts included in the bibliography. Sophisticated acceleration-compensated strain-gage balances have been developed for impulse facilities which, when installed in the target, can measure up to six components of force on specific test objects. Balances can be fabricated with semiconductor strain-gage accelerometers to provide compensation for target mass-induced inertial loads in order to separate impulsively applied forces from inertial response of the target. A typical strain-gage balance designed for fast-response and high aerodynamic loads is shown in Figure 18. Numerous government facilities design and build their own aerodynamic balances. One commercial U.S. firm specializes in such equipment and provides both off-the-shelf and individually designed systems:

Able Corporation (Formerly TASK)
1061 N. Shepard Street
Anaheim, CA 92806

On-board single, dual, and tri-axial accelerometers can be obtained from many U.S. manufacturing sources.* Levels of acceleration will be from a few to thousands of g's loading depending on target component, target mass, and LB/TS test condition. The best known manufacturers in terms of development are:

*The **1983-84 ISA Directory** lists 37 manufacturers under the heading, Accelerometers.

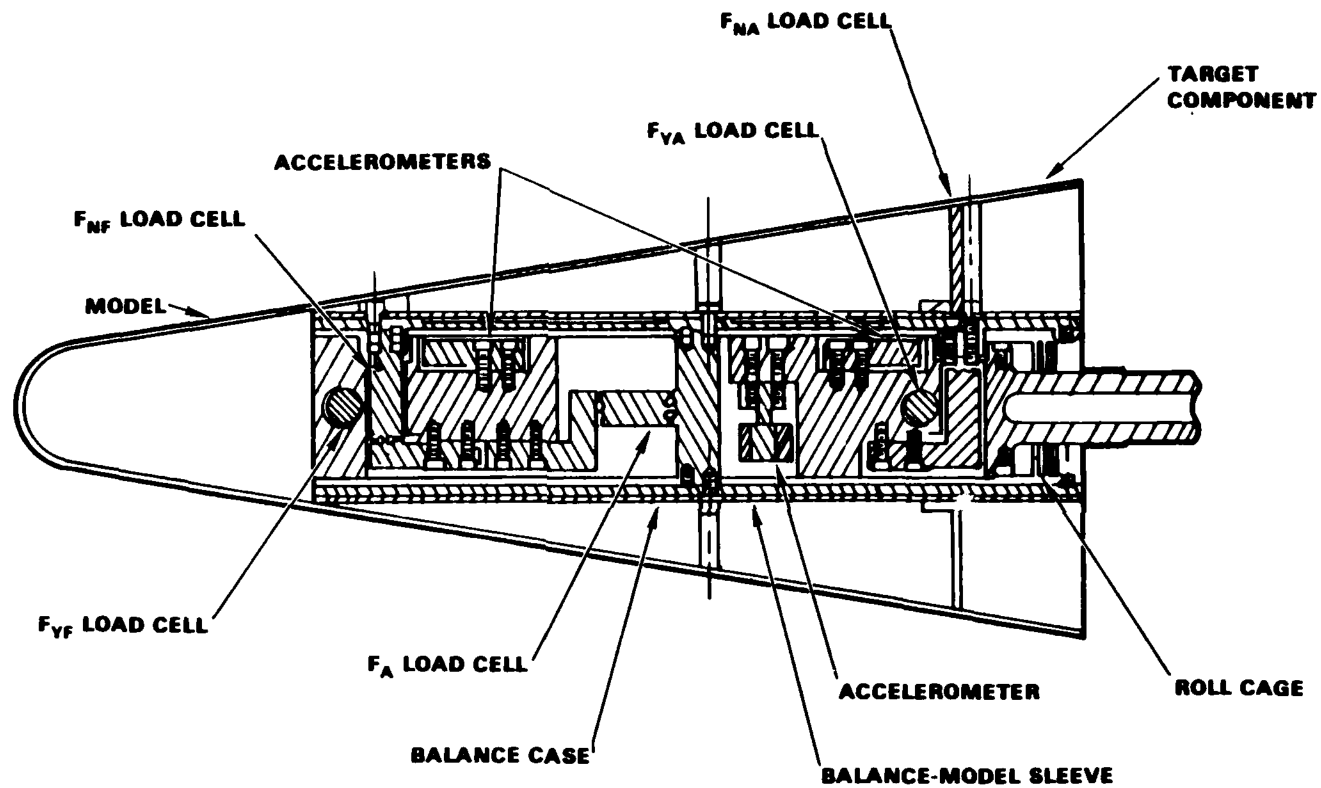


Figure 18. Force balance detail suitable for target response measurement.

Kulite Semiconductor Products, Inc.
1039 Hoyt Avenue
Ridgefield, NJ 07657

Kistler Instrument Corporation
75 John Glen Drive
Amherst, NY 14120

Entran Devices, Inc.
10 Washington Avenue
Fairfield, NJ 07006

PCB Piezotronics, Inc.
3425 Walden Avenue
Depew, NY 14043

Endevco
Rancho Viejo Road
San Juan Capistrano, CA 22675

Linear motion of the target and target components can be measured with on-board potentiometers. These sensors are manufactured by a very large number of U.S. firms and are relatively inexpensive and easy to use. Use of such sensors in the LB/TS will be occasionally complicated under blast loadings due to changing frequency response resulting from attaching the sensor to low-mass target components and maintaining the integrity of the attachment once high acceleration target motion is initiated by the blast. These effects can be alleviated by attachment of low-mass rotary potentiometers to the target component using stiff but lightweight wires.

Table 10 summarizes on-board displacement, strain, and acceleration sensor specifications and requirements for monitoring target mechanical response.

3.4 INERTIAL REFERENCE UNIT.

One technique for measuring angular and linear displacement is by use of an Inertial Reference Unit. This is a device developed originally for aircraft and rockets for purposes of navigation and guidance but more recently applied to land vehicles. The Inertial Reference Unit is the heart of modern Inertial Navigation Systems.

The unit consists of three angular rate sensors and three linear accelerometers, with supporting electronic circuitry. In early units, the angular rate sensors were mechanical gyros and measured angular

Table 10. Strain, displacement, and acceleration sensor requirements.

	Target Response	Facility Measurements
Range	5 - 1500 g's acceleration; Strains and forces dependent on target; 0.03 to 25 cm displacement	0-25 cm valve position movement
Types	Accelerometers Force Balances Strain Gages Potentiometers (linear and rotary)	Potentiometers
Response	as low as 0.0001 sec. desired	0.1 sec.

acceleration using a rotating mass and gimbals. Modern units are called "strapdown" units, indicating that the mechanical gimbals have been eliminated and replaced by an electronic technique, some units even using a laser beam technique. All units are small, modular and easily mounted in the target vehicle (see Appendix A for selected manufacturer brochure information).

Several companies can supply Inertial Reference Units, and units built by Northrup Precision Products Division, Litton Guidance and Control Division, Humphrey, Inc., and Honeywell Military Avionics Division were investigated. No conclusions were reached as to which company produces the most appropriate and cost-effective unit for this application, requiring considerably more detailed study to do so. The Litton unit is currently priced at about $35,000; prices of other units are estimated to be comparable.

The Northrop Tactical Inertial Reference Unit, no model number presently assigned, appears to have the most desirable specifications for this application. Northrop Document Number PPD-E-80-10509 provides a detailed description of this unit and its specifications (see Appendix A). This unit is in volume production and is believed to be the lowest cost unit on the market.

Principal specifications are as follows:

Acceleration range: ±40g (3-direction)
Angular rate range: ±500 degrees/sec. (3-axis)
Position Accuracy: See Note 1.
Size: 16.13 cm dia. x 7.44 cm (6.35 in. dia. x 2.92 in.)
Weight: 1.6 Kg
Power Consumption: Approximately 50 Watts @ various DC voltages

Note 1: Position accuracy is dependent upon the rate at which the unit is moved, accuracy improving as rate of movement increases. At the rates anticipated in this application, position accuracy is estimated to be ±0.5% or better, equating to about one centimeter for whole-body motions of one mete-

Company and model number information for commercial inertial reference units are:

Honeywell, Inc.
Military Avionics Division
13350 U.S. Highway 19
Clearwater, FL 33546
813-531-4611
Model H-478F

Humphrey, Inc.
9212 Balboa Avenue
San Diego, CA 92123
619-565-6631
Model CF32-0201-1

Litton Guidance & Control Systems
5500 Conoga Avenue
Woodland Hills, CA 91365
818-715-3530
Model LLN-83

Northrup Corporation
Precision Products Division
100 Morse Street
Norwood, MA 02062
617-762-5300
Tactical Inertial Reference Unit

3.5 MICROWAVE TRACKING SYSTEM.

Position of the target vehicle can also be tracked and determined by use of two or three Microwave Tracking Systems. Datron Systems, Inc., of Chatsworth, CA, builds a Model 8000 X-band Microwave Tracker. A two-unit system would cost approximately $500,000, a three-unit system approximately $650,000. The best accuracy would be achieved with a three-unit tracking system and use of the outputs of the two units at the largest azimuth angles. The three units could be operated at different frequencies to prevent unit-to-unit interference in the close environment of the LB/TS. An X-band beacon (transponder), costing approximately $500, would have to be installed in the target vehicle.

Preliminary discussions with Datron did not indicate any means of significantly reducing the system cost for the LB/TS environment. Hence, accuracy, time response, and other details of the application of the system were not pursued.

3.6 SUMMARY OF PHYSICAL/INTRUSIVE SENSORS AND BUDGET COST ESTIMATE.

An inventory of sensors for use in the LB/TS will range from relatively inexpensive thermocouples ($50 per sensor) to expensive pressure transducers and heat flux devices costing as much as $1,000 per sensor. Although not a significant portion of the facility capital cost, sensor inventory cost will not be small. Table 11 summarizes the preceding intrusive sensor review and adds an approximate budget estimate for the minimum number of channels identified in Table 4 along with a reasonable number of spare sensors for each channel. Brief descriptions of the application, minimum number of channels, total number of each type that may be required, basic specifications, sensor availability, and a budget cost estimate are included in the table.

A range of 64 high-performance pressure sensors based both on the piezoelectric and strain gage concepts will provide a sufficient inventory to accomplish facility control, blast wave, and target response measurements as shown in the first column of the table. Pressure range will vary widely and will include flush-mounted as well as remote installation of sensors. Total budget cost for pressure sensors will be on the order of $38,000 which includes manufacture of a few stagnation and differential pressure probes.

A family of discrete temperature sensors will be required to make a wide variety of measurements in the LB/TS facility. It is estimated that an inventory of thermocouple and similar devices costing $14,000 will be required covering the temperature range up to 2000°K.

No specific type of heat flux sensor (coax, Gardon, etc.) is identified in Table 11 since these sensors will be selected to meet specific LB/TS measurements. However, an approximate number of sensors by heat flux range is listed. A total of 31 sensors at a cost of approximately $33,000, with allowance for mounting several on reference plates or probes, should be adequate to obtain the necessary measurements.

Accelerometers and strain gages are also included in the fourth column of Table 11, with a total sensor cost of $19,000. On-board potentiometers to measure small deflections are not expensive sensors; a variety of devices covering very small to large deflections should be in the facility inventory at an approximate total cost of $4,000.

An inertial reference measurement system, including three pre-packaged units would cost about $100,000.

The total cost of the physical sensor inventory could range up to $200,000 to $300,000, depending on the specific options taken.

TYPE OF SENSOR	PRESSURE SENSORS: PIEZOELECTRIC, METAL DIAPHRAGM AND SILICON DIAPHRAGM GAGES	TEMPERA[illegible] SENSO[illegible]: [illegible] THERMOCOUPLES
APPLICATIONS	FACILITY CONTROL, BLAST WAVE AND FLOW, TARGET RESPONSE MEASUREMENTS	FACILITY CO[illegible] BLAST WAVE [illegible]W, TARGET RES[illegible] MEASUREMENTS
TOTAL NUMBER OF SENSORS REQUIRED INCLUDING SPARES FOR INVENTORY	PIEZO OR SILICON DIAPHRAGM / METAL DIAPHRAGM / OTHER / RANGE: -- / 8 / -- / 25,000 kPa 10 / 20 / 3 / 300 kPa 15 / 5 / 3 / 100 kPa 25 / 33 / 6 / TOTALS	RTD'S / THIN FILM / TC / RANGE: 30 / [illegible] / [illegible] / [illegible] K -- / [illegible] / [illegible] / 1000 K -- / / [illegible] / 2000 K 30 / 20 / 90 / TOTALS
MINIMUM NUMBER OF CHANNELS REQUIRED	15 FACILITY CONTROL 21 BLAST WAVE AND FLOW 10 TARGET RESPONSE 46	23 FACILITY CONTROL 6 BLAST WAVE AND FLOW 10 TRS 18 TARGET RESPONSE 57
SPECIFICATIONS	SEE APPENDIX A AND TABLE 3-1	SEE TABLE 3-2, FIGURE 3-[illegible], AND TABLE 3-3
AVAILABILITY	MANUFACTURED BY MANY U. S. FIRMS	MANUFACTURED BY MANY U. S. FIRMS
[illegible] COST ESTIMATE	25 $900 33 400 } $38,100 6 400 64 TOTAL REQUIRED	140 51[illegible] } [illegible]

①

Table 11. Intrusive sensor summary.

[illegible]RATURE [illegible]NSORS: RTD'S, THIN FILM, THERMOCOUPLES	HEAT FLUX SENSORS: COAX, GARDON, RT'S, THIN FILM, SCHMIDT-BOELTER	STRAIN GAGES AND ACCELEROMETERS	[illegible]
[illegible]TY CONTRO[illegible] [illegible] WAVE AND FLOW [illegible] RESPONSE MEASUREMENTS	BLAST WAVE AND FLOW, TRS OUTPUT TARGET RESPONSE	TARGET RESPONSE	
[illegible] / THIN FILM / TC / RANGE: 20 / 20 / 5[illegible]0 K — / 30 / 1000 K — / 40 / 2[illegible]0 K TOTALS: 20 / 90	TRS / FLOW / TARGET / RANGE (cal/cm^2 sec): — / 3 / 10 / 0-10 5 / 3 / 5 / 0-30 5 / — / — / 0-80 TOTALS: 10 / 6 / 15	STRAIN GAGES / ACCELEROMETERS: 50 / — — / 3 / 10[illegible] — / 10 / 100[illegible] — / 5 / 2[illegible] TOTAL: 52 / 18	BOTH / FACI[illegible] 1[illegible] 1[illegible]
[illegible] FACILITY CONTROL [illegible] BLAST WAVE AND FLOW [illegible] TRS [illegible] TARGET RESPONSE [illegible]57	5 TRS OUTPUT 3 FLOW 10 TARGET 18	10 STRAIN GAGES 10 ACCELEROMETERS 21	
[illegible]	SEE APPENDIX A AND TABLE 3-4	SEE APPENDIX A AND TABLE 3-5	
MANUFACTURED BY MANY [illegible]	LIMITED TO 3 U.S. FIRMS	MANUFACTURED BY MANY U.S. FIRMS	[illegible]
[illegible] $[illegible]4 0[illegible]	10 @ $8[illegible]0 21 @ 1200 — $[illegible]000	10 STRAIN GAGES @ $100 18 ACCELEROMETERS @ $[illegible]00 — $[illegible]	

2

OELTER	STRAIN GAGES AND ACCELEROMETERS	POTENTIOMETERS { LINEAR / ROTARY
	TARGET RESPONSE	FACILITY CONTROL TARGET RESPONSE
ANGE [illegible] cm [illegible]-10 [illegible] [illegible]-30 OTALS	STRAIN GAGES: 50 — ACCELEROMETERS: —, 3, 10, 5 — (range): —, 10g, 100g, 2000g 52 / 18 / TOTAL	POTENTIOMETERS (FACILITY / TARGET) — RANGE: — / 5 — 1 cm 15 / 5 — 10 cm 15 / — — 30 cm 30 / 10 / TOTAL
	10 STRAIN GAGES 10 ACCELEROMETERS 21	18 FACILITY 5 TARGET 23
	SEE APPENDIX A AND TABLE 3-5	SEE TABLE 3-5
	MANUFACTURED BY MANY U.S. FIRMS	MANUFACTURED BY MANY U.S. FIRMS
[illegible]	50 STRAIN GAGES $100 18 ACCELEROMETERS $800 } $19,000	40 × $100 } $4000

3

SECTION 4

SURVEY OF OPTICAL/NON-INTRUSIVE SENSORS

4.1 GENERAL.

Eleven separate optical/non-intrusive sensor systems have been selected for evaluation for use in the LB/TS. These systems are listed in Table 2. Two primary applications of these sensor systems are envisioned:

- Target measurements such as surface temperature at specific points on the target, surface temperature distribution on the target, and structural deformation and displacement of the target--These measurement requirements can be met by the IR, x-ray, high-speed camera, Moire, and optical follower systems listed in Table 2.
- Flow and TRS measurements such as flow velocity, flow density, and TRS source temperature--These requirements can be met with optical pyrometers, a CVF spectrometer, an LDV, and a shadowgraph.

The characteristics of each sensor--field of view, time response, parameter resolution--were selected to be consistent with practical limitations of each device (see Table 2) considering the LB/TS environment. In selection of the optical systems, it is recognized that the intense radiant energy output of the TRS will:

- negate use of all but carefully selected sensors during the period of TRS burn
- require selection of substantially different IR devices for TRS and target measurements
- necessitate evaluation of saturation recovery times for target sensors and application of high-speed shuttering if recovery periods are too long
- prevent acquisition of photographic or IR data on the target during the TRS burn unless special filters are used and views are selected which are not obscured by the optically thick TRS aluminum oxide dust

The eleven systems will be discussed in the subsequent subsections.

4.2 INFRARED SYSTEMS.

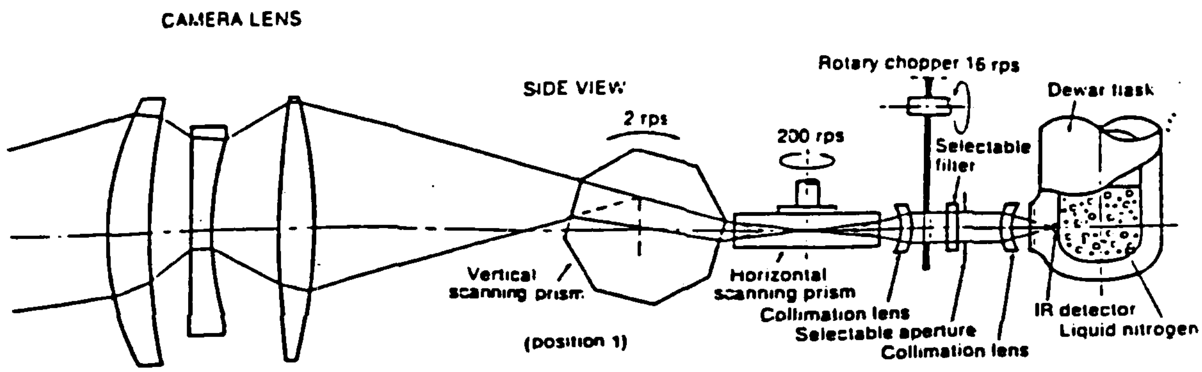
Several infrared instruments were evaluated as a means of measuring spatial and temporal temperature distribution of the test article as well as radiant output of the TRS.

During facility checkout, the TRS can be characterized using a Circular Variable Filter (CVF) radiometer, and a thermovision system (IR imaging camera). These instruments will yield the spectral signature and temperature profile, respectively.

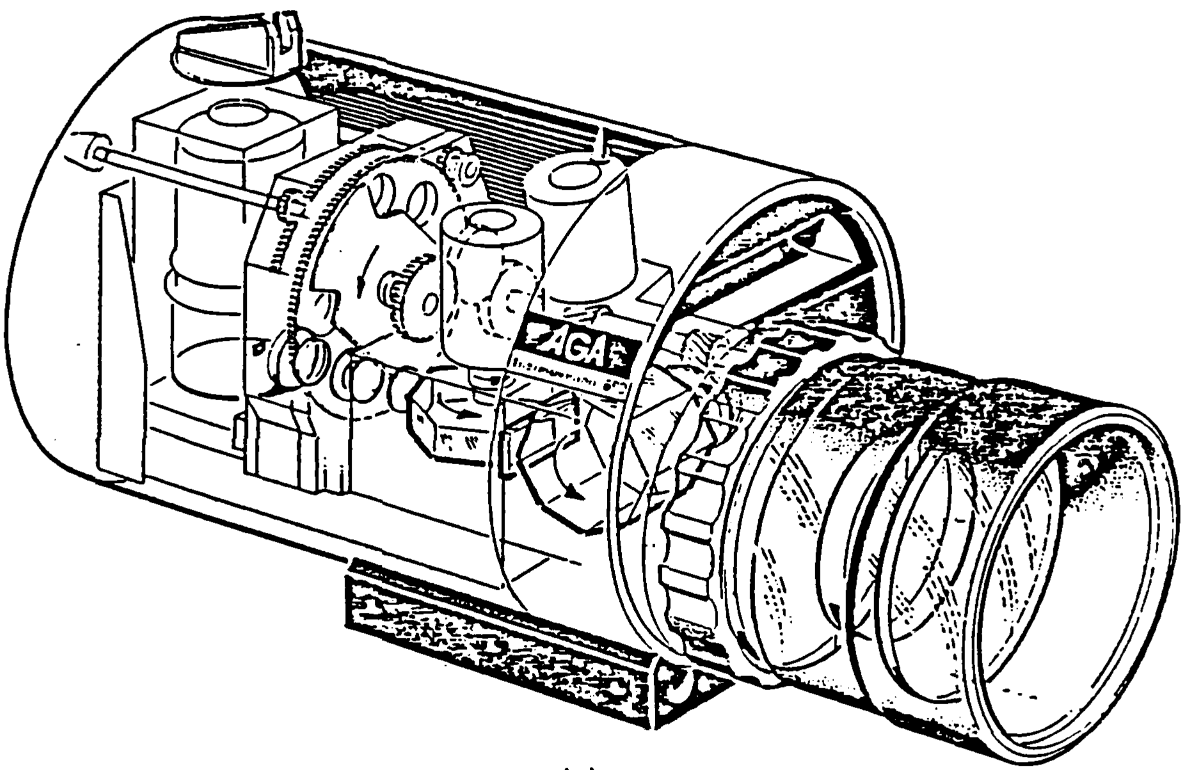
During testing periods of the LB/TS facility, the TRS performance will be monitored using optical pyrometers while the surface temperature of the target will be measured using optical pyrometers and a thermovision system. The CVF radiometer is not required for routine testing in the LB/TS because of its slow response and represents a reference device used only on special occasions

4.2.1 Thermovision System.

For determining the temperature profile of the TRS during facility checkout and for monitoring surface temperature variations of the target during testing, an IR imaging camera system will be used. A Thermovision® 680 manufactured by AGA of Sweden is the candidate system for this task [see Figure 19 (a) and (b)]. The system has a temperature measuring range from 240 to 1150°K which can be extended to 2300°K by installing a grey or neutral density filter into the optics system. The temperature range of this instrument can be further increased to 5000°K with additional filtering, but calibration tends to become difficult. Figure 20 shows an AGA 680 camera with a remote display unit. This remote display unit will be replaced by a 16-bit microcomputer incorporating an 8-channel A/D converter which would yield not only visual output but also any temperature profiles requested. Again referring to Figure 19, the receiving optics view the target--scanning is accomplished by a vertical and horizontal prism--passed through a chopper, detector optics, selectable filters and apertures, and focused upon the photovoltaic detector cell. This unit and method of data collection is typical of those used in medical and research facilities.



(a)



(b)

Figure 19. Thermovision camera and scanning optics configuration.

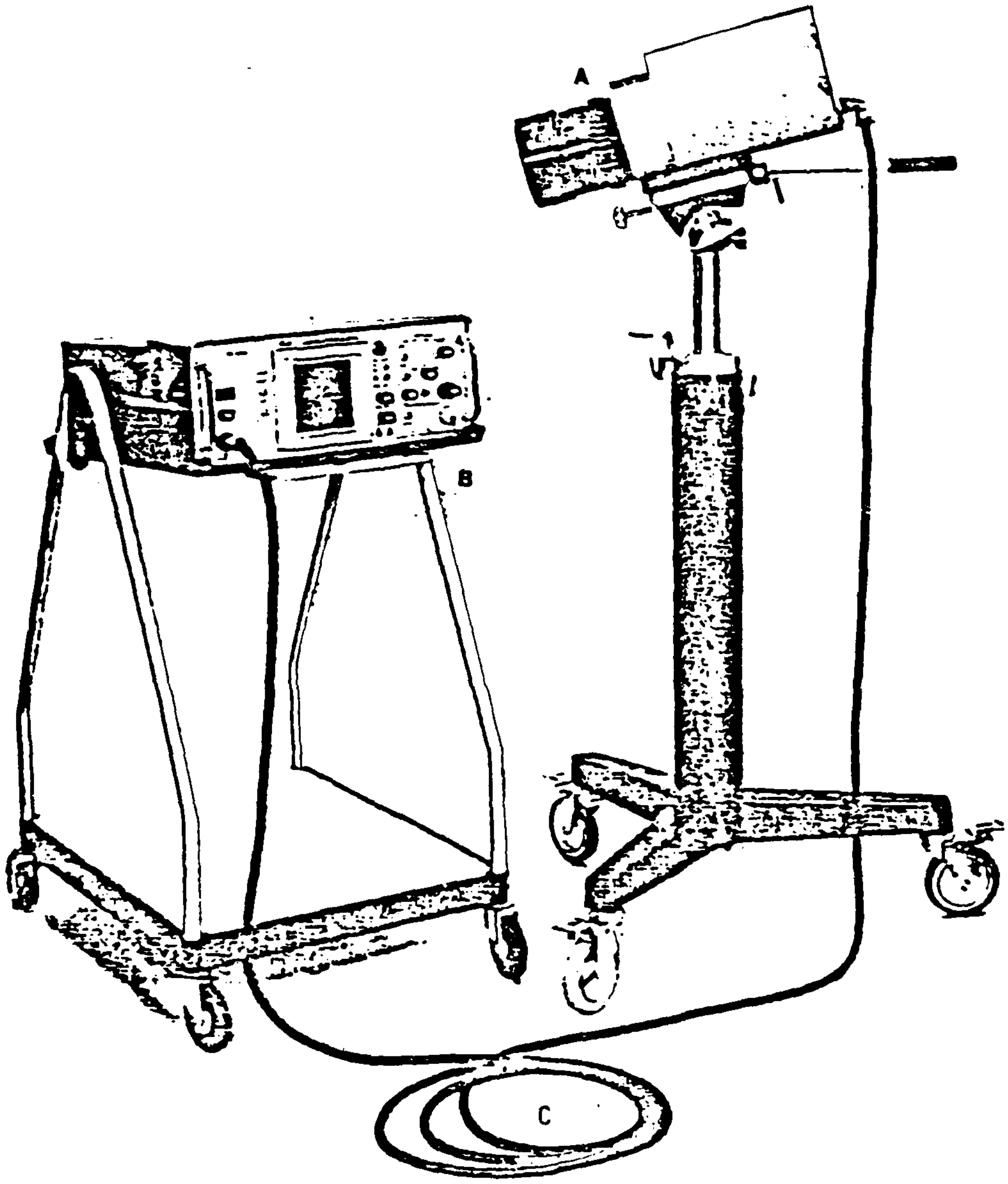


Figure 20. Thermovision system.

A. Thermovision Camera
B. Remote Display Unit
C. Interconnecting Cable

Thermovision® 680 specifications

Field of View	8° to 45°
Range of Focus	0.3m to ∞
Scan Rate	30 frames/sec
Picture Resolution	210 raster lines/frame
Aperture	seven selectable
IR Filters	eight selectable
Measurement Range	240 to 2300°K depending on aperture/filter combination. Ranges will have approximately 20% overlap.
Minimum detectable temperature Δ	0.5° at 300°K
Detector	Indium antimonide (InSb) photovoltaic cells. Liquid nitrogen cooled to 67°K.

System Cost

Thermovision® 680	$ 35,000
Required Filters and Apetures	15,000
Data Acquisition and Reduction System	30,000
Software Development	10,000
System Installation and checkout	15,000
Total	$105,000

This system has a maximum scan rate of 30 scans/sec. which is too slow to sense changes occurring during the diffraction period but is sufficient for the drag period. Also, some mating of imaging system to the data acquisition system with corresponding software development is needed if more than a visual display is required. The AGA 680 as shown in Figure 19 will only scan at 16 frames/sec. since the remote display unit cannot be updated at a faster rate. Therefore, an A/D converter in conjunction with a data acquisition system must be utilized to achieve a scan rate of 30 frames/sec.

All IR imagining camera systems are one-color systems, i.e., they view one selected narrow bandpass filter at a time; therefore, they will be affected if the emissivity of the target surface or the TRS flame changes during the measurement period. Development of a two-color IR imaging camera system is presently in progress. Prototype systems are expected to be operational in 1985.

4.2.2 Optical Pyrometers.

Optical pryometers were evaluated to monitor the surface temperature of the target in several selected points (areas) and to monitor TRS performance. Both single- and two-color pyrometers were evaluated and the possibility of using fiber optic cables to view inaccessible surfaces in conjunction with these pyrometers was also investigated. Figure 21 shows a line drawing of both a single- and two-color pyrometer.

Target Surface Measurements

The purpose of these measurements is to record the temperature of the target surface during the diffraction and drag phases. Survey of available systems reveals that there is no instrumentation available with a response time rapid enough to record data during the diffraction period.

Single-color pyrometers have a sufficiently low measurement range but will be severely affected by emissivity changes at the target surface.

Dual-color radiometers are relatively insensitive to emissivity changes but have a lower temperature limit which is above the normal temperature range of the target surface.

Therefore, the system proposed to make target surface measurements is a modified Series 8100 instrument manufactured by Williamson of Concord, MA. This series will be designated the 4200 series and is a **two-color optical pyrometer with a temperature range significantly lower** than other two-color pyrometers. This unit will be available in mid-1984 The unit will also be interfaced to the high-speed data acquisition system in order to obtain data at a rate significantly above that of the commercial unit which uses a slow real-time display.

Fiber optic transmission cables can be used for viewing surfaces at elevated temperatures, but at the anticipated surface temperature ranges, transmission losses will probably attenuate the signal sufficiently to render the system unusable, i.e., the system will not function below 450°K.

System Specifications

Temperature ranges	320° to 700°K, 500 to 1100°K
Spectral lines	0.71 and 1.0 ±0.02
Accuracy	1% of full scale
Repeatability	0.5% of full scale
Detector	silicon pyroelectric
Response time	0.5 sec (this can be modified to 10 msec)
Field of view	must be modified to suit application

System Cost (on a per-unit basis)

Series 4200	$3,500
Response time modification	250
FOV modification	250
Installation and checkout	1,000
Total	$5,000

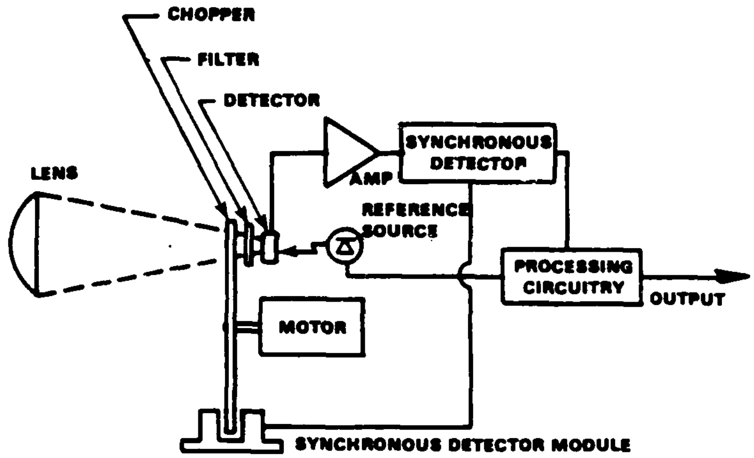
Note that as the temperature range of interest is from ambient to 1000°K, two of these units will have to simultaneously monitor the same area. Therefore, to monitor five discrete areas of the target, the instrumentation costs would be $50,000.

TRS Performance Monitoring Measurements

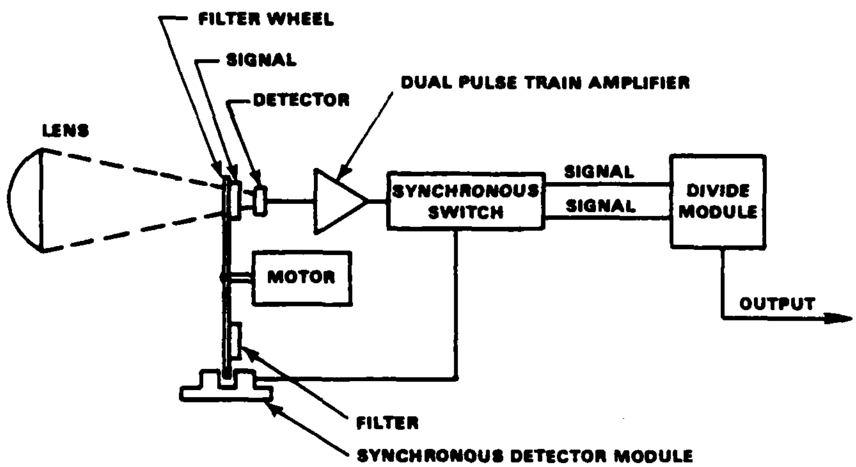
A two-color optical radiometer will be used to monitor the temperature of each TRS during operation so that output for a particular test will be known as well as provide a test to test comparison of the TRS temperature. The two-color radiometer is filtered to view two specific wavelengths 0.71 ±0.02 and 1.05 ±0.02 micrometers and then computes the ratio of radiant energies at those two wavelengths. This ratio is a function of temperature only, so that the temperature is easily calculated once this ratio has been measured. A Modline Series R Model #R-35C10-4 two-color pyrometer manufactured by Incon, Inc., of Skokie, Illinois, could be used to perform this task. Figure 22 shows a block diagram and line drawing of a typical unit. This Modline series of instruments is the most extensively used in the manufacturing industry for making non-contact temperature measurements.

Instrument Specifications

Spectral Response	Two adjacent bands with narrow band centered at 1.05 micrometers
Single Reduction Range	Above 800°C will tolerate a 95% signal loss before activating an invalid data alarm
Ambient Temperature Range:	30 to 130°F
Calibration Accuracy:	1% of Full Scale
Repeatability:	0.3% of Full Scale

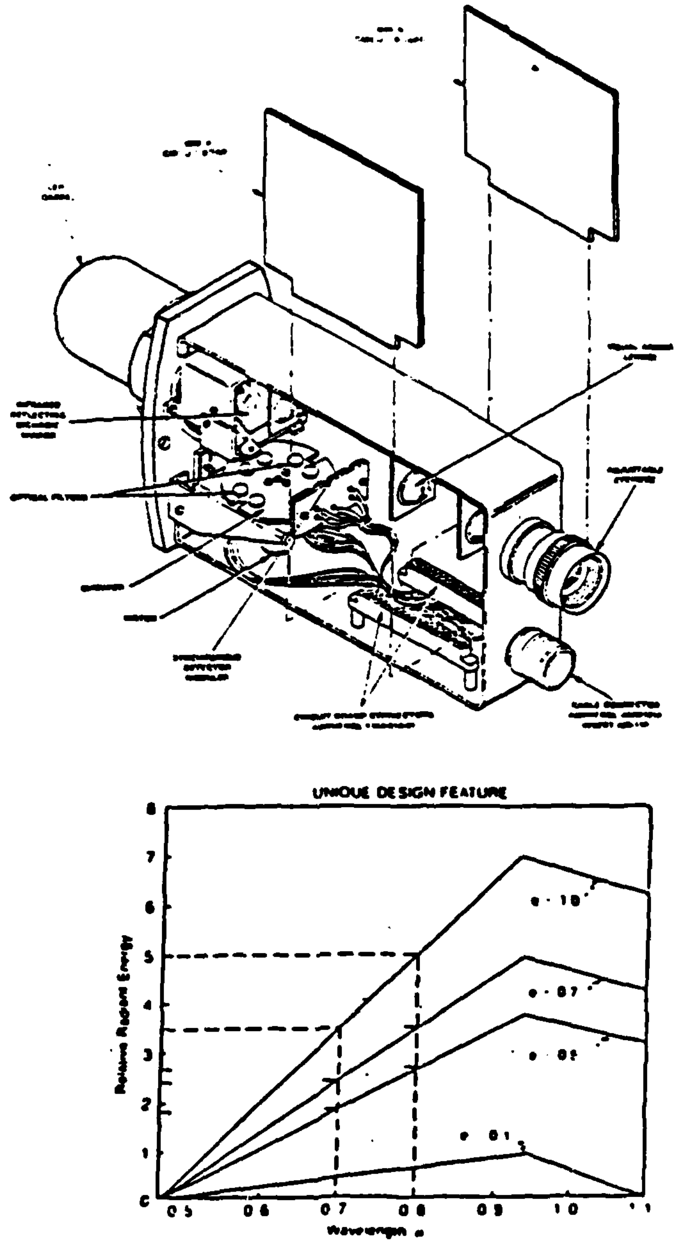


COMPONENTS OF A TYPICAL SINGLE
NARROW-BAND-FILTERED RADIOMETER



COMPONENTS OF A TYPICAL
DUAL-WAVELENGTH SYSTEM

Figure 21. Single- and two-color pyrometer.



RATIO FACTOR AS A FUNCTION OF EMISSIVITY

At E = 1: $\frac{5.0}{3.5}$ = 1.429 At E = 0.5: $\frac{0.65}{0.45}$ = 1.429

At E = 0.7: $\frac{3.5}{2.45}$ = 1.429 At E = 0.1: $\frac{0.25}{0.175}$ = 1.429

The dual-wavelength system automatically eliminates measurement errors by computing the ratio of the radiant energies emitted by the target in two adjacent wavebands, i.e. 0.7 and 0.8 micron.

Figure 22. Wavelength (two-color) radiometer.

Response Time:	0.01 seconds
Standard View at 10 Meters	4"
Analog Output	0 to 100 MV D.C.
Temperature Range	1800 to 3700°K

System Cost (Per Unit Basis)

Series R	$ 3,900
High-Response Option	100
FOV Modification*	500
Installation and checkout	1,000
	$ [illegible],500
System Cost for 5 Units	$27,500

It should be noted that for a two-color system to work with respect to viewing a plume, the plume must be optically thick.

4.2.3 Circular Variable Filter Radiometer

A CVF radiometer will be used during facility checkout to determine the spectral signature of the TRS by spectrally scanning of one of the plumes for several seconds. A CVF is a radiometer which uses a 4"-diameter rotating filter wheel which allows the unit to scan the IR spectrum from 0.7 to 7.8 micrometers. The unit has a narrow field of view of 1.0° but can be modified to operate with a 20° FOV. The device can also function as a total radiometer/spectrometer.

A complete scan can be accomplished in one second. A Barnes Engineering Company Model 12-550 Mark II Research Radiometer will be used to accomplish this task. Figure 23 is a line drawing of the components of a CVF radiometer. On the following page are listed the Mark II specifications.

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*The field of view could be modified to give a rectangular FOV covering a greater portion of the plume in order to account for gradients within the TRS plume. A ½-by-2-meter area is selected.

Field of View	1°, with 20° FOV optional
Scan Time	1 second (this requires a single-stage buffer)
Spectral Response	0.7 to 8.0 micrometers can be expanded to 0.4 to 14.5 micrometers
Detector	Indium antimonide (InSb) liquid nitrogen cooled to 67°K
Chopper	High-speed - 11,000 Hz with 250 Hz bandwidth
Output	Dual Direction IEEE 488

Automatic gain controls will be incorporated for remote operation.

System Costs:

Model 12-550 - Mark II	$28,500
Single-stage buffer	3,000
20° FOV option	8,500
Detector/preamp/cooling kit	8,400
CVF module includes filters	10,800
Calibration of filter module	2,800
CVF housing and encoder	5,200
Motor Drive Unit	5,400
Dual Direction IEEE 488 output bus	9,600
Automatic gain controls	2,400
Installation and checkout	15,000
Total	$99,600

The output of this system can be fed to the facility data system or can be handled on an Apple 2E microcomputer with minimum software required.

This instrument should be used to characterize the TRS initially but is not expected to be needed during actual running periods. The one-second scan time is sufficient if the TRS is run for a period of approximately five seconds.

4.3 X-RAY SYSTEMS.

X-raying as a method of determining the deformation and motion of rigid structures within the outer skin of the target vehicle was evaluated. Two types of x-ray systems were studied. One is a pulsed or

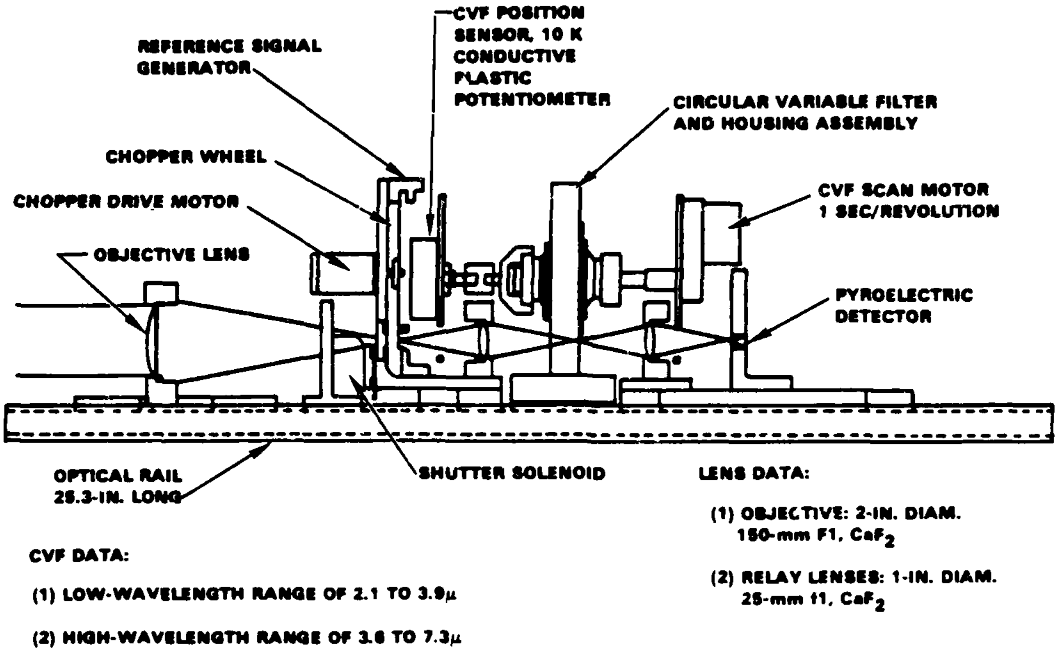

Figure 23. Circular variable filter radiometer components.

flash x-ray system in which individual radiographs are exposed sequentially by means of a rapid film changer. The other system is a videographic system wher ' the response of a fluorescent screen to a continuous x-ray sourc is photographed using a high-speed video camera and video tape system.

4.3.1 Pulsed X-Ray System.

A flash x-ray system can be utilized to determine the motion of rigid structures within the outer skin of the target vehicle. Displacement of internal parts can be measured with a resolution of 0.05 inches.

The flash x-ray system consists or x-ray tube head with associated pulsar (capacitor bank), power supply, and controllers along with a compatible film changer. Radiographs can be acquired at the rate of 6 to 8 per second depending on the type of film changer employed.

A flash x-ray installation is shown in Figure 4.6 with the x-ray source at the top of the test chamber and the film changer installed in a chamber below the target. This arrangement is necessary to minimize object-to-film distance (OTFD) since resolution is inversely proportional to OTFD. A Hewlet Packard 1.0 or 2.3 MeV flash x-ray system will be employed depending on the amount of penetration needed. If the test article can be configured so that penetration of major structural members is not required then a less powerful system such as a 450 KeV system could be utilized. Listed below is a summary of penetration capabilities of these systems for steel.

Film-to-Source Distance (FTSD)	.45 MeV	1 MeV	2.3 MeV
5 feet	1.0"	2.0"	3.7"
10 feet	.5"	1.25"	2.7"

These are the industry standards for x-ray units and hav: commercial controls and operating systems. The difference between the two systems lies in the size of the power supply and pulsar (the capacitor bank). Figure 24(a) shows the required installation and it should be noted that freon (gaseous) and high-purity air supplies are needed to act as dielectrics in the pulsar assembly.

There are three film changers available which can handle 12"x10" to 14"x17" sheets of film. The one needed in this application is the Franklin film changer which accommodates 12"-wide roll film. The proper film/screen combination can also be accommodated by the Franklin without modification. The Franklin film changer is a standard piece of equipment in the medical field and can change film at the rate of six frames per second, a rate which is marginal for LB/TS use.

Costs

HP 0.45 MeV System	$130,000
HP 1 MeV System	200,000
Franklin Film Changer	75,000
Installation	30,000
Checkout	10,000
Total System Cost (1.0 MeV)	$315,000
(1.0 MeV)	$245,000

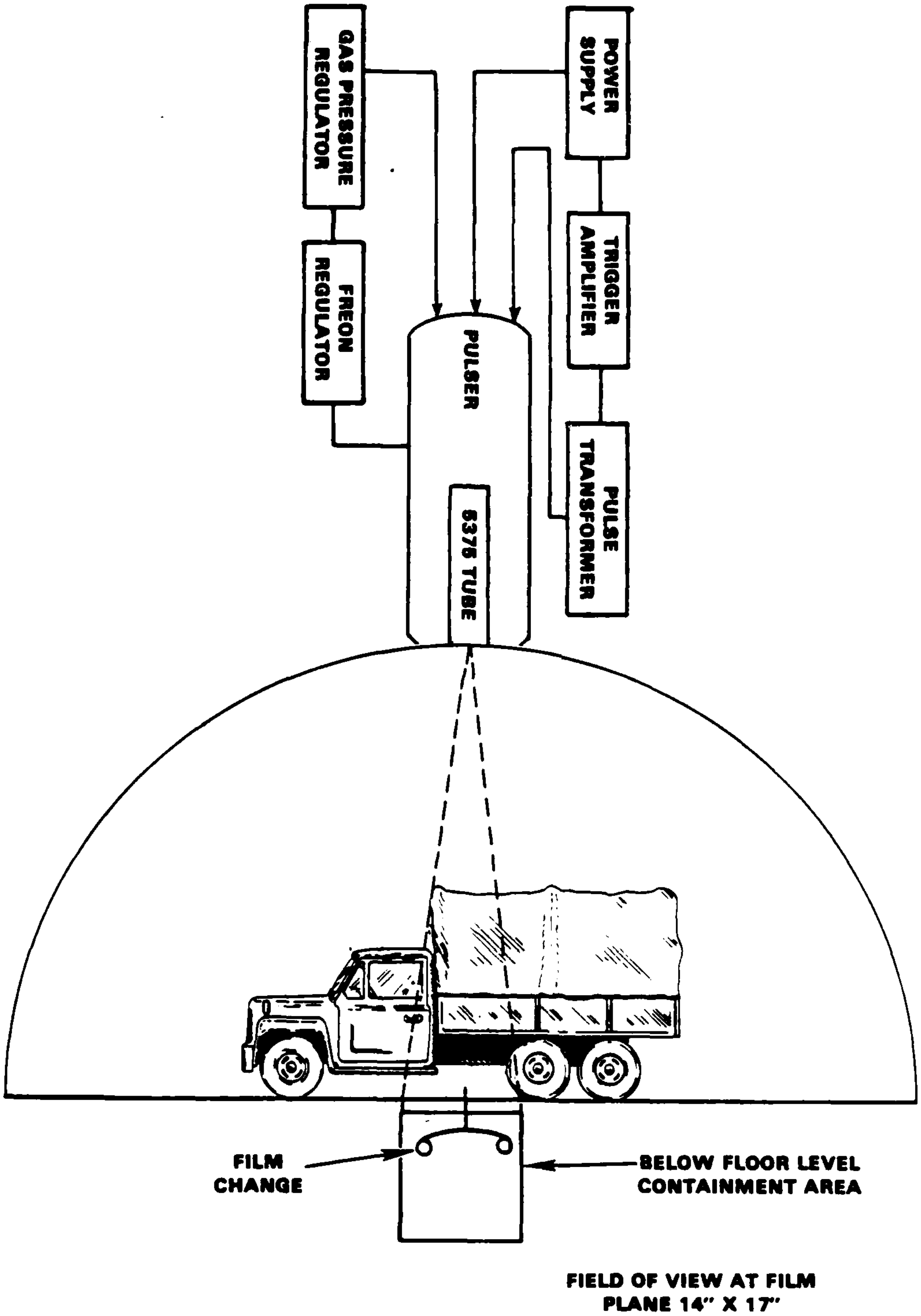

Figure 24(a). Flash x-ray installation.

It should be noted that x-ray systems of the energy level required for the LB/TS pose a severe hazard to personnel without proper safeguards. The radiation output per pulse is 2 rads where the allowable limit per personnel is 2 millirads/hr. Any photographic film used in the LB/TS facility will also have to be shielded or fogging will occur.

The addition of small lead targets inside the target vehicle will not decrease the penetration power required, but will greatly enhance the contrast of the radiographs obtained when the device is used to precisely track motion of internal elements of the target structure over limited distances.

4.3.2 Fluorescopic Real-Time X-Ray.

A real-time continuous output radiography system can also be utilized to detect structural movement within the target vehicle. This system would emit a continuous source of x-rays which would penetrate the area of interest and illuminate a fluorescent screen which has a rapid decay time. This screen is imaged on a mirror and photographed using a high-speed video system. This system would consist of a *Varian Linatron Model 3000 continuous x-ray source and an Industrial* Research Technology (IRT) IRIS-100 Real-Time Digital Radiography System. Again, if the test article can be configured so that the penetration requirements can be relaxed, then a Linatron Model 1000 source can be used. Figure 24(b) shows a block diagram of the system in the test facility and Figure 24(c) shows the components within the IRT IRIS system.

Linatron 3000 System Specifications

Beam Energy	5.5 MeV
X-Ray Output (Rads/min. @ 1 meter)	1000
Source Focal Spot	2mm
Penetration (for steel)	1 inch
Power Requirements	3 phase, 208 volts
Cooling Water Flow	4 gals/min. @ 50 PSIG @ 50°F

IRT IR'S System Specifications

Framing Rate*	120 frames/sec.
Video Output	512x512 pixels (1024x1024 available)
Resolution	.03"

The IRT IRIS system has complete data acquisition and data reduction capability, and the system is delivered as a unit.

Linatron 1000 Cost:

Linatron Model 1000	$320,000
Spare Parts Package	15,000
Water Circulation System With Chiller	18,000
Installation and Checkout	35,000

IRT IRIS System Cost:

IRIS-100 system	$210,000
Installation of Camera Box	15,000
Installation of Control Console	10,000
System Checkout	5,000
Integrated System Checkout	10,000
Total System Cost	$638,000

If the Model 3000 Linatron is required, system cost would increase by $122,000.

Figure 24(a) shows the camera box mounted below the target since the object-to-film distance (OTFD) should be minimized to maximize system resolution. Contrast can be enhanced by using lead sheeting or lead elements attached to the internal structures of interest. This will also add flexibility to setting the intensity level of the fluorescent screen, which is proportional to the flux density bombarding the screen.

*This is the maximum rate for the IRT system.

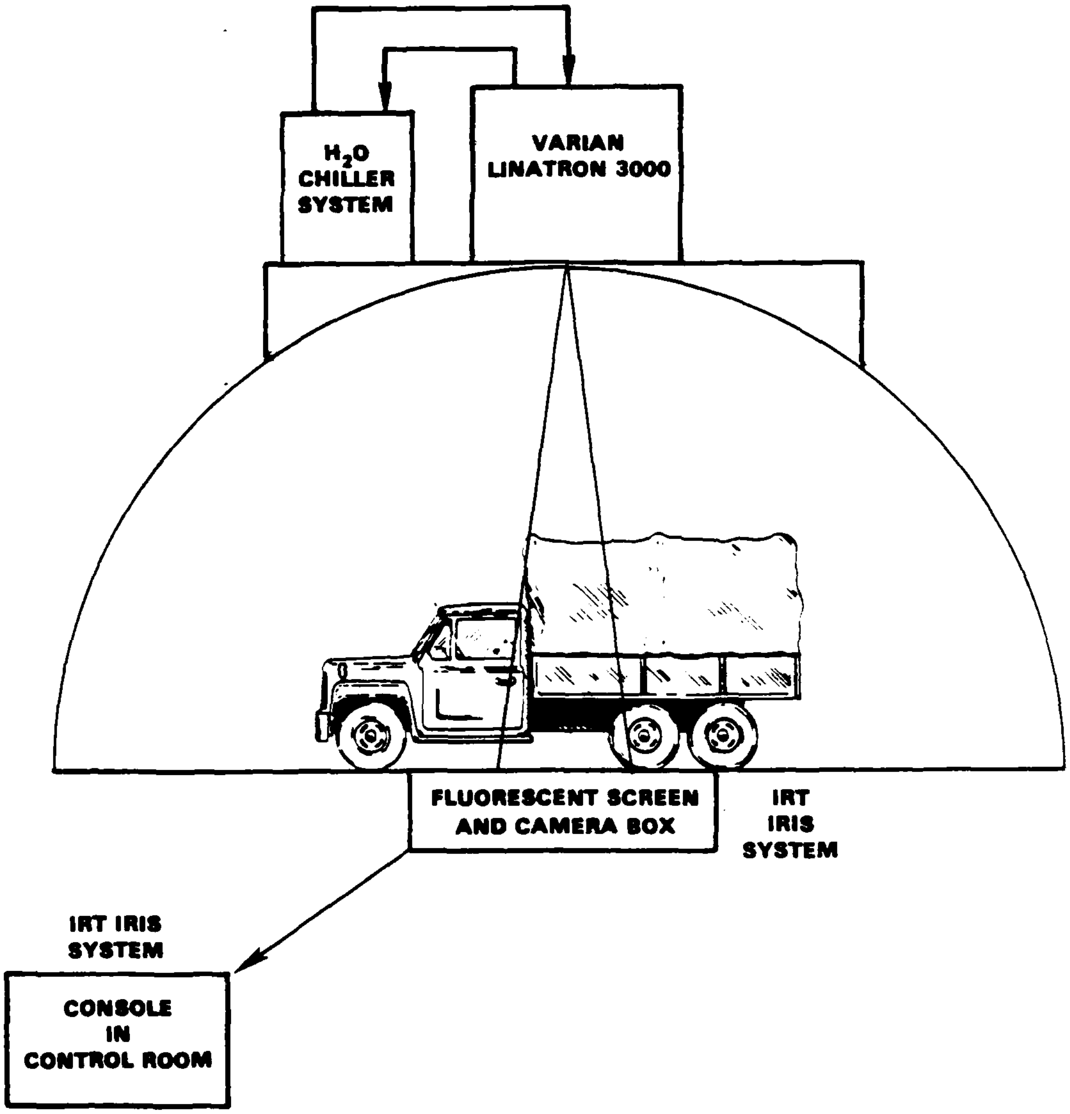

Figure 24(b). Block diagram of system installation.

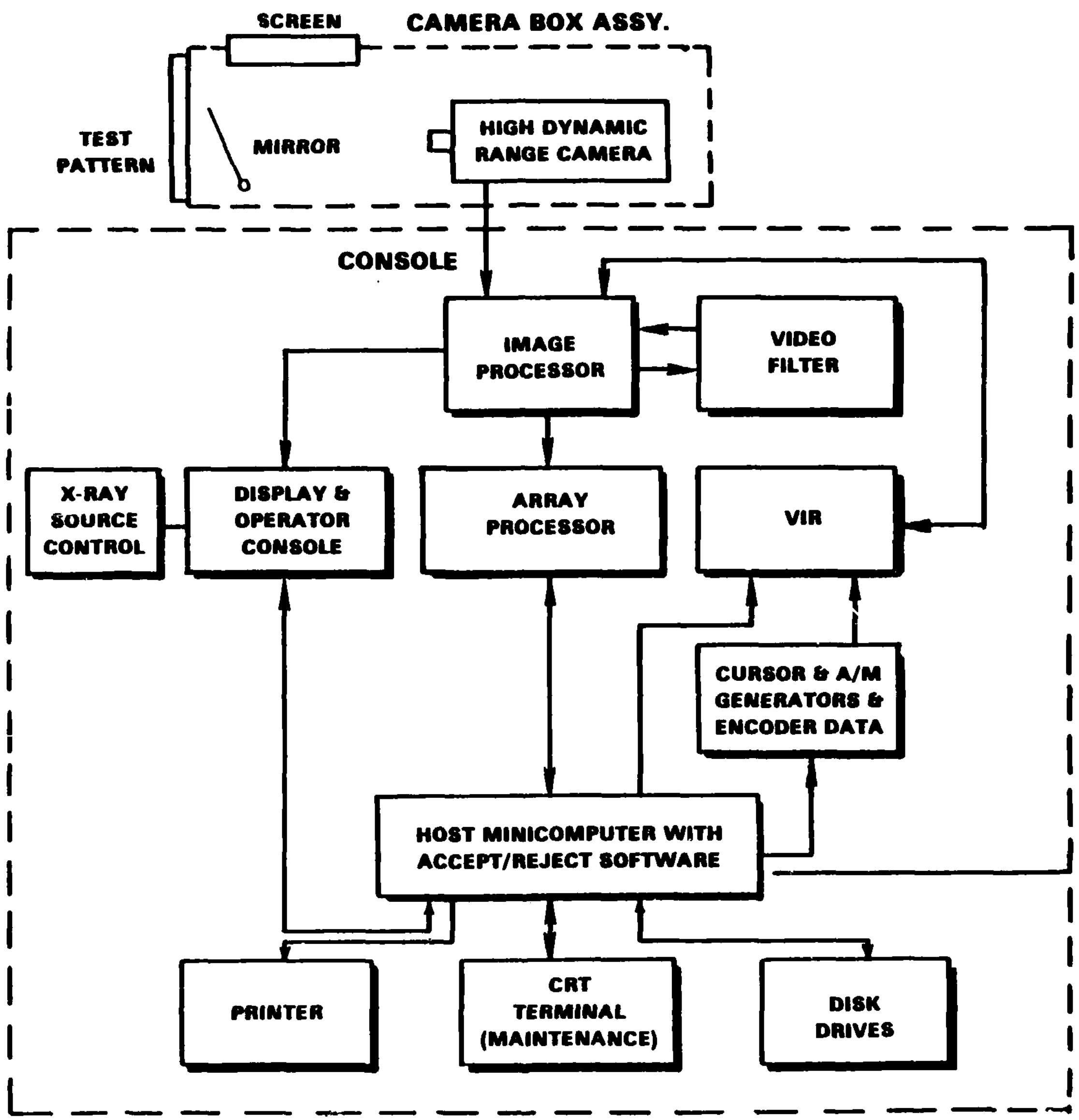

Figure 24(c). Block diagram of IRT IRIS digital radiography system.

It must be noted that any x-ray system of this size is to be considered a significant health hazard to personnel when it is in operation since it emits six orders of magnitude more radiation than the allowable limit. Precautions must also be taken to shield any photograph film near this Linatron unit or fogging equivalent to several f-stops exposure will result.

4.4 LASER DOPPLER VELOCIMETRY, LDV.

A time history of flow velocity can be determined using a commercially available nonintrusive two-component backscatter laser doppler velocimeter system. Single-point measurements will be made approximately three feet from the test cell vertical centerline and the vertical height will be determined by the location of test cell windows.

The proposed system will be purchased from Thermo Systems, Inc. (TSI), of St. Paul, Minnesota. A 2-watt Lexel laser will be used in conjunction with a TSI-designed optical system, signal processors, and a microcomputer for data acquisition and display. The system is capable of a maximum velocity measurement of 2300 m/sec. and maximum data rate of 8000 samples per second for a single channel and 5000 samples per second in the 2-channel coincidence mode.

The system 9100-8 uses a 2W Argon-Ion laser operating at 514.5 nm and 488.0 nm and a dichroic color separator to accomplish the color separation in the transmitting optics. The system transmitting optics are designed so that many of the functions needed for the transmitting section are built into a complete single unit. This high-density packaging enables one to mount the laser and transmitting optic in an area of approximately 2' x 6'.

The transmitting optics will generate a measuring volume with the following characteristics:

Distance from transmitting lens	1,524 mm
Diameter of probe volume	265 μm
Fringe spacing	23.2 μm
# of fringes in probe volume	11

Half angle between beams	0.634 degrees
Length of probe volume	24 mm
Signal-to-noise ratio	14

The receiving optics included with this system are a compact dichroic color splitter and photomultiplier system. A field stop system is included to minimize the effects caused by reflections.

The processor supplied with the system (Model #1980A) has a 2-nanosecond resolution (equivalent to a 500-MHZ clock). The digital output from the processor will be interfaced to the TSI Model 6250 Two-Channel Data Analysis System. The Model 6250 Data Analysis System is a complete two-channel package for on-line data analysis using an Apple II computer. Data can be taken in blocks of up to 4096 points each and analyzed or stored on disk. Velocity statistics calculated for each channel include mean velocity, standard deviation, and turbulence intensity as well as plots of the amplitude probability distribution. The coincidence mode of operation provides cross-correlation and Reynolds stress values.

Data is displayed directly in engineering units since all optical parameters for both channels are entered prior to taking data. Selectable scaling allows the user to expand the scales on the amplitude probability distributions and obtain optimum resolution.

Given below is a cost breakdown for the TSI 9100-8 LV System.

Model #	Item Description	Cost
(1) 9196-2	Base and Argon-Ion Laser for 2W	$ 21,745
(1) 9109	Mirror Set	1,945
(1) 9112	Dichroic 3-Beam Two-Color Transmitting Optics	3,640
(1) 9108	Beam collimator	435
(1) 9180-12	Frequency Shifter	7,630
(1) 9114-22	Beam Spacer	1,460
(1) 9189	3.75x Beam Expander	3,620
(1) 9144	Color Separator-Scattered Light	3,455
(1) 9178-1	Rotating Mount for Beam Splitter	1,185
(1) 9179	Rotating Mount	500
(2) 9160	Photomultiplier System	4,985
(2) 1980A	Counter (11,340 each)	22,680
(1) 9143	Field Stop System	1,815
(1) 9169-1500	Lens	1,530
(1) 9158	Color Filter	375

Model #	Item Description	Cost
(1) 9159	Color Filter	375
(1) 10096	Alignment Eyepiece	260
(1) 10097	Optics Case and Accessories Kit	245
(1) 10092	Microscope Objective	285
(1) 6250	Two-Channel Data Analysis System (includes Apple II Computer with 48K RAM, Monitor, Disk Drive, Software, and Printer)	9,300
	System Installation And Checkout	25,000
	System Total	$112,500

Shown in Figure 25(a) is a block diagram of the proposed LV system.

As stated earlier, the maximum velocity measurement capability of this system is 2300 m/sec.; therefore, this system will easily measure the specified range of 6 to 600 m/sec. encountered in the LB/TS. Depending on the number of particles present, and effective sample time or intervals between velocity measurement points of 10 msec. to 0.1 sec. can be achieved with this system (100 to 1000 particles per velocity sample).

The LDV system makes a point measurement, in particular, the measurement area of the specified system is a 265-μm-diameter by 24-mm-long area shown in Figure 25(b). Shown in Figure 25(c) is a graph of the PMT signal output versus time as a particle passes through the probe volume. The velocity of the particle is determined by measuring the period between adjacent peaks and dividing this into the known fringe spacing of the probe volume. It is necessary to keep the probe volume as small as possible in order to prevent multiple occurrences of particles in the volume which would distort the signal and thereby prevent an accurate measurement of the period. Because of the small measuring volume of the LV, it will be necessary to reposition the LV system in order to cover the full 3-m x 3-m space ahead of the target which may be of interest in the LB/TS. Due to the short duration of the test it is not feasible to traverse the system during this time frame.

It has been assumed that the naturally occurring particles in the flow (dust and aerosols) will be of sufficient size and number density to provide adequate seeding. The data rate which can ultimately be achieved is influenced by the density of naturally occurring seeding

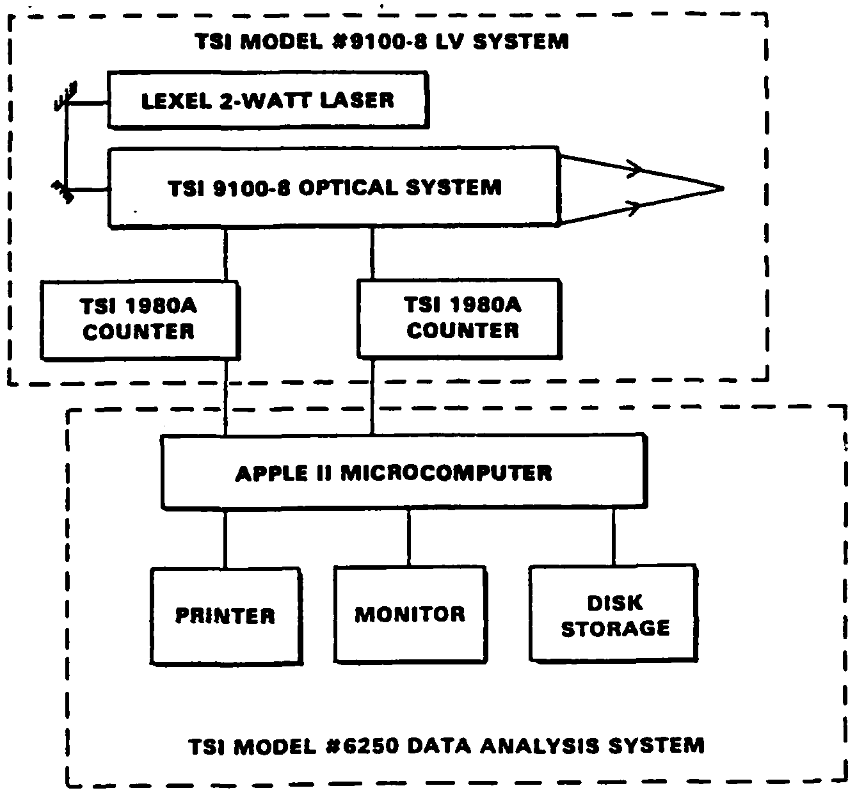

Figure 25(a). Block Diagram of LV system.

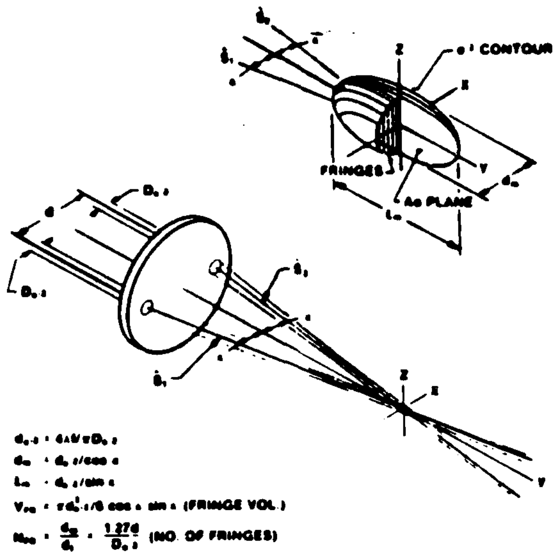

Figure 25(b). LV measurement volume.

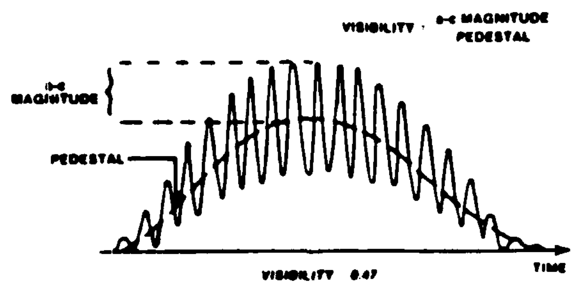

Figure 25(c). LV signal-particle velocity proportional to signal period.

material. If this is not the case, an atomizing injector of an aerosol or powder seed in one driver and the driven tube will enhance accuracy and time response. The quantity of artifically induced particles required is not sufficient to visibly obscure the target. A plot of sample size versus precision in velocity measurement for the LV system is given in Figure 25(d). For low turbulence level freestream flow (TI ~ 2 percent), a measurement of the mean flow velocity to one-percent accuracy can be achieved with as few as 20 particles (less than 5 msec per measurement in the LB/TS). However, if the flow velocity is highly unsteady, then 1000 particles (~100 msec) will be required to achieve the one percent accuracy measurement of mean velocity. In any event, the velocity histogram, including every particle velocity measurement at 8000 per second is available for more sophisticated analysis following the test. Assuming that all particles are small and uniform in size, rather large velocity transients (in time) can be tracked for time rate of change above the relaxation time for the specific particle size and flow density.

4.5 HIGH-SPEED PHOTOGRAPHY.

It is required to monitor component displacements that the target may undergo and also monitor the overall effect of the blast and blowing on the target. In order to fully document the effect of the blast on the article it will be necessary to monitor as much of the test article as possible, thereby requiring multiple views. Of primary interest will be a time history of the blast on both a localized and overall area.

The proposed high-speed photography system will consist of eight high-speed rotating-prism cameras operating at 4000 fps (Hycam) and eight high-speed intermittent pin-registered cameras operating at 500 fps (Locam). An extensive inventory of spares, multiple lenses, etc., is also considered essential for the versatile photography system envisioned. Also available, but not absolutely necessary, is a high-speed video system which will provide an immediate playback of the test. The disadvantage of the video system is the cost which will be discussed later.

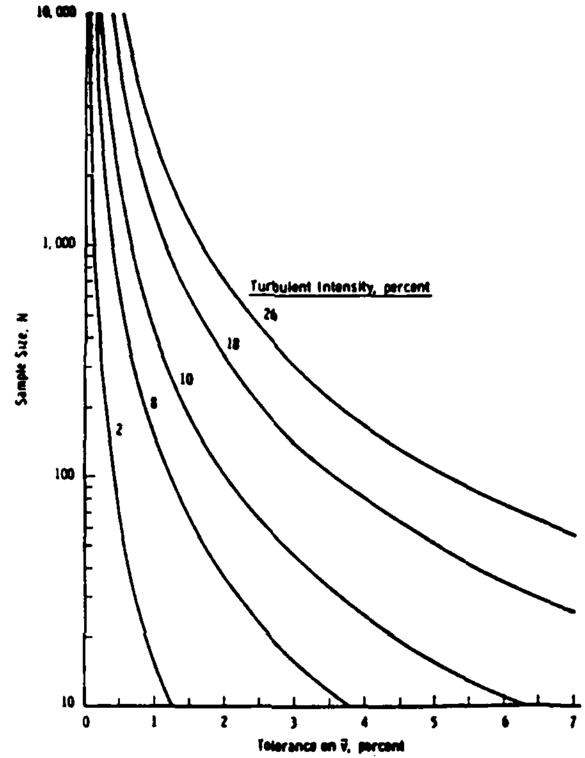

Figure 25(d). Tolerance on mean velocity versus sample size for 2σ confidence level.

The high-speed cameras will consist of two Series 41 Hycam II cameras, two Series 51 Locam II cameras, both manufactured by Redlake Corporation, and the high-speed video system, which will consist of the SP2000 Motion Analysis System manufactured by Spin Physics.

Specification of each system is as follows:

Series 41 - Hycam II Camera

Film Capacity:	16 mm x 400 feet acetate base film or 16 mm x 450 feet 4 mil. polyester base film
Speed Range:	20 to 11,000 frames per second (full frame) 40 to 22,000 frames per second (half frame) 80 to 44,000 frames per second (quarter frame)
Speed Control:	Electronic Servo Control, provides regulation over entire speed range to ±1%
Speed Selector:	Thumbwheel speed selectro switch in 10 FR/sec. increments
Acceleration:	1.5 seconds to 5000 FR/sec., utilizes 75' of film to reach speed
Event Synchronizer:	Thumbwheel selector, 4 to 336 feet in 4-foot increments. Accuracy ±5%
Power Requirements:	115VAC 60 Hz
Lens:	10 mm FL f/1.8 15'FOV @ 15' working distance
Lens Mount:	"C" ASA Standard
Footage Indicator:	Manual Level Type

Series 51 - Locam II Camera (Intermittent Pin-Registered)

Film Capacity:	16 mm - Accepts 100', 200', and 400' daylight load spools
Speed Range:	Continuously variable from 2 to 500 FR/sec
Speed Requirements:	115 VAL, 60 Hz
Start/Stop:	Connector provided for remote operation
Shutter:	Variable from 0° to 160°
Footage Indicator:	Positive displacement type indicating film remaining
Lens:	150 mm FL f/4.0 1' FOV @ 15' working distance

High-Speed Video System

Recording:	60-2000 full pictures/second with capability of 12,000 pictures/second in split frame mode
Recording Time:	8 minutes @ 200 frames per second 45 seconds @ 12,000 frames per second
Direct Live Viewing	
Instant-Replay Slow Motion	
Freeze-Frame Display	
Standard Video Format	
Pre-event and Post-event trigger controls.	
Lens:	12.5-75mm marco zoom lens. f/1.8
Standard C-M print lens.	

The only interface requirements of the described systems will be that of a start pulse from LB/TS sequencing control.

Shown in Figure 26 is a layout of the camera systems' relation to the test article for a basic position measurement system. The Hycam systems will be located 45° off test cell centerline and will each have a horizontal field of view of approximately 15' at a working distance of 15'. Having a camera on each side of the test cell will allow viewing the front surface and both ends of the test article simultaneously.

The Locam system's position will be located so as to view a 1 ft^2 area at a working distance of 15'. The camera placement on the test cell will be determined by the specific area of interest on the test article. The pin-registered optics of the Locam are better suited for close-up viewing of specific points of interest. A large number of viewing ports should be provided in the LB/TS to facilitate camera setup for each specific test with multiple camera viewing angles and fields of view possible on each test.

The single camera high-speed video system could be positioned in-line and upstream of the test article, i.e., on the top of the test cell looking down toward the model providing an overall view of the test.

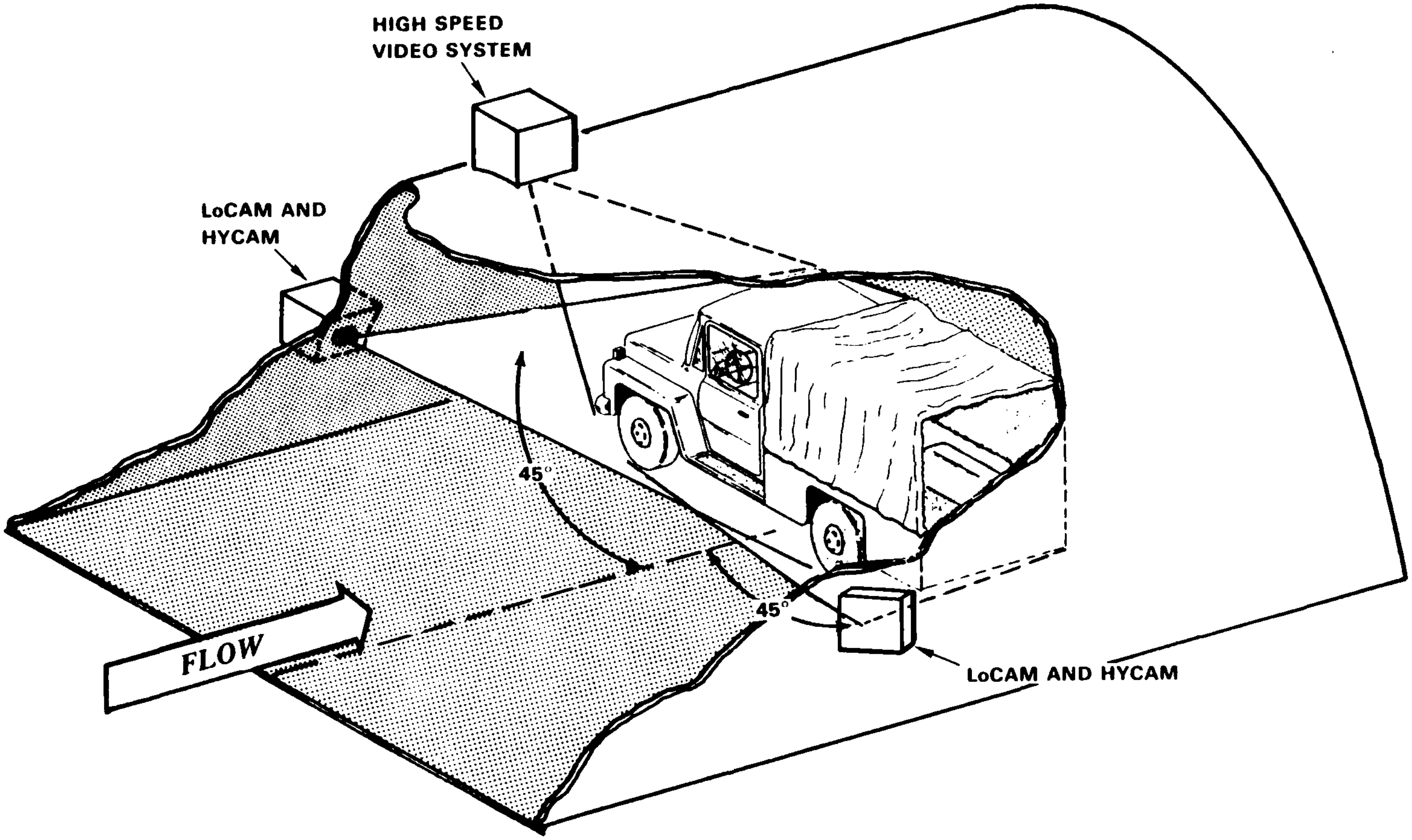

Figure 26. High speed camera system installation.
(orthogonal view)

This system will provide real-time viewing and instant-replay in slow motion. The primary advantage of this system is the instant-replay capability.

A itemized cost breakdown is given as follows:

Hycam Systems

Model	Description	Qty	Price Ea	Total
41-0064	Camera-Full Frame	8	$ 7,875	$ 63,000
	Multiple Lens Sets	10	431	4,310
41-0192	Timing System	6	510	3,060
41-0115	Case	8	225	1,800
41-2119	1/5 Shutter	5	32	320
41-2120	1/10 Shutter	5	32	320
	8-High Speed Hycam Systems (up to 5 in use at any given time)			$ 72,810

Intermittent Pin-Registered Systems - Locam

Model	Description	Qty	Price Ea	Total
51-0003	Locam Camera	8	$ 6,850	$ 54,800
9001-0026	Lens 150 mm F.L.	8	690	5,520
51-0197	Timing System	6	385	2,310
50-0152	Shutter Pulse Unit	6	190	1,140
50-0599	Reflex Optics	5	550	2,750
50-0743	Boresight Tool	2	475	950
51-0196	Case	8	200	1,600
	8 Pin-Registered Systems (up to 5 in use at any given time)			$ 69,070

Lighting

Model	Description	Qty	Price Ea	Total
121-031	Cine Queen Flood (1,000 watts ea.)	100	250	$ 25,000

High-Speed Video System

SP2000	Motion Analysis Sys.	1	110,000	110,000

Including control board, video monitor, tape recorder, power supplies, and all electronics. Also includes one high-speed camera complete with attached video finder, f/1.8, and 12.5-75 mm, macro zoom lens. Also includes one 25-foot cable (camera to console) three blank recording cassettes, one test cassette, a service manual, an operation and maintenance manual, a tape head cleaning kit, and two ATA approved reusable shipping cases.

System Cost:

Hycam System	$ 72,810
Locam System	69,070
High-Speed Video System	110,000
Photography and Video System Installation, Checkout	25,000
Lighting System	25,000
Total High-Speed Photography and Video System Cost:	$301,880

Note that the cost cited above includes a high-intensity lighting system. Lighting requirements were determined based on the short test time, possible clouding in the flow, and high proposed framing rates which are representative of the LB/TS.

4.6 LB/TS MOTION ANALYSIS SYSTEM.

The high-speed photographic and video camera equipment discussed in the previous section used to record the target impulse response will generate large quantities of information requiring some form of data reduction. Film analysis is commonly accomplished manually, by examining the film frame by frame. Manual analysis of film is an expensive, time-consuming process which could be made more efficient with the use of computer automated techniques. Data reduction for the high-speed cameras can be facilitated with the use of commercially available digital analysis systems. The degree of automation available for analyzing displacement, velocity, and acceleration range from almost totally manual operation to computer controlled digitizing and frame counting. In order to be cost effective, the type of system chosen will ultimately depend on the quantity of film generated and the turnaround time required for the completed analysis.

Separate systems are available for the analysis of high-speed video tape recordings and high-speed photographic film. This choice will be dictated by the primary recording medium chosen. Some advantages for using photographic film over video include higher image resolution and frame rates, and more fully automated data analysis systems are available on the commercial market for film. The disadvantages may be system cost and time (due to film processing) as discussed below.

The two best options available today for photographic film analysis are the Model 78-1 and Model 80 Automatic Film Reading Digital Analysis Systems from Instrumentation Marketing Corporation. Both systems have an automated tracking capability requiring the use of cooperative targets such as light emitting diodes or high-contrast quadrant targets. The targets are recognized with a pre-programmed algorithm based on contrast requirements. The X and Y coordinates are automatically digitized and stored in the system computer, a Nova 4/X 16-bit microprocessor. Degraded imagery and non-cooperative targets may be read manually in the semi-automatic mode. In this case, the operator manually positions a cursor or crosshairs at the point of interest and then digitizes the coordinate information.

The cost breakdowns of the automatic film reading systems are as follows:

Model 78-1 — Automatic film reading system

System includes Nac film motion analyzer, scanning camera, control console, scan converter, Nova 4/X computer, video display terminal, 12.5 Mbyte fixed disc, and 1.26 Mbyte floppy disc drive

System base price		$285,000
16mm projection head	#161	8,000
35mm projection head	#351	12,000
70mm projection head	#701	38,000
9-track mag tape drive		27,000
Total system price		$370,000

AD-A166 252 CONCEPTUAL STUDY OF THE LB/TS (LARGE BLAST/THERMAL SIMULATOR) INSTRUMENTA..(U) SVERDRUP TECHNOLOGY INC TULLAHOMA TN R F STARR ET AL. 12 SEP 84 DNA-TR-84-340 2/3

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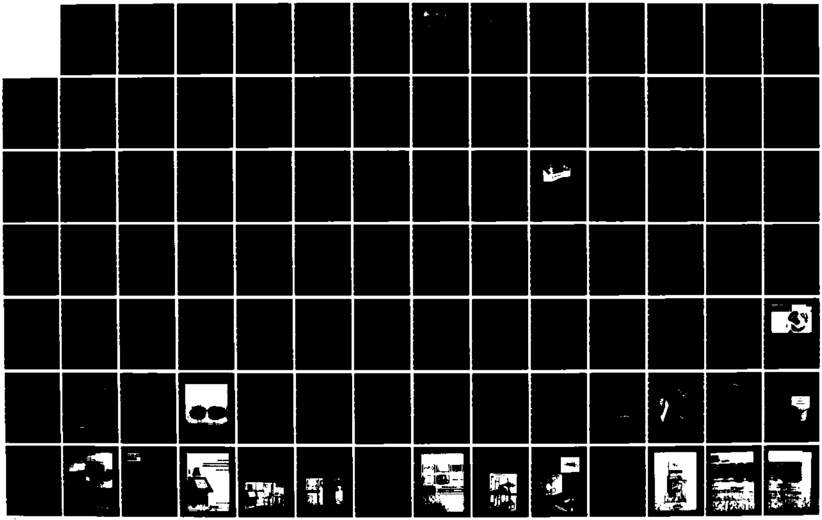

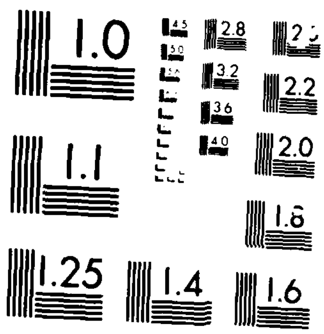

MICROCOPY RESOLUTION TEST CHART

Model 80 Automatic film reading system

System includes 16, 35, and 70mm film transports, solid-state analyzing table, digitizing camera, scan converter, Nova 4/X computer, keyboard, 12" and 9" displays, disk drive, mag tape, and line printer

Total system price $950,000

Additional features of the system software for the Model 78-1 include:

1. Automatically locates specified targets and determines X and Y coordinates of each target center
2. Automatically locates cooperative fiducials in each frame
3. Automatically reads either BCD LED data, 7-segment alphanumeric LED data, or frame edge timing pulses
4. Allows for manual input of data by placement of crosshairs on the target

In addition to the above features, the Model 80 software offers a more advanced operating system, FORTRAN and FORTRAN V compilers, and a package with FORTRAN diagnostic software.

Video analysis systems are available from two sources, Spin Physics and Instrumentation Marketing Corporation. Neither of these systems currently offers fully automated motion analysis. The Spin Physics model SP2000 Motion Analysis System has been described previously in terms of its high-speed video framing and recording capabilities (Section 4.5). Note that the image digitizing capability is included in the basic system price of $110,000. The SP2000 offers semi-automated two-axis position measurement capable of handling approximately 2000 frames/sec. Measurement of displacements is accomplished manually by positioning integral crosshairs over the target and obtaining a numerical readout of the X and Y coordinates. This information is digitized and stored, frame by frame, for later use in calculations. Calculations of displacement, velocity, and acceleration may then be performed on commercially available microcomputers such as an HP-85, an HP-2628A, or a PDP-11, for example. This computer is not included in the basic price of the system. Software is currently under development to recognize and track cooperative targets based on a contrast resolving algorithm. One potential drawback of this system is that the cameras must be located within 100 feet of the recording unit.

Additional options required to give the system its full analysis capability for measuring three-axis motion, assuming availability of the software in the near future, are:

SP2020	(2) additional high-speed cameras - one provides second view, one spare	$40,000
1001996	RS-232 or IEEE 4888 interface	5,000
1001540	Strobe interface assembly	2,250
1001760	Pre/post-event trigger PC board	2,600
	(2) Schneider zoom lens	1,800
	(2) Nikkor f/2.8 lens	750
	(2) Nikkor f/4 lens	1,550
	Minicomputer	5,000
	Total options price	$58,950

The total cost for the SP2000-based video analysis system is then $168,950.

The Videometrics/200 Video Analysis System from Instrumentation Marketing Corporation has the same basic features as the SP2000. Semi-automated image analysis is accomplished as before, by manually positioning a cursor over the desired target location and then digitizing the coordinates. The frame rate is limited to 200 frames/sec in split frame mode. The price breakdown for the Videometric/200 analysis system is:

PDS-200	Basic system consisting of control console, scan converter, power supply, and scanning camera	$ 94,050
	Nova 4/S computer, terminal, 12.5 Mbyte disc system, RDOS operating system, and FORTRAN IV software	24,600
	Total analysis system price	$118,650

This package does not include the recording system.

Brochures describing these systems are included in Appendix A.

4.7 SHADOWGRAPH SYSTEM.

A qualitative analysis of the shock formation about the test article can be determined by the use of a shadowgraph system. Data acquisition will be initiated just prior to the diffraction period and extend into the drag phase. Due to the cost of optical windows, mirrors, and the high-intensity lighting system, a small 24"-diameter shadowgraph was selected for evaluation. This system is marginal for LB/TS application, giving only limited views of the flow field around specific portions of a target.

The system will consist of a nanosecond light source, a high-speed camera, and 24" schilieren optics. The light source and camera will be operated at a 10,000-Hz rep rate which will provide 100 frames of data during the 10-millisecond diffraction period. Due to the speed of the shock (on the order of 400 m/sec.) during this period and a 10-kHz rep rate on the shadowgraph system, there will be an approximate shock displacement of 4 cm/frame. Given below is a price breakdown of the system:

Light Source:	PRA Model #501C 1-20 nsec pulse width, spectral output from 190 nm-800 nm 4 watts peak power @ 5-kHz rep rate, 106 m watts @ 50-kHz rep rate	$11,280
Camera:	Redlake - Hycam #41-0064 with accessories, speed range 20-11000 frames/second	$ 9,105
	Beam splitter and TV	5,000
Optics:	24" schlieren quality, single pass 24" windows with mounts $35,000 parabolic mirrors $34,000 mirrors $5,000	74,000
	Control panel and cables	15,000
System Design, Manufacturing, and Installation		45,000
	Total System Cost	$160,000

Provision should be made for vertically and axially traversing this system for coverage around various targets using combinations of multiple ports on both sides of the test station. It should be pointed out that the use of a pulsed laser is not practical because of the limited amount of data that would be required due to low rep rates of existing lasers. For example, a laser pulse of 750 μsec would provide 8 frames of data during each laser pulse (one pulse per second) and a Q-switched laser pulse of 20 n seconds would provide 1 frame of data during the 10-millisecond diffraction period (one laser pulse per second, maximum).

4.8 MOIRE PHOTOGRAPHY.

In the large blast thermal simulator facility, displacement of various sections of the test vehicle must be monitored during and after passage of the shock to determine the extent of deformation and damage. A non-contact technique for measuring relatively small out-of-plane displacements (5 mm) is Moire photography. This optical imaging technique can measure displacement independent of object contours. Moire fringes are formed by overlaying two sets of grids--one grid is projected on the object, the image of the object is viewed through the second grid. Changes in object grid spacing generate the larger Moire fringes. The sensitivity of the technique is given by

$$\Delta z = P/(\tan \delta + \tan \beta)$$

where P is the period of the grid projected on the object, δ is the projecting angle of the fringes, and β is the viewing angle.

The proposed Moire system would be set up in the LB/TS facility to observe a section of the vehicle, such as hood, fender, door panel, cab roof, or windshield. An area 3.25 ft x 2 ft can be viewed for analysis. Source and viewing optics would be located outside the facility with grid protection through optical ports. Transient measurements can be made using a standard CCTV system, a Spin Physics 2000 system, or a high-speed camera. Images of the undeformed surface would be compared to those of the deformed surface to highlight the deformation.

The only commercially available Moire system found in this study is manufactured by Fujinon, Inc., of Scarsdale, NY. A picture of this system is shown in Figure 27. The lower of the two lens projects a grid onto the surface and the upper lens focuses the gridded surface onto a second grid which is viewed by the camera. The camera image contains Moire fringes of the surface contour. Any changes in contour are indicated by changes in the Moire fringe pattern. System sensitivity is 2.5 mm (black to black). An example of the fringe pattern produced by a car fender is shown in Figure 28. The standard optics package for this system permits displacement of surfaces to be measured at distances of up to 1.8 m from the device. Simple adjustment of this optic package will permit viewing at 5 m from the device. Whole body, inplane, motion of the target cannot be easily distinguished from deformation of the target--both result in fringe movement at 2 to 5 mm per fringe. Deformation relative to any fixed point on the target can be determined, however. In addition, for cases in which large-scale rigid body motions develop, the target will move out of focus after a travel of one-half to one meter.

Cost of the Fujinon system is $19,500. This includes a closed-circuit television camera and monitor along with a photographic camera which can be switched to view the object under study.

Large as well as small object deformation can be observed with the Moire system. Gross motion of the test object, however, is restricted and its practical utility in the LB/TS is questioned.

4.9 OPTRON DISPLACEMENT FOLLOWER.

Target response can be measured with a non-intrusive optical device such as an optron follower. Real-time motion and vibration are also displayed in linear or angular directions.

Optron displacement followers track the motion of a discontinuity in the image formed by light reflected from or emitted by a moving object. The spectral response extends from ultraviolet to near infrared. The discontinuity may be an actual edge of the object or a half-dark/half-light target attached to or painted on the object.

The image of the edge or target is focused on the photocathode of an image dissector tube in the optical head. Electrons are emitted from each point of the photocathode in proportion to the intensity of the light image. The resulting electron image is refocused on a plate containing a small aperture. Electrons passing through the aperture constitute a signal current proportional to the intensity at the corresponding point on the original optical image. This small current is

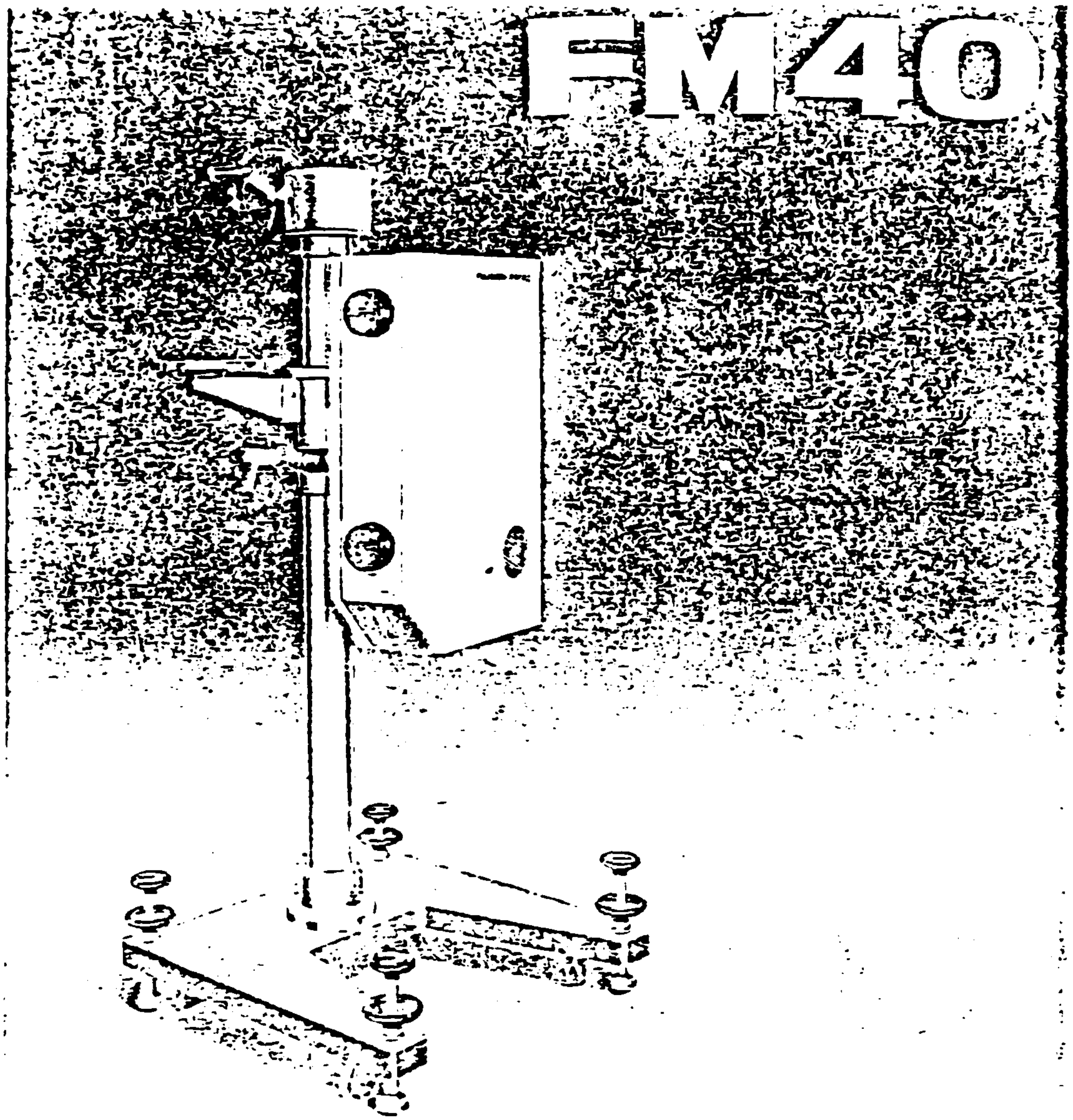

Figure 27. Moire' camera.

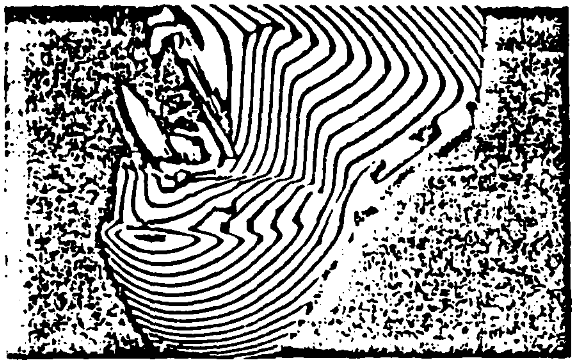

Figure 28. Moire' fringes on a car fender.

amplified first in a low-noise electron multiplier within the image dissector tube, and further by solid-state amplifiers in the control unit.

Working distances from the measurement device to the target can vary up to 3 m for a measurement range of 1 to 10 centimeters. Working distances are restricted to about one meter for measurement ranges less than one centimeter.

A brochure describing the optron system is included in Appendix A. Cost of the system, including mounts, calibrators, light sources, fiber optic target illuminator, two-channel digital storage oscilloscope, and other equipment is approximately $30,000.

4.10 SUMMARY OF OPTICAL/NONINTRUSIVE SENSORS AND BUDGET COSTS.

The optical sensors surveyed in this section range in cost from a few thousand dollars per unit to $750,000 each. Hence some judgment is required to define a complement of optical sensors which meets critical measurement requirements at an acceptable cost.

Of all the systems evaluated, the x-ray systems (pulsed or fluoroscopic) are both the most expensive and provide significant operational problems for the LB/TS relative to the potential gain in defining target deformation/motion. The high-speed video and photography systems discussed should provide adequate measurement of whole body motion. As such, these x-ray systems, though capable of providing meaningful measurements within the target or in dust-obscured flows, can be deleted from the initial LB/TS system and only be employed when a specific test requirement is identified which can support the x-ray acquisition cost.

In the IR sensor area, both optical pyrometers and thermovision systems are important for the LB/TS. Both types are, or will soon be, available as two-color devices with lower temperature limits sufficient for target surface measurements. The two-color feature is essential for reliable measurement of the TRS source or target surface temperature with changing emissivity.

The following table summarizes the nonintrusive sensors used for system planning and provides budgetary costs for each. Note that a number of candidate systems discussed in the previous sections of this report are not included in this list due their questionable benefit in the LB/TS environment.

NonIntrusive System	Number	Cost Estimate
Thermovision (Section 4.2.1)	1	$105,000
Optical Pyrometers, Target Surface, Two-Color (Section 4.2.2)	10	50,000
Optical Pyrometers, TRS Monitor, Two-Color (Section 4.2.2)	5	27,500
CVF Radiometer (Section 4.2.3)	1	99,600
Laser Doppler Velocimeter, Two-axis (Section 4.4)	1	112,500
High-Speed Photography System (Section 4.5)	16	182,000
High-Speed Video System (Section 4.5)	3	160,000

Automatic Video Reading System (Section 4.6)	1	20,000
Optron Displacement Follower	1	30,000

Total cost for this representative complement of nonintrusive sensors is approximately $787,000.

SECTION 5
SURVEY OF DATA ACQUISITION SYSTEMS

The traditional method of measuring rapidly changing transient phenomena is with analog recorders. However, with the advent of solid-state technology and high-resolution analog-to-digital converters capable of performing millions of conversions each second, most test facilities are turning to digital data systems as the primary method of acquiring transient data with analog recording relegated to a secondary or backup role. While digital recording provides an improvement in measurement accuracy as well as improvements in data analysis, it is not a panacea. Depending upon number of channels, bandwidth, and test duration, there may be significant disadvantages with a digital system. These are considered in more detail in the subsections below.

A complete digital system, an analog recording system, and a hybrid combination of digital and analog equipment are considered here as candidate data acquisition systems for the specialized LB/TS application. The critical technical requirements for the **data acquisition system** are extracted from Table 4 and include the following:

No. of Channels: 113 minimum
Bandwidth: 1 KHz to 250 KHz
Test Duration: 10 seconds maximum

While accuracy has not been addressed, the assumption here is that measurement amplitude accuracy -- excluding sensor and probe -- of ±0.25 percent is required. Additionally, linear phase and a channel-to-channel phase match of ±2° are required.

5.1 DIGITAL DATA ACQUISITION SYSTEM.

Typical elements of a digital data system include signal conditioners, amplifiers, anti-alias filters, sample-and-hold circuits, and an analog-to-digital converter (ADC). Of these, the technical performance characteristics of the filter and ADC are critical. Failure to properly select these components for a transient system will introduce a dynamic distortion error which is indistinguishable from data.

Individual channel sampling rates are presented in Table 5.1. The minimum sampling rates shown are theoretical values based on the Nyquist Sampling Theorem which assumes that the signal is ideally bandlimited and that the sampling occurs in zero time. For this ideal case, sampling at twice the highest frequency is adequate to ensure that no aliasing occurs. The maximum sampling rates are established empirically based on the assumption that the signal must be sampled at twelve times the filter cutoff frequency to adequately reconstruct a complex waveform.

Table 12. Individual channel sampling rates required.

BW Required	No. Ch.	Min. Ch. Sampl. Rate	Max. Ch. Sampl. Rate
1,000 Hz	40	2,000 S/Sec	12,000 S/Sec
20,000 Hz	25	40,000 S/Sec	240,000 S/Sec
50,000 Hz	40	100,000 S/Sec	1,200,000 S/Sec
250,000 Hz	8	500,000 S/Sec	6,000,000 S/Sec

Establishing sampling rates is further complicated since the anti-aliasing filters are not perfect low-pass filters. That is, depending upon the incoming spectra, energy may be present at frequencies greater than the filter cutoff frequency. Accordingly, it is desirable to use anti-alias filters which exhibit fast rolloff characteristics. Because of the complexities associated with determining sampling rates, it is reasonable to use anti-alias filters with 36 db/octave rolloff in conjunction with sampling rates of five times the filter cutoff frequency. The combination provides assurance that all aliases, regardless of incoming spectra, will be attenuated by at least 83.5 db. This is less than the resolution of a 13-bit ADC.

Table 13 summarizes the sampling and data volume requirements for each of the four required bandwidths. Here, the ADC sampling rates are chosen to be five times the bandwidth and the data volumes are computed based on a 10-second test. The significant points to note from the data presented in Table 13 are the aggregate sampling rates and data volumes.

Table 13. Sampling and data volume requirements.

BW Required	No. Ch.	Sampling Rate Ch.	Sampling Rate Aggregate	Data Volume Ch.	Data Volume Aggregate
1,000 Hz	40	5K	200K	50K	2M
20,000 Hz	25	100K	2.5M	1M	25M
50,000 Hz	40	250K	10M	2.5M	100M
250,000 Hz	8	1.25M	10M	12.5M	100M

Notes:

1. Sampling rates expressed in samples/seconds
2. Data volume expressed in words and is based on 10-second test

Considering that 1 MHz ADCs are state-of-the-art in 1984, the aggregate sampling rates suggest that 23 ADCs will be required to implement a completely digital system. These would produce 23 separate 1-million words/second (2 MBytes/sec) data streams for processing and storage. Considering that the I/O bandwidth for modern 16-bit mini-computers is approximately 4 MBytes/second, this suggests that multiple processors would be required. The block diagram for such a digital system is shown in Figure 29.

Assuming that a two-tier processing arrangement is used to implement a digital system, where the lower tier is dedicated to processing and local storage of the incoming data streams and the top tier represents a supervisory processor responsible for coordinating all data storage after test completion, then the data volumes presented in Table 13 indicate the storage capacity required at both levels. For a single 10-second test, the aggregate data volume is computed to be 227 MWords (454 MBytes). While this storage volume is realizable, it does indicate the extensive storage requirements at the lower tier (e.g., 25 MBytes required to provide storage for a single 250-KHz channel). Assuming that this data can be transferred from the lower tier storage media to the supervisor at the completion of a test at a 500-K bits/second rate, approximately seven minutes would be required for transmission of each of the 23 storage volumes.

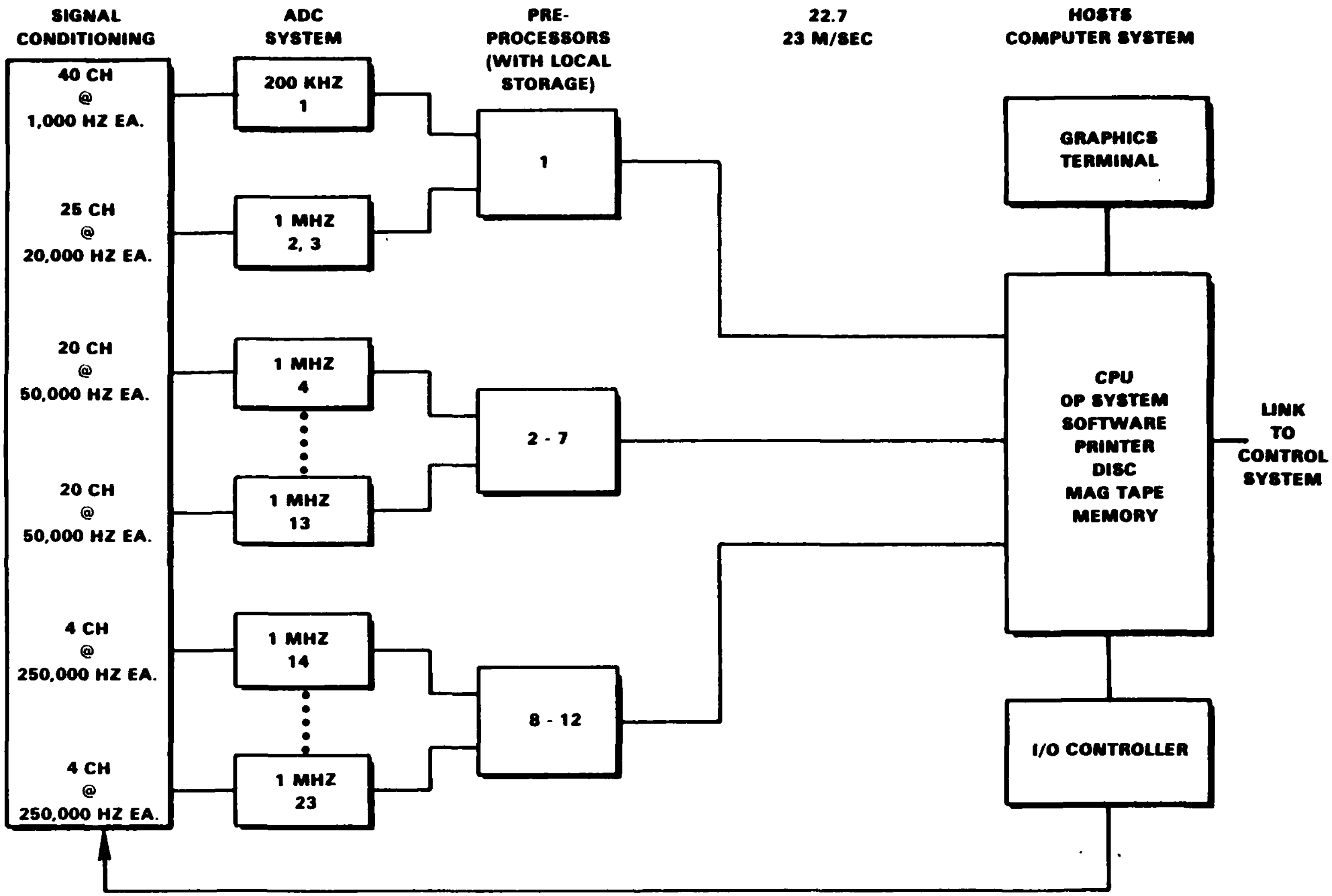

Figure 29. Digital data acquisition system.

5.2 ANALOG TAPE SYSTEM.

A conventional analog data system consists of two subsystems -- record and playback. The record subsystem provides the functions of signal conditioning and recording of raw data onto analog tape. The playback subsystem enables reproduction of selected portions of test data and provides off-line digitizing and data analysis. An analog tape system equipped with FM recording capabilities is well suited for applications involving a large quantity of high-speed data. However, amplitude accuracy in an analog system is poor relative to a digital system, data analysis is time consuming, and real-time data are unavailable for controls and display. Figure 30 illustrates in block diagram form an analog tape system configured to meet the requirements of Table 4.

5.2.1 Record Subsystem.

The record portion of the analog tape system provides signal conditioning on a per-channel basis, an FM multiplexing scheme to concentrate the raw test data onto one 28-track FM tape recorder, direct and FM record amplifiers, and a computer-controlled, 28-track FM tape recorder to store the analog data.

To accommodate the large quantity of data channels, data are multiplexed onto the first 17 tracks of the tape recorder using a mixed data FM technique. Each multiplexer takes 4 to 10 channels of data (depending on signal bandwidth) and modulates each channel to a separate frequency band. The resulting 12 composite data signals are then recorded on tape using direct record amplifiers. The high bandwidth signals are routed to 8 dedicated tracks through FM record amplifiers.

5.2.2 Playback Subsystem.

The playback portion of the analog tape system provides selection and reproduction of data from the tape recorder as well as off-line digitization and data analysis. The major elements are reproduce amplifiers, a computer controlled playback selector, demultiplexer and discriminator, and an ADC system similar to the digital data system described in Section 5.1 (i.e., anti-alias filters, sample and hold circuits, and an analog-to-digital converter). The playback subsystem also includes a computer system to perform data analysis and provide set-up and control of the signal conditioners, analog tape recorder, and playback selector.

The reproduce scheme takes the 18 tracks of FM multiplexed data from the tape through direct reproduce amplifier. These signals are then demultiplexed from 18 tracks into 108 channels (on a 2 tracks at a time basis) and discriminated from FM back to analog. These signals are then routed to the ADC for digitizing. The eight tracks which were not multiplexed are simply played back through FM reproduce amplifiers into the ADC system.

The ADC system for the analog tape system includes basically the same elements as the digital data system described in Section 5.1 and hence is subject to the same critical performance characteristics. Sampling rates and anti-alias filter distortion are still important considerations. However, the impact on system design is decreased by the off-line nature and the ability to use the tape recorder speed to reduce individual channel bandwidth.

The host computer consists of a high-speed data processor, memory, disk storage, magnetic tape storage, line printer, graphics and system terminals, and an I/O controller. All data analysis, display, and control software resides in this machine.

5.3 HYBRID DATA SYSTEM.

Several problems exist with either the fully digital data system or the analog tape systems discussed above. The major problem with the digital system is the high digital data rates and the corresponding large volume of data. Although the analog recording system overcomes these problems, this system provides no capability for real-time data analysis. An attractive alternative is a hybrid combination of the two system types. Figure 31 presents a configuration which will accommodate the data volume as well as provide a limited amount of digitized data for near real-time display and analysis.

For the configuration shown, the digital channels are limited to the 40 low-frequency (1000 Hz BW) channels. With this arrangement, the 1 MHz ADC provides adequate sampling rates for both real-time data acquisition and off-line digital analysis capabilities. [The 65 moderate-bandwidth channels (20 and 50 KHz) are multiplexed and recorded on 10 tape tracks.] The eight high-bandwidth channels (250 KHz) are each individually recorded on single tracks using FM techniques.

5.4 SUMMARY.

For this application, a totally digital system is inappropriate. This is a direct consequence of the number of channels, bandwidth requirements, and test duration. Although a digital data system concept can be established which will satisfy the requirements, there are significant technical risks associated with the high-speed digitizing of multiple signals as well as transmitting and storing multiple high-speed data streams. The analog recording system offers some advantages in that proven high bandwidth, multiplexed recording systems are available. However, to provide digital off-line analysis, there is still a need for high-speed digitizing of selected portions of tape. This digital requirement is significantly less complex since only selected segments of the total test duration are digitized and the digitizing rates can be reduced through reductions in tape playback speed.

Since a need exists for digital equipment within an analog recording system, an arrangement such as the hybrid configuration described in Section 5.3 which permits the digital equipment to be used in real-time for limited data acquisition is recommended. This hardware arrangement is comparable in price to the analog system yet offers the advantage of limited real-time digital data analysis.

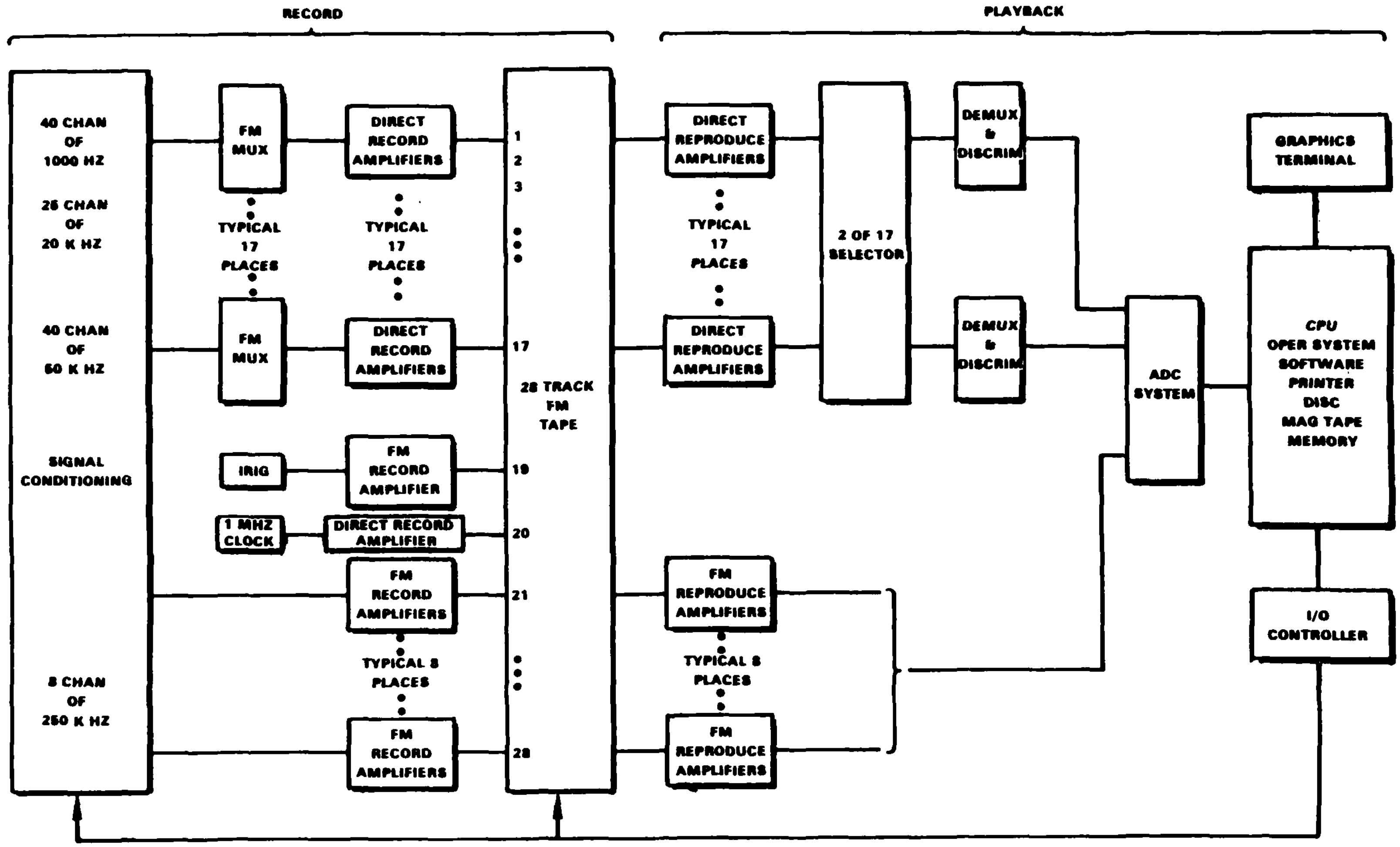

Figure 30. Analog tape system.

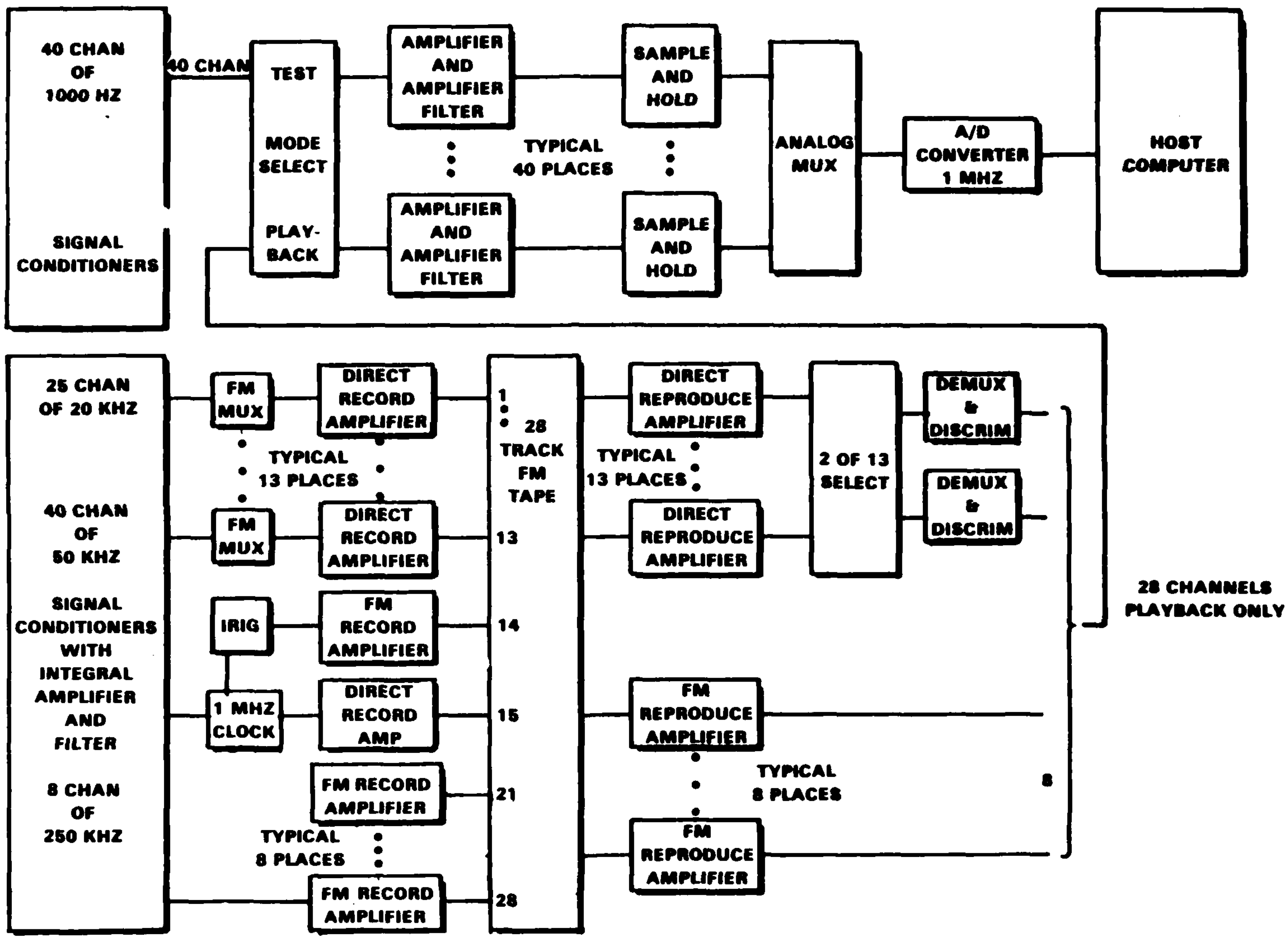

Figure 31. Hybrid data system.

SECTION 6
FACILITY CONTROL AND STATUS MONITORING SYSTEM

6.1 CONTROL SYSTEM REQUIREMENTS.

The Facility Control and Status Monitoring System (FCSMS) for the LB/TS serves basically a sequence control and subsystem monitoring function with built in logic to evaluate and confirm status of the system prior to the next sequential step in a run preparation process. Upper and lower tolerance limits in engineering units would be placed on each measurement channel, with the limits automatically changed at selected points in the pre-run sequence. Multiple sensors, logic for identification and exclusion of faulty sensors, and hold for operator intervention or abort logic would be built into the system software to provide a safe, reliable system.

Examples of sequential control and monitoring functions of the system are given below:

1. Monitor and control pressurization of drivers and heating of driver gas (nominal 24-hour process) by opening and closing valves in the compressor system and switching compressors on and off and turning strip heaters on and off to achieve the required temperature and pressure as measured by various facility pressure and temperature sensors. Independent protection of the system from malfunction, including control system failure, would be a mechanical set of relief valves and multiple thermostats on the strip heaters. Out of tolerance events would result in annunciation to the system operator, a hold awaiting operator input, and/or system shutdown, depending on programmed logic
2. Initiate TRS firing and maintain firing until pre-established criteria are met. In this case, the following specific functions would take place in orderly sequence:
   - Open TRS vents in the top of the driven tube (confirmed by position sensors and limit switches)
   - Light five TRS pilots (confirmed by sensors in each pilot flame)
   - Initiate oxidizer flow (contirmed by valve position readings and selected pressure readings)
   - Initiate aluminum flow (confirmed by valve position readings)
   - Initiate air curtain flow (confirmed by valve position readings and selected pressure readings)

- Measure TRS output on reference sensors (optical pyrometers and reference calorimeters)
- Shut down TRS system when pre-established criteria are met
- Close TRS vents
- Return TRS to safe status with critical systems purged

Criteria for shutdown could be either a preset elapsed time or a pre-established integrated heat flux (fluence) level. Tolerance level on either fluence or number of TRS units which light could be established by the operator prior to the run dependent on the criticality of the heating portion of the LB/TS cycle. These would lead to a hold for operator review or abort actions, depending on the time at which the fault condition is detected in the sequence. Logic and redundant sensors would be provided to permit real-time screening for inoperative sensors without initiating abort actions. At any rate, the target can be spared excessive heat load or damage from the blast wave input on a test in which heat input is critical, if sufficient TRS units do not function properly.

3. Control RWE position based on an algorithm defining the RWE position relationship to wall pressures near the end of the drive tube. Redundant systems with logic for detection of faulty sensors would be included. Detection of an out of tolerance or fault condition would result in the controller attempting to return the RWE to full open position.

The total number of sensors to be monitored are the 70 facility measurements (Item 1.0, Table 4), three of the wall pressures (Item 2.0, Table 4), and the five optical pyrometers and 10 radiant gages (Item 3.0, Table 4), for a total of about ninety channels. Real-time conversion to engineering units, checking against preset limits for each channel in engineering units, and accumulation of fault information are required. Other real-time computations involve integration over time of sensor readings of the 10 radiant gages to calculate fluence and computation of the RWE position based on the three wall pressure readings.

6.2 CONTROL SYSTEM DESCRIPTION.

Figure 32 provides a block diagram of the conceptual design of a digital FCSMS. The system includes signal conditioning on a per-channel basis to convert sensor input signals to ±10V levels, a dedicated input/output controller providing analog-to-digital conversion

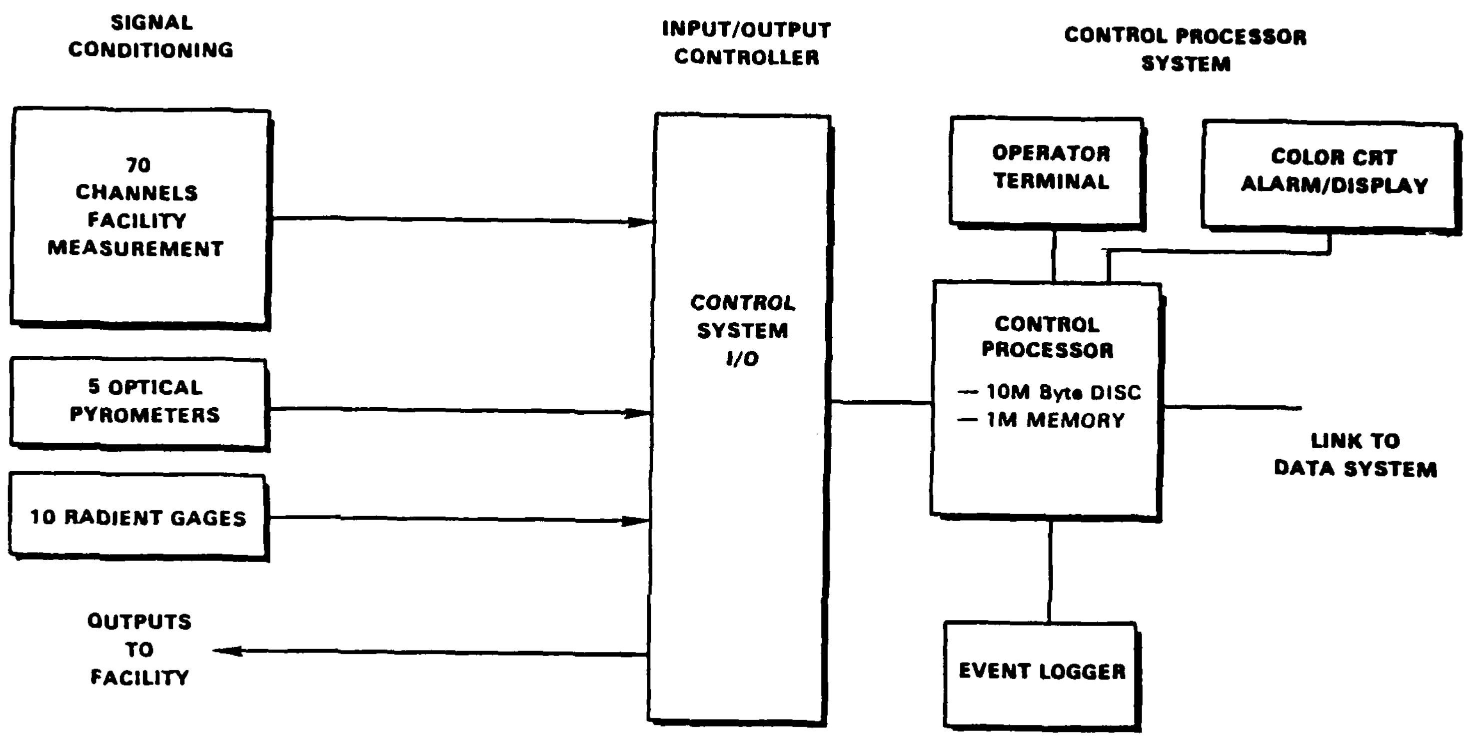

Figure 32. Facility control and status monitoring system.

of all input signals and appropriate output drivers for solenoids, actuators, and control valves as needed to effect facility control, and a control processor system to handle all sequence and control logic as well as generate alarms and event printouts, a event logger to provide listings of status, control, and alarm conditions, a color CRT to provide operator indications of alarms and facility status, and a link to the data system to allow coordination of the total facility operation.

6.2.1 Signal Conditioning.

Modular signal conditioning is provided on a per-channel basis configured as needed to meet the requirement of the sensor. The signal conditioning system is configured to normalize all outputs to ±10V levels for further processing. Included in the signal conditioning system are amplifiers, bridge completion units, charge amplifiers, T/C amplifiers, and other types as needed. In addition, individual buffer amplifiers are provided for any signals shared with the data system to minimize interference problems.

6.2.2 Input/Output Controller.

The input/output controller provides the analog-to-digital conversion of all input signals from the signal conditioning section and subsequent interfacing to the control processor. Also included are all output driver required for solenoid, actuators, and control valve control Hardware is available from various vendors including Computer Products, Analogic, Analog Devices, Hewlett-Packard, and Burr-Brown.

6.2.3 Control Processor System.

The control processor provides all sequence and logic control processing, generates all operator displays, alarms and event printout interfaces to the data system, and provides all operator interfacing. This system will consist of a high-speed data pressure and appropriate peripherals to accomplish FCSMS functions. Included is a link to the data system processor to coordinate activities between the two processors.

A color CRT is planned to provide operator interfacing including alarm and status display.

6.3 ESTIMATED HARDWARE AND SOFTWARE COST.

Order-of-magnitude cost estimates for hardware for the FCSMS are given below.

•	Signal Conditioning	$150,000
•	Input/Output Controller	60,000
•	Control Processor System	48,000
	Total Hardware	$258,000

Special application software to accomplish all required control and status monitoring operations and systems integration is estimated to cost $100,000.

SECTION 7
SYSTEM CONCEPT PLAN

Figure 33 illustrates a simplified block diagram of an integrated data acquisition and control system reflecting the considerations discussed in Sections 5 and 6. As shown, the operator's principal interface to the system is at the control processor. With this arrangement, the control processor serves to provide all sequencing including initiating the data acquisition cycle. Upon receipt of a start command from the control processor, the data system processor will initiate a continuous digital data acquisition cycle as well as start continuous analog recording. Because of the short test duration, it is anticipated that minimum processor-to-processor data transfers will occur during testing.

It is intended that the control processor be restricted to facility control and sequencing. As such, only a limited number of peripherals are required. However, with the arrangement shown in Figure 33, the control processor does have access to shared peripherals such as digital magnetic tape, line printer, etc.

7.1 DATA ACQUISITION SYSTEM.

After evaluating various data acquisition approaches (Section 5) a specific data acquisition system concept (Figure 34) was selected for the LB/TS. This hybrid configuration includes a digital data acquisition subsystem for the low-bandwidth measurements, an analog recording system for the high-bandwidth measurements, and a host computer system to control various instrumentation and perform data analysis.

7.1.1 Digital Data Acquisition Subsystem.

The digital data acquisition subsystem serves a dual role. Besides providing real-time data acquisition for the low-bandwidth channels, the system provides off-line digital data analysis capability for the signals recorded by the analog tape system. Hence, the system must have the flexibility to accommodate a variety of different signal levels and bandwidths. This capability is provided by variable-gain amplifiers and

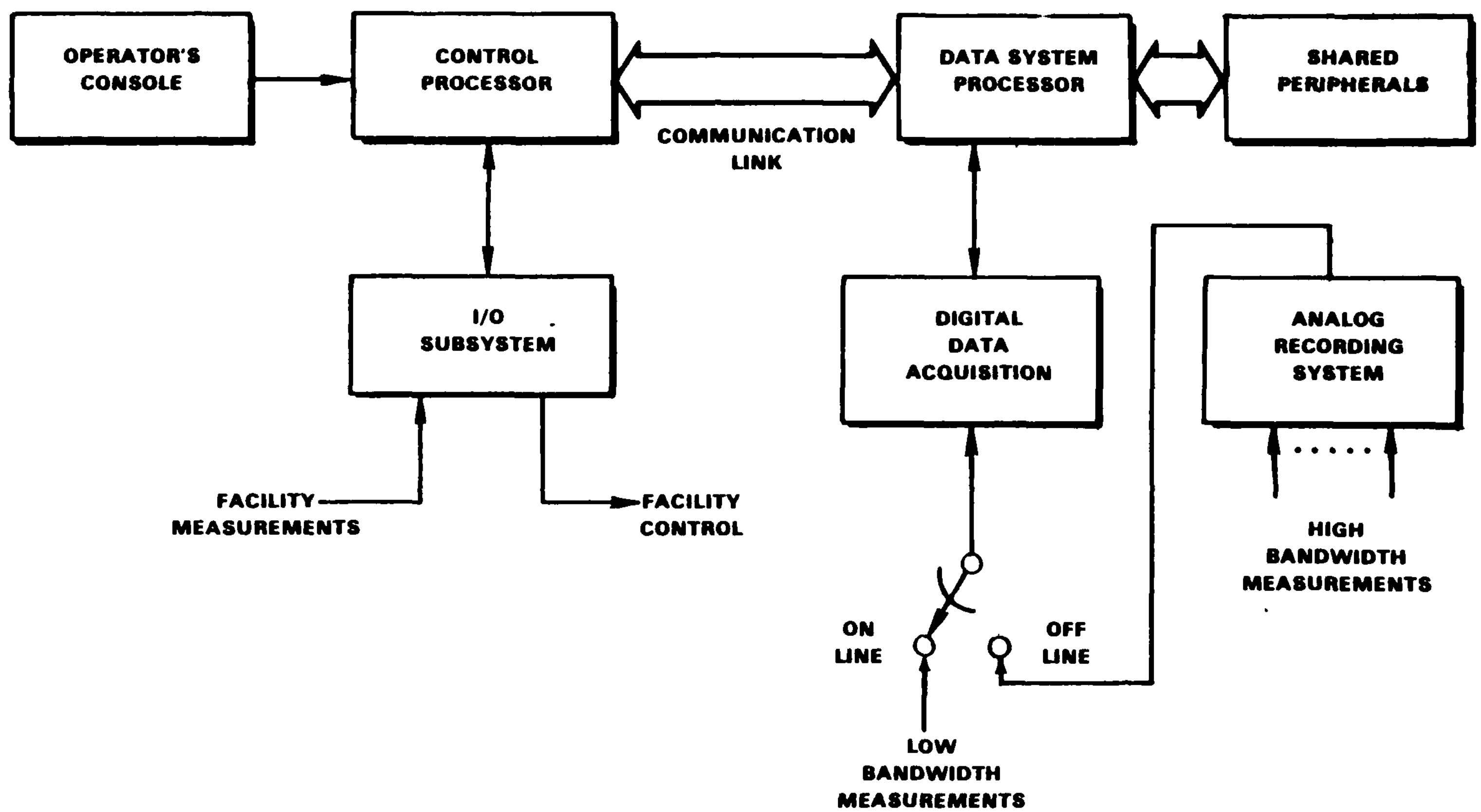

Figure 33. Integrated data acquisition and control system.

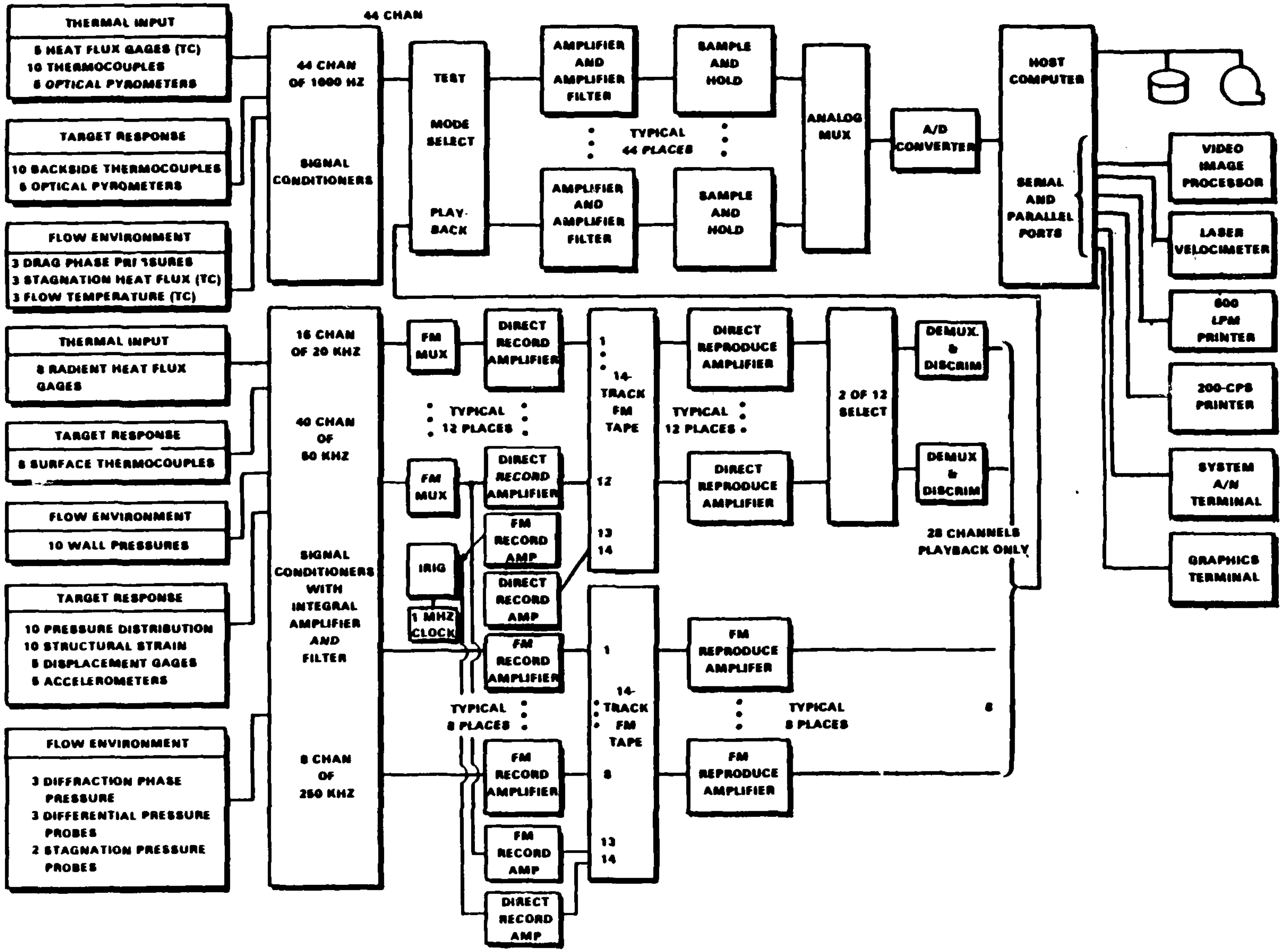

Figure 34. Proposed data acquisition system.

anti-alias filters, sample and hold circuits, analog multiplexer, and an analog-to-digital converter. An analog switching scheme is used to select between real-time acquisition mode and playback.

7.1.1.1 Signal Conditioning.

To accommodate different sensors, a 40-channel signal conditioning system will be provided that includes various mode cards which are used to tailor the conditioner for temperature, pressure, or other analog signals. These units will include an excitation power supply for each channel, interchangeable plug-in bridge completion circuits, offset suppression, and resistance and voltage calibration. For voltage calibration, a computer-controlled signal conditioner input switching circuit is used to disconnect the sensor input and to insert a precise dc voltage source. This voltage insertion technique provides for complete multi-point static calibration (excluding sensor) traceable to NBS as well as provides a convenient computer-controlled method for determining that each channel is operable immediately prior to testing.

7.1.1.2 Analog Switching.

The configuration shown in Figure 34 shares the digital system between the 40 real-time measurements and the off-line digitizing. To accommodate this, the signal outputs of the 40 signal conditioners and the 29 playback channels are terminated at the Mode Switch patch panel. Additionally, the inputs to the 40 amplifiers are also terminated here. Inputs to the digital system (amplifier inputs) are thus established for each channel through a 3-wire patch (signal high, signal low, shield).

7.1.1.3 Amplifier and Anti-Alias Filter.

Variable-gain amplifiers with integral 6-pole low-pass filters will be supplied. Seven amplifier fixed-gain selections and seven filter cutoff frequencies will be front panel switch selectable. Digital code representations of both the amplifier gain and the filter cutoff switches are input to the computer system for verification.

7.1.1.4 Sample and Hold Circuits.

An individual sample and hold amplifier will be provided for each channel. This will enable precise time correlation to be established during playback for multiple analog input signals. A common clock will be used to coordinate capturing data from all channels at a given time and hold the signals until the digitization process is complete.

7.1.1.5 Multiplexer and Analog-to-Digital Converter.

A 40-channel analog multiplexer/ADC system is required. As shown in Table 13, the minimum aggregate sampling rate for the 40 low-bandwidth (1 KHz) channels is 200K samples/second. However, since the ADC is also used in an offline mode to digitize the high-bandwidth channels, a higher sampling rate than the minimum required for the real-time measurements (200K samples/second) is recommended. Since sampling rates for the playback channels can be reduced by reproducing the signals at a tape speed less than the record speed, the aggregate sampling rates presented in Table 13 are inappropriate. Assuming that a tape speed of 60 or 120 ips will be used for recording the high-bandwidth signals, then a reduced playback speed effectively reduces the bandwidth and thus the required sampling rate. Accordingly, a 1-MHz ADC is recommended for this application.

The ADC requires a high-speed versatile interface capable of transmitting a 2 MByte/second data stream to processor memory. To accommodate the dual real-time data acquisition and offline digitizing functions, the ADC scan list and sampling rate must be programmable. Additionally, since not all tape channels can be reduced simultaneously, the system must have the capability of using a signal from tape such that the digitizing process always beings at the same time. This is essential for correlation.

7.1.2 Analog Record System.

To accommodate the high-bandwidth measurements, an analog record system is recommended. This system features signal conditioning, an FM multiplexing scheme, direct and FM record amplifiers, and two 14-track FM tape recorders. Also provided are playback capabilities including FM and direct reproduce amplifiers, a computer-controlled playback selector, and two demultiplexer/discriminators. As the signals are reproduced, they are routed through the digital data system described in Section 7.1.1 for data analysis.

7.1.2.1 Signal Conditioning.

A 73-channel signal conditioning system will be provided with the same features discussed in Section 7.1.1.1. In addition, these signal conditioners will include integral amplifiers and six-pole low-pass filters to adequately prepare the input signal for analog recording. The amplifiers will have fixed gain and the filters will have a fixed cutoff frequency based on the type of transducer required.

7.1.2.2 FM Multiplexer/Demultiplexer.

FM multiplexers are used to concentrate the raw test data onto one tape recorder. Each multiplexer takes 4 to 10 channels of analog data (depending on signal bandwidth) and modulates each channel to a separate frequency band. These signals are then combined into one FM signal.

The demultiplexers take the FM signals and filters out each of the frequency bands, separates them, and returns the signals to their analog data form.

7.1.2.3 Tape Recorder System.

The tape recorder system consists of FM and direct record amplifiers, two 14-track FM tape recorders, and the reproduce amplifiers. The record amplifiers are required to convert the analog signal to a power level compatible with the tape recorder and to condition the signal to produce a more accurate recording/reproducing process. Direct record amplifiers place an AC bias on the analog signal to make the recording characteristic more linear. FM record amplifiers improve accuracy by frequency modulating the data signal. FM recording provides approximately twice as good linearity as direct recording.

However, in this system since FM techniques were used for the multiplexing scheme, direct record amplifiers should be used for the multiplexed channels.

Two 14-track laboratory-quality wide band (Group II) FM tape recorders are provided to store high-bandwidth data during a test. Features include computer control, 9 bidirectional tape speeds, and a 5-digit footage counter.

The reproduce amplifiers return the tape recorded signals to the same form they were in prior to the record amplifiers. That is, direct reproduce amplifiers remove the AC bias while FM reproduce amplifiers demodulate the signal. Both the record and reproduce amplifiers are supplied as integral parts of the FM tape recorder.

7.1.3 Data System Processor.

A computer system is provided to set-up and initiate digital data acquisition and analog recording. As a secondary function, the processor also will perform post-test data analysis. Prior to a test or analog tape playback, the data system processor will be responsible for verifying amplifier and filter settings, and establishing sampling rates. During a 10-second test, the processor will provide limited re -time data analysis and display, with minimal communication with the control processor. At the conclusion of a test, the data system processor is available for data analysis and data reduction.

The data system processor will be a 16-bit minicomputer equipped with 2 MBytes of memory for real-time storage of digitized data. The processor will be configured with various peripherals. A 132-MByte fixed disc drive and controller will be used primarily for storing the operating system and applications software. A 9-track magnetic tape unit will provide fixed disc back-up and archival storage of real-time digitized data and post-test results. An intelligent serial communications controller is included to allow up to 8 peripherals to communicate with the processor. Two console terminals are attached to the processor through serial ports--an 80-column system display terminal and a graphics terminal. A 200-CPS dot matrix printer also attaches to the serial port for status logging or other similar low data volume functions. Parallel ports to the microprocessor-based video image processor and laser velocimeter are included to accommodate special post-test data processing, and a parallel port to a high-speed printer (600 lines per second) is provided to accommodate data printout after test completion.

7.1.4 Application Software.

Numerous application software programs are required to implement the various system functions discussed above. Because of the system's complexity, application software should be designed using structured programming techniques. This will result in a system which is modular, maintainable, and can be both modified and expanded. All custom application software will be written in FORTRAN 77 unless timing constraints for critical modules require otherwise. Documentation will include a user's manual, high-level flow charts, program abstracts, and annotated source listings.

The application software has been arranged into several major categories. Although the details cannot be established until the design is completed, the various programs required are functionally detailed below.

7.1.4.1 System Calibration.

The purpose of this program is to periodically evaluate the total performance of the data acquisition system by applying precise inputs to the system automatically from the voltage source and measuring its performance. The analog system, excluding sensor power supplies, will be tested as one complete unit on a per-channel basis to determine each analog channel's measurement uncertainty. The components tested include signal conditioners, amplifiers, filters, multiplexer, and analog-to-digital converter. Analog signals from a precision voltage source are to be input to each channel and the digital response recorded on each amplifier gain setting.

Automatic calibrations can be accomplished at convenient intervals before test runs and reduced functional checks immediately prior to testing as a final system check. Critical measurement channels with calibration results different from previous checked and verified calibrations would be flagged to the facility operations staff for run/abort decisions.

Depending on the volume of calibration and number of sensors, an automatic calibration data transfer option from a remote calibration lab is possible. In this mode, lab data would be stored in the host system by sensor serial number for automatic retrieval whenever that sensor is used in the facility. In either case, the data acquisition setup below would be based on a stored sensor data file.

7.1.4.2 Data Acquisition Setup.

This program enables the operator to input the system measurement requirements for a specific test. These include channel assignments, bandwidth, expected peak measurement values, sensitivity, and sensor excitation. Based on this, the system automatically establishes a configuration report including computed amplifier gain settings and sampling rate. This system test information is printed enabling the operator to set amplifier gain, filter position, and sensor excitation.

7.1.4.3 Real-Time Run.

This program enables the operator to initiate real-time data acquisition. Once the system has been set up and all pretest checks completed, the operator initiates the real-time program from the control processor's terminal. Upon receipt of a start signal, the data system processor initiates data acquisition placing data onto disk. Upon either a timeout or a terminate data acquisition signal from the control processor, the data system processor halts data collection.

7.1.4.4 Data Monitor.

This program enables the operator to analyze test results after a run. Once selected, the operator is presented with a menu of available options which include graphic displays, graphic plots, and tabulated data. If the graphic display option is chosen, the data are transformed into engineering units and displayed on the graphics terminal. The graphics programs enable the operator to view data from selected channels or a pre-established list of channels. Provisions are made to view either the entire run data or to zoom in on a segment. Although axis scales are normally automatically established, they can be manually chosen from the terminal or preprogrammed for consistency. Once the operator is satisfied with the presentation, he can command a hard copy plot of the viewed data. Additionally, data can be tabulated either on a single- or multiple-channel basis. Because of the vast amount of data, provisions will be made to control printout start/stop times as well as increment time.

7.2 FACILITY CONTROL AND STATUS MONITORING SYSTEM (FCSMS).

As shown in Figure 33, the FCSMS is a computer-based data acquisition and control system which provides the LB/TS with a sequence control, real-time event control, and subsystem monitoring function. It is able to evaluate and confirm the status of the system prior to the next sequential step in a run preparation process. Upper and lower parameters limits would be placed on each measurement channel with acceptable limits changed automatically at selected points in the pre-run sequence. Multiple sensors, logic for identification and exclusion of faulty sensors, and hold for operator intervention or abort logic would be built into the software to provide a safe, reliable system. Included is a link to the data system processor to coordinate activities between the two.

7.2.1 Signal Conditioning.

As with the data system, the FCSMS signal conditioning is provided to convert sensor input signals from pressure transducers, thermocouples, etc., to levels compatible with the ADC. For compatibility purposes, it is recommended that the signal conditioners used with the control system be identical to those used with the data system. Primary inputs to the system are the 70 facility measurements tabulated in Table 4 which are used for either facility control or status monitoring. Additionally, three flow environment and 15 thermal measurements are redundantly measured.

7.2.2 Input/Output Controller.

The input/output controller provides the analog-to-digital conversion of all input signals from the signal conditioning section and subsequent interfacing to the control processor. The multiplexer is selected for a nominal 100-KHz rate, based on sampling of channels for facility control purposes of 1000 S/S.

The output drivers required for solenoids, actuators, relays, and control valves as needed to effect facility control and timing coordination are also included in the input/output controller.

Functions to be controlled include:

- Run preparation events such as driver pump-up, status check of systems, etc.
- Run initiation events such as TRS light-off, high intensity camera light switch-on, camera starts, take data starts, etc.
- Run control events such as TRS monitoring and shut-off based on measured fluence, diaphragm rupture or valve opening, camera shutter control based on radiant intensity, RWE position control, etc.

The input/output controller consists of several relay output cards, analog output cards, digital input and output cards, and possibly a pulse train output channel to accomplish the real-time control outlined above.

7.2.3 FCSMS Computer System (Control Processor).

The FCSMS uses a high-speed minicomputer with 1 MByte of dedicated memory to accomplish the facility control. Because of the shared peripheral concept, the FCSMS processor is equipped with minimum peripherals. These include a small fixed disk, event recorder, and operator terminal. Processor performance data are identical with the data system processor performance.

7.2.4 System Operating Console.

All equipment required by the facility operations team, including system operating terminals for both the data acquisition system and the FCSMS, color display terminals, graphics terminals, basic annunciators, and visual system outputs, and video monitors will be included in the system operating console. A photograph of a system similar to that planned for the LB/TS is given in Figure 35. The console will be arranged to permit close coordination of test setup activities and post test data analysis activities without interference between separate functions. A five-camera video system--with monitors, remote camera control, and video recorders--is included for operator overview of the entire test complex.

7.2.5 Application Software.

Special application software programs are required to implement the various control system functions discussed above. As discussed in 7.1.4, application software should be designed using structured programming techniques to produce modular, maintainable, and modifiable/expandable software with full documentation.

Application software for the FCSMS falls into four major categories. Although the details cannot be established until the design is completed, a functional description of the various programs is detailed below.

7.2.5.1 System Calibration.

The purpose of this program is to periodically evaluate the total performance of the facility measurements acquisition system by applying precise inputs to the system automatically from the voltage source and measuring its performance. The analog system, excluding sensor power supplies, is tested as one complete unit on a per-channel basis to determine each analog channel's measurement uncertainty. The components tested include signal conditioners, amplifiers, filters, multiplexer, and analog-to-digital converter. Analog signals from a precision voltage source are to be input to each channel and to the digital response recorded.

7.2.5.2 FCSMS Monitoring.

This program is used to monitor and control pressurization of the drivers and heating of the driver gas and monitor the system status at

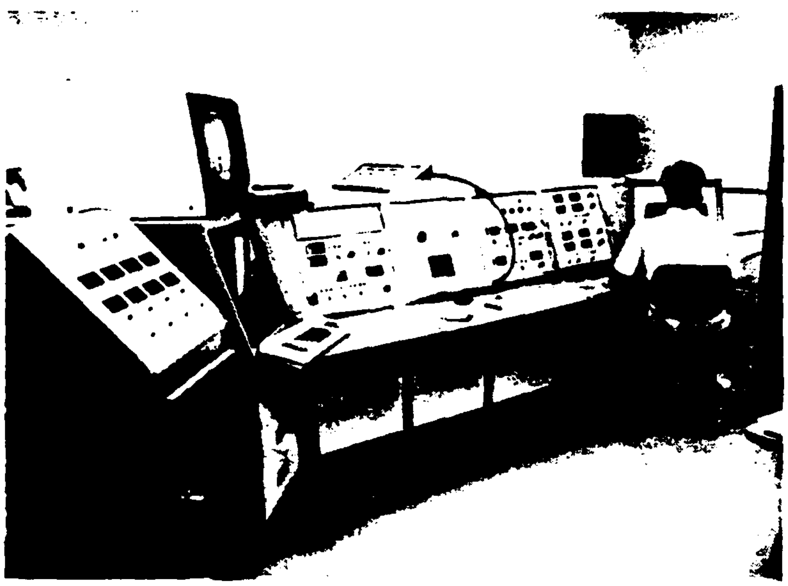

Figure 35. Representative system operating console.

all times. Out-of-tolerance events would result in annunciation to the system operator, generate a hold awaiting operator input, and/or system shutdown depending on the severity.

7.2.5.3 LB/TS Run.

This program is used to start the immediate prerun sequence and control events during the run itself. Real-time data conversion, checking against preset limits, accumulation of fault information, integration of sensor data, computation of control algorithms, control of events based on elapsed time and other similar functions are accomplished by this software routine.

7.2.5.4 LB/TS Post-Op.

A thorough functional check of the LB/TS system would be accomplished with this software routine and the system returned to a safe, secure status. A quick summary of status would be supplied to the system operator to permit plans for the next run to be made and to direct sensor repair efforts.

7.3 SYSTEM ACQUISITION PLAN.

The primary sensors, data acquisition, and control systems selected for the LB/TS concept study are based on either:

- existing technology which is commercially available in mid-1984, or
- modifications to current technology which are only a few months from commercial release and for which firm specifications and initial marketing dates are available

Technology which is clearly developmental and for which no firm performance levels or certain, high probability of success can be ascertained were avoided for primary systems. Such developmental sensors or system approaches were only included in the conceptual system where they provide a complement to another more proven approach. As an example, Inertial Reference Units are included even though their utility for measurement of whole body motion in the LB/TS remains to be proven. The most probable means for measuring whole body motion is the high-speed camera system as discussed in Section 4. In addition, several systems evaluated were discarded from the final conceptual systems due to a high cost/benefit ratio for the LB/TS environment as discussed in Section 4.

While proven, the LB/TS Sensor Data Acquisition and Control system (SDAC) is not available from a single manufacturer and must be:

- procured as individual hardware components from a number of manufacturers and integrated as a system by the Government or a third party. Such an acquisition plan necessitates a thorough, detailed system design (hardware and software) to ensure that all hardware interface constraints and operating software limitations are addressed in sufficient detail to produce a functional system meeting the performance specifications. In this mode, the third party can only assume responsibility for integration of equipment as designed, not for the performance of the equipment in the system or for the design itself.
- procured as a single system from a system integrator who accomplishes the detailed system design and selects specific hardware options to meet requirements. In this case, the system performance specification governs and the system integrator is responsible for selected hardware, interfacing hardware, and developing software to meet the performance requirements. Resolution of problems involving hardware, hardware interface, software or other system interaction problems are the responsibility of the integrator.

For complicated systems, such as the LB/TS SDAC with 1) specialized subsystems and hardware components from many manufacturers, 2) severe data transmission timing budgets, 3) the need for unique interface hardware, and 4) extensive special application and system operating software, Sverdrup recommends the second approach listed above.

This system acquisition process (design/build or turnkey) is illustrated for the LB/TS in Figure 36. Following the contract award, a period of about 15 months will be required to complete the design based on a well defined functional specification for the system, procure hardware and subsystems, integrate hardware in consoles, racks, etc., develop all software routines, functionally check all hardware and software, and install the system on-site. At the end of this period, a system which is ready and proven operational in all specified modes will be available.

The acquisition cost for the LB/TS SDAC is detailed in Table 14. Cost estimates for system hardware, software, sensors, special calibration equipment, installation and design/management are given. Data acquisition and FCSMS hardware costs shown in the table include interface hardware, racks, junction boxes, and other similar system integration costs associated with assembling the vendor-supplied equipment into a functional system.

Recall that the sensor costs discussed in Sections 3 and 4 include allowance for manufacture of numbers of specialized probes into which some sensors must be installed and for alignment and basic checkout of the non-intrusive systems. These special added costs for the sensors are included under Item IV in Table 14.

Total acquisition and installation cost for the system will be about $2,700,000, based on the complement of sensors listed. It is evident that compromises in the system--numbers of channels, numbers of sensors, etc.--can be made to reduce the cost estimate by 10 to 30 percent.

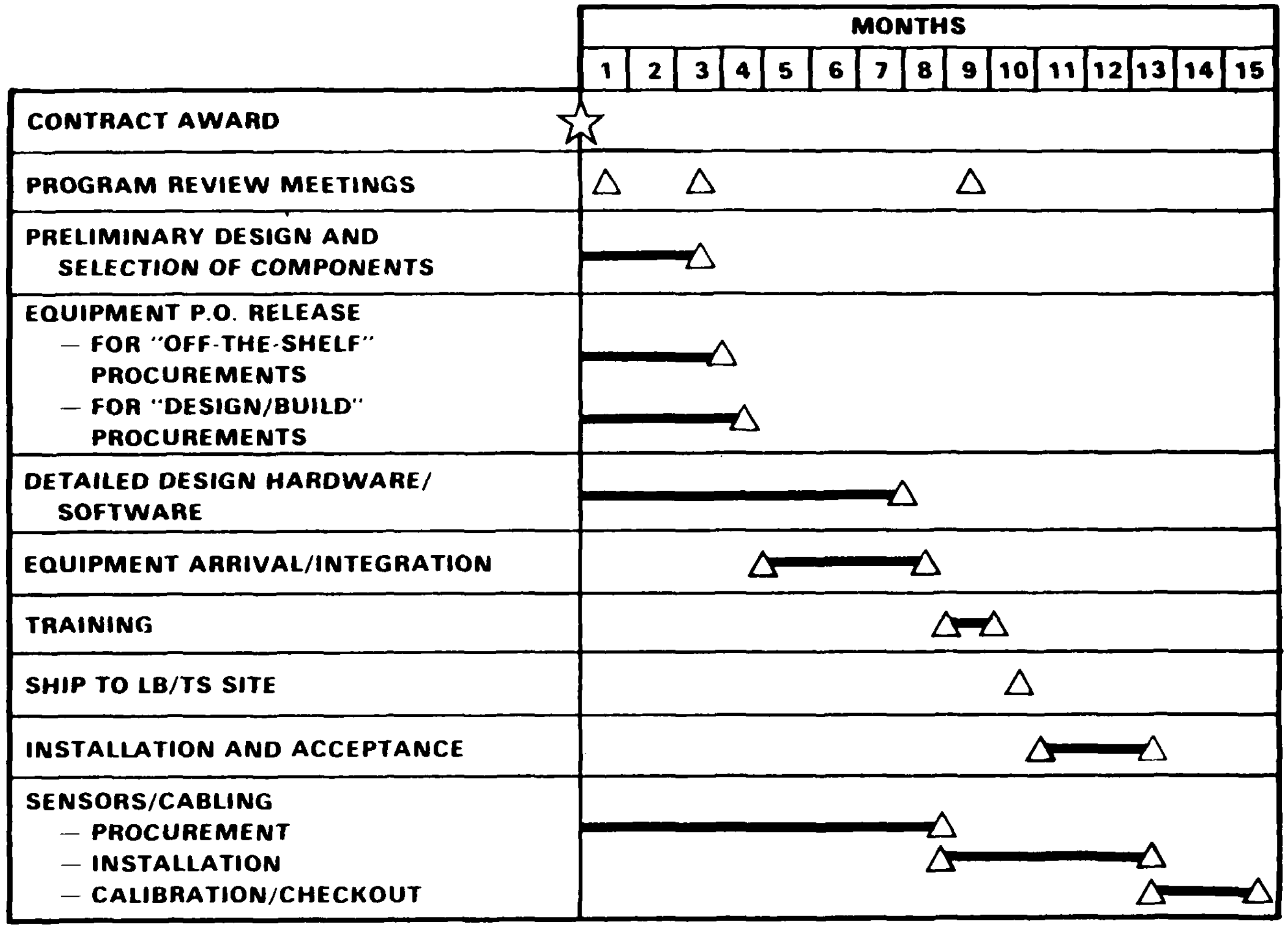

Figure 36. LB/TS system acquisition process.

Table 14. LB/TS sensor, data acquisition, and facility control system cost.

I. Hybrid Data Acquisition System

	Quantity	Cost Estimate
1) Digital - Signal Conditioning/ Amplifiers/Filters	44	$ 60,000
2) Digital - Sample/Hold	44	10,000
3) Digital - ADC with Driver	1	30,000
4) Digital - Selector	1	25,000
5) Analog - Signal Conditioners	64	85,000
6) Analog - Mux/Demux	10	99,500
7) Analog - Tape Recorder with Playback Combine	2	100,000
8) Processor with Memory	1	40,000
9) Fixed Disk, Mag Tape	1	28,000
10) Terminals	2	6,000
11) 200 CPS and 600 LPM Printers	2	17,500
12) Communications	1	12,000
13) Interface Cards	2	10,000
14) Operating System Software, Compiler	1	8,000
15) Voltage Standard	1	2,000
16) Misc Hardware	1	30,000
	I. Subtotal	$ 563,000

II. FCSMS

1) Signal Conditioning/Amplifiers/Filters	85	$ 85,000
2) Host Processor with Peripherals	1	40,000
3) Communications	1	10,000
4) Operating System Software, Compiler	1	8,000
5) Voltage Standard	1	2,000
6) I/O System	1	60,000
7) Video Monitor/Record System	5	25,000
8) Misc Hardware	1	40,000
	II. Subtotal	$ 270,000

III. Application Software Allowance $ 250,000

IV. Sensors and Measurement Systems (see Sections 3 and 4)

1) Pressure Transducers (incl. 4 reference probes)	64	$ 38,000
2) Temperature Sensors	140	14,000
3) Heat Flux Gages (incl. 5 reference probes	31	33,000
4) Strain Gages	50	5,000
5) Accelerometers	18	14,000

Table 14. LB/TS sensor, data acquisition, and facility control system cost. (Concluded)

	Quantity	Cost Estimate
6) Linear Potentiometers	40	4,000
7) Inertial Reference Unit	2	70,000
8) IR Pyrometers, Target Surface (two-color)	10	50,000
9) IR Pyrometers, TRS (two-color)	5	28,000
10) Thermovision System (two-color)	1	105,000
11) CVF Radiometer	1	100,000
12) Laser Velocimeter	1	113,000
13) High-Speed Photography System	16	182,000
14) High-Speed Video System	3	150,000
15) Automatic Video Reading System	1	20,000
16) Optron Displacement Follower	1	30,000
17) Sensor Procurement and Integration	LS	150,000
	IV. Subtotal	$1,106,000
V. Special Calibration Equipment		
1) Pressure Calibrator (portable)		$ 12,000
2) Temperature Calibrator (portable)		10,000
3) Heat Flux Calibrator (portable)		15,000
VI. Installation		
1) For Data Acquisition System (excluding sensors or cable)		$ 19,000
2) For FCSMS (excluding sensors or cables)		16,000
3) Sensors and Cabling		50,000
VII. Preliminary and Final Design, System Integration, and Management		$ 350,000
SDAC SYSTEM TOTAL		$2,661,000

SECTION 8
CONCLUSIONS

1. Parameter levels in the LB/TS flow (including the TRS) are not excessive compared to typical shock tube operating conditions. An incident shock Mach number of two or less with static overpressure of 240 kPa (340 kPa absolute) behind the shock, static temperature ratio of less than two times ambient, and flow velocity of about the speed of sound will occur. While rise times are of a few microseconds, important flow transients develop over seconds in the very large LB/TS.

2. Physical sensors for measurement of pressure, temperature, and heat flux in the ranges and with the response required by the LB/TS in both the diffraction and drag phases are available from many manufacturers. Mounting of these sensors within each specific target without compromising response--while protecting the sensor from damage and permitting in-place calibration--will present recurrent operation constraints for their use in the LB/TS.

3. Physical sensors for measurement of strain, acceleration, and displacement in the LB/TS environment are more specialized, more difficult to utilize in practice, and can be obtained from fewer commercial sources. Inertial rate gyro-based systems appear to be a possible method for measuring whole body motions if dust or other problems (condensation) obscure the target and prevent the use of optical (photographic) techniques for measuring whole body motion.

4. Reliable optical sensors exist for making selected flow and target response measurements over rather restricted parameter ranges and for limited environmental conditions. The most versatile system for many qualitative and quantitative measurements in the LB/TS is a complement of high-speed cameras and two special high-speed video cameras. Systems for automatic determination of

target position (and motion) from either film or video tape are available. Infrared sensors are also essential for monitoring the TRS source temperature and measuring target surface temperature distributions.

5. X-ray systems were evaluated to provide motion data for elements within the target or the whole target in the event of significant flow obscuration. Due to significant operating problems and high cost, the x-ray should only be used in the event of large flow obscuration beyond the levels presently anticipated.

6. Initial cost of a suitable inventory of physical sensors could approach $200,000 to $300,000 (see Section 3.6).

7. Cost of the optical systems ranges from $30,000 to $75,000 each with the total for all surveyed approaching $3,000,000. Cost for a complement of optical sensors including only those found to be practical in this study--IR pyrometers, thermovision, CVF radiometer, laser velocimeter, high-speed photography system, high-speed video system, automatic video reading system, and an Optron displacement follower--is $790,000 (see Section 4.10).

8. Both analog and digital data acquisition systems are commercially available which meet the very high speed data processing requirements of the 113 data channels of the LB/TS [1000-250,000 Hz bandwidth], including signal conditioning, data acquisition, host computer, etc. However, the aggregate sampling rates and commensurate storage volume for a 10-second run using a digital sampling theorem of 5 samples per cycle introduce an unwarranted element of risk into the pure digital system. For this reason, a hybrid analog/digital system is selected for the LB/TS data acquisition function.

9. A digital based facility control and status monitoring system, capable of monitoring facility preparation for a run and providing limited real-time control during a run, is practical at a total hardware and software cost of approximately $400,000.

10. A comprehensive sensor, data acquisition, and control (SDAC) system for the LB/TS is configured in Section 7 to accommodate the large number of system channels, the high sampling rates, and the real-time facility control. The system utilizes the hybrid analog/digital data acquisition concept and the digital FCSMS concept. Software to accomplish system calibration, data acquisition system setup, data acquisition during the run, data reduction and display, facility control, and facility status monitoring are defined.

11. A system acquisition plan for the LB/TS SDAC is shown to require 15 months and a budget of approximately $2,700,000, excluding inflation from mid-1984 and contingency.

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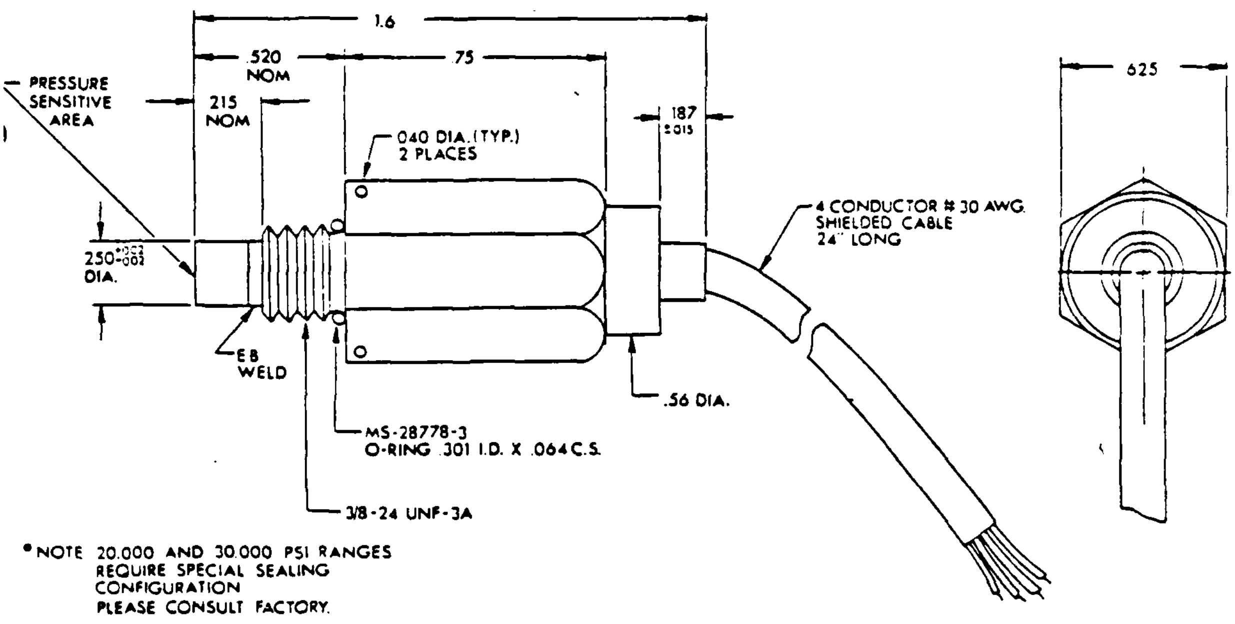
APPENDIX A

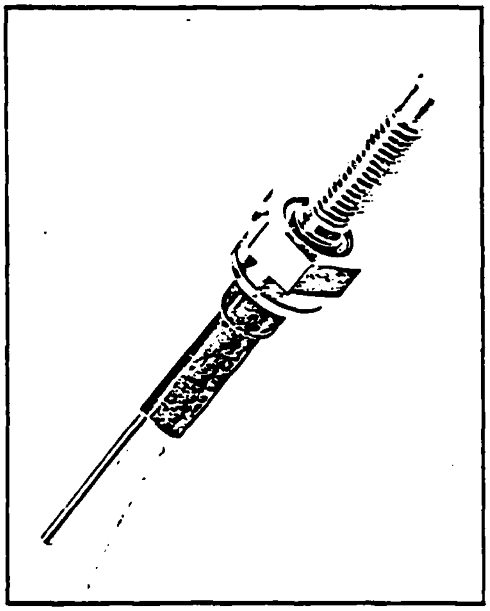
INTRUSIVE SENSOR SPECIFICATIONS APPLICABLE TO THE LB/TS FACILITY

kulite

BULLETIN KM-1000C

Kulite Miniature Metal Diaphragm Pressure Transducers





PRESSURE TRANSDUCERS

XTM-190/XTME-190 SERIES

Metal Diaphragm-Ruggedized

- Excellent Stability
- High Natural Frequencies
- 10-32 UNF Thread
- Robust Construction
- Inorganically Bonded Sensor

The XTM-190/XTME-190 miniature pressure transducers utilize a metal diaphragm as a force collector with a Piezoresistive Sensor as its sensing element. With the 10-32 UNF threaded body, hexagonal head and "O" ring seal, the XTM-190/XTME-190 is easy to mount and simple to apply. The small size and flush diaphragm permit direct installation of the transducer in the wall of pressure containers, tubes, pipes, etc., eliminating the need for costly, space consuming hardware.

Designed to be very rugged, the XTM-190/XTME-190 feature an internal temperature compensation module. In addition, a sturdy, four conductor shielded cable, with strain relief, is provided for electrical connection.

The standard XTM-190/XTME-190 transducers are designated as gage units. Pressure ranges of 250 psig and below are supplied with a venting tube.

Differential versions of all ranges are available. The reference pressure source should be dry, non-corrosive gas. Absolute and sealed versions of the XTM-190/XTME-190 have a reference pressure sealed in the transducer.

The all electron beam welded construction, and the wetted parts being of 17-4 PH stainless steel, make the XTM-190/XTME-190 sensing sides suitable for immersion in media which are compatible with the materials of construction. The "O" ring supplied as standard is a Buna N. Other materials can be supplied on request.

The XTME-190 is a high temperature version with maximum operating temperature of +500°F (260°C).

Kulite pressure transducers are calibrated individually by qualified technicians using equipment traceable to National Bureau of Standards. Pertinent data are included with units.

XTM-190/XTME-190 Specifications

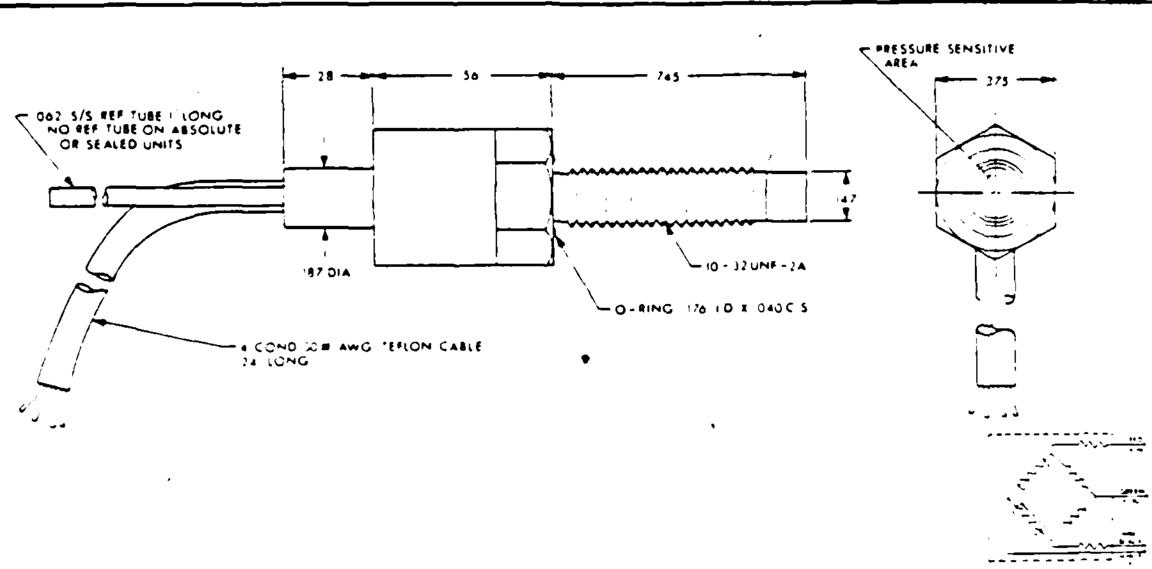
Model Number	Pressure (Rated)	Pressure (Maximum)	Output Sensitivity (Nom.)	Input Impedance (Ohms)	Output Impedance (Ohms)	Acceleration Sensitivity (Perpendicular)	Acceleration Sensitivity (Transverse)	Natural Frequency (Approx.)
XTM-190-10	10 psi	30 psi	30 mv	650 min.	650 max.	0.003% FS/g	0.0006% FS/g	30 KHz
XTM-190-25	25 psi	50 psi	75 mv	650 min.	650 max.	0.002% FS/g	0.0004% FS/g	50 KHz
XTM-190-50	50 psi	100 psi	75 mv	650 min.	750 max.	0.001% FS/g	0.0002% FS/g	60 KHz
XTM-190-100	100 psi	200 psi	75 mv	650 min.	750 max.	0.0007% FS/g	0.00014% FS/g	80 KHz
XTM-190-250	250 psi	500 psi	75 mv	650 min.	750 max.	0.0005% FS/g	0.0001% FS/g	125 KHz
XTM-190-500	500 psi	1000 psi	75 mv	650 min.	750 max.	0.0003% FS/g	0.00006% FS/g	160 KHz
XTM-190-1000	1000 psi	2000 psi	75 mv	650 min.	750 max.	0.0002% FS/g	0.00004% FS/g	225 KHz
XTM-190-2000	2000 psi	3000 psi	75 mv	650 min.	750 max.	0.00015% FS/g	0.00003% FS/g	300 KHz
XTM-190-5000	5000 psi	6000 psi	75 mv	650 min.	750 max.	0.0001% FS/g	0.00002% FS/g	400 KHz

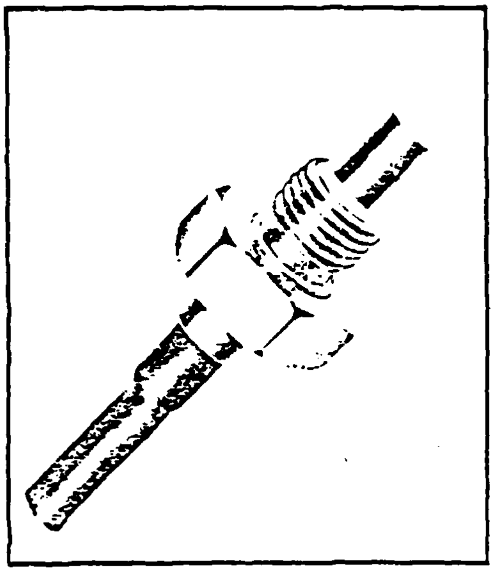
Sensing Principle	Inorganically bonded piezoresistive active half bridge
Pressure Media	Liquids and gases compatible with 17-4-PH stainless steel and "O" ring selected for the application (Buna-N "O" ring is supplied with standard units).
Excitation	10 VDC (15 VDC Max)
Zero Balance	±3% FS (±5% FS for 10psi units)
Combined Non-Linearity and Hysteresis	±1% FS max.
Repeatability	±0.25%
Compensated Temperature Range	80 F to 180 F (25 C to 80 C) Any 100 F range within the operating range on request.
Operating Temperature Range	O F to 250 F (−20 C to 120 C) Temperatures to 350 F (175 C) available on special order.
Change of Sensitivity with Temperature	±2%/100 F
Change of No-Load Output with Temperature	±2% FS/100 F (±5% FS for 10psi units)
Resolution	Infinite
Electrical connections	Per ISA-S37.3

XTME-190 High Temperature Version

Compensated Temperature Range	80°F to 450°F (27°C to 232°C)
Operating Temperature Range	−65°F to +500°F (−55°C to +260°C)
Change of Sensitivity with Temperature	Within 7% Over Compensated Temperature Range
Change of No-Load Output with Temperature	Within 10% Over Compensated Temperature Range

XTM-190/XTME-190 Series Outline





HIGH PRESSURE TRANSDUCER

HEM-375 SERIES

- High Temperature
- Excellent Stability
- High Natural Frequencies
- ⅜-24 UNF Thread
- Robust Construction
- Inorganically Bonded Sensor

The HEM-375 transducer has been developed by Kulite for duty at temperatures of up to 500°F.

An all metal, electron beam welded assembly, the HEM-375 features a metal diaphragm as a force collector with a Kulite Piezoresistive Sensor as its sensing element, inorganically bonded. This advanced construction results in a highly stable, reliable and rugged transducer.

The small size of the force collector allows the HEM-375 to be used for high frequency measurements. Shock pressure measurements can also be made successfully due to the high natural frequency and flat response of the transducer. High output and low impedance inherent in piezoresistive sensors make the HEM-375 ideal for use in hostile environments.

The Wheatstone bridge sensing principle is compatible with most strain gage signal conditioning equipment, avoiding the need for charge amplifiers, coaxial cables and impedance matching devices.

Materials of construction are 17-4 PH stainless steel and the silicone rubber O-ring. The all welded construction allows the transducer to be immersed in liquids compatible with the materials of construction.

Sealed and absolute units feature secondary containment.

kulite

BULLETIN KU-1000B

Kulite Subminiature IS® Silicon Diaphragm Pressure Transducers
(Probe Series)

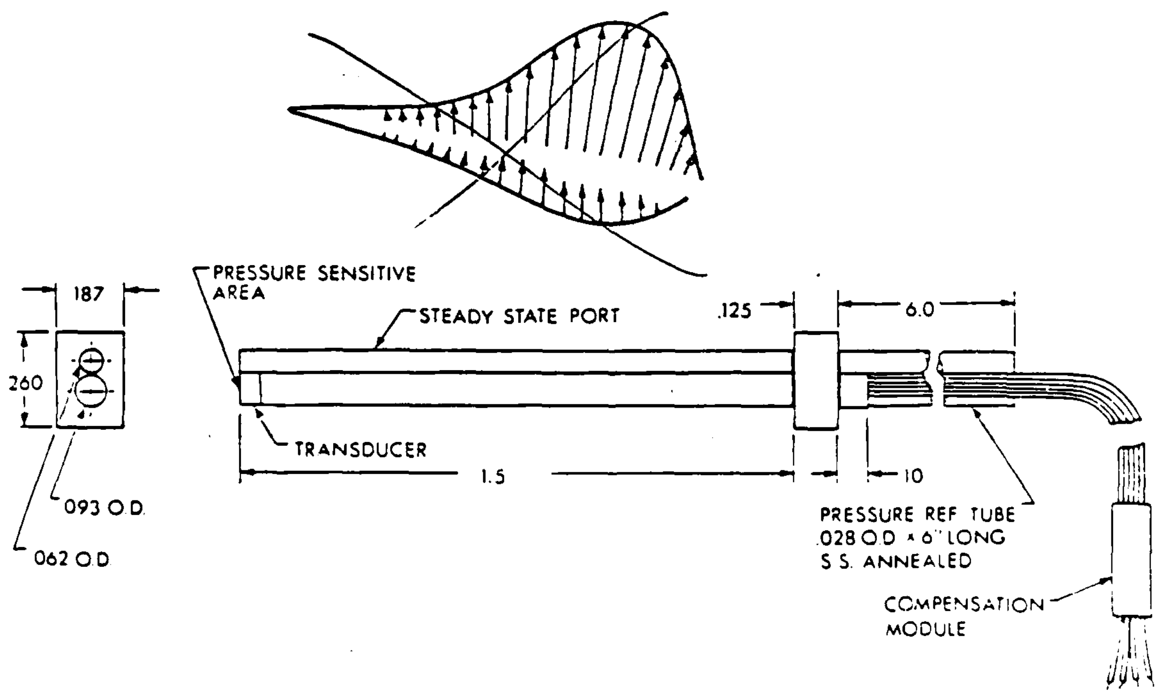


TABLE OF CONTENTS

INTRODUCTION

This product bulletin describes Kulite's unique line of Integrated Sensor Pressure Probes.

These solid state devices incorporate a diffused four arm wheatstone bridge on the surface of a silicon diaphragm. This approach originated by Kulite to meet the demands of the Aerospace Industry has been under constant development and evolution over the last fifteen years. Kulite pioneered the development of miniature dynamic pressure probes and today offers a line of miniature and ultraminiature devices with static and dynamic performance comparable to the very best transducers of any size currently commercially available.

These transducers have found wide acceptance in aerospace, for wind tunnel, flight test and acoustic measurements. They have established the industry standard of excellence for dynamic pressure measurement. The small size of these devices has made them uniquely suited to a large variety of test and production applications in industry, research and development and medicine.

Of particular note is the high natural frequency, low hysteresis and superior thermal and environmental performance. These features are the result of the integrated silicon sensor and silicon force collector. Silicon was originally adopted because of its large piezoresistive coefficient and compatibility with transistor fabrication techniques. Silicon has been found to possess excellent transducer characteristics.

Its combination of a high elastic modulus and low density along with the ability to be fabricated in very small sizes by photolithography allows for a sensor with a very high resonant frequency. The single crystal nature of silicon means virtually no creep or hysteresis. Piezoresistive Integrated Sensor technology is today's emergent transducer technology. Kulite continues to develop this piezoresistive technology and welcomes the challenge to meet the new requirements of the future.

The probes described in this bulletin are of a modular nature and allow the measurement system designer a maximum of flexibility in the mechanical design of his system. A variety of special probes are shown on pages 12 and 13. Kulite welcomes the opportunity to tailor a sensor to your specific requirements.

All Kulite probes are hermetically sealed to vacuum or ambient pressure when offered in sealed gage or absolute versions. Reference tubes are supplied with gage and differential versions.

Integrated Sensor probes are conventionally supplied with an external compensation module which provides zero balance, and temperature compensation. These modules contain only temperature insensitive trimming resistors and do not need to be at the same temperature as the transducer.

All transducers .080" and larger are provided standard with an "M" screen. This is a protective mesh which provides mechanical protection for the pressure sensitive surface. In applications such as wind tunnels where maximum protection from particles impact is required, a "B" type screen should be specified. This screen has a peripheral array of aperatures which provide increased particle protection while having a minimal effect on frequency response.

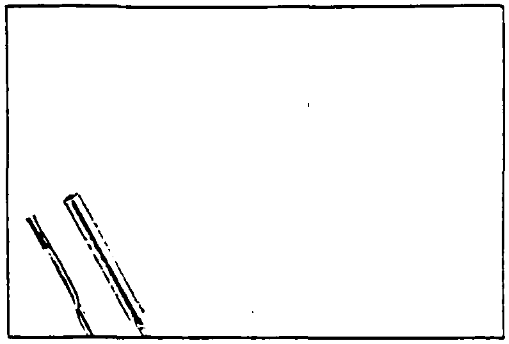
The .093" and larger probes are available in longer versions with internal compensation modules and shielded cables. Contact the factory for further information.

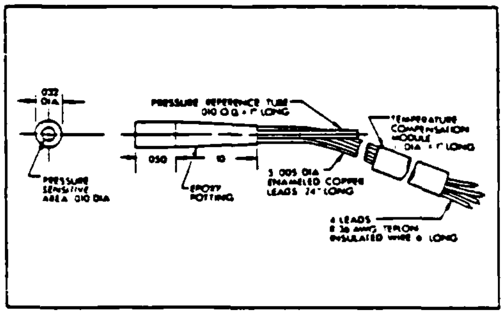
Kulite recognizes that the needs of the test community are unique. We have available a product support team of engineers experienced in this field ready to work with you to provide the proper instrument for a given application. Kulite stands ready to offer in depth technical assistance and rapid turnaround times when required.

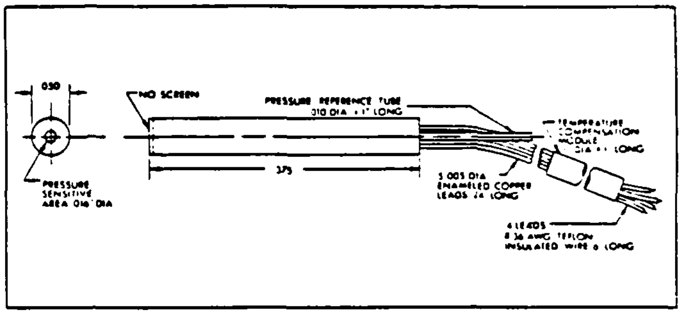
ULTRAMINIATURE IS® PRESSURE TRANSDUCERS

CQ-030 SERIES
XCQ-050 SERIES

- 1/32" Diameter
- For Dynamic Use Only
- Smallest Pressure Sensor Available
- Available Gage (G), Differential (D)





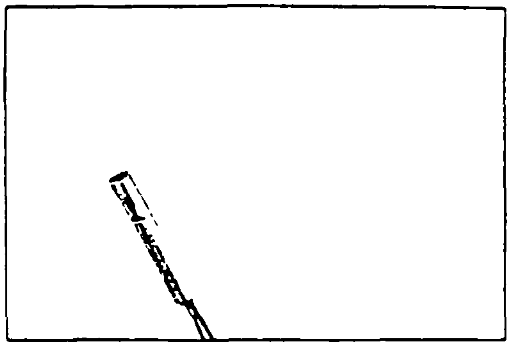


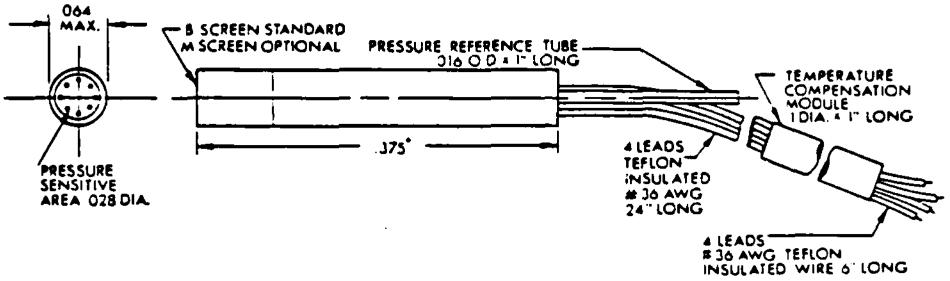
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm
Rated Pressure (psi)	100 (higher pressure ranges on request)
Over Pressure (psi)	3 Times rated pressure with no change in calibration
Full Scale Output (nom)	40mV
Excitation	5V DC or AC (7.5V max)
Input Impedance (min) Output Impedance (nom)	500Ω 750Ω
Combined Nonlinearity and Hysteresis	1.0% BFSL
Repeatability	0.5% FS
Natural Frequency	1500 kHz
Zero Balance	10% FS
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 100°F range within the operating range on request
Operating Temperature Range	0°F to 250°F (−20°C to 120°C) Temperatures to 350°F (175°C) optional
Maximum Change of Sensitivity With Temperature	8%/100°F—constant voltage excitation 4%/100°F—constant current excitation
Maximum Change of No Load Output With Temperature	±5% FS/100°F
Resolution	Infinite
Acceleration Sensitivity % FS/g Perpendicular Transverse	 001 0002
Weight (Excluding Module and Leads)	1 Gram (nom)

ULTRAMINIATURE IS® PRESSURE TRANSDUCER

XCQ-062 SERIES

- 1/16″ Diameter
- Available All Standard Pressure Ranges
- Ideal For Wind Tunnel Applications
- Excellent Static And Dynamic Performance
- Rugged
- Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)

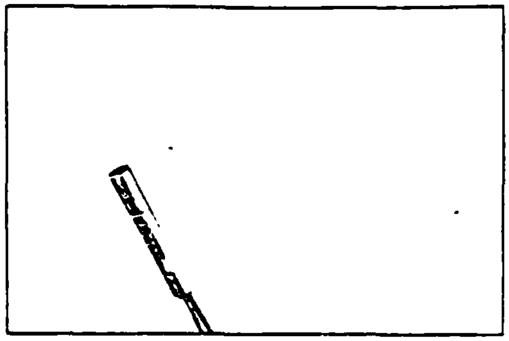




Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm			
Rated Pressure (psi)	25	50	100	250
Over Pressure (psi)	3 Times rated pressure with no change in calibration			
Full Scale Output (nom)	65mV	75mV		
Excitation	5V DC or AC (7.5V max)			
Input Impedance (min) Output Impedance (nom)	500Ω 750Ω			
Combined Nonlinearity and Hysteresis	0.5% BFSL			
Repeatability	0.1% FS			
Natural Frequency	500kHz	600kHz	1000kHz	1600kHz
Zero Balance	3% FS			
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 200°F range within the operating range on request			
Operating Temperature Range	−65°F to 250°F (−55°C to 120°C) Temperatures to 350°F (175°C) optional			
Maximum Change of Sensitivity with Temperature	8%/100°F—constant voltage excitation 2.5%/100°F—when excited as in note 1			
Maximum Change of No-Load Output With Temperature	2% FS/100°F			
Resolution	Infinite			
Acceleration Sensitivity % FS/g Perpendicular Transverse	0002 00004	00015 00003	0001 00002	00005 00001
Weight (Excluding Module and Leads)	2 Gram (nom)			

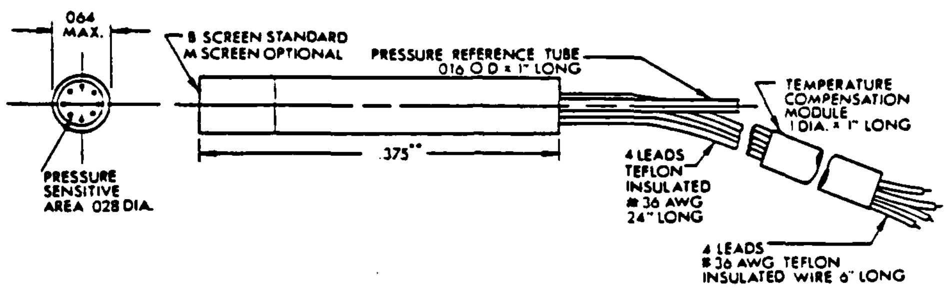
Note 1: When using a 15V constant voltage source with 1500 ohms in series with the transducer. This resistor may be supplied as part of compensation module.

HIGH SENSITIVITY ULTRAMINIATURE IS® PRESSURE TRANSDUCERS



XCS-062 SERIES HIGH IMPEDANCE
XCW-062 SERIES LOW IMPEDANCE

- **High Sensitivity**
- **Superior Signal To Noise Ratio**
- **Static And Dynamic Capability**
- **Wide Dynamic Range**
- **Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)**



	XCS-062		XCW-062	
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm			
Rated Pressure (psi)	5	15*	5	15*
Over Pressure (psi)	3 Times rated pressure with no change in calibration			
Full Scale Output (nom)	225mV	225mV	125mV	225mV
Excitation	15V DC or AC (20V max)			
Input Impedance (min) Output Impedance (nom)	1200Ω 2500Ω		800Ω 750Ω	
Combined Nonlinearity and Hysteresis	0.5% BFSL			
Repeatability	0.1% FS			
Natural Frequency	150kHz	250kHz	150kHz	250kHz
Zero Balance	3% FS			
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 200°F range within the operating range on request			
Operating Temperature Range	−65°F to 250°F (−55°C to 120°C) Temperatures to 350°F (175°C) optional			
Maximum Change of Sensitivity With Temperature	±2%/100°F			
Maximum Change of No-Load Output With Temperature	±2% FS/100°F			
Resolution	Infinite			
Acceleration Sensitivity % FS/g Perpendicular Transverse	005 0005	002 0002	005 0005	002 0002
Weight (Excluding Module and Leads)	2 Gram (nom)			

*Higher pressure ranges available upon request

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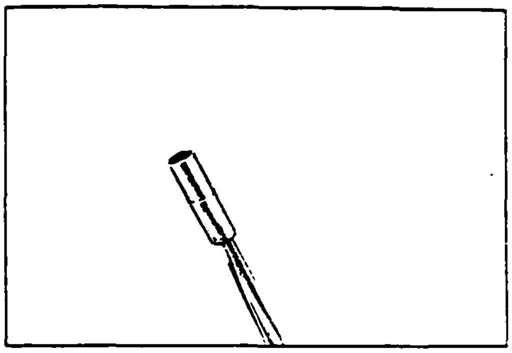
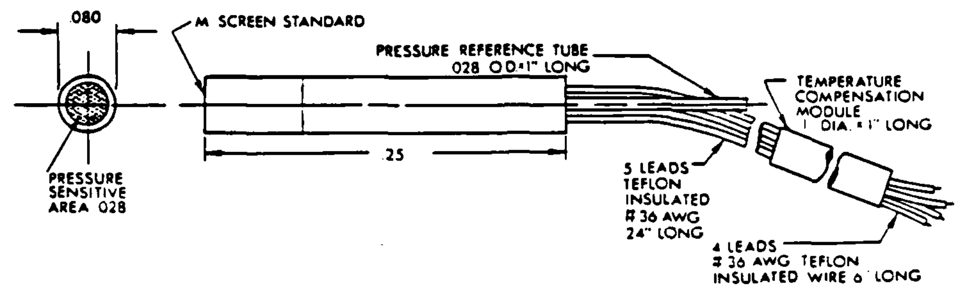
MINIATURE IS® PRESSURE TRANSDUCERS

XCQ-080 SERIES

- 2mm Diameter
- Static And Dynamic Capability
- High Natural Frequency
- 15 Year History Of Successful Applications In Wind Tunnel And Flight Test Programs
- Excellent Linearity
- Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)



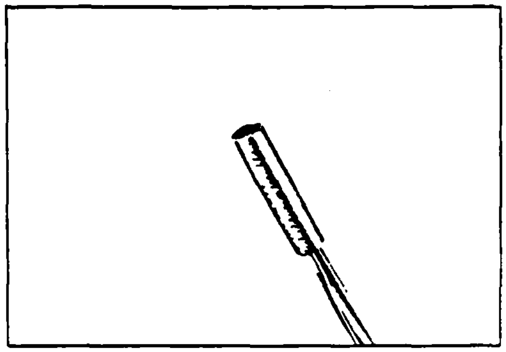


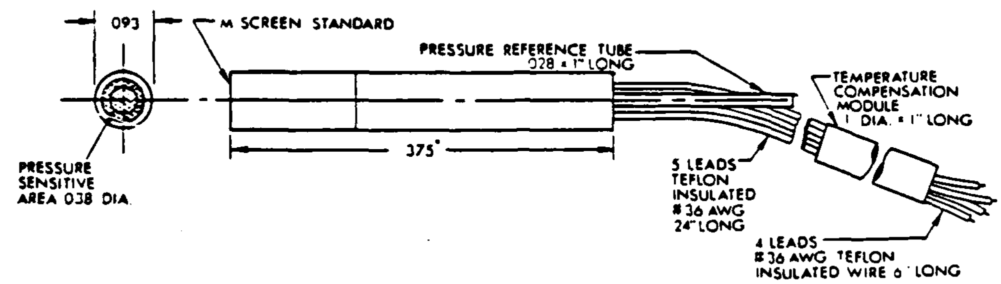
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm				
Rated Pressure (psi)	25	50	100	250	500
Over Pressure (psi)	3 Times rated pressure with no change in calibration				
Full Scale Output (nom)	65mV	75mV	100mV	100mV	100mV
Excitation	5V DC or AC (7.5V max)				
Input Impedance (min) Output Impedance (nom)	600Ω 750Ω				
Combined Nonlinearity and Hysteresis	0.5% BFSL				
Repeatability	0.1% FS				
Natural Frequency	200kHz	290kHz	360kHz	570kHz	810kHz
Zero Balance	3% FS				
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 200°F range within the operating range on request				
Operating Temperature Range	−65°F to 250°F (−55°C to 120°C) Temperatures to 350°F (175°C) optional				
Maximum Change of Sensitivity With Temperature	1.5%/100°F when excited as in note 1				
Maximum Change of No-Load Output With Temperature	.5% FS/100°F				
Resolution	Infinite				
Acceleration Sensitivity % FS/g Perpendicular Transverse	0002 00004	00015 00003	00009 000018	00005 00001	00004 0000C8
Weight (Excluding Module and Leads)	2 Gram (nom)				

STANDARD VERSION MINIATURE IS® PRESSURE TRANSDUCER

XCQ-093 SERIES

- 3/32" Diameter
- Industry Standard
- Superb Stability
- Program Qualified In U.S.A. And Europe
- Size And Shape Ideal For Incorporation In User Designed Probes
- Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)





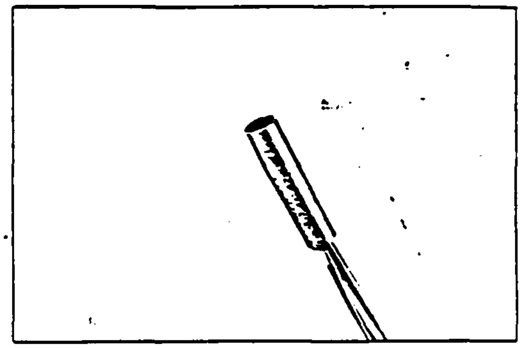
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm				
Rated Pressure (psi)	25	50	100	250	500
Over Pressure (psi)	3 Times rated pressure with no change in calibration				
Full Scale Output (nom)	65mV	75mV	100mV	100mV	100mV
Excitation	5V DC or AC (7.5V max)				
Input Impedance (min) Output Impedance (nom)	600Ω 750Ω				
Combined Nonlinearity and Hysteresis	0.5% BFSL				
Repeatability	0.1% FS				
Natural Frequency	200kHz	290kHz	360kHz	570kHz	810kHz
Zero Balance	3% FS				
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 200°F range within the operating range on request				
Operating Temperature Range	−65°F to 250°F (−55°C to 120°C) Temperatures to 350°F (175°C) optional				
Maximum Change of Sensitivity With Temperature	1.5%/100°F when excited as in note 1				
Maximum Change of No-Load Output With Temperature	.5% FS/100°F				
Resolution	Infinite				
Acceleration Sensitivity % FS/g Perpendicular Transverse	0002 00004	00015 00003	00009 000018	00005 .00001	00004 000008
Weight (Excluding Module and Leads)	4 Gram (nom)				

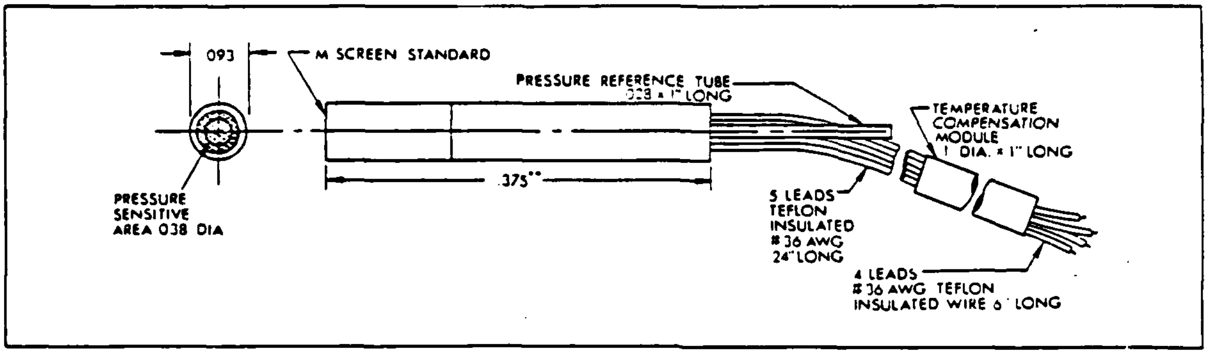
Note 1: When using a 15V constant voltage source with 1500 ohms in series with the transducer

HIGH SENSITIVITY MINIATURE IS® PRESSURE TRANSDUCERS

XCS-093 SERIES HIGH IMPEDANCE
XCW-093 LOW IMPEDANCE

- 3/32" Diameter
- High Sensitivity
- High Signal To Noise Ratio
- Static And Dynamic Capability
- Wide Dynamic Range
- Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)





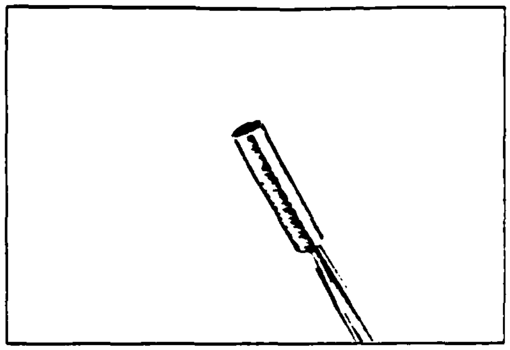
	XCS-093				XCW-093	
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm					
Rated Pressure (psi)	5	15	25	50*	5	15
Over Pressure (psi)	3 Times rated pressure with no change in calibration					
Full Scale Output (nom)	225mV	225mV	300mV	300mV	150mV	200mV
Excitation	15V DC or AC (20V max)					
Input Impedance (min) Output Impedance (nom)	1200Ω 2500Ω				800Ω 750Ω	
Combined Nonlinearity and Hysteresis	0.5% BFSL					
Repeatability	0.1% FS					
Natural Frequency	100kHz	150kHz	200kHz	275kHz	100kHz	150kHz
Zero Balance	3% FS					
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 200°F range within the operating range on request					
Operating Temperature Range	−65°F to 250°F (−55°C to 120°C) *Temperatures to 350°F (175°C) optional*					
Maximum Change of Sensitivity With Temperature	±2%/100°F					
Maximum Change of No-Load Output With Temperature	±2% FS/100°F					
Resolution	Infinite					
Acceleration Sensitivity % FS/g Perpendicular Transverse	005 0005	002 0002	0016 00016	001 0001	005 0005	002 0002
Weight (Excluding Module and Leads)	4 Gram (nom)					

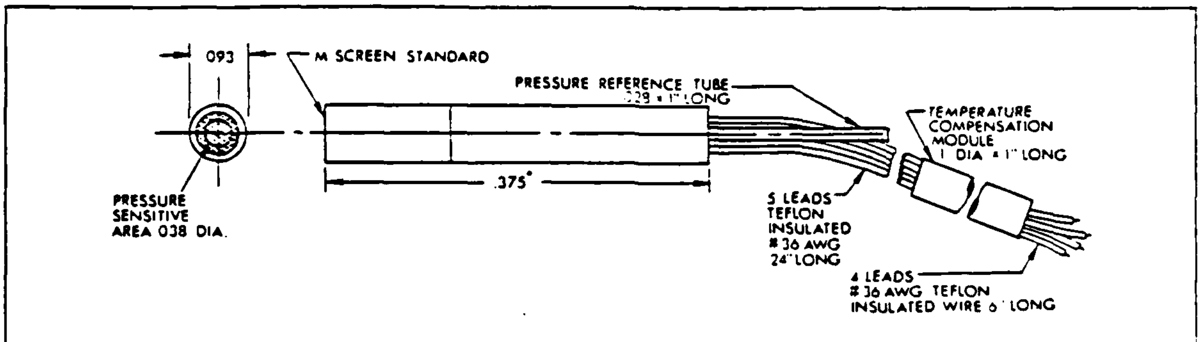
*Higher pressure ranges available upon request

HIGH TEMPERATURE MINIATURE IS® PRESSURE TRANSDUCER

XCE-093 SERIES

- 3/32" Diameter
- New Product 1980's Technology
- Wide Temperature Capability −65°F To 525°F
- Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)





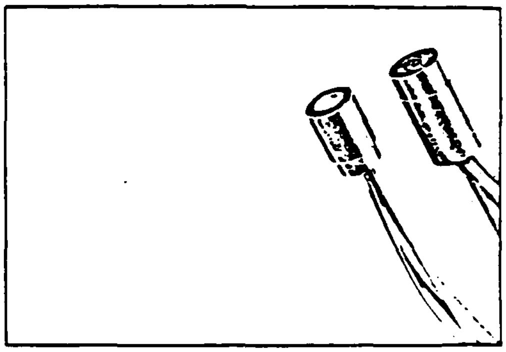
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm			
Rated Pressure (psi)	25	50	100	250
Over Pressure (psi)	3 Times rated pressure with no change in calibration			
Full Scale Output (nom)	50mV	100mV	100mV	100mV
Excitation	15V DC or AC (20V max)			
Input Impedance (min) Output Impedance (nom)	1000Ω 750Ω			
Combined Nonlinearity and Hysteresis	0.5% BFSL			
Repeatability	0.25%			
Natural Frequency	200kHz	290kHz	360kHz	510kHz
Zero Balance	5% FS			
Compensated Temperature Range	80°F to 450°F (25°C to 235°C)			
Operating Temperature Range	−65°F to 525°F (−55°C to 273°C)			
Maximum Change of Sensitivity With Temperature	Within 10% over compensated range			
Maximum Change of No-Load Output With Temperature	Within 20% over compensated range			
Resolution	Infinite			
Acceleration Sensitivity %FS g Perpendicular Transverse	0002 00004	00015 00003	00009 000018	00006 000012
Weight (Excluding Module and Leads)	4 Gram (nom)			

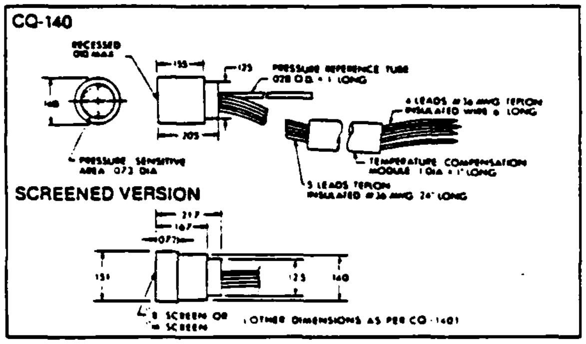
*Shorter or longer lengths available on request

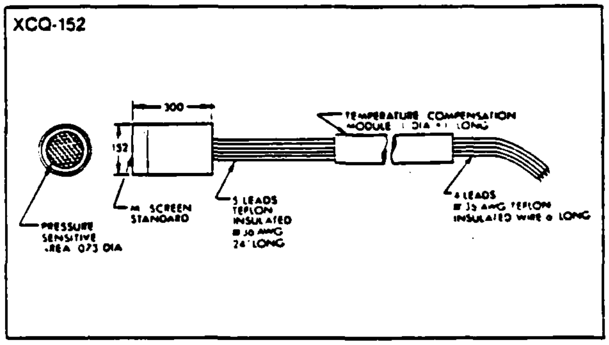
SHORT LENGTH IS® PRESSURE TRANSDUCERS

CQ-140 SERIES
XCQ-152 SERIES

- .140" And .152" Diameter
- High Natural Frequency
- Available 5 PSI to 500 PSI
- Short Body
- Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)







Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm						
Rated Pressure (psi)	5	10	25	50	100	250	500
Over Pressure (psi)	3 Times rated pressure with no change in calibration						
Full Scale Output (nom)	100mV						
Excitation	10V DC or AC (15V max)						
Input Impedance (min) Output Impedance (nom)	500Ω 350Ω						
Combined Nonlinearity and Hysteresis	0.5% BFSL						
Repeatability	0.1%						
Natural Frequency	70kHz	70kHz	100kHz	130kHz	160kHz	240kHz	350kHz
Zero Balance	3% FS						
Compensated Temperature Range	80°F to 180°F (25°C to 80°C) Any 200°F range within the operating range on request						
Operating Temperature Range	−65°F to 250°F (−20°C to 150°C) Temperatures to 350°F (175°C) optional						
Maximum Change of Sensitivity With Temperature	± 2%/100°F						
Maximum Change of No-Load Output With Temperature	± 1% FS/100°F						
Resolution	Infinite						
Acceleration Sensitivity % FS/g Perpendicular Transverse	002 0004	001 0002	0005 0001	0004 00008	0002 0000 4	00012 000024	00009 000018
Weight (Excluding Module and Leads)	4 Gram (nom) CQ-140				6 Gram (nom) XCQ-152		

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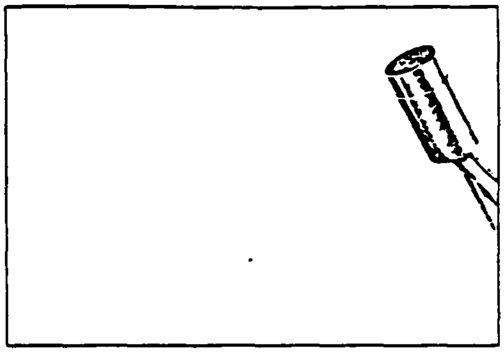
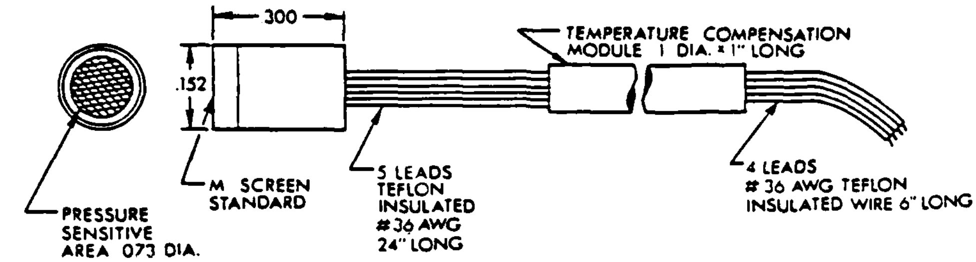
HIGH TEMPERATURE IS® PRESSURE TRANSDUCER

XCE-152 SERIES

- **Wide Temperature Capability − 65°F To 525°F**
- **High Natural Frequency**
- **Extra Low g Sensitivity**
- **Advanced Dielectric Technology**
- **Available Gage (G), Sealed Gage (SG), Differential (D), Absolute (A)**





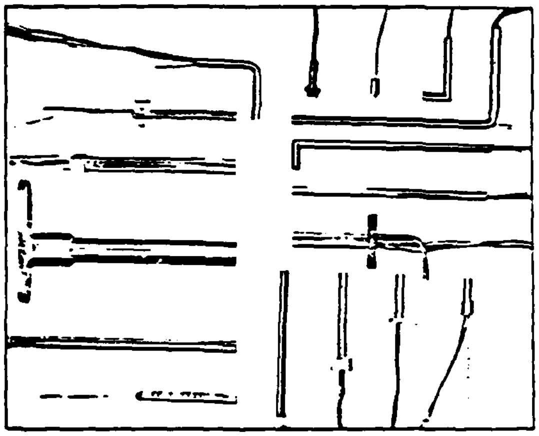
Bridge Type	Fully active four arm Wheatstone Bridge diffused into silicon diaphragm				
Rated Pressure (psi)	25	50	100	250	500
Over Pressure (psi)	3 Times rated pressure with no change in calibration				
Full Scale Output (nom)	50mV	100mV	100mV	100mV	75mV
Excitation	15V DC or AC (20V max)	10V DC or AC (20V max)			
Input Impedance (min) Output Impedance (nom)	2000Ω 1000Ω				
Combined Nonlinearity and Hysteresis	0.5% BFSL				
Repeatability	0.2% FS				
Natural Frequency	100kHz	100kHz	130kHz	240kHz	350kHz
Zero Balance	5% FS				
Compensated Temperature Range*	80°F to 450°F (25°C to 235°C)				
Operating Temperature Range	− 65°F to 525°F (− 55°C to 273°C)				
Maximum Change of Sensitivity With Temperature	Within 5% over compensated range				
Maximum Change of No-Load Output With Temperature	2% FS/100°F				
Resolution	Infinite				
Acceleration Sensitivity % FS/g Perpendicular Transverse	0005 0001	00025 00005	0002 00004	00014 00002	00008 000016
Weight (Excluding Module and Leads)	6 Gram (nom)				

*Compensated temperature range to 525°F available

TYPICAL PROBE CONFIGURATIONS

Integrated Sensor Pressure Transducers are ideally suited for adaptation into custom packages.

The probes illustrated represent a sampling of hundreds of probes designed together by Kulite and our customers to meet a specific application. They are representative of our capability to provide custom instrumentation suited to the needs of the user.



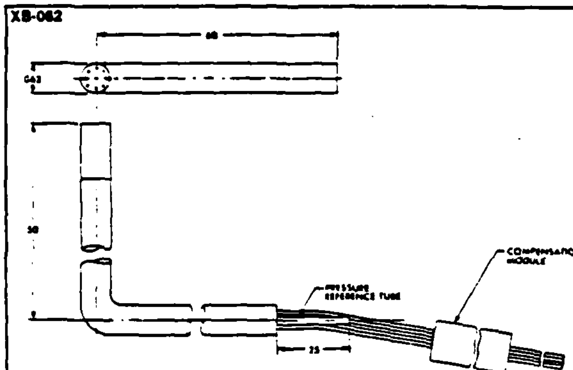
ORDERING INFORMATION

Probes should be ordered by type, and reference must be *made to the relevant electrical performance specifications*, for example:

XB-4-062 Mechanical Configuration

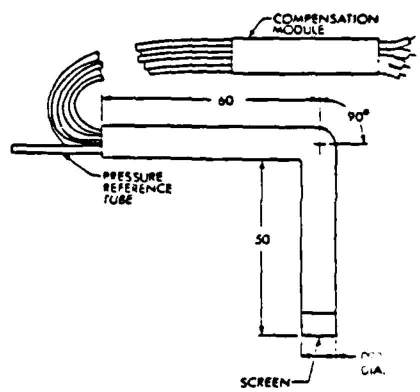
XCW-062-5 Performance Specification

XB-062



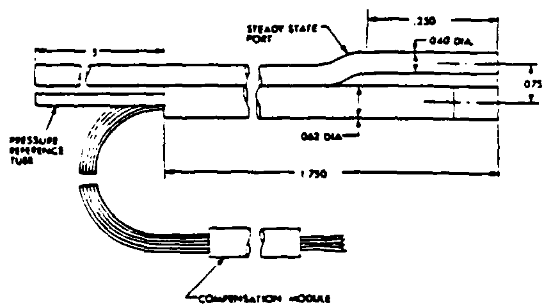
Specifications see: XCQ, XCS/XCW-062

XB-093



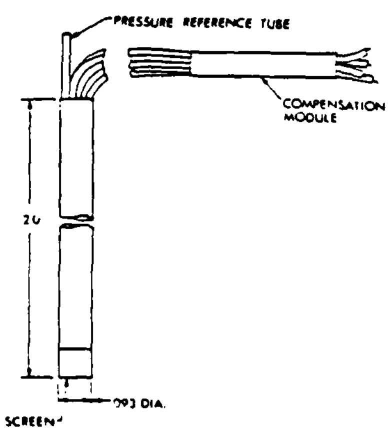
Specifications see: XCQ, XCS/XCW-093

XDB-062



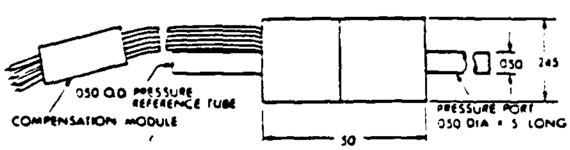
Specifications see: XCQ, XCS/XCW-062

XQ-093



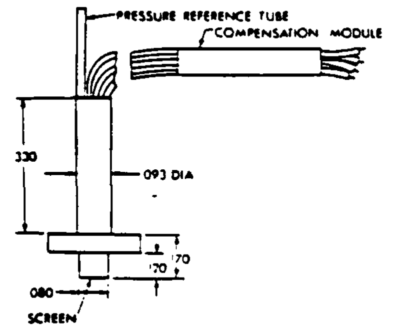
Specifications see: XCQ, XCS/XCW-093

YQC-250



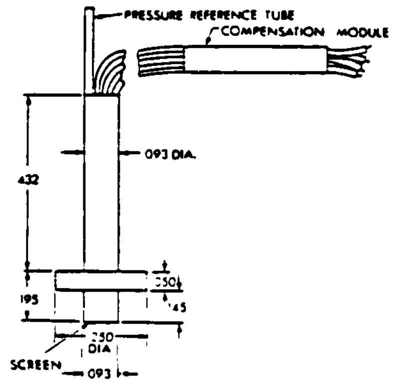
Specifications see: CQ-140

XS-080



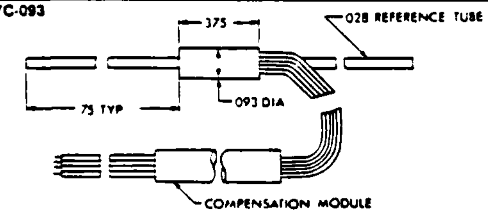
Specifications see: XCQ-080

XS-093



Specifications see: XCQ, XCS/XCW-093

YC-093



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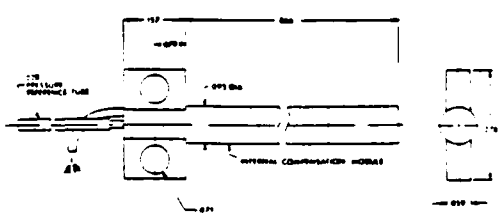
XC-10-093



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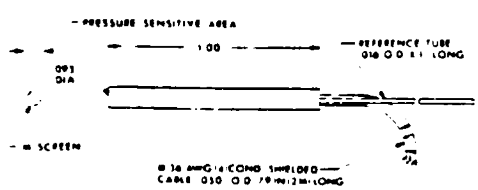
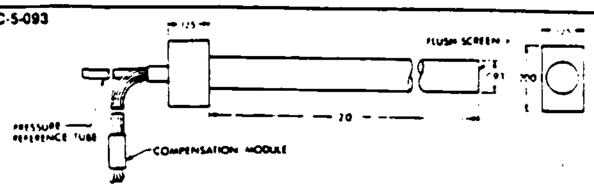
XC-77-093



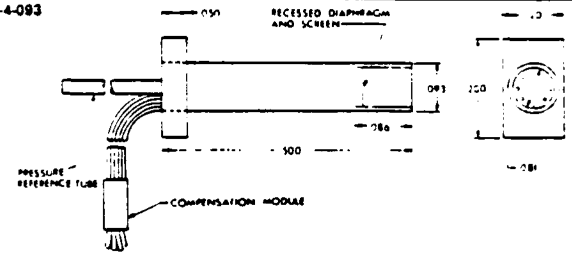
Specifications see: XCQ, XCS/XCW-093

XC-5-093



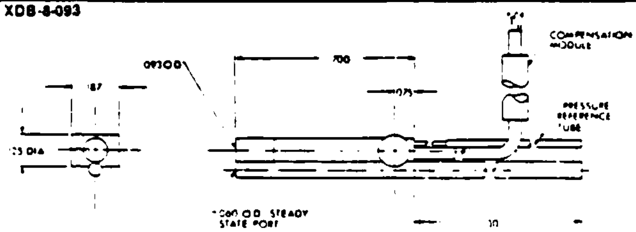
Specifications see: XCQ, XCS/XCW-093

XC-4-093



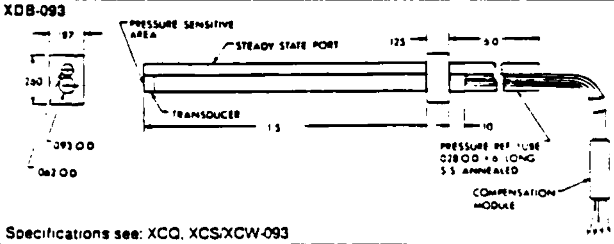
Specifications see: XCQ, XCS/XCW-093

XDB-8-093



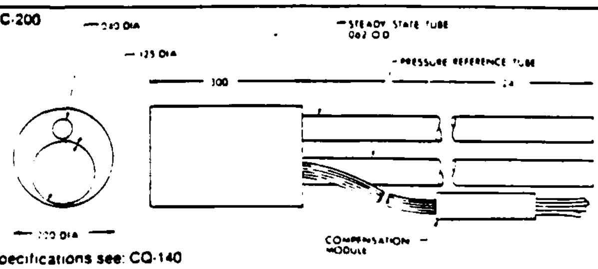
Specifications see: XCQ, XCS/XCW-093

XDB-093



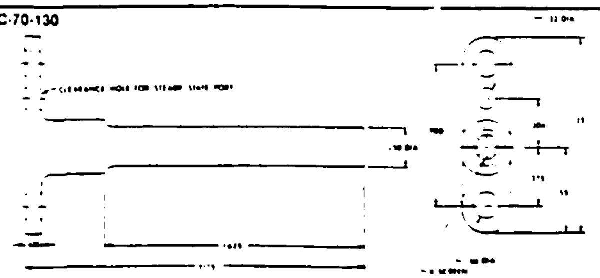
Specifications see: XCQ, XCS/XCW-093

XC-200



Specifications see: CQ-140

XC-70-130



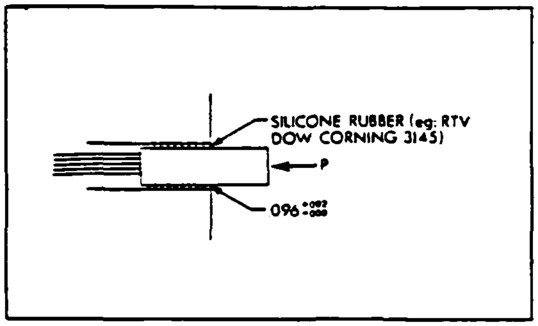
Specifications see: CQ-140, XCE-152

APPLICATION DATA

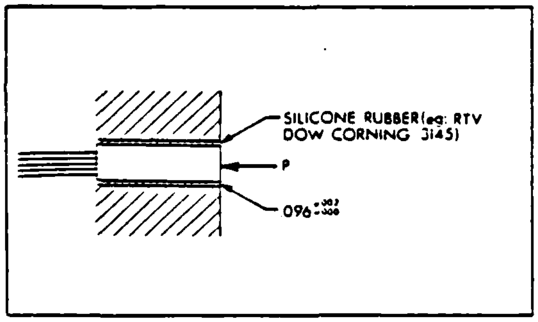
MOUNTING

Integrated Sensor pressure sensing probes are suitable for mounting in a variety of installations. The transducer should be soft mounted if it is to be removed at a later date. These transducers have a minimal case sensitivity and hard mounting with epoxy is acceptable. Some typical installations are shown below:

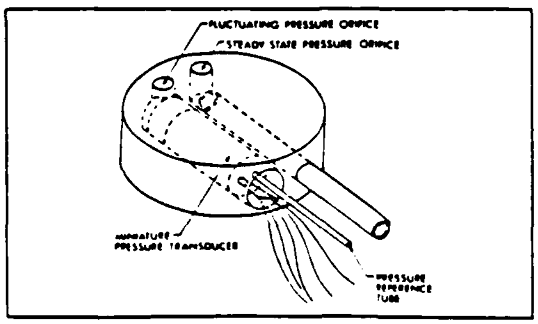
END MOUNT



FLUSH MOUNT

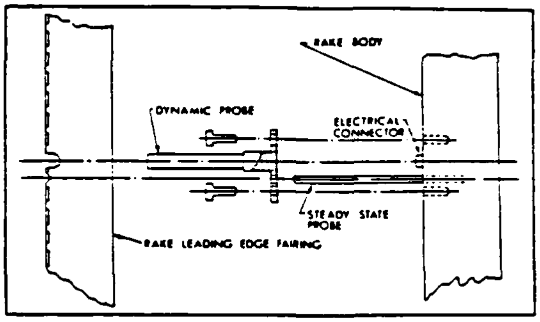


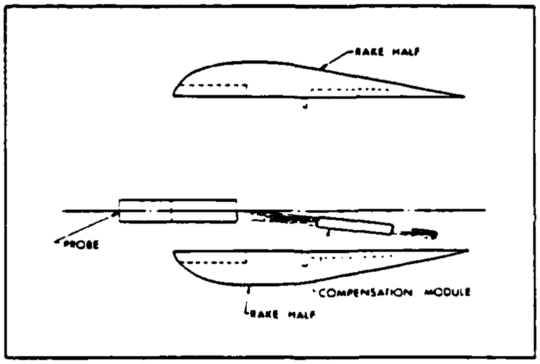
SIDE MOUNT



The external compensation module contains only temperature insensitive resistors and need not be in the same temperature environment as the transducer and may be mounted at any convenient location.

These probes are particularly suitable for rake fabrication. Two techniques which have been very successfully employed are shown below:





PARTICLE IMPACT AND THERMAL TRANSIENT PROTECTION

The Kulite Integrated Pressure Probes have found a wide application in wind tunnel, engine and flight test work. In certain applications such as total pressure measurement in supersonic wind tunnels, it is desirable to provide means for protecting the diaphragm.

Two basic methods used for protection are:

1. Coating the diaphragm with a protective layer such as Silicone Rubber, RTV, Silastic, etc.
2. Shielding the diaphragm with a perforated screen.

Typically, both a protective layer and screen are utilized. Many versions of the Kulite Pressure Probes with protective devices are commonly employed. They have satisfactorily performed under the most severe conditions and have resisted particle impingement in supersonic wind tunnel work. The data available indicates that the most effective method for general purpose protection is the use of both a protective coating and a perforated screen.

COATING

The material used by Kulite to coat the diaphragm is RTV-511, manufactured by General Electric. It has a low modulus of elasticity and is easy to apply. Generally a nominal thickness of .003" is used.

Tests indicate that the protective layer does not significantly change the static or dynamic characteristics of the transducer. A slight deterioration in the acceleration sensitivity of the transducer is to be expected. However, since the inherent acceleration sensitivity of the uncoated units is extremely low, the coated units still have an acceleration sensitivity superior to other commercially available miniature pressure transducers.

All Kulite Transducers can be supplied with RTV coating at no extra charge.

SCREENS

Two types of screens are available from Kulite.

"M" TYPE SCREEN

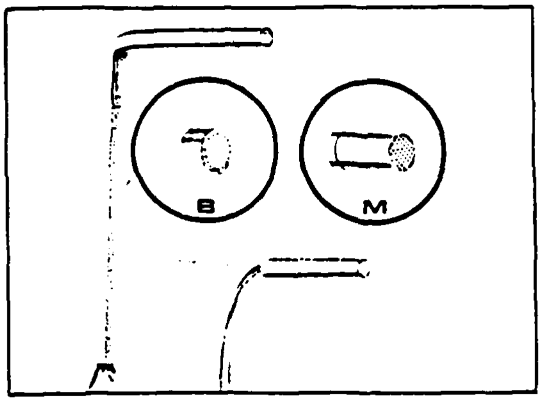
This screen consists of a .005" thick fine metallic mesh. The hole sizes are .006" diameter.

"B" TYPE SCREEN

This screen consists of a .005" thick plate with .006" diameter holes positioned on a circle. The diameter of the circle is greater than the active diameter of the diaphragm. This arrangement eliminates any possibility of a particle penetrating through the holes and hitting the unclamped portion of the diaphragm.

These screens are mounted in a screen holder which is installed on the transducer housing in front of the diaphragm. The minimum distance between the diaphragm and the screen is .005". Other distances may be used in accordance with application requirements. Distances of .006" and .013" between the diaphragm and screen are used in the standard Kulite probes.

Most Kulite Integrated Sensor Pressure Probes are supplied standard with an "M" screen. "B" screens may be ordered as an option.



Test results indicate that the screen assembly does not cause a deterioration in the static performance of the transducer. Furthermore, it does not have any effect on the dynamic response from 20 Hz to 20 kHz as shown in the curves of Figures 1 and 2.

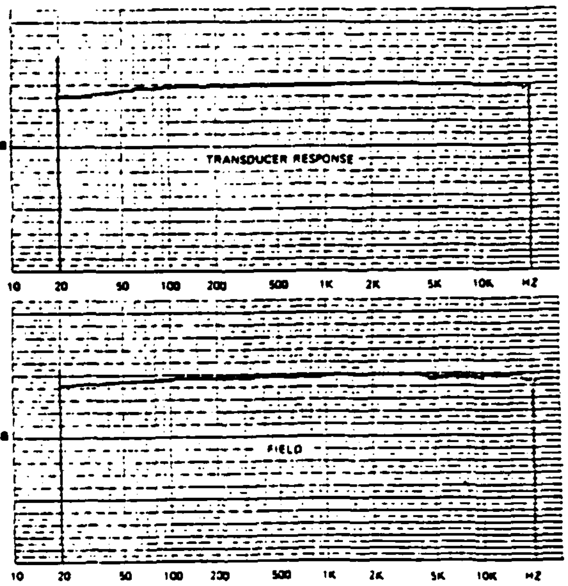
Figure 1 is obtained by subjecting a CQL-080-25 transducer fitted with a screen assembly, to a constant sound pressure field of 140 dB acoustic over a frequency range of 20 Hz to 20 kHz. The sound pressure field and the resultant dynamic response curve indicated that the transducer's response is flat.

The curves shown in Figure 2 were obtained using an air jet which produced a white noise spectrum. The transducer both with and without a screen assembly was subjected to the air jet at angles of 0° and 30°. The transducer output was subjected to a narrow band analysis which established that up to 30° angle of attack there were no noticeable effects.

The screen assembly can be supplied either permanently mounted on the transducer or separately for applications where it is desirable to have a removable screen.

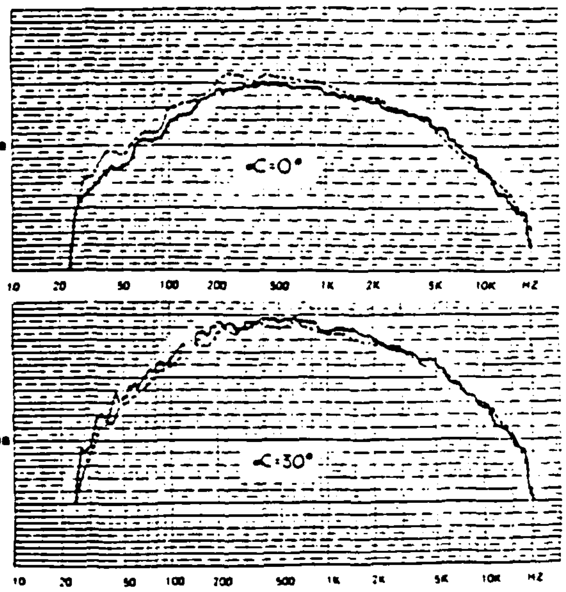
Screen assemblies for standard Kulite pressure sensors and probes may be obtained at a small additional charge. For additional details, contact Kulite Semiconductor - Applications Engineering - telephone (201) 945-3000.

FIGURE 1



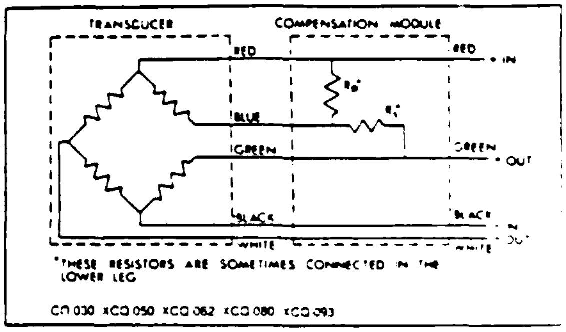
Note All ordinate divisions are equivalent to .5 dba

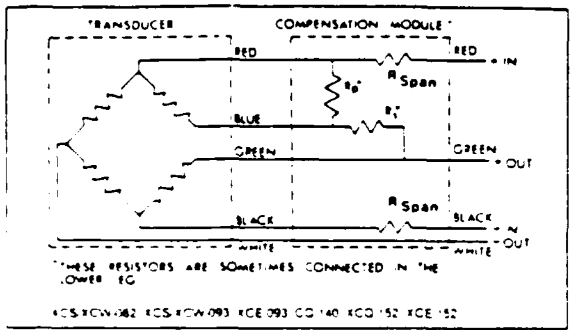
FIGURE 2



··· BARE TRANSDUCER —— WITH SCREEN

WIRING (ISA STANDARD)





SOUND PRESSURE LEVEL (SPL) TO PSI CONVERSION CHART

SPL	PSI (RMS)	SPL	PSI (RMS)	SPL	PSI (RMS)	SPL	PSI (RMS)	SPL	PSI (RMS)	SPL	PSI (RMS)
110	0.0009	124	0.0046	138	0.0230	152	0.12	166	0.58	180	2.90
111	0.0010	125	0.0052	139	0.0258	153	0.13	167	0.65	181	3.25
112	0.0012	126	0.0058	140	0.0290	154	0.15	168	0.73	182	3.65
113	0.0013	127	0.0065	141	0.0325	155	0.16	169	0.82	183	4.10
114	0.0015	128	0.0073	142	0.0365	156	0.18	170	0.92	184	4.60
115	0.0016	129	0.0082	143	0.0410	157	0.21	171	1.03	185	5.16
116	0.0018	130	0.0092	144	0.0460	158	0.23	172	1.15	186	5.79
117	0.0021	131	0.0103	145	0.0516	159	0.26	173	1.30	187	6.49
118	0.0023	132	0.0115	146	0.0579	160	0.29	174	1.45	188	7.28
119	0.0026	133	0.0130	147	0.0649	161	0.33	175	1.63	189	8.17
120	0.0029	134	0.0145	148	0.0728	162	0.37	176	1.83	190	9.17
121	0.0033	135	0.0163	149	0.0817	163	0.41	177	2.05	191	10.29
122	0.0037	136	0.0183	150	0.0917	164	0.46	178	2.30	192	11.54
123	0.0041	137	0.0205	151	0.1029	165	0.52	179	2.58	193	12.95

SPL in dba re .0002 dynes/cm²

REF: GAIN 1	Ratio	2	5	10	20	50	100	200	316	500	1000
	DB	6	14	20	26	34	40	46	50	54	60
REF: GAIN 1000	Ratio	2	5	10	20	50	100	200	316	500	1000
	DB	−54	−46	−40	−34	−26	−20	−14	−10	−6	0

PRESSURE CONVERSION CHART

1 UNIT OF ↓ EQUALS →	PSI	PSF	Dyne/cm²	Newton/m² (Pascal)	Atmos	Bar	Inch of Water	mm of Mercury (Torr)	Inch of Mercury	k Pa
PSI	1.000	1.440 × 10[illegible]	6.895 × 10[illegible]	6.895 × 10[illegible]	6.804 × 10[illegible]	6.895 × 10[illegible]	2.768 × 10[illegible]	5.171 × 10[illegible]	2.036	6.895
PSF	6.944 × 10[illegible]	1.000	4.788 × 10[illegible]	4.[illegible] × 10[illegible]	4.[illegible] × 10[illegible]	4.[illegible] × 10[illegible]	1.922 × 10[illegible]	3.591 × 10[illegible]	1.414 × 10[illegible]	4.[illegible] × 10[illegible]
Dyne/cm²	1.450 × 10[illegible]	2.089 × 10[illegible]	1.000	1.000 × 10[illegible]	9.869 × 10[illegible]	1.000 × 10[illegible]	4.015 × 10[illegible]	7.501 × 10[illegible]	2.953 × 10[illegible]	1.000 × 10[illegible]
Newton/m² (Pascal)	1.450 × 10[illegible]	2.089 × 10[illegible]	1.000 × 10[illegible]	1.000	9.869 × 10[illegible]	1.000 × 10[illegible]	4.015 × 10[illegible]	7.501 × 10[illegible]	2.953 × 10[illegible]	1.000 × 10[illegible]
Atmos	1.470 × 10[illegible]	2.117 × 10[illegible]	1.013 × 10[illegible]	1.013 × 10[illegible]	1.000	1.013	4.068 × 10[illegible]	7.600 × 10[illegible]	2.992 × 10[illegible]	1.013 × 10[illegible]
Bar	1.450 × 10[illegible]	2.089 × 10[illegible]	1.000 × 10[illegible]	1.000 × 10[illegible]	9.869 × 10[illegible]	1.000	4.015 × 10[illegible]	7.501 × 10[illegible]	2.953 × 10[illegible]	1.000 × 10[illegible]
Inch of Water	3.613 × 10[illegible]	5.204	2.491 × 10[illegible]	2.491 × 10[illegible]	2.456 × 10[illegible]	2.491 × 10[illegible]	1.000	1.868	7.355 × 10[illegible]	2.491 × 10[illegible]
mm of Mercury (Torr)	1.934 × 10[illegible]	2.785	1.333 × 10[illegible]	1.333 × 10[illegible]	1.316 × 10[illegible]	1.333 × 10[illegible]	5.354 × 10[illegible]	1.000	3.937 × 10[illegible]	1.333 × 10[illegible]
Inch of Mercury	4.912 × 10[illegible]	7.073 × 10[illegible]	3.386 × 10[illegible]	3.386 × 10[illegible]	3.342 × 10[illegible]	3.386 × 10[illegible]	1.360 × 10[illegible]	2.540 × 10[illegible]	1.000	3.386
k Pa	1.450 × 10[illegible]	2.089 × 10[illegible]	1.000 × 10[illegible]	1.000 × 10[illegible]	9.869 × 10[illegible]	1.000 × 10[illegible]	4.015	7.501	2.953 × 10[illegible]	1.000

Continuous development and refinement of our products may result in specification changes without notice

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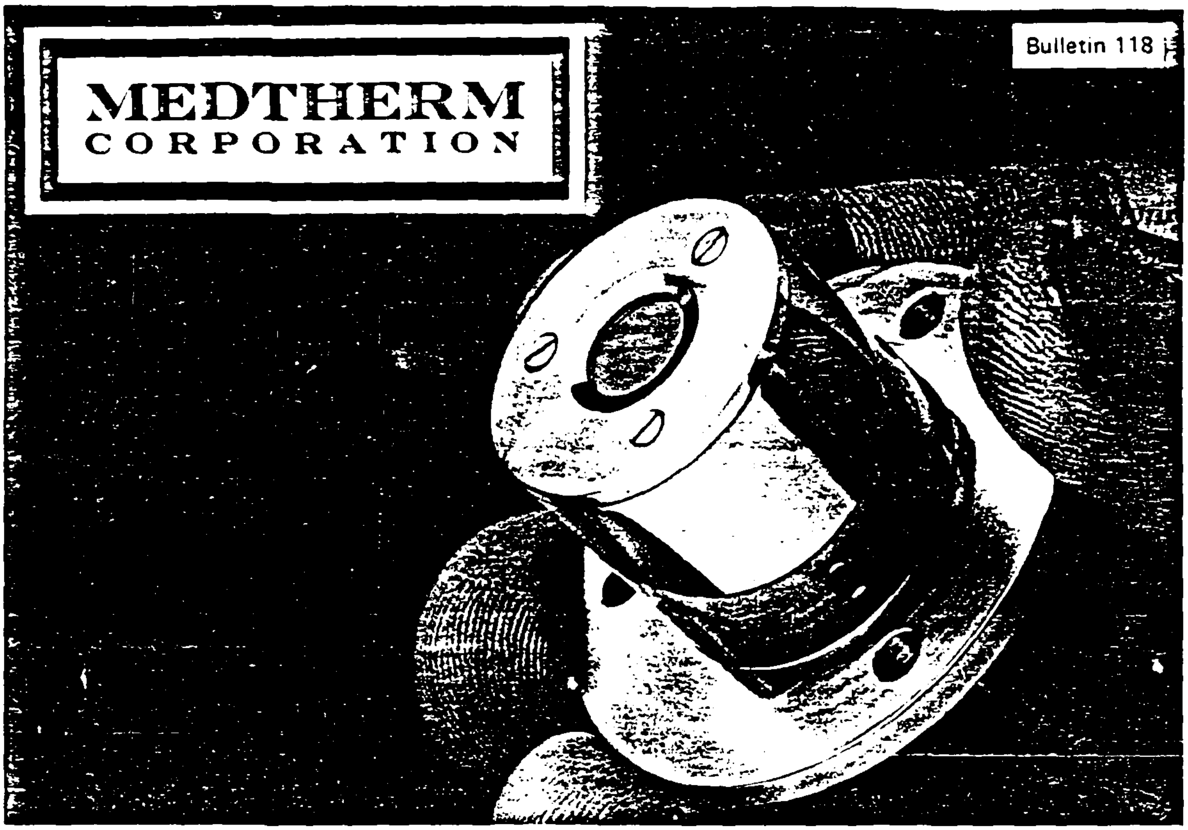


64 Series

HEAT FLUX TRANSDUCERS

for the DIRECT MEASUREMENT OF HEAT TRANSFER RATES

- LINEAR OUTPUT
- OUTPUT DIRECTLY PROPORTIONAL TO HEAT TRANSFER RATE
- ACCURATE, RUGGED, RELIABLE
- CONVENIENT MOUNTING
- UNCOOLED MODELS, WATER COOLED MODELS, GAS PURGED MODELS
- RADIOMETER AND LIMITED VIEW ACCESSORIES
- MEASURE TOTAL HEAT FLUX
- MEASURE RADIANT HEAT FLUX
- REMOTE MEASUREMENT OF SURFACE TEMPERATURE

64 Series HEAT FLUX TRANSDUCERS

DESCRIPTION

MEDTHERM 64 Series Heat Flux Transducers offer dependable direct measurement of heat transfer rates in a variety of applications due to careful design, rugged quality construction and versatile mounting configuration. Each transducer will provide a self-generated 10 millivolt output at the design heat flux level. Continuous readings from zero to 150% design heat flux are made with infinite resolution. The transducer output is directly proportional to the net heat transfer rate absorbed by the sensor. Each transducer is provided with a certified calibration traceable through temperature standards to the National Bureau of Standards. These transducers have been proven in thousands of applications in aerospace applications, heat transfer research, and boiler design.

FEATURES

- LINEAR OUTPUT
- OUTPUT PROPORTIONAL TO HEAT TRANSFER RATE
- ACCURATE, RUGGED, RELIABLE
- CONVENIENT MOUNTING
- UNCOOLED, WATER COOLED, GAS PURGED MODELS
- RADIOMETER AND LIMITED VIEW ACCESSORIES
- MEASURE TOTAL HEAT FLUX
- MEASURE RADIANT HEAT FLUX
- REMOTE MEASUREMENT OF SURFACE TEMPERATURE

CONSTRUCTION FEATURES

ACCURACY, RUGGEDNESS AND RELIABILITY are provided by the thoroughly proven Gardon and Schmidt Boelter sensors.

LONG TRANSDUCER LIFE AND SIGNAL STABILITY are enhanced by the massive bod of pure copper, gold plated to protect against corrosion, contamination, and excess radiant heat absorption by the heat sink.

PROTECTION AGAINST ROUGH HANDLING in mounting is provided by a stainless steel flange when specified.

SIGNAL INTEGRITY is protected by the use of welded connections, stranded lead wire with braided copper shielding and teflon insulation firmly secured in the transducer body with strain relief to ensure resistance to rough handling and stray signals.

ACCESSORIES

REMOVABLE SAPPHIRE WINDOW ATTACHMENTS are available to limit the basic transducer to measurement of radiation heat flux only.

VIEW RESTRICTOR ATTACHMENTS are available to limit the angle of view for the basic transducer to 60°, 30°, 15 °, or 7° for narrow view angle measurements.

DIRECT READING HEAT FLUX METER Model H-200 is available for direct meter readout in any heat flux units from any linear heat flux transducer input. A 0-1 volt recorder output is also provided. Ask for Bulletin 700.

BODY TEMPERATURE THERMOCOUPLE measurement is provided by an optional copper constantan 30 AWG solid conductor thermocouple, TIG welded junction, with fiberglass insulation and metallic overbraid.

OPERATING PRINCIPLES

The 64 Series transducers are of two basic sensor types, the Gardon type (5 to 4000 BTU/ft^2-sec) and the Schmidt-Boelter thermopile type (0.2 to 5 BTU/ft^{2}sec). In both type sensors heat flux is absorbed at the sensor surface and is transferred to an integral heat sink which remains at a temperature below that of the sensor surface. The difference in temperature between two points along the path of the heat flow from the sensor to the sink is proportional to the heat being transferred, and, therefore proportional to the heat flux being absorbed. At two such points, MEDTHERM transducers have thermocouple junctions which form a differential thermoelectric circuit providing a self-generated emf between the two output leads directly proportional to the heat transfer rate. No reference junction is needed.

Gardon Gauges absorb heat in a thin metallic circular foil and transfer the heat radially (parallel to the absorbing surface) to the heat sink attached at the periphery of the foil, the difference in temperature is taken between the center and edge of the foil.

Schmidt-Boelter gauges absorb the heat at one surface and transfer the heat in a directi n normal to the absorbing surface, the difference in temperature is taken between the surface and a plane beneath the surface.

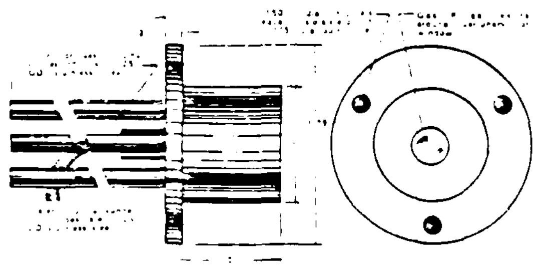
OPTIONAL FEATURES include four mounting configurations, water cooling provisions, gas purge provisions, or thermocouples for body temperature measurement. Water cooling should be specified if the uncooled transducer is expected to reach above 400°F.

The gas purging provision should be included on radiation transducers to be used in a sooty environment. The MEDTHERM purge is designed to pass rigid NASA performance tests with fuel-rich oxy-acetylene flames directed toward the window at close range.

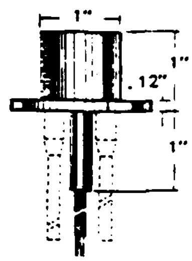
STANDARD CONFIGURATIONS

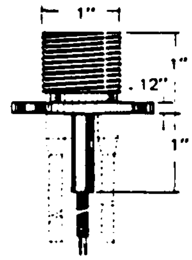
The basic transducer may be selected with either of four mounting configurations and with or without provisions for water cooling of transducer body. It may also be provided with gaseous purging to keep the radiation-transmitting window clean, but when the purging provision is included, the window is installed and is not an accessory.

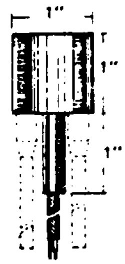
RADIOMETER WITH GAS PURGING PROVISIONS

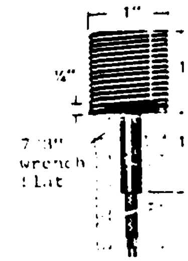


The four available mounting configurations are illustrated below. There is the smooth body with flange, the threaded body with flange, the smooth body without flange, and the threaded body without flange. All mounting flanges are 1.75" dia. with .150" dia. mounting holes equally spaced on a 1.38" dia. bolt circle. Water cooling tubes (when specified) are .1/8" dia. stainless steel and gas purge tubes are 1/8" dia. stainless steel. All tubes are 2" long. The threaded transducer bodies are 1-12 UNF-2A threads.



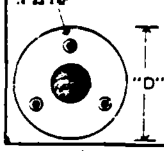






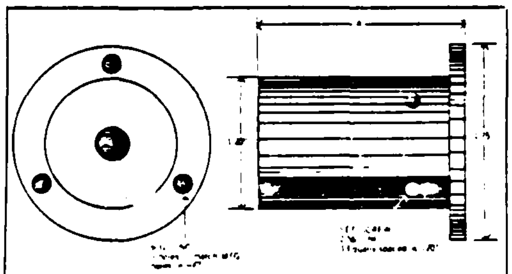
SMOOTH BODY WITH FLANGE		THREADED BODY WITH FLANGE		SMOOTH BODY, NO FLANGE		THREADED BODY, NO FLANGE	
VERSION	MODEL NO.	VERSION	MODEL NO.	VERSION	MODEL NO.	VERSION	MODEL NO.
BASIC, NO COOLING	64-xx-16	BASIC, NO COOLING	64-xx-17	BASIC, NO COOLING	64-xx-14	BASIC, NO COOLING	64-xx-15
WATER COOLED	64-xx-20	WATER COOLED	64-xx-21	WATER COOLED	64-xx-18	WATER COOLED	64-xx-19
RADIATION, PURGED COOLED	64P-xx-24	RADIATION, PURGED COOLED	64TP-xx-25	RADIATION, PURGED COOLED	64P-xx-22	RADIATION, PURGED COOLED	64TP-xx-23

SAPPHIRE WINDOW ATTACHMENT may be added for elimination of convective heat transfer, thus making the transducer a radiometer or radiation heat flux transducer. Three view angles are available: 90°, 120°, and 150°. Windows are removable and replaceable by user. When the window is used the sensitivity of the basic transducer is reduced to a nominal fraction of the original as follows: 90°, 43%, 120°, 64%, 150°, 79%. Thickness of the attachment varies with view angle and sensor type from 1/16" to 3/8".



BODY STYLE	"D"	CALIB?	MODEL
SMOOTH	1.0	NO	SW-1-YY
THREADED	.84	NO	SW-2-YY
SMOOTH	1.0	YES	SW-1C-YY
THREADED	.84	YES	SW-2C-YY

VIEW RESTRICTOR ATTACHMENTS for limiting the area view or seen by the sensor are sometimes desired for making radiation or remote temperature measurements.



VIEW ANGLE	"A"	NOMINAL % BASIC SENSITIVITY	MODEL NO.
7°	3.0"	.4%	VR-7
15	2.3	1.7	VR-15
30	1.6	6.6	VR-30
60	1.2	25.0	VR-60

SPECIFICATIONS

RANGES AVAILABLE: 4000, 3000, 2000, 1000, 500, 200, 100, 50, 20, 10, 5, 2, 1, 0.2 BTU/ft^2-sec. design heat flux level.

OUTPUT SIGNAL: 10 millivolts ± 1.5 millivolts at full range.

MAXIMUM ALLOWABLE OPERATING BODY TEMPERATURE: 400°F.

OVERRANGE CAPABILITY: 150% for 5-2000 BTU/ft^2-sec ranges, 500% for 0.2-2 BTU/ft^2 sec ranges.

MAXIMUM NON-LINEARITY ±2% of full range

REPEATABILITY ± 1/2%

ACCURACY: ± 3% for most ranges

CALIBRATION: Certified calibration provided with each transducer.

SENSOR ABSORPTANCE. 92%, nominal, from 0.6 to 15.0 microns.

SPECTRUM TRANSMITTED BY SAPPHIRE WINDOW (When used): 85% nominal from 0.15 to 5.0 microns.

LEAD WIRE 24 AWG stranded copper, two conductor, teflon insulation over each, metallic overbraid, teflon overall, 36" long, stripped ends.

RESPONSE TIME (63.2%)

500 to 4000 BTU/ft^{2}sec less than 50 msec.
50 to 200 BTU/ft^{2}sec less than 100 msec
5 to 20 BTU/ft^{2}sec less than 290 msec.
0.2 to 2 BTU/ft^{2}sec less than 1500 msec

SENSOR TYPE

5 to 4000 BTU/ft^{2}sec Gardon Gauge
0.2 to 4 BTU/ft^{2}sec Schmidt Boelter

NOMINAL IMPEDANCE

Less than 10 ohms on Gardon Gauges
Less than 100 ohms on Schmidt-Boelter Gauges

Amount of heat which can be absorbed by transducer in an adiabatic (perfectly insulated thermally) installation before exceeding the 400°F limitation

Models without water cooling provisions [illegible]

Models with water cooling provision but without water in passages 4.2 BTU

Maximum gas pressure for gas purged models [illegible] psig

ORDERING INFORMATION:

TRANSDUCERS		
DESCRIPTION	MODEL NO.	PRICE
••••••••••••••••••••••••BASIC TRANSDUCER, NO WATER COOLING PROVISIONS••••••••••••••••••••••••		
SMOOTH BODY, NO FLANGE	64-xx-14	$225.00
THREADED BODY, NO FLANGE	64-xx-15	$245.00
SMOOTH BODY, WITH FLANGE	64-xx-16	$235.00
THREADED BODY, WITH FLANGE	64-xx-17	$250.00
•••••••••••••••••••••••• BASIC TRANSDUCER WITH WATER COOLING PROVISIONS••••••••••••••••••••••••		
SMOOTH BODY, NO FLANGE	64-xx-18	$310.00
THREADED BODY, NO FLANGE	64-xx-19	$330.00
SMOOTH BODY, WITH FLANGE	64-xx-20	$315.00
THREADED BODY, WITH FLANGE	64-xx-21	$340.00
•••••••••••• ••RADIATION TRANSDUCER WITH GAS PURGE AND WATER COOLING PROVISIONS••••••••••••		
SMOOTH BODY, NO FLANGE	64P-xx-22	$385.00
THREADED BODY, NO FLANGE	64TP-xx-23	$410.00
SMOOTH BODY, WITH FLANGE	64P-xx-24	$400.00
THREADED BODY, WITH FLANGE	64TP-xx-25	$430.00

1. Specify model number.
2. Insert desired design heat flux level in place of xx in the model number, in BTU/ft^{2}sec.
3. Add $100.00 to basic price for 0.2 BTU/ft^{2}sec range.
4. For body temperature thermocouple on any of the above transducers, add "T" to model number and $20.00 to price.

ACCESSORIES		
DESCRIPTION	MODEL NO.	PRICE
SAPPHIRE WINDOW ATTACHMENT w/o CALIB.	SW-1-YY or SW-2-YY	$50.00
SAPPHIRE WINDOW ATTACHMENT w/CALIB.	SW-1C-YY or SW-2C-YY	$95.00
VIEW RESTRICTOR ATTACHMENTS	VR-7,VR-15, VR-30, VR-60	$70.00
VIEW RESTRICTOR ATTACHMENTS, WATER COOLED	VRW-7,VRW-15,VRW-30,VRW-60	$120.00
DIGITAL HEAT FLUX METER	H—201	$695.00
RECALIBRATION OF TRANSDUCER	ALL 64 SERIES	$70.00

TO SUBSTITUTE WINDOWS INSTEAD OF SAPPHIRE AT ADDITIONAL COST	
QUARTZ	ADD $5.00
CALCIUM FLUORIDE	ADD $35.00
KRS-5	ADD $85.00
KODAK IRTRAN 2	ADD $40.00
BARIUM FLUORIDE	ADD $45.00

OTHER WINDOW AND FILTER MATERIALS CAN ALSO BE SUPPLIED ON REQUEST.

In addition to the size ranges offered in the 64 Series Heat Flux Transducers (1 inch basic diameter) MEDTHERM offers the 8 Series (1/8 inch basic diameter), the 16 Series 1/4 inch basic diameter), the 24 Series (3/8 inch basic diameter), the 32 Series (1/2 inch basic diameter), and the 48 Series (3/4 inch basic diameter), as well as flat and rectangular transducers of a variety of sensor types. We specialize in the rapid design and manufacture of custom heat flux transducers for your particular applications. Write or call the factory for recommendations and price quotations for your requirements.

Bulletin 118
9—81

MEDTHERM
CORPORATION

POST OFFICE BOX 412 . HUNTSVILLE, ALABAMA 35804 , TELEPHONE (205) 837-2000

Quartz

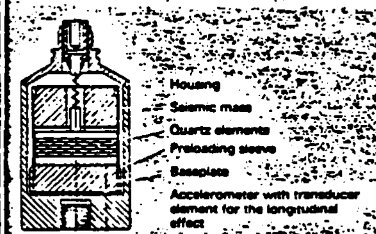
Piezoelectric instrumentation is based on the piezoelectric effect discovered by the Curie brothers in 1880: the surfaces of certain crystals become charged electrically when the crystal is loaded mechanically. Quartz is an excellent piezoelectric material. The following properties make it particularly ideal for use in accelerometers:

- Outstanding stability
- High mechanical strength
- High rigidity
- Wide temperature range
- Minimal temperature coefficient of sensitivity
- No hysteresis

KISTLER has been making transducers incorporating quartz sensing elements for more than 25 years, and has achieved a leading position worldwide by virtue of its own intensive research and development in piezo-instrumentation. KISTLER measuring instruments are synonymous with accurate and dependable measuring.

Technique

Quartz accelerometers consist essentially of three elements: the transducer body, quartz sensing element, and seismic mass. The sensing element is preloaded between the transducer body and the seismic mass by a preloading element. Because of the constant seismic mass, the force acting on the measuring element is proportional to the acceleration in accordance with Newton's first law: $F = ma$. The quartz measuring element gives an electrical charge proportional to the force and hence to the acceleration in turn. Depending on the design principle of the transducer, the individual quartz plates are stressed in compression (longitudinal and transverse effect) or in shear (shear effect).



Through judicious application of the different piezoelectric effects and the latest technology, KISTLER is able to offer a wide selection of accelerometers. It is sure to include the right instrument for your measuring problem.

Application

Contemporary engineering would be unthinl able without the measurement and analysis of vibration.

The KISTLER transducer product line offers the right accelerometer for practically every measuring problem. In addition to the standard types there are several transducers for special applications.

- Accelerations from 0.0003 g to 100 000
- Frequencies from ≈ 0 Hz (quasistatic) to 40 kHz (+10%)
- Operating temperature ranges from −150 to 600°C
- Ambient pressures up to 200 bar
- Measuring accelerations in 3 axes

These are no problem for KISTLER accelerometers. Let us solve yours, too.

Measuring systems

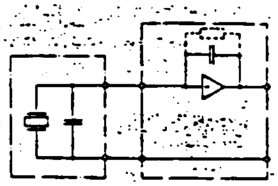
To provide the optimum answer to every acceleration measuring problem, there are two measuring systems (i.e. two transducer categories) available:

— Piezoelectric accelerometers
— Piezotron® accelerometers

The two systems differ in the way the electrical charge from the accelerometer is converted into a proportional voltage.

- With the conventional *piezoelectric measuring system*, the charge is converted into a voltage in a charge amplifier following the transducer.
- With the *Piezotron system*, a miniature impedance converter is fitted in the transducer. For power supply and signal processing, a Piezotron coupler is needed between the transducer and the display or evaluation instrument as the case may be. The different features of the two systems are described on the right.

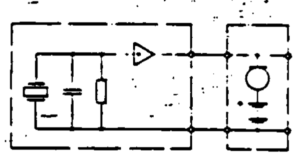
Piezoelectric system



Special properties:

- Electrical transducer output with high insulation resistance requires suitable (highly insulating and low-noise) connecting cables.
- Measuring range or scale in g/V easily selectable with the transducer range.
- Quasistatic measurements possible.
- Operating temperature range of piezoelectric measuring elements can be fully utilized.

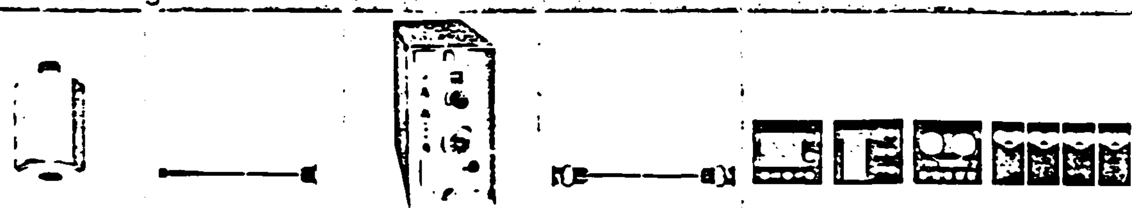
Piezotron® system



Special properties:

- Low impedance transducer output
- No special (highly insulating and low-noise) connecting cables are necessary
- Fixed measuring range
- Operating temperature range −50 to 120°(
- Low cost per channel
- Simple and inexpensive signal conditioner

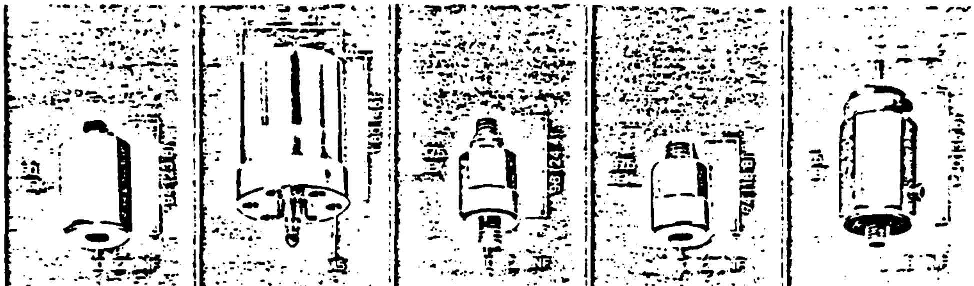
The measuring chain



Accelerometer and accessories	Transducer connecting cable	Charge amplifier for piezoelectric or coupler for Piezotron	Connecting cable	Display and evaluation units (e.g. oscilloscopes, analog displays, transient recorders, frequency analyzers, magnetic tape.

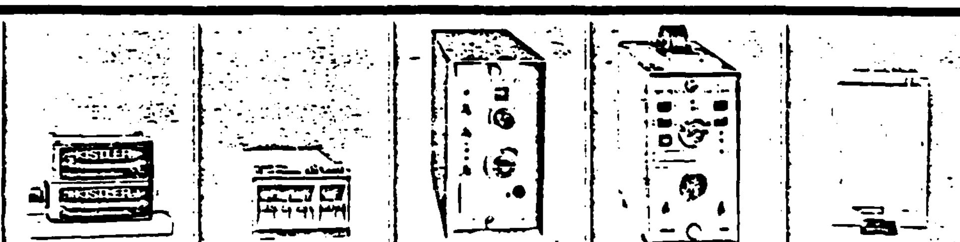
Piezoelectric quartz accelerometers

mensions in parentheses ( ) are mm



'pe		8002	8002K	8007	8042	8044	8076K
ormerly. Type		808A	808K	817A	805B	905A	809K
roperties		• Excellent, versatile performance • Rugged construction • Wide operating temperature range		• Very high sensitivity • Low threshold • Wide operating temperature range	• Wide measuring range • Small size • Rugged and light titanium housing • Integral mounting stud	• Similar to 8042 except higher sensitivity, smaller acceleration range, and no integral mounting stud	• Rugged design • Low base strain sensitivity • Low mass loading sensitivity • Ground-isolated
chnical data							
celeration range	g	±10000	±1000	±100	−50000 to 100000	−20000 to 30000	±250
reshold	g rms	0.03	0.003	0.0003	0.6	0.1	0.01
cceleration limit	g	±20000	±2000	±200	−60000 to 110000	−30000 to 100000	±500
ensitivity	pC/g	−1		−100	−0.05	−0.3	−1.0
sonant frequency ounted)	kHz	40		1.8	60	60	40
equency range 5%) nom.	Hz	≈0 to 7000		≈0 to 400	≈0 to 12000	≈0 to 12000	0.5 to 6000
ansverse sensitivity	%	≤5	≤2	≤3	≤5	≤5	≤2
erating temperature nge	°C	−195 to 260	−70 to 120	−150 to 240	−195 to 200	−195 to 200	−0.02
mperature coefficient sensitivity	%/°C	−0.02		−0.01	−0.04	−0.04	−20 to −65
ulation resistance room temp.	TΩ	>10		>10	>10	>1	>1
apacitance	pF	90		22	25	50	100
eight	g	20		490	8	7	65
ta sheet		8.8002	8.8002K	8.8007	8.8042	8.8044	8.8076K
pical applications		• General vibration measurements in medium amplitude and frequency range • 8002K laboratory vibration calibration standard		• Measuring accelerations in lower frequency and amplitude range, e.g. on large structures	• High amplitude shock measurements, metal impacting, explosive forming	• Same as Type 8042	• Laboratory vibration calibration standard

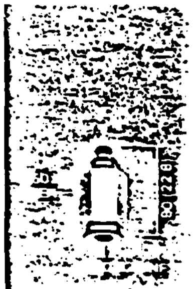
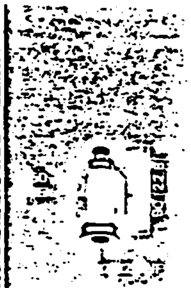
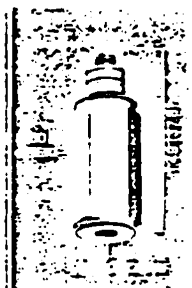
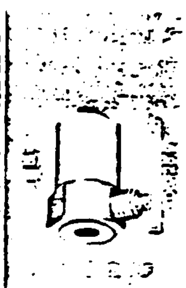
harge amplifiers or operating iezoelectric ccelerometers



e	5021	5041	5004	5026*	5053A
signation	Miniature charge amplifier	Charge amplifier with digital adjustment	Charge amplifier	Charge amplifier with differential type input	Charge amplifier on Euro-card
operties	• Measuring range permanently adjusted • Shock- and vibration-proof design • Power supply +20 to +32 V dc • Output voltage ±5 V	• Digital setting of the measuring range • Simple snap-in mounting allows integration in the front panel • Power supply ±15 V dc, ±5% • Output voltage ±10 V	• Dual mode: piezoelectric or Piezotron* operation • 12 calibrated measuring ranges • 3 selectable time constants • Plug-in low-pass and notch filters • Zero and overload monitoring • Remote reset capability • Two-color LED shows Piezotron operation	• Differential operation rejects 120 Vpp common mode • Input, output and case grounds all isolated • Dual mode: piezoelectric or Piezotron* operation • Near dc to 350 kHz response • Built-in calibrator (Dial Cal feature) • Plug-in filter capability • 110 V ac power	• Modular design • 5 measuring ranges • Fully remote controllable • Frequency range quasistatic up to 10 kHz (−3dB) • Power supply ±15 V dc, ±5% • Output voltage ±10 V

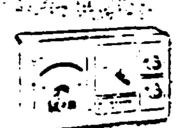
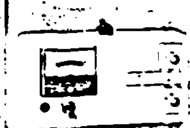
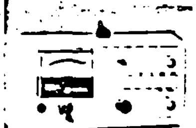
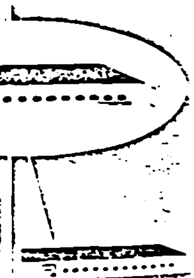
Piezotron® accelerometers

Dimensions in parentheses ( ) are mm

					
Type	8602A500 8602A5000	8602A501	8604A500 8604A5000	8606A100 8606A500	8608A50 8608A100
Formerly, Type			815A2 815A1	815A5 815A7	816A6
Properties	• Inexpensive construction with efficient, versatile performance • Not hermetically sealed	• Inexpensive construction with efficient, versatile performance • Not hermetically sealed	• Wide measuring range • Rugged, hermetically sealed, welded construction • Nonmagnetic • Top connector	• Same as 8604 series • 8606A100 has high sensitivity • 8606A500 has wide frequency response	• High sensitivity • Hermetically sealed

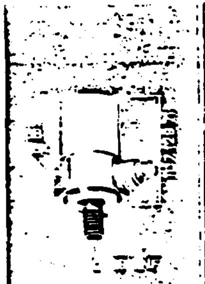
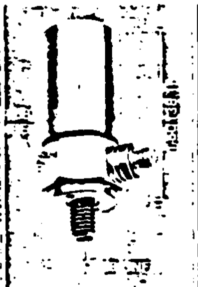
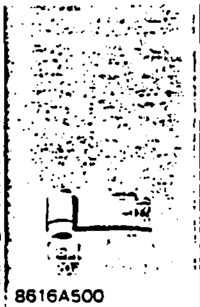
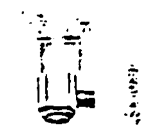
Technical data		A500 / A5000		A500 / A5000	A100 / A500	A50 / A100
Acceleration range	g	±500 / ±5000	±500	±500 / ±5000	±100 / ±500	±50 / ±100
Threshold	g_{rms}	0.01 / 0.1	0.01	0.01 / 0.1	0.002 / 0.01	0.005 / 0.01
Acceleration limit	g	±2000 / ±6000	2000	±1000 / ±6000	±500 / ±750	±300 / ±500
Sensitivity	mV/g	10 ± 2% / 1 ± 2%	10 ± 2%	10 ± 2% / 1 ± 2%	50 ± 2% / 10 ± 2%	100 ± 2% / 50 ± 2%
Resonant frequency (mounted)	kHz	40	40	40	40	25
Frequency range (± 5%)	Hz	1 to 5000 / 0.6 to 5000	0.06 to 5000	2 to 6000 / 0.2 to 6000	0.1 to 5000 / 0.02 to 5000	0.5 to 6000
Transverse sensitivity	%	≤5	≤5	≤5	≤5	≤5
Operating temperature range	°C	−55 to 120	−55 to 120	−55 to 120	−55 to 120	−55 to 120
Temperature coefficient of sensitivity	%/°C	−0.06	−0.06	−0.06	−0.06	−0.06
Supply current	mA	4 (constant)	4 (constant)	4 (constant)	4 (constant)	4 (constant)
Supply voltage	V	20 to 30	20 to 30	20 to 30	20 to 30	20 to 30
Output impedance	Ω	< 100	< 100	< 100	< 100	< 100
Output bias	V	11	11	11	11	11
Ground isolation		no	no	no	no	no
Weight	g	12	12	14	14	60
Data sheet		8.8602	8.8602	8.8604	8.8606	8.8608
Typical applications		• Routine vibration measurements on structures and objects in laboratory and nonhostile, industrial environments	• Shock measurements on structures and objects in laboratory and nonhostile, industrial environments	• General vibration measurements in severe environments	• Same as 8604 series • 8606A500 suitable for vehicle impact measurements	• Rotating machinery monitoring • Vehicle suspension development

Couplers for operating Piezotron® accelerometers

					
Type	5108	5112	5116	5120	5124*
Designation	Coupler, external-powered (24 to 32 VDC, unregulated)	Coupler, battery-powered (three x 9 V)	Coupler, line-powered	Coupler, line-powered, like 5116 but with:	Coupler, 12-channel, line-powered
Properties	• Small size permits direct attachment to display (oscilloscope) with BNC connector • AC-coupling eliminates transducer bias voltage from measuring signal	• Analog meter monitors transducer bias voltage, indicates integrity of transducer circuit and condition of internal batteries • AC-coupling eliminates transducer bias voltage from measuring signal	• Analog meter monitors transducer bias voltage and indicates integrity of transducer circuit • AC-coupling eliminates transducer bias voltage from measured signal • Internal plug-in low-pass filters	• Internally adjustable gain (0.5 to 5) • DC-coupling mode with adjustable zero level, suitable for transducers with long time constant • Analog meter monitors transducer bias voltage, indicates integrity of transducer circuit and zero level when used in DC mode	• 19 in. rack-mounted • Plug-in filters • Constant current supply • Buffer stage to prevent filter loading • Meter for line test • Bias decoupling removes dc bias level *Formerly 581A

iezotron® ccelerometers

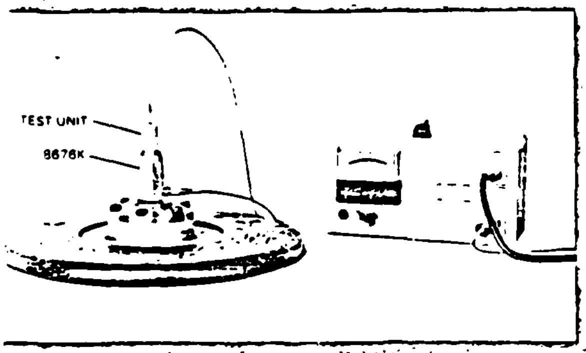
iensions in parentheses ( ) are mm

						
pe		8610A50 8610A100	8612A5	8616A500 8616A1000	8618A500 8618A2000	8620
rmerly, Type		816A7		8118 81181	818 818A1	
operties		• High sensitivity • Hermetically sealed • Ground-isolated	• Very high sensitivity • Hermetically sealed • Ground-isolated	• Extremely small and light (0.5 g) • Very high resonant frequency • Integral cable	• Efficient, versatile performance • Ground-isolated • Side connector	• Miniature, welded construction • Ground-isolation • Side connector • Adhesive mounting
hnical data		A50 A100		A500 A1000	A500 A2000	
celeration range	g	± 50 ± 100	± 5	± 500 ± 1000	± 500 ± 2000	± 500
reshold	g rms	0.005 0.01	0.0003	0.01 0.02	0.01 0.1	0.01
celeration limit	g	± 300 ± 500	± 50	± 2000 ± 2000	± 1000 ± 5000	± 2000
sitivity	mV/g	100 ± 2% 50 ± 2%	1000 ± 2%	4 2.5	10 ± 2% 1 ± 2%	10
onant frequency ounted)	kHz	23	23	125	30	50
equency range (± 5%)	Hz	0.5 to 6000	0.5 to 6000	1 to 25 000	2 to 5000 0.8 to 5000	1 to 10 000
nsverse sensitivity	%	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5
erating temperature ge	°C	−55 to 120	−65 to 100	−55 to 120	−55 to 120	−55 to 120
mperature coefficient sensitivity	%/°C	−0.06	−0.06	−0.06	−0.07	−0.06
ply current	mA	4 (constant)	4 (constant)	4 (constant)	4 (constant)	4 (constant)
ply voltage	V	20 to 30	20 to 30	12 to 30 20 to 30	20 to 30	20 to 30
put impedance	Ω	< 100	< 10	< 100	< 100	< 100
tput bias	V	11	11	2.5 11	11	11
ound isolation		yes	yes	with mounting adaptor	yes	yes
ight	g	62	70	0.5	20	3.5
a sheet		8.8610	8.8612	8.8616	8.8618	8.8620
ical applications		• Vibration measurements on process equipment • Machine tool wear	• Low and medium frequency vibrations on heavy structures, suspensions, buildings, and machines	• Vibration investigations on very light structures • Measurements at very high frequencies	• General vibration measurements • Ground-isolated design eliminates ground loop problems	• Modal analysis of structures • Vibration measurements on light structures

ccelerometer alibration stem

8676K/5116*

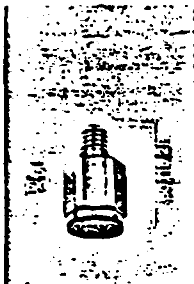
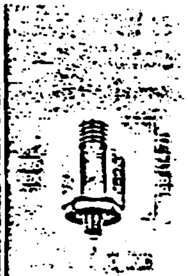
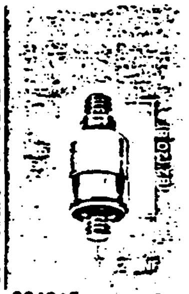
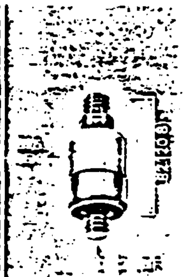
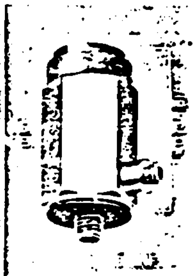
Offers a low cost, low impedance Piezotron alternative for field calibration of accelerometers. Features rugged design, low base strain sensitivity, and low mass loading sensitivity. Beryllium mounting base, lapped optically flat, provides optimum coupling between calibration standard and test transducer.



Technical data:		8676K/5116
Acceleration range	g	± 250
Threshold	g rms	0.01
Acceleration limit	g	± 1.000
Amplitude linearity	%	0.5
Reference voltage sensitivity @ (100 Hz, 24°C, ± 10g)	mV/g	10 ± 0.1
Resonant frequency (nom.), mtd.	kHz	40
Frequency response, ± 1% (± 2%)	kHz	3 (4)
Transverse sensitivity @ 100 Hz	%	≤ 2
Operating temperature range	°C	− 18 to 66
Temperature sensitivity shift	%/°C	0.04
Mass loading error @ 2 kHz (from 5 to 100g)	%	0.5
Output voltage, FS	V	± 2.5
Supply voltage	VAC	115
Weight of transducer	g	65

Piezotron® accelerometers

Dimensions in parentheses ( ) are mm

						
Type		8624	8626	8642A5 8642A10	8642A50 8642A100	8676K
Formerly, Type						819K
Properties		• Same as 8620 except top connector	• Miniature, welded construction • Top connector • Stud mounting	• Small size • Rugged, light titanium housing • Integral mounting stud	• Same as 8642A5	• Rugged design • Low base strain sensitivity • Low mass loading • Ground-isolated
Technical data:				A5 / A10	A50 / A100	
Acceleration range	g	± 500	± 500	± 5000 / ± 10000	± 50000 / − 50000 to 100000	± 250
Threshold	g_{rms}	0.01	0.01	0.1 / 0.2	1.0 / 2.0	0.01
Acceleration limit	g	± 2000	± 2000	± 20000 / ± 50000	− 50000 to 100000 / − 50000 to 110000	± 500
Sensitivity	mV/g	10	10	1 / 0.5	0.1 / 0.05	10 ± 2%
Resonant frequency (mounted)	kHz	50	65	70	70	40
Frequency range (± 5%)	Hz	1 to 10000	1 to 12000	0.25 to 8000	0.25 to 8000	0.5 to 5000
Transverse sensitivity	%	≤5	≤5	≤5	≤5	≤2
Operating temperature range	°C	− 55 to 120	− 55 to 120	− 55 to 120	− 55 to 120	− 20 to 65
Temperature coefficient of sensitivity	%/°C	− 0.06	− 0.06	− 0.06	− 0.06	− 0.02
Supply current	mA	4 (constant)	4 (constant)	4 (constant)	4 (constant)	4 (constant)
Supply voltage	V	20 to 30	20 to 30	20 to 30	20 to 30	20 to 30
Output impedance	Ω	< 100	< 100	< 100	< 100	< 100
Output bias	V	11	11	11	11	11
Ground isolation		yes	no	no	no	yes
Weight	g	3.5	3.5	7.5	7.5	65
Data sheet		8.8624	8.8626	8.8642	8.8642	8.8676
Typical applications		• Same as 8620	• Same as 8620	• High amplitude shock measurements, metal impacting, closed bombs, and explosive forming	• Same as 8642A5	• Field calibration of accelerometers

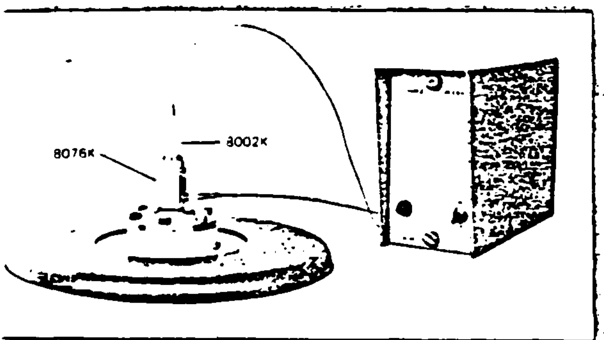
Accelerometer calibration systems

8002K/5020*
A system featuring unique stability, linearity, and repeatability of quartz crystal accelerometer and charge amplifier. Used primarily as laboratory reference standard. Provides constant 10 mV/g sensitivity from 10 to 10,000 Hz (±1%) over a wide amplitude range.

*Formerly 808K1/561T

8076K/5020*
Kistler's most accurate and repeatable laboratory vibration standard for back-to-back calibration of accelerometers. Incorporates 5020 frequency-compensated charge amplifier. Provides constant 10 mV/g sensitivity from 10 to 10,000 Hz (±1%) over a wide amplitude range.

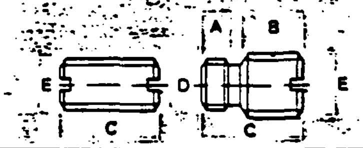
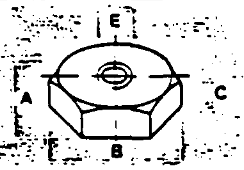
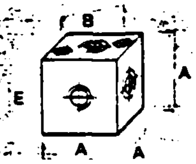
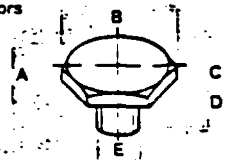
*Formerly 809K/561T



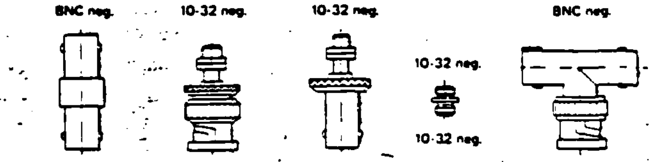
Technical data:		8002K/ 5020	8076K/ 5020
Acceleration range	g	± 250	± 250
Threshold	g_{rms}	0.02	0.01
Acceleration limit	g	± 1000	± 1000
Amplitude linearity	%	0.5	0.5
Reference voltage sensitivity @ (100 Hz, 24°C, ± 10g)	mV/g	10 ± 0.01	10 ± 0.2
Resonant frequency (nom.), mtd.	kHz	40	40
Frequency response, ±1%	kHz	10 to 10,000	10
Transverse sensitivity @ 100 Hz	%	≤1.0	≤2.0
Operating temperature range	°C	− 1 to 55	− 18 to 66
Temperature sensitivity shift	%/°C	0.04	0.04
Mass loading error @ 2 kHz (from 5 to 100g)	%	—	0.5
Output voltage, FS	V	± 2.5	± 2.5
Supply voltage	VAC	115	115
Weight of transducer	g	20	65

Mounting accessories

Dimensions in parentheses ( ) are mm

	Type	A	B	C	D	E	For types
Mounting stud 	8402	.10 (2.5)	.10 (2.5)	.28 (7.1)	10-32 UNF	10-32 UNF	8002, 8604A, 8606A
	8404	.10 (2.5)	.10 (2.5)	.28 (7.1)	10-32 UNF	10-32 UNF	8044
	8411	.13 (3.4)	.24 (6.3)	.43 (11)	10-32 UNF	M6	8002, 8044, 8604 8606A
	8421	.12 (3.3)	.29 (7.5)	.48 (12.3)	¼-28 UNF	M8	8005, 8608A
	8423	.12 (3.3)	.29 (7.5)	.48 (12.3)	¼-28 UNF	5/16-24 UNF	8005
	8412	—	—	.50 (12.7)		¼-28 UNF	8005, 8608A
Adhesive mounting base 	8436	.56 (14.2)	.62 (15.7)	.19 (4.8)	—	10-32 UNF	8604A, 8606A, 8618
	8438	.75 (19)	.83 (21.1)	.31 (7.9)	—	¼-28 UNF	8608A
Adaptor for triaxial mounting 	8508	.35 (6.4)	—	—	—	—	8616A
	8504	.57 (14.5)	.55 (13.9)	—	—	10-32 UNF	8042, 8044
	8502	1.0 (25.4)	1.0 (25.4)	—	—	10-32 UNF	8002, 8604A, 8606A
	8506	1.13 (28.7)	1.15 (29.2)	—	—	¼-28 UNF	8608A
Mounting adaptors 	8439	.25 (6.5)	.28 (7.2)	.06 (1.5)	.14 (3.5)	M3	8616A
	8440	.25 (6.5)	.28 (7.2)	.06 (1.5)	.14 (3.5)	4-40 UNF	8616A

Cable adaptors

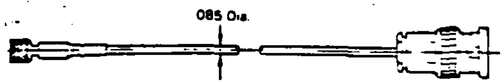


Type: 1701, 1721, 1725, 1729, 1743

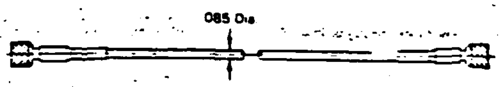
Connecting cables

- Transducer connecting cables, Series 1514 & 1516, are all-purpose cables for use with low impedance PIEZOTRON transducers.
- Series 1631 & 1635 are low-noise, Teflon cables for use with high impedance quartz transducers.
- Available in standard and special lengths.

Series 1514 & 1631

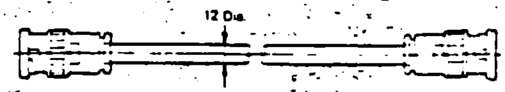


Series 1516 & 1635

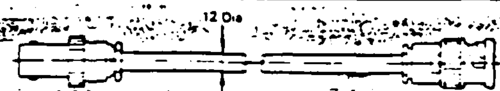


- Multi-use cables Series 1601 & 1603 are ultra-low-noise transducer extension cables.
- Series 1511 is a general purpose output cable for use with couplers and amplifiers.
- Available in standard and special lengths.

Series 1511 & 1601



Series 1603



High-temperature accelerometer

Type 8121A3

Range	g	± 1000
Overload	g	± 1200
Sensitivity	pC/g	−5
Linearity	% FSO	≤ ± 1
Transverse Sensitivity	%	≤ 4
Resonant frequency (mounted)	kHz	9
Operating temperature range	°C	− 100 to 600
Ambient pressure	bar	≤ 200
Housing material		Inconel
Weight	g	200

For additional data see data sheet 8.8121

The high-temperature accelerometer Type 8121A3 is particularly suited for operating at temperatures up to 600°C and ambient pressures up to 200 bar. In particular this transducer incorporates these latest technology features:

- Minimal thermal sensitivity shift
- Very small temperature transient error
- Ground-isolated design with integral metallic triaxial cable
- Inconel housing, welded pressure-sealed

Typical applications:

- Reactor engineering
- Combustion engines and turbines
- Acceleration measurements in extreme environments

3-component seismometer

Type 8131

Measuring range (each axis)	g	± 2
Overload (each axis)	g	± 100
Threshold	g	< 0.001
Resonant frequency mounted (each axis)	Hz	> 300
Crosstalk (each axis)	%	≤ ± 3
Output voltage	V	± 5
Power supply	V	± 15 V dc, ± 5%

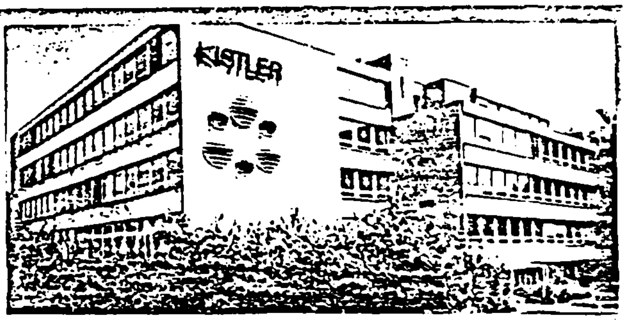
Type 8131 is a highly sensitive piezoelectric 3-component seismometer for measuring acceleration in three orthogonal directions.

Only one seismic mass is needed with this unique, 3-component force measuring element. Three miniature charge amplifiers are contained in the transducer housing. The three channels can be tested remotely for proper operation by using an internal test circuit. This is particularly useful when the accelerometer is mounted in a secured location.

Typical applications:

- Geophysical investigations
- Measuring and monitoring earth tremors in the vicinity of nuclear power stations, dams, etc.
- Measuring vibration on buildings, bridges, etc.

KISTLER INSTRUMENT CORPORATION, Amherst, New York

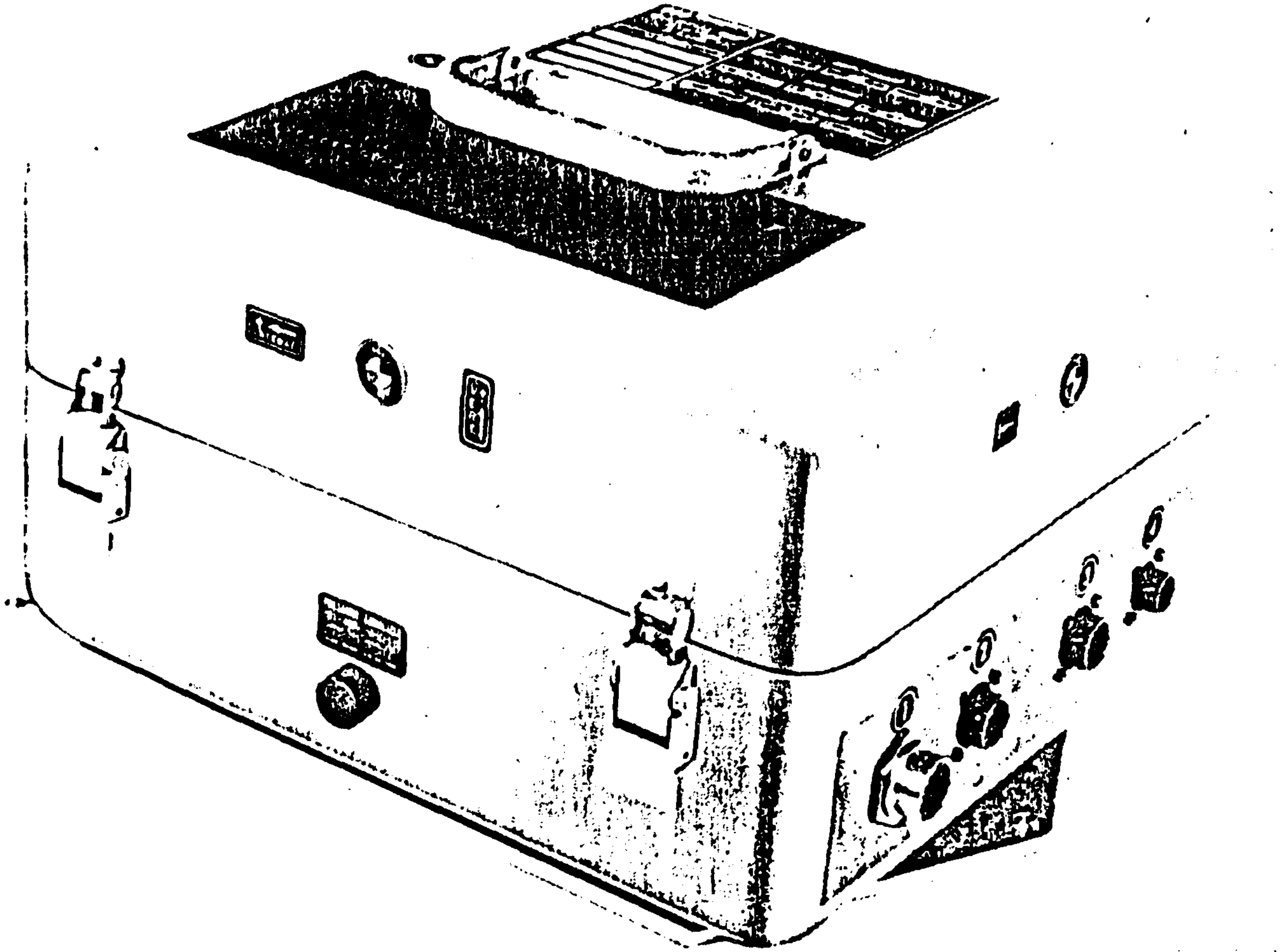


KISTLER INSTRUMENTE AG, Winterthur, Switzerland

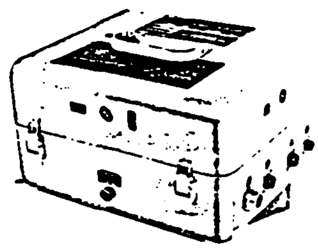
KISTLER

● Manufacturing and sales facilities in Amherst, NY; Hamden, CT; Winterthur, Switzerland, Hartley Whitney, Hants, Great Britain; Stuttgart, West Germany.

▲ Sales distribution in Argentina, Australia, Austria, Belgium



HUMPHREY MODEL CF32-0201-1 INERTIAL REFERENCE UNIT



A precision, 3-axis inertial reference system that provides continuous measurements on the dynamic performance of almost any vehicle, including position and rate outputs for pitch, roll, and yaw, as well as three axes of linear acceleration. The system comes complete with calibration data and is compatible for use with nearly all telemetering and recording equipment. The Model CF32 Test Unit requires 28 VDC power input and uses 4.5 amps in operation. All power regulation and signal conditioning is provided within the package.

SPECIFICATIONS

Power Input 25-28.5 VDC (Ref. MIL-STD-704A Equip. Cat. "A")
4.5 Amp Running, 5.0 Starting

Power to Cage Directional
Gyro Pickoff .... 28 VDC, 2.0 Amp Pulse 0.6 Amp Hold

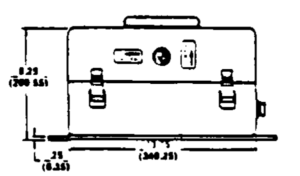
VERTICAL REFERENCE (pitch and roll)
- Pitch .... ±85 Degrees
- Roll .... 360 Degrees
- Electrical Outputs from Size 11 Synchro ... 3-Wire Output 11.6 V
- Accuracy ...... 0.1 Degree Reference to True Vertical

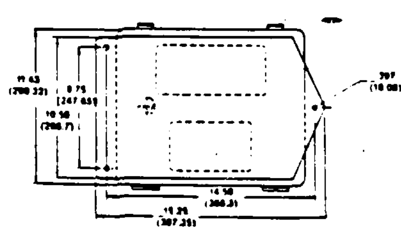
AZIMUTH REFERENCE (yaw)
- Yaw .... 360 Degrees
- Electrical Outputs from Size 11 Synchro ... 3-Wire Output 11.6 V
- Accuracy ... 0.1 Degree
- Yaw Drift ... Less than 0.1 Degree/Min.
- Yaw caging system locks gyro pick off in zero position.
- Spin axis of yaw gyro erects to horizontal for continuous operation, non-tumbling.

PITCH, ROLL AND YAW RATE OUTPUTS
- Rate Range ±40 Degrees/Second (Min.)
- Detectable rate .... 0.01°/Sec.
- Output .... ±5.0 VDC
- Accuracy 0.5% at Null, 1.0% at Full Rate
- Damping ... 0.7 Nominal
- Natural Frequency ... More than 23 Hz

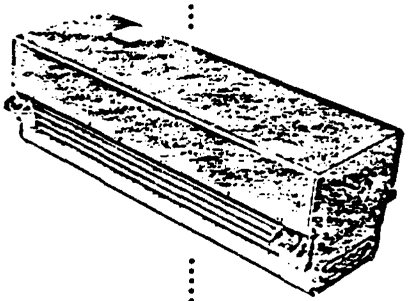
VERTICAL, FORE-AFT AND LATERAL ACCELERATION OUTPUTS
- Acceleration Range ... ±5 G
- Output ... ±5.0 VDC
- Accuracy ... Null 0.1% of Full Range to 0.2% at Full Scale
- Natural Frequency ... More than 130 Hz
- Damping (Electrical) ... 0.4 to 0.7

ENVIRONMENTAL CONDITIONS
- NOTE: Rate and acceleration outputs for nominal 100 K load
- Temperature ... −30°F to +165°F
- Vibration 2 G from 20 to 33 Hz; 0.036 D.A. from 33 to 52 Hz; 5 G from 52 to 500 Hz. (Ref. MIL-STD-810B Curve 514-1M)
- Shock ... 50 G, 11 ±1 Millisecond
- Case Seal ... Pressure Tight, Altitude 0 to 30,000 Ft.
- Weight ... 35 Lbs.





we're confident...



...H-478F makes the differance

SPECIFICATIONS

H-478F

Size:	4.1 x 4.5 x 12.3
Volume:	232 cu. in.
Weight:	7.7 lbs.
Power:	35 watts (operating) 28vdc
Body Rate Capability:	± 220°/sec all axis
Acceleration Range:	± 25 g's all axis

Honeywell GG1111 Gyroscopes (1σ)

G-Insensitive Bias Stability	2.7 Deg/Hr (6 Months)
G-Sensitive Drift	2.3 Deg/Hr/G (6 Months)
Scale Factor Stability	300 PPM (6 Months)

Sundstrand Q-Flex Accelerometers (1σ)

Bias Stability	300 μg (6 Months)
Scale Factor Stability	300 PPM (6 Months)
Scale Factor Linearity	300 PPM to 25g

H-478F Scaling – All Axis

Scaling can be tailored to your specific application.

Signal	Max. Pulse Rate	Digital	Analog
Acceleration	12800 PPS	0.0625 Ft/Sec/Pulse	8MV/Ft/Sec/Sec
Angle	12800 PPS	.62 Arc-Sec/Pulse	30MV/Deg/Sec

Performance Variables

Alternate sensors with improved stability or dynamic input range can be substituted directly without device change.

For more detailed information, contact...
YOUR NEAREST HONEYWELL REPRESENTATIVE
...or write directly to:

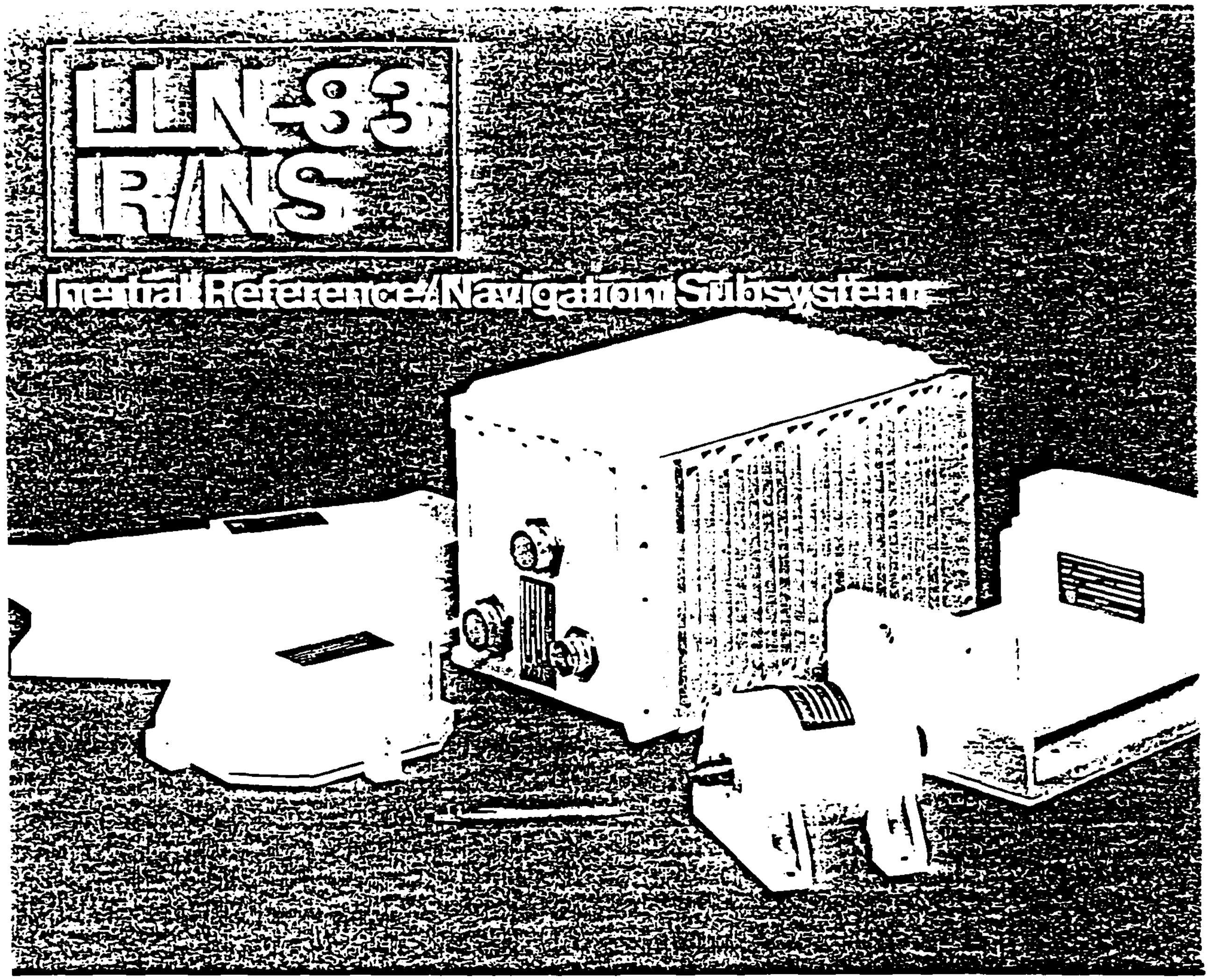
Honeywell

AVIONICS DIVISION

Marketing Department
13350 U.S. HIGHWAY 19
ST. PETERSBURG, FLORIDA 33733

Phone 813/531-4611

379-15747
Printed in U.S.A.



Land vehicle strapdown inertial orientation and positioning system

- Multi-function output capability
  - Full attitude
  - 3-dimensional angular rate
  - 3-dimensional position
- Azimuth self-align to 1.0 mil; verticality to 0.5 mils
- Azimuth drift rate 0.7 mil/hr bounded to 3 mils maximum
- Horizontal and vertical position to 0.25% of distance traveled (with or without odometer aiding)
- *Pitch, roll, azimuth angular rate data* 0.001 to 100 degrees per second for gun stabilization
- Nonflammable, secure, self-contained
- High reliability, full self-test (BITE)
- Rugged construction for harsh land vehicle environment
- Small size, low power, rapid installation
- Field proven in track and wheel vehicles

SPECIFICATION

Position and Navigation (Odometer damping, as a % of distance travelled)

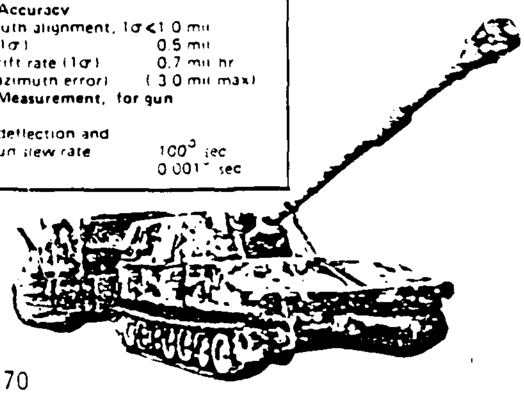
• Northing	0.25%
• Easting	0.25%
• Altitude	0.25% (20M max.)

Gun pointing Accuracy

• Initial azimuth alignment, 1σ	<1.0 mil
• Elevation (1σ)	0.5 mil
• Azimuth drift rate (1σ) (Bounded azimuth error)	0.7 mil/hr (3.0 mil max)

Angular Rate Measurement, for gun stabilization

• Maximum deflection and elevation gun slew rate	100°/sec
• Accuracy	0.001°/sec



LITTON
GUIDANCE & CONTROL SYSTEMS

LLN-83 IR/NS

Inertial Reference/ Navigation Subsystem

FEATURES

- Inertial reference unit from Litton LR-80 family of strapdown technology (AAH, "Sgt York" DIVADS equipment)
- Designed for various Army land vehicles (M-109, self-propelled howitzer, Jeep)
- Multi-function capability — pointing, positioning, rate stabilization
- Operates worldwide in ±75° latitude
- Meets full U.S. Army specifications
- Reliability/Maintainability
  - MTBF > 2000 hours
  - MTTR < 30 minutes
  - Built-in test — 95% detected, 95% isolate to SRU
  - Automatic self-calibration
  - No on-board test equipment required
- RS 422 digital serial output, available MIL-STD-1553, RS232C, ARINC-575, or customized as required

REACTION TIME

- Realignment
  - Interval between alignments ≤ 3 hours
  - Time to realign to full accuracy ≤ 3.5 minutes
- Initial Alignment
  - Warmup time -54C ≤ 7 minutes
  - Alignment time ≤ 10 minutes
- Stored Heading Mode
  - Total time from -30C ≤ 5 minutes
  - Azimuth accuracy (1σ) 2.0 mils
  - Elevation accuracy (1σ) 2.0 mils

Free Inertial Navigation (No odometer input)

- Time interval between stops to meet full positional accuracy ≈ 5 minutes

Power Requirements

- 24 VDC, (14v to 40 vdc) 82 watts nominal, 450 watts initial warm-up
- MIL-STD-1275 compatible

Cooling

- Ambient air

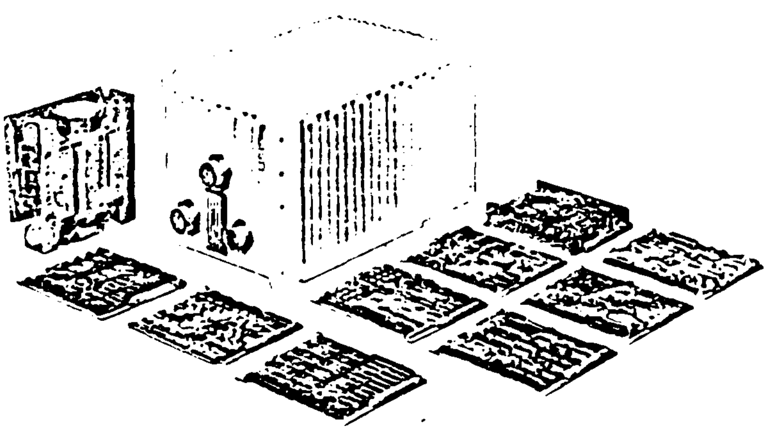
Physical Characteristics

Unit	Size (L × W × H)	Weight
IRU	14.5" x 8.5" x 8.4"	28 lbs
OCU	10.2" x 6.5" x 2.8"	9 lbs
O/ACU	7.0" x 6.0" x 2.5"	4 lbs
EDU	8.3" x 5.4" x 3.0"	3 lbs
OTU	6.6" x 5.4" x 3.8"	3 lbs

Environmental

Temperature	-50F to +125F
Humidity	100%
Immersion	3 feet depth for 2 hours
Shock	M203 (Super 8 charge)
Vibration	MIL-STD-810 Method 514.2
EMI	MIL-STD-461

For additional information call (213) 715-3530 or write . .



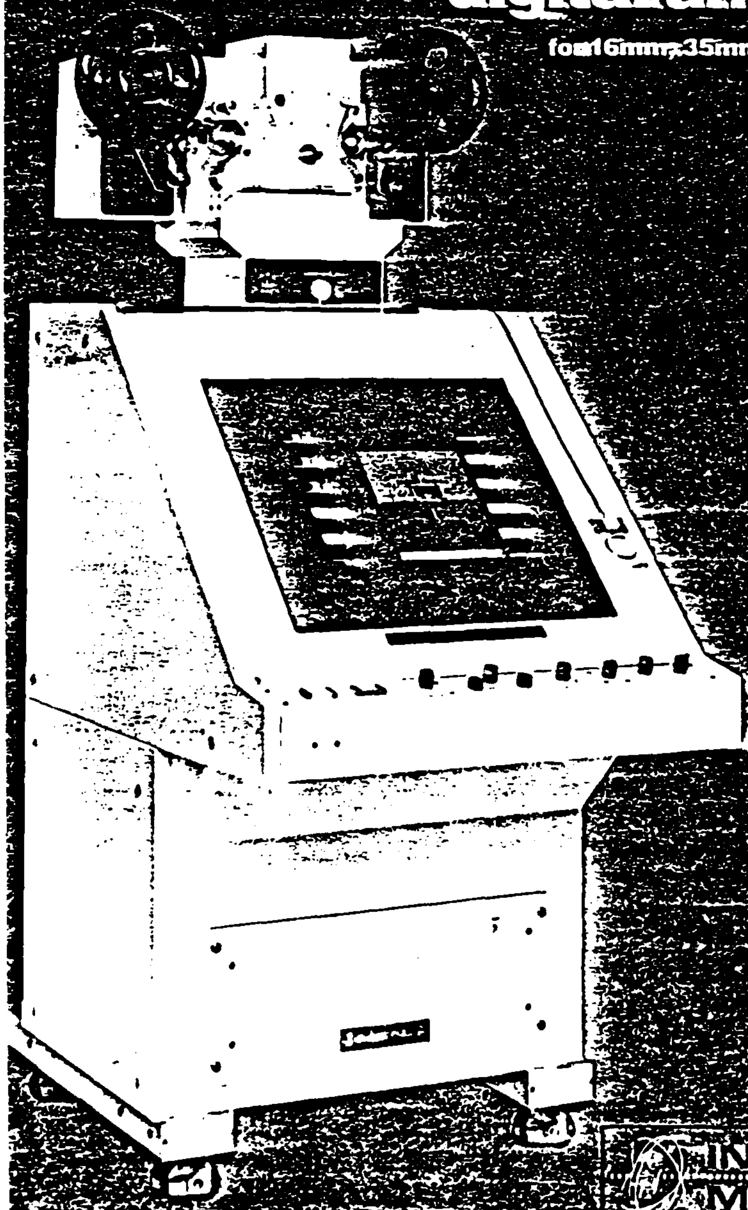
Litton GUIDANCE & CONTROL SYSTEMS
5500 Canoga Avenue, Woodland Hills, California 91365

NAC/PDS

automatic film reading digital analysis system

for 16mm, 35mm and 70mm instrumentation films

Model 78-1



Spec/Data Sheet

INSTRUMENTATION MARKETING CORP

Introduction —

High-speed photography has been a primary means of acquiring data during the recording of special events for well over two decades. The art of high speed photography has progressed to the point where framing rates are regularly used in excess of ten thousand frames-per-second while still maintaining remarkable clarity and image integrity over the entire film format. There have also been major advances in digital electro-optical imaging systems in recent times. However, the application of these digital imaging systems to high-speed motion is still far inferior to that of photographic means. A conservative estimate of the capabilities of high-speed photography is that one million picture elements (pixels) can be recorded per one 35mm film frame. At one thousand frames-per-second, one billion pixels per second can be recorded. It has been estimated that digital techniques will not be capable of attaining these recording rates any earlier than 1990.

Many scientific and technical experiments rely heavily on film recording because of the permanence, high information content, and flexibility in terms of speed of the film medium as well as its availability, storage capabilities, and ease of handling of large quantities of data as it relates to pixel content. Since there are few analytical tools available for automatic data reduction, manual analysis is often the only procedure used. Manual analysis of film is a time-consuming and expensive process, and accurate data retrieval is difficult resulting in large quantities of unreduced data.

Applications —

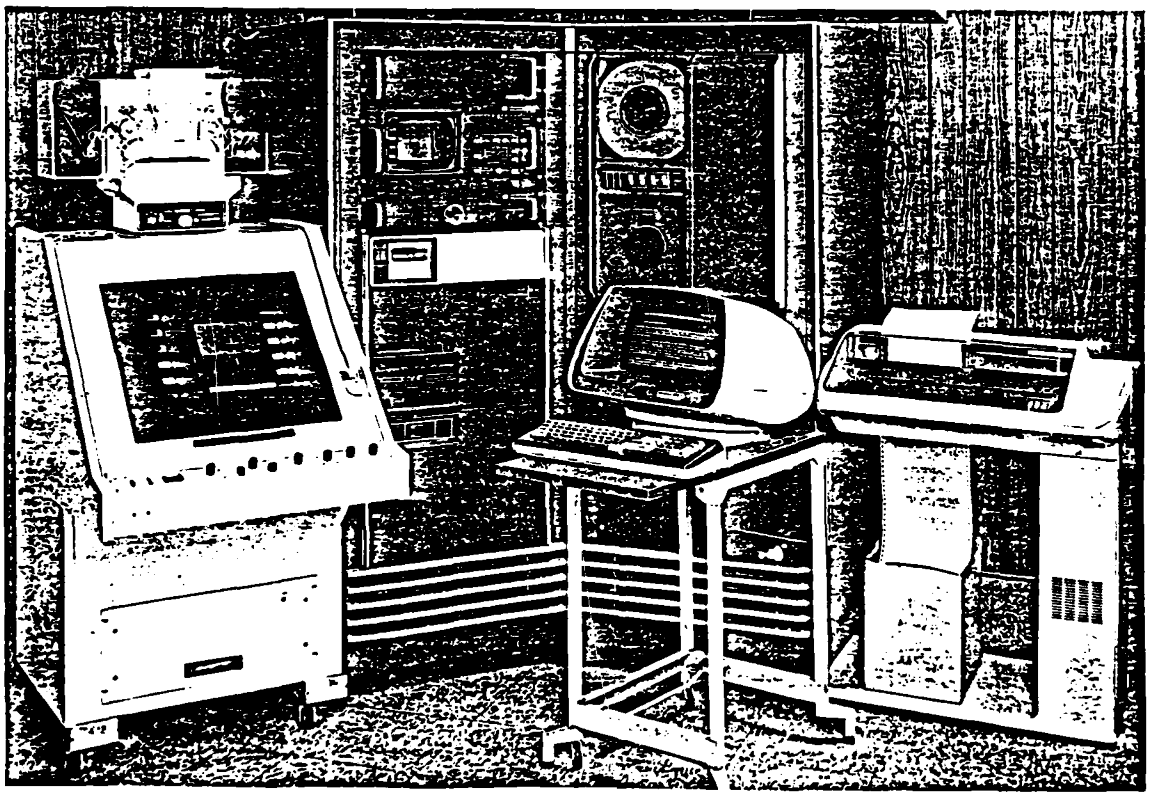
The Model 78-1 lends itself to fully automatic film reading jobs, with no human intervention, where specific types of information are recorded on film such as dot matrices or alphanumerics plus cooperative shapes which might include a dot, cross or quadradic target.

These are often found in high-speed instrumentation films used in range tracking applications, car crash studies, biomechanics research, the medical field, plus a host of other categories. With non-cooperative targets the Model 78-1 is very fast with the utilization of a digitizing tablet. X-Y target points may be quickly digitized manually while other information such as dot matrices may be read automatically.

The digitizing screen also allows strip charts, graphs, illustrations, etc. to be digitized direct from the screen.

The standard Model 78-1

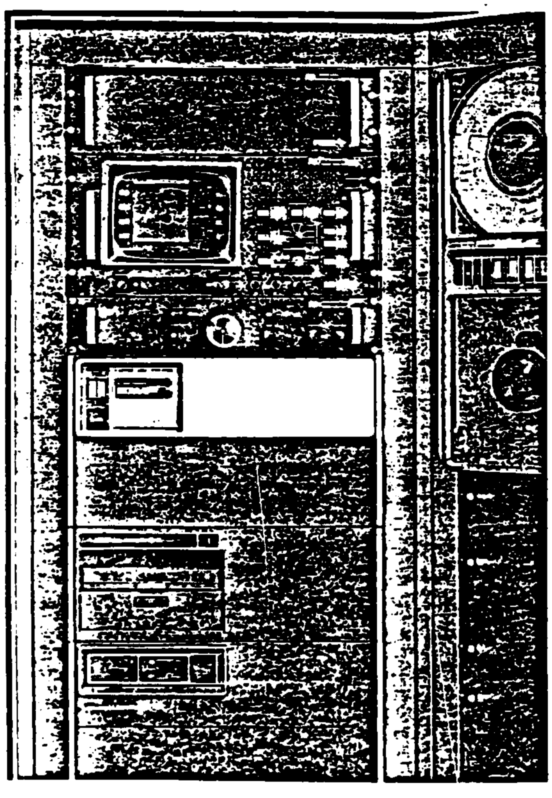
The Model 78-1 consists of NAC rear projection case and projection head, digitizing tablet, PDS electronic control console with scan converter, computer, teletype, magnetic tape recorder and software. Variations might include video display terminal and disc. Your own computer and peripheral equipment may be used by incorporating our smart interface.



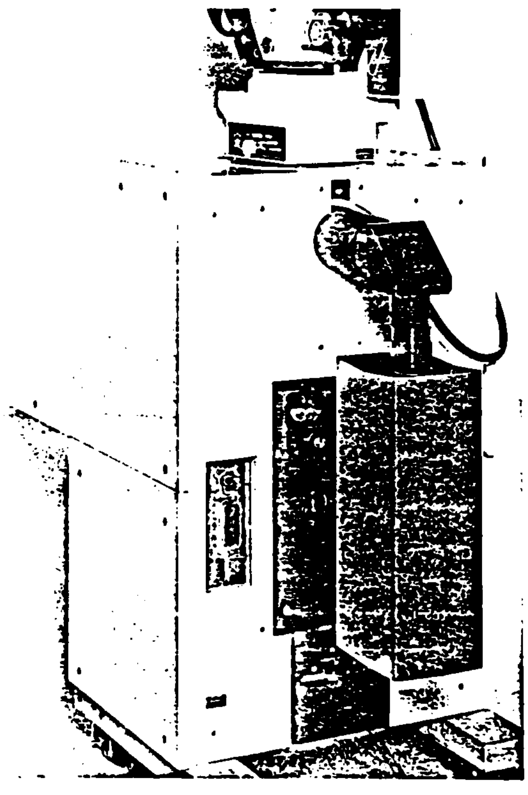
A computer-controlled system designed specifically for the analysis of pictorial data would be the ideal tool for data extraction and reduction. Such a system should possess high film movement accuracy, optics capable of high spatial resolution, and the flexibility to accept different film sizes and formats. The system must be capable of accurately and reliably extracting and enhancing digital data with high repeatability over a wide dynamic range at sufficient speed to be cost effective. Above all, since the system would not necessarily always be used for the same function, it must be flexible enough to handle multiple data recording formats on a customized basis. Additional and most important, the man/machine interface must be proper in order to apply human instruction when targets become questionable to computers.

The system described is designated the NAC PDS Model 78-1 automatic film reading digital analysis system.

Extensive hours of research, development and testing and working directly with users of this equipment have lead to the general conclusion that this system, in automatic mode, is approximately ten times faster and seven times more accurate than existing manual systems.



The electronic control console —
incorporates the control unit, scan converter and computer with a specially designed PDS high-speed interface board and power supply drawer



The digitizing camera —
mounted to back of projection case, consists of an image dissector tube, deflection yoke electronics module and optics

General Specifications —

Projection case (Model MC-78-1) —

Viewing screen: 14" × 14" (355mm × 355mm) coated acrylic, suitable for use in rooms with moderate background lighting

Cursor: With data entry (floating)

Tablet resolution: The absolute accuracy of the system is ±0.003". Repeatability, stability and resolution are .001"

Outputs: RS 232-C, IEEE 488, IBM 029, Binary BCD

Image position controls: Knobs for positioning image on screen vertically and horizontally

Size: 25.4"W, 31"D, 45"H (640 × 815 × 1140mm)

Weight: 225 lbs approx (102 kg)

Control panel (Projection case) —

Power: ON-OFF switch for power supply

Film advance direction switches: Forward and reverse

"Auto-step" switch: Change-over switch from Cine mode to Auto-step (multiple frame advance) mode

Cine speed control dial: Cine speed is continuously variable from stop-motion to full speed

"Auto-step" frame selection dial: Automatic film advance at any number of frames pre-selected from 1 to 10 frames

Light intensity control dial: Variable from Dim to Full

Display: Frame count, X and Y

Frame count: Can be manually or computer preset

Digitizer mode control:

External —	Allows X-Y entry from external source
Point —	Allows X-Y entry from pushbutton on cursor
Rate 1 —	Continuous X-Y entry stream while pushbutton is continuously held down
Rate 2 —	Continuous X-Y entry stream while pushbutton is momentarily depressed. Data stops when pushbutton is depressed second time
Rate min-max —	Speed of X-Y data points for Rate 1 and Rate 2

Projection head (16mm) (Model PH-161) —

Film capacity: 16mm × 800 ft ASA STD PH22.5, 22.12, 22.109, 22.110 (perforated two edges or one edge) .2994" pitch or .3000" pitch

Film advance: Two modes, forward and reverse
(1) Motorized variable speed motion picture type advance from approximately 1 to 32 fps. Complete flicker-free projection at all cine speeds
(2) Motorized free selection of frame number between 1-10 frames with registration by pin

Frame counter: Electrical output

Illumination: 300W Halogen lamp, blower-cooled

Size: 20"W, 13"D, 10.6"H (510 × 330 × 270mm)

Weight: 35 lbs approx (16 kg)

Projection aperture: 0.582" × 0.322" (14.8 × 8.2mm). Aperture covers the viewing of film edge

Rewind: High speed rewind mode provided

Magnification: Nominally 20X (includes viewing full width of film)

Projection head (35mm) (Model PH-351) —

Film capacity: 35mm × 400 ft ASA STD PH22.1, 22.36, 22.93, perforated two edges .187" pitch

Film advance: Two modes, forward and reverse
(1) Motorized variable speed motion picture type advance from approximately 1 to 32 fps. Complete flicker-free projection at all cine speeds
(2) Motorized free selection of frame number between 1-10 frames with registration by pin

Frame counter: Electrical output

Illumination: 300W Halogen lamp, blower-cooled

Size: 20.5"W, 13"D, 15.4"H (520 × 330 × 390mm)

Weight: 45 lbs approx (20 kg)

Projection aperture: 1.248" × 0.905" (31.7mm × 23mm). Aperture covers the viewing of film edge

Rewind: High-speed rewind mode provided

Magnification: Nominally 10X

Projection head (70mm) (Model PH-701) —

Film capacity: 70mm × 1,000 ft available in Type I or II perforation (perforated 2 edges)

Film advance: Two modes, forward and reverse
(1) Motorized variable speed motion picture type advance from 1-5 fps
(2) Motorized free selection of frame number between 1-10 frames with pin registration

Frame counter: Electrical output

Illumination: 300W Halogen lamp, blower-cooled

Size: 22.8"W, 14.2"D, 21.25"H (580 × 360 × 540mm)

Weight: 101 lbs approx (45 kg)

Projection aperture: 2.283" × 2.267" (58 × 57.6mm). Aperture covers the viewing of film edge

Rewind: High-speed rewind mode provided

Magnification: Nominally 3.4X

Digitizing camera —

Optics: Nikkor focal length depends on film size

Lens mount: Ruggedized bayonet mount for Nikon F standard lens

Photo tube: Image dissector 2.25 inch diameter with 1 mil aperture standard

Spectral response: S-20 Standard, S-1, S-11 and S-25 available

Photocathode sensitive area: 1.5 inch diameter

Image dissector output uniformity: ±15% over effective area of 1 inch diameter. Image dissector output uniformity vs X-Y coordinates can be empirically determined and be supplied as information for computer correction techniques

Image resolution: 1000 × 1000 point matrix for 1 × 1 inch effective cathode sensitive area with a 1 mil aperture

X-Y axis orthogonality: Less than ± ½°

Dimensions: 13⅛"L, 5⅝"W, 6¼"H

Weight: 16 lbs. approx (7.26 kg).

Electronic control console —

CONTROL UNIT

Deflection resolution: 12-bit digital to analog conversion (0.025% ± ½ bit) standard (4906 × 4096 stepping increments)

Deflection linearity: ±0.5% over effective cathode area standard

Gray scale resolution: 8-bit analog to digital (256 levels)

Raster scanning rate: 1 frame/sec

Digitizing rate: (computer or manually controlled)
Sequential — 1000,000 points/sec
Random — 50,000 points/sec
Integrating rate — 4 rates standard

Operating modes: Focus, manual, or computer mode

Video amplifier: Linear or logarithmic

Video threshold selector: Computer Mode — 8-bit digital to analog converter
Manual Mode — 0 to +10 VDC Video Selector — White or black

Image dissector protection: A protection circuit is provided to turn off the high voltage automatically when an excessive photocathode current is detected

SCAN CONVERTER

Gray scales: 7 shades of gray

Dot writing speed: 500 nanoseconds

Zoom: Magnification of selected areas

Read video: Standard composite video per EIA Specifications RS-380 or RS-343

Video output: Positive or negative

Display: TV monitor 9-inch diagonal, multiple remote display with large screen TV monitors are possible (529 to 1029 lines)

Operating modes: Focus, manual, computer, superimposed and graphic modes

DIGITAL PROCESSOR

Mini-computer: Nova 4X (standard), 12-bit digital to analog deflection resolution at 0.5% linearity

Interface board: PDS high-speed board

Video gray scale: 8-bit analog to digital

Digitizing rates: Up to 100 KHz normal, including linear or logarithmic video amplification and hardware thresholding

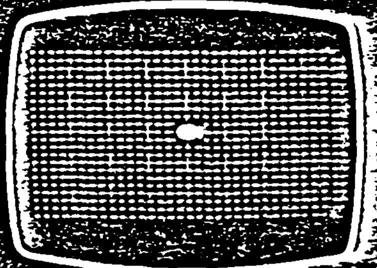
Standard Model 78-1 system —

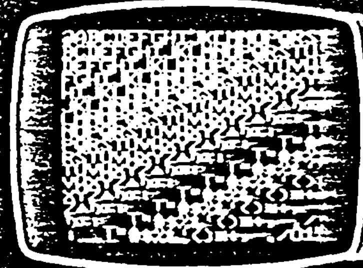
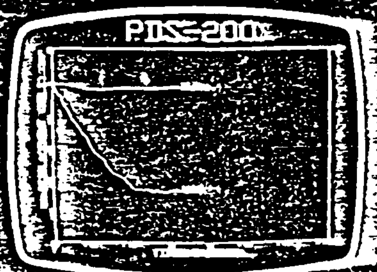
Power requirements: 115V AC ± 10%, 50/60 Hz, 1200 Watts

Operating temperature: 60°F to 80°F (15°C to 27°C)

Specifications subject to change without notice

Printed in U.S.A.




Model 80

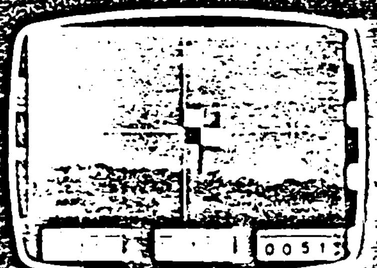


Photo-Sonics/PDS automatic film reading digital analysis system

for 16mm, 35mm and 70mm instrumentation film

Spec/Data Sheet

July 1980

INSTRUMENTATION MARKETING CORP.

Introduction—

The Photo-Sonics Model 80 film reading system is a total facility capable of reducing and digitizing information from film and converting that data into a digital format, suitable for input to a large computer center for further processing.

A variety of film reading equipment is presently being used to perform the basic data conversion from cinetheodolites, telescopes and fixed cameras. Some have been fitted with automatic decoding devices, but the decision of the specific target is still left to the operator. With multiple targets in the film imagery, and with manually controlled wire cursors, the outputting of data to magnetic tape or card reader, makes film reading a very tedious process.

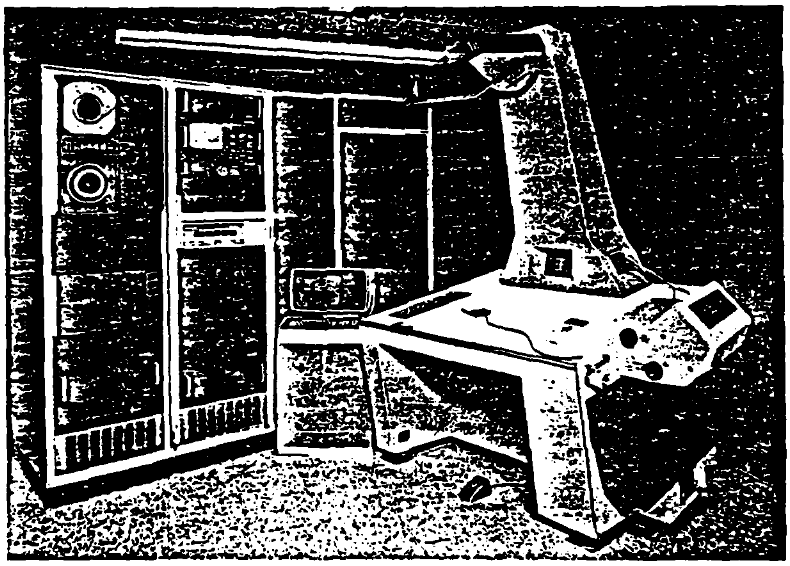
With recent developments in recording coded information with pictorial data, information available from film has increased considerably over the past ten years. In addition the wide variety of formats and variations in codes, plus the general increase of work load with existing work force, necessitated a new look into the optical data conversion field. Photo-Sonics undertook this task to attempt to automate the process of data reduction from film. It was determined that specific types of information such as coded information, LED or alpha-numeric, cooperative targets, and distinct targets of reasonable contrast could be detected and automatically read. Degraded imagery and non-cooperative targets can be

Applications—

The Model 80 lends itself to automatic film reading jobs where specific types of information are recorded on film, such as dot matrices, alpha-numerics and vernier dials plus cooperative shapes which might include a dot, cross or quadratic target. These are often found in high-speed instrumentation film used in range tracking applications, car crash studies, bio-mechanics research, the medical field plus a host of other categories.

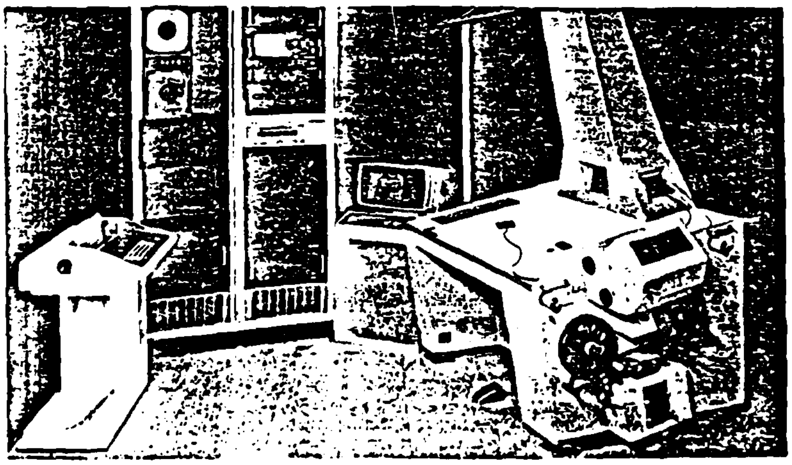
Model 80 subsystems include—

1) film reader console with digitizer table, control panel, cursor, floating keyboard and display, foot switch, x, y, frame LED display, film transport, light source and optics.
2) PDS Digitizing camera and relay optics
3) electronic control console with control unit, scan converter and Nova 3/12 digital processor
4) Magnetic tape recorder
5) CRT remote display terminal
6) Disc
7) Software



Model 80 variation—

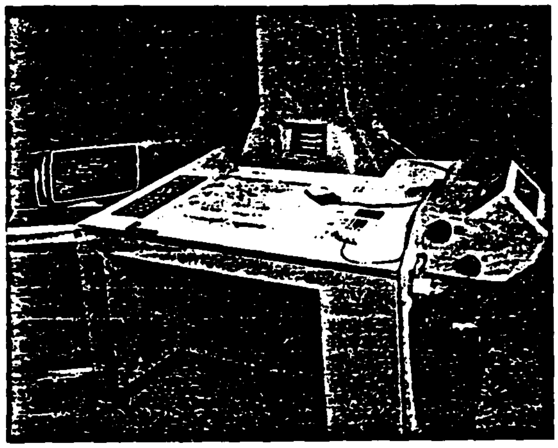
includes the addition of a TTY terminal. Illustration also shows protective dust cover removed from film transport movement, on side of film reader console providing quick and easy access



read manually while the coded data can automatically and simultaneously be digitized.

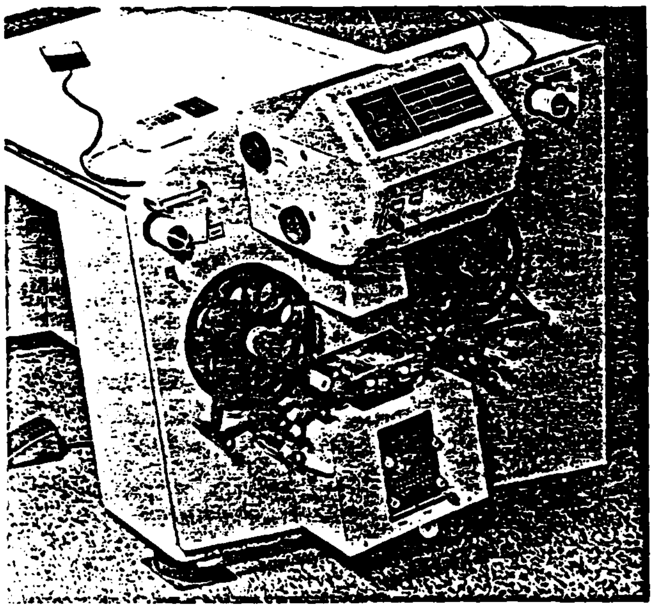
In this semiautomatic mode, the wire cursor system has been replaced by a solid state digitizing table. The free-moving cursor can be moved about with one hand and data entered with the index finger.

The combination of this new digitizer table with an automatic system has the distinct advantage that no matter what the quality is of the film to be read, both the semiautomatic or the fully automatic mode will provide data reduction personnel with a fast and most efficient tool.



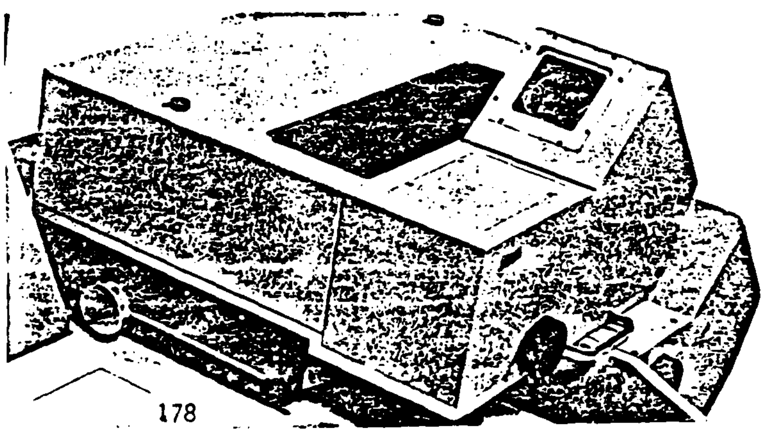
Digitizer table —

control panel, cursor, floating keyboard and display, and projected 26"x26" image area are clearly shown.



Projection optics —

Controls for changing magnification and intensity are conveniently located at operator level on the projection housing. Local film transport controls for loading the film are located near the film movement. An easy-to-read film threading diagram provides instructions for the many ways film can be wound.



140mm film transport —

A special 140mm film transport can be provided which slides into position easily by the operator. Film advance is done manually by the operator. This transport holds approximately 25 feet of film.

System operation—

With the computer de-activated, some controls are available for set-up, checkout and for previewing a roll of film. Film motion is manually controlled with the speed and direction being varied by corresponding knobs and switches located on the operator's control panel. Some of these controls associated with film loading are placed on an auxiliary panel near the film transport.

Under computer control, when dealing with non-cooperative targets, the operator measures desired data points by manually positioning the handheld cursor and depressing the record button on the cursor or a foot switch. The cursor, which is not constrained by any guide bars and whose only attachment to the digitizer table is a light, flexible, electrical conductor, enables the operator to freely slide it in any direction and at any speed up to 300 inches per second. In most cases the LED matrix, fiducials and other reference targets are automatically and simultaneously read. By reading fiducial marks the accuracy of the measurement is not affected by film transport inaccuracies and film sprocket hole tolerances.

When dealing with cooperative targets, all coordinate points are automatically entered to the computer without operator interference. This operation allows the reading of any number of targets, reference points or fiducials and LED matricies fully automatically. Additionally the system can read different size matrix blocks which may be located at any place within a given film frame, by merely calling up the corresponding software program. In this mode, a portion of the program is used for checking abnormal conditions and detecting errors. Should an abnormality or error be detected, the system will call for operator's intervention. The nature of the abnormality is displayed on a monitor and the operator then can decide whether to resume automatic reading or to use the cursor. All communications are via the VDT. Programming functions are provided with the system to enable the operator to initialize and control all system operations from the keyboard.

System specifications—

Reader console—

OPTICAL SYSTEM

Magnifications: 10X, 24X, 42X

For film size: 70mm, 35mm, 16mm

Light Source: Tungsten-halogen type

Cooling: Forced air

Screen: 26" x 26"

Aperture masks: 2 each for 16, 35, and 70mm film formats

FILM TYPE

Any perforated type from 16mm to 70mm. Film thickness from 0.0025" to 0.0056"

FILM TRANSPORT

Modes: (all forward and reversed) • Cine • Rewind • Single frame • Multiple frame, 1 to 10 • Multiple frame with pause 0.2 to 5 seconds

Film speeds: 16 & 35mm: 0 to 24 fps; 70mm: 0 to 10 fps

Film movements: 3 units supplied with system. Configuration as per customer's option. These can be furnished for any perforated 16mm, 35mm, and 70mm film with standard, extended or special apertures. 140mm not included in standard configuration.

Film registration: Mechanical: 0.0015". Not applicable to 140mm

Corrected film registration: (with electronic camera)
0.00031" for 16mm film
0.00055" for 35mm film
0.00128" for 70mm film

Frame counter: ±99,999 in reader console

V-ANGLE MEASURING

Means: Straight edge and cursor

Range: 360° unlimited

Accuracy: Better than 0.1°

DIMENSIONS

Width: 67"

Depth: 45" door clearance

Height: 35" installed; 45" without mirror support

Weight: 1000 lbs. maximum

DIGITIZER TABLE

Digitizing area: 29" x 29"

Effective area: 26" x 26"

Resolution: 0.001"

Repeatability: ±0.001"

Accuracy: ±0.002"

Tracing speed: 300"/second

Cursor: Free-moving, white opaque with parallax-free crosshair 0.007" line width with data enter switch

Foot switch: Used as an alternate data entering device

Electronic digitizing camera—

Photo tube: Image dissector [illegible] diameter with 0.001" aperture standard

Spectral response: S-20

Sensitive area: 1.50" diameter

Effective area: 1.00" x 1.00"

Output uniformity: ±10% over effective area

Stepping resolution: 0.0005" (12.5mm) over effective area; 0.00025" (8mm) max.

Lens Group:			
Demagnifications	4.20X	1.100X	2.562X
For film size	16mm	35mm	70mm

Digitizing rate: 10,000 points/second maximum

Protection: Automatic high voltage turn-off at excessive current on photo cathode

Scan converter and display—

Storage time: 25 minutes minimum

Gray scales: 7 shades

Zoom: 6X magnification

Monitor video: Standard composite per EIA specs RS-330 or RS-343 (European Standard CCIR625/50 available on request)

Video output: Positive or negative (525 lines)

Displays: 9" diagonal monitor

Digital processor—

Mini-computer: Nova series, 16 bit, general purpose computer with up to 32K of word memory

Operating system: Data General RDOS (with disk) or SOS (without disk)

Interface boards: 1. Film reader interface
2. Digitizer table interface
3. Electronic camera high speed interface

These boards are 15" x 15" boards and housed in the main frame of the computer

Mag tape: 75 ips, 9-channel, 800 BPI

Data format: Odd parity, IBM-compatible

Operating modes: Data channel and interrupt handling

Mass storage: 5 mega byte fixed, moving head disk

Terminals—

High speed teletype terminal: 600 BPS

Video display terminal: Up to 9600 BPS

Floating keyboard: 1200 BPS with LED display

Calibration tools—

A) One each Mylar calibration target for 16, 35, and 70mm film movement

B) Two Mylar overlay templates for data block troubleshooting on digitizer table
One template with customer's data block pattern
One blank (additional patterns optional)

Software features—

Targets: Quadrant
Circular—dark or light
Cross—dark or light
Special fiducial mark (crow feet)

LEDs: Variable configuration
Operator defined format
Parity check
First and/or second difference check
Jitter search software

Dial: Cinetheodolite azimuth and elevation to ±.001°

Edge tracing

Graphics plotting for quick data verification

General—

Operating temperature range: 60°F to 100°F (computer system up to [illegible])

Maximum permissible temperature variation: ±5°F

System total shipping weight: 2500 lbs. maximum (without isolation transformers)

Power requirements: 115V AC ±10%, 60 Hz ±5%, 1 phase standard
220V AC ±10%, 50 Hz ±5%, 1 phase on request

Power consumption: 5000 watts maximum

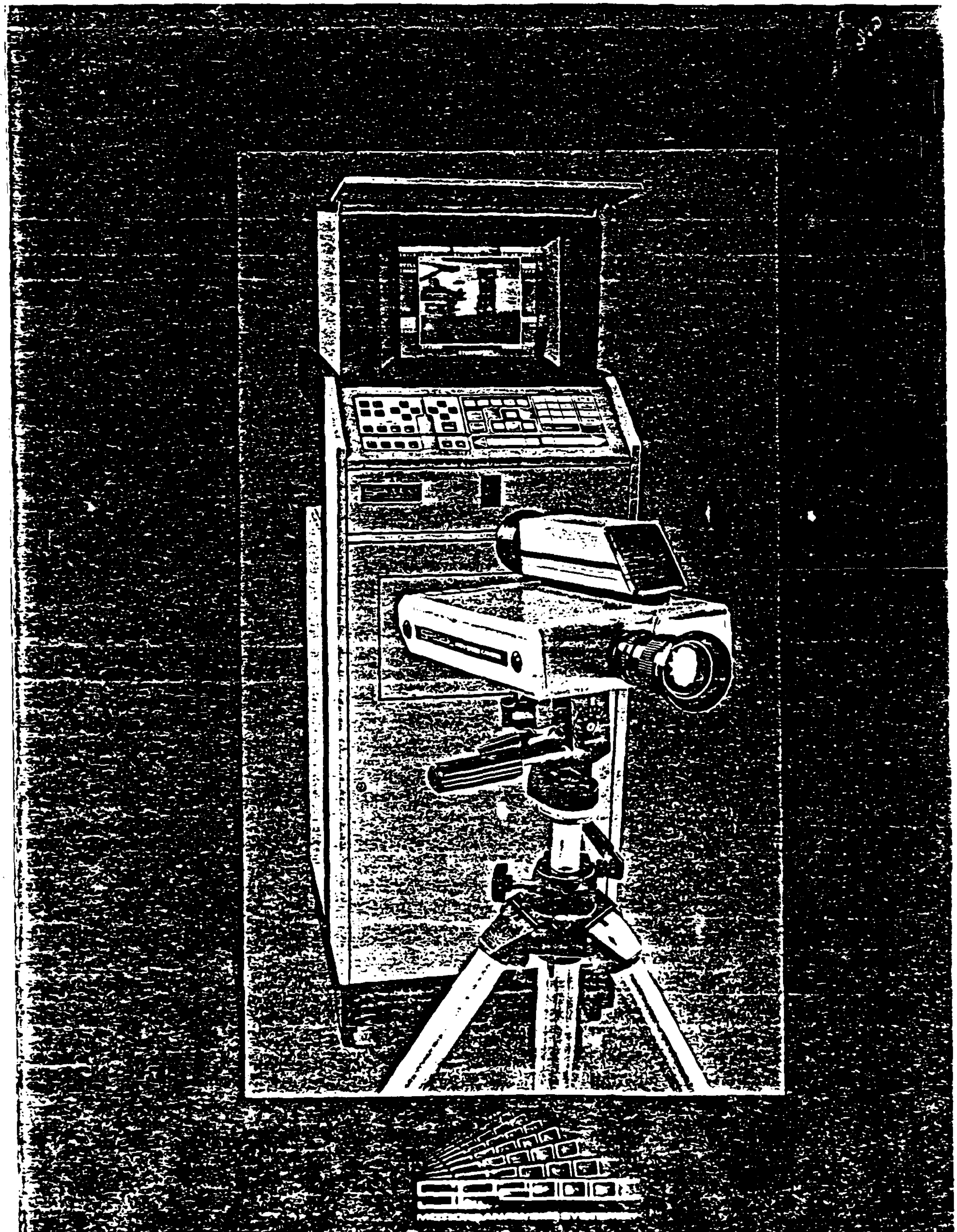
Power cables: 10 ft. supplied with each major component

Plugs and outlets: U.S. standard for 115V AC
European standard for 220V AC

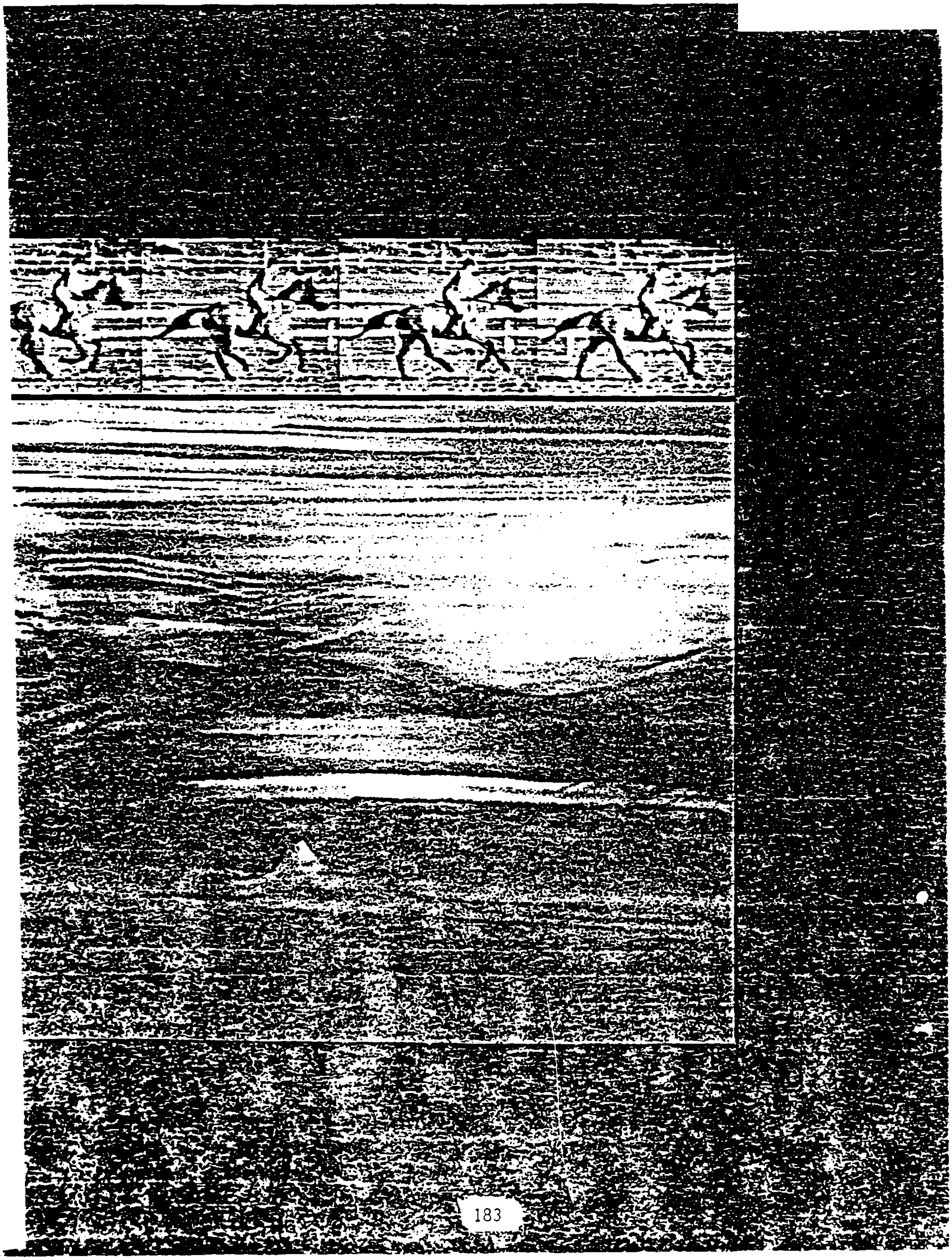
Front panels: Standard 19" wide rack mounted. All drawers provided with slides supplied for each major subsystem

Isolation transformer: Dependent upon user's power condition

Specifications subject to change without notice.




EADWEARD MUYBRIDGE IN 1877
MADE A CLASSIC SERIES OF
PHOTOGRAPHS OF A GALLOPING
HORSE PROVING CONCLUSIVELY
THAT PERIODICALLY ALL FOUR
HOOVES LEAVE THE GROUND
SIMULTANEOUSLY. THUS WAS BORN
MOTION ANALYSIS BY IMAGING
TECHNIQUES. RECAPTURED BELOW IS
MUYBRIDGE'S FAMOUS EXPERIMENT,
USING IMAGING TECHNOLOGY OF
THE 1980s: THE SPIN PHYSICS
SP-2000 MOTION ANALYSIS
SYSTEM.
THIS ACTION SEQUENCE WAS
RECORDED AT 1000 FRAMES PER
SECOND. SHOWN BELOW IS EVERY
FORTIETH PICTURE FROM A
SINGLE STRIDE.



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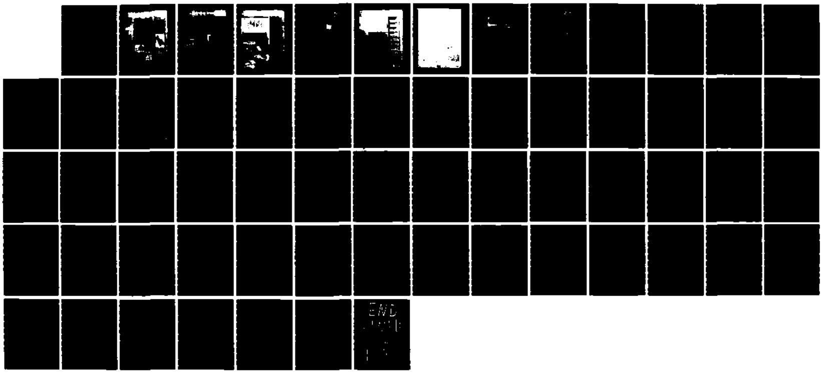
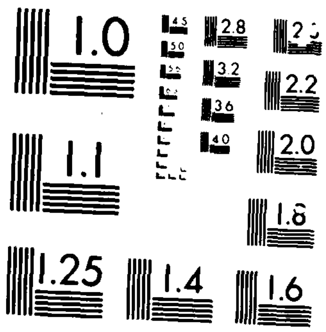
UNCLASSIFIED DNA001-83-C-0414 F/G 14/2 NL





MICROCOPY RESOLUTION TEST CHART

WELCOME TO THE WORLDS OF MOTION ANALYSIS

A WORLD OF INSIGHT

There are many examples of beautiful high-speed images enjoyed by us all—a bullet frozen in flight, a milk-drop tiara, a humming bird poised with motionless wings. Perhaps you're more familiar with the Sunday afternoon athlete, slowly tumbling, twisting, reaching for that agonizingly slow football arching down just out of reach. Or maybe you're one of a growing number who use high-speed motion analysis in their work, studying in great detail events which are just too fast to be seen with the unaided eye.

This is the world of motion analysis, recording a great number of pictures during an event, and then playing them back slowly to analyze the movement which has occurred in step-by-step progression. It's a world previously open to only a few specialist practitioners, a world now open to you through advanced technology from Spin Physics.

[illegible]

A WORLD OF ANSWERS

Practical, real-life applications for motion analysis surround us everyday. For decades engineers, scientists, and photographers have used this powerful technique, and there have been many books and articles published on successful solutions to a wide variety of products and problems. Included are such applications as the following:

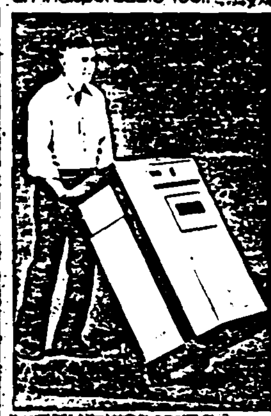
- Paper-making and converting machinery
- Primary and secondary metal-forming processes
- Transportation systems development, crash testing
- Packaging equipment
- Aerospace hardware development
- Gear train, kinematic analysis
- Vibration studies
- Biomechanics
- Printing press operation
- Fluid mechanics, wind tunnel, and cavitation studies
- Ballistics

Similar application possibilities exist in virtually every branch of science, engineering, and production, providing opportunity for savings in time and money.

[illegible]

A WORLD OF TODAY

For over twenty years high-speed imaging has been confined to the technologies of the 1950s and '60s. Now comes a series of breakthroughs which moves motion analysis up into the '80s. The SP2000 system is the motion analysis system for today, combining State-of-the-Art advances in video sensors, video recording, magnetic tape, and electro-mechanical design. The result? An instrument which delivers astounding performance and is so easy to use it will quickly become an indispensable tool.



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A WORLD OF PERFORMANCE

INSTANT RECORDING OF HIGH-SPEED EVENTS

Using patented video techniques, the SP2000 system captures events as they happen by recording from 60 to 2,000 full pictures per second. In the split-frame mode, the picture may be divided into 2, 3 or 6 horizontal segments, achieving speeds up to 12,000 pictures per second. All speeds are instantly selectable.

EXTENDED RECORDING TIMES

Ultra-high density data recording provides recording times of almost 8 minutes at 200 frames per second and 45 seconds at 2000 frames per second. And, due to the unique recording format of the SP2000 system, the recording time at 12,000 pictures per second is also 45 seconds.

[illegible]

DIRECT, LIVE VIEWING

There is no guessing at proper exposure, framing, focus, or lighting. There are no complicated calculations. Just watch the five results on the monitor or camera video viewfinder as you adjust the controls. Everything can be set for perfect results, first time, every time.

INSTANT-REPLAY SLOW MOTION

Push-button controls allow instantaneous slow motion tape review after recording with no delay for processing. A microprocessor automatically searches out the beginning of the last recording, and the tape is played back in continuous slow motion. You can also choose one of four JOG-MODE™ playback rates allowing step-by-step replay. And, there is a single-picture advance feature which allows manual choice of specific frames for study. The JOG-MODE playback and single-picture review features also work in reverse. Use the auto-playback to be sure you have captured the right information; use the JOG-MODE playback to analyze a phenomenon on the spot. You can even change a parameter, rerun the test, and compare results within seconds.

FREEZE-FRAME DISPLAY

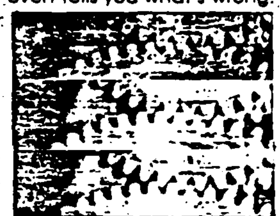
Use of a digital buffer memory permits flickerless, full intensity pictures to be displayed indefinitely, with the tape recorder inactive. This allows you to perform a detailed study of an image with no noise bars and no tape wear.

INTEGRAL POSITION RETICLE

Measurement of exact positional change is fast and simple using the integral cross-hairs with numerical readout of X and Y coordinates. Enabled at the push of a switch, these cross-hairs may be quickly positioned over the subject of interest, and the frame-by-frame change in position accurately measured. Velocity, acceleration, growth rate, and a host of similar properties may be calculated using this handy feature instead of more expensive special-purpose film analysis equipment.

DATA-FRAME™ BORDER

The active image area of the SP2000 Motion Analysis System is surrounded with a border, providing a wealth of information which is recorded on the tape with the image. Included is a wide variety of parameters regarding the image captured on tape—an electronic log book recorded simultaneously with each frame. There are also messages indicating the source of the current image, the status of the recorder, and certain error signals such as a "NO-TAPE" signal when trying to record before loading a cassette. The SP2000 system not only helps prevent mistakes, it even tells you what's wrong.



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EASY-TOUCH CONTROL PANEL

It takes only a few minutes to learn how to use the controls on the SP2000 system, which are grouped and color-coded by function. A high-reliability membrane touch panel gives protection against dust and liquids.

EASY-LOAD CASSETTE

The special SPI recording tape comes in easy-load cassettes, and changing is almost as fast and simple as for an audio cassette deck. This allows you to run a large number of tests without delay, subsequently examining each cassette for valuable information. Tapes may be stored for future reference or are easily erased for reuse.

DUAL CAMERAS

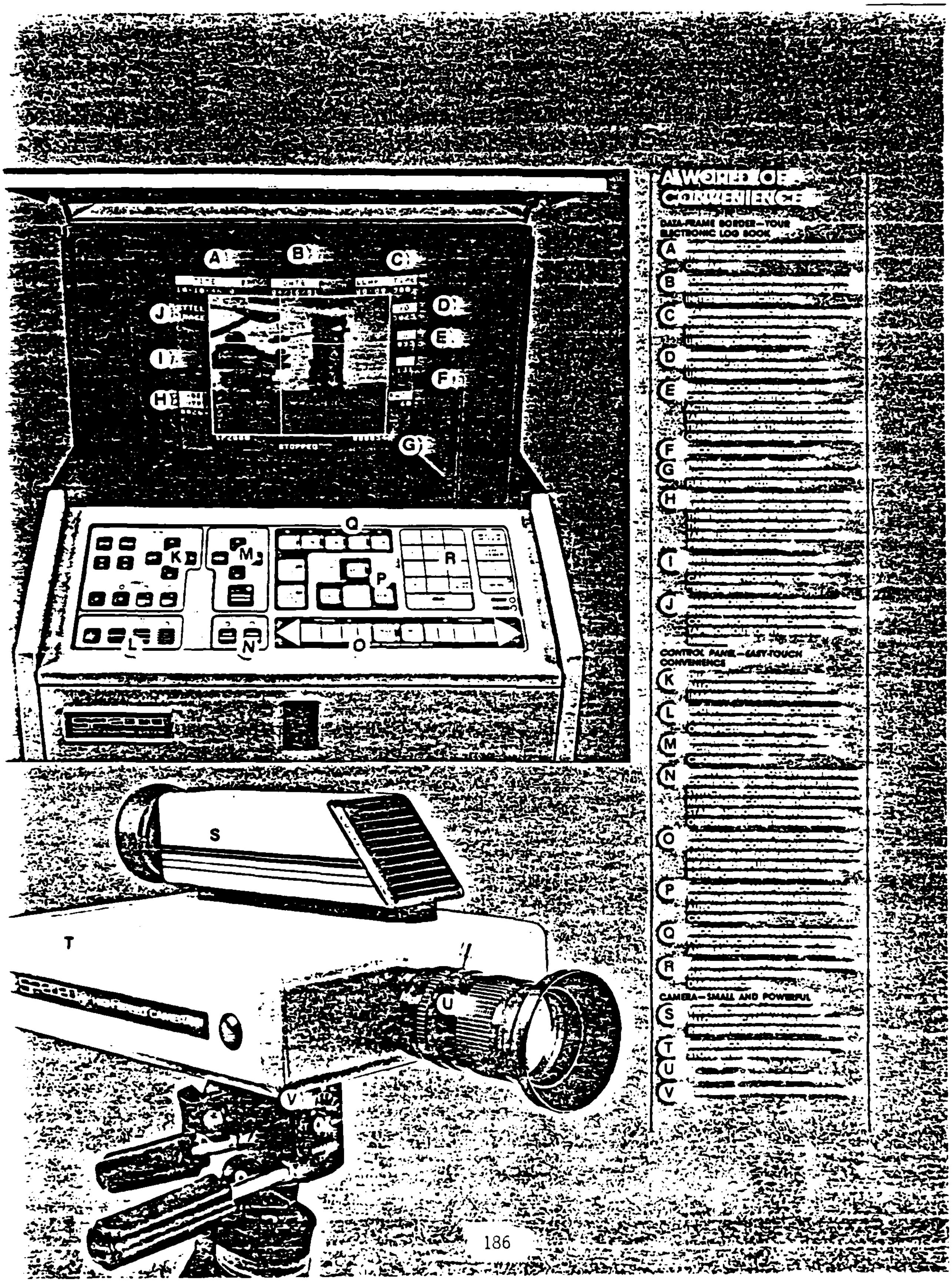
The SP2000 console will support two cameras, and the optional second camera may be used in a variety of ways. Simple push-button controls give you the choice of recording from either camera individually, or from both simultaneously in a wide variety of formats. You can even record stereo pairs for a unique high-speed analysis approach.

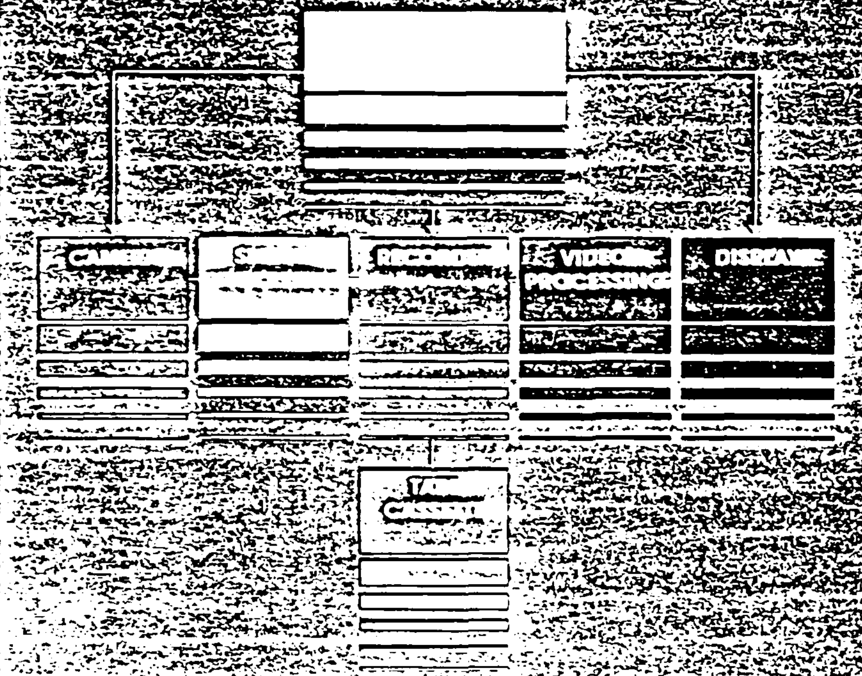
STANDARD VIDEO FORMAT

The video output of the SP2000 system is fully compatible with standard TV monitors and can be transferred directly by a single cable to standard Betamax, VHS, U-matic, and other video recorders. You can study your problem and find a solution, copy the images from the SP2000 system onto a standard cassette, and mail it to a colleague for review on a standard video cassette recorder. Hard-copy units designed for use with video output may be used to generate pictorial copies.

AUXILIARY DATA RECORDING

Additional data may be recorded on the tape of the SP2000 system simultaneously with the image through the use of a digital input port. When used with optional interface modules, the output of various instruments such as test transducers or range clocks may be stored in digital format to be read off the video screen upon slow motion playback.


A WORLD OF CONVENIENCE
DATA-FRAME BORDER—YOUR ELECTRONIC LOG BOOK
CONTROL PANEL—EASY-TOUCH CONVENIENCE
CAMERA—SMALL AND POWERFUL
STOPPED



THE CAMERA

Using a solid-state video sensor developed at Kodak Research Labs, the camera of the SP2000 system is a unique visual recording tool. The secret of its incredible framing rate is the ability to transfer 32 lines of photographic data in parallel at rates approaching 10^8 pixels per second. Unlike more conventional video-imaging tubes, the sensor of the SP2000 system exhibits no lag, thus ending forever the ghosting problem. And it is not damaged by an overload of light.

SIGNAL PROCESSING

The data provided by the camera are converted to an FM-modulated signal, thus providing a well-known and understood recording technique for data storage. These data are fed in turn to the recorder with a special timing track to keep all the signals fully synchronized.

THE RECORDER

The SP2000 system is based on linear video-recording techniques. Patented Spin Physics microgap recording heads are used to achieve very high data packing density at very high data transfer rates not achievable with current rotating head designs. This allows recording of almost 10^8 pixels per second of data, at a density over 5×10^6 bits per square inch. The recorder transport mechanism is a precision data tape recorder, in a small package and designed for cassette loading. It reaches high operating speeds in minimal time, provides long recording times, and offers a wide variety of playback modes including continuous slow motion playback and freeze frame.

THE TAPE

Spin Physics, Inc. manufactures an outstanding recording tape jointly developed with Kodak Pathe. This tape exhibits a signal-to-noise ratio unmatched in the industry, and it provides a perfect match for the high-density recording required by the SP2000 system. Packaged in convenient cassettes, it may be stored for future viewing.

VIDEO PROCESSING

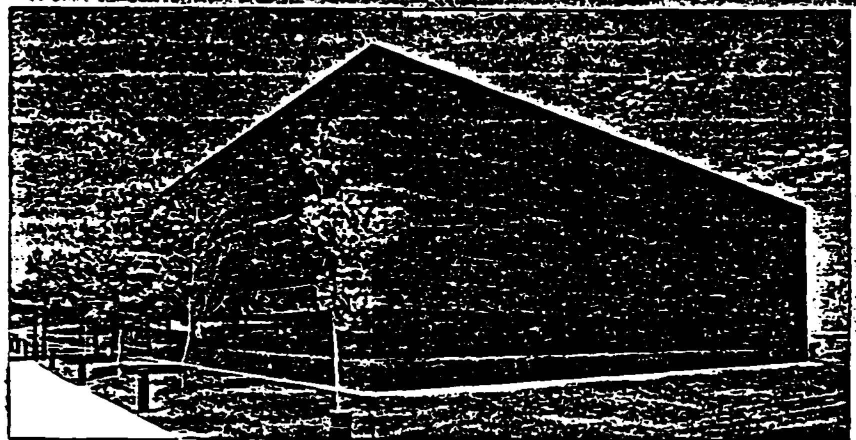
In playback, the parallel FM signals on tape are demodulated and then digitized for storage in a digital buffer memory, one TV frame at a time. This stored image is then fed in NTSC format to a standard television monitor. In freeze-frame playback, one frame may be stored and repetitively fed to the monitor from the buffer so that this image may be frozen on the screen indefinitely with the recorder stopped.

THE CONTROLS

6809 microprocessors are used to provide a wide range of simple yet sophisticated controls. Firmware has been developed to allow operation of the system without extensive training, and includes safeguards which render the SP2000 system virtually immune to operator error. Diagnostic routines are included for troubleshooting many areas of system performance. Continuing firmware developments are expected to expand the application capabilities of the SP2000 system for years to come.

THE DISPLAY

The SP2000 Motion Analysis System incorporates a 12-inch diagonal monitor screen and further provides parallel outputs for a monitor or video tape recorder. The monitor retracts into the console for easy transport and storage and is raised back into viewing position by an automatic [illegible]



A WORLD OF SUPPORT

SPIN PHYSICS, INC.

Established in 1968, Spin Physics quickly become a leading supplier of high-quality, high-performance magnetic heads for recording and playback of analog and video signals. Today SPI is the most respected name in the field, and has extensive experience in all phases of magnetic recording.

Purchased by Eastman Kodak Company in 1972, SPI is now part of Eastman Technology, Inc., and provides advanced electronics development capabilities.

TECHNICAL SUPPORT

Spin Physics, Inc. maintains a direct field force of technical representatives, thoroughly trained in the details of the SP2000 system. Application backup is provided through engineers who are conversant with your requirements and have the special knowledge to use the system to solve your problems. Our development engineering group is continually involved in system and application refinements to make certain that the latest in technical advances can be applied to your needs.

RELIABILITY/SERVICEABILITY

Each SP2000 system undergoes stringent performance and reliability testing before shipment. Dedicated computerized test equipment allows extensive tests to be made on each system following burn-in procedures. Solid-state design and extensive use of integrated circuits provides high reliability once the system has passed initial acceptance tests.

The SP2000 system has been designed with ease of service as a prime requisite. Self-diagnostics help to quickly locate system malfunctions. Most electronics problems can be solved at the board level, a procedure easily performed by users if they so desire. All printed-circuit boards contain numbered test points for troubleshooting and are easily accessible through the hinged card rack which allows one to work on the boards from the front of the console. Tape recorder components can be reached and serviced without extensive dismantling of the equipment.

SERVICE HOT LINE

Each user is given a Hot Line telephone number, which is manned during normal working hours by a service specialist who can help troubleshoot over the phone. During off hours, incoming calls are recorded for fast followup. This line may also be used for operation and application questions.

INSTALLATION AND TRAINING

A trained service representative installs each SP2000 system, performs acceptance tests, and trains the user in operation and operator maintenance procedures. Further formal training can also be provided to cover indepth servicing of the equipment, and in its use and application in a variety of sophisticated photographic settings.

FIELD SERVICE/SERVICE CONTRACTS

In addition to warranty service and emergency repair service, the Field Service Department also offers Service Contracts. Ask our Technical Representative for further details.

THE WORLDS OF MOTION ANALYSIS

A WORLD OF INSIGHT

A WORLD OF ANSWERS

A WORLD OF TODAY

A WORLD OF PERFORMANCE

A WORLD OF CONVENIENCE

A WORLD OF TECHNOLOGY

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THE WORLD OF

SPIN PHYSICS

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SPIN PHYSICS
SYSTEMS DIVISION
3099 Science Park Road
San Diego, CA 92121
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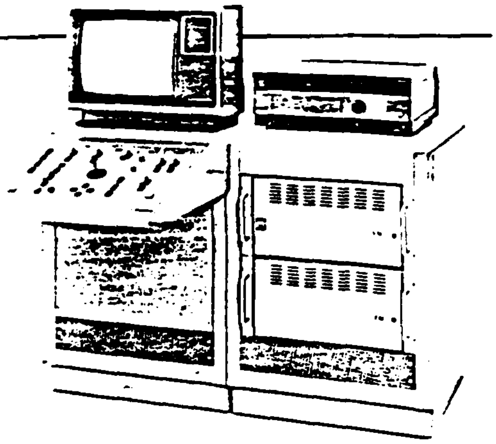
OPERATION



The VM-200 receives a standard RS170 or NTSC video signal from virtually any source including cameras, scan converters, VCR's or other recording system. The video is applied to the disk and recorded while being presented on the monitor display. When the recording is halted, the preceeding ten (10) seconds* has been stored and is available for analysis. Playback rate is controlled by a "step rate" slider or a single step push button. A Forward/Reverse switch controls the step direction. Two cursors are used to measure points of interest within the displayed field. One is used to set a zero reference and the other establishes the X, Y coordinate referred to the reference.

Position of each cursor is controlled by a joy stick, for course adjustment, and four single step switches for fine positioning. Also inserted into the displayed video, under operator command, are:

1. Field count
2. X, Y coordinate values for each cursor
3. Data decoded from vertical interval
4. Graphic overlays, i.e. grid, dot matrix

*20 second storage optional

INSERTED VIDEO DATA DISPLAY

All data inserted into the Video display is on a 320 X 240 pixel matrix. Alphanumeric characters are generated on a 5 X 7 dot matrix with a dot equal to one pixel. All alphanumeric information is displayed in the lower left corner of the video frame. The cursors and graphic overlays have a line breadth of one pixel.

VIDEO INSERTION MODE

The generated video may be mixed with the existing video any one of three ways depending upon the position of a panel selector switch:

CONSTANT LEVEL WHITE
In this method, a fixed level is overlaid on the existing video. The added video amplitude is, therefore, constant and unaffected by original video. The technique is satisfactory when the original video is of generally constant level, such as a flat field background.

BLACK
The generated video is again overlaid on the existing video, but in this case in the opposite polarity. The level is not adjustable as in the white.

RELATIVE WHITE
This is the most commonly used method of adding the generated video. It provides a pleasing display over a wide range of original video light levels. A level set by an intensity control is added to the existing level of the original video and the "added" generated video is therefore constant. This helps prevent wash out at the high light levels and assures a non-glaring display at the low levels. An additional feature of this mode is that it doesn't obscure the existing video. Features will show through the overlayed video.

CONTROLS AND INDICATORS

POWER
SEND Momentary Push Button
DISK CONTROL
- Record
- Play
- FWD BKWD
- Step Rate
- Single Step
- Reset

GRAPHICS CONTROL
- Cursor A
  - Open Close Dot
- Cursor B
  - Open Close Dot
- Curser A
  - ON/OFF

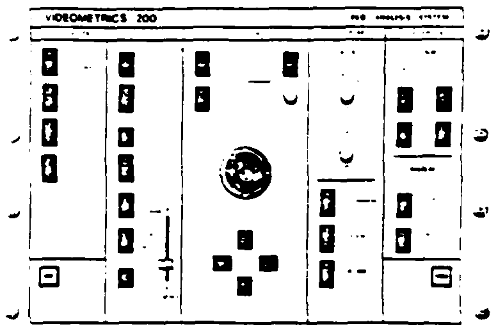
GRAPHICS CONTROL (cont.)
- Cursor B.
  - ON/OFF
- Overlay ON OFF
- Overlay Grid Dots

CURSOR CONTROL
- Remote Local
- A/B
- Position

DISPLAY
- Mode
- Intensity
- Coordinate
  - Display
- Field ID
- Decoder

another advanced video product from

CONTROL PANEL



SPECIFICATIONS

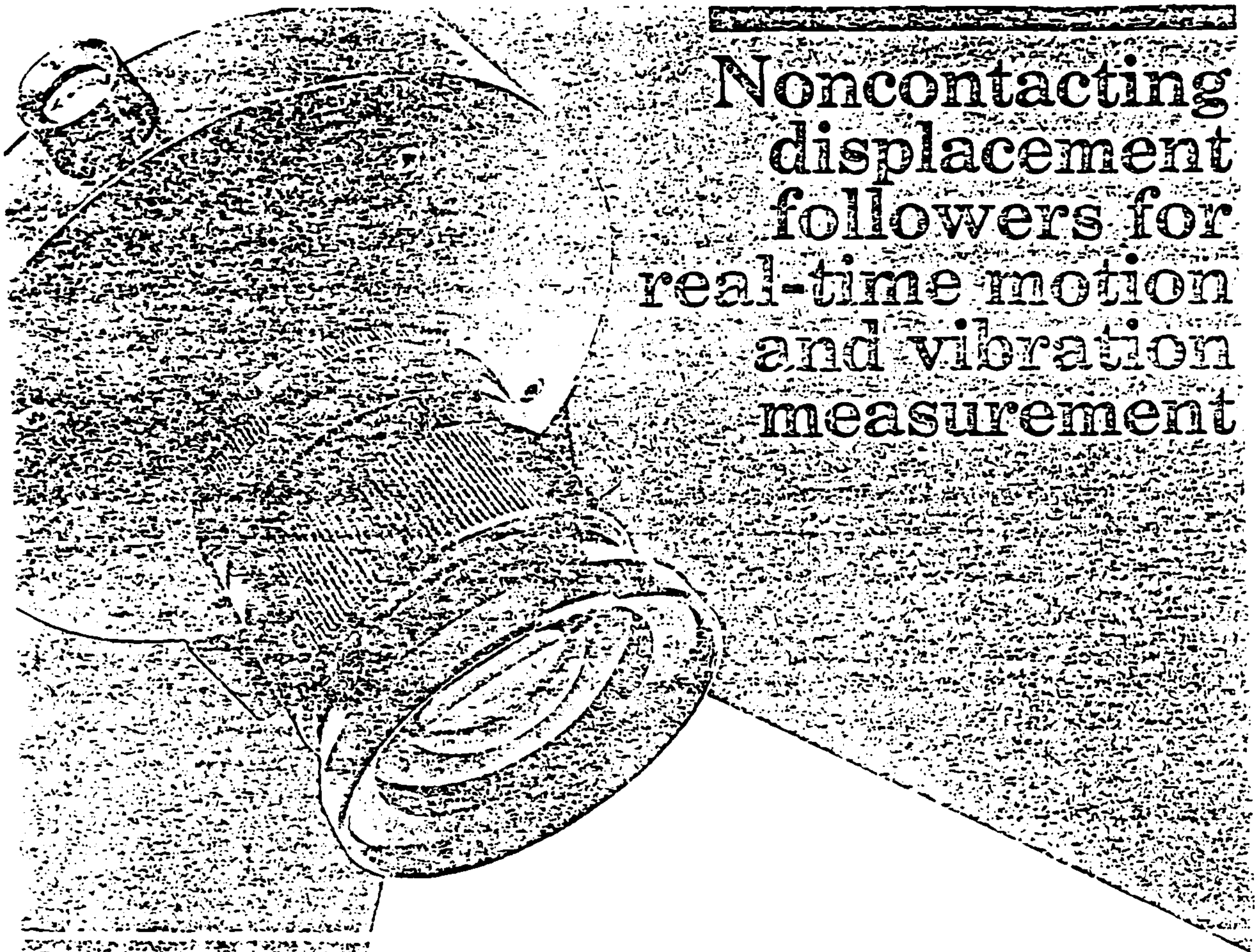
Video Input: 525/60 I A W EIA RS170 or NTSC, 1 volt peak to peak, black negative interlaced 2:1
75-OHM impedance.
Disc Bandwidth: 4.2MHz ±3db
Field Step Rate: Single to 60 fields per second
Cursor Position:
Resolution: 320 pixels horizontal (640 optional), 240 pixels (equal to raster) vertically
Inserted Characters:
Format: 5 X 7 dot matrix, 3 pixels between characters horizontally, 1 pixel (scan line) between character lines
Graphic Overlay Format:
Grid: Crosshatch pattern with lines appearing every 20 pixels both horizontally and vertically
Dot: Dot matrix with dots appearing every 20 pixels horizontally and vertically
Interface: RS232C (IEEE 488 GPIB optional)
CPU: Z80A
Memory: 16K bytes dynamic RAM
4K bytes EPROM
Power Requirements: 115AC 60Hz

Specifications subject to change without notice

Printed in U.S.A. 6 83

exclusive distributors

INSTRUMENTATION MARKETING CORP.
820 South Mariposa Street, Burbank, CA 91506
Phone 213 849-6251 Telex 67-3205

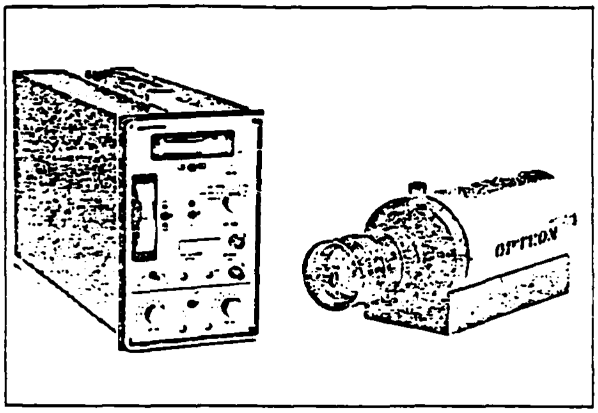


Noncontacting displacement followers for real-time motion and vibration measurement

- Measure remote or inaccessible objects
- Biaxial displacements - linear or angular
- Differential displacements - extensometry
- Non Contacting

OPTRON

Model 5600 Biaxial Displacement Follower



The Model 5600 Biaxial Follower permits simultaneous measurement of target motion in two orthogonal axes. Target orientation and tracking mode is front panel selectable, allowing any of the four corners of a rectangular target to be tracked. Single axis operation in either axis is also possible.

In the biaxial mode of operation, an electronic network switches the tracking axis between vertical and horizontal at a 50 KHz rate. Hold amplifiers in the servo loop remember the previous target position, and furnish the drive for the deflection amplifiers. Separate horizontal and vertical data amplifiers drive separate meters and provide individual signal outputs.

The Model 5600 tracks either rectangular or circular targets whose dimensions can be as small as 10% of the full scale measurement range. If the target leaves the field of view, an automatic search of the entire field takes place. When a proper target enters the field of view, the image is captured and tracked, and output signals are restored.

Model 5100 Single Axis Displacement Follower

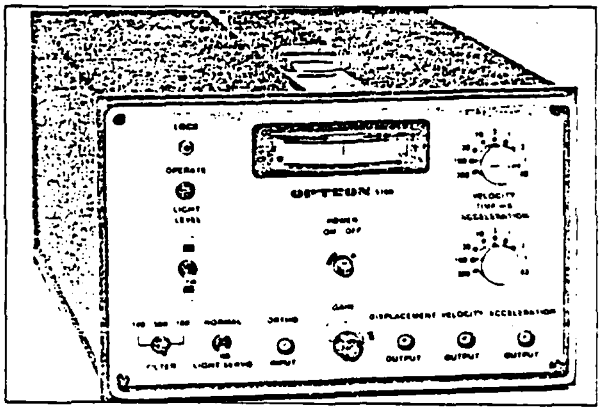
The Model 5100 Single Axis Follower features simple operation for measurement applications as diverse as bending of large structures to runout, vibration, ultrasonic motion, and ballistic motion. Angular measurements can be made by autocollimator targeting techniques.

The optical head can be rotated to align the measuring axis with the target movement, while the target phase or orientation is front panel selectable.

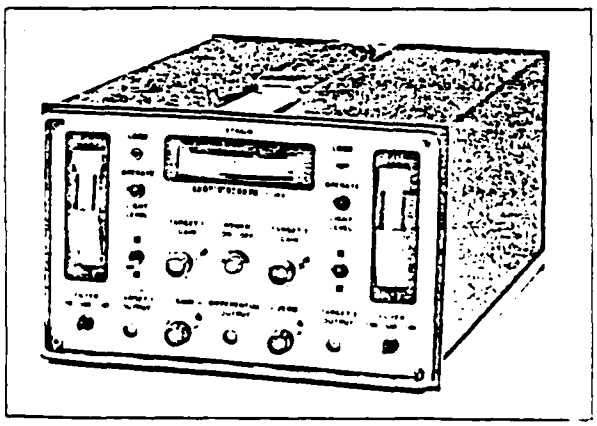
The 5100 is complete with Optron's light servo circuitry which monitors target illumination changes and automatically adjusts the electron multiplier gain to compensate for changes in image intensity. This feature is especially useful in outdoor applications where ambient lighting cannot be easily controlled.

The 5100 also contains differentiator circuitry to provide analog velocity and acceleration outputs in addition to displacement data.

Conventional instrumentation such as analog or digital oscilloscopes, transient recorders, or waveform digitizers can be used to record the outputs from the Model 5100.



Model 5100X Differential Displacement Follower/Extensometer



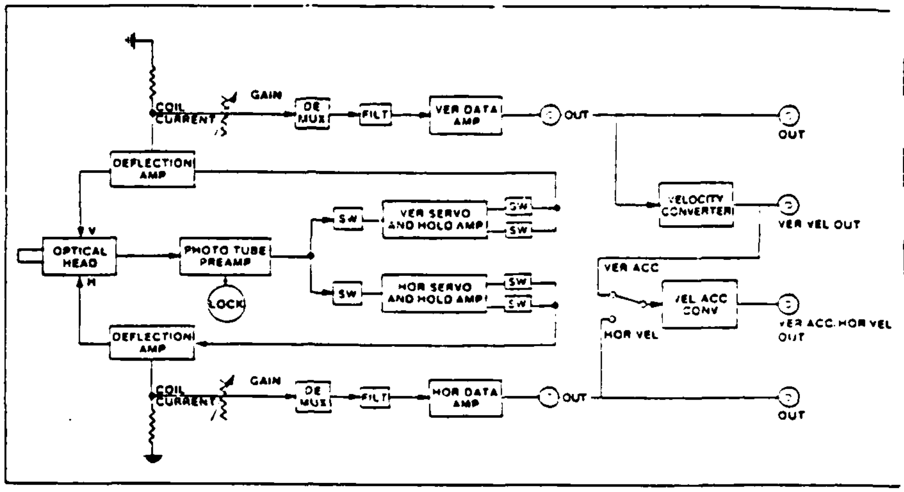
The Model 5100X is essentially two single axis displacement followers combined in one convenient instrument. This system permits simultaneous displacement measurement of two targets, providing *differential* as well as individual target displacement outputs.

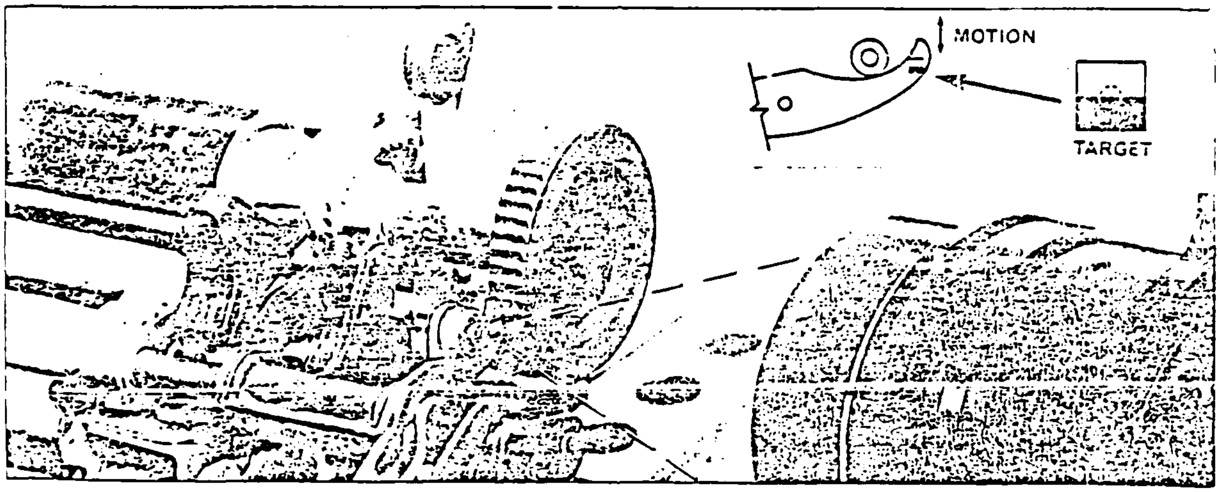
The 5100X, having extremely high frequency response (up to 200KHz), is especially suited to measurement of materials subjected to high strain rate testing, either at ambient or high or low temperatures. It is employed in many applications involving the rapid movement between two objects or targets.

The 5100X can be supplied with two individual optical heads (as shown), permitting virtually unlimited separation between targets, or, the 5100X split image extensometer head which permits differential measurements with a single optical assembly.

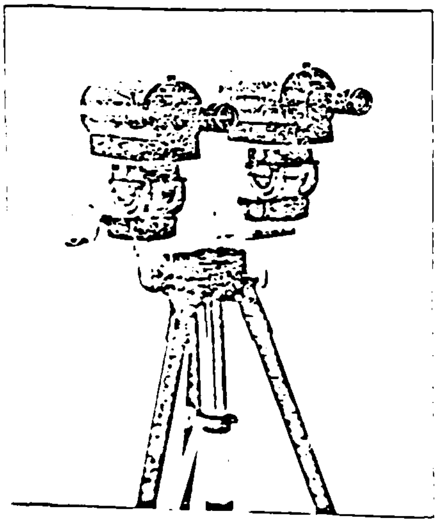
Frequently, in the study of high speed motion, the variable of interest may not be displacement but velocity or acceleration. The Model 5600 incorporates two high performance differentiators that convert the displacement outputs to velocity and acceleration.

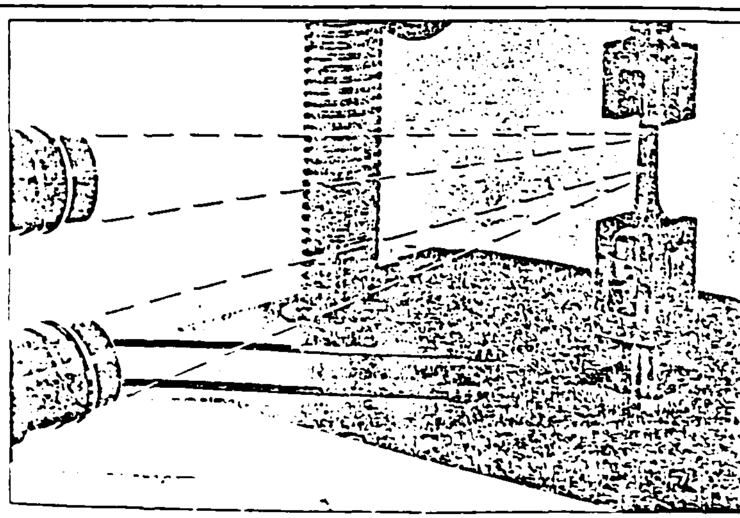
The outputs of all three parameters (displacement, velocity, and acceleration) are suitable for simultaneous recording or oscilloscope display.





Model 5100 measuring cam pawl of adding machine.





Model 5100-X measuring strain of tensile specimen.

Key Features and Specifications

5600

Full Scale Measurement Ranges	020" to infinity, depending on lens
Resolution	To 00001", depending on lens
Measurement Modes	Biaxial (x-y) Single Axis (x or y)
Built-In Differentiation	Provides Velocity/Acceleration Outputs
Frequency Response	Biaxial DC-10KHz Single Axis DC-50KHz

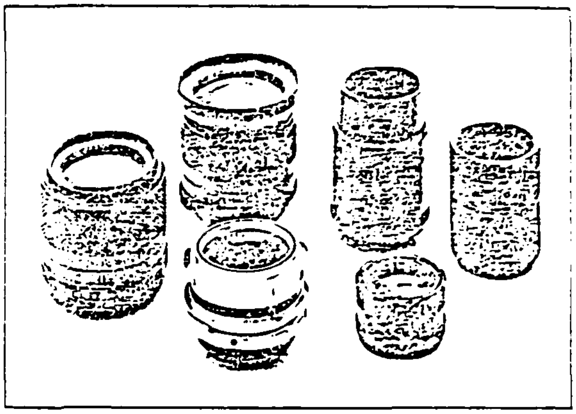
5100

Full Scale Measurement Ranges	020" to infinity, depending on lens
Resolution	To 00001" depending on lens
Measurement Modes	Single Axis (x or y)
Light Servo Function	Automatically compensates for target illumination variations
Built-In Differentiation	Provides Velocity Acceleration Outputs
Frequency Response	DC - 50KHz, Standard 200KHz Optional

5100-X

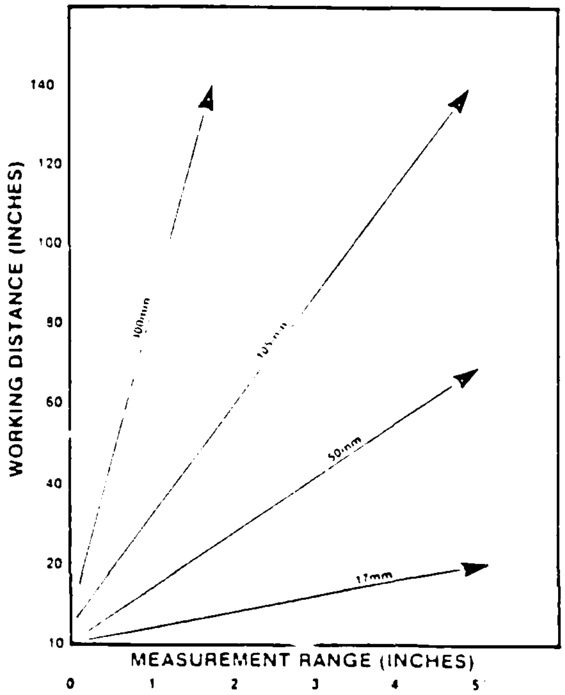
Full Scale Measurement Ranges	020" to infinity depending on lens
Resolution	To 00001" depending on lens
Measurement Modes	Differential - Single Axis (Requires dual optical heads or split-image extensometer head)
Light Servo Function	Automatically compensates for target illumination variations
Frequency Response	DC - 50KHz, Standard 200KHz, Optional

Lenses and Full Scale Measurement Range



The tracking area of the image dissector photocathode, over which the electron image is deflected, is 150" x 150" (3.75 x 3.75 mm) square. Thus, the full scale measurement range or field of view can be fixed by the choice of a lens and extension tube that will form a 150" square image of the desired range. Lens charts provided with each instrument permits lens selection without calculation.

Different applications require different working distances between the lens and the object, as well as different full scale measurement ranges. The standard lens set and extension tubes supplied provide full scale measurement ranges from 0.1" to infinity with convenient working distances for many applications. Optron will help you determine the lens and configuration best for your application, and will design and build lens assemblies to meet specific requirements.



OPTRON

Non-Contacting Displacement Followers

REMOTE MOTION MEASUREMENT

- No mechanical loading or change in specimen dynamics
- Measure movement of soft or fragile specimens
- Measure inaccessible objects from a distance
- *Measure from outside of hostile environments—hot cold,* vacuum, radioactive, high voltage, corrosive, explosive
- Follow very small movements from far away

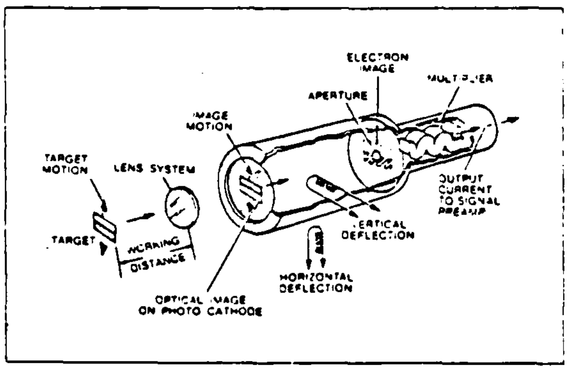
METHOD OF OPERATION PROVIDES VERSATILITY

- Simultaneous, multiple axis measurements
- Differential measurements
- Static or dynamic measurements—dc to 200KHz
- Fixed viewing port allows continuous observation
- Spectral response comparable to human eye
- Real time tracking of displacement, velocity and acceleration
- No need for elaborate laser, strobe, or collimated lighting
- High resolution angular measurements readily implemented by autocollimator methods
- Can replace high speed photography by eliminating film processing and data reduction

CURRENT APPLICATIONS OF OPTRON DISPLACEMENT FOLLOWERS INCLUDE:

- Valve displacement in internal combustion engines
- High speed motions in impact character printers
- *Bending and twisting of ship hulls, bridges and other* structures
- Dynamic resonance and tracking of magnetic heads over hard and soft disc drives
- Motions in weapon firing mechanisms
- Relay contact bounce
- High speed camera shutter motion
- Turbine blade motion through excitation and operation
- Solid rocket propellant burn rates
- Displacement, vibration, and run-out in tools, machinery, and consumer goods
- Biaxial movement of laser disc optics
- Strain and fatigue in material testing
- Pressure burst testing
- Power transmission line motion
- High strain rate testing

Theory of Operation

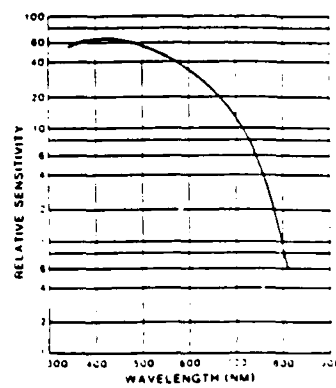


Optron displacement followers track the motion of a discontinuity in the image formed by light reflected from or emitted by a moving object. The spectral response extends from ultraviolet to near infrared. The discontinuity may be an actual edge of the object or a half dark, half light target attached to or painted on the object.

The image of the edge or target is focused on the photocathode of an image dissector tube in the optical head (fig. 1). Electrons are emitted from each point of the photocathode in proportion to the intensity of the light image. The resulting electron image is refocused on a plate containing a small aperture. Electrons passing through the aperture constitute a signal current proportional to the intensity at the corresponding point on the original optical image. This small current is amplified first in a low noise electron multiplier within the image dissector tube, and further by solid state amplifiers in the control unit.

The amplified signal is used by Optron's patented servo loop to keep the electron image of the target discontinuity centered on the dissector aperture. As the optical image moves, the servo control changes the current in deflecting coils so that the electron image is returned to its original position. The deflection current required to recenter the image is a measure of target displacement.

The dissector aperture is a small, centrally located hole. Thus the optical head may be rotated so that the direction of deflection is parallel to the target motion, or two orthogonal deflection coils may be used to move the electron image in whatever direction is needed. This and other servo loop features implement the different functions provided by the various Optron models.



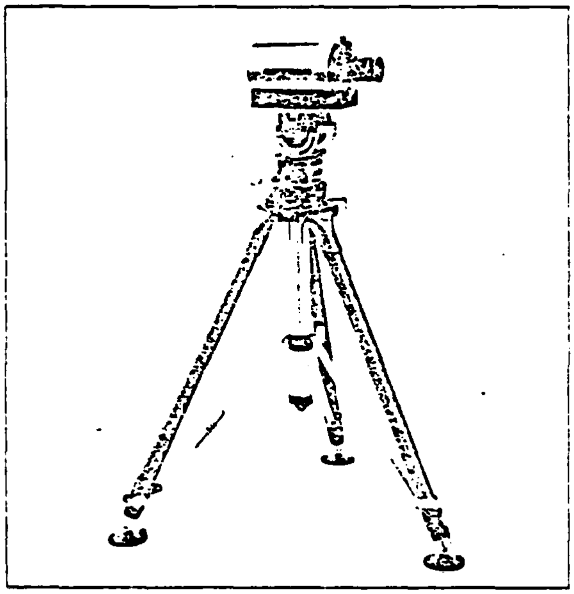
Typical spectral response of S20 photocathode used in standard Optron optical heads extends from ultraviolet to near infrared. Standard photographic filters may be used to eliminate background illumination or enhance target contrast.

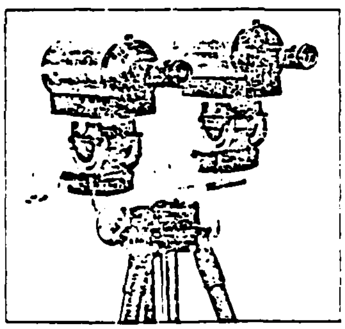
Accessories

Accessories for use with Optron noncontacting displacement followers perform three important functions:

1. Support and orient the optical head relative to the object to be measured.
2. Illuminate the object to be measured.
3. Calibrate the measurement range and output signals.

Model 736 Heavy Duty Tripod provides rigid support for any Optron optical head. Especially suitable for precise displacement measurements or extensometry where perfectly steady support is necessary. 2-section, 1.75" diameter braced legs have swiveled foot plates with nonslip treads. Leg adjustments plus gear driven elevator column with 18" travel provide height range of 33" to 73". Furnished with gear driven pan and tilt table for optical head. Weight 26 lb. Optional rubber tired dolly available.

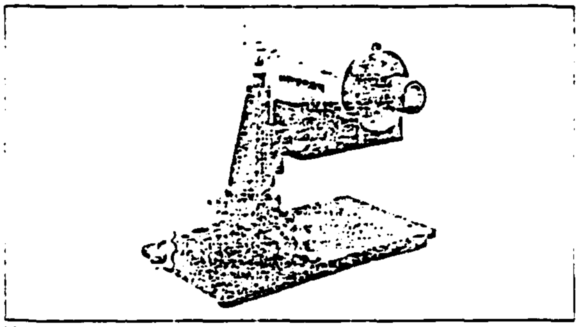




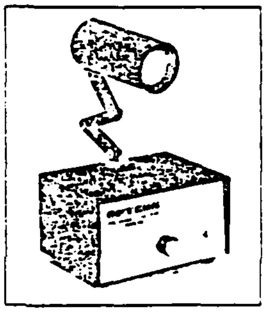
Model 736A Tripod with 2-axis micrometer table surmounted on pan/tilt head provides 5.5" travel in X and Y directions.

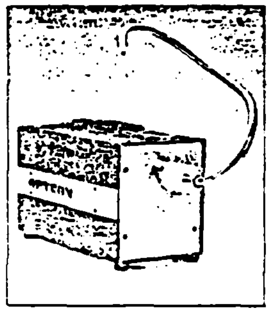
Model 737 Tripod, same as Model 736 except equipped with crossarm and dual pan/tilt heads for side by side mounting of two Optron optical heads. 2-axis micrometer tables optional.

Model 738 Triaxial Positioner. Three screw driven cross slides provide accurate X, Y, and Z positioning for any Optron optical head. Vertical travel (Y axis) 1.75" (44 mm). X and Z axes 5.5" (137 mm). In some applications it may be convenient to mount the test object on the model 738 while the optical head is stationary.



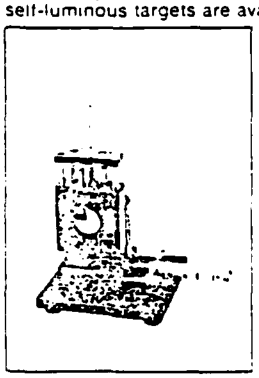
Model 560 Target Illuminator. Consists of a small, reflector photo-flood lamp that can be aimed and positioned by means of an integral adjustable support, and a regulated DC power supply.

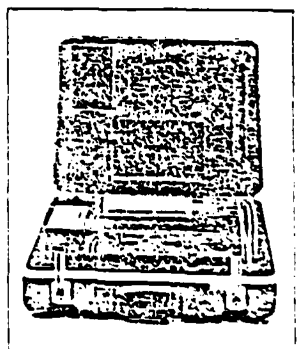




Model 860 Fiber Optic Target Illuminator. Complete with voltage regulated DC power supply, the 860 is designed for illuminating hard to reach areas. It provides a cool, even field of illumination.

Model 855 Calibrators are micrometer driven precision slides used for precise calibration of Optron measuring instruments. One and two axis models available (855-2 shown). Total travel 1" each axis. High contrast targets are designed for front illumination, using standard illuminator supplied with head. Optional self-luminous targets are available.





Storage Case. Provided with each system to house the optical head, lenses, etc. Handy for transporting system from one location to another or simply for protecting the optical components when not in use.

APPENDIX B

BIBLIOGRAPHY

B-1. PRESSURE.

952146 AD-A121 600/1

Blast Wave Loading of a Two-Dimensional Circular Cylinder (Final Report).

Coulter, George A.

Army Armament Research and Development Command, Aberdeen Proving Ground, MD, Ballistic Research Lab

Corp. Source Codes: 054817004; 393471

Sponsor: Shared Bibliographic Input

Report No.: ARBRL-MR-03207; SBI-AD-F300 118

Nov 82 92p

Languages: English

NTIS Prices: PC A05/MF A01 **Journal Announcement:** GRAI8307

Country of Publication: United States

Contract No.: 1L162618AH80

A two-dimensional non-responding cylinder was exposed to decaying shock waves induced in the BRL 57.5 cm shock tube. Pressure-time records are shown for transducer locations spaced at 15-degree intervals around the cylinder for input side-on overpressure levels of 42.3, 75.9, and 112.2 kPa. Pertinent loading results are listed in tabular form.

Descriptions: *Blast waves; *Blast loads; *Cylindrical bodies; Two dimensional; Shock tubes; Test methods; Pressure measurement; Transducers; Loads (Forces); Diffraction; Stagnation; Firing tests (Ordnance); Shock waves; Drag

Identifiers: Blast effects; Model cylinder; Overpressure; NTISDODXA

Section Headings: 19D (Ordnance--Explosions, Ballistics, and Armor); 79E Ordnance--Detonations, Explosion Effects, and Ballistics)

880547 AD-A106 141/5

Reconstruction of a Blast Field from Pressure History Observations (Technical Report)

Celmins, Aivars

Army Armament Research and Development Command, Aberdeen Proving Ground, MD, Ballistic Research Lab

Corp. Source Codes: 054817004; 393471

Report No.: ARBRL-TR-02367

September 81 91p

Languages: English

NTIS Prices: PC A05/MF A01 **Journal Announcement:** GRAI8205

Country of Publication: United States

Contract No.: 1L161102AH43

This report describes a method for the calculation of parts of spherical blast field from pressure history observations at stations placed at various distances from the blast center. The method consists of a determination of the pressure field by model fitting and of a subsequent numerical integration of the flow governing equations. The results provided a complete flow description (pressure, density, and particle velocity) as well as estimates of the accuracy of the results within the region of observations. A check of some basic assumptions (spherical symmetry and negligible viscosity) is provided by an independent calculation of the particle velocity. Application examples are shown for a theoretically computed strong blast field and for data from a high energy blast experiment. (Author)

Descriptors: *Blast; *Pressure distribution; Overpressure; Experimental data; Numerical integration; Range (Distance); Nuclear explosion simulation; Spheres; Density; Particles; Ideal gas law; Flow fields; High energy; Pressure measurement; Variables; Mathematical models; Estimates; Accuracy

Identifiers: *Blast fields; Spherical blast; Model fitting; MISERS BLUFF-2 shot; Pressure histories; NTISDODXA

Section Headings: 19D (Ordnance--Explosions, Ballistics, and Armor); 180 (Nuclear Science and Technology--Nuclear Explosions); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics); 77D (Nuclear Science and Technology--Nuclear Explosions and Devices)

883899 AD-A107 319/6

Shock Tube Tests of Muzzle Blast Transducers (Final Report)

Gion, Edmund J.; Coulter, George A.

Army Armament Research and Development Command, Aberdeen Proving Ground, MD, Ballistic Research Lab

Corp. Source Codes: 054817004; 393471

Sponsor: Shared Bibliographic Input Experiment

Report No.: ARBRL-MR-03141; AD-E430 701

September 81 62p

Supersedes ARBRL-IMR-691

Languages: English

NTIS Prices: PC A04/MF A01 **Journal Announcement:** GRAI8206

Country of Publication: United States

Contract No.: 1L161102AH43

A fairly extensive comparison testing of blast transducers is presented. A number of blast transducers were exposed to a series of shock waves from the BRL 58 cm shock tube. Both the angle of shock incidence and the incident pressure levels were varied during the tests. The purpose of the study was to check the transducer's response and accuracy when misaligned to the flow direction. The complete sets of pressure-time records for representative transducer types are presented. The results show that, in general, none of the tested blast transducers measures the static or side-on pressures accurately independent of orientation. As a consequence, continual attention must be given to optimal transducer orientation and other considerations relevant to the blast transducer used.

Descriptors: *Pressure transducers; *Gun muzzles; *Pressure gages; *Blast waves; *Pressure measurement; Overpressure; Shock waves; Misalignment; Flow; Shock tubes; Gun barrels

Identifiers: Blast transducers; NTISDODXA

Section Headings: 19D (Ordnance--Explosions, Ballistics, and Armor); 19F (Ordnance--Guns); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics); 79G (Ordnance--Guns)

785051 AD-A086 087/4

Airblast Pressure Transducer for Measurements in Nuclear Blast Simulators (Final Report)

Quintana, J. V.

Air Force Weapons Lab., Kirtland AFB, NM

Corp. Source Codes: 000905000; 013150

Sponsor: Shared Bibliographic Input Experiment

Report No.: AFWL-TR-79-59; AD-E200 497

April 80 33p

Languages: English

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI8021

Country of Publication: United States

Contract No.: 1088; 21

An extremely rugged resistance-based blast pressure transducer is developed over a number of years for use in the blast and shock environment of high explosive-driven nuclear blast simulators. A novel silicon display with integral (diffused) strain sensitive regions is used as the transduction element for measurements of peaks to 69 MPa and requiring microsecond rise time response. Evolution of the transducer geometry, internal configuration, and special thermal barriers enable sensing applications in e: tremely violent shock environments to 50 kgs with intense flash and burn thermal environments. A variety of transducer mounting hardware configurations enables side-on sensing of incident overpressure and head-on sensing of reflected and stagnation pressures in a variety of simulator field test configurations.

Descriptors: *Pressure; *Transducers; *Pressure transducers; *Nuclear explosion simulation; Nuclear explosions; Simulation; Pressure measurement; Silicon; Shock resistance; Blast; Disks; Overpressure

Identifiers: ICBM (Intercontinental Ballistic Missiles); Rise time; Blast simulators; NTISDODXA

Section Headings: 18C (Nuclear Science and Technology--Nuclear Explosions); 77D (Nuclear Science and Technology--Nuclear Explosions and Devices)

806238 AD-A090 123/1

Development of Airblast and Soil Strength Instrumentation (Final Report, 1 May 78--1 January 80)

Coleman, P. L.; Groethe, M. A.

Systems, Science and Software, La Jolla, CA

Corp. Source Codes: 026555000; 388507

Sponsor: Defense Nuclear Agency, Washington, DC

Report No.: SSS-R-80-4367; DNA-5225F

1 February 80 123p

Languages: English

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI8103

Country of Publication: United States

Contract No.: DNA001-78-C-0244; H11CAXS; X352

The development and testing of airblast and soil strength gages are presented. The airblast sensors include an accelerometer instrumented drag sphere to measure dynamic pressure and bar gage probes to measure static, stagnation and reflected pressures at levels to 10 to the 8th power Pa (1 kilobar). The soil strength gauge is a shock hardened dynamic cone penetrator. An analysis of a slug type heat flux sensor is given. (Author)

Descriptors: *Gages; Pressure gages; Accelerometers; Temperature measuring instruments; Heat flux; Blast waves; Soil tests; Strength (Mechanics); Earth penetrating devices; Conical bodies; Stagnation pressure; Static pressure; Supersonic flow; Dynamic pressure; Pressure measurement; Drag; Spheres; Soil dynamics; Cratering; Nuclear explosion testing; Nuclear explosion simulation; High explosives; Shock tubes

Identifiers: Airblast; Dynamic cone penetrators; Bar gages; Soil strength gages WU81; NTISDODXA; NTISDODSD

Section Headings: 8M (Earth Sciences and Oceanography--Soil Mechanics); 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics); 50D (Civil Engineering--Soil and Rock Mechanics)

1117359 E1810217359

Fiber-Optic Coupled Pressure Transducer

Tallman, C. R.; Wingate, F. P.; Ballard, E. O.

Los Alamos Science Lab, NM

ISA Trans, v 19, n 2, 1980, p 49-53 CODEN: ISATAZ
ISSN: 0019-0578

A fiber-optic coupled pressure transducer has been developed for measurement of pressure transients produced by fast electrical discharge in laser cavities. The design is described in detail, and the performance of the transducer in shock tube and direct electrical discharge environments is discussed. 2 references.

Descriptors: *PRESSURE TRANSDUCERS *Design; FIBER OPTICS-Applications; LASERS, GAS-Resonators; ELECTRIC DISCHARGES-Pressure Measurement; SHOCK TUBES-Pressure Measurement

Classification Codes: 944; 741; 744; 701; 651

725559 N79-27462/7

A Study of Response Time of Pitot Pressure Probes Designed for Rapid Response and Protection of Transducer

Moore, J. A.

National Aeronautics and Space Administration. Langley Research Center, Hampton, VA

Report No.: NASA-TM-80091

May 79 32p

Languages: English

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI7922; STAR1718

An eight-orifice probe, designed to protect the transducer without the use of a baffle, was compared to a standard orifice-baffle probe in the small shock tube and in the expansion tube under normal run conditions. In both facilities, the response time of eight-orifice probe was considerable better than the standard probe design.

Descriptors: *Circuit protection; *Pitot tubes; *Pressure measurements; *Shock tubes; *Transducers; Baffles; Dynamic response; Orifice flow

Identifiers: NTISNASA

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 1A (Aeronautics--Aerodynamics); 51F (Aeronautics and Aerodynamics--Test Facilities and Equipment)

539225 A80062678, B80031789

Determination of the Transient Characteristics of Pulse-Pressure Transducers

Plotnikov, I. V.; Dunaieva, V. A.; Efimov, V. A.; Evdokimov, O. B.; Medvedev, V. M.

Izmer, Tekh. (USSR) Vol. 22, No. 4 394-6 April 1979
Coden: IZTEAW

Trans in: Meas. Tech. (USA) Vol. 22, No. 4 April 1979
Coden: MSTCAL

Treatment: New Developments

Document Type: Journal Paper

Languages: English

(5 References)

Describes a pulse-pressure generator system used in testing and calibrating pressure transducers. The measured pressures are in the range 10/SUP 4/ to 10/SUP 8/PA with durations of 10/SUP -6/ to 10/SUP 1/S. The system is based upon a shock tube with piezoelectric shock-wave velocity transducer and contact-indicator for shock-wave arrival time. The operating principle is based upon the quasistatic method for measuring stepped pressure

Descriptors: Pressure measurement; Pressure transducers; Shock tubes

Identifiers: Transient Characteristics; Pressure Transducers; Shock Tube; Piezoelectric; Quasistatic Method; Stepped Pressure; Shock Wave

Class Codes: A0735; A0670M; B7320V; B7230

742960 AD-D006 394/1

Differential Pressure Gauge (Patent Application)

Ethridge, Noel H.

Department of the Army, Washington, DC

Corp. Source Codes: 000137000

Report No.: PAT-APPL-6-020 890

Filed 15 March 79 13p

This Government-owned invention available for U.S. licensing and; possibly, for foreign licensing. Copy of application available NTIS.

Languages: English **Document Type:** Patent

NTIS Prices: PC A02/MF A01 **Journal Announcement:** GRAI8004

Country of Publication: United States

A gage for measuring differential pressure in an explosive blast wave, wind tunnel, or shock tube, utilizes a tubular housing having a conical axially aligned inlet port, a cylindrical cavity which is divided into fore and aft sections by a transversely disposed pressure responsive diaphragm. A plurality of symetrically disposed off-set stagnation inlet tubes and a plurality of circumferentially positioned flow compensated side-on overpressure input slots are used to communicate with each of the respective fore and aft sections of the cavity. Variation in stagnation and side-on overpressures cause diaphragm movement which is detected by a friction-free sensing member. (Author)

Descriptors: *Patent applications; *Pressure gages; *Dynamic pressure; *Blast waves; Shock tubes; Overpressure; Diaphragms (Mechanics); Stagnation pressure; Air flow; Wind tunnels

Identifiers: Differential pressure; NTISGPA

Section Headings: 19D (Ordnance--Explosions, Ballistics, and Armor); 20D (Physics--Fluid Mechanics); 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics); 90G (Government Inventions for Licensing--Instruments); 90I (Government Inventions for Licensing--Ordnance)

651616 AD-A054 372/8

Proposed Design for a Differential Pressure Gage to Measure Dynamic Pressure in Blast Waves (Final Report)

Ethridge, Noel H.

Army Armament Research and Development Command, Aberdeen Proving Ground Md, Ballistics Research Lab

Corp. Source Codes: 393471

Report No.: ARBRL-MR-02814; AD-E430 012

March 78 27p

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI7817

Contract No.: J11AAXS; X352

The current technique for determining dynamic pressure in blast waves is subject to large errors below incident shock overpressures of 69 kPa (10 psi). It is shown that if a single pressure-sensing element can be used to measure the differential pressure between stagnation and side-on overpressures, then dynamic pressure can be determined with much less error. A design for a differential pressure gage is presented. A particular diaphragm size and material are proposed, and several diaphragm deflection-sensing techniques are indicated. The frequency response of the gage seems adequate for measurements of blast waves from large HE charges. (Author)

Descriptors: *Pressure gages; *Blast waves; Dynamic pressure; Diaphragms (Mechanics); Pressure measurement; Comparison; Stagnation pressure; Overpressure; Frequency response; Drag; Air flow; Shock tubes; Instrumentation; Time

Identifiers: NTISDODXA

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 19D (Ordnance--Explosions, Ballistics, and Armor); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics)

365308 N73-33221/5

On the Calibration of Pressure Transducers for Use in Shock-Tunnels

Goodchild, R. O.; Bernstein, L.

Queen Mary College, London (England)

Report No.: ARC-CP-1240; ARC-33832

1973 46p

Misc-Supersedes ARC-33832

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI7402; STAR1124

The calibration of high sensitivity, fast response pressure transducers is discussed, particular attention being given to those factors which can lead to significant calibration errors. It is shown that static and dynamic calibrations of piezoelectric transducers are consistent, contrary to the experience of some earlier investigators, so that where static calibration is possible, that is sufficient. In cases where static calibration is not possible, the semi-dynamic technique using a quick-acting valve is both more convenient and potentially more accurate than the shock tube technique, especially when digital recording can be employed. (Author)

Descriptors: *Electrostatics; *Piezoelectric transducers; *Pressure sensors; *Shock tubes; Calibrating; Pressure measurements

Identifiers: NTISNASA

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment)

167778 EI71X167778

Fast miniature pitot pressure transducer

McIntosh MK

Australian National University, Canberra

J. Phys E, Sci Instrum, v 4 number 1, Jan 1971, p 145-6

A small (2mm diam) fast (time constant equal 1. 5Us), shielded pitot pressure transducer is described, and examples are given of its use in a high enthalpy shock tunnel.

Descriptors: *Pressure measuring instruments; Transducer; Flow of LUIDS-nozzle; Shock tubes; Shock waves-measurement

Classification Codes: 422; 631; 651; 704; 944

144698 EI71X044698

Primary calibration of pressure transducers to 10,000 Hz

Favour J. D.; Stewart, R.

Boeing Co., Seattle, Washington

Proc 15th Int ISA Aerosp Instrum Symp, May 5-7 1969, Las Vegas, Nev, p. 89-96

A shock tube is used to provide excitation to the transducer in the form of a definable pressure step function. The transducer output, time domain data, is analyzed by digital computer using the '%' Colley - Tukey '%' Fast Fourier Transform to provide the frequency domain calibration data. Calibration traceability is accomplished by measurement of basic standards of time, distance, force and temperature, and the mathematics of shock tube behavior. A trial calibration has been performed with excellent results. 9 References.

Descriptors: *Transducers - *Calibration; Pressure measuring instruments; Shock tubes

Classification Codes: 631; 704; 752; 944

110806 A70019230

An Evaluation of Glass as a Passive Shock Pressure Gage Material

Eggert, G. L.

Issued by: Sandia Labs., Albuquerque, New Mexico, USA; April 1969

14 pp.

Availability: CFSTI, Springfield, VA 22151, USA

Report No.: SC-TM-69-88

Document Type: Report

Languages: English

USGRDR No.: PB-184349

Eight compositions of glasses were evaluated for application as the sensors in the construction of passive shock pressure gages. Although all of the glasses displayed irreversible densification under static loading, none densified sufficiently under shock loading to be considered for a passive pressure measurement sensor.

Descriptors: Glass; Pressure measurement; Shock tubes

Class Codes: 1A0350; 1A0120

567166 AD-804 917/3

Miniature Instrumentation for Use in Shock-Driven Facilities (Final Report, July 65-September 66)

Weisblatt, H.; Clemente, A. R.; Wood, A. D.; Pallone, A. J.

Avco Corporation; Wilmington, Mass., Avco Space Systems Division

Corp. Source Codes: 400877

Report No.: AVSSD-280-66-RR; AFAPL-TR-66-129

30 December 66 110p

Distribution limitation now removed.

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI7711

Contract No.: AF 33(615)-3037

The development of miniature probes for the measurement of stagnation and static pressure, stagnation temperature, and high heat-transfer rate in shock-driven facilities is described. A basic piezoelectric sensing unit is used in conjunction with different probes to measure the stagnation of static pressure over a pressure range of 0.02 to 100 psia. For temperature measurements a fast response thermocouple, which can be used to 3,500 K at pressures above 400 psia, is described. Heat-transfer rate is obtained by means of a modified calorimeter heat-transfer gage. Basic concepts are presented, together with details of fabrication, calibration, the associated electronic circuitry, and test results obtained in shock-driven facilities. (Author)

Descriptors: *Shock tubes; Instrumentation; Pressure; Temperature; Detectors; Piezoelectric gages; Thermocouples; Strain gages; Heat transfer

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment)

B-2. TEMPERATURE.

1002713 DE83006300

Transient-Temperature-Measurement Errors

Keltner, N. R.; Bainbridge, B. L.; Beck, J. V.

Sandia National Labs., Albuquerque, New Mexico

Corp. Source Codes: 068123000; 9511100

Sponsor: Michigan State University, East Lansing; Department of Energy, Washington, DC

Report No.: SAND-83-0161C; CONF-830702-4

1983 19p

21, ASME/AIChE National Heat Transfer Conference, Seattle, WA, USA, 24 July 1983

Languages: English **Document Type:** Conference proceeding

NTIS Prices: PC A02/MF A01 **Journal Announcement:** GRAI8323; NSA0800

Country of Publication: United States

Contract No.: AC04-76DP00789

The estimation of transient-temperature-measurement errors is often required to help understand thermal experiments and improve the accuracy of estimated thermal parameters. Thermal-response models used in conjunction with experimental techniques are very effective. A hybrid of finite differences and the Unsteady Surface Element method is developed and used for modeling temperature measurements made with intrinsic thermocouples and resistance temperature detectors. In the latter case, experimental data obtained with the Loop Current Step Response method is used to estimate model parameters. (ERA citation 08:037063)

Descriptors: *Temperature measurement; Transients; Errors; Finite difference method; Thermocouples; Mathematical models

Identifiers: ERDA/440300; NTISDE

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 94GE (Industrial and Mechanical Engineering--General)

0989608 DE83009877

Development of a Fuel-Rod Simulator and Small-Diameter Thermocouples for High-Temperature, High-Heat-Flux Tests in the Gas-Cooled Fast Reactor Core Flow Test Loop

McCulloch, R. W.; MacPherson, R. E.

Oak Ridge National Lab., TN

Corp. Source Codes: 021310000; 4832000

Sponsor: Department of Energy, Washington, DC

Report No.: ORNL-5864

March 83 121p

Portions are illegible in microfiche products. Original copy available until stock is exhausted.

Languages: English

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI8318; NSA0800

Country of Publication: United States

Contract No.: W-7405-ENG-26

The Core Flow Test Loop was constructed to perform many of the safety, core design, and mechanical interaction tests in support of the Gas-Cooled Fast Reactor (GCFR) using electrically heated fuel rod simulators (FRSs). Operation includes many off-normal or postulated accident sequences including transient, high-power, and high-temperature operation. The FRS was developed to survive: (1) hundreds of hours of operation at 200 W/cm exp 2, 1000 exp 0 C cladding temperature, and (2) 40h at 40 W/cm exp 2, 1200 exp 0 C cladding temperature. Six 0.5-mm type K sheathed thermocouples were placed inside the FRS cladding to measure steady-state and transient temperatures through clad melting at 1370 exp 0 C. (ERA citation 08:026094).

Descriptors: *Gcfr reactor; Fuel rods; Test facilities; Reactor simulators; Fabrication

Identifiers: ERDA/210500; NTISDE

Section Headings: 18I (Nuclear Science and Technology--Reactor Engineering and Operation); 18J (Nuclear Science and Technology--Reactor Materials); 77H (Nuclear Science and Technology--Reactor Engineering and Nuclear Power Plants); 77I (Nuclear Science and Technology--Reactor Fuels and Fuel Processing)

907137 NUREG/CR-0169-V13

LOFT Experimental Measurements Uncertainty Analyses. Volume XIII: Temperature Measurements

Lassahn, Gordon D.

EG and G Idaho, Inc., Idaho Falls

Corp. Source Codes: 046580000

Sponsor: Nuclear Regulatory Commission, Washington, DC

Report No.: EGG-2037-VOL-13

March 82 45p

See also NUREG/CR-0169-V12

Languages: English

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI8215

Country of Publication: United States

Estimates of measurement uncertainties for thermocouples and the resistance thermometer used to measure temperatures in the Loss-of-Fluid Test (LOFT) system during experiments are provided. The estimated uncertainties were obtained by evaluating the temperature measurements to determine possible errors and then combining the errors for each measurement. The evaluation showed that different uncertainty components are important for different temperature measurements and that no one error source is a major source of uncertainty for all the LOFT temperature measurements.

Descriptors: *Nuclear reactor safety; Temperature measurement; Thermocouples

Identifiers: LOFT reactor; Reactor safety experiments; Loss of coolant; PWR type reactors; Probability; NTISNUREG; NTISDE

Section Headings: 18I (Nuclear Science and Technology--Reactor Engineering and Operation); 77H (Nuclear Science and Technology--Reactor Engineering and Nuclear Power Plants)

923448 PB82-240029

Combustion Diagnostic Instrumentation. Part I: Probe Measurements (Final Report, September 81-March 82)

Pederson, Robert J.

Science Applications, Inc., Chatsworth, CA, Combustion Science and Advanced Technology Department

Corp. Source Codes: 075876001

Sponsor: Gas Research Inst., Chicago, IL

Report No.: SAI-82-033-CHATS; GRI-81/0053.1

March 82 86p

Language: English

NTIS Prices: PC A05/MF A01 **Journal Announcement:** GRAI8221

Country of Publication: United States

Contract No.: GRI-5011-345-0100

Probe measurement techniques and capabilities have been reviewed with respect to measurements of temperature, pressure, velocity and species concentrations in a combustion environment. Individual probe design, sources of measurement errors and methods for reducing these errors are discussed as well as measurement errors common to all probe measurements. Bare wire thermocouple measurement techniques are examined together with several types of water-cooled aspirating thermocouple probes having a maximum design dependent temperature range of 3000°F to 4000°F. Velocity measurements using unidirectional and multidirectional pneumatic probes are discussed, along with hot wire/hot film anemometers for measurement of turbulent intensity and stress components as well as mean velocity. Gas sampling techniques using isokinetic and aerodynamic quenching probes are surveyed for gas species concentrations. Instrumentation to determine convective and radiative heat transfer to the wall within a combustion environment is reviewed.

Descriptors: *Probes; *Combustion; *Measuring instrumentation; *Gas burners; Design criteria; Sampling; Concentration (Composition); Thermocouples; Performance evaluation; Industrial wastes; Residential buildings

Identifiers: *Air pollution detection; NTISGRI

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities and Test Equipment); 68A (Environmental Pollution and Control--Air Pollution and Control)

952501 DE82008683

Testing of Thermocouples for Inhomogeneities

Mossman, C. A.; Horton, J. L.; Anderson, R. L.

Oak Ridge National Lab., TN

Corp. Source Codes: 021310000; 4832000

Sponsor: Department of Energy, Washington, DC

Report No.: CONF-820306-3

March 82 22p

Symposium on Temperature, Washington, DC, USA, 14 March 1982, Portions of document are illegible.

Languages: English **Document Type:** Conference proceeding

NTIS Prices: PC A02/MF A01 **Journal Announcement:** GRAI8307; NSA0700

Country of Publication: United States

Contract No.: W-7405-ENG-26

The effect of inhomogeneities on the behavior of thermocoup is examined in detail. Methods of testing for inhomogeneities are outlined, and the methods employed at the Oak Ridge National Laboratory are described. Examples are given of the uses of an Inhomogeneity Test Facility as a diagnostic tool to determine the cause of temperature measurement errors. (ERA citation 07:047921)

Descriptors: *Thermocouples; Testing; Test facilities; Temperature measurement; Electromotive force; Seebeck effect; Thermoelectricity; Accuracy; Reliability; Chromel; Alumel; Inconel 600; Platinum; Rhodium

Identifiers: ERDA/440300; NTISDE

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 94GE (Industrial and Mechanical Engineering--General)

917145 DE82008844

Lifetime Improvement of Sheathed Thermocouples for Use in High-Temperature and Thermal Transient Operations

McCulloch, R. W.; Clift, J. H.

Oak Ridge National Lab., TN

Corp. Source Codes: 021310000; 4832000

Sponsor: Oak Ridge Y-12 Plant, TN; Department of Energy, Washington, DC

Report No.: CONF-820306-4

1982 34p

Symposium on Temperature, Washington, DC, USA, 14 March 1982

Language: English **Document Type:** Conference proceeding

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI8222; NSA0000

Country of Publication: United States

Contract No.: W-7405-ENG-26

Premature failure of small-diameter, magnesium-oxide-insulated sheathed thermocouples occurred when they were placed within nuclear fuel rod simulators (FRSs) to measure high temperatures and to follow severe thermal transients encountered during simulation of nuclear reactor accidents in Oak Ridge National Laboratory (ORNL) thermal-hydraulic test facilities. Investigation of thermally cycled thermocouples yielded three criteria for improvement of thermocouple lifetime: (1) reduction of oxygen impurities prior to and during their fabrication, (2) refinement of thermoelement grain size during their fabrication, and (3) elimination of prestrain prior to use above their recrystallization temperature. The first and third criteria were satisfied by improved techniques of thermocouple assembly and by a recovery anneal prior to thermocouple use.

Descriptors: *Gcfr type reactors; *Fuel pins; *Thermocouples; Mockup; Failures; Thermal stresses; Annealing; Fabrication; Magnesium oxides; Inconel 600; Chromel; Alumel; Grain boundaries; Performance

Identifiers: ERDA/210500; ERDA/220300; ERDA/440300; NTISDE

Section Headings: 18I (Nuclear Science and Technology--Reactor Engineering and Operation); 77H (Nuclear Science and Technology--Reactor Engineering and Nuclear Power Plants)

932068 DE82012778

Validation Diagnostics for Defective Thermocouple Circuits

Reed, R. P.

Sandia National Labs., Albuquerque, New Mexico

Corp. Source Codes: 068123000; 9511100

Sponsor: Department of Energy, Washington, DC

Report No.: SAND-82-1518C; CONF-820306-9

1982 9p

Symposium on Temperature, Washington, DC, USA, 14 March 1982, Portions of document are illegible.

Best available copy from document source. Available in microfiche only

Languages: English **Document Type:** Conference proceeding

NTIS Prices: MF A01 **Journal Announcement:** GRAI8224; NSA0700

Country of Publication: United States

Contract No.: AC04-76DP00789

Thermocouples, properly used under favorable conditions, can measure temperature with an accepted tolerance. However, when improperly applied or exposed to hostile mechanical, chemical, thermal, or radiation environments, they often fail without the error being evident in the temperature record. Conversely, features that appear to be unreasonable in temperature records can be authentic. When hidden failure occurs during measurement, deliberate recording of supplementary information is necessary to distinguish valid from faulty data. Loop resistance change, circuit isolation, isolated noise potential, and other measures can reveal symptoms of developing defects. Monitored continually along with temperature, they can reveal the occurrence, location, and natures of damage incurred during measurement. Special multiterminal branched thermocouple circuits and combinatorial multiplex switching allow detection of dc measurement noise and decalibration. Symptoms of insidious failure, often consequential, are illustrated by examples from field experience in measuring temperature of a propagating retorting front in underground coal gasification. (ERA citation 07:047940)

Descriptors: *Thermocouples; Failures; Validation; Electronic circuits; Temperature measurement; Noise; Errors; Thermometers; Defects

Identifiers: ERDA/440300; ERDA/420800; NTISDE

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 94GE (Industrial and Mechanical Engineering--General)

0991761 DE83008888

Instrument Response During Overpower Transients at TREAT

Meek, C. C.; Bauer; T. H.; Hill, D. J.; Froehle, P. H.; Klickman, A. E.

Argonne National Lab., IL

Corp. Source Codes: 001960000; 0448000

Sponsor: Department of Energy, Washington, DC

Report No.: CONF-820406-37

1982 11p

ANS Topical Meeting on Fast, Thermal and Fusion Reactor Experiments, Salt Lake City, UT, USA, 12 April 1982

Languages: English **Document Type:** Conference proceeding

NTIS Prices: PC A02/MF A01 **Journal Announcement:** GRAI8319; NSA0800

Country of Publication: United Sttes

Contract No.: W-31-109-ENG-38

A program to empirically analyze data residuals or noise to determine instrument response that occurs during in-pile transient tests is outlined. As an example, thermocouple response in the Mark III loop during a severe overpower transient in TREAT is studied both in frequency space and in real-time. Time intervals studied included both constant power and burst portions of the power transient. Thermocouples time constants were computed. Benefits and limitations of the method are discussed. (ERA citation 08:026082)

Descriptors: *LMFBR type reactors; *Fuel pins; *TREAT reactor; Performance testing; Transients; Reactor instrumentation

Identifiers: ERDA/210500; ERDA/220600; NTISDE

Section Headings: 18I (Nuclear Science and Technology--Reactor Engineering and Operation); 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 77H (Nuclear Science and Technology--Reactor Engineering and Nuclear Power Plants)

849068 SAND-80-2655

Error Analysis of Thermocouple Measurements in the Radiant Heat Facility

Nakos, J. T.; Strait, B. G.

Sandia National Labs., Albuquerque, New Mexico

Corp. Source Codes: 068127000; 9511100

Sponsor: Department of Energy, Washington, DC

December 80 56p

Languages: English

NTIS Prices: PC A04/MF A01 **Journal Announcement:** GRAI8118; NSA0600

Country of Publication: United States

Contract No.: AC04-76DP00789

The measurement most frequently made in the Radiant Heat Facility is temperature, and the transducer which is used almost exclusively is the thermocouple. Other methods, such as resistance thermometers and thermistors, are used but very rarely. Since a majority of the information gathered at Radiant Heat is from thermocouples, a reasonable measure of the quality of the measurements made at the facility is the accuracy of the thermocouple temperature data. (ERA citation 06:014626)

Descriptors: *Thermocouples; Data acquisition systems; Errors; Radiations; Temperature measurement; Test facilities; Transducers

Identifiers: ERDA/440300; NTISDE

Section Headings: 14R (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment)

805060 NUREG/CR-0961

Qualification Test Results on 1550 degrees C and 2200 degrees C 1/16-Inch O.D. Fuel Centerline Thermocouples for the LOFT Program (Topical Report 1977-79)

Cannon, C. P.; Chan, A. I. Y.

Hanford Engineering Development Lab., Richland, WA

Corp. Source Codes: 056188000

Sponsor: Nuclear Regulatory Commission, Washington, DC, Office of Nuclear Regulatory Research

Report No.: HEDL-TME-79-50

September 80 65p

Languages: English

NTIS Prices: PC A04/MF A01 **Journal Announcement:** GRAI8102

Country of Publication: United States

The technology and commercial vendors have been developed for fabrication of thermocouples to measure fuel centerline temperatures to 22000°C in the LOFT reactor. Two model A and one model B qualification thermocouples satisfied all test requirements during life tests at 2200°C and 1550°C. The emf output drifted less than 2% during 400 hour tests at the maximum test temperatures of 2200°C and 1550°C. Measurement performance remained unimpaired after 145C/s transient survival tests. The thermocouples did not meet the time response requirement of one second. Time responses of 4½ seconds at 1550°C and 2½ seconds at 2200°C were measured. However, this result was not considered too negative to preclude useful temperature measurement of fuel centerline temperatures in the LOFT reactor. The first qualification thermocouples satisfied all other test requirements.

Descriptors: *Thermocouples; Tests; Thermal measurement; Pressurized water reactors; Requirements; Nuclear reactor safety; Reactor cores; Nuclear reactor accidents

Identifiers: *LOFT reactor; Loss of coolant; NTISNUREG: NTISDE

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 18I (Nuclear Science and Technology--Reactor Engineering and Operation); 77II (Nuclear Science and Technology--Reactor Engineering and Nuclear Power Plants)

0997751 EGG/LTR-141-118

Feasibility Transient Test of a Correlation Type Transit Time Flowmeter in the LTSF Blowdown Facility

Baker, A. G.

Idaho National Engineering Lab., Idaho Falls

Corp. Source Codes: 056198000; 9502158

Sponsor: Department of Energy, Washington, DC

February 80 102p

Languages: English

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI8321; NSA0500

Country of Publication: United States

Contract No.: AC07-76ID01570

A feasibility test was made in September 1977 to determine the suitability of various transducer types as sensors for a cross-correlation type transit time flowmeter. The sensor types tested were single beam gamma densitometers, conductivity probes and passive thermocouples. Three forms of signal conditioning were applied to the thermocouple signals: bandpass amplification, frequency compensation and signal compression. The gamma densitometer was the most successful, the conductivity probe less successful, and the thermocouple least successful. Further work is recommended. (ERA citation 05:030678)

Descriptors: *Loft reactors; Flowmeters; Performance testing; Reactor instrumentation; Transducers

Identifiers: ERDA/220600; NTISDE

Section Headings: 18I (Nuclear Science and Technology--Reactor Engineering and Operation); 77H (Nuclear Science and Technology--Reactor Engineering and Nuclear Power Plants)

786329 N80-26649/7

Development and Calibration of a Total Temperature Probe for the Imperial College Aeronautics Department Gun Tunnel

Bartlett, R. P.; Edwards, A. J.; Hillier, R.

Imperial College of Science and Technology, London (England), Department of Aeronautics

Corp. Source Codes: IC623688

Sponsor: National Aeronautics and Space Administration, Washington, DC

Report No.: IC-AERO-79-02

June 79 32p

Languages: English

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI8021; STAR1817

Country of Publication: United Kingdom

Contract No.: AT/2037/084

Development of a vented-shield thermocouple probe for total temperature measurements in a hypersonic turbulent boundary layer concentrated on maximizing both the transient response rates and the steady state recovery factor (which eventually reached about 98% at the highest test Reynolds numbers) is described. This performance was achieved by maximizing the unit Reynolds number within the shield and hence the convective heating of the sensor; and by improving the sensor aspect ratio parameters which control the conduction losses. The probe was operated with an unheated shield. It is argued that shielding a probe affords aerodynamic and response advantages compared with its unshielded counterpart. Performance deteriorates with reduction in Reynolds number and hence with immersion in the boundary layer. The critical limit in a short duration facility must always be failure to reach a steady state. Probes were calibrated against Reynolds number for the required range but at fixed total temperature. It is expected that the worst error in steady state temperature for a given probe would be of order 40 K with a considerable improvement in overall accuracy for profile data averaged from several probes.

Descriptors: *Calibrating; *Hypersonic wind tunnels; *Temperature probes; *Thermocouples; Heat transfer; Instrument compensation; Nusselt number; Shielding

Identifiers: *Foreign technology; NTISNASAE

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 51F (Aeronautics and Aerodynamics--Test Facilities and Equipment)

775284 AD-A084 477/9

Transducer Workshop (10th), Colorado Springs, Colorado, 12-14 June 1979

Anderson, William D.; Thomas, Charles E.

Range Commanders Council, White Sands Missile Range, New Mexico, Telemetry Group

Corp. Source Codes: 013429034; 401435

1979 501p

Languages: English

NTIS Prices: PC A22/MF A01 **Journal Announcement:** GRAI8018

Country of Publication: United States

High Speed Data Systems for Energy Sensitive Facilities; A 1000-MPa Ballistic Pressure Transducer; Calibration of Laboratory Condenser Microphones; Reducing Effects of Pneumatic Lag; A New Microprocessor Based Pressure Standard; Use of an Inertial Navigation System as Airborne Instrumentation for Performance Flight Testing; Aerial Camera Vibration Instrumentation; Absolute Calibration of Accelerometers at the National Bureau of Standards; Response of Transducers to Fast Transient Motion Inputs; A Measurement System for Large Motions; Pressure and Acceleration Measurements in Large Caliber Cannons; Deriving the Transfer Function of Spatial Averaging Transducers; Steam/BTU Metering System; Transducer Field Test Set; Internal Transducer Electronic Amplifiers; Thermocouple Error Analysis in the Design of Large Engineering Experiments; Triaxial Measurement of Stress Waves in the Free-Field; A Low Impedance Manganin Stress Gauge System for Severe Shock Wave Environments; Improved Stress Transducer Design and Stability Evaluation; Fast Recovery Strain Measurements in a Nuclear Test Environment; Measurement of Pipeline Strains from Buried Explosive Detonations.

Descriptors: *Pressure transducers; *Navigational aids; Strain gages; Stress analysis; Shock waves; Deformation; Inertial navigation; Flight testing; Response; Transients; Accelerometers; Calibration; Thermocouples; Mechanical impedance; Transfer functions; Vibration; Aerial cameras; Workshops

Identifiers: NTISDODXA

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment)

738230 CONF-790505-14

Limitations of Thermocouples in Temperature Measurements

Anderson, R. L.; Adams, R. K.; Duggins, B. C.

Oak Ridge National Lab., TN

Corp. Source Codes: 021310000; 4832000

Sponsor: Department of Energy

1979 33p

25, ISA International Instrumentation Symposium, Anaheim, CA, USA, 7 May 1979

Languages: English **Document Type:** Conference proceeding

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI8001; NSA0400

Country of Publication: United States

Contract No.: W-7405-ENG-26

Factors limiting the accuracy of temperature measurements with Type K and Type S sheathed thermocouple assemblies are discussed. The effect of short-range ordering in Chromel is shown to limit the accuracy of temperature measurements made with Type K thermocouple to about 1%. Errors of as much as 150% have been observed in Type K thermocouples in magnetic fields at temperatures below the Curie temperature of Alumel. Both positive and negative errors were observed when the orientations of the applied magnetic field, the temperature gradient and the axis of the Alumel wire were such as to produce an emf along the thermocouple wire due to the Nernst--Ettingshausen effect. (ERA citation 04:049083)

Descriptors: *Thermocouples; Accuracy; Performance

Identifiers: ERDA/440300; NTISDE

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment)

542376 SAND-75-6154

Intrinsic Thermocouple Measurement Errors

Keltner, N. R.; Bickle, L. W.

Sandia Labs., Albuquerque, New Mexico

Corp. Source Codes: 5659000; 9502551

Sponsor: New Mexico University, Albuquerque, Department of Mechanical Engineering, Energy Research and Development Administration

Report No.: CONF-760816-4

1975 24p

National Heat Transfer Conference, St. Louis, Missouri, United States of America (USA), 8 August 1976

Document Type: Conference proceeding

NTIS Prices: PC A02/MF A01 **Journal Announcement:** GRAI7703; NSA0100

An approximate analytical model is given for the transient response of an intrinsic thermocouple. Thermocouple response charts are developed. The model is used with numerical convolution and deconvolution to estimate and correct for transient temperature measurement errors. The methods are illustrated by example applications. (ERA citation 01:026383)

Descriptors: *Thermocouples; Errors; Mathematical models; Sensitivity; Transients

Identifiers: ERDA/440300; NTISERDA

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment)

B-3. HEAT FLUX.

867956 AD-A103 539/3

Measurement of Heat Flux and Pressure in a Turbine Stage (Final Report, July 79-October 80)

Dunn, Michael G.

Calspan Advanced Technology Center, Buffalo, NY

Corp. Source Codes: 058685000; 410803

Sponsor: Air Force Wright Aeronautical Labs., Wright-Patterson AFB, OH

Report No.: CALSPAN-6549-A-2; AFWAL-TR-81-2055

July 81 48p

Languages: English

NTIS Prices: PC A03/MF A01 **Journal Announcement:** GRAI8126

Country of Publication: United States

Contract No.: F33615-79-C-2075; 3066; 06

Selected portions of the first-stage stationary inlet nozzle, shroud, and rotor of the AiResearch TFE 731-2 turbine were instrumented with thin-film heat-transfer gages and heat-flux measurements were performed using a shock tunnel as a source of high-temperature, high-pressure gas. Experiments were performed over a range of Reynolds numbers, based on mid-annular stator chord, from 160,000 to 310,000 and corrected speeds from approximately 70% to 106%. The full-stage heat-flux results are cast in the form of a Stanton number and are compared to previous measurements obtained with a stator only, in the absence of a rotor. The previous results are shown to be in good agreement with the full-stage data for the tip end-wall region, but the stator-only Stanton numbers for the stator airfoil are shown to be approximately 20% less than the corresponding full-stage results. Pressure measurements were obtained throughout the model and these results are shown to be in excellent agreement with the steady-state rig data for this turbine. Stanton-number results are also presented for the stationary shroud as a function of rotor mid-annular chord. The shroud Stanton-number data are shown to be in excess of the rotor blade results. Rotor-tip Stanton-number data are likewise shown to be slightly greater than the shroud results. (Author)

Descriptors: *Temperature measuring instruments; *Heat flux; *Turbine stators; Gages, Thin films; Platinum; Shock tubes; Heat transfer; Turbofan engines; Hot gages; High temperature; High pressure; Pressure measurement; Reynolds number; Static pressure; Test methods; Transients

Identifiers: Stanton number; Heat transfer gages; TFE-731-2 turbines; NTISDODXA; NTISDODAF

Section Headings: 21E (Propulsion and Fuels--Jet and Gas Turbine Engines); 81D (Combustion, Engines, and Propellants--Jet and Gas Turbine Engines)

568654 380041483

How to Measure Heat Transfer Through Walls of Unknown Thermal Conductivity

Can. Controls and Instrumentation (Canada) Vol. 19, No. 3, p. 36, March 1980

Coden: CCISAU

Treatment: Practical

Document Type: Journal Paper

Languages: English

Discusses the use of disc gauges to measure heat transfer-in materials with eroding surfaces or unknown thermal conductivity. The disc calorimeter described is developed by Nanmac Corporation.

Descriptors: Transducers; Heat transfer; Thermal variables measurement

Identifiers: Nanmac Corp.; Heat transfer measurement; Transducers; Disc gauges

Class Codes: B7230; B7320R

806238 AD-A090 123/1

Development of Airblast and Soil Strength Instrumentation (Final Report, 1 May 78-1 January 80)

Coleman, P. L.; Groethe, M. A.

Systems, Science and Software, La Jolla, CA

Corp. Source Codes: 026555000; 388507

Sponsor: Defense Nuclear Agency, Washington, DC

Report No.: SSS-R-80-4367; DNA-5225F

1 February 80 123p

Languages: English

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI8103

Country of Publication: United States

Contract No.: DNA001-78-C-0244; H11CAXS; X352

The development and testing of airblast and soil strength gauges are presented. The airblast sensors include an accelerometer instrumented drag sphere to measure dynamic pressure and bar gauge probes to measure static, stagnation and reflected pressures at levels to 10 to the 8th power Pa (1 kilobar). The soil strength gauge is a shock hardened dynamic cone penetrator. An analysis of a slug type heat flux sensor is given. (Author)

Descriptors: *Gages; Pressure gages; Accelerometers; Temperature measuring instruments; Heat flux; Blast waves; Soil tests; Strength (mechanics); Earth penetrating devices; Conical bodies; Stagnation pressure; Static pressure; Supersonic flow; Dynamic pressure; Pressure measurement; Drag; Spheres; Soil dynamics; Cratering; Nuclear explosion testing; Nuclear explosion simulation; High explosives; Shock tubes

Identifiers: Airblast; Dynamic cone penetrators; Bar gages; Soil strength gages WU81; NTISDODXA; NTISDODSD

Section Headings: 8M (Earth Sciences and Oceanography--Soil Mechanics); 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics); 50D (Civil Engineering--Soil and Rock Mechanics)

186626 A78034210

Laminar Flat Plate Heat Transfer Measurements From a Dissociated *High* Enthalpy Hypersonic Air Flow

East, R. A.; Stalker, R. J.; Baird, J. P.

Issued by: University Southampton, England

October 1977

43pp

Report No.: AASU-338

Treatment: Experimental

Document Type: Report

Languages: English

Heat transfer rates from a non-equilibrium hypersonic air flow to flat plates at zero and 12 degrees incidence have been measured in a free piston shock tunnel at stagnation enthalpy levels up to 51 MJ/KG. Nozzle flow conditions resulted in test section velocities up to 8.1 KM/S and in an experimental regime in which the free stream was chemically frozen and the flat plate boundary layer was laminar. Estimates of the gas phase and surface reaction Damkohler numbers have been made and the heat transfer results are discussed in this context.

Descriptors: Laminar flow; boundary layers, heat transfer; hypersonic flow

Descriptors: Heat transfer measurements; Dissociated high enthalpy hypersonic air flow; Stagnation enthalpy; Surface reaction; Damkohler numbers; Nonequilibrium flow; Nozzle flow conditions; Chemically frozen free stream; Laminar flat plate boundary layer; 51 MJ/KG; 8.1 KM S/SUP-1

Class Codes: A4770; A4725Q; A4740K; A4715C

156502 C78004304

An On-Line Interactive Mini-Computer System for Heat Transfer Measurements in a Transient Turbine Cascade

Oldfield, M. L. G.; Jones, T. V.; Schultz, D. L.

Issued by: University Oxford, England

September 1977

12pp

Report No.: QUEL-1217/77

Treatment: Practical

Document Type: Report

Languages: English

A 32 channel computer based data acquisition and processing system has been developed for use with the new type of transient cascade facility at Oxford. This is used for testing turbine blades and nozzle guide vanes at full scale engine Reynolds and Mach numbers with correct wall to flow temperature ratios. A novel technique for processing transient heat transfer data from thin film surface resistance thermometers has been developed. Measurements of Surface pressure around blades, and of the upstream turbulence level have been made. The cascade and instrumentation are shown to have advantages both in cost and effectiveness over continuous running cascades.

Descriptors: Gas turbines; Heat transfer; Automatic test equipment; Data acquisition

Identifiers: Heat transfer measurements; transient turbine cascade; Computer based data acquisition; Nozzle guide vanes; On-line interactive minicomputer system

Class Codes: C7440

128644 A77080258, B77044311

Developments in Heat Transfer Measurements Using Transient Techniques

Richards, B. E.

Sponsor: IEEE

International Congress on Instrumentation in Aerospace Simulation Facilities 81-8 1977

6-8 September 1977 Shrivenham, England

Publ: IEEE, New York, USA

VII+208pp.

Treatment: Applic.; Practical

Document Type: Conference paper (9 References)

Languages: English

Presents three developments in the measurement of heat transfer using transient techniques for application to research in hypersonic aerodynamics and cooling of heated turbine components. These are composed of: (a) accurate data reduction of transient temperature data from calorimeters used in unsteady or time dependent flows; (b) the semi-infinite conductor technique (using thin film gauges to measure surface temperature) for use in conventional intermittent blow down tunnels; and (c) the use of an isentropic light piston tube for the direct calibration of transient heat transfer measurements devices.

Descriptors: Aerospace test facilities; Heat transfer; Cooling

Identifiers: Heat transfer measurements; Transient techniques; Hypersonic aerodynamics; Data reduction; Isentropic light piston tube; Turbine cooling; Semi infinite conductor technique; Aerospace test facility

Class Codes: A4780; A4724Q; B7620; B7320R

863902 A76015805

Trnsient Response of Circular-Foil Heat-Flux Gauges to Radiative Fluxes

Keltner, N. R.; Wildin, M. W.

Sandia Labs., Albuquerque, New Mexico, USA

Rev. Sci. Instrum. (USA), Vol. 46, No. 9, p. 1161-6 September 1975

Coden: RSINAK

Treatment: Applic., Theoretical

Document Type: Journal paper (12 References)

Languages: English

Reports the development of a new model for describing the transient response to a step change in incident radiative flux of a CFHFG (Gardon-type gauge) particularly as it is affected by heat flow from the foil to the central lead wire. The authors give the step response solution, compare analytical and experimental results, identify sensitivity and response parameters, estimate the effect of heat loss from the foil surface and discuss applications.

Descriptors: Thermal variables measurement; Transient response; Sensitivity

Identifiers: Sensitivity; Response parameters; Circular foil heat flux gauges; Gardon type gauge; Incident radiative flux step change; Foil surface heat loss; Foil lead wire heat flow

Class Codes: 2A0620

844836 B76002371, C75026831

Problems in Estimating Front Surface Heat Fluxes From Rear Surface Temperature Measurements

Wally, K.; Bickle, L. W.; Keltner, N. R.

University of New Mexico, Albuquerque, New Mexico, USA

Washburn, B. (Editors)

Sponsor: ISA

Proceedings of the 21st International Instrumentation Symposium 121-6 1975

19-21 May 1975 Philadelphia, PA., USA

Publ.: ISA, Pittsburgh, PA, USA

XI+580pp. ISBN 0 87664 261 X

Treatment: Theoretical

Document Type: Conference paper (17 References)

Languages: English

(17 References)

Estimating front surface heat fluxes on a plate from rear surface temperature measurments requires accurate knowledge of the temperature sensor's response characteristics. The classical assumption of an exponential step response for a beaded thermocouple is inaccurate and can lead to large errors in the estimated heat flux. A model is postulated for the characteristic response of a beaded thermocouple attached to a plate; data are presented to support the model. Direct heat flux measurements are compared with values estimated by using both the postulated response model and an exponential response model.

Descriptors: Modelling; Temperature measurement; Thermocouples

Identifiers: Front surface heat fluxes; Rear surface temperature measurements; Exponential step response; Beaded thermocouple; Exponential response model

Class Cldes: 2B4447; 2C7447; 2B4250; 2C7630; 2C6420

508593 A73022286, B73017875, C73010254

Sensitive Platinum Film Resistance Thermometers for Heat Transfer Measurement

Evans, N. A.

University of Pennsylvania, Philadelphia, USA

Sponsor: Instrument Soc. America

Proceedings of the 27th Annual ISA Conference 632/8pp. 1972

9-12 October 1972 New York, USA

Publ.: Instrument Soc. America, Pittsburgh, PA, USA

VII+232PP pp. ISBN 87664 191 5

Treatment: Practical, Experimental

Document Type: Conference paper (2 References)

Languages: English

A detailed description is given of the manufacture, calibration and operation of sensitive platinum film resistance thermometers for use as heat transfer gauges. For a ceramic substrate thickness of 0.1 inch, the associated circuitry allows measurement of: steady heat transfer rates with temperature differences as low as 0.5 degrees F; changes in the level of steady heat transfer with temperature difference changes of 0.05 degrees F; and unsteady heat transfer rates at frequencies up to 1 MHZ with temperature amplitudes of less than 0.005 degrees F. Such films have shown good stability, the calibration factor having changed by approximately 2 percent over a three-month period.

Descriptors: Resistance thermometers; Heat transfer; Thin film devices; Platinum

Identifiers: Temperature measurement; Platinum film; Resistance thermometers; Heat transfer measurement; Ceramic substrate; Stability; Calibration

Class Codes: 2B4447; 2C7447; 2B4240; 2C7622; 2A0620

B-4. TARGET RESPONSE.

398699 AD-780 557/5

Development and Evaluation of Measurement Systems for Blast-Induced Motions in Buried Structures (Final Report, January-December 1972)

Pickett, Stephen F.

New Mexico University Albuquerque, Eric H. Wang Civil Engineering Research Facility

Corp. Source Codes: 400976

Report No.: AFWL-TR-73-230

April 74 124p

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI7417

Contract No.: F29601-72-C-0024; DNA-NWED-J11AAXS; X352

Four types of transducers for measuring blast-induced motions in buried structures were developed and/or evaluated. Potentiometric linear displacement transducers were evaluated based on vendor-supplied data. Application techniques, load error analysis and vendor-suggested improvements were also studied. A gage for measuring relative structure/media interface (shear) displacement was designed, developed, and tested in teh CERF 2- x 40-ft shock tube. This gage performed well over the low displacement range for which it was designed. A seismometer for simultaneously measuring absolute structural displacement and velocity was also designed, built, and tested. This transducer also performed well. The suitability of WES Air Force Modified (WAM) stress gages and Simmons concrete stress gages for measuring dynamic structural media interface normal stress was tested in the CERF 2- x 4-ft shock tube. During this test program unexpected results were obtained because of reverberations in the test configuration. Although the results were useful, the data were not adequate for complete evaluation of these gages. (Author)

Descriptors: *Underground structures; *Blast loads; *Measuring instruments; Potentiometers; Transducers; Stresses; Seismometers; Shock tubes; Dynamic tests; Nuclear explosions

Identifiers: NTISAF

Section Headings: 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 13M (Mechanical, Industrial, Civil, and Marine Engineering--Structural Engineering); 18C (Nuclear Science and Technology--Nuclear Explosions); 19D (Ordnance--Explosions, Ballistics, and Armor); 73D (Methods, Instrumentation, and Equipment--Test Facilities, Equipment, Methods, and Laboratories); 77D (Nuclear Science and Technology--Nuclear Explosions and Devices)

028117 AD-605 407

A Program to Induce High Blast-Induced Airloads and Structural Response of Lifting Surfaces

Jarvis, R. L.; Kaspar, J. J.; Mills, R. R.; Wolf, I. O.

Aircraft Armaments Inc., Cockeysville, M

Corp. Source Codes: 000000

Report No.: ASD-TDR63 764;--V2

July 64 2p

See also AD-436 114

NTIS Prices: PC A02 **Journal Announcement:** USGRDR

Contract No.: AF33 616 7099; 1350; 135002

Six experiments were conducted to measure the transient character of the airloads induced by the interaction of blast generated shock waves on a moving airfoil. The tests were conducted on a rigid (airloads) model of swept planform, similar in type to a B47/B52 aircraft. Airfoil motion was simulated by the shock tube which produced a jet flow of Mach 0.7. Shock waves were generated by explosive charges which were varied in size and proximity to obtain airloads on the wing that changed both the angle of attack and blast duration through a range from small to large. The wind specimens were heavily instrumented with pressure transducers to measure the time history of the variation in the airloads. Response of the wing to the airloads was measured by strain gages and accelerometers. Pressure instrumentation was also used to measure the character of the blast environment. Blast parameters were varied to obtain induced airloads with nominal values for the angle of attack of 8, 20, and 30 degrees. At each of these angles of attack, an experiment was run with a short and long duration shock wave to study the effect of decay rate on the airloads. (Author)

Descriptors: *Airfoils; Shock waves; *Wings; Aerodynamic loading; Swept wings; Airplane models; Shock tubes; Lift; Blast; Angle of attack

522889 AD-A029 437/1

Blast Tests of a Mobile Satellite Tracking Antenna and of Two Model Antennas (Final Report)

Abrahams, Rodney; Bertrand, Brian P.; Pearson, Richard J.

Ballistic Research Labs, Aberdeen Proving Ground, MD

Corp. Source Codes: 050750

Report No.: BRL-MR-2661

August 76 63p

NTIS Prices: PC A04/MF A01 **Journal Announcement:** GRAI7623

Contract No.: DA-1-W-162118-AH-75

A mobile satellite tracking antenna was subjected to blast waves emerging from the open end of an eight foot diameter shock tube. Response data were obtained by the use of strain gages and an accelerometer. Twc similarly instrumented simple model antennas were also tested within the shock tube. (Author)

Descriptors: *Parabolic antennas; *Satellite tracking systems; *Shock resistance; *Satellite communications; Shock tubes; Scale models; Response; Strain gages; Blast loads; Accelerometers; Antenna masts; Shock waves

Identifiers: AN/GSC-86; Communication antennas; NTISDODXA

Section Headings: 9E (Electronics and Electrical Engineering--Subsystems); 49A (Electrotechnology--Antennas)

806238 AD-A090 123/1

Development of Airblast and Soil Strength Instrumentation (Final Report, 1 May 78-1 January 80)

Coleman, P. L.; Groether, M. A.

Systems, Science and Software, La Jolla, CA

Corp. Source Codes: 026555000; 388507

Sponsor: Defense Nuclear Agency, Washington, DC

Report No.: SSS-R-80-4367; DNA-5225F

1 February 80 123p

Langauges: English

NTIS Prices: PC A06/MF A01 **Journal Announcement:** GRAI8103

Country of Publication: United States

Contract No.: DNA001-78-C-0244; H11CAXS; X352

The development and testing of airblast and soil strength gauges are presented. The airblast sensors include an accelerometer instrumented drag sphere to measure dynamic pressure and bar gauge probes to measure static, stagnation and reflected pressures at levels to 10 to the 8th power Pa (1 kilobar). The soil strength gauge is a shock hardened dynamic cone penetrator. An analysis of a slug type heat flux sensor is given. (Author)

Descriptors: *Gages; Pressure gages; Accelerometers; Temperature measuring instruments; Heat flux; Blast waves; Soil tests; Strength (mechanics); Earth penetrating devices; Conical bodies; Stagnation pressure; Static pressure; Supersonic flow; Dynamic pressure; Pressure measurement; Drag; Spheres; Soil dynamics; Cratering; Nuclear explosion testing; Nuclear explosion simulation; High explosives; Shock tubes

Identifiers: Airblast; Dynamic cone penetrators; Bar gages; Soil strength gages WU81; NTISDODXA; NTISDODSD

Section Headings: 8M (Earth Sciences and Oceanography--Soil Mechanics); 14B (Methods and Equipment--Laboratories, Test Facilities, and Test Equipment); 79E (Ordnance--Detonations, Explosion Effects, and Ballistics); 50D (Civil Engineering--Soil and Rock Mechanics)

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US Army Foreign Science & Tech Ctr
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US Army Material Command
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Naval Surface Weapons Center
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Strategic Systems Programs (PM-1)
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Theater Nuclear Warfare Program Ofc
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<u>DEPARTMENT OF THE AIR FORCE</u>

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