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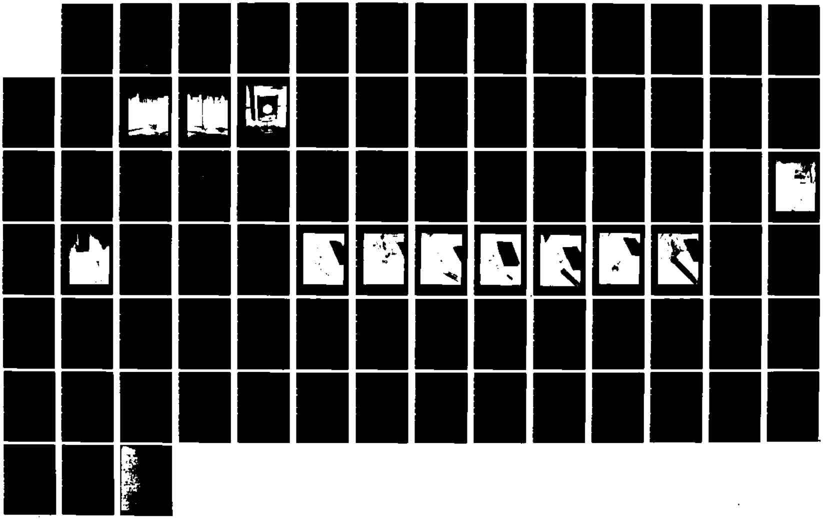

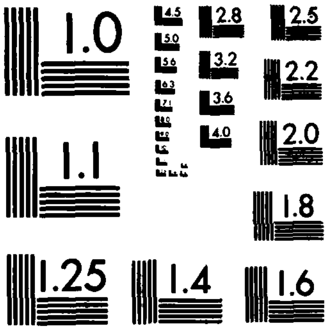

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Program Engineering &
Maintenance Service
Washington, D.C. 20591

Frangible Microwave Landing System (Inverted Azimuth Waveguide Array Configuration)

P.D. Wienhold
E.F. Kolb

December 1982

Final Report

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16. Abstract

This final report concerns a feasibility study of the increased frangibility of Microwave Landing System equipment mounted on the extended runway centerline and an assessment of the FAA requirements in regard to frangibility.

As described herein, a conceptual design known as the inverted AZ array was developed and fabricated as a mechanical prototype. The primary structural components of the antenna are vertical cantilever waveguides and frangible joints incorporated into their base. Impact and static load tests proved that several joint designs meet the FAA requirements for frangibility.

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Frangibility, Microwave Landing System, Waveguide, Antenna, Phased Array, Composites

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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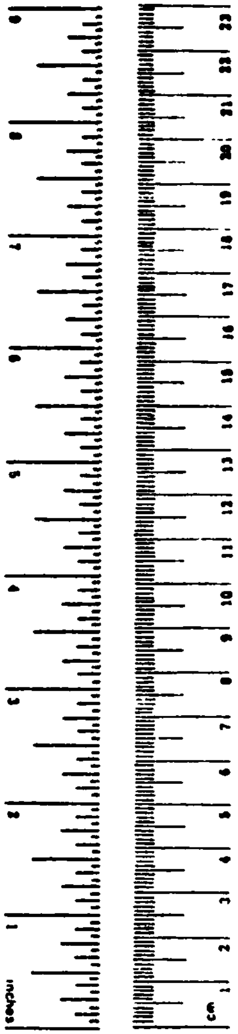
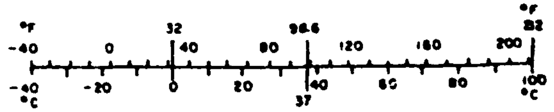
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



60 mph = 52.1 knots (nautical miles per hour)
60 mph = 88'/sec
1g = 32.2'sec^2

1 mph = .87 knots
1 knot - 1.15 mph

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SECTION 1. INTRODUCTION

1.1 GENERAL

This final report is submitted in compliance with Task 3 of the Statement of Work under Department of Transportation Contract No. DTFA01-81-C-10068. This task called for a feasibility study of the increased frangibility of Microwave Landing System equipment mounted on the extended runway centerline and an assessment of the FAA requirements in regard to frangibility. This report includes descriptions of a preliminary frangible AZ antenna design, test results of the associated frangible components, and recommendations for further development work.

1.2 PROGRAM OBJECTIVES

The investigative portion of the program involved developing a thorough understanding of all FAA requirements concerning frangibility and the hardware implications thereof. Design concepts were developed around these requirements and current performance standards for a frangible Azimuth antenna to determine the feasibility and to provide hardware for testing. There are two basic objectives, both of which must be pursued to achieve some degree of frangibility in a structure design. The first is to minimize the probability of a collision by reducing size, especially height, as much as possible. The second is to minimize the severity of a collision should it occur, determined by the damage, deceleration, and course change incurred by the aircraft. This is generally achieved by (1) minimizing the energy absorbed by the structure by incorporating design details to make the components involved break away and separate upon impace, reducing the load induced by the stiffness of the structure, and by (2) minimizing the mass of these components to reduce the inertial load. The other MLS equipment located on or near the extended runway centerline (the field monitor and DME antennas) was not included in the study.

This was due to the fact that much less technical challenge exists in making these structures meet frangibility requirements. All basic field monitor designs consist of an antenna supported by a mast of circular cross section. In a frangible system, the antenna element could be a frangible waveguide element per the AZ antenna design, and the mast could be a design developed as a frangible approach light support by previous FAA studies.

1.3 SUMMARY OF TASK

The FAA requirements for frangibility were investigated, the primary source being document FAA-ER-530-81-04. Background information on other frangible structures was found in several other FAA and DOT documents. In developing a frangible AZ antenna, concept definitions were generated for different design configurations. Calculations of strength, stiffness, and impact energy absorption of waveguides of different materials or similar structural elements aided in the selection of one concept for prototype hardware development. This was followed by layout, detail design, fabrication, and assembly of the inverted AZ array support and alignment structure. The final alignment of the dummy antenna elements served as the basic test of the design. Several concepts for frangible joints at the base of each waveguide were devised. A test program was conducted for the evaluation of adhesives to be used in these joints. The design, fabrication, and assembly of each of these designs of frangible waveguide elements was done, followed by a program of static and impact load testing per the customer's specifications. Finally, this report was written, thoroughly documenting the results of the investigation and summarizing recommendations for further work.

1.4 CONTENTS OF REPORT

The remainder of this report describes the results of the project. Section 2 deals with the requirements for a frangible array and the design approach taken by Bendix as well as some analytical work and related design concepts. Section 2 also described the hardware designed and fabricated for testing, and discusses implications of the design details. Section 3 outlines the test procedures performed and the basic results thereof. These tests are primarily impact and static load tests of the frangible waveguide elements. Section 4 summarizes the results of the project, pointing out specific achievements with respect to original g[illegible] and requirements. Section 5 describes, in detail, areas where f[illegible]her work is needed to complete and prove current system designs a[illegible]ell as some new areas where development is likely to yield su[illegible]tial gains. Finally, documentation and data are contained [illegible] the Appendix.

SECTION 2. GENERAL FRANGIBLE ANTENNA DESCRIPTION

2.1 INTRODUCTION

2.1.1 BASIC REQUIREMENTS

A frangible MLS AZ antenna has to be designed to meet the following FAA requirements. The antenna will be subjected to environmental conditions of FAA-G-2100 Environment III, which is survivability in a wind load of 100 mph and temperatures of -50 to 70°C at 5 to 100% relative humidity. The specific frangibility requirements are called out in FAA-ER-530-81-04, "Structural/Mechanical Design Requirements for Low Impact Resistance MLS Structures." This also calls out FAA-G-2100 Environment III, but adds wind load requirements (equipment operational) of 60 mph and survivability in 150 mph jet blasts for 2 minute intervals. The frangibility requirements described for Low Impact Resistance Structures (LIRS) require that the antenna be designed "to withstand the static and operational/survival wind/jet blasts loads with a suitable factor of safety, but fail readily when subjected to the sudden collision forces of a 6000# lightweight aircraft traveling at 75 knots. The 'break-away' mechanisms (joints etc.) of the structure shall be design to separate at a peak force no higher than 5700# acting for approximately 0.008 seconds (8 milliseconds) and absorbing no more than 700 ft-lb of energy". The document also prescribes the related test procedures.

As with all federally approved MLS systems, the antenna must meet the performance standards of FAA-STD-022 in accordance with ICAO Standards and Recommended Practices.

2.1.2 ANTENNA DEFLECTION CONSTRAINTS

In order to meet the system performance standards maximum values of static deflection in the fore/aft direction under wind load are established as design constraints. Similar constraints are neglected in other directions since deflections are insignificant. FAA-E-2721/2, para. 2-3.4.2.5.1 requires that the roll-off of the vertical pattern of the AZ station be 8 dB/deg ($\pm$10%) at 0° elevation. Using the theoretical pattern of the Bendix 4 foot waveguide element as a model, the roll-off at 0° is 8.9 dB/deg. Assuming windloading will cause the waveguide to bend as a third-order curve ($y = ax^3$), then the pattern roll-off can be computed for various loadings (see Figure 1). With the bottom of the waveguide fixed, the top can only move 0.073 inches before the roll-off has degraded by 10 percent.

2.2 INVERTED AZIMUTH ARRAY

2.2.1 DESIGN APPROACH AND DETAILS

The most common and prevalent MLS AZ antennas are vertically polarized C-band phased arrays using, depending on system accuracy requirements, 40 to 120 four-foot slotted elements of WR-159 aluminum waveguide material. In order to minimize cost and unnecessary complication, the frangible AZ antenna was designed around the smallest array using 40 elements and having a 3° beam width and ±40° scan. Two types of structural designs have been used in the past to support the waveguide elements. In more recent designs, the elements are mounted to a space frame on a pedestal encased in a shroud or shelter. Previously, elements were attached to a sandwich ground plane connected to a rigid case supported by tripod legs. In both cases, stretched membrane or rigid sandwich radomes served as the window for R.F. transmission out of the enclosure.

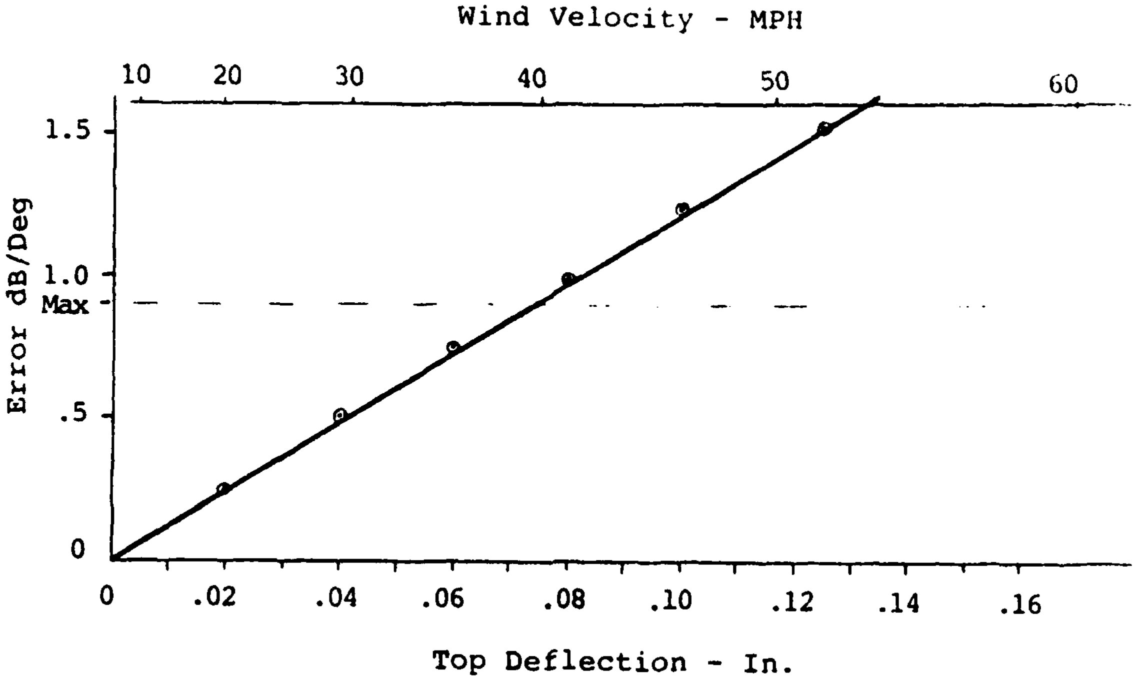


Figure 1. Computed Error Vs. Deflection and Wind Velocity for WR-159 AZ Cantilever Waveguide

In the design of the frangible antenna, complete reconfiguration was necessary. An approach to the minimization of the energy absorbed in a collision is the incorporation of breakaway joints in the high-moment areas of the structural elements. Since energy is a function of load times displacement, the reduction of the constant load deflection after impact has a proportional effect in reducing energy absorbed. The second general design approach serves a dual function, reducing the energy absorbed by minimizing the mass of the structure and reducing the probability of a collision by minimizing the size of the antenna, primarily the height. This consists of dispensing with all unnecessary components in the antenna case. They will be located remotely below ground level or 500 feet off the runway centerline where frangibility is not a requirement. Those components required to be in close proximity to the array will be located at the base of the antenna. An additional design approach incorporated to reduce the energy absorbed by inertial effects is that referred to as the "open a window" approach. In this approach, portions of the frangible structure segment or rotate out of the way preventing the structure from accelerating to the speed of the impacting aircraft.

The minimum requirement for an antenna such as this, in regard to size and mass, is the group of waveguides serving as the radiating aperture. Thus, the design of the frangible AZ antenna, termed the inverted waveguide array (see Figures 2 and 3), consists of forty 48-inch waveguide elements cantilevered from the support and alignment structure at their base. This device was fabricated from stainless steel metal and is a one-foot square sheet metal box section running the length of the array (see Figure 4). The design incorporates a device for the independent fore/aft adjustment of each element. The spacing between the elements is controlled by hole tolerance in the mountings at the base and clamping devices at the top of the waveguide which keep the spacing constant, but allow the elements to separate upon impact through the use of ceramic

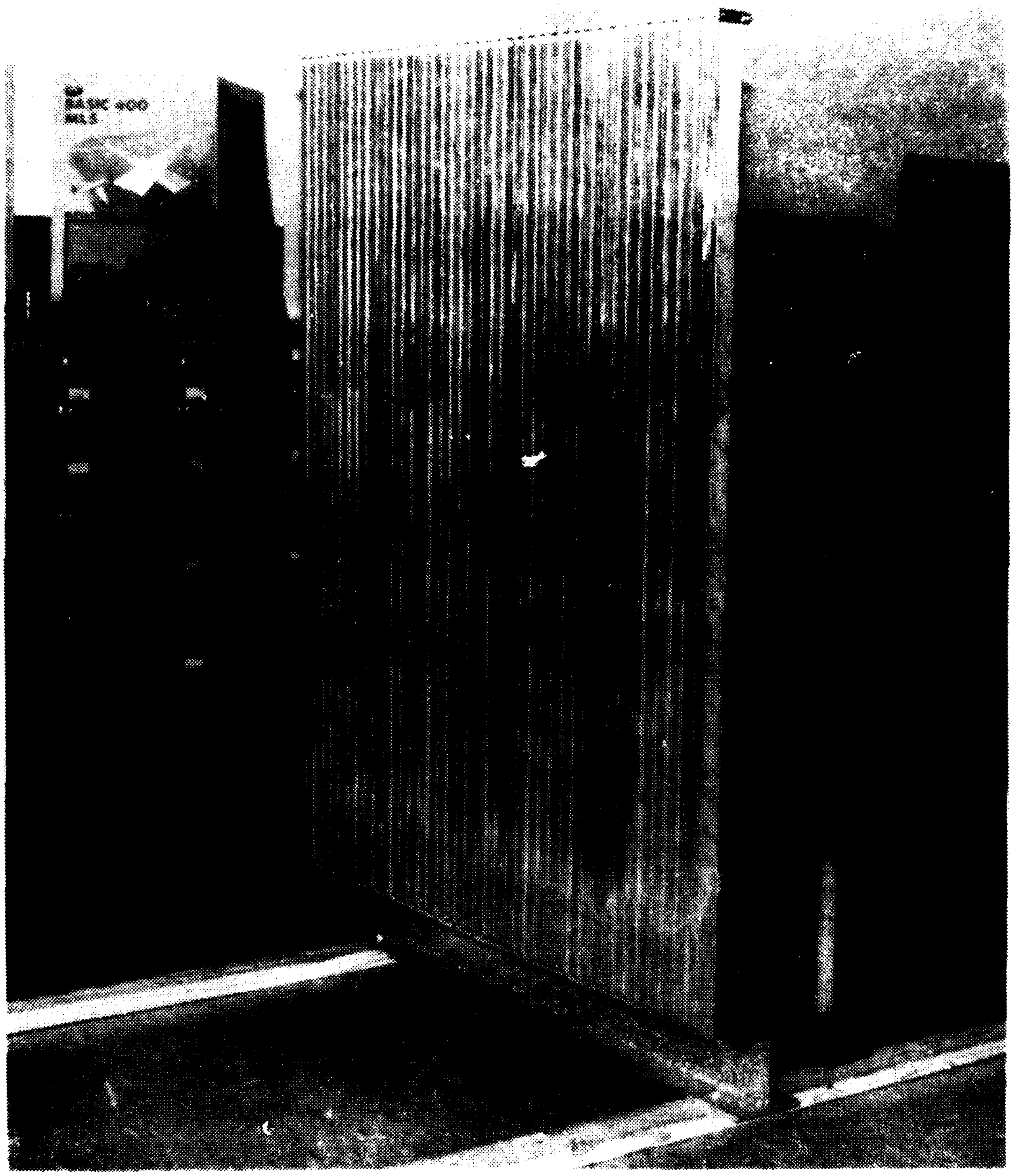
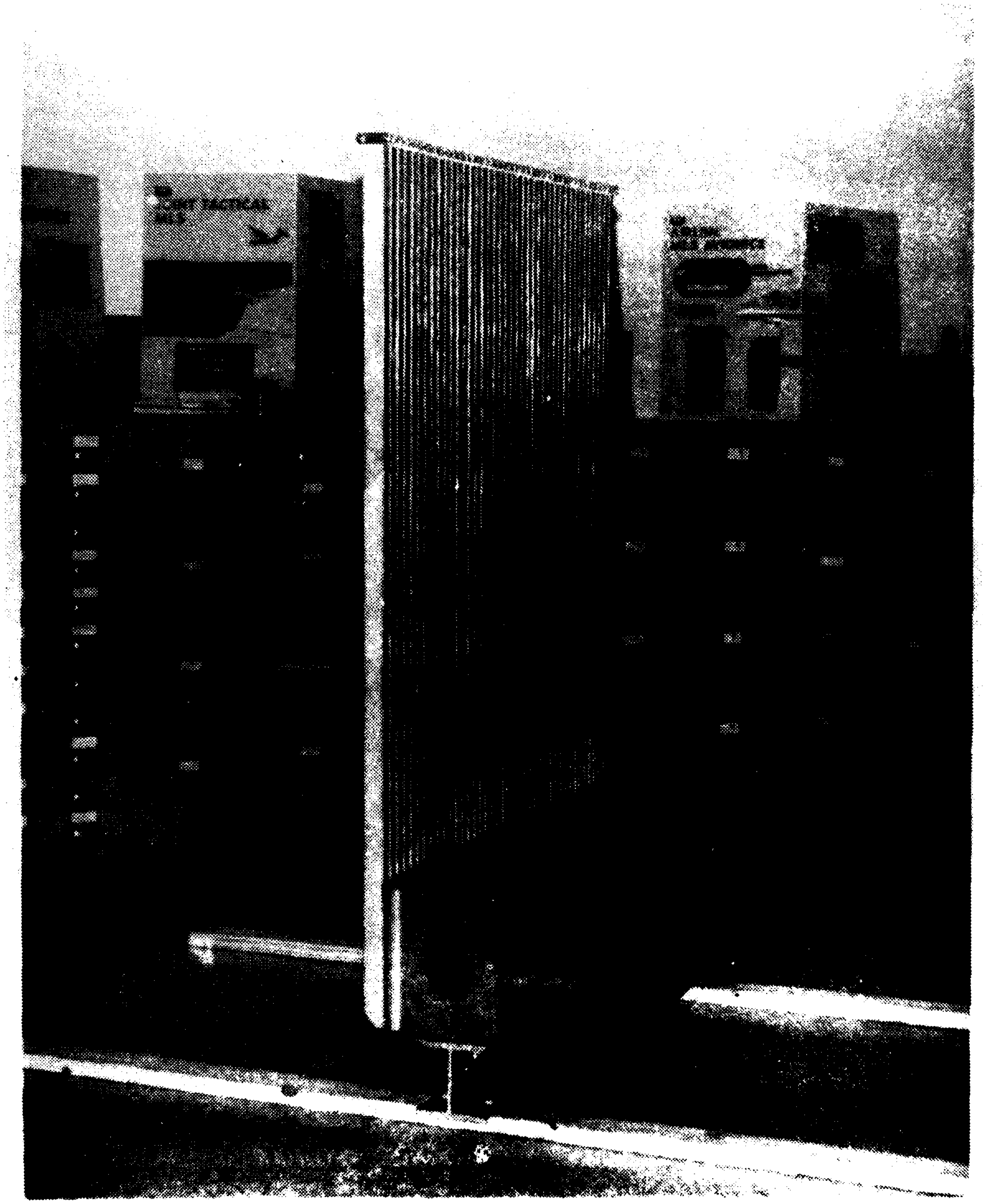


Figure 2. Inverted Waveguide Array, [illegible]



JOINT TACTICAL MLS

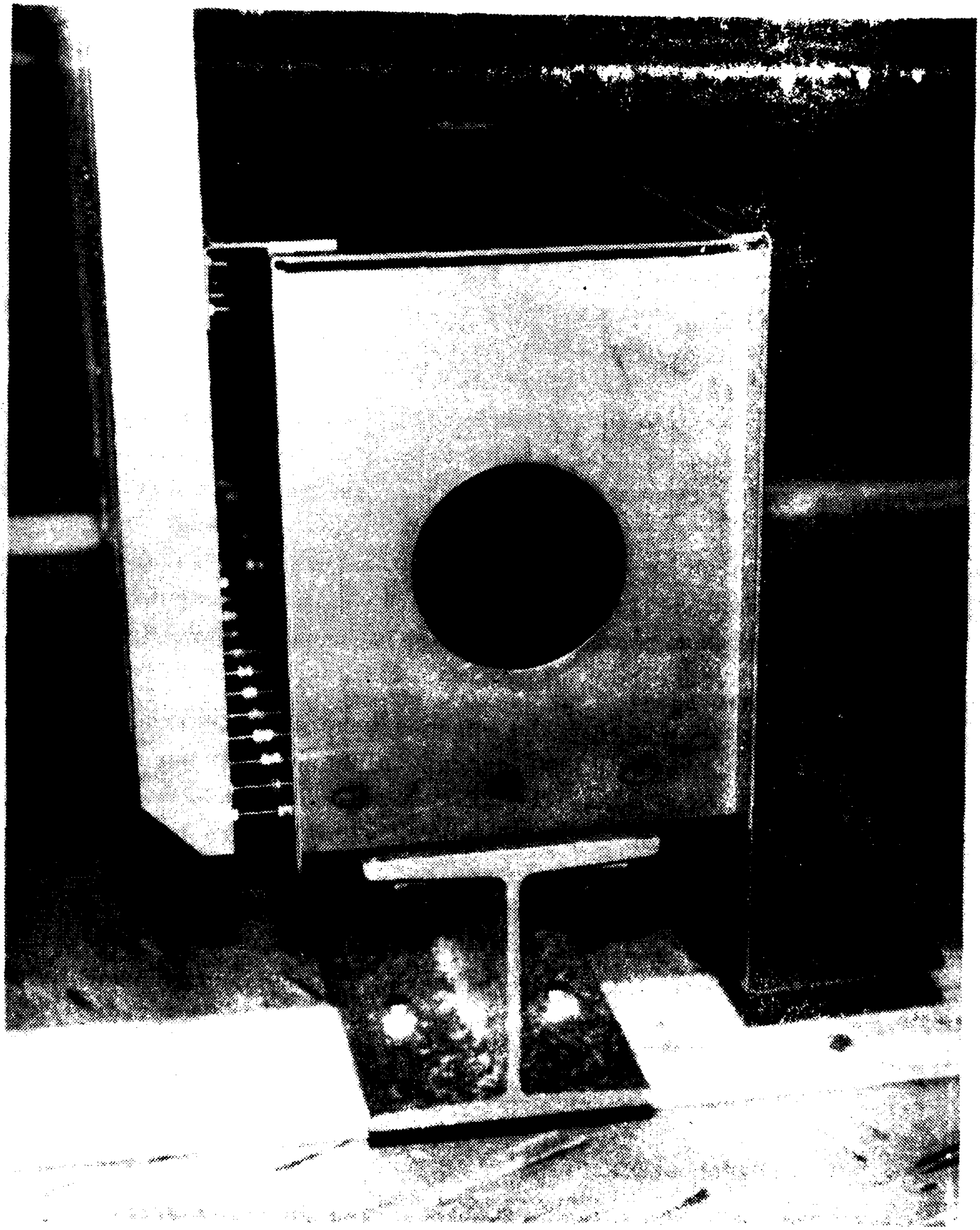


Figure [illegible]
[illegible]

rods or tensioned springs. Although it is assumed that the requirement for the maximum energy absorbed on impact applies to all forty waveguides, the selective destruction of elements, as by contact with an aircraft landing gear, would serve to further reduce the severity of many collisions.

Provisions are made on the support and alignment structure for the mounting of phase shifters, power dividers, and signal distribution boards. Beam steering electronics are packaged in an adjacent card rack. All other major components will be located elsewhere, primarily the transmitter, modulator, and exciter assemblies, the timing control and monitor electronics, and the power supplies and batteries. The structure is mounted to its foundation via a section of structural aluminum. A sheet metal shroud, independently mounted to the foundation, shields the fixture from solar loads and environmental conditions. Waveguide elements protrude through gasketed openings in the top of the shroud. Removeable covers allow access to the internal components for servicing.

The elimination of the antenna case greatly reduces the mass of the array. Additionally, since air passes between the exposed elements, the total wind load is reduced and thus a less stiff structure is required. The waveguide elements are not quite stiff enough in their current design to meet the performance standards. Simple modifications to the drawing die will provide sufficient increase in stiffness in a deliverable system. Also, individual radomes are required for each element. This has been done before on field monitor antennas.

2.2.2 FRANGIBLE WAVEGUIDE ELEMENTS

2.2.2.1 GENERAL DESCRIPTION

The waveguide elements used in the inverted array design are the same as those used in previous MLS AZ antennas. They are WR-159 aluminum waveguides, 56 inches in length above the shroud, 1.718 x 0.923 inches in cross section, with a 0.064 inch wall thickness. A frangible joint detail is fabricated at the base of the waveguide where the greatest moments occur. Unaltered waveguides are unacceptable from a frangibility viewpoint. Due to the ductility of aluminum and the geometry of the waveguides, the walls buckle at the base in cantilever bending, folding up to a reduced section where catastrophic failure never occurs. This continuous resistance to bending load results in a nearly constant rate of energy absorption over the entire deflection. In contrast, an element with a frangible joint displays a similar rate of energy absorption, but only over the short initial period of elastic strain prior to catastrophic failure.

Several designs of frangible joints were devised, incorporating different combinations of several details (see Figure 5). For strength reduction, some designs were severed at the joint, while others used shallow notches to avoid fatigue failures. The latter method affords the best conductivity, the requirement for which will not be established until some R.F. testing is performed. Splice pieces of several designs attached with high performance adhesives in shear load conditions provide controlled strength to the joint, eliminating ductility. These external splice pieces are designed to be separable to prevent binding in the process of failure. Quantitative and qualitative tests of adhesive systems and calculations of shear loads were used to select the best materials and design parameters.

2.2.2.2 DEFLECTION AND FAILURE CHARACTERISTICS

Some insight to the frangibility performance of vertical cantilever waveguides can be gained through several simple analyses. Some analytical considerations will be described as background, then the actual calculations and their results will be summarized.

CANDIDATE FRANGIBLE JOINTS
(CROSS-SECTIONS, ONE TYPICAL WALL)

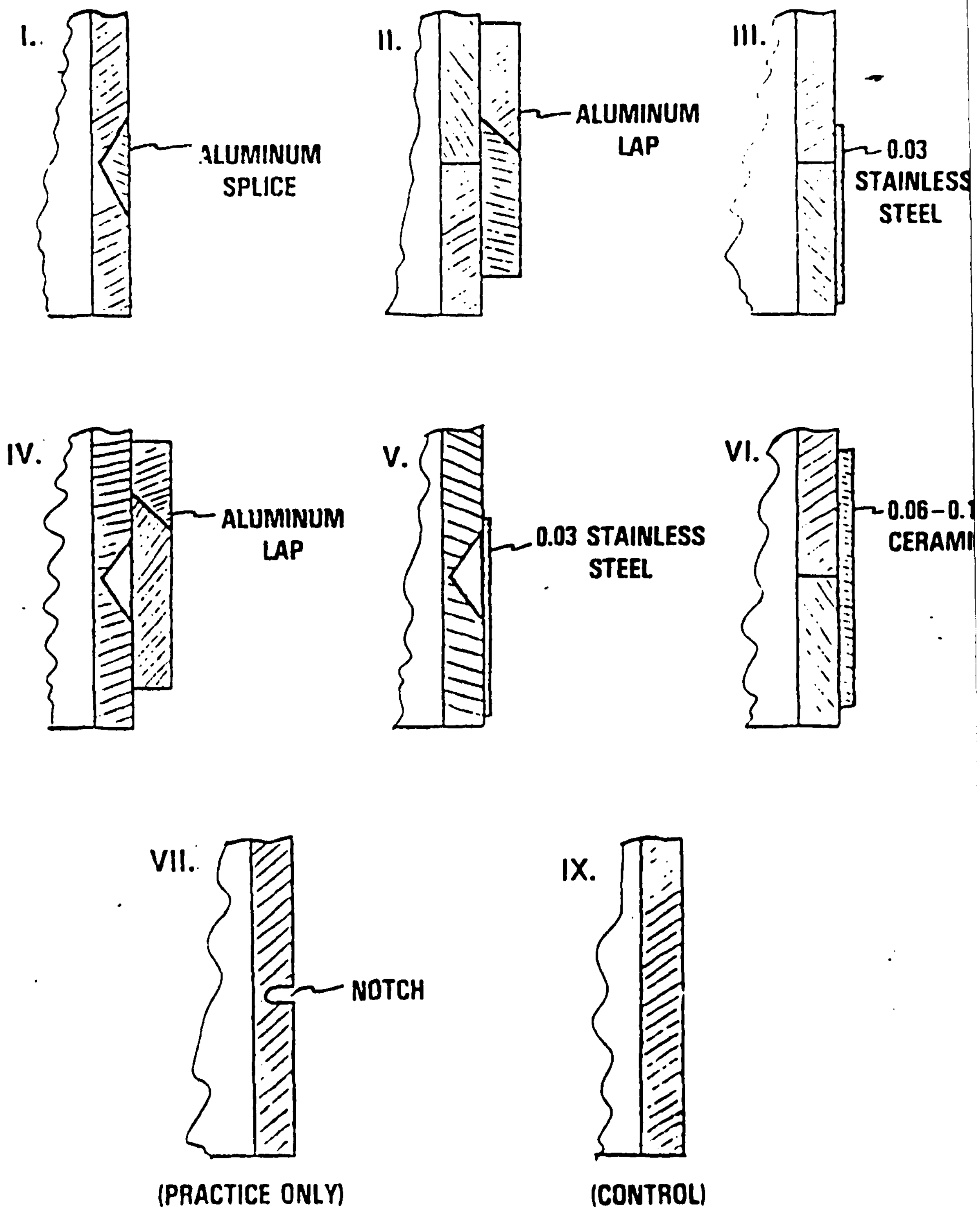


Figure 5. Frangible Waveguide Joint Designs

The amount of energy absorbed by a simple structural section like a waveguide in a cantilever-type impact is determined by two independent factors. One component is the inertial load, the kinetic energy required to accelerate the impacted material to the velocity of the aircraft. This in turn depends linearly upon the mass and the mass distribution of the waveguive as well as the ballistic response of the impacted sections of the structure (the "window opening" effect). Complete momentum transfer is assumed since the total kinetic energy of the aircraft is several orders of magnitude greater than that it imparts to the waveguide.

The other component of the energy absorbed is that caused by the deflection and deformation of the waveguide. This depends upon the strength, stiffness, and geometry of the structural element, and is composed of the elastic strain energy and the plastic strain energy. The former is inversely proportional to the stiffness or the modulus of the material and the moment of inertia as determined by geometry. The deflection is proportional to the third power of the length from the base to the position of impact. Plastic strain energy is absorbed in the post-yield, constant load regime of the failure. It is directly proportional to the length and inversely proportional to the moment of inertia. It is not material-insensitive since the strength and mode of failure determine the magnitude of the applied load, the strain to fracture, and the possible change in moment of inertia. The yield point in the load versus deflection curve (see Figure 6) may not be determined by the yield stress of the material, but, as in the case of waveguides, by geometry-induced elastic instability or buckling of the side walls at some lower stress, changing the moment of inertia, and thus the stiffness. The limit of deformation or the end of the curve is a function of the fracture mechanics response, or the ductility/brittleness versus the ultimate strength of the material and, if applicable, the frangible joint. In the case of very ductile materials, such as an unaltered aluminum waveguide, fracture may never occur and energy will continue to be absorbed until some point in the rotational deflection where contact ceases

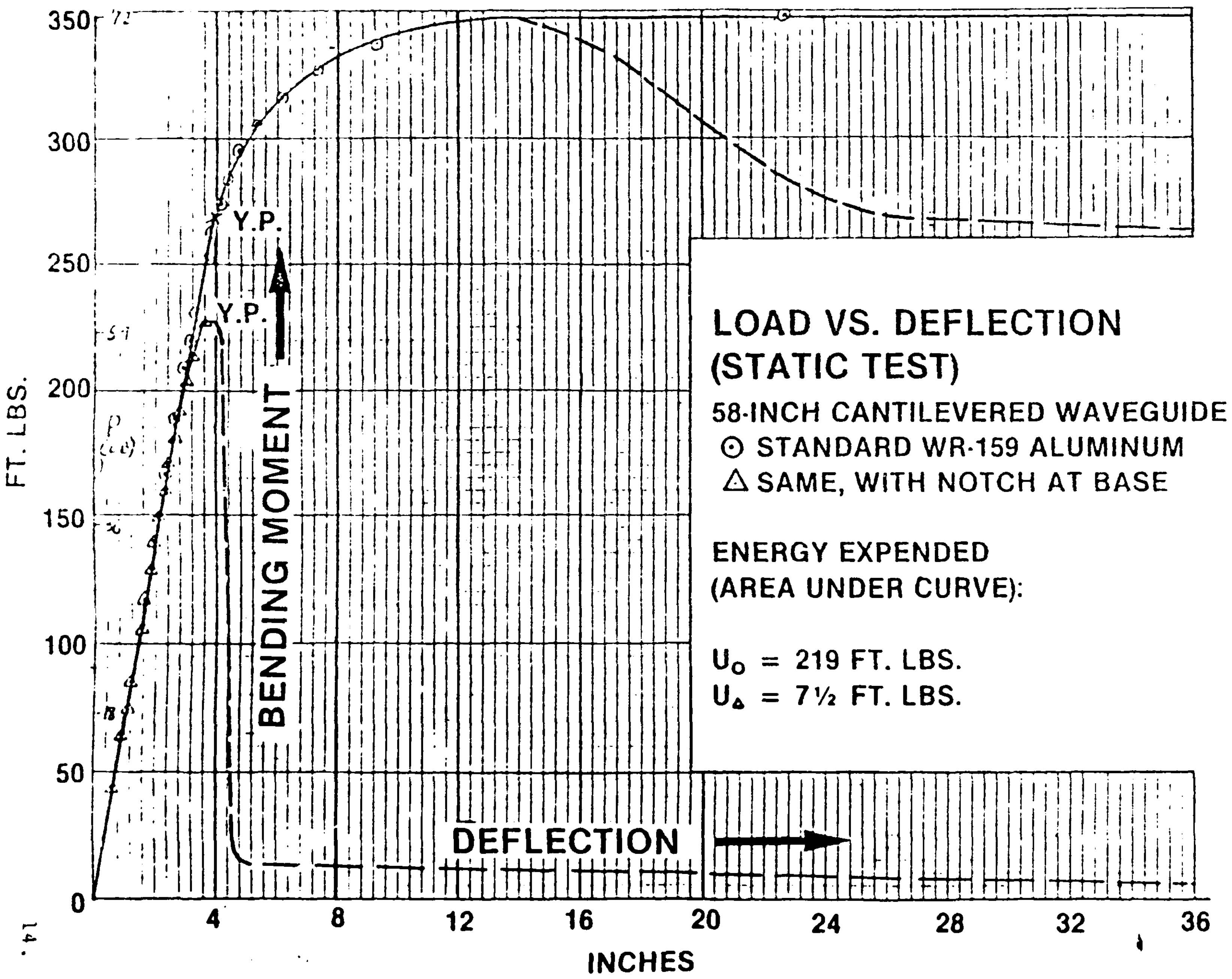


Figure 6. Preliminary Load Tests of Waveguides to Failure

This need not be defined, however, since the energy absorbed in such a situation would be prohibitively high. A truly frangible waveguide must be quickly severed, long before such ductile failure.

In actual testing at relatively low speeds (less than 10 knots) the inertial effects were observed to cause a prominent spike in the load history followed by smaller spikes as the waveguide bounces off the impacting tup. In any frangible design the waveguide severs and continues in free body motion or rotates away freely and runs out of travel, thus having absorbed more energy than necessary for failure. This effect is not easily quantified but should be consistent between designs, such that these analytical results are valid on a relative basis.

In the general case of impact deformation, neglecting inertial effects, energy absorption is equal to the area under the load vs. deflection curve. Not considering variations in mode of failure, the shape of the load vs. deflection curve should be approximately the same as that of the stress-strain curve of the material in tension. Ductile materials like aluminum exhibit constantly increasing strain at constant stress after yield, absorbing large amounts of energy. Brittle materials exhibit little or no plastic behavior, absorbing little energy. The latter would also apply to waveguides of ductile materials with frangible joints which act as stress concentrations. High modulus materials inherently have less area under the elastic portion of the curve and require less volume for equal stiffness, reducing the inertial load if density is held constant. Thus, without the use of frangible joints, the optimum material for frangible waveguide elements would be a high modulus, low density, brittle material such as composites or ceramics. This is shown in Table 1 by a calculated parameter known as resilience, or the strain energy per unit volume, with both elastic and plastic components. This data in turn was used to estimate the energy absorbed in impact by a waveguide design using each of these materials. (See Table 2.)

TABLE 1. MATERIAL DESIGN DATA*

MATERIAL	E_x	ρ	u_{el}	u_{pl}	u_{TOT}	σ_Y	σ_{ULT}
METALS:							
Aluminum 6061-T4 (Std. WR-159)	10×10^6 psi	0.10 lb/in^3	22 psi	7627 psi	7649 psi	21 Ksi	35 Ksi
Above with Groove	10	.10	22	0	22	~21	~21
Aluminum 1100-0	10	.10	1.25	4544	4545	5	13
Stainless Steel 301	30	.29	18	64,220	64,240	33	117
COMPOSITES:							
Kevlar Fabric	3.8	.05	118	0	118	33	[illegible]
Graphite Fabric	10	.057	320	0	320	80	80
Kevlar Layup 0,45,-45,-45,45,0	4.5	.05	7.1	-	7.1	8	8
Graphite Layup 0,45,-45,-45,45,0	8.4	.055	65	-	65	33	33
CERAMICS:							
Silicon Carbide	13	.10	8.7	0	8.7	15	15
Alumina	32	.13	6.3	0	6.3	20	20
Cordierite	7	.09	0.6	0	0.6	[illegible]	3

*See Table 3 for Description of Terms.

TABLE 2. WAVEGUIDE DESIGN DATA*

MATERIAL	I_{FR}	I_{SD}	m	K.E.	U	W	Y	M_Y	f.s.
METALS:									
Aluminum 6061-T4	0.1237in^4	0.0460in^4	0.82 KG	2705in-lb	2630in-lb**	5335in-lb	0.118 in	3220in-lb*	3.0
Above w/Groove	0.1237	0.0460	0.82	2705	90**	2795	0.118	2720*	2.5
Aluminum 1100-0	0.1237	0.0460	0.82	2705	385	3090	0.118	720***	0.7
St. Steel	0.0412	0.0153	2.38	7839	19.6	7859	.12	1583***	1.5
COMPOSITES:									
Kevlar Fabric	0.3255	0.1296	.41	1350	849	2199	0.069	10420	8.2
Graphite Fabric	0.1237	0.0460	.47	1548	1037	2585	0.059	11520	10.6
Kevlar Lay-up	0.2749	0.1022	.41	1350	51.2	1401	0.10	2560	2.0
Graphite Lay-up	0.1473	0.0548	.45	1482	250	1732	0.10	5659	5.3
CERAMICS:									
Silicon Carbide	.0952	.0354	.82	2705	21.6	2727	.10	1662	1.5
Alumina	.0387	.0144	1.07	3524	7.3	3530	.10	901	.9
Cordierite	.1767	.0657	.74	2437	3.0	2740	.10	617	.6

* See Table 3 for Description of Terms.

**Per Test

***Plus Plastic Strain Energy

TABLE 3. LIST OF TERMS

E_x = MODULUS OF ELASTICITY

ρ = DENSITY

u_{el} = ELASTIC STRAIN ENERGY PER UNIT VOLUME (RESILIENCE)

u_{pl} = PLASTIC STRAIN ENERGY PER UNIT VOLUME (RESILIENCE)

u_{TOT} = TOTAL STRAIN ENERGY PER UNIT VOLUME (RESILIENCE)

σ_y = YIELD STRESS

σ_{ULT} = ULTIMATE FAILURE STRESS

I_{FR} = MOMENT OF INERTIA WRT FRONTAL LOADS

I_{SD} = MOMENT OF INERTIA WRT SIDE LOADS

m = MASS

K.E. = KINETIC ENERGY

U = STRAIN ENERGY

W = TOTAL ENERGY ABSORBED

y = DEFLECTION AT TIP

M_y = YIELD MOMENT

f.s. = FACTOR OF SAFETY

Preliminary load tests revealed a 43% increase in static deflection (See Figure 7) for a slotted waveguide element over that of an unaltered waveguide used in calculations. In tests to failure, unaltered waveguides displayed the ductile high energy absorbing mode of failure described above. On the other hand, waveguides with simple stress concentration grooves at their base failed without plastic deformation like brittle materials.

The strain rate at the frangible joint of a waveguide was calculated for the appropriate impact parameters and geometry. At 3 in/in/sec, it is in the low end of high strain in terms of general material behavior. Most materials, including aluminum, exhibit strain rate sensitivity such that higher strain rates cause greater strengths. Some polymers, however, can display more brittle behavior and lower strengths in these conditions.

2.2.3 ALTERNATE DESIGNS

The primary deficiency in the current design of the inverted AZ array is the excessive deflection of the waveguide elements in the maximum operational wind load conditions. A deflection of .169 inch is predicted at the top of the elements as opposed to a maximum allowable deflection of .075 inch. (See 2.1.2) The design change will be accomplished by a change in the waveguide cross-section. The most efficient design will provide the necessary increase in the moment of inertia, increasing stiffness with the minimum increase in volume, which corresponds to mass and thus inertial load. Since most of the deflection occurs near the base, the addition of material in this area only might be sufficient. Such an added structural shape would be attached with a high performance structural adhesive. If the change is to be for the entire length, it might be incorporated through the use of a different drawing die by the waveguide manufacturer. Due to the nature of stiffness and deflection of this type of structure, an increase in volume of approximately 15% should be sufficient to solve the problem.

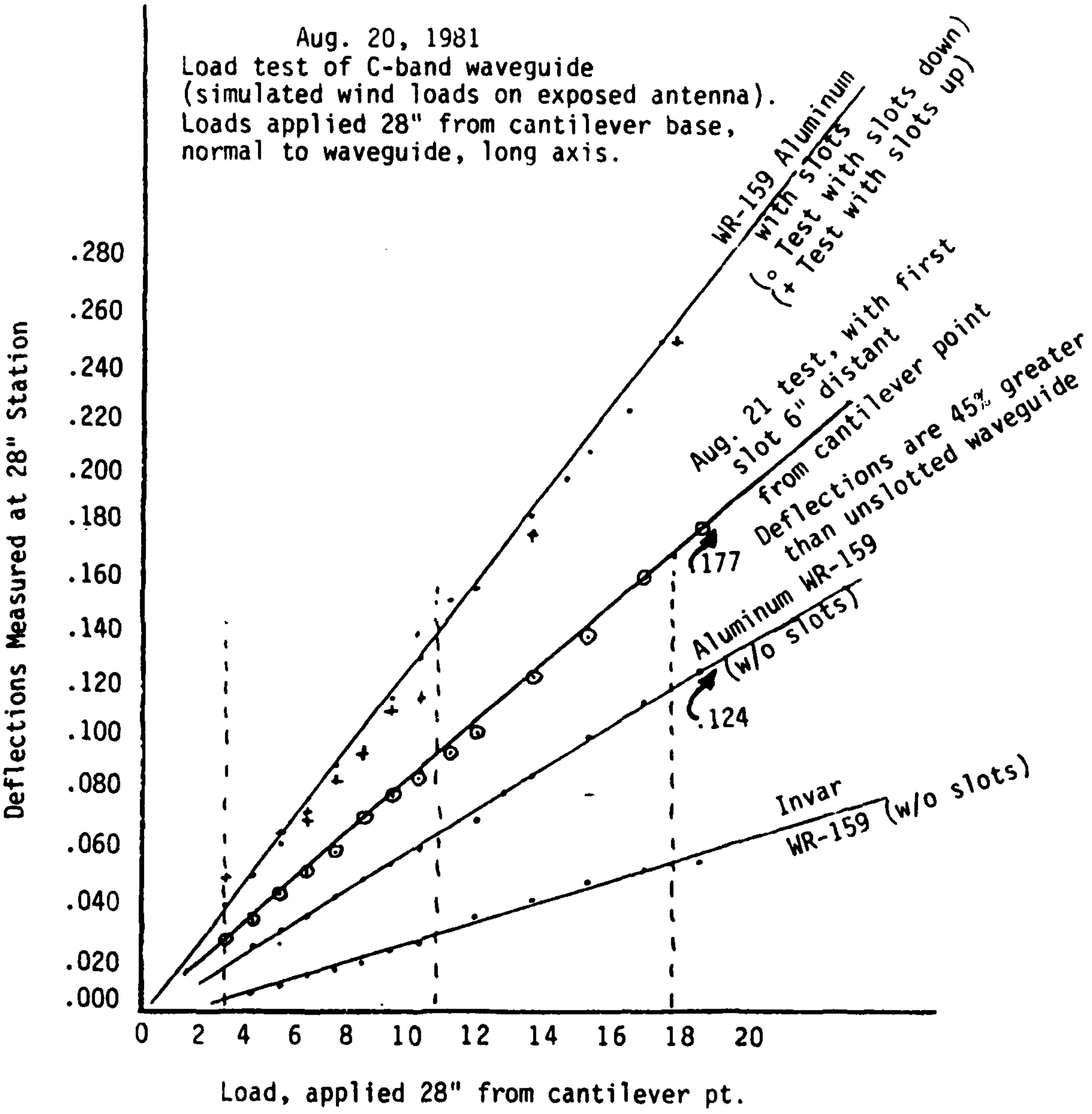


Figure 7. Preliminary Load Test of Slotted and Unslotted Waveguides

An alternative solution to several problems, including the excessive wind load deflection, would be the use of dielectric waveguide elements. This type of antenna element (See Figure 8) has been developed by one or more fabricators (especially ITT Gilfillan) as a slotted element with slots photographically applied as clear areas in the plated inner surface of a completely sealed Kevlar/epoxy waveguide shell. Since the Kevlar/epoxy is a dielectric material, RF energy readily radiates through the solid walls of the waveguide, eliminating the need for a radome. The mass of the waveguide element would be less than its aluminum counterpart as shown in Table 2. Also since the section of the part would be increased and since a Kevlar/epoxy laminate is inherently more brittle than aluminum, elaborate adhesive joints would not be required and fracture would be easily controlled. The necessary stiffness would be easily obtained by effective fiber lay-up design. A laminate characterization program known as CMAP was used to determine the overall properties of the composite waveguide elements described in Table 2. Some development of fabrication processes would be required for this approach.

Several different configurations for an inverted array were suggested, but not developed for various reasons. In one case, known as Configuration A, shown in Figure 9, the waveguide elements are supported by a space frame with frangible joints at its base. Thus no conductive joints are required. Also, this is a much more practical application for the composite approach since the structural elements are separate from the RF elements. Since only two frangible supports exist, the total energy absorbed in impact is much less than for all 40 independent frangible waveguide elements, but more than for just a few.

The fact that individual radomes are still required leads to the next approach, Configuration B, shown in Figure 10. In this case, a radome/enclosure encases the entire array and thinwall

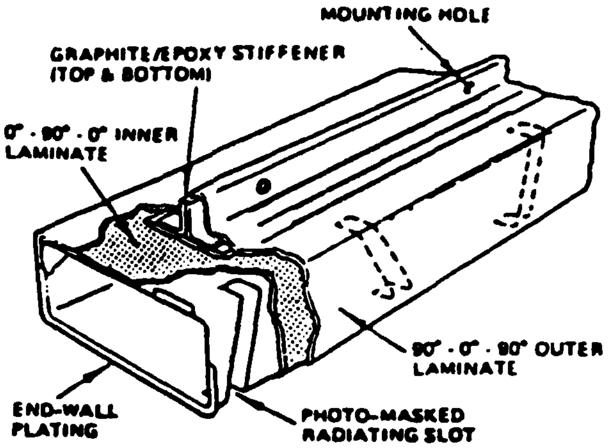


Figure 8. Dielectric Waveguide Element

(From: "Development of a Fiber-Reinforced Composite Design Concept for Large, Mechanically Scanning, Planar Slot Arrays", John W. Small, ITT Gilfillan, Van Nuys, California 91409, The Record of the IEEE, 1977, Mechanical Engineering in Radar Symposium.)

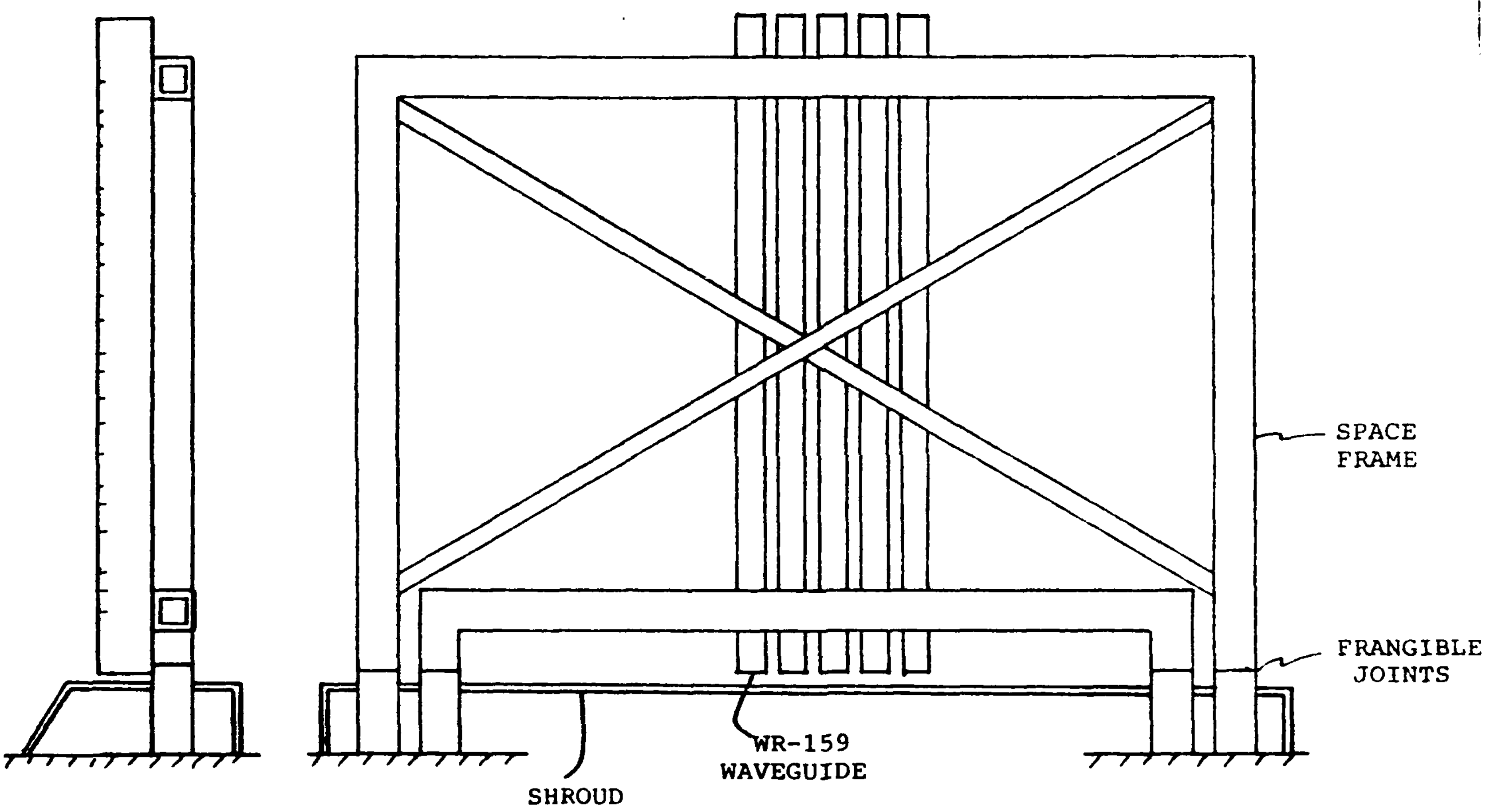


Figure 9. Configuration A - Alternate Inverted AZ Antenna Design

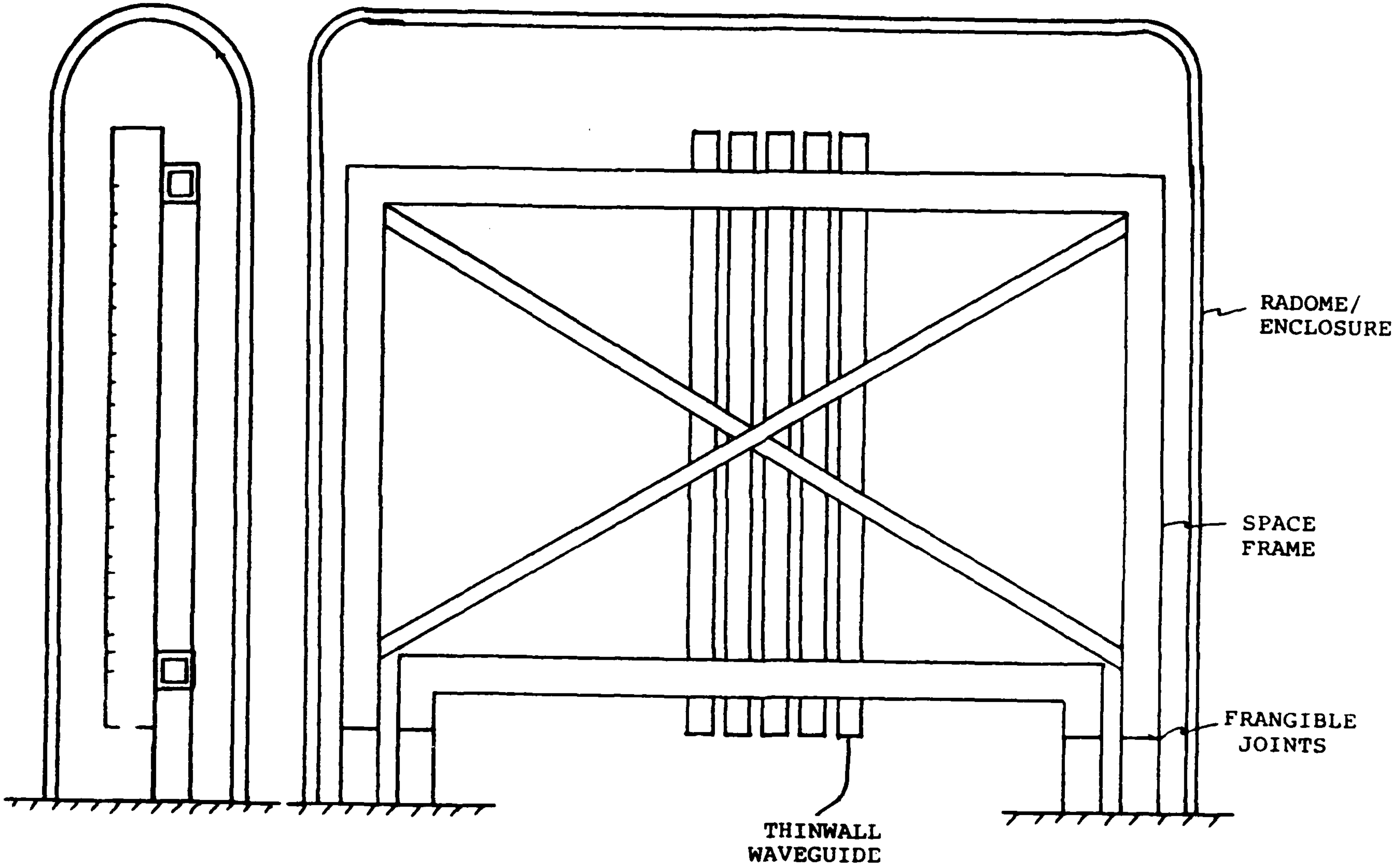


Figure 10. Configuration B - Alternate
Inverted AZ Array Design

(.010 to .015 inch thick) waveguide elements, developed on the JTMLS (Joint Tactical Microwave Landing System) program, are used to reduce the inertial load. Although the wind load increases since the radome/enclosure is continuous, the deflection constraints are greatly reduced since it is mechanically isolated from the array. The mass increase should not be significant since sandwich radome designs are very efficient. Frangibility of the radome should be easily achieved due to the brittle nature of the materials, especially in impact loads. Also, since wind loads are absorbed by the radome/enclosure, the stiffness and mass of the space frame could be significantly reduced. Development costs would be incurred for the radome/enclosure as well as replacement costs for those destroyed in testing.

SECTION 3. TEST PROGRAM AND RESULTS

3.1 INTRODUCTION

3.1.1 TEST REQUIREMENTS

General test procedures for frangible MLS antennas are prescribed by the FAA document FAA-ER-530-81-04. The tests applicable to the inverted array concept described in Sections 2.2.1 and 2.2.2 were performed on a component basis. That is, due to the nature of the design, numerous identical vertical cantilever structural elements, the tests were performed on single elements only. Also, the test procedures were modified or deleted to correspond to the particular application instead of the general case of structural supports of great length, to which they were designed. Since no significant tension, compression, or sheer loads are carried by the structure in service, these tests were not performed. Instead of the flexural test, a simple bending load test of cantilever waveguides was performed. This test was more representative of the actual application than the three-point bending test prescribed. The impact tests, however, were performed very nearly as prescribed. Also, several tests were performed in the selection of adhesives.

3.2 MATERIALS TESTING

3.2.1 ADHESIVE TESTING

Adhesive systems for the assembly of the frangible waveguide joints were tested prior to the selection of those to be used. The candidates were selected from personal experience and by recommendations from several major manufacturers. They are listed along with the test results in Table 4. In all cases, manufacturers' instructions for application and curing were followed. Three types of tests were performed, two were quantitative, while one was qualitative.

The qualitative test, termed a hammer test, tested the shear strength of the adhesives under impact loads. The test configuration (see Figure 11.a) consisted of two short sections of aluminum angle attached over equal areas. One angle was clamped over the edge of a rigid surface, and the other was struck with a hammer in a downward motion. The tests were performed in rapid succession so that a calibrated comparison could be made.

The first quantitative test consisted of a standard Charpy impact test for notched metal samples. Samples of the same geometry required for testing metals were used, but with a cross sectional adhesive joint in place of the notch (see Figure 11.b). Thus the test was mostly tensile in nature. A Tinius-Olsen Model 74 pendulum-type universal impact tester was used with a Charpy vise, striking the sample at 16.8 ft/sec. All data was close to zero on the scale, causing poor resolution.

The second quantitative test, the shear test, measured the overall quality of the adhesive joint, not the impact performance. Simple strips of aluminum, .090 inch thick, were attached in a one square inch overlap adhesive joint (see Figure 11.c). Two strips of each sample were pulled apart in tension to measure the shear strength of the adhesive.

TABLE 4. ADHESIVE TEST RESULTS

ASHESIVE	QUALITATIVE TEST DESC.	QUALITATIVE TEST TYPE*	IMPACT TEST ENERGY ABSORBED	IMPACT TEST TYPE*	SHEAR STRENGTH	SHEAR TEST MFG.**	SHEAR TEST TYPE*
1	Very Brittle	ADH	N/A	ADH/COH	281/297 psi	N/A	ADH
2	Brittle	ADH	0.15 ft-lb	COH/ADH	578/197	3150	ADH
3	Very Tough (Toughest)	COH/ADH	2.3	COH	3180/2765	4680	ADH/COH
4	Moderate	COH	0.8	COH	1346/1239	1400	COH
5	Moderate	ADH	0.8	ADH	408/450	4150	ADH
6	Very Tough	COH	1.3	COH	2433/2575	2000-4600	ADH/COH
7	Tough	ADH	0.8	ADH/COH	663/804	2500	ADH

Description of Adhesives

(1) Hysol Super Drop III, CM-150, Cyanoacrylate
(2) Hysol EA 934, two-part Epoxy
(3) Hysol EA 9320, two-part Epoxy
(4) American Cyanamid 4533, one-part Epoxy
(5) American Cyanamid 4535, one-part Epoxy
(6) Lord Hughson Versilok 204/4 Acrylic
(7) 3M 2216, two-part Epoxy

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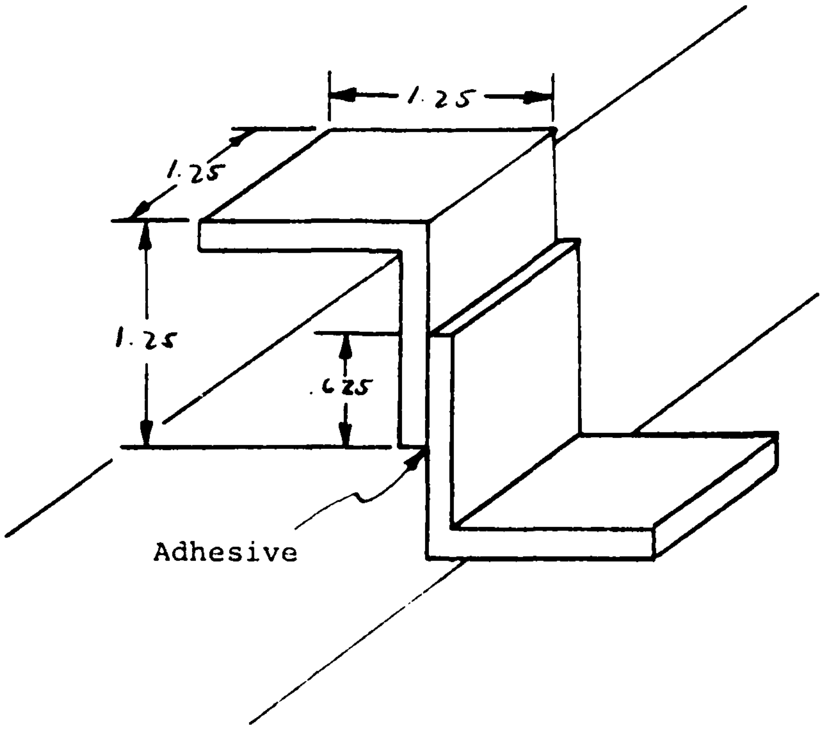
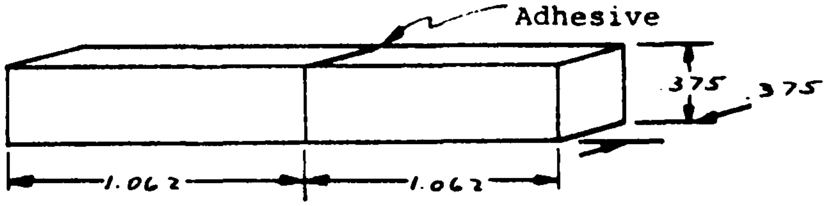
*Type of Failure - Adhesive or Cohesive

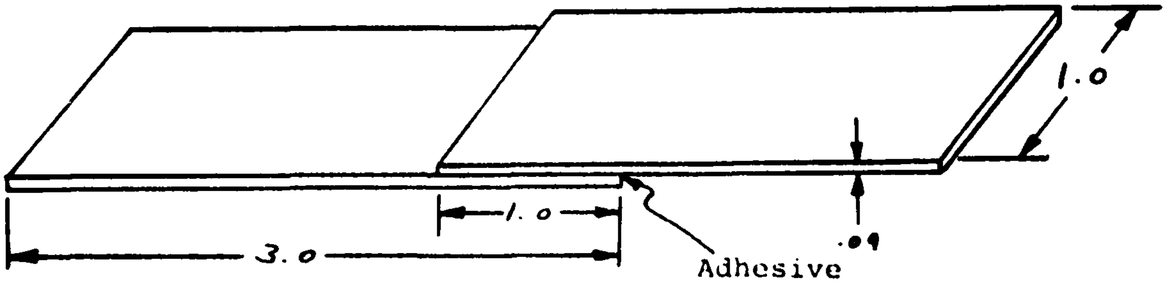
**Manufacturer's advertised shear strength.



a. Angles for Qualitative Hammer Test



b. Blocks for Charpy Impact Test



c. Strips for Shear Test

Figure 11. Adhesive Test Configurations

Two adhesive systems were selected, one for cases where the adhesive itself must separate upon impact, and another for when it should remain intact. A fairly brittle adhesive is required for the former case, and a tough adhesive for the latter. In both cases, however, a system exhbiting cohesive failure was selected. This mode of failure implies that a more controlled and repeatable joint strength can be achieved. This is not necessarily true when an adhesive failure occurs since insufficient surface preparation might have been the cause. The adhesives selected were American Cyanamid 4533, one part epoxy for brittle requirements, and Hysol EA 9320, two parts epoxy for tough requirements.

3.3 STRUCTURAL TESTING

3.3.1 IMPACT TESTING

3.3.1.1 TEST REQUIREMENTS

The requirements for impact testing of this structure are put forth in FAA-ER-53-81-04. In summary, it states that any standard impact test equipment may be used that delivers 1800 ft-lb of kinetic energy to a specimen rigidly fixtured so that the contact point be 12 inches from the breakaway mechanism. The instrumentation utilized must measure and/or compute the following data:

(a) kinetic energy of impact head at contact time
(b) velocity of impact head at contact time
(c) peak force at impact
(d) energy absorbed by "breakaway" mechanism

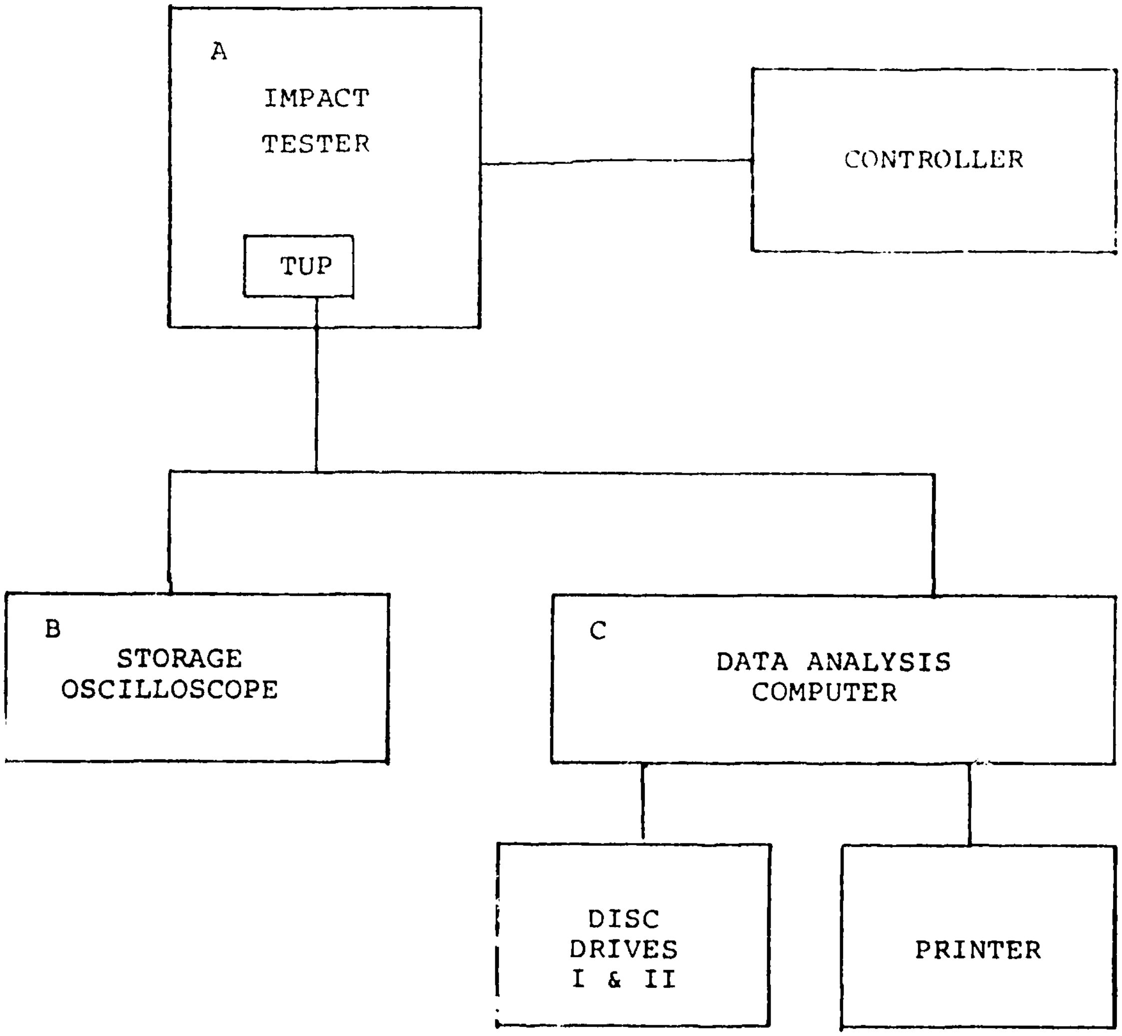
A statement of work was written (see Appendix A) incorporating these requirements with the addition of the recording of load and energy absorption histories for each test. The SOW was submitted to ten testing organizations and companies. The U.S. Army's Aberdeen Proving Ground Balistic Research Labs proved to be the most practical source of assistance, with very modern, powerful equipment and helpful, knowledgeable personnel. Assisting with the testing were Bill Bruckey, Ph.D., David Hanson, Ph.D., and Ray Purdum, all of APG-BRL.

Two minor compromises were made to the requirements for testing due to limitations of the equipment and idiosyncracies of the design. The total amount of kinetic energy delivered to the specimen was 1455 ft-lb. This is the maximum available from the impact tester when a fixture was used of sufficient height to avoid binding of a specimen of the desired length. The length of the specimen, too, was changed. A length of 19.25 inches to the point of impact was used, corresponding to that calculated to provide the same strain rate at the frangible joint as that encountered in the hypothetical aircraft collision specified (see Section 2.1.1). The reduction in available kinetic energy is tolerated since less than one percent of the reduced amount is used, not enough to detract from the accuracy of the test through inertial effects.

3.3.1.2 TEST EQUIPMENT AND SETTINGS

The test set-up and the test equipment used are described in Figures 12 and 13. The data analysis computer takes and records the raw test data from strain gages in the tup, storing it on a floppy disc. It then analyzes the data to arrive at the outputs described in Section 4.3.1.1, which it will print on demand. The storage oscilloscope displays load versus time for each test run. It is used to find proper settings for the computer and troubleshoot the set-up.

A series of preliminary test were run to check out the fixtures and the data-taking system as well as to find the optimum parameters for the system. These values, concerning the timing of the impact event and the form of the output data, are contained in the sample printout created in the computer's interactive mode, found in Appendix B.



A) Effects Technology, Inc. Model 8000C

B) Nicolet Model 206

C) Effects Technology, Model 300

Figure 12. Impact Test Configuration Diagram

Figure 13. Impact Test Set-up

3.3.1.3 FIXTURING

A welded aluminum fixture (see Figure 14) was designed and fabricated to hold the waveguide section as rigid cantilever beams. Provisions were made in the interface with the drop tower base to make position adjustments for a range of specimen lengths.

3.3.1.4 HIGH-SPEED MOVIES

High-speed motion pictures were made of the waveguide sections during the impact events as is required by FAA-ER-530-81-04. A Kodak high-speed camera was used with its 25mm, f1.9 lense, a Colortran "Mini-Brute 9", Model LQD9 studio floodlight bank, and 100' reels of Kodak TxR-430, Tri-X, No. 7278, 16mm black and white reversal movie film, spooled for high-speed projectors. The camera's exposure rate was set to its slowest speed of 750 to 1000 frames/second, corresponding to a shutter speed of 1/3750 to 1/5000 of a second per frame. Lighting and aperture settings were used such that the film was overexposed one stop to account for reciprocity failure. This was determined by the exposure of several practice rolls of film, also used for the purpose of checking the camera operation and determining the timing of the event.

Prior to a test run, the specimen is securely clamped into the fixture in the correct position. The required test parameters are inputted to the computer (see Appendix A). The test can proceed when the prompt "Test may be run" is printed. When the camera is triggered, an automatic rheostat continuously increases the speed to the proper setting. This corresponds to an increase in the pitch and volume of the audible noise up to a leveling-off point which serves as a signal that the camera has reached its maximum speed, at which time the impact test is triggered. Only one test run of each particular specimen type was filmed. After the test, the specimen is removed and the required data reduction parameters are inputted to the computer which, in turn, prints the results.

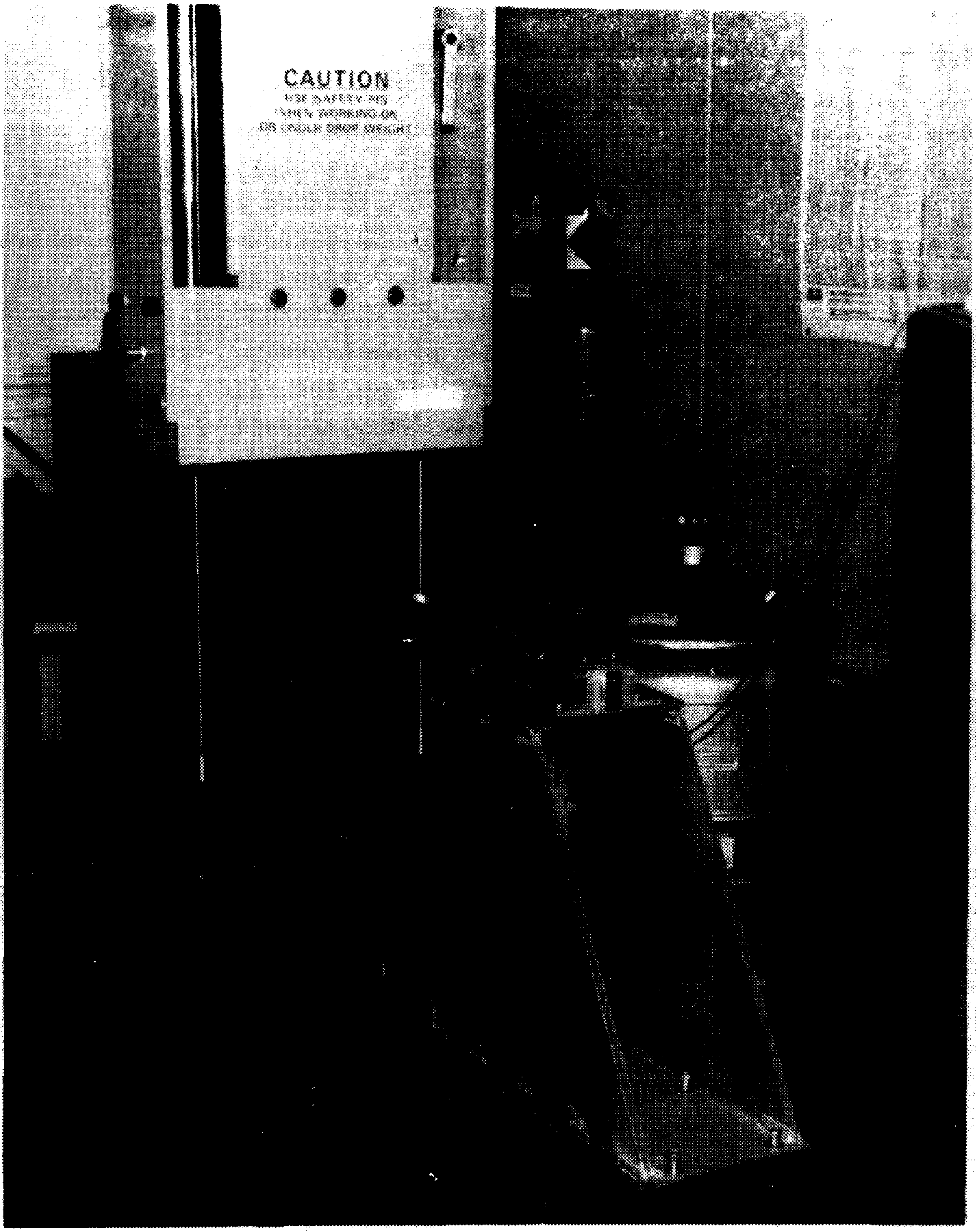


Figure 14. Impact Test Fixture

3.3.1.5 TEST RESULTS

The impact test results, in the form of maximum load and total energy absorbed, are found in Table 5 for all frangible waveguide joint specimens tested, as well as the notched practice specimens and the unaltered control specimen. Plots of the load and energy absorption histories and the related tabular output data of measured parameters are included in Appendix B for all specimens tested. Still photographs of one specimen of each design (see Figures 15 through 21) were taken immediately after the tests. The designs displaying the best performance failed with partial or complete separation at the joint as intended. Some others, however, proved to be too strong, and deformation of the waveguide adjacent to the joint resulted with excessive energy absorption.

In order to compare these test results with the performance goals for the entire array, each value of energy absorbed must be multiplied by 40, the total number of waveguide elements in an array. By this method, designs I, II, III, and VI show extrapolated values of 89 to 579 ft-lb, all well below the specified maximum value of 700 ft-lb.

Impact tests were performed on design VII (the practice specimen with a frangible joint using no adhesives), using lengths to the point of impact from the standard of 19.25 inches down to 6 inches. The small variations between the energy absorbed by these specimens prove that the variation in the length of the specimen to the point of impact has no significant effect on the test, other than the quadratic relation of the length to the strain rate at the joint.

3.3.2 STATIC WIND LOAD TESTING

TABLE 5. RESULTS OF STRUCTURAL TESTS OF FRANGIBLE WAVEGUIDE JOINTS

S/N PER FIG. 5	STATIC TEST MAX LOAD	f.s.	IMPACT TEST MAX LOAD	ENERGY ABSORBED	IMMINENT SEPARATION	COMPLETE SEPARATION	DEFORMATION
IA-1	32.25 KG(171.1 lb)	1.9					
IA-2	39.55 KG(87.2)	2.3					
IB-1			4453N (1001 lb)	8.52J (6.59 ft-lb)	X		
IB-2			4433N (997)	18.7J (14.47)	X		
IIA-1	39.79 KG (87.7)	2.3					
IIA-2	26.11 KG (57.6)	1.5					
IIB-1			2616N (588)	3.54J (2.74)		X	
IIB-2			BAD DATA			X	
IIB-3			4628N (1040)	2.86J (2.23)		X	
IIIA-1(.37)*	79.85 KG (176.0)	4.7					
IIIA-2(.25)							
IIIB-1(.37)			4179N (940)	5.53J (4.28)	X		
IIIB-2(.37)			3281N (738)	5.03J (3.89)		X	
IIIB-3(.25)			4316N (970)	5.73J (4.43)		X	
IIIB-4(.25)			4433N (997)	3.43J (2.65)		X	
IVB-1(.18)			4375 (984)	63.2J (48.89)			X
VB-1 (.37)			4316 (970)	58.4J (45.18)			X
VB-3 (.25)			4355 (799)	59.2J (45.80)			X
VIB-1 2" MACOR			4375N (984)	5.85J (4.53)		X	
VIB-2 1½"Alumina			4550N (1023)	56.0J (43.32)			X

*Length of overlap - inches.

TABLE 5. (CONTINUED) RESULTS OF STRUCTURAL TESTS OF FRANGIBLE WAVEGUIDE JOINTS

S/N (Per Fig.5)	STATIC TEST MAX LOAD	STATIC TEST f.s.	IMPACT TEST MAX LOAD	IMPACT TEST ENERGY ABSORBED	IMMINENT SEPARATION	COMPLETE SEPARATION	DEFORMATION
VIIB-1 6"			4472N (1005)	9.79J (7.57)	X		
VIIB-3 12"			4296N (966)	8.25J (6.38)	X		
VIIB-5 18.25"			4218N (948)	9.65J (7.47)	X		
VIIIA-1	24.19 KG (53.3)	1.4					
VIIIB-1			4121N (926)	6.07J (4.70)	X		
IXA-1	67.7 KG (149)	3.9					
IXB-2			4375N (984)	115J (88.96)			X

Figure 15. Impact Test Specimen IB-2

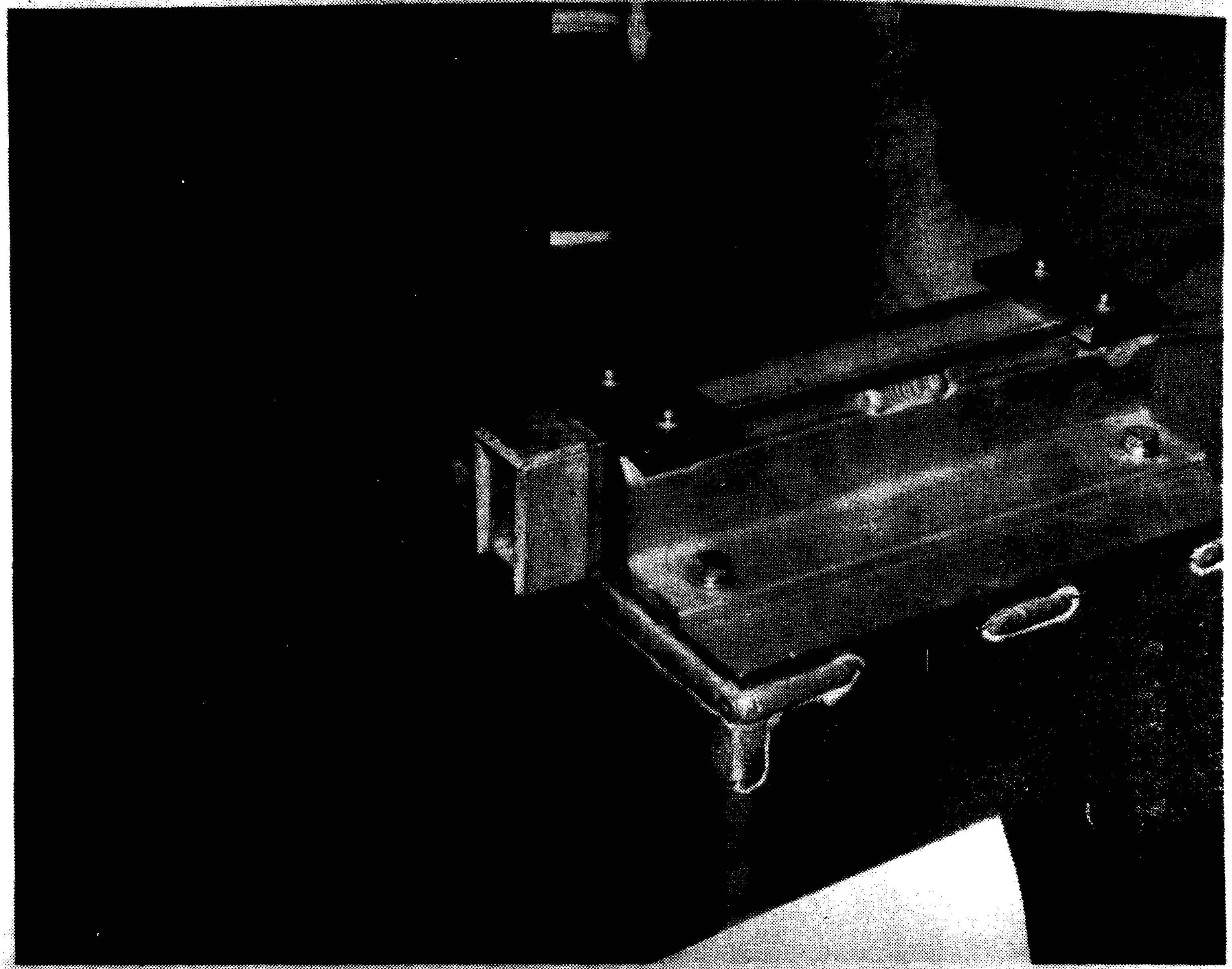


Figure 16. Impact Test Specimen II B-1

Figure 17. Impact Test Specimen III B-1

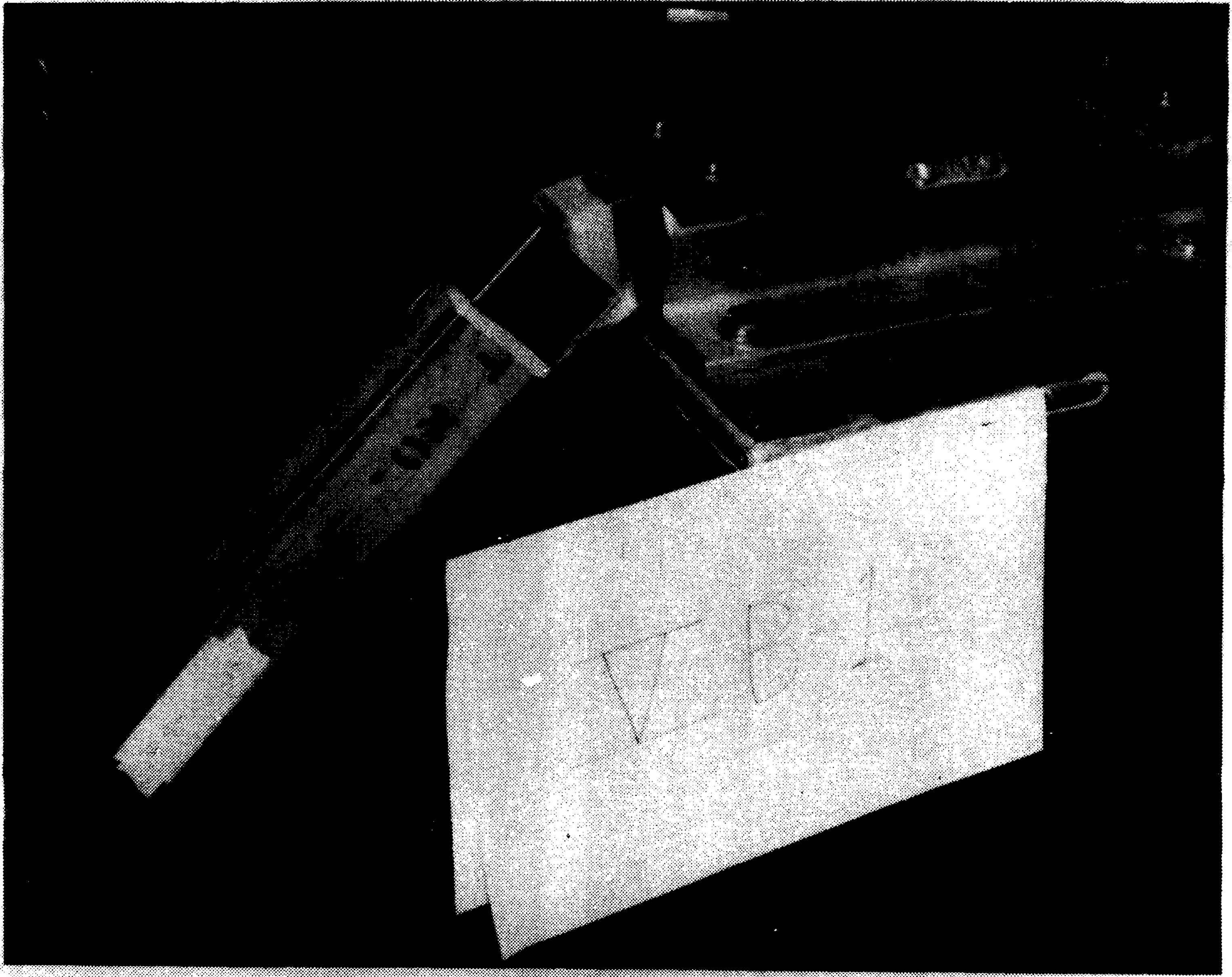


Figure 18. Impact Test Specimen V B-1

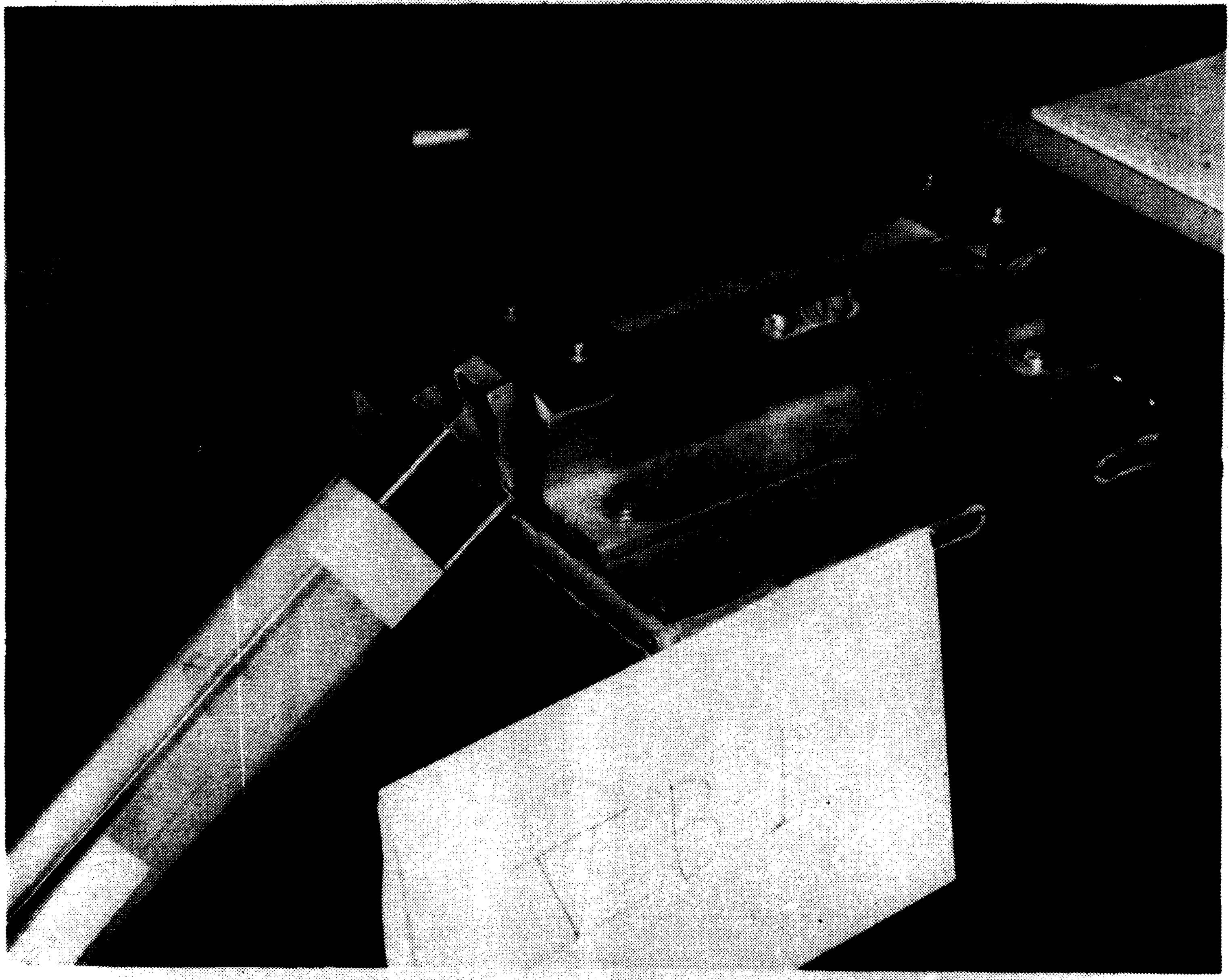


Figure 19. Impact Test Specimen V B-3

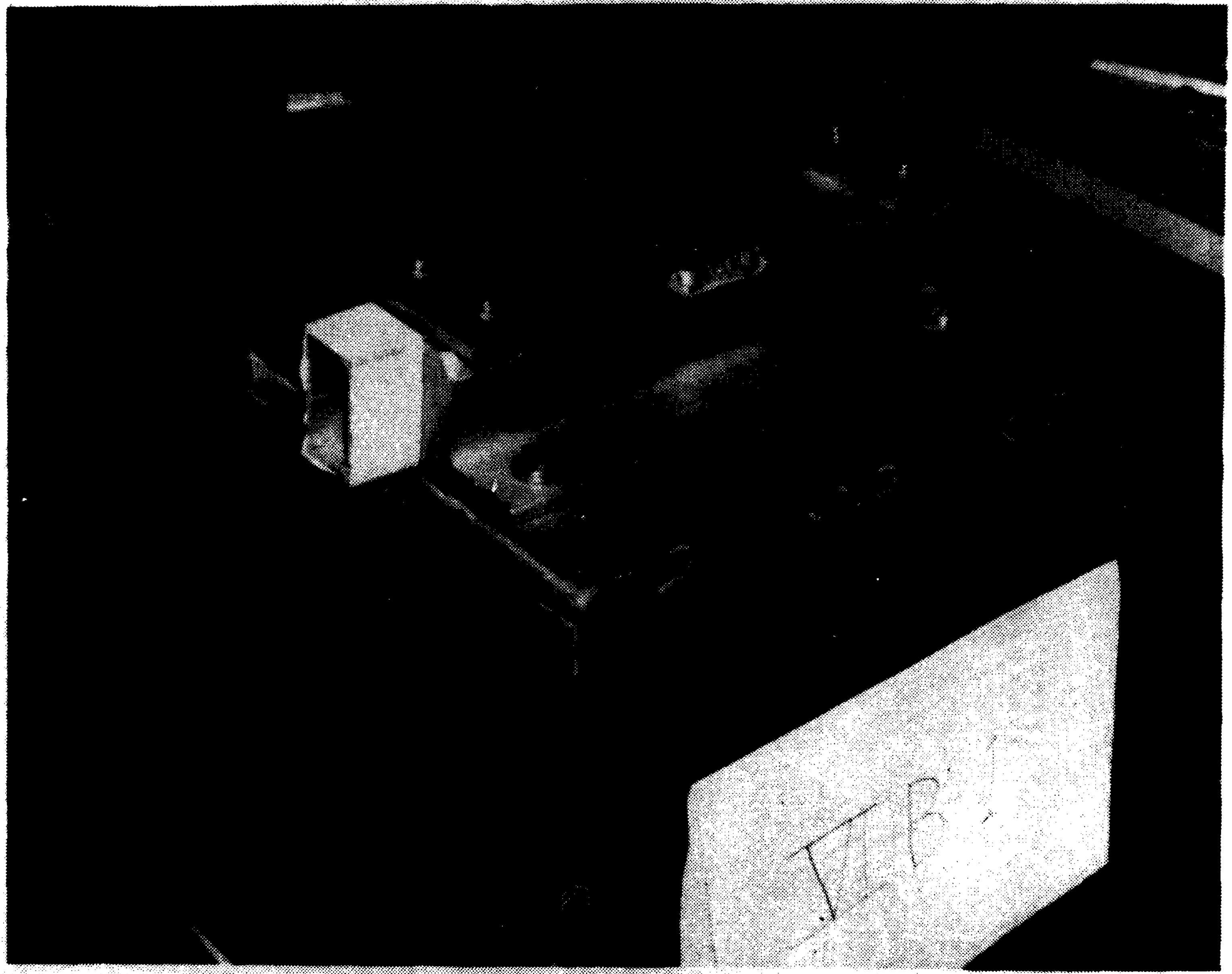


Figure 20. Impact Test Specimen VI B-1

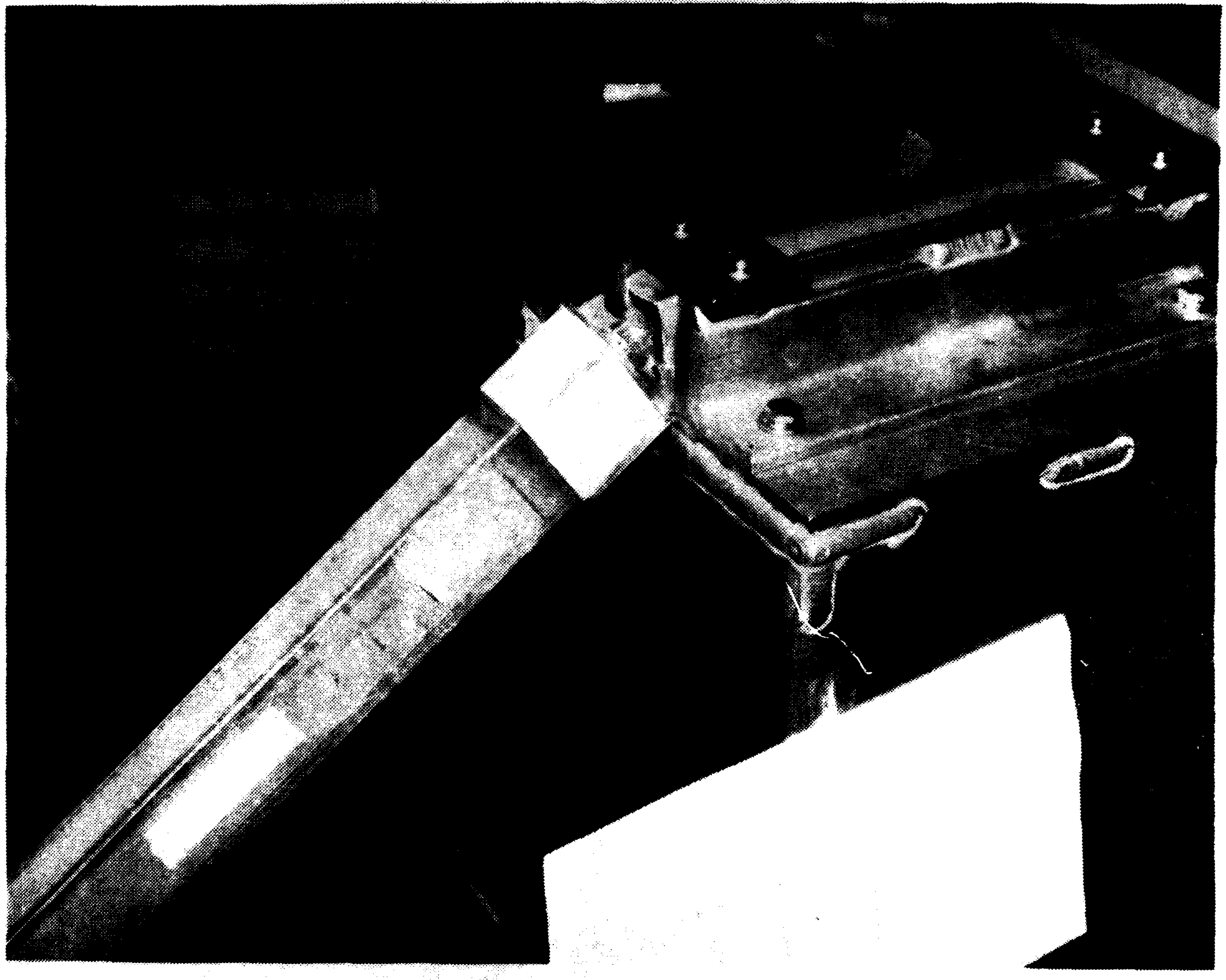


Figure 21. Impact Test Specimen VI B-2

3.3.2.1 INTERPRETATION OF REQUIREMENTS

Static wind load testing to failure was performed by the gradual application of weights to the equivalent center of pressure of the waveguide specimens clamped as cantilever beams, simulating the service conditions. Factors of safety were determined through comparison of the failure loads with the specified maximum survival wind load of a 150 mph jet blast (from Section 2.1.1). The actual load is determined from simple aerodynamic theory as a pressure of 0.70 lb/in^2.

3.3.2.2 TEST SET-UP

The waveguide specimen is rigidly clamped to the edge of a granite surface plate, one inch below the frangible joint. Load is gradually applied, via hanging weights, 28 inches from the clamping surfaces. See Figure 22 for a graphic description of the set-up.

3.3.2.3 TEST RESULTS

The static load test results, in the form of the load at point of failure, and the related factor of safety, is found in Table 4 for all frangible waveguide joint specimens and an unaltered control specimen.

4. CONCLUSIONS

4.1 GENERAL

This section will include a listing of the significant achievements accomplished during the period of this study program, plus some specific conclusions drawn from the design/test/evaluation efforts of specific component developments. It concludes with a general evaluation of the frangibility concept as applicable to MLS, and a listing of expressed concerns regarding the concept.

4.2 SIGNIFICANT ACHIEVEMENTS

a. Concept Development. The concept developed in the early phases of this study (the inverted AZ array), after close scrutiny, remains a viable concept. The concept drastically reduces mass (the upper 4½ feet of the antenna weighs approximately 100 lbs.) and provides a maximum degree of frangibility in a novel configuration, recognized as a design which can be practicably manufactured and which will likely maintain performance within spec limits.

b. Frangible Joints for AZ Waveguide Elements. Design of the frangible waveguide joint was quite successful. Impact tests of normal slotted waveguide elements made from WR-159 aluminum waveguide and supported at their bases cantilever fashion clearly demonstrated their unacceptability; conversely, using the frangible joints designed and built in response to the requirement showed generally very good results, with several designs meeting requirements. Static load tests showed the joints to have adequate strength to withstand survival wind loads.

The frangible element designs meet the design requirements on the basis of the test tesults described in sections 3.3.1.5 and 3.3.2.3. Since these tests are performed at a relatively low speed (approximately 7.7 kt), and since the inertial load increases with the square of the velocity, the full requirements may not be met. These results should be sufficient, however, since, in the case of frangible approach light supports, the same energy absorption was observed in high speed tests (at 69 kt) as in low speed drop weight tests similar to those performed here.

c. Design of the Support and Alignment Structure. Construction of this unit, and installation of the full complement of waveguide elements on it, generally verified the concept; the need for certain minor improvements was indicated in some areas.

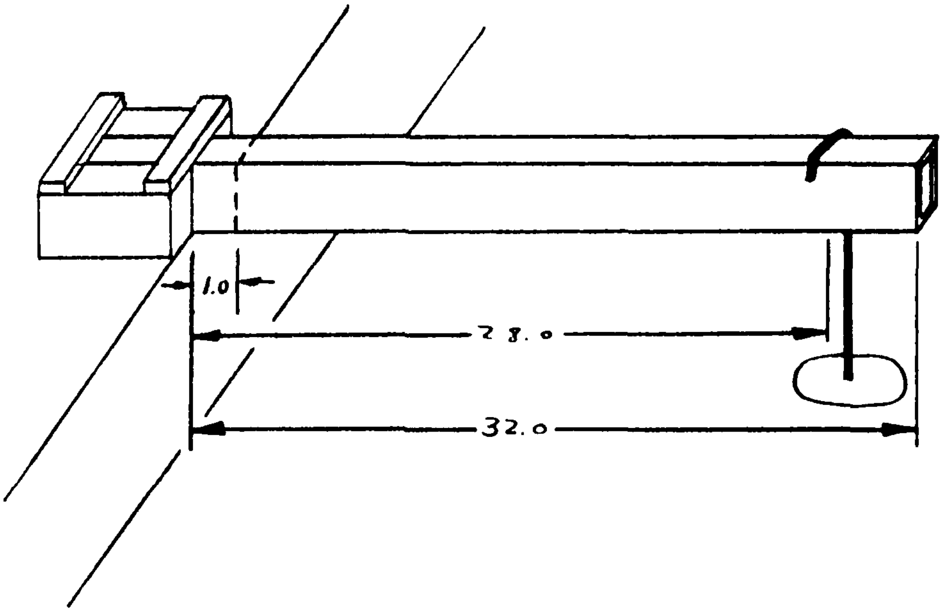


Figure 22. Static Wind Load Test Set-up

4.3 SPECIFIC CONCLUSIONS

a. Frangible Joints. Aluminum WR-159 is a suitable material when a frangible joint is incorporated into the waveguide. The preferred joint designs (based on the very limited number of test samples) are number III (see Figure 5, p. 12) overall, and number I if better conductivity is required. Design number VI might be more reliable than III, but more testing is required. Also, number V should be the best, more conductive design, but requires further development.

b. Adhesive Systems. The adhesive systems of preference are American Cyanamid 4533, one part epoxy for brittle applications, and Hysol EA 9320 for tough applications.

c. Waveguide Deflection. Elements made of standard WR-159 are not adequately stiff to withstand operating wind load without excessive deflection. Heavy wall waveguide (or locally reinforced special cross section waveguide) will have to be procured to meet the ultimate requirements.

d. Support and Alignment Structure. The support and alignment structure functions adequately to permit accurate alignment of the individual elements at time of assembly. Some local stiffening is required at the points of attachment to the underlying foundation beam, and strengthening/stiffening of the points of attachment of the waveguides.

4.4 GENERAL EVALUATION

The basic concept for an exposed, inverted AZ array, as proposed herein, incorporates the best engineering ideas to date regarding achievement of the frangibility goal; conceptually, there is not much more that can be done. Most of the constraints regarding the antenna design and site selection for the AZ antenna are non-negotiable. Aperture size (height and width) is a matter of physics, as is a line-of-sight requirement regarding site selection. Physical location of the site, and collocation with other

Navaids (approach lights, etc.) are inherent requirements. Tolerance of the ambient environment (winds, temperature extremes, etc.) is required by FAA specifications based on real-world situations. Finally, performance of the antenna (signal-in-space) is mandated by ICAO SARPs and various FAA regulations. None of these aforementioned requirements can be abridged.

Within these constraints, we have applied whatever techniques possible to provide a high degree of frangibility:

a. Antenna size and mass has been reduced drastically (by virtue of eliminating the antenna enclosure, and eliminating or relocating most of the associated electronics and the support structure).

b. Frangible joints have been incorporated into those few items that must remain on center line, and elevated well above the base of the antenna.

Inevitable comparisons will be made with frangible approach light configurations (where the pioneering work on frangibility has been done) and also possibly with ILS. When making comparisons, it must be remembered that MLS seeks to achieve accuracies of ±.05 degree, while approach lights are rather uncritical regarding their aiming. Also, each approach light weighs perhaps 2 pounds, while MLS (in prior configurations) has typically weighed 2000 pounds, so that expecting MLS to be equally frangible (as compared with an approach light) is not realistic. On the positive side, at a typical installation, there is only one very compact MLS, while there are at least ten groups of approach lights to collide with, spread over 1000 feet.

MLS is typically mounted two to four feet above the adjacent approach lights so that a slightly greater probability of being hit does exist. The most probable type of collision, in our judgement, would be a grazing collision involving the upper extremities of the antenna (as would occur on a low approach or a low rate-of-climb on take-off). The exposed, inverted array addresses that situation very well. The situation wherein an aircraft might strike the antenna at its base, however, is problematical, in that a greater mass exists here, plus a requirement for a high degree of structure rigidity. The problem of how much, if any, frangibility can be designed into this area has not been addressed.

Antenna elements four feet in length have been equipped with frangible joints which absord only 5 ft-lb of kinetic energy to break at impact. If, for example, we combine forty such elements (serving as a 3-degree antenna), the combined impact is only 200 ft-lb, yet less than the 700 ft-lb required in the FAA's frangibility requirement.* Please note, however, that the array is designed to permit breakaway of only a few elements, depending on how many are struck - a nose wheel of a single-engine plane, for example, would perhaps break out only 6 or 8 adjacent elements, leaving the remainder standing, thus absorbing only 30 to 40 ft lb of work.

In evaluating the concept and the test results, we would conclude that the inverted AZ array shows a great deal of promise. Much work remains to be done, however, before it can be declared a practical solution to the frangibility problem. Specific areas of concern include the following:

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*The specification, FAA-ER-530-81-04, states only that "the breakaway mechanisms (joints, etc.) of the structure shall be designed to separate at a peak force no higher than 5700 pounds acting for approximately 8 milliseconds, and absorbing no more than 700 ft-lb of energy". Treating each of the 40 waveguides as a frangible unit, we could apply 40 x 700, or 28,000 ft-lb. as the impact load for the entire array; this, of course, would not really address the spirit of this specification, and would seriously impede the aircraft. This statement in the spec needs some clarification and elaboration.

(a) Feeding R.F. to the inverted array.

(b) Practicability of the exposed element; precipitation (radome problems), response to wind, sun, etc.

(c) Development of a frangible radome/enclosure as an alternative for item (b). (This might sacrifice some degree of frangibility, but would enhance environmental tolerance.)

(d) Durability of the frangible waveguide joint in a real-world environment, will it fail from daily exposure to varying wind gusts, etc.?

(e) Design for accessibility – Can the concept of mounting all the antenna electronics at the base be made consistent with reasonable accessibility for maintenance?

(f) Underground (or remotely-located) support electronics – Is the concept of a ground level (or possibly below ground) electronics box (as would house the transmitter, UPS, timing, control, and monitor equipment) feasible and practical? Can the equipment, thus located, be serviced without undue hardship and with adequate safety? Can the equipment be made to withstand the constant high humidity expected for a below-ground installation?

(g) If frangibility is to be addressed at levels below the frangible joint on the AZ array, the support structure (and array electronics) needs to be studied in detail in this regard. Also, more critically perhaps, the design of frangible tower supports (for sites where the MLS antenna would have to be mounted well above ground level) needs to be considered.

In enumerating these various concerns, there is no intention of impugning the feasibility of the concept. Rather, it is a list of tasks to be addressed in proceeding with development. In the section to follow, a specific plan is proposed as a recommendation for development of a frangible version of the MLS AZ antenna. (The use of the frangible version, in all probability somewhat more expensive than the non-frangible version, would have to be invoked only at those locations where MLS AZ would be located within the first 1000 feet beyond the runway end.)

5. RECOMMENDED COURSE OF ACTION

Having completed this first phase of study, where a viable concept has been developed and where the basic design of frangible antenna elements has been substantiated by construction and test, we would propose a second phase of study and feasibility demonstration, consisting of the following tasks:

(a) Investigate further the mechanics of wind loading on the exposed, inverted array, including any oscillatory effects such as might result from Von Karman forces.

(b) Perform various tests on the array support and alignment structure (the mechanical prototype of which was built during the current phase). Conduct loading tests to determine static stiffness, and to assure that failure of the frangible elements would occur well before any failures in the support. Conduct wind tunnel tests to determine actual loads imposed by (1) operating wind loads, (2) survival wind loads, and (3) jet blast loads. Update the design as appropriate based on test results.

(c) Design and test a method of feeding the inverted element, maintaining performance regarding underside cut-off, maintaining insertion loss within appropriate limits, and minimizing insertion phase variations, element-to-element.

(d) Look further into strain-rate sensitive materials, particularly the non-metallics, to determine whether a better element (or better frangible joints) could be built.

(e) Refine the current design of the frangible waveguide joint, and build and test a pilot group of joints (1) to establish repeatibility of impact fracture data and (2) to verify endurance under varying environmental loads (winds) at levels less than those where fracture would be expected (fatigue considerations). Evaluate also any effects of high and low temperature, humidity, and aging.

(f) Experiment with the exposed-element concept, with a goal of developing a covering for the single-slotted waveguide which would shed moisture (including ice and snow) to the extent that required antenna performance would be maintained within limits, regardless of the types and rates of precipitation.

(g) Pursue development of a plated dielectric waveguide element, where the slots would be etched into the inside layer of the plating, without disturbing the structural integrity of the composite waveguide, thus permitting the waveguide to remain airtight. The resulting element would be inherently frangible due to the nature of the material.

(h) Complete the development of a clamping/alignment device to be used along the upper edge of the array (a device necessary to prevent independent deflection of the waveguides under environmental loading, yet permit individual elements to be impacted separately and broken away, without substantially adding to the loads required to break the frangible joint at the base).

(i) Design, build, and test a working breadboard AZ array based upon the support and alignment structure built during the current phase, using surplus components from previous MLS projects. The intent would be to build an array which could be electrically tested, with some long term testing to determine performance as a function of environmental exposure (e.g., will it retain accuracy in high winds, under sun loading, in blowing snow. etc.).

(j) Study further the possibilities of incorporating some frangibility measures into the design of the support and alignment structure.

(k) Develop a specific configuration for a ground-level enclosure housing the supporting electronic equipment (transmitter, power supply and UPS batteries, and the timing/control/monitor unit). Consider also the effects of mounting this enclosure below ground, the top flush with the ground surface. Conduct a data search to learn from the experiences of others in dealing with at or below, ground installations. Consult with FAA maintenance personnel to obtain design guidance.

(l) Study the feasibility of a frangible radome/enclosure to cover the inverted array as an alternative to the exposed array concept. The front face of the enclosure (as a minimum) would have to be RF-transparent, serving as the radome. (If such an alternative were to be used, the design of the array itself would be significantly simpler since the enclosure shields the individual elements from the wind and jet blast loads; the waveguide elements could be made much lighter, and the frangible joints yet weaker.)

(m) Depending on the outcome of the feasibility investigation in item (l), build all or all appropriate parts of a frangible enclosure to further evaluate practicability. Make tests as appropriate, both RF tests and impact tests.

(n) Do some preliminary investigation into the feasibility of the development of a three-dimensional tower using frangible joints. Consult with both the developers of the frangible approach light poles, and various tower manufacturers. It should be noted that frangibility work thus far has been limited to two-dimensional devices.

(o) Work out the details of the enclosure housing, the support and alignment structure, and the array electronics, especially how to accomplish a weather seal at the points where the exposed waveguide elements protrude from the base enclosure.

(p) Perform a cost analysis to determine the overall cost impact of achieving frangibility.

A third phase, in the logical progression of development, would be the design and construction of a prototype array, for actual use in tests at an airport. This development would be based upon the developments resulting from phase 2. Also, development and construction of a frangible tower might be considered during this phase, and/or frangibility modifications to the base of the inverted array.

APPENDIX A

IMPACT TESTING DOCUMENTATION

STATEMENT OF WORK

IMPACT TESTING OF FRANGIBLE MLS ANTENNA STRUCTURAL COMPONENTS INVERTED AZIMUTH ARRAY WAVEGUIDES

Bendix, in the business of building developmental microwave landing systems for aircraft for the FAA and military customers, is currently contracted to research and design a frangible Azimuth antenna, one of the major components of an airport ground system. Due to the empirical nature of impact dynamics, prototype testing is an important input to the design. It is currently foreseen that, as a design detail, one of several break-away mechanisms will be incorporated into the waveguide elements, the primary functional and structural components of the inverted Azimuth antenna array as currently designed. These tests will be conducted to determine the amount of energy which the break-away mechanisms will absorb upon impact to total failure. It is the purpose of this document to solicit input on the feasibility, scheduling, and cost of such testing.

The equipment used must be a drop-weight type impact tester generally in accordance with ASTM E208-75, with the exception that the minimum kinetic energy of the impact head at time of contact shall be 1800-foot pounds. The impact tester should be of the approximate configuration described in Figure 1 or equivalent to Dynatup Model 8100 from Effects Technology, Inc., Santa Barbara, California. Its instrumentation needs to include an instrumented tup with continuously recording measurement equipment. The equipment must provide histories of loading and energy absorption during the impact event as well as a means to determine the velocity and kinetic energy of the impact head at the time of first contact and the peak force applied in the impact.

The test set-up, as described in Figure 1, will have the specimen held as a cantilever with the break-away joint being centered one inch away from the support fixture. The fixture will be positioned so that the tup will strike the specimen at a point twelve inches beyond the center of the break-away joint. All fixturing can be designed and fabricated by Bendix with input from the testing organization.

The total quantity of tests to be performed will depend somewhat on the results. The first session in late June 1982 will consist of 8 to 12 specimens, with one or two more similar sessions to follow in 1982.

Please respond as soon as possible to my requirements with price and scheduling information. An informal quote will be sufficient.

Paul D. Wienhold

Paul D. Wienhold, 11 May 1982
The Bendix Corporation
Communications Division
1300 East Joppa Road
Baltimore, Maryland 21204
A/C 301-583-4277

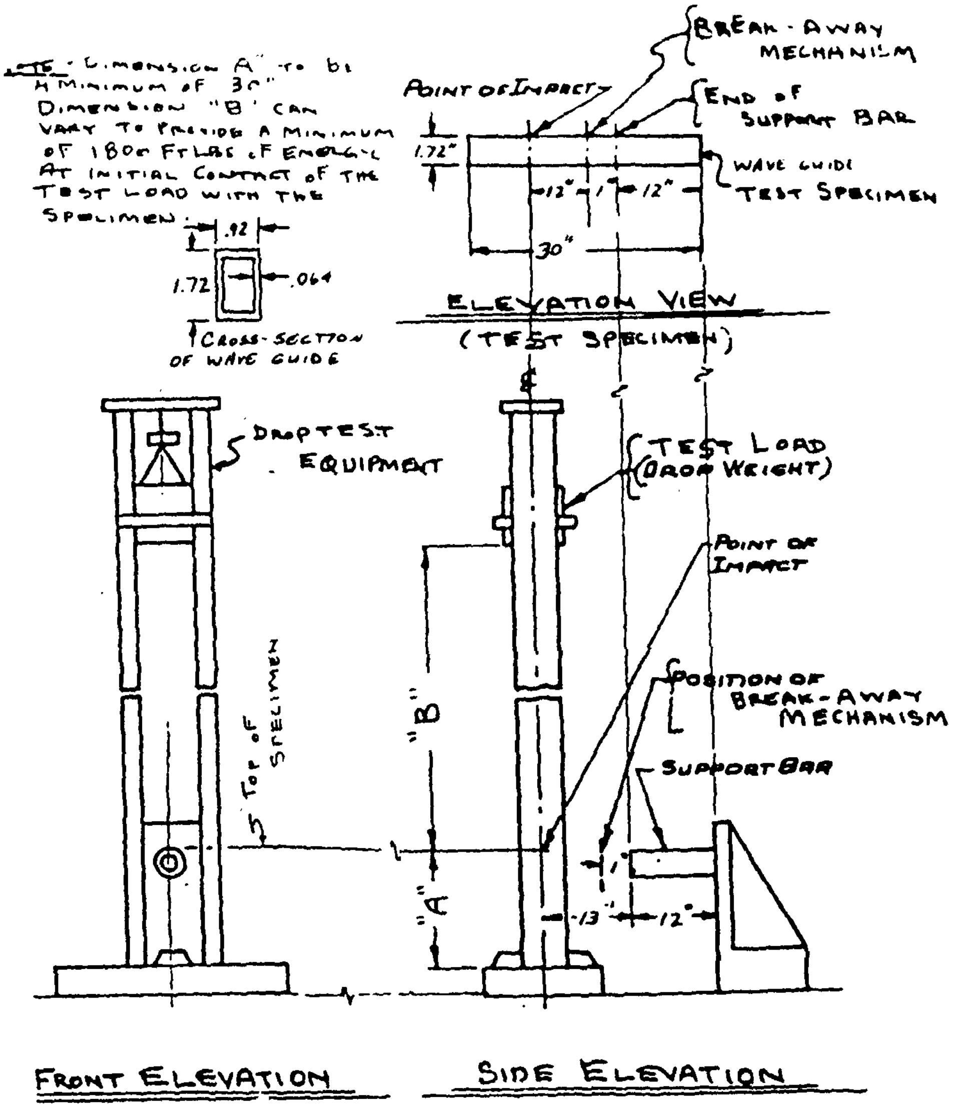


Figure B1. Typical Impact Test Set-up

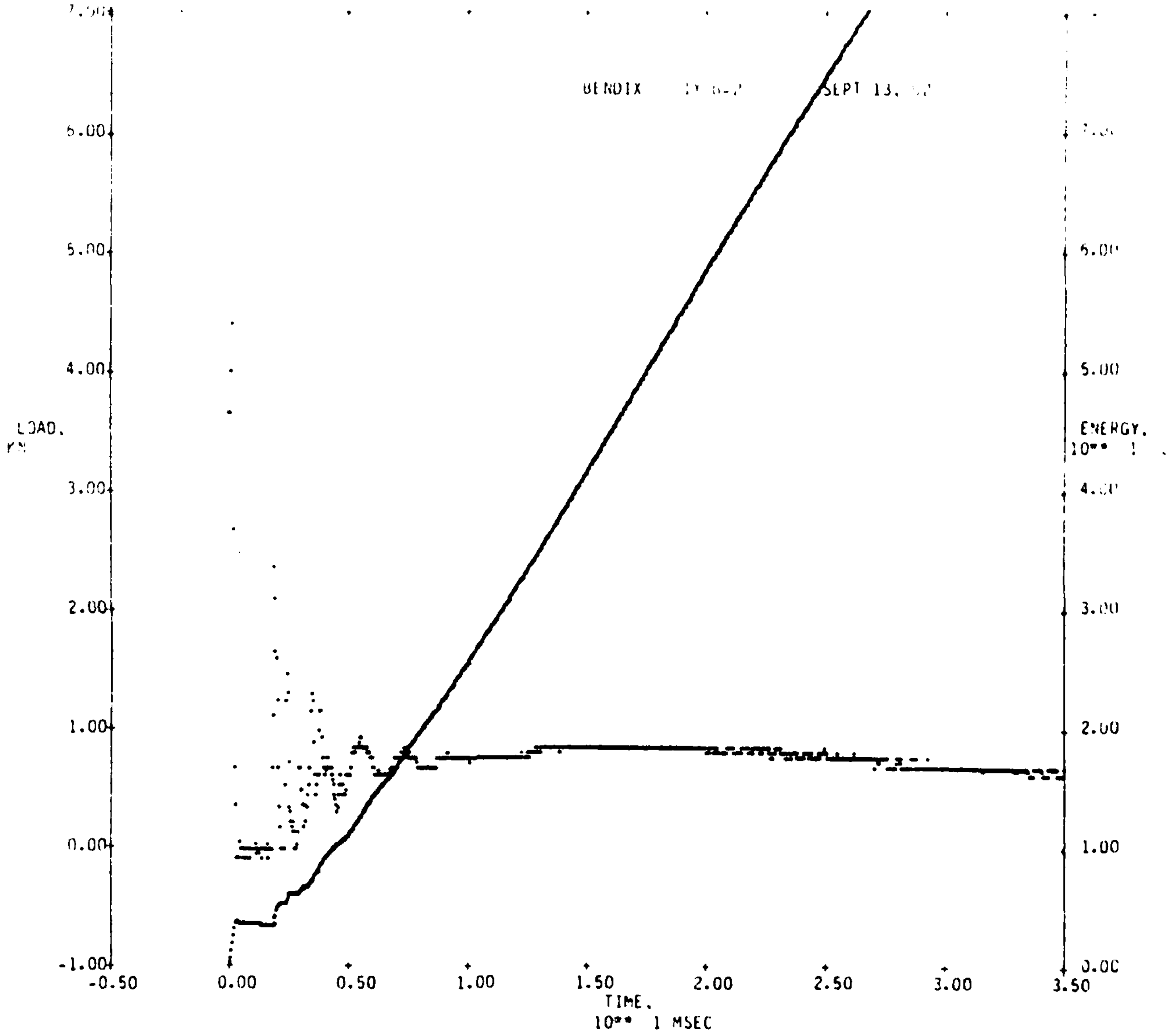
```
COMMAND MAY BE ENTERED
?*NEW
*****TEST NO. 19******
LOAD RANGE=    20.00 KN
WEIGHT=   238.29 KG
5. EXPECTED TOTAL TEST TIME(MS)-    .200000E+02
?
6. REQUIRED DELAY(MS)-    .000000E+00
?
TEST MAY BE RUN
ENTER RETURN WHEN READY
?
TEST COMPLETE
8. SPECIMEN ID-  VI B-2      VII B -1
9. TEST TEMP(C )  .230000E+02
?
COMMAND MAY BE ENTERED
?*STN
DATA STORED
COMMAND MAY BE ENTERED
?*ANA
AUTO MAX LOAD?- YES
?
COMPUTE YIELD/FRACTURE QUANTITIES? NO
?
REPEAT ANALYSIS QUESTIONS?
?NO
COMPUTING
COMMAND MAY BE ENTERED
?*PLO
PLOT VS. DEFLECTION?  NO
?
PLOT YIELD/FRACTURE QUANTITIES?  NO
?
AUTO SCALING?  NO
?
INIT TIME(MSEC)?-0.200000E+01
?
UNITS/DIVISION? 0.200000E+01
?
INIT LOAD(KN)?-0.100000E+01
?
UNITS/DIVISION? 0.100000E+01
?
INIT ENERGY( J    )? 0.000000E+00
?
UNITS/DIVISION? 0.500000E+01
?
REPEAT PLOT QUESTIONS?
?
REPEAT PLOT QUESTIONS?
?
REPEAT PLOT QUESTIONS?
?
REPEAT PLOT QUESTIONS?
?NO
```

Sample Printout
of Interactive
Mode of
Data Analysis

APPENDIX B

LOAD AND ENERGY ABSORPTION DATA FROM IMPACT TESTS

(S/Ns Per Table 4 and Figure 5)



TEST	TEMP	IMPACT VELOCITY	ENERGY	TIME.10** 1 MSEC		LOAD.10**-3KN	ENERGY.10** 1 J		
	C	M/S	J	INIA	TOTAL	MAX	INIA	PROP	TOTAL
IX B-2	23.0	3.99	1898.42	0.01	3.99	4375	0.2	11.3	11.5

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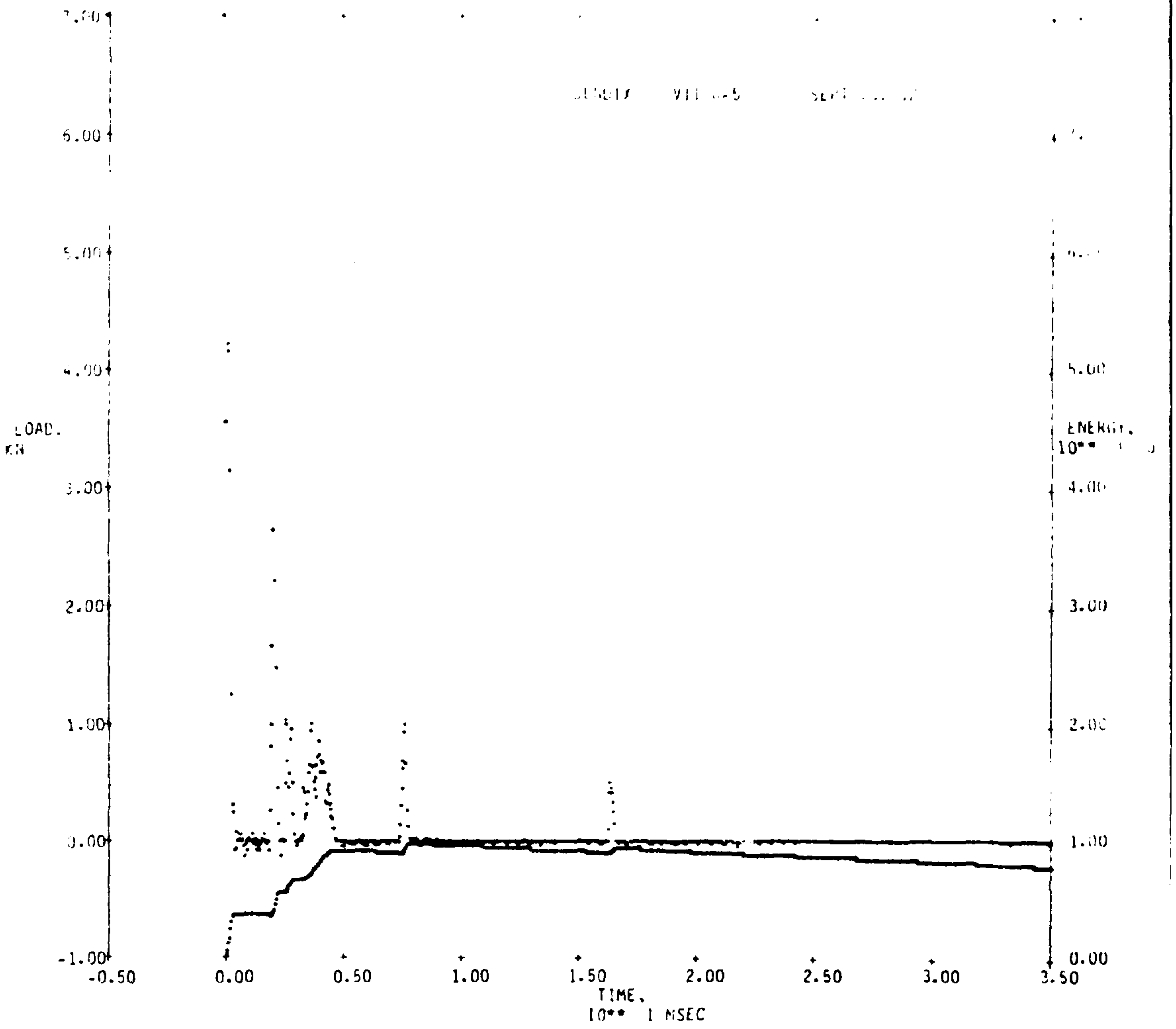

TEST	TEMP C	IMPACT VELOCITY M/S	ENERGY J	TIME.10** 0 MSEC INIA	TIME.10** 0 MSEC TOTAL	LOAD.10**-3KN MAX	ENERGY.10** -1 J INIA	ENERGY.10** -1 J PROP	ENERGY.10** -1 J TOTAL
VII B-5	23.0	3.95	1862.89	0.11	7.81	4218	16.4	80.1	96.5

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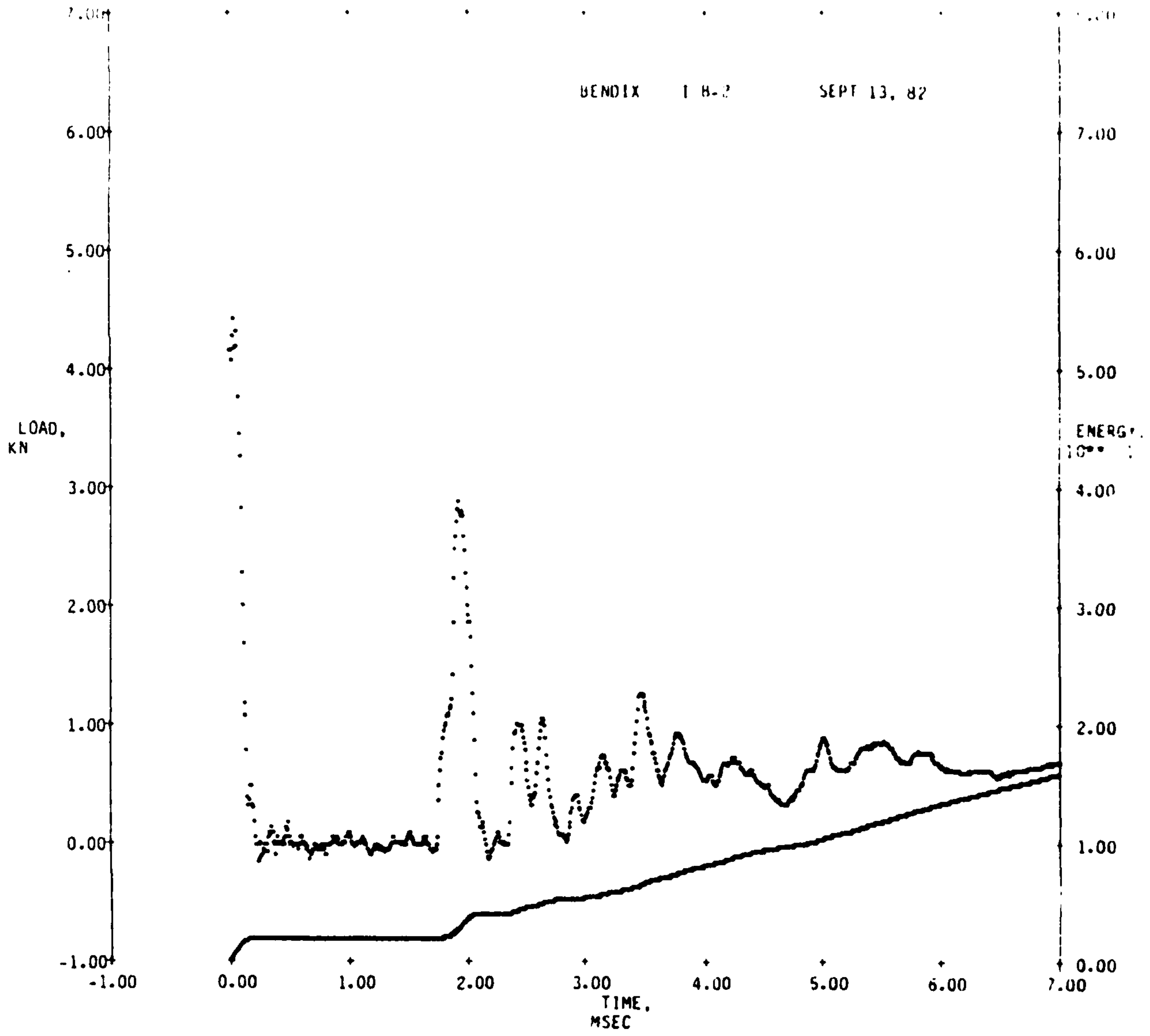
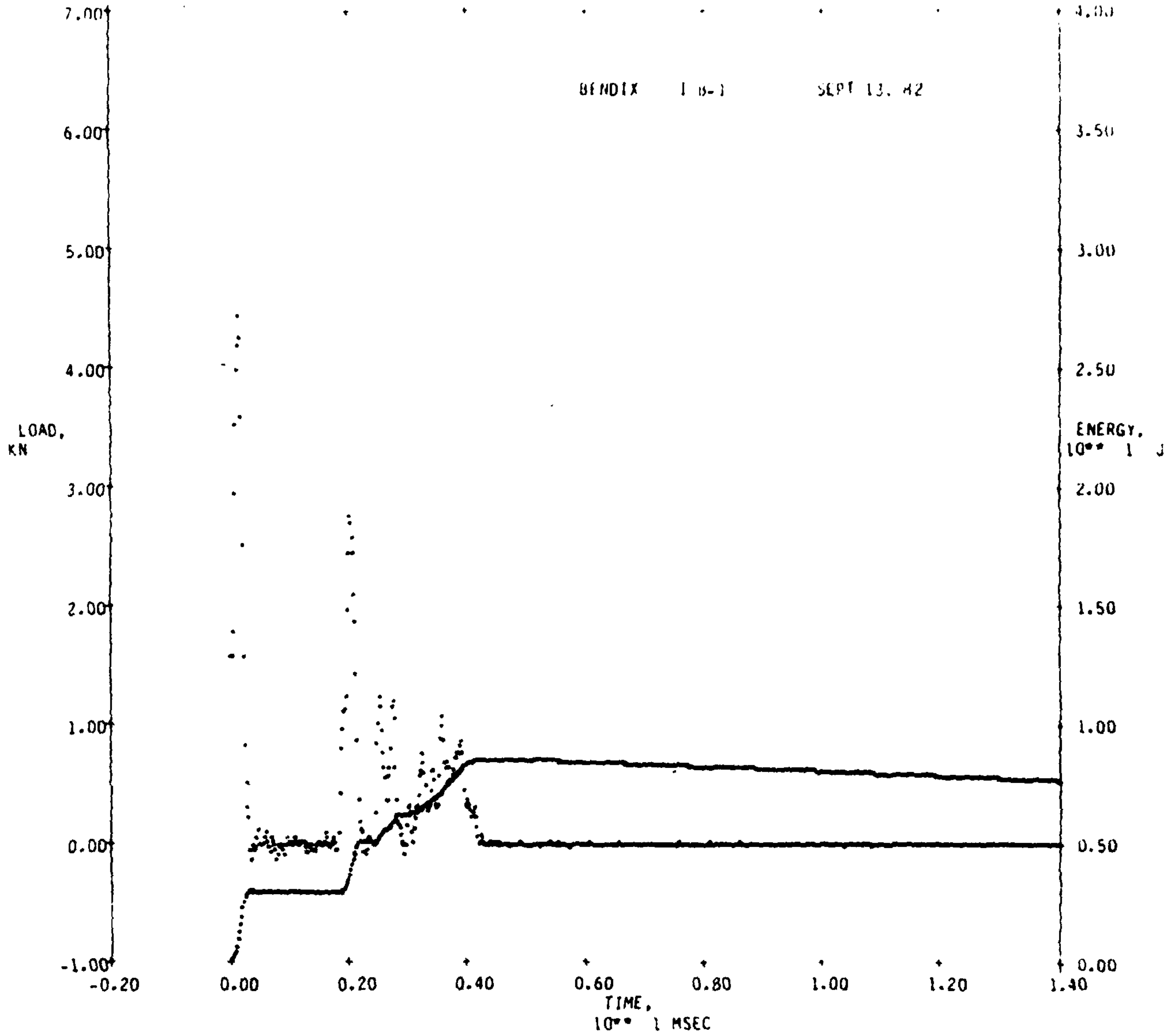
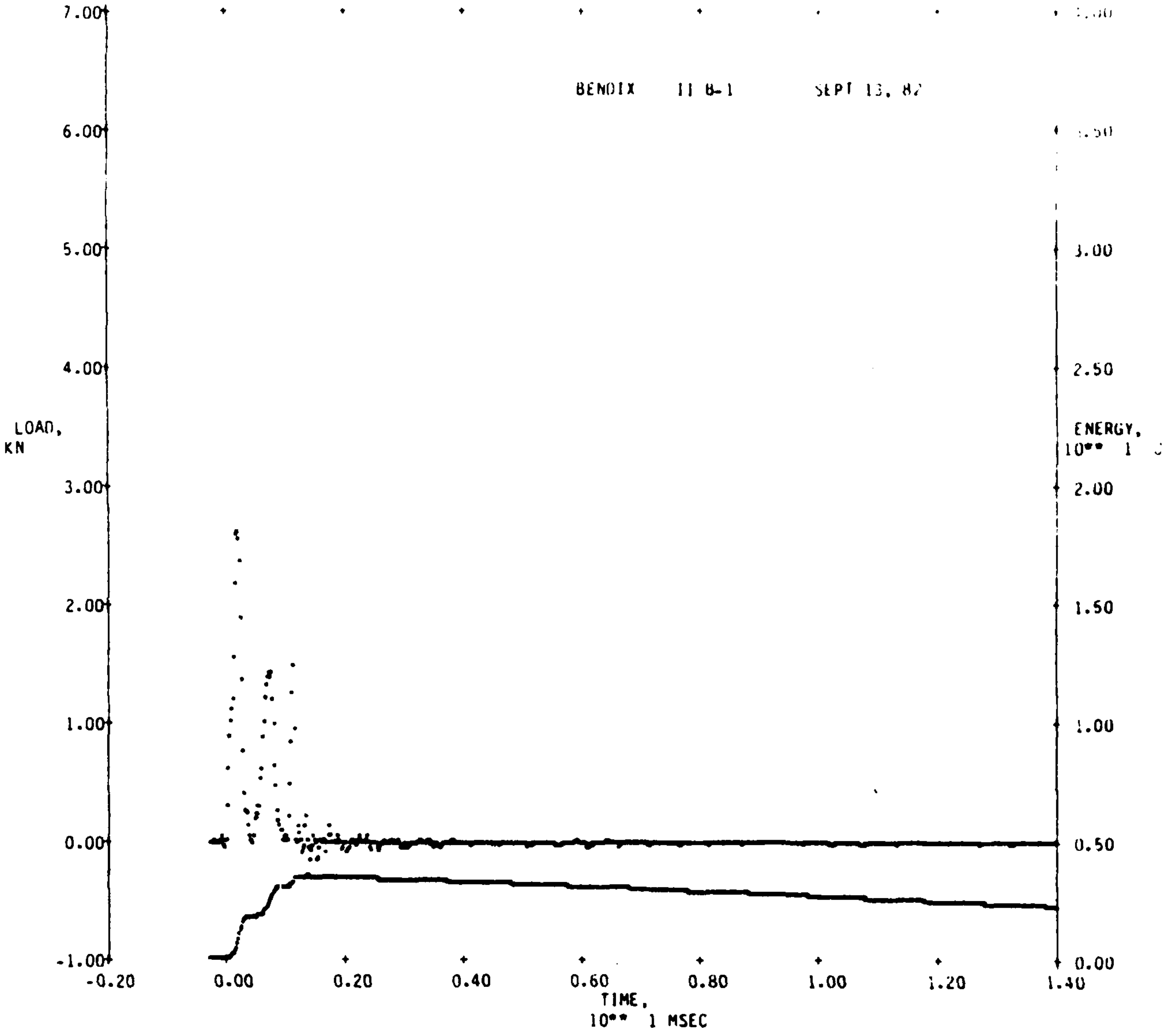


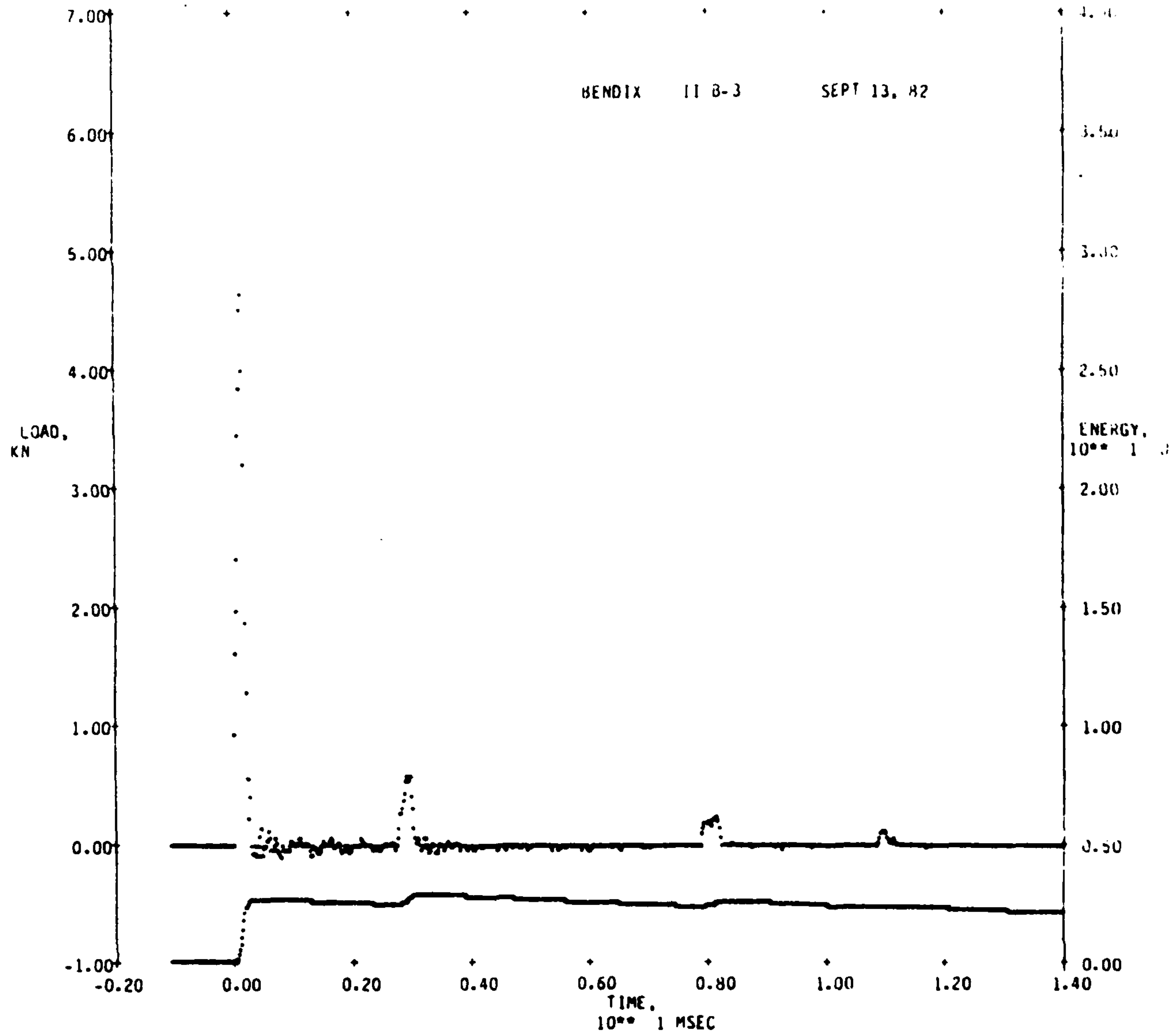
		IMPACT							
	TEMP	VELOCITY	ENERGY	TIME,10** 0 MSEC		LOAD,10**-3KN	ENERGY,10** 0 J		
TEST	C	M/S	J	INIA	TOTAL	MAX	INIA	PROP	TOTAL
I 8-2	23.0	3.95	1862.89	0.03	7.98	4433	0.6	18.0	18.7



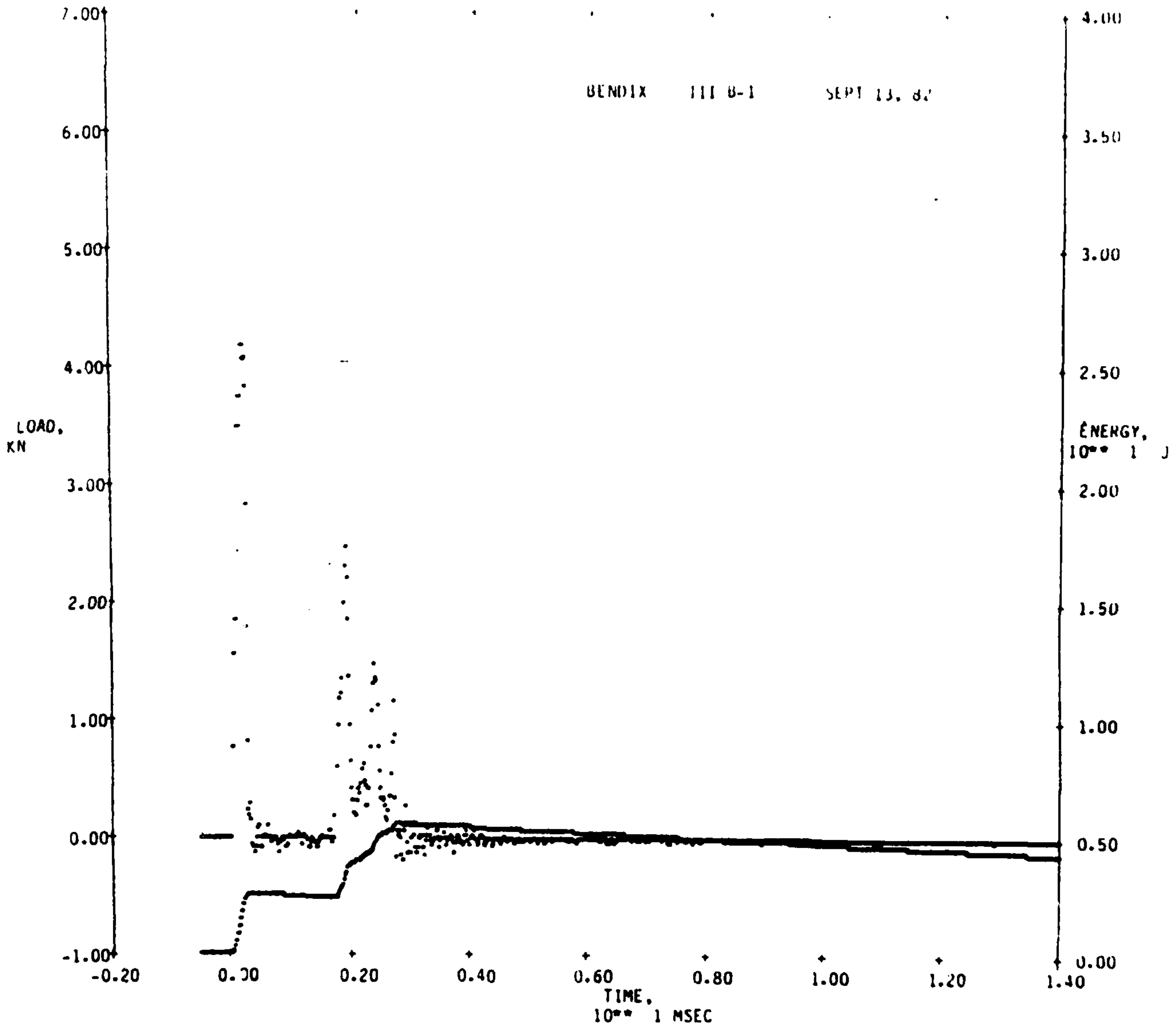
```
                   IMPACT
          TEMP   VELOCITY  ENERGY  TIME,10**  0 MSEC  LOAD,10**-3KN   ENERGY,10** -1 J
 TEST      C       M/S      J          INIA   TOTAL        MAX        INIA   PROP   TOTAL
I B-1     23.0     3.93  1845.50      0.15    4.31        4453        16.2   69.0    85.2
```



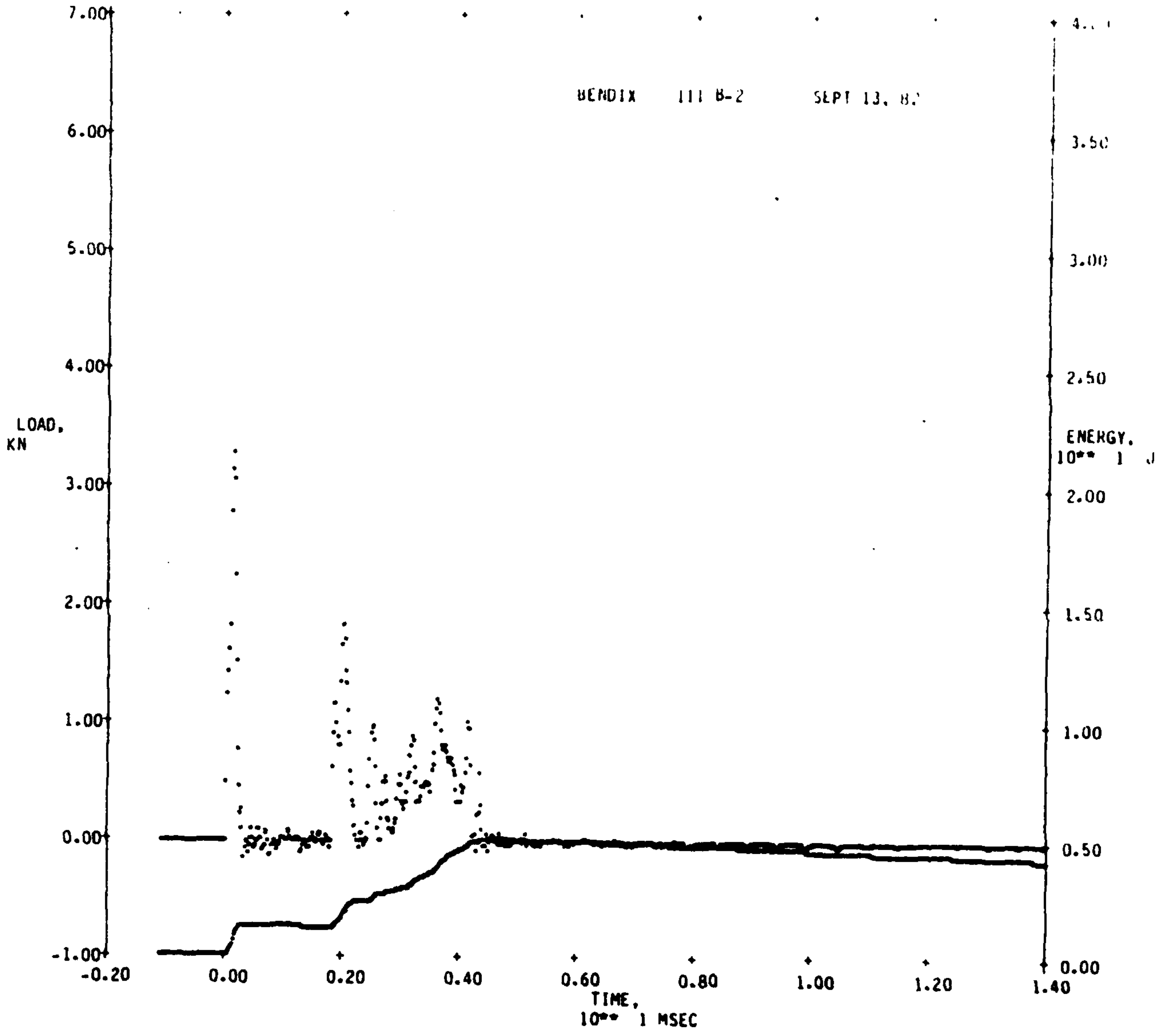
		IMPACT							
	TEMP	VELOCITY	ENERGY	TIME,10**	0 MSEC	LOAD,10**-3KN	ENERGY,10**	-1 J	
TEST	C	M/S	J	INIA	TOTAL	MAX	INIA	PROP	TOTAL
II B-1	23.0	3.91	1828.36	0.19	1.38	2617	8.7	26.7	35.4



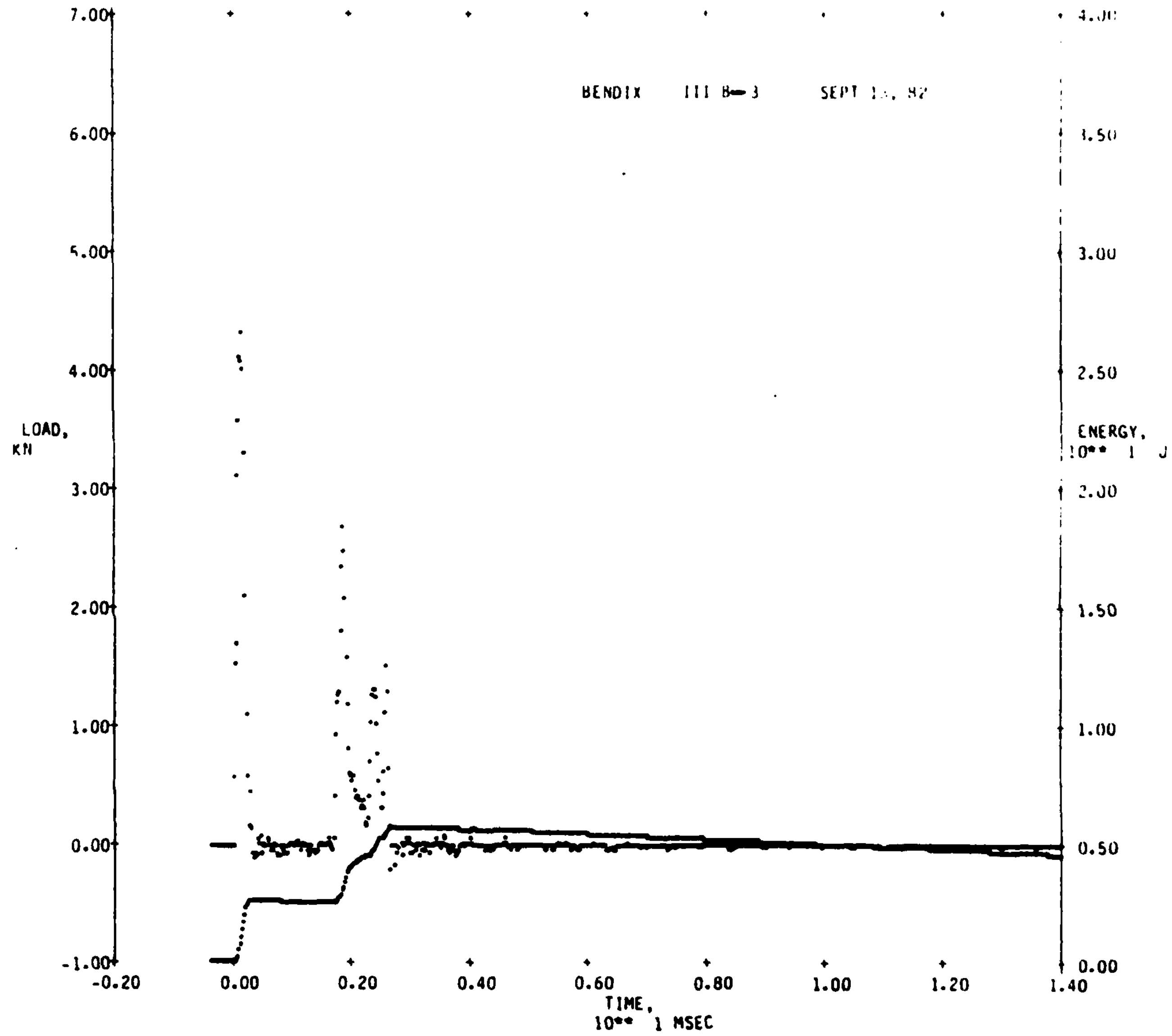
TEST	TEMP C	IMPACT VELOCITY M/S	ENERGY J	TIME,10** 0 MSEC INIA	TOTAL	LOAD,10**-3KN MAX	ENERGY,10** -1 J INIA	PROP	TOTAL
II B-3	23.0	3.95	1862.89	0.15	3.12	4628	14.4	14.3	28.8



TEST	TEMP C	IMPACT VELOCITY M/S	ENERGY J	TIME,10** 0 MSEC INIA	TOTAL	LOAD,10**-3KN MAX	ENERGY,10** -1 J INIA	PROP	TOTAL
III B-1	23.0	3.9[illegible]	1828.36	0.11	2.73	4179	8.6	46.6	55.3



```
                  IMPACT
           TEMP  VELOCITY  ENERGY  TIME,10**  0 MSEC  LOAD,10**-3KN   ENERGY,10** -1 J
  TEST      C      M/S      J         INIA    TOTAL       MAX        INIA   PROP   TOTAL
 III B-2   23.0    2.78   922.45      0.15    4.41        3281        6.7   43.5    50.3
```



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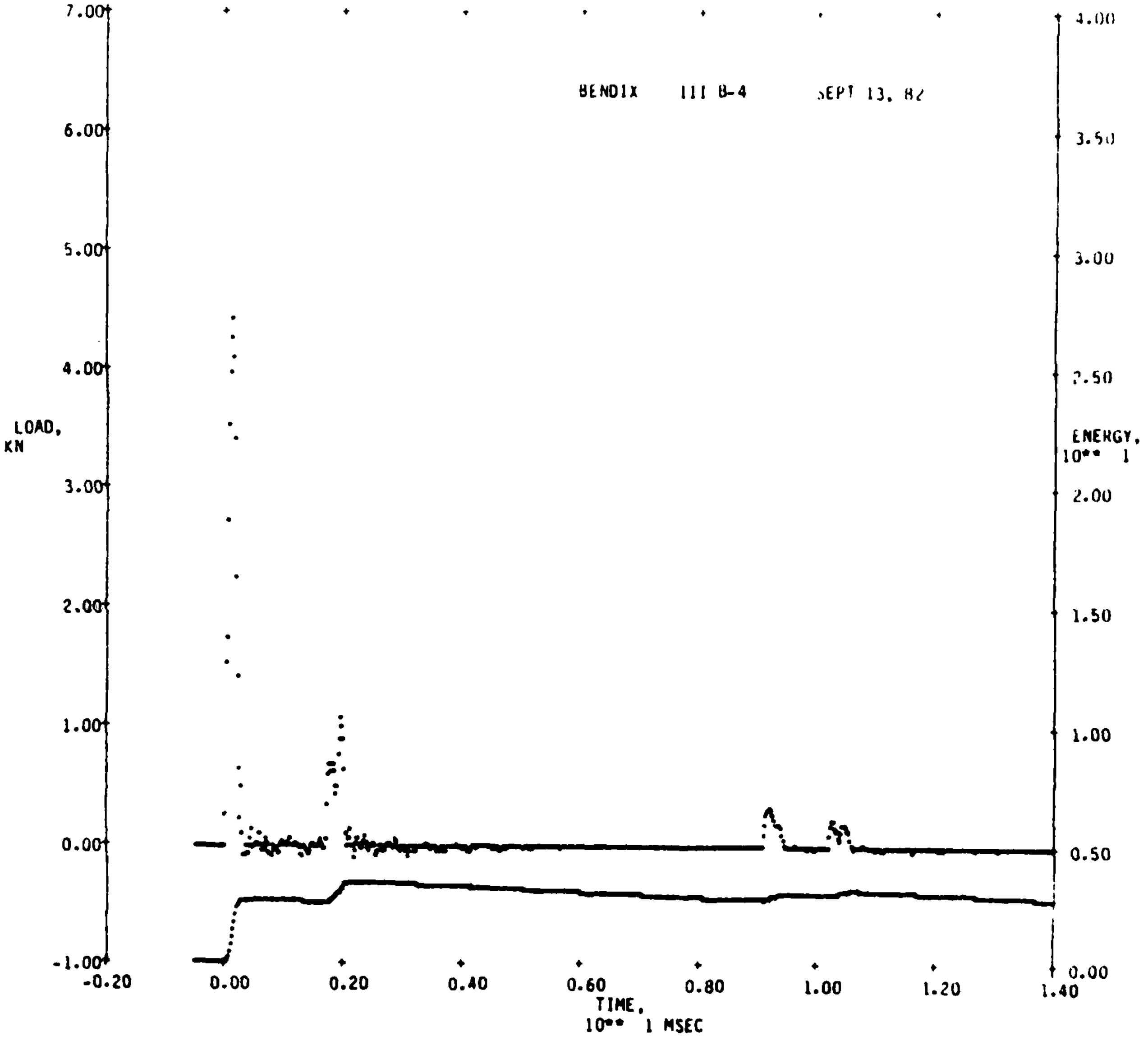
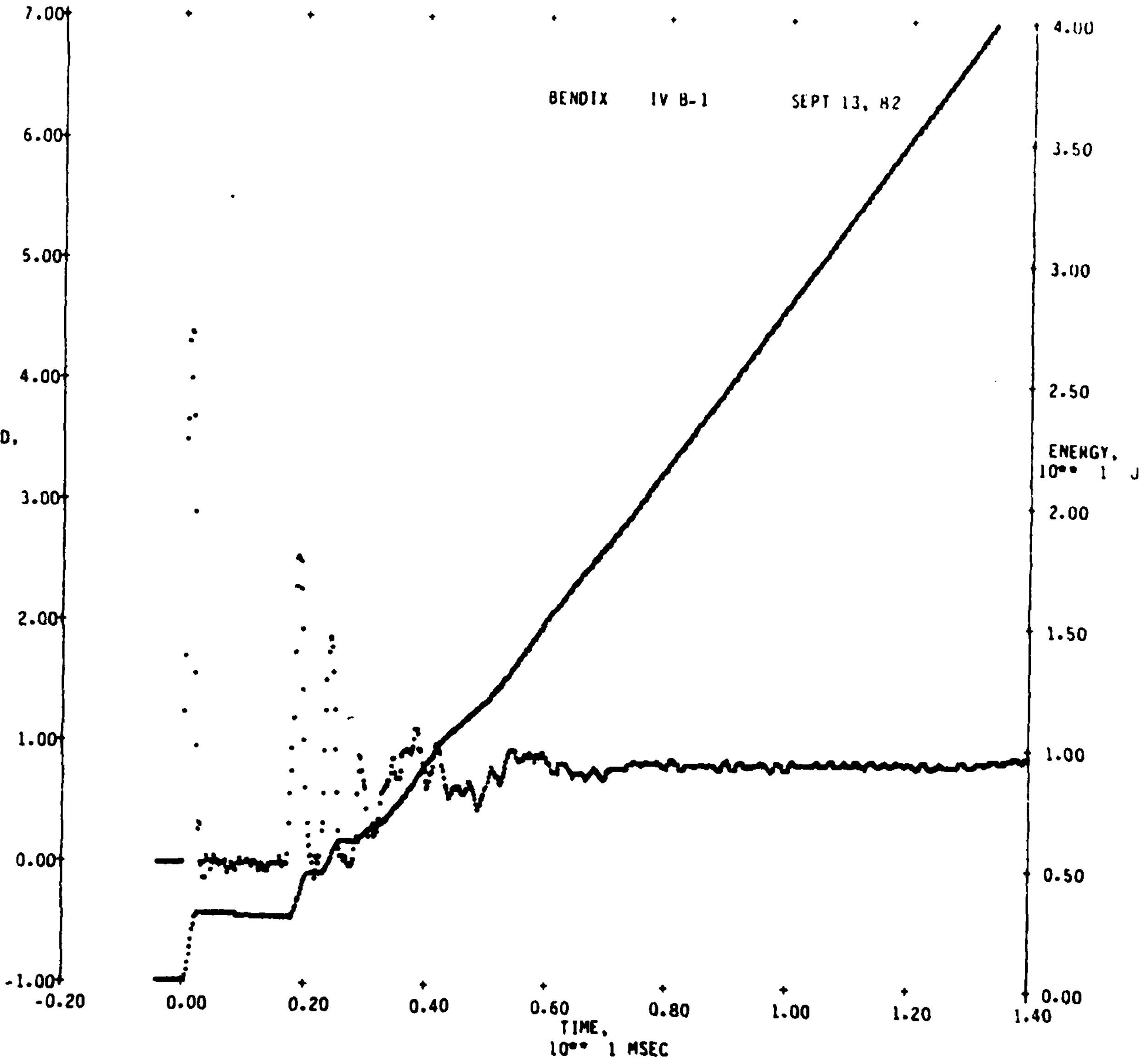
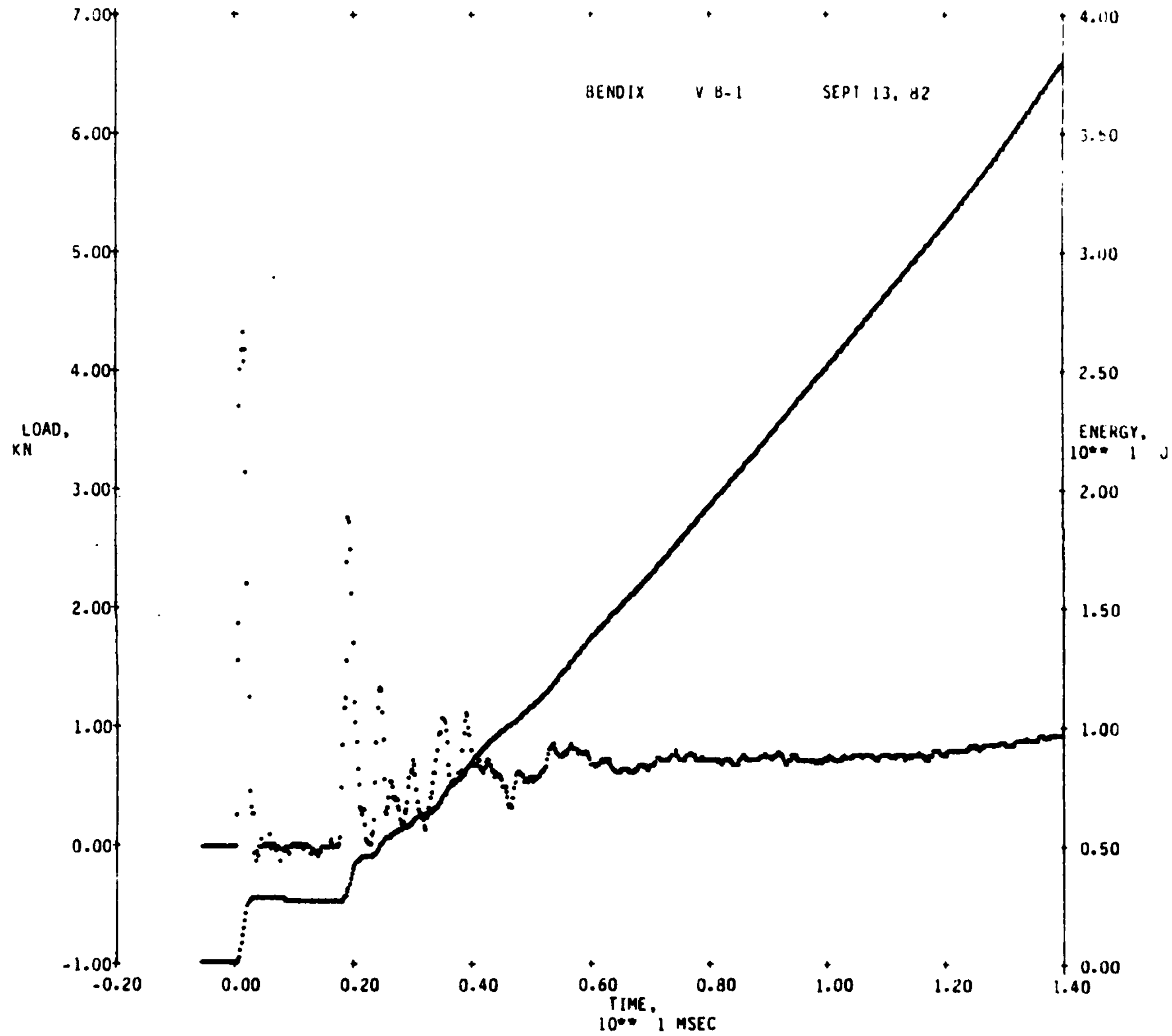
                  IMPACT
           TEMP  VELOCITY  ENERGY  TIME,10**  0 MSEC  LOAD,10**-3KN   ENERGY,10** -1 J
  TEST      C      M/S      J           INIA   TOTAL        MAX       INIA  PROP  TOTAL
III B- 3   23.0     3.93  1845.50       0.15    2.65        4316      14.3  43.0   57.3
```



TEST	TEMP C	IMPACT VELOCITY M/S	ENERGY J	TIME,10** 0 MSEC INIA	TOTAL	LOAD,10**-3KN MAX	ENERGY,10** -1 J INIA	PROP	TOTAL
III B-4	23.0	3.93	1845.50	0.15	2.14	4433	13.7	20.5	34.3



	TEMP	IMPACT VELOCITY	ENERGY	TIME,10** 1 MSEC		LOAD,10**-3KN	ENERGY,10** 0 J		
TEST	C	M/S	J	INIA	TOTAL	MAX	INIA	PROP	TOTAL
IV B-1	23.0	3.99	1898.42	0.01	1.95	4375	1.4	61.7	63.2



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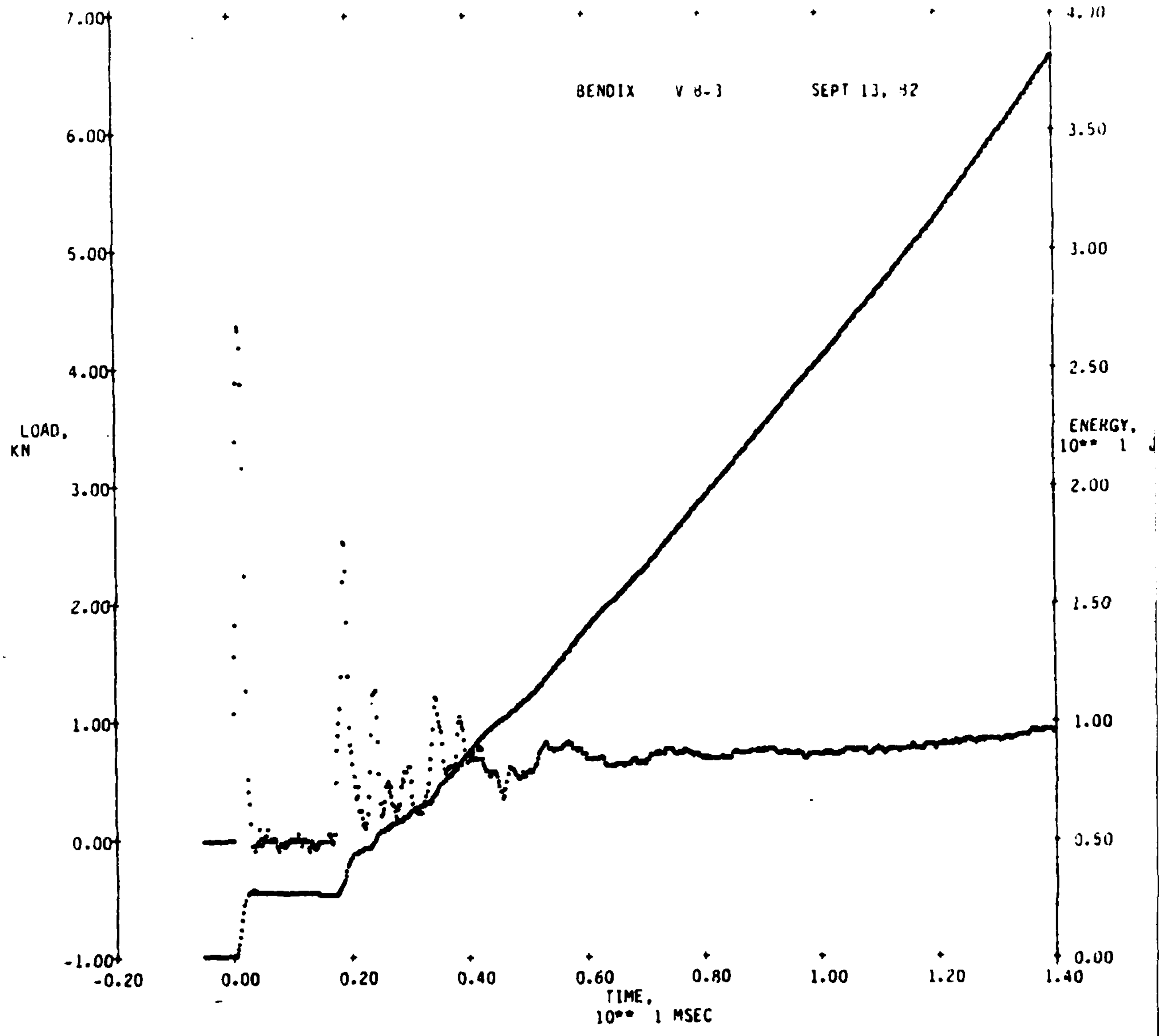
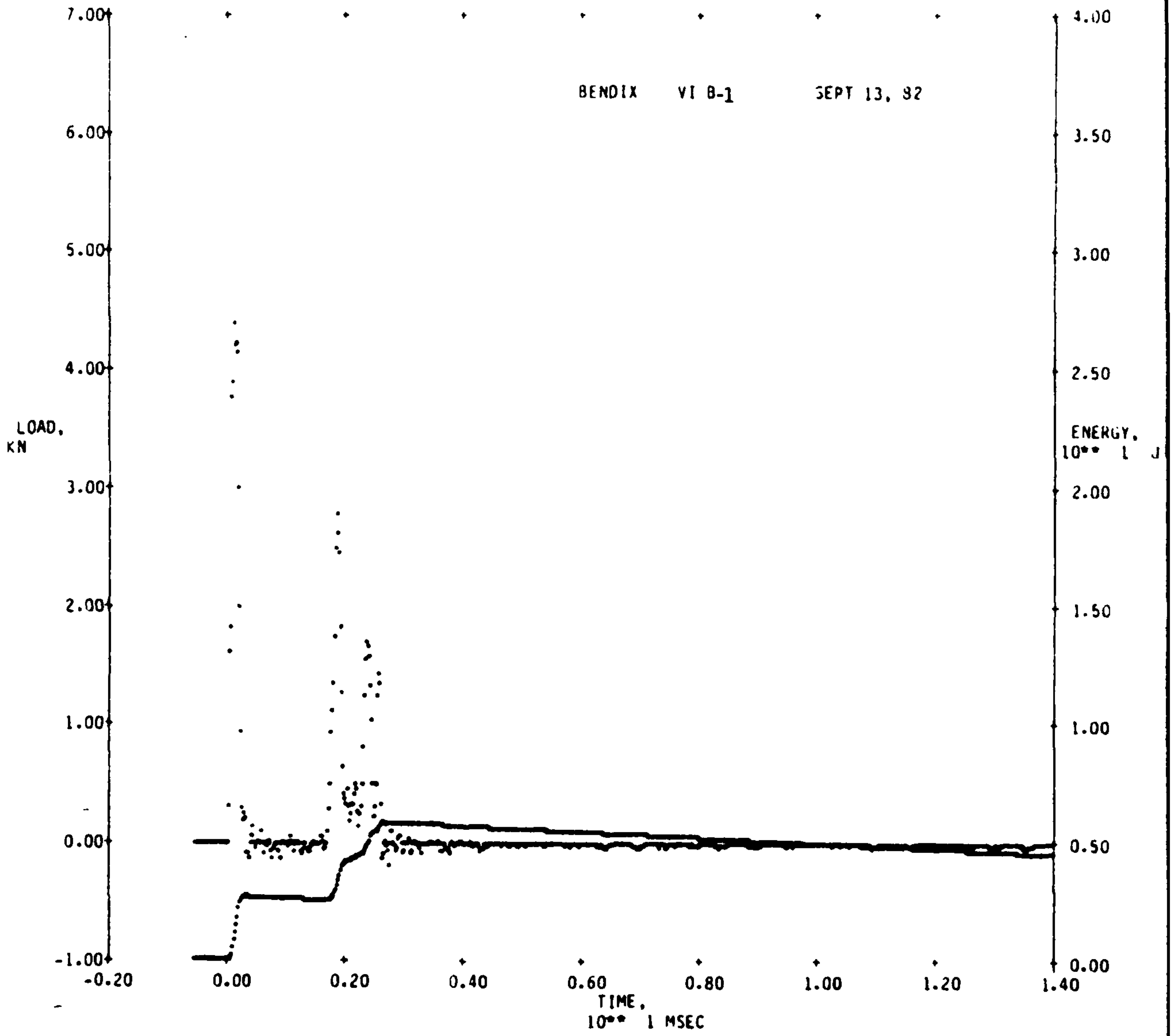
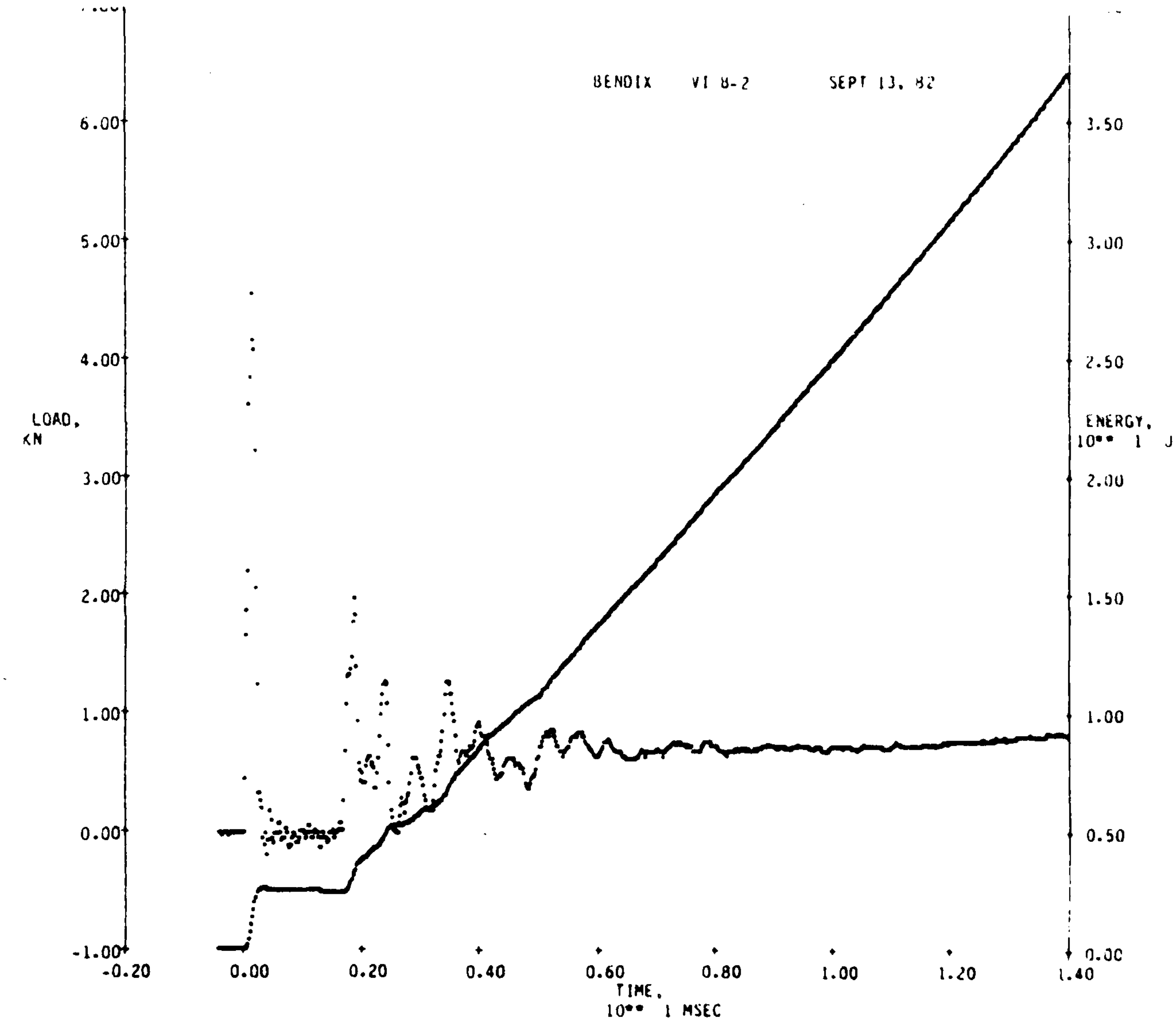
                     IMPACT
             TEMP  VELOCITY  ENERGY  TIME,10**  1 MSEC  LOAD,10**-3KN   ENERGY,10**  0 J
TEST          C      M/S      J         INIA    TOTAL       MAX         INIA   PROP   TOTAL
V B-1        23.0     3.95  1862.30     0.01    1.93        4316         1.1   57.2    58.1
```



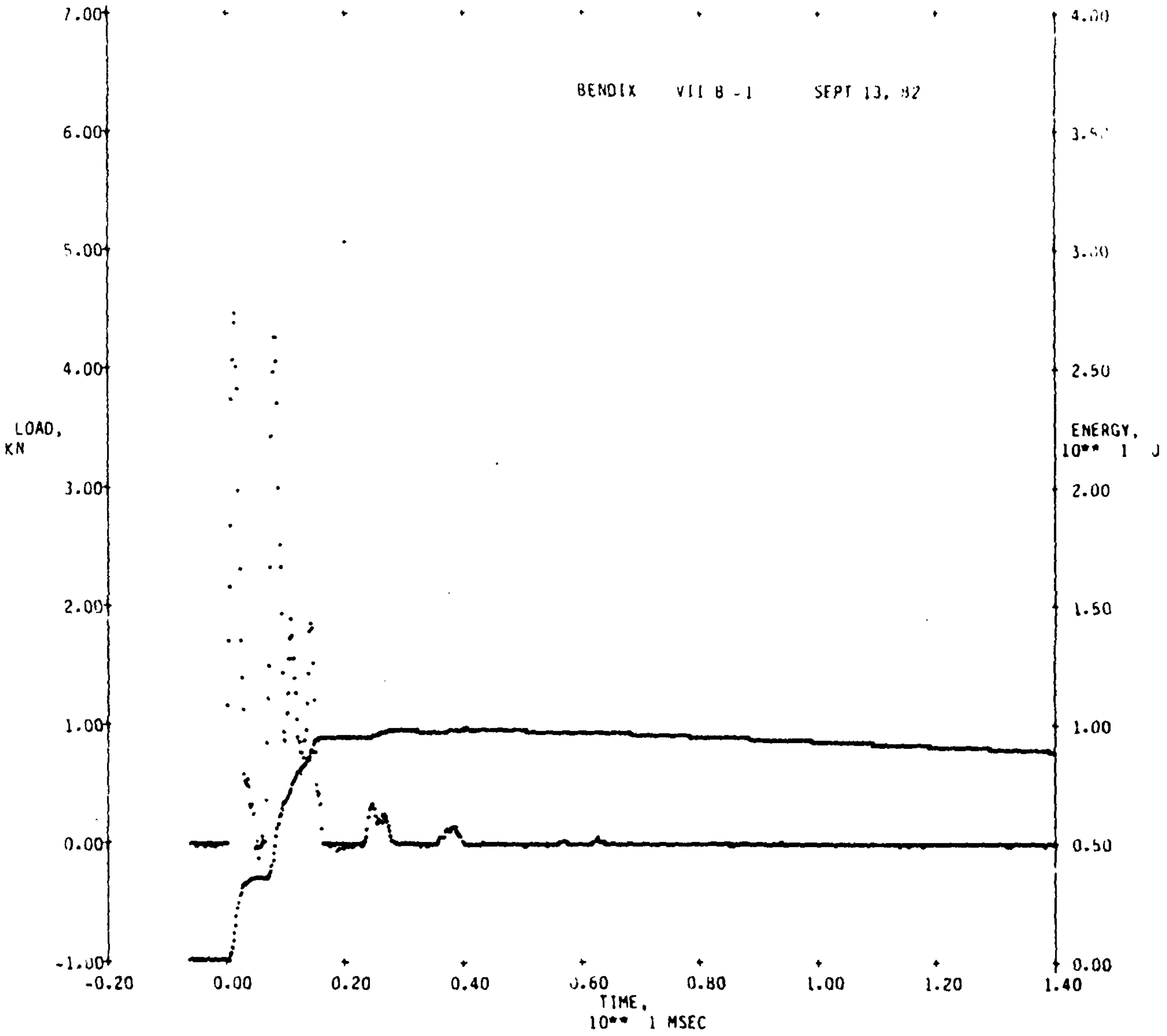
TEST	TEMP C	IMPACT VELOCITY M/S	ENERGY J	TIME,10** 1 MSEC INIA	TIME,10** 1 MSEC TOTAL	LOAD,10**-3KN MAX	ENERGY,10** 0 J INIA	ENERGY,10** 0 J PROP	ENERGY,10** 0 J TOTAL
V 8-3	23.0	3.97	1000.53	0.01	1.94	1355	0.9	58.3	59.2



TEST	TEMP C	IMPACT VELOCITY M/S	ENERGY J	TIME,10** 0 MSEC		LOAD,10**-3KN	ENERGY,10** -1 J		
				INIA	TOTAL	MAX	INIA	PROP	TOTAL
VI B-1	23.0	3.97	1880.53	0.11	2.63	4375	8.8	49.6	58.5



```
                  IMPACT
          TEMP  VELOCITY  ENERGY  TIME,10**  1 MSEC  LOAD,10**-3KN  ENERGY,10**  0 J
  TEST      C      M/S      J        INIA    TOTAL        MAX       INIA  PROP  TOTAL
VI 8-2    23.0     3.95  1862.89     0.01     1.95        4550       1.0  55.0   56.0
```



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                   IMPACT
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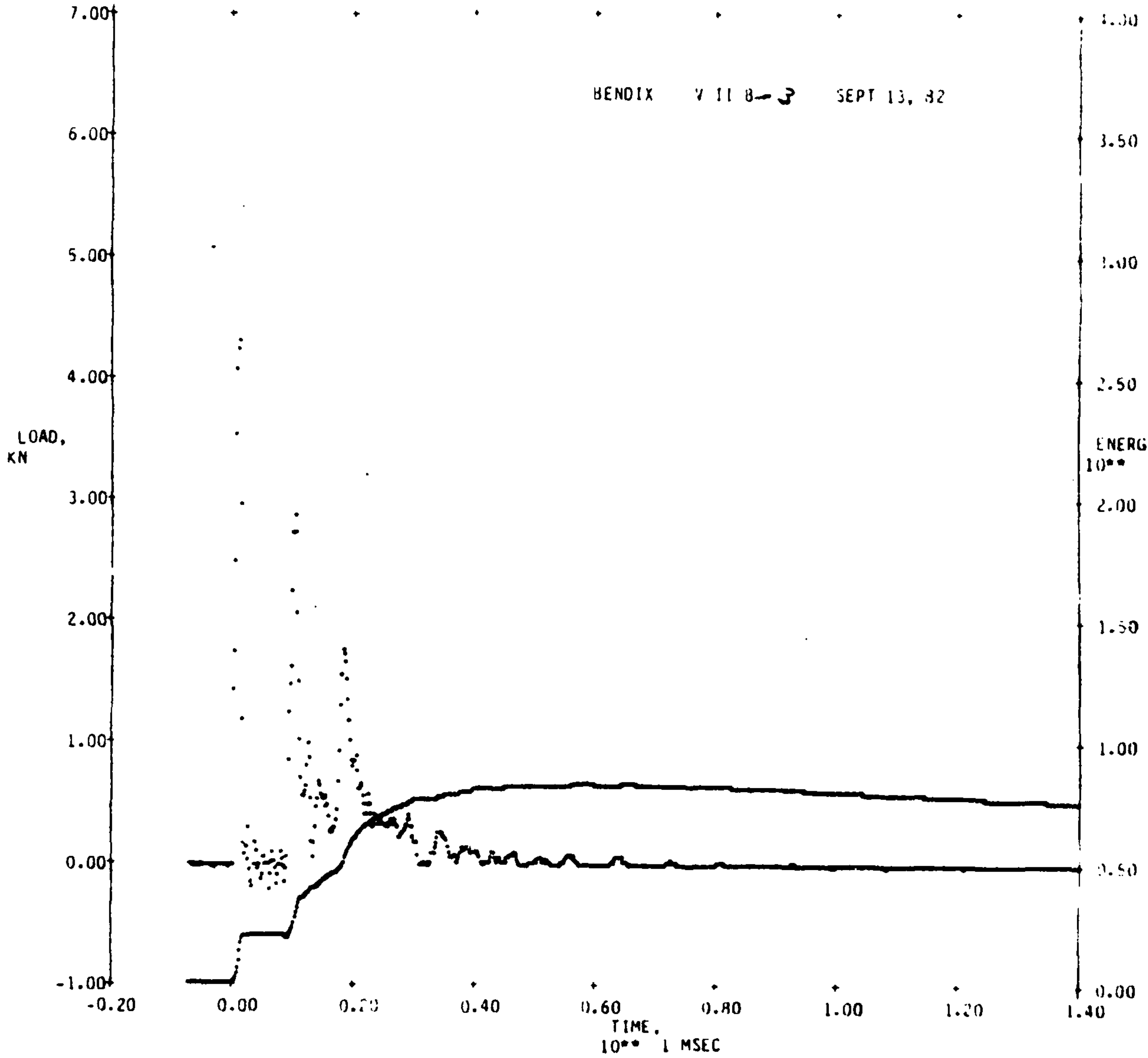
 TEST       C       M/S     J          INIA   TOTAL        MAX        INIA   PROP   TOTAL
VII B -1  23.0      3.97  1880.53      0.15    4.02        4472       15.4   82.5    97.9
```



	TEMP	IMPACT VELOCITY	ENERGY	TIME,10** 0 MSEC		LOAD,10**-3KN	ENERGY,10** -1 J		
TEST	C	M/S	J	INIA	TOTAL	MAX	INIA	PROP	TOTAL
V II 8-3	23.0	3.97	1880.53	0.13	5.72	4296	13.5	68.9	82.5

END

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