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EVALUATION OF EXPLOSAFE EXPLOSION SUPPRESSION SYSTEM FOR AIRCRAFT FUEL TANK PROTECTION

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A joint USAF/Canadian government development program conducted during the period July 1977 to July 1980, to evaluate the fuel tank ullage explosion suppression performance and to qualify the airborne military use of EXPLOSAFE® void filler material, is reported.

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The material was subjected to laboratory testing to characterize its performance with regard to the manufacturing variables and subsequently exposed to typical ballistic threats up to 23mm HEI-T. The material properties are extensively defined together with the operational penalties associated with its use. Operational and environmental tests are described which determined the tolerance of the material to static loading, fuel slosh vibration, and exposure to fuel, fuel + additives, and corrosive fuel contaminants. Further tests demonstrate that the material does not affect fuel system operation with regard to flow, free motion of fuel during aircraft inversion and fuel tank venting. Installation stu 'ies were conducted on fuel tanks of varying complexity to demonstrate feasibility of assembly using existing access apertures.

FOREWORD

This report was prepared by Andrew Szego, Karim Premji and Robert D. Appleyard of the Research and Engineering Group of Explosafe Division, Vulcan Industrial Packaging Limited, Toronto, Ontario. The work reported herein was carried out under a joint U.S. Air Force/Canadian Government Contract No. F33615-77-C-3115, Project 3048, Task 304807, Work Unit 30480782, "Evaluation of Explosafe Suppression Material", and was administered by the Fire Protection Branch, Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories (AFWAL), Air Force Systems Command, Wright Patterson Air Force Base, Ohio, with Thomas A. Hogan, AFWAL/POSH, as Project Engineer.

The report describes the results of work conducted during the period July, 1977 to July, 1980.

The authors wish to express their special thanks to Mr. T. A. Hogan, AFWAL/POSH, Mr. T. O. Reed, ASD/ENFEF, Mr. C. Pedriani, AVRADCOM, and all the individuals and organizations who contributed towards this effort. The authors would like to express their appreciation to Mr. W. E. Bessant and Mr. R. A. Kemp, Department of Industry, Trade and Commerce, Government of Canada, and also Mr. D. C. Webb, Director of Defence Production, MCLDDP, Government of Canada, and his predecessors Mr. E. A. Coolen and Mr. E. Johnston for their valuable assistance and contribution.

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SUMMARY

Fuel tank ullage explosion resulting from ignition of vapors by various means is a major cause of military aircraft loss in combat. Over the years, many concepts which seek to prevent or suppress such explosions have been explored. Nitrogen dilution, chemical quenching and polyurethane foam explosion suppression materials have emerged as the primary candidate systems.

This report presents the results of a four-year performance study and qualification test program conducted on Explosafe, one of the latest, most advanced explosion suppression material. This is an expanded metal mesh manufactured from thin aluminum foil. Coiled, or otherwise layered into a three dimensional structure of controlled density, it can be shaped to match the interior geometry of fuel tanks and installed through existing access areas.

The system has the passive, logistics-free advantages of the foam filler materials, yet, because of its metallic nature, it is free of limitations on operating temperature; is hydrolytically stable; and does not encourage electrostatic charge generation during fuel filling operations - the primary disadvantages of polyurethane foam materials.

A weight optimized configuration of thickness, expansion, web strand width and layering of the aluminum foil has been established at 2 lb/ft^3. The performance of this optimized arrangement has been proven satisfactory from the standpoints of ballistic impact, slosh, vibration, compaction, contamination, corrosion, static attenuation, fuel displacement, fuel retention, handling and installation. While installation and removal can present some difficulties, the system in its present form is equal or superior to tank filler materials previously used or contemplated for equivalent explosion protection, and is now ready for use in airborne applications.

Even though the dry weight of the material is somewhat greater than that of other explosion suppressant materials, its overall effect on aircraft range is comparable due to its lower fuel retention and displacement characteristics.

The Explosafe explosion suppression system has been developed by the Explosafe Division of Vulcan Industrial Packaging Limited (VIPL) of Canada, and is currently in use in a variety of surface vehicles. In view of the many proven advantages offered by the Explosafe system in reducing or eliminating fuel tank explosion hazards, it must be concluded that the system now merits serious consideration for application wherever such hazards exist.

Initial combustion tests on Explosafe conducted at Wright-Patterson Air Force Base, Aero Propulsion Laboratory were sufficiently promising to warrant a program of tests and demonstrations to study all factors relating to the use of Explosafe as a passive system for aircraft fuel tank protection. The program was conducted by the USAF and VIPL under a joint USAF-Canadian Government contract. The positive results obtained have justified the extensive effort involved in determining the practicality of the system for future airborne applications.

The test program was divided into two phases:

a) Phase I was conducted jointly by AFWAL and the US Army to characterize the explosion suppression performance of the system, with regard to its manufacturing variables, in "worst case" laboratory and full scale ballistic environments. This work is reported as Task I.

b) Phase II was conducted by the manufacturer of the material, sub-contracted by the Canadian Government. Their responsibilities were: to determine if the material would withstand operational and environmental conditions to which it would be subject in airborne military service; to demonstrate that the material would not affect aircraft operation; to explore the feasibility of its installation; and to define the physical properties and operational penalties of the system. These various areas of study are reported in Tasks II through IV.

Task I

In Task I, the evaluation conducted by AFWAL studied the effects of material orientation, specific weight and specific surface area on performance using electrical discharge ignition of a "worst case" propane/air mixture. It was concluded that the material orientation was not significant and the optimum material was one having a specific weight of 2 lb/ft^3 manufactured from .002 inch foil. This material met the overpressure requirements of MIL-B-83054 B for types I, II and IV with a material maximum allowable void volume of 10%.

The US Army evaluated a narrower range of material variables by subjecting them to typical ballistic threats in tanks of varying sizes. The optimum selection was confirmed and demonstrated the ability to withstand threats up to 23 mm HEI-T with acceptable overpressures in typically voided configurations. The report describes further tests wherein an external wing tank equipped with the optimum material was exposed to the same threats and dramatically demonstrated the performance.

Task II

In Task II, the manufacturer defined the materials' properties and its effect on fuel systems. The relationships of material specific weight and specific surface area to foil expansion and thickness were established. The level of entrained solid contamination was measured under both laboratory and field conditions, successfully meeting the military requirement.

The penalties of fuel displacement and fuel retention were defined, again under both laboratory and field conditions. This data is used to evaluate the system weight penalty and effect on usable fuel in a typical fuel tank. In a static system comparison with the latest type of polyurethane foam explosion suppression, the lighter weight of the latter is offset by the greater usable fuel of the Explosafe system. In a dynamic situation, further reduction in fuel retention with the polyurethane foam and the Explosafe material can be anticipated.

The material was found to have no effect on fuel system operation with regard to flow, flight inversion, and vent icing characteristics. The additional benefit of slosh suppression was evaluated, demonstrating reduction in dynamic wave forces by an order of magnitude. In a study of the electrostatic charging/discharging characteristics of a fuel system using the material, reduced charge generation (no spark discharges) and the potential of continuous, safe charge dissipation were noted.

Task III

In Task III, the material was subjected to typical operational stresses and environmental exposures which included static loading, dynamic slosh, dynamic slosh with vibration in both metal and bladder tanks, dynamic vibration alone, and exposure to fuels, additives, and typical corrosive fuel contaminants. In each field of study, the material itself proved to be acceptable with insignificant effects on tank structures, coatings and environments.

Task IV

Finally, in Task IV, the feasibility of installing the material in fuel tanks of increasing complexity culminating in the center wingbox tank of a Fairchild-Republic A-10 aircraft was studied. Access was limited to existing apertures and a maximum void limitation of 10% was defined. The installations in the more simple fuel tanks were easily accomplished and, while demanding much design consideration and a great number of individual sections, the wingbox installation also was successfully demonstrated.

The test program has yielded a wealth of information on this candidate's performance, properties, manufacturing techniques and design criteria. This information is the basis of a military specification presently being drafted.

Explosafe explosion suppression material meeting that specification and engineered to conform with the design criteria is qualified for consideration for use in military aircraft. Actual selection for use will be determined by specific advanced aircraft system survivability needs and assessment of specific advantages offered compared to other state-of-the-art protection measures.

SECTION I

INTRODUCTION

Background

The problem of fuel tank explosions has been with us since the invention of the internal-combustion engine. The hazard is amplified under the ballistic threat to aircraft in combat. In fact, the most vulnerable parts of an aircraft are the fuel tanks.

In the 1960's, a polyurethane foam capable of suppressing explosions was demonstrated by U.S. and British authorities. The passive nature of this type of system and its associated reduction in logistic problems, together with full time protection, made it a viable alternative to the existing fuel tank inerting schemes employed at that time. The USAF experience in South East Asia further exemplified the vulnerability of its aircraft in the fuel tank area. The tropical climate of South East Asia subjected the foam to extremes of temperature and humidity which revealed deficiencies. The foremost was a lack of hydrolytic stability (humidity resistance). Limited service life of 2 to 5 years was experienced with the foam, and as breakdown occurred, fuel systems became contaminated and fuel filters were clogged.

The Air Force realized these problems and in 1967 initiated a Technical Need (TN) for a high temperature explosion suppression material for aircraft fuel tanks and dry bay areas (Reference 1). In 1970 another TN was initiated to evaluate advanced flame arrestor technology for aircraft fuel tanks. In 1974 this TN was updated to include the Explosafe material (Reference 2).

The objectives of both these TNs were two-fold:

a) to provide alternate materials to the present polyester polyurethane foam for use in high performance aircraft where temperatures can exceed 200°F.

b) to provide improved materials in terms of humidity resistance for use in current systems where temperatures do not exceed 200°F.

Explosafe, a fuel tank explosion suppression system, has been under development for some 25 years. In its present form it is an expanded aluminum foil matrix that was conceived in the late 1960's. Being metallic the material is able to withstand the high temperature environments and the aluminum alloy selected can tolerate high humidity. It therefore satisfies the TN expressed by the USAF.

The Explosafe material is manufactured by slitting, then expanding a thin aluminum alloy foil. The resulting material is then coiled or fan-folded into a 3-dimensional batt. In the first operation, a rotary gang-slitter is used to impart an offset series of interrupted slits to a 14 inch wide web of material. The width of each inter-connected strand, typically .055 inch wide, is determined by the thickness of the slitting knife employed. The second operation is a transition of the web from the slit to the expanded state. This is performed by advancing the slit web, held by its edge, continuously over a pair of divergent triangular arms. As the foil strands are separated, they form the sides of a series of irregular hexagons, as illustrated in Figure 1, and they also twist out of the plane of the web. This strand incline gives the web an increased effective thickness.

To prevent nesting of the inclined strands, adjacent layers of the material are inverted as shown in Figure 2, resulting in an edge to edge lay-up. The density of the material is thus controlled and settling or shifting eliminated. Opposed in this way, two webs can then be coiled into cylindrical batts. The preferred method of fanfolding however is shown in Figure 3. The web, creased perpendicular to its direction of travel, is allowed to fold along these regularly placed indentations. Using a single web the resultant layers contain strands twisted in the required

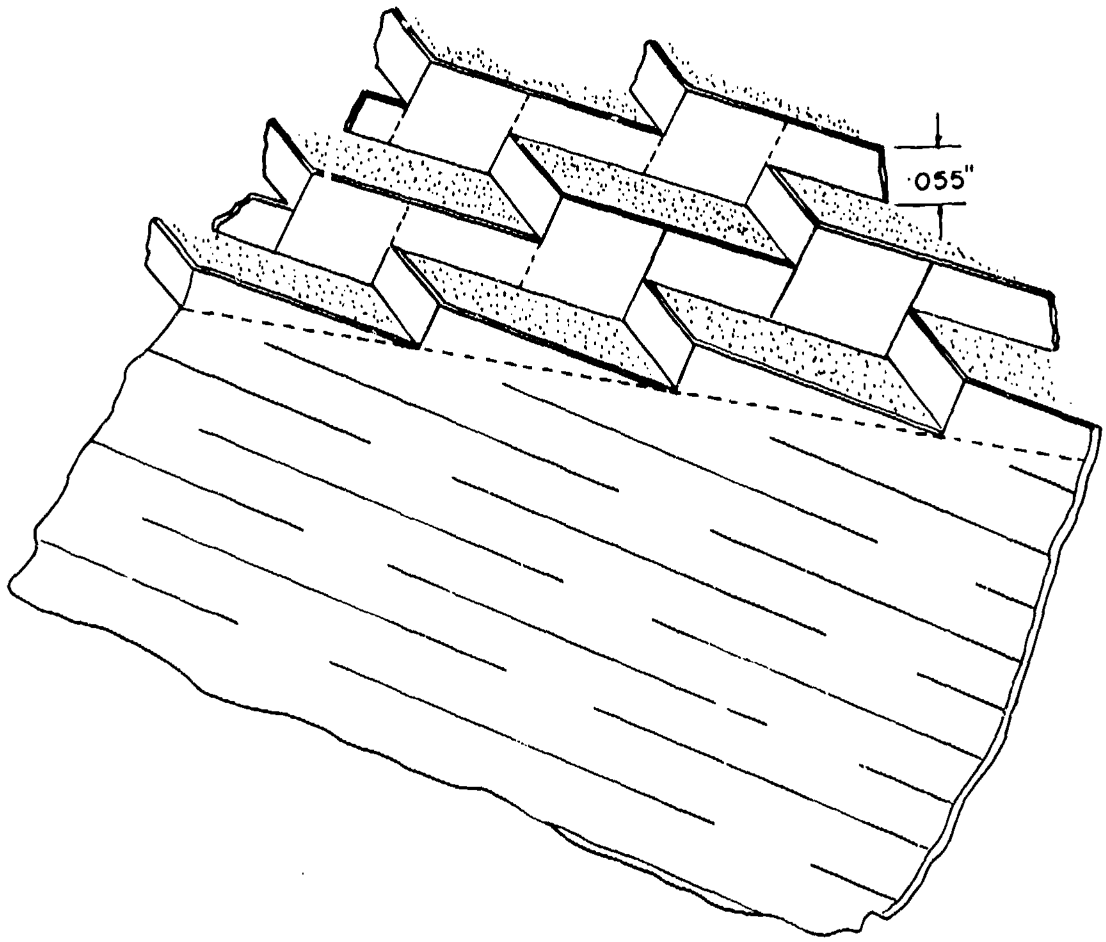

Figure 1. Transition from Slit to Expanded Foil

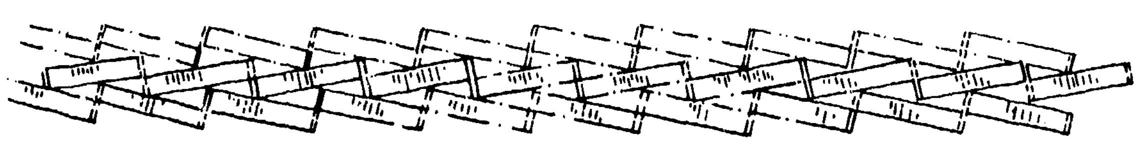

Figure 2. Layer Spacing in Opposed-Strand Layup

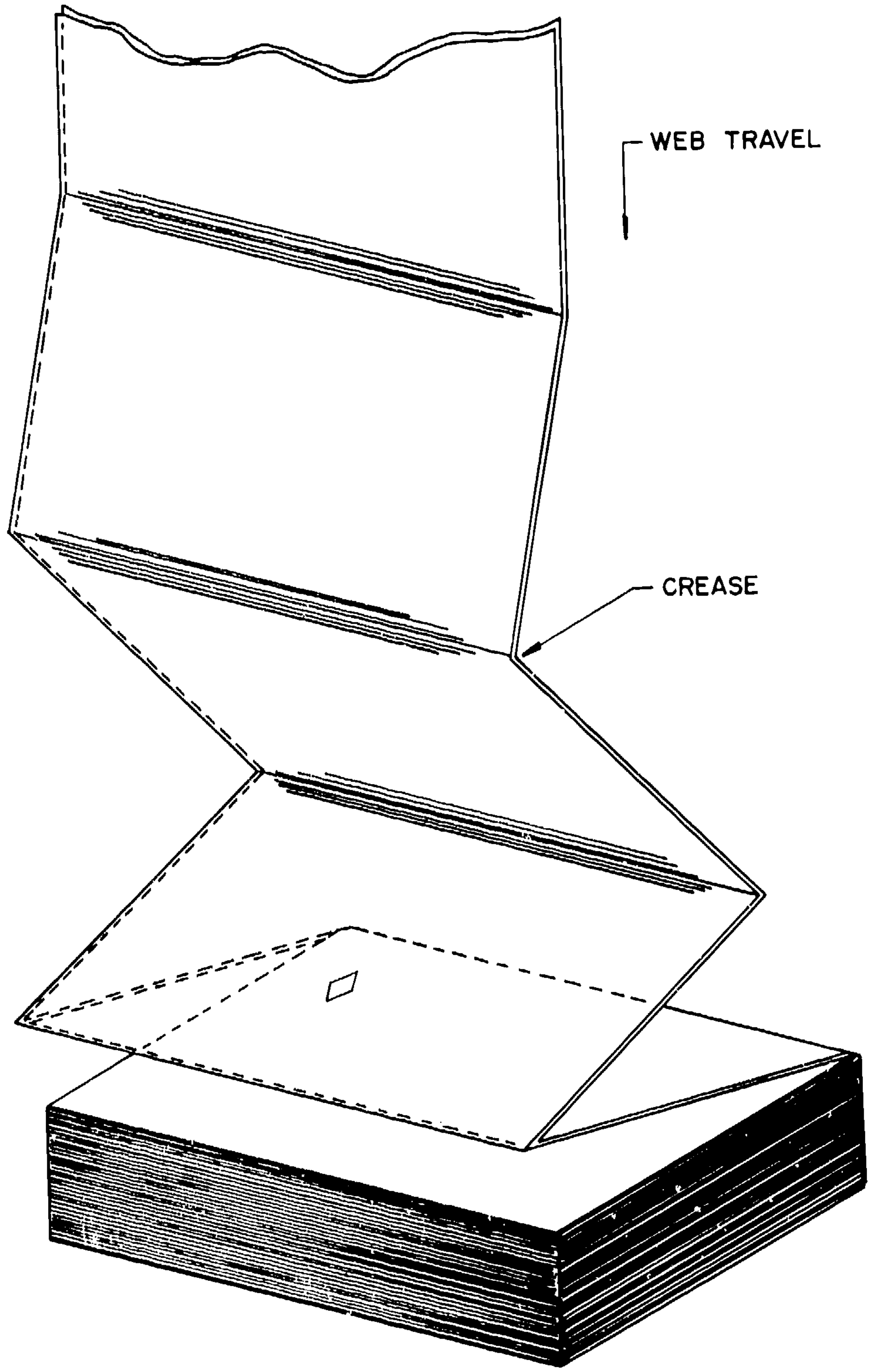

Figure 3. Fanfolding Expanded Foil into Rectangular Batt

opposite directions. The use of two opposed webs doubles the output of the fanfolder while maintaining the reversed layup.

The Explosafe Division of Vulcan Industrial Packaging Limited, (VIPL) is the developer of this technology. A Canadian Company, VIPL is involved in the world-wide marketing of the material.

Scope

The Explosafe system was introduced to the Air Force as a possible candidate in the search for an improved method of explosion suppression. Tests conducted by AFWAL/POSH and ASD/ENFEF during the third quarter of 1975 verified its ability to suppress explosions. In fact, the explosion suppression performance on this initial screening was equal to the large pore polyurethane foams. This performance, together with the advantages of being metallic, justified a research and development program to assess and qualify the material for use in aircraft fuel tanks. This was initiated in the form of a joint Canadian Government/USAF program to evaluate Explosafe. The contractor on this program was the Canadian Commercial Corp. who, in turn, sub-contracted Vulcan Industrial Packaging Limited, Explosafe Division, to carry out the contractor portion of the program.

The technical requirements of the program were divided between the contractor, who became responsible for the qualification testing, and the USAF/US Army who jointly assumed responsibility for the explosion suppression performance evaluation.

Objectives

The program was divided into four tasks:

Task I - Performance Testing

Phase I

Parallel series of tests were to be performed by VIPL and AFWAL to assess the effects of material orientation on suppression performance. On completion of this program, a trade off study was to be conducted to evaluate, under laboratory conditions, optimum material configurations.

Phase II

Tests were to be conducted to assess the ballistic response of the material in its optimum configurations. This would be conducted jointly by the USAF and the US Army, and include API and HEI-T impacts. Blast attenuation and explosion suppression were to be investigated in a full scale simulator.

Task II - Material Properties and Effects on Fuel Systems

Tests were to be conducted on production explosion suppression material to establish significant physical properties and characteristics. Although emphasis was placed on the products' specific weight and its fuel displacement and fluid retention characteristics, tests were also to be performed to assess the operational characteristics of slosh suppression and electrostatic charge dissipation. Resistance imposed on fuel flow, susceptibility to vent icing under worst case airflow conditions and foil-entrained solid contamination were also to be examined.

Task III - Operational and Environmental Effects on Materials

Operational

Static tests were necessary to determine the ability of the material to withstand steady loads imposed either by storage or 'g' forces in operation. The effects of operational vibration were to be determined by cycling the material through typical frequencies and amplitudes while fuel was flowing. The continuous flow would allow continual monitoring of contaminants being generated by the vibration by intermittent filter sampling.

A simultaneous slosh and vibration test was to be conducted on a rubber bladder tank fully packed with the material to evaluate the interaction of the material with the soft, inner wall surface of the tank, and to assess the reaction of the foil to intense operating conditions. Here, disintegration, settling and compacting of the foil would be pertinent points of assessment.

In addition, two dynamic slosh tests were to be performed on a specially prepared 200 gallon external pylon tank packed with the material. Under investigation would be the influence of the material on typical sealant and corrosion preventive fuel tank coatings. Again, friability of the foil, and measurable settling or shrinkage of the material were factors to be appraised, together with shifts in orientation of the material. The slosh attenuating characteristic of the foil was to be photographically documented.

Both types of tests represent life-time fuel tank operating conditions.

Environmental

The chemical compatibility of the material with fuels, additives, tank construction/fuel system components materials, and fuel contaminants such as water were of primary concern to the evaluation. Tests and literature surveys were to be conducted in each of these areas to ascertain the durability and inert properties of the material in simulated or comparable environments and to determine its limitations, if any.

Task IV - Installation Studies

Installation studies were to be conducted on a range of aircraft fuel tanks to determine the feasibility of designing the material for installation into tanks of various complexity, and to evaluate techniques associated with shaping and bundling the material to accomplish these installations. The study was to be performed in three phases. Successive phases would deal with techniques required to design, fabricate and install the material into tanks of increasing complexity, culminating in installation for a fighter type wing tank complete with all associated integral plumbing.

SECTION II

TASK I - PERFORMANCE TESTING

1.0 COMBUSTION

1.1 Procedure

The procedure for comparatively evaluating explosion suppression performance has been established by MIL-B-83054B and is extensively described in Reference 3. Summarizing, the procedure consists of inserting the specimen system in a pressure resistant test chamber, known as a flame tube, having a minimum total volume of 5.0 cubic feet and a 100 square inch cross-sectional area. The flame tube used by the AFWAL is 7.5 cubic feet with a cross-section of 144 square inches. A propane/air mixture of the ratio which previously has been found to result in the highest combustion overpressure is created within the chamber, verified by bomb sampling, and ignited with a high energy spark source having a minimum 0.25 millijoules energy. Evaluation of the performance is based on the recorded overpressure vs time curve, with particular reference to peak overpressure and pressure rise time, with respect to the initial conditions. Visual observations of the reaction within the chamber and the condition of the specimens after test are also considered.

The testing conducted by AFWAL is fully reported in Reference 3, and it is on the results recorded therein that the Explosafe explosion suppression system is to be evaluated. VIPL conducted a parallel test program to confirm and augment the AFWAL effort. Small deviations in the test apparatus and procedure exist but the VIPL test contributed to the analysis of the AFWAL results. The VIPL apparatus and proceduresare described in Appendix A.

1.2 Results

The AFWAL test results are summarized here.

1.2.1 Orientation Study

The program studied the effects of the material orientation within the test chamber relative to the direction of flame propagation. The material, being a layered, asymmetric cell structure, might be expected to affect the flame propagation by virtue of the different surface area and cell geometry presented to an oncoming flame front in the three mutually perpendicular planes as illustrated in Figure 4.

The tests were conducted with the 3 mil material at an expansion of 38 inches yielding a specific weight of 2.75 lb/ft^3 and a specific surface area of 130.6 ft^2/ft^3. Initial pressures of 14.7 psia and 17.7 psia were tested. Some of the material submitted for these tests was oversized and, in modifying, was subject to damage and undersizing. Also, other material had shrunk during transportation and was therefore undersized. The resultant gaps between material and flame tube walls may have resulted in scatter and inconsistencies in the test data. It was decided to repeat the tests. However, the remainder of the program had to be started and with the intent of selecting the 'worst case' orientation for all subsequent testing, the data was reviewed. Despite the inconsistencies and scatter, it was possible to conclude that the orientation did not affect the suppression performance. The S33 orientation, as illustrated in Figure 4, was then selected for the subsequent testing because of its ease of handling and installation.

The repeat testing was conducted at the end of the program and Figure 5 illustrates the data. It is evident that the data scatter is greater than the inconsistent difference between each orientation, confirming the conclusion made from the first set of results.

1.2.2 Optimization Study

The second part of the combustion test program explored the effects of material specific weight and specific surface area on suppression performance. The intent was to define, if

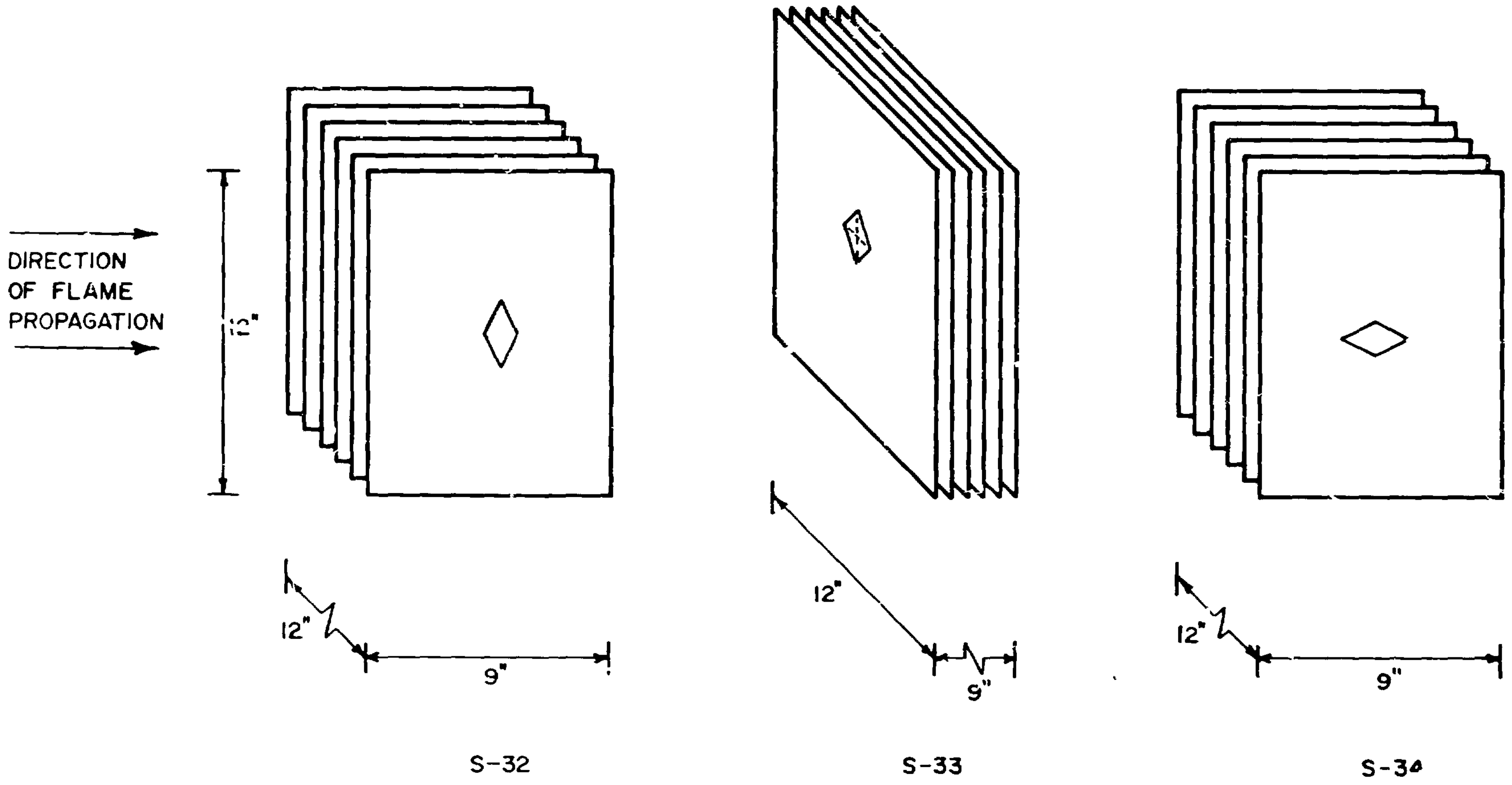

Figure 4. Foil Orientations

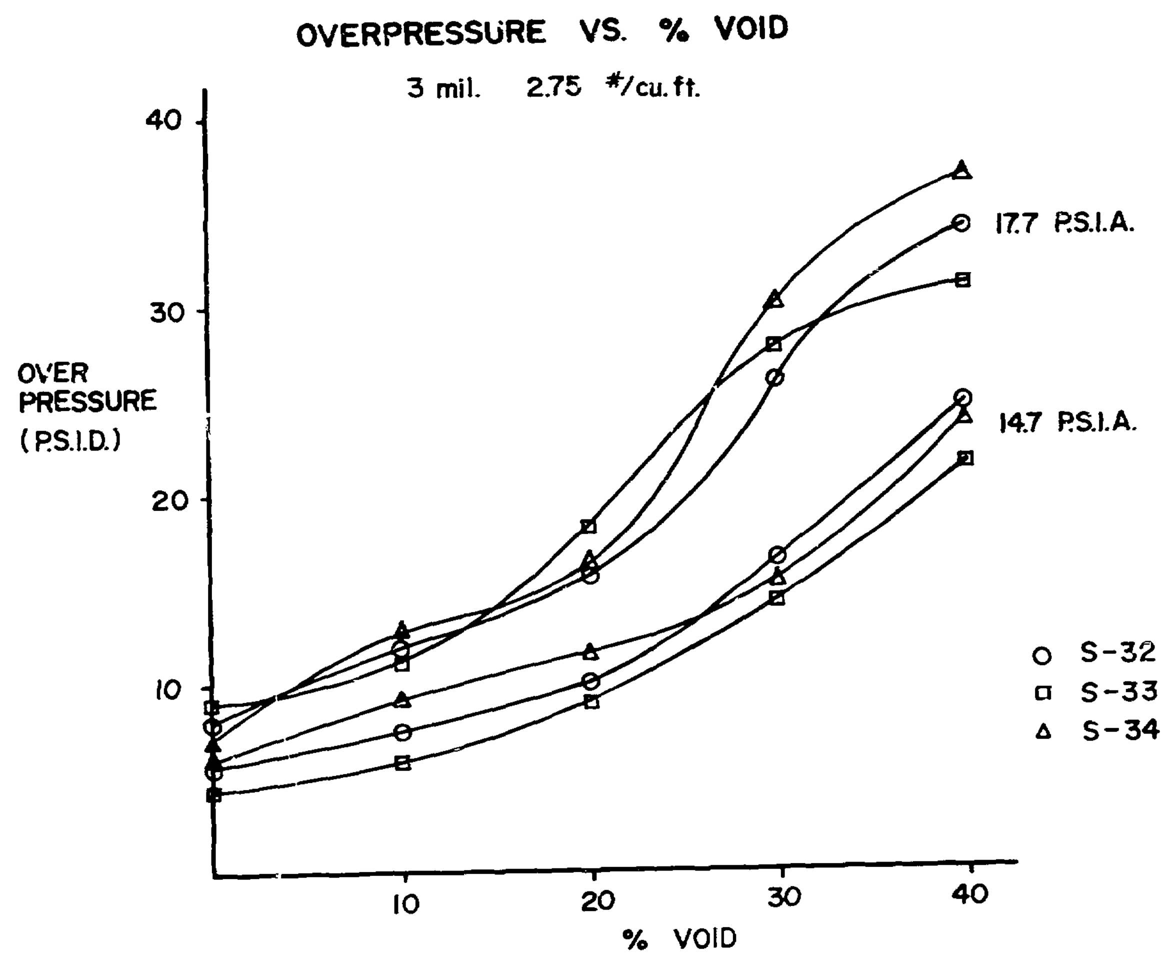

Figure 5. Orientation Study Results - Set 2

possible, an optimum material with regard to weight and performance, and involved testing with a range of material thicknesses, several expansion widths and combustion void levels (Vc). A summary of the results is presented in Table 1.

Figures 6 and 7 depict all the results plotted as combustion overpressure versus specific weight at initial pressures of 14.7 psia and 17.7 psia respectively. It is immediately apparent that there is a general trend of reducing overpressure as specific weight increases.

However, the individual sets of data for each foil thickness show a secondary effect which conflicts with the general trend; e.g. in Figure 7, the 2 mil foil at a specific weight of 2.17 lb/ft^3 consistently outperforms the 2 mil foil at the higher 2.33 lb/ft^3 and both of these outperform the 3 mil foil up to a specific weight of 2.75 lb/ft^3. The graphs suggest that for each thickness of material there is an optimum density.

The surface area of the Explosafe material is a function of the expansion and is sensibly independent of material thickness (strand edge area is ignored). Table 2 records this information as well as other properties of the samples under test. Figure 8 depicts some of the typical results obtained at an initial pressure of 17.7 psia plotting combustion overpressure versus material expansion (and hence surface area) for the 2 mil and 3 mil materials at various void levels. The overpressure with the 3 mil material is always lower than that with the 2 mil, confirming the general trend of reducing overpressure as specific weight is increased. The curves again show the secondary effect noted above which produces an optimum for each foil thickness.

To explain this behavior we will consider the properties of the material which influence the suppression performance, and examine the work conducted by VIPL to augment the AFWAL testing.

TABLE 1. COMBUSTION OVERPRESSURE TEST RESULTS

Combustion Void V_c (%)	Expansion (Inches)	ΔP_1 (psid) - Left Transducer					
		P_I, Initial Pressure (psia)					
		14.7			17.7		
		Thickness (mil)					
		1.5	2.0	3.0	1.5	2.0	3.0
0	32	6.4	5.0	3.5	12.5	7.5	6.5
	35		8.0			8.2	
	38	8.8		6.0	10.1		9.1
	44			9.4		13.3	11.6
10	32	7.6		5.5	18.5	13.0	8.5
	35		8.0			12.8	
	38	12.5		9.0	21.5		13.0
	44			12.8		19.8	18.2
20	32	20.5		8.8	23.0	20.6	14.5
	35		11.2			19.3	
	38	16.8		11.5	25.0		13.2
	44			13.4		25.3	26.8
30	32	29.0		12.5	37.0	31.0	25.0
	35		25.5			29.3	
	38	24.8		15.3	38.0		30.0
	44			16.6		34.0	33.0
40	32	37.5		26.5	45.0		43.0
	35					37.0	
	38			23.6			35.5
	44			24.0		51.0	41.8

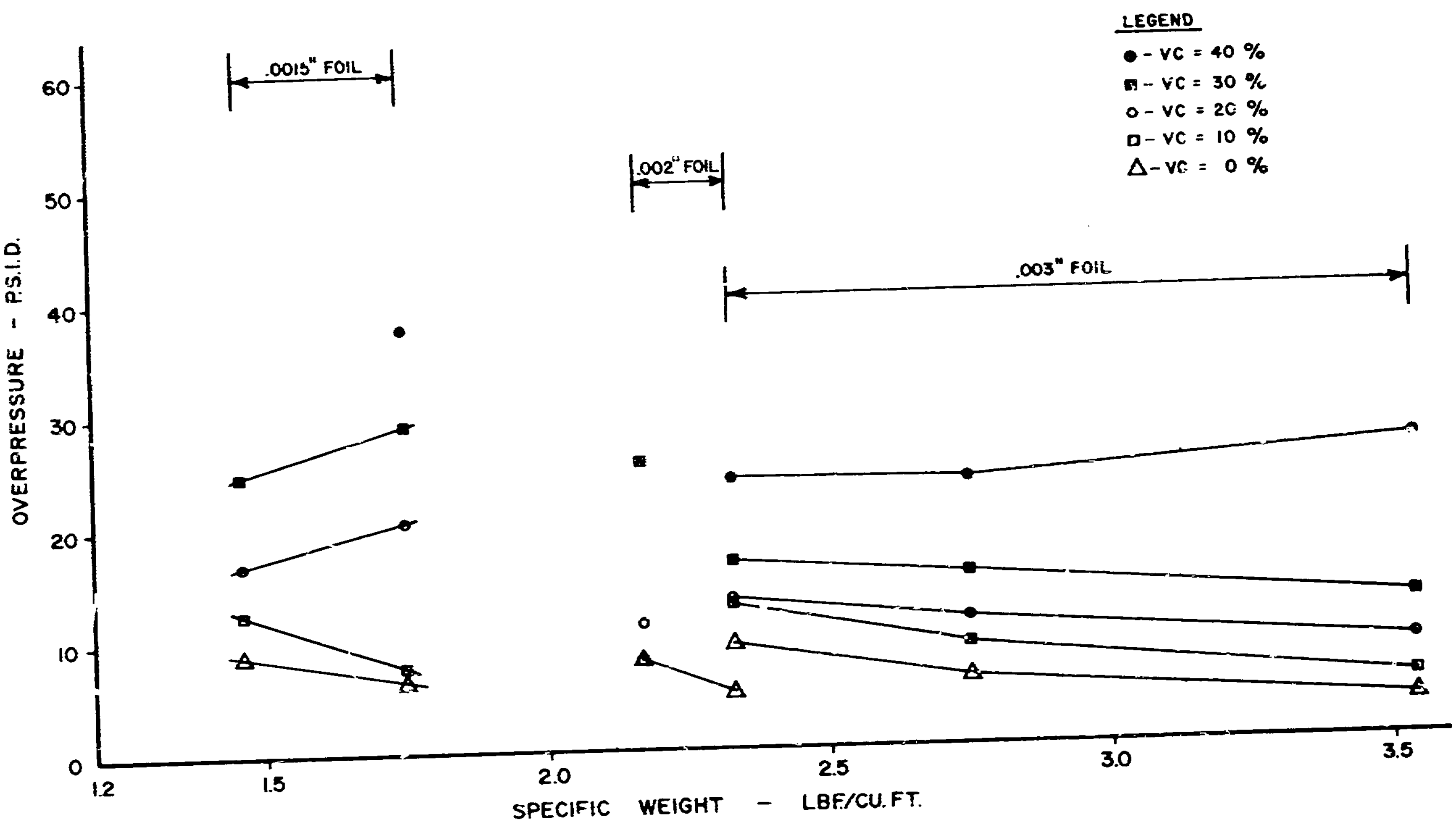

Figure 6. Optimization Study Results - Atmospheric Pressure

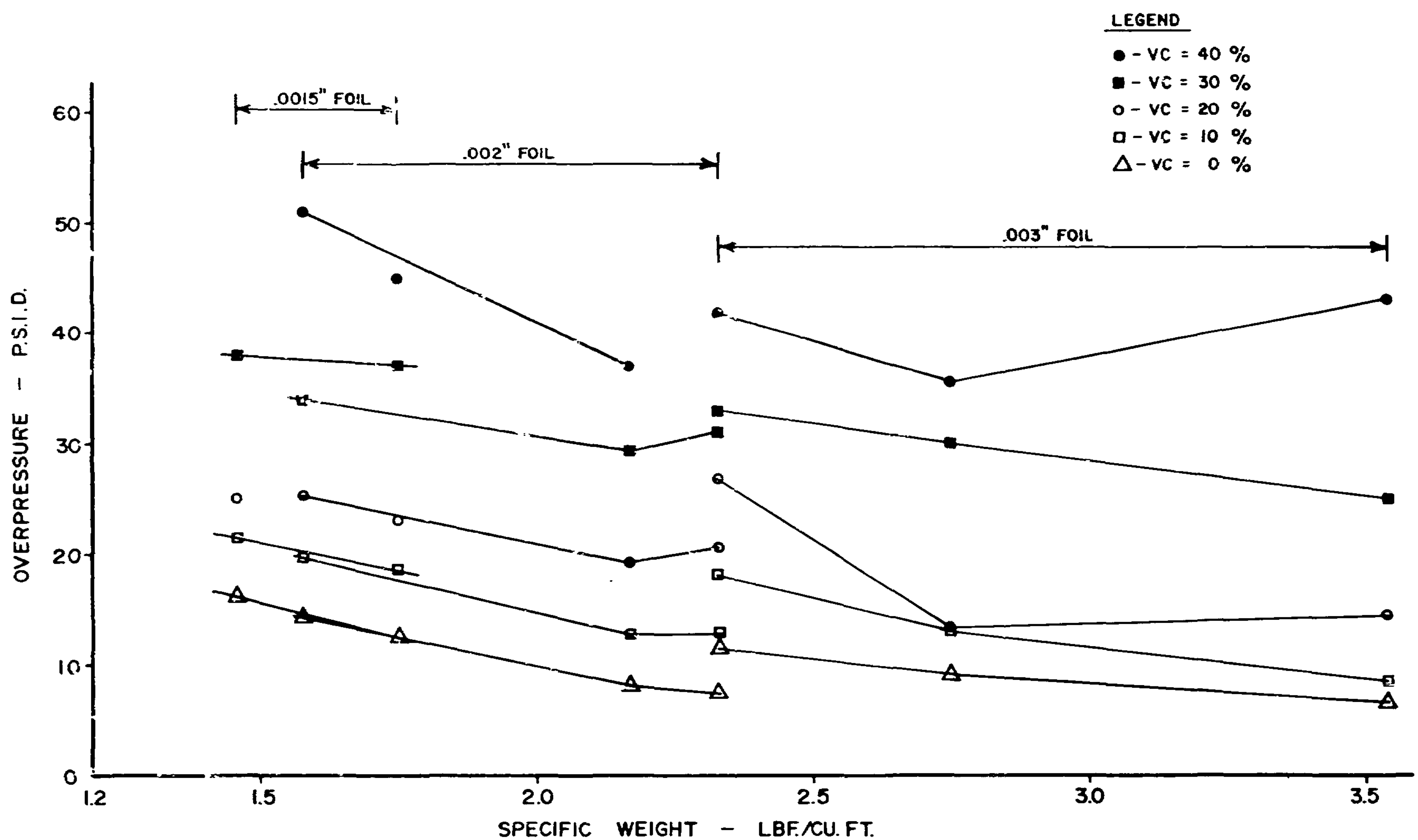

Figure 7. Optimization Study Results - 3 psig

TABLE 2. SPECIFIC WEIGHT AND SURFACE AREA VERSUS EXPANSION AND THICKNESS

Expansion (in)	Specific Weight (lbs/ft^3)			Surface Area (ft^2/ft^3)		
	Thickness (mil)			Thickness (mil)		
	1.5	2.0	3.0	1.5	2.0	3.0
32	1.75	2.33	3.54	166.3	166.0	168.2
35	(1.55)	2.17	(3.23)	(151.5)	154.6	(151.5)
38	1.46	(2.03)	2.75	138.6	(136.2)	130.6
44	(~1.20)	1.58	2.33	(113.5)	112.6	110.5

NOTE: Values in () are theoretical values

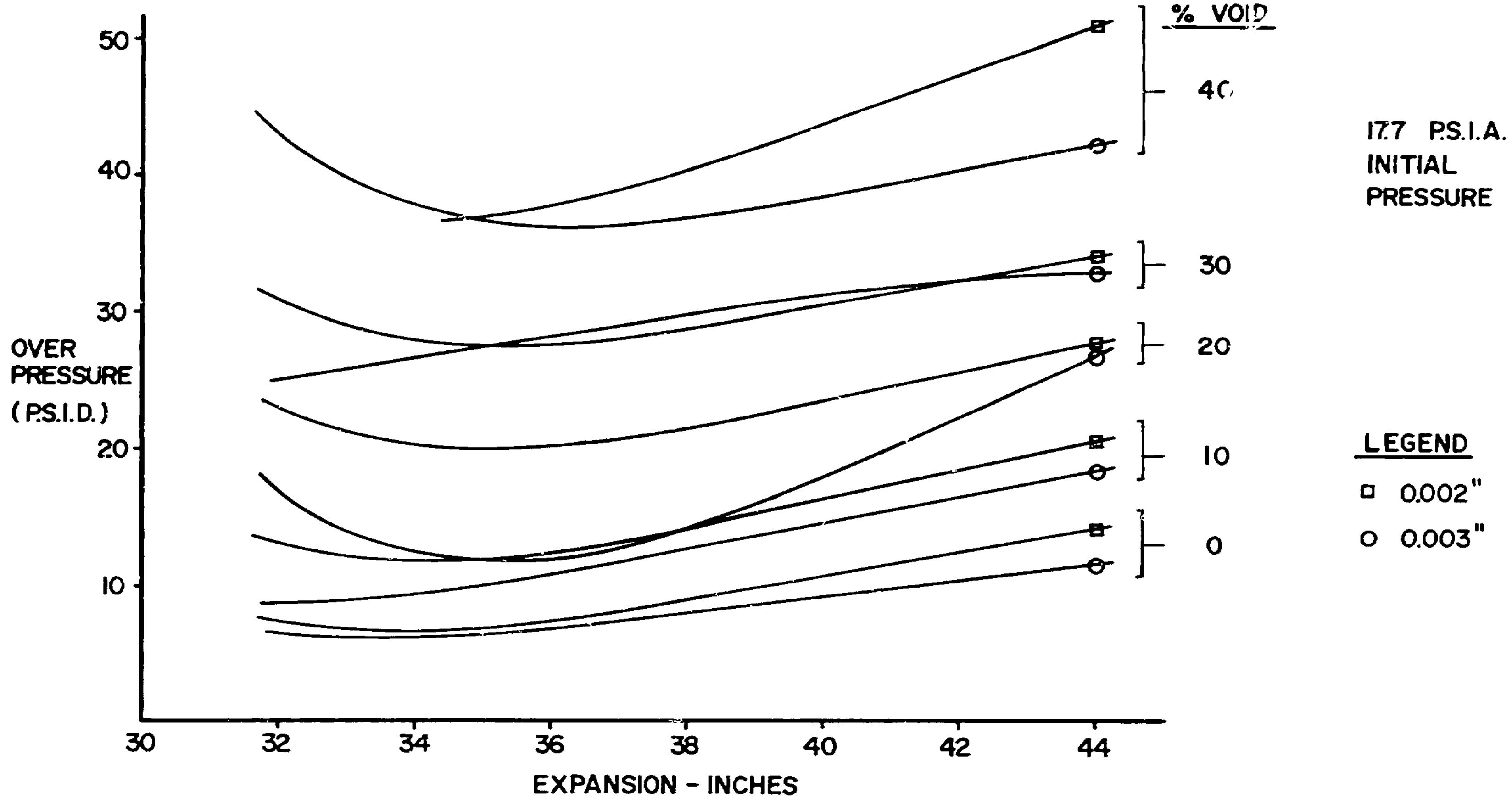

Figure 8. Effect of Foil Thickness on Combustion Overpressure

The Explosafe material is not a flame arrestor and the basic reason for its ability to suppress combustion overpressure is the rapid absorption of heat as the reaction proceeds. That ability is influenced by the mass of the material and by its surface area - these parameters were expected to control the heat capacity of the system and the heat transfer rate that could be achieved respectively. Figures 6 and 7 have shown this to be generally true with respect to the mass, but Figure 8 clearly demonstrates that there is a point beyond which increasing the surface area (reducing expansion) has a negative return and suppression performance deteriorates. This would defy the laws of thermodynamics, therefore, there has to be some secondary mechanism by which changing the expansion of the foil affects the heat absorption.

The only other characteristic of the material affected by expansion is the geometry of the cells. While, as noted earlier, the material is not a flame arrestor, it could locally quench a combustion reaction, particularly at the strand bond regions and interlayer contact points. The expansion controls the geometry and number of these areas and therefore, would influence the degree of quenching. By so doing, a secondary mechanism of suppression would be obtained; that of influencing the amount of heat released by the reaction.

To explore these theories, VIPL produced material with smaller cells for any given expansion by using a reduced strand width (.040 vs .055 inch). The properties of the two materials are identical with respect to specific weight and surface area. A full series of tests was conducted on the .040 inch strand width, 3 mil thick material with several expansions at various void levels and the two initial pressures. The test data is recorded in Table A-1 of Appendix A and is summarized in Table 3. The overpressures with the two cell geometries are illustrated in Figures 9 and 10.

TABLE 3. COMBUSTION OVERPRESSURE TEST RESULTS
.003 inch Material x .040 inch Strandwidth

Expansion (in)	Specific Weight (lb/ft^3)	Void (%)	0 psig Initial Pressure Overpressure (psid)	0 psig Initial Pressure Flamespeed (ft/sec)	3 psig Initial Pressure Overpressure (psid)	3 psig Initial Pressure Flamespeed (ft/sec)
33.5	3.49	0	2.2	29	4.6	37
33.5	3.49	20	5.7		9.3	
33.5	3.49	40	11.7		23.3	
35.0	3.26	0	2.1	18	3.7	29
35.0	3.26	20	5.8		7.5	
35.0	3.26	40	10.5		20.5	
38.0	3.00	0	3.8	21	5.0	33
38.0	3.00	.0	7.1		14.5	
38.0	3.00	40	12.0		22.2	
42.0	2.78	0	2.5	22	4.8	39
42.0	2.78	20	6.0		12.8	
42.0	2.78	40	15.5		16.8	

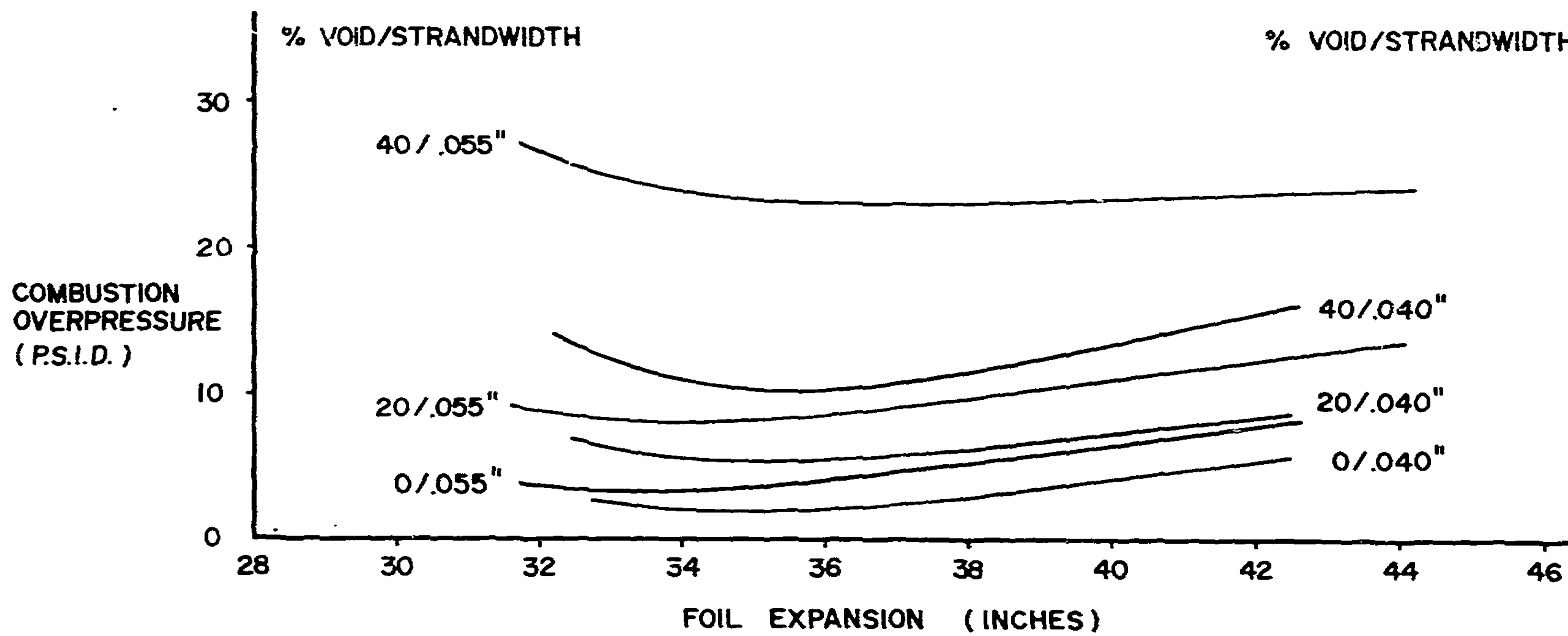

Figure 9. Effect of Strand Width on Combustion Overpressure - 0 psig

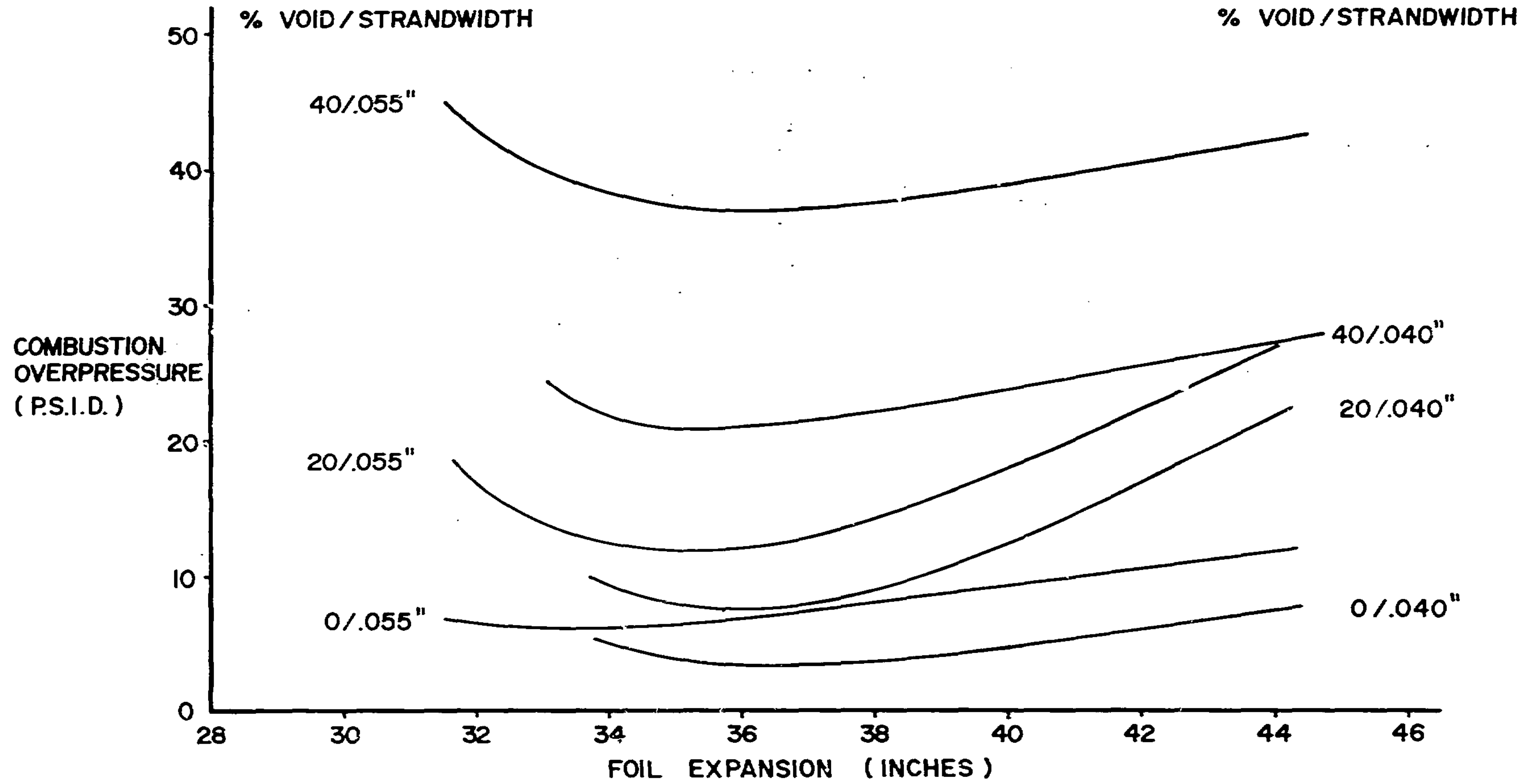

Figure 10. Effect of Strand Width on Combustion Overpressure - 3 psig

The smaller cells consistently result in reduced overpressure and it is believed this is due to the quenching effects argued in the foregoing paragraphs. Further study of this phenomena, using combustion efficiency measurements, will yield a more definite conclusion.

During the testing of the reduced strand width foil, measurements of flame propagation speeds were made and yielded greater insight into the materials' ability to control the combustion reaction. The results are recorded in Table 3. Figure 11 depicts the flame propagation speeds in the fully packed configuration ($V_C = 0$) and, here, the primary reason for the shape of the suppression vs expansion characteristics is apparent. It has been deduced that the cell geometry relates the turbulence of the reaction and the porosity of the material in an inverse manner, i.e. as the cells are reduced in size the turbulence increases and the porosity reduces. At some point these parameters combine to yield a minimum flame propagation speed, which, in turn, extends the duration of the reaction so that the heat is released over a longer time allowing greater heat absorption and reduced overpressure.

Summarizing, the material suppresses combustion overpressure in four ways:

a) by the amount of heat absorption, which is related to specific weight,
b) by the rate of heat absorption, which is related to surface area,
c) by the amount of heat release of the combustion reaction, which is related to the quenching controlled by cell geometry,
d) by the rate of heat release, which is related to flame propagation speed controlled by cell geometry.

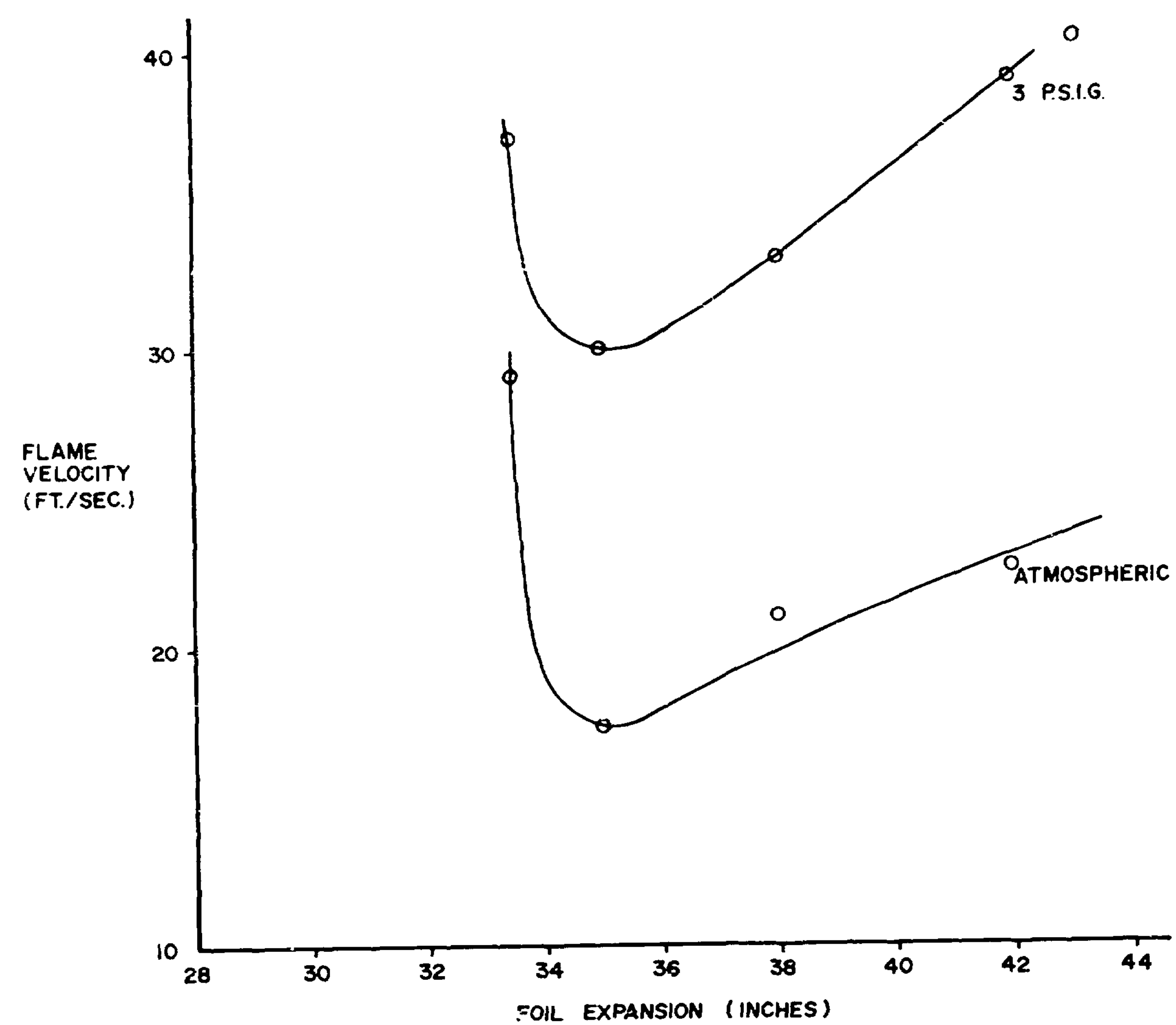

Figure 11. Effect of Foil Expansion on Flame Propagation Speed

1.3 Conclusions

The purpose of evaluating the Explosafe material in the 'worst case' conditions of the flame tube was to define an optimum material with regard to weight, preferably having comparable suppression performance to the polyurethane foams in use by the USAF. Tolerable void level with respect to acceptable overpressure and durability of the material during handling and installation were additional factors to be considered in the selection process. The optimum material was then to be used in the remaining tests of the joint USAF/U.S. Army and VIPL program where the material would be evaluated for aircraft use.

After evaluating each of the material thicknesses over the range of specific weights offered, the 2 mil material at approximately 2 lb/ft^3 was determined to be the optimum. MIL-B-83054B, the specification for polyurethane foam, requires that at a void level of 20% and an initial pressure of 17.7 psia, the combustion overpressure in the flame tube test shall not exceed 15 psid. With the selected Explosafe material, a maximum void level of only 10% is permissible in order to meet the overpressure limit. The 3 mil material offered better performance and could tolerate higher void levels but the weight penalty was greater. The 1.5 mil material offered substantial weight savings but overpressures exceeded 15 psid with a 10% void.

The 2 lb/ft^3 material is a little lighter than that which in this gauge yielded the best performance - the 36 inch expansion 2.1 lb/ft^3 type. In the event that better performance was more important than weight, this density could be specified. Conversely, if weight consideration was more important than performance and/or the application was capable of withstanding higher overpressure, then a lighter density or higher void level could be specified.

The durability of the 2 mil/3 mil materials was considered satisfactory. The 1.5 mil material was easily deformed.

1.4 Recommendations

The alternative strand width material, .040 rather than .055 inch, has demonstrated significant improvement in performance without incurring weight penalty. The tests were only conducted on the 3 mil material and were carried out by VIPL. It is recommended that more extensive testing be conducted by VIPL using the 2 mil material. If the testing confirms the improved performance, then AFWAL should undertake to validate the results with their own test program. The change offers three possible benefits - significant weight savings, higher permissible void level, or extension of the system to pressure limited applications.

It is also recommended that in the interest of further weight reduction, means of increasing the durability of the 1.5 mil material be explored.

2.0 BALLISTICS

2.1 Procedure - Rigid Tank

A ballistic optimization program was conducted by the Applied Technology Laboratory, U.S. Army and Mobility R & D Laboratories (SAVDL-EU-MOS), Fort Eustis, Virginia. The work is fully reported in Reference 3 and the test procedure and results will be summarized in this report for completeness.

The concept of the ballistic test is to determine the effectiveness of an explosion suppression system in a typical environment by direct measurement of the combustion pressure attenuation. To this end, a rigid, rectangular steel tank capable of withstanding both the high explosive blast of typical projectiles and the subsequent fuel/air combustion overpressure is used as a test chamber. The volume of the basic chamber can be increased by the removal of sidepanels and the addition of extension tanks on up to three sides. The basic tank and the tank with all extensions are illustrated in Figures 12, and 13, respectively. During the course of the testing, it was decided to conduct further tests on the 2 mil material in an intermediate tank volume made up of the basic tank plus the aft extension only, as illustrated in Figure 14.

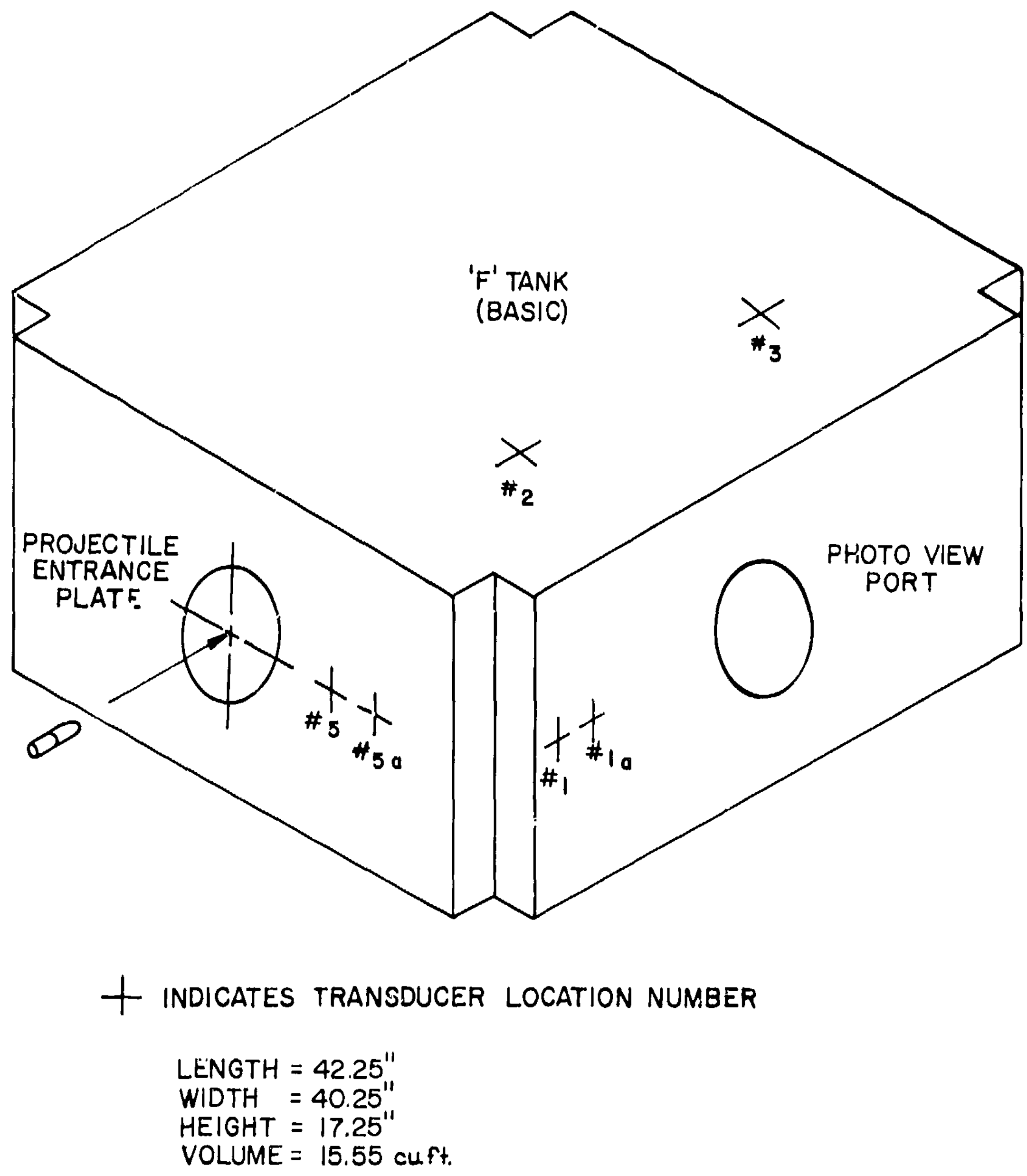

Figure 12. Ballistic Test Tank - Basic

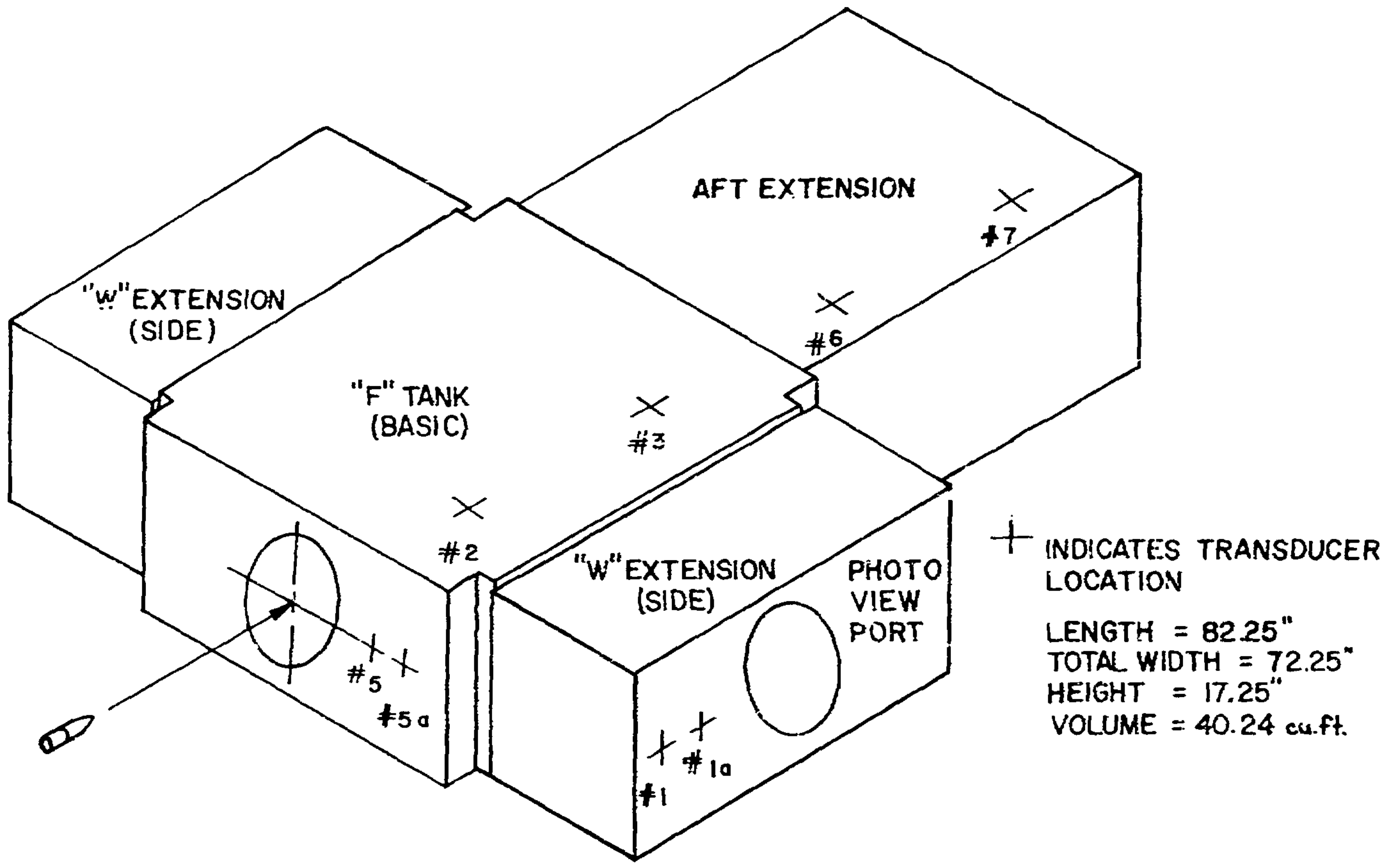

Figure 13. Ballistic Test Tank - Basic with Side and Aft Extensions

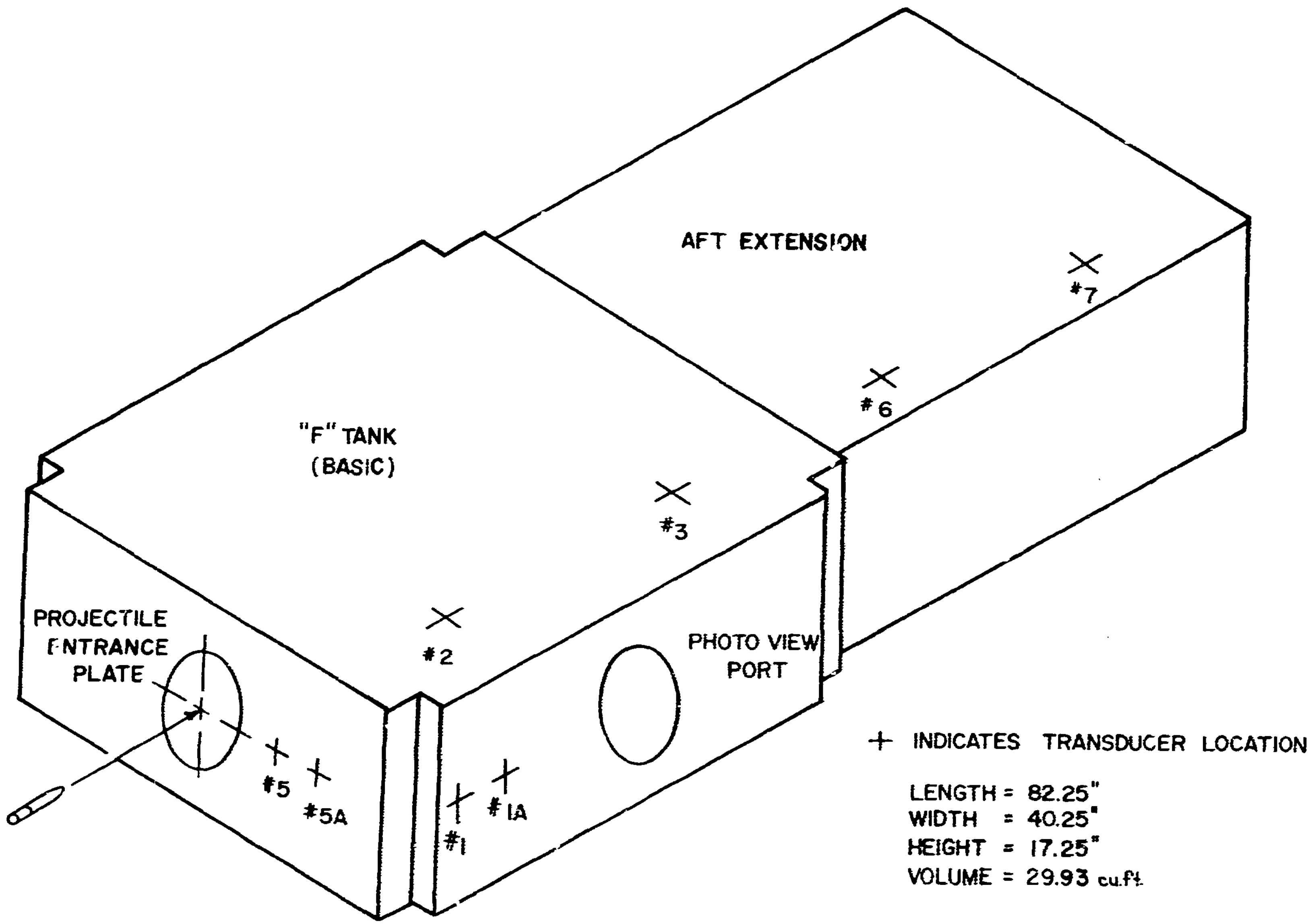

Figure 14. Ballistic Test Tank - Basic with Aft Extension Only

Figure 15, is a schematic diagram of the test site and equipment. After being evacuated to 1 psia, the test tank, containing the specimen suppression system, is pressurized with a propane/air mixture of the ratio resulting in the highest overpressure for the particular projectile as determined by base-line tests. The mixture ratio is controlled by the partial pressure method and the gases assumed to obey the ideal gas laws. The ratio is confirmed by bomb sampling and the tank pressure is then returned to ambient by venting prior to firing.

A high speed camera is provided to record the internal events through a viewing port, and numerous transducers monitor the blast and combustion pressures at selected locations. This data is stored on magnetic tape for later retrieval.

The projectiles are fired from a 23 mm Mann barrel directed at the front face of the tank on which there is mounted a detachable entry plate. Projectile velocity is measured by screens located in the trajectory and the moment of impact is recorded with the transducer data via an electrically conductive grid mounted on the entry plate.

2.2. Results - Rigid Tank

The test program was designed to evaluate the three thicknesses of foil at the optimum 3/8 inch expansion determined by the AFWAL flame tube test program. Two tank volumes were to be tested with both, fully packed and 40% voided installations. The suppression performance was to be studied with two types of projectile - the 23 mm HEI-T and .30 cal. API M-1 ammunition.

Baseline testing with the basic test tank (volume of 15.55 cubic feet) and the same tank with the aft extension and two side extensions (volume of 40.24 cubic feet) determined that maximum peak combustion overpressure occurred at a gas concentration of 4.0 volume percent propane in air with the HEI-T ignition source. With the .30 cal. API ammunition, the equivalent concentration was found to be 4.5. volume percent. These, then, were the

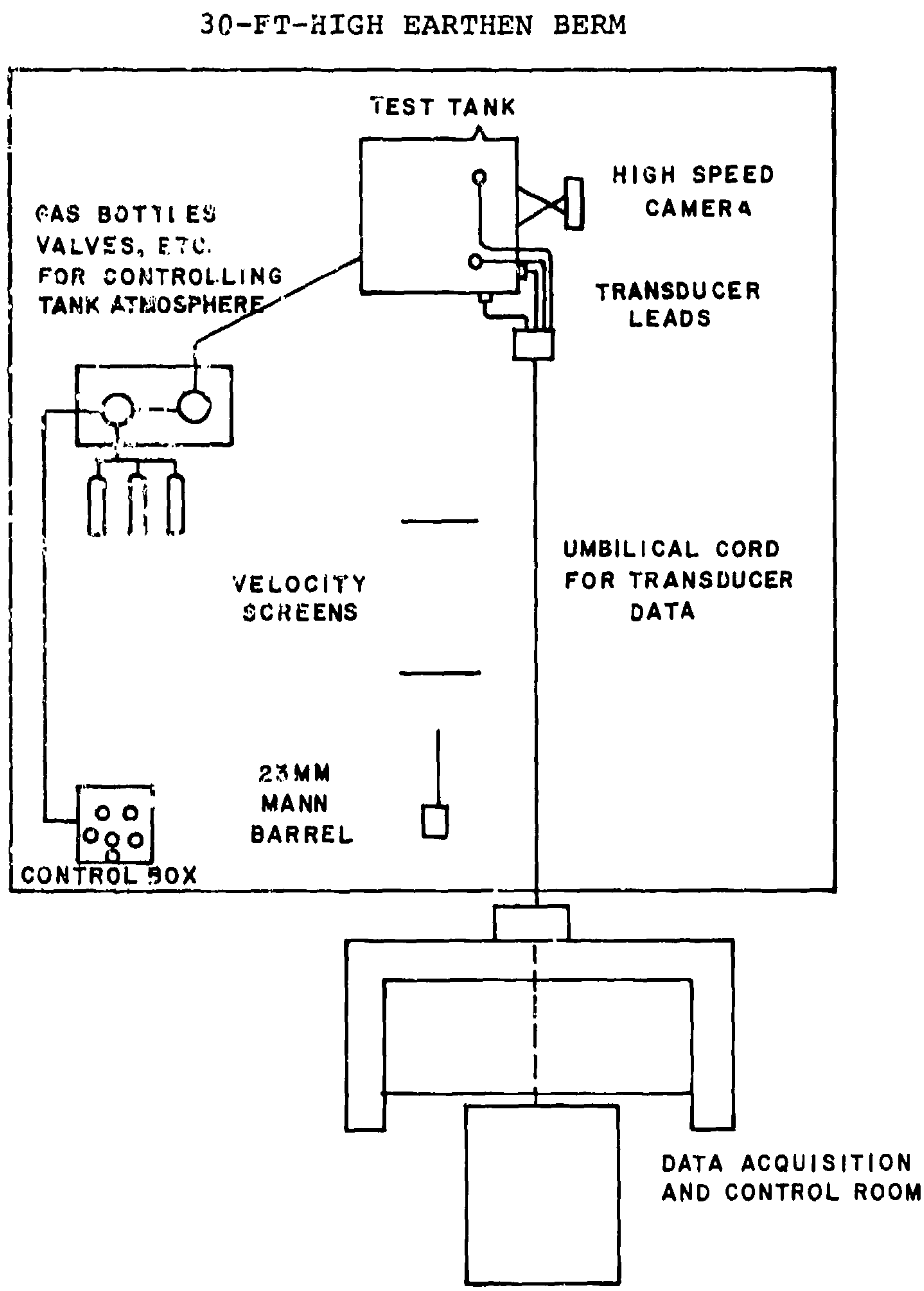

Figure 15. Ballistic Test Site and Equipment

mixtures used for the subsequent evaluation tests.

The test results with the HEI-T ignition source are summarized in Table 4. Note that the average peak overpressure is recorded here and is an arithmetic mean of 4 measurements with the large tank, 5 measurements with the intermediate tank and 3 measurements with the basic tank.

Theory predicts that during the constant volume deflagration of propane/air mixture initiated by a simple ignition source in a rigid tank, the pressure is uniform throughout the tank. This was not the case in these tests, however, because of the ignition source characteristics: the source was large relative to the tank and moved from one end of the tank to the other at a speed greatly in excess of flame front propagation speeds for this gas mixture; the incendiary particles released by the projectile were scattered throughout the tank and persisted for about one second resulting in numerous ignition sources; the release of fragments during projectile detonation caused numerous impacts and hence local ignition sites at the walls of the tank. The combustion of the gas mixture, therefore, did not depend on flame front propagation.

Despite these factors and the resulting variance, the relative magnitude of the pressure measurements was essentially predictable. Generally, the transducers located close to the projectile entrance recorded higher pressures than those further away and the transducer oriented to record the reflected pressure wave measured the highest pressure. Location of transducers in voided areas did not noticeably affect this behavior. The results in the large and small tanks are summarized in the bar charts of Figures 16 and 17, respectively. In most cases, decreasing the density of the Explosafe material by changing to a thinner gauge resulted in increased overpressure as might be expected from the flame tube tests in the previous section. Of particular interest is the reduction in overpressures as the tank volume is increased. This observation concurs with unreported work conducted by VIPL

TABLE 4. BALLISTIC TEST RESULTS SUMMARY - 23mm HEI-T

Tank Filler Material	Tank Volume (cu.ft.)	Installation Configuration	Average Peak Combustion Pressure
.003 in x 38 in Expansion 2.75 lb/ft^3 Density	15.55	Fully Packed	6.8 psig
	15.55	40% Void at Entry	40.5 psig
	15.55	40% Void at Rear	12.2 psig
	40.24	Fully Packed	3.0 psig
	40.24	40% Void at Entry	27.4 psig
	40.24	40% Void at Rear	13.8 psig
.002 in x 38 in Expansion 2.00 lb/ft^3 Density	15.55	Fully Packed	7.6 psig
	15.55	40% Void at Entry	47.0 psig
	15.55	40% Void at Rear	15.5 psig
	29.93	7.6% Void at Entry	11.7 psig
	29.93	12% Void at Rear	7.1 psig
	29.93	7.6% Void at Entry and 12% Void at Rear	7.9 psig
	29.93	22% Void at Entry	14.2 psig
	29.93	15% Void at Entry and 12% Void at Rear	11.5 psig
	40.24	Fully Packed	5.6 psig
	40.24	40% Void at Entry	23.2 psig
	40.24	40% Void at Rear	30.3 psig
.0015 in x 38 in Expansion 1.80 lb/ft^3 Density	15.55	Fully Packed	12.3 psig
	15.55	Fully Packed - 2nd Test	14.5 psig
	15.55	40% Void at Entry	41.8 psig
	15.55	40% Void at Rear	28.0 psig
	40.24	Fully Packed	5.5 psig
	40.24	40% Void at Entry	23.3 psig
	40.24	40% Void at Rear	22.3 psig

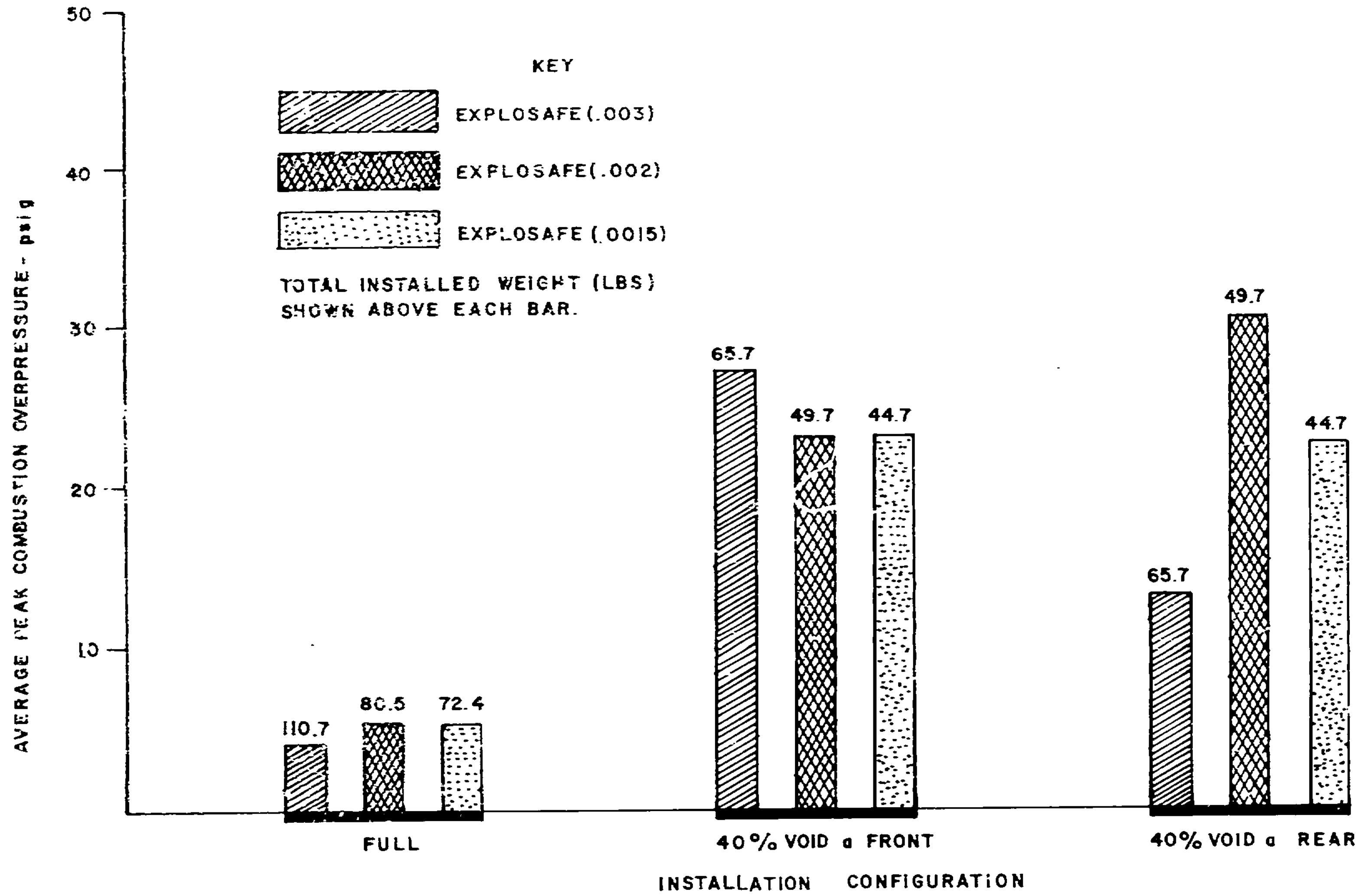

Figure 16. Ballistic Test Results - Basic Tank with Side and Aft Extensions

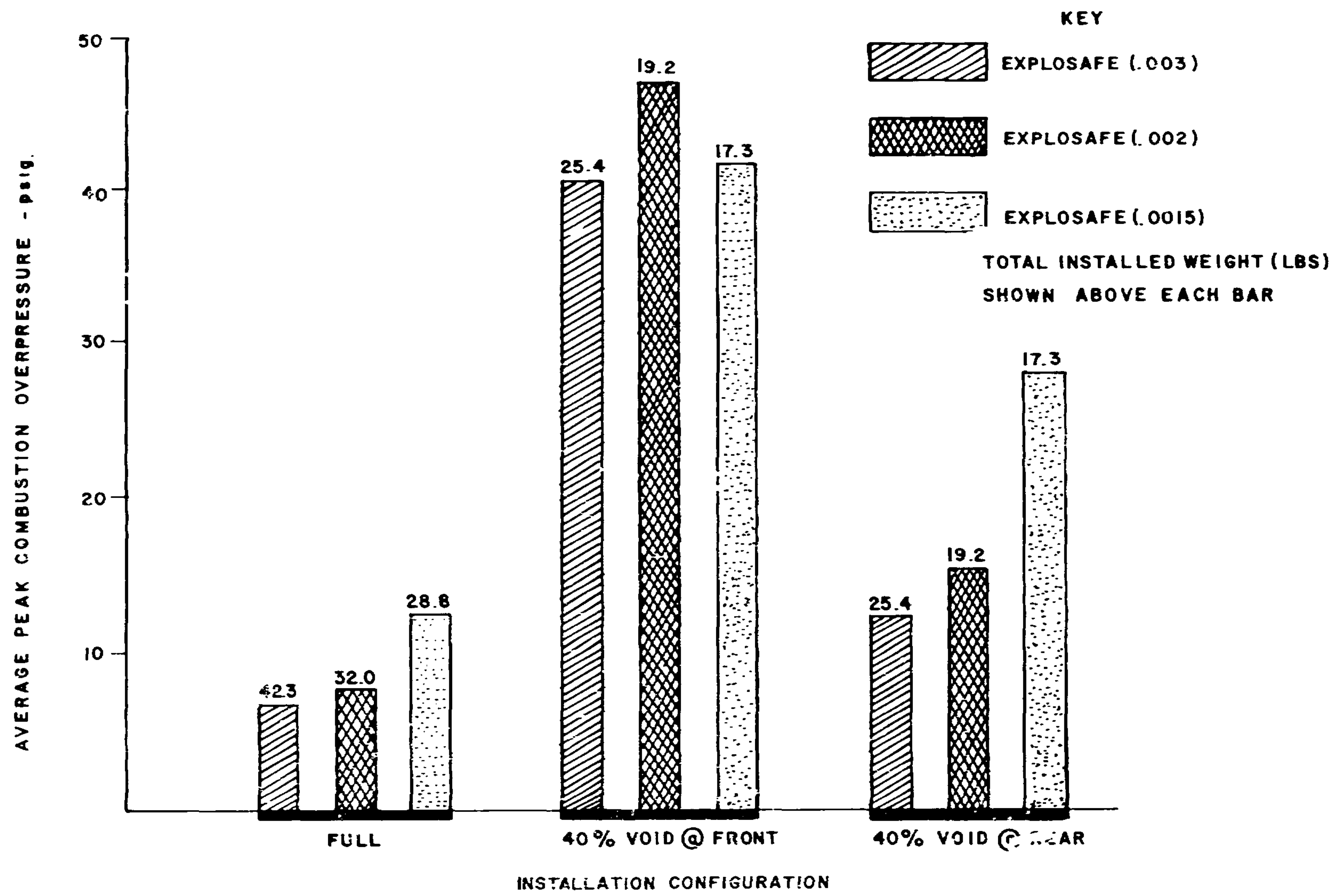

Figure 17. Ballistic Test Results - Basic Tank

on various tanks having a wide range of volumes using single point capacitor discharge spark ignition.

The effects of void location should also be noted. In the majority of cases the overpressure measured with the projectile entering a filled area of the tank is lower than when it enters a voided area. This strongly suggests that the filler mass absorbs a significant portion of the projectile blast resulting in reduced initial pressure for the subsequent combustion and hence decreased overpressure. This effect is less noticeable as the tank volume is increased, as might be expected.

Damage to the material by the projectile was proportional to the material thickness. Figures 18, 19, and 20, show typical damage to 1.5, 2, and 3 mil materials respectively. Figure 21 compares the 2 mil, 3 mil and typical reticulated polyurethane foam (RPF). The 3 mil and RPF have comparable damage; the 2 mil slightly more.

The test results obtained with the .030 cal. M-1 API ignition source are summarized in Table 5. Only the 1.5 and 2 mil materials were tested with each of the largest and basic test tanks under fully packed and 40% voided conditions. The average pressures are derived from 5 measurements with the largest volume and 4 with the small volume. The transducer data showed much less variance than with the HEI-T, obviously due to the absence of a detonation subsequent to entry. The trends are clearly evident from the table and are therefore not plotted in graph form. In general, higher combustion pressure attenuation is achieved than with the HEI-T, particularly with the larger volume tank. This also is probably a result of the absence of a detonation by the projectile. The exception to this observation, however, is the very high pressures measured in the grossly voided small tank where the projectile entered the void. This suggests that the location of the incendiary activation in small, grossly voided tanks may be a significant factor in determining peak combustion pressure.

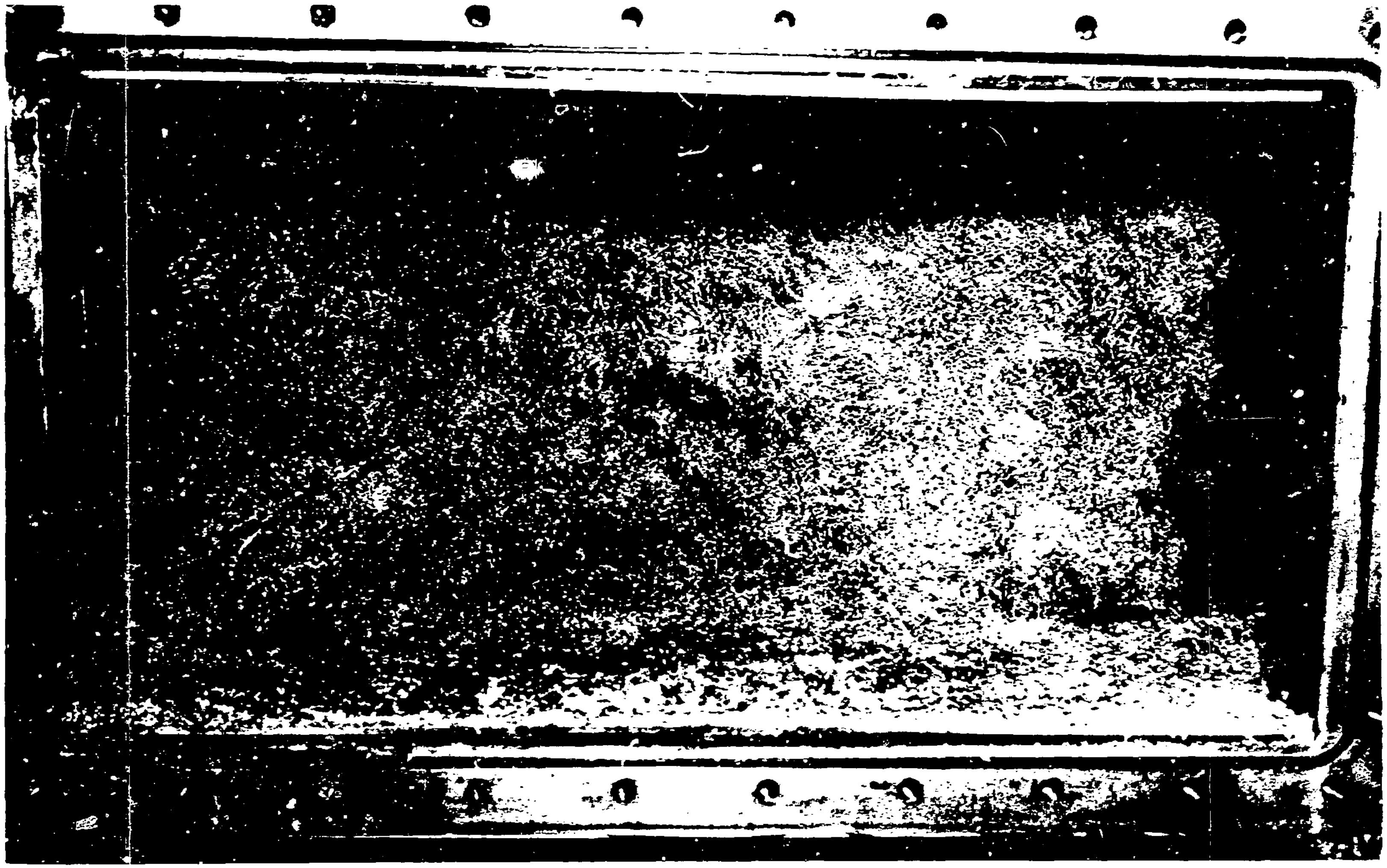

Figure 18. Damage Inflicted on 1.5 mil Explosafe Material by 23mm HEI-T

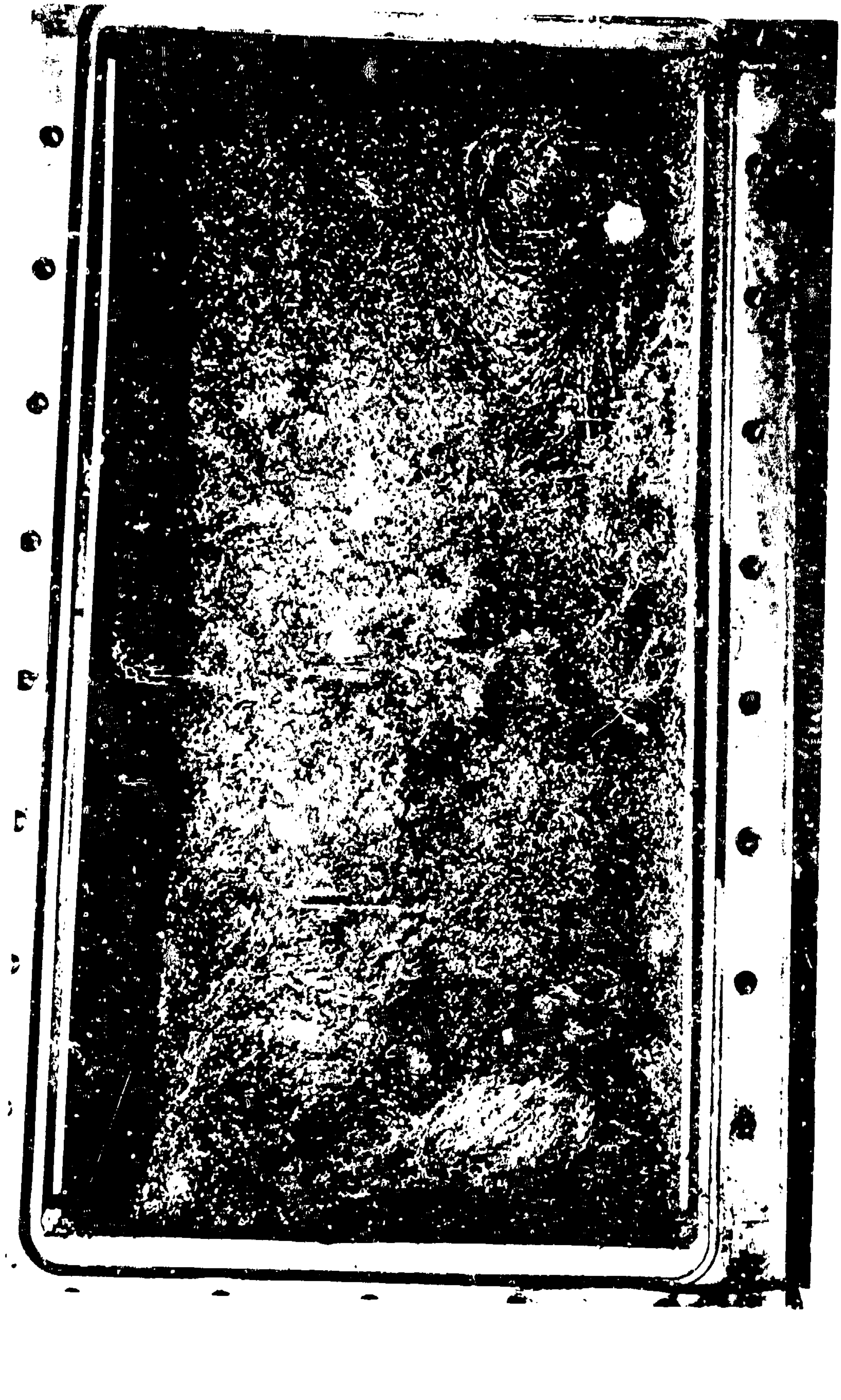

Figure 19. Damage Inflicted on 2.0 mil Explosafe Material by 23mm HEI-T

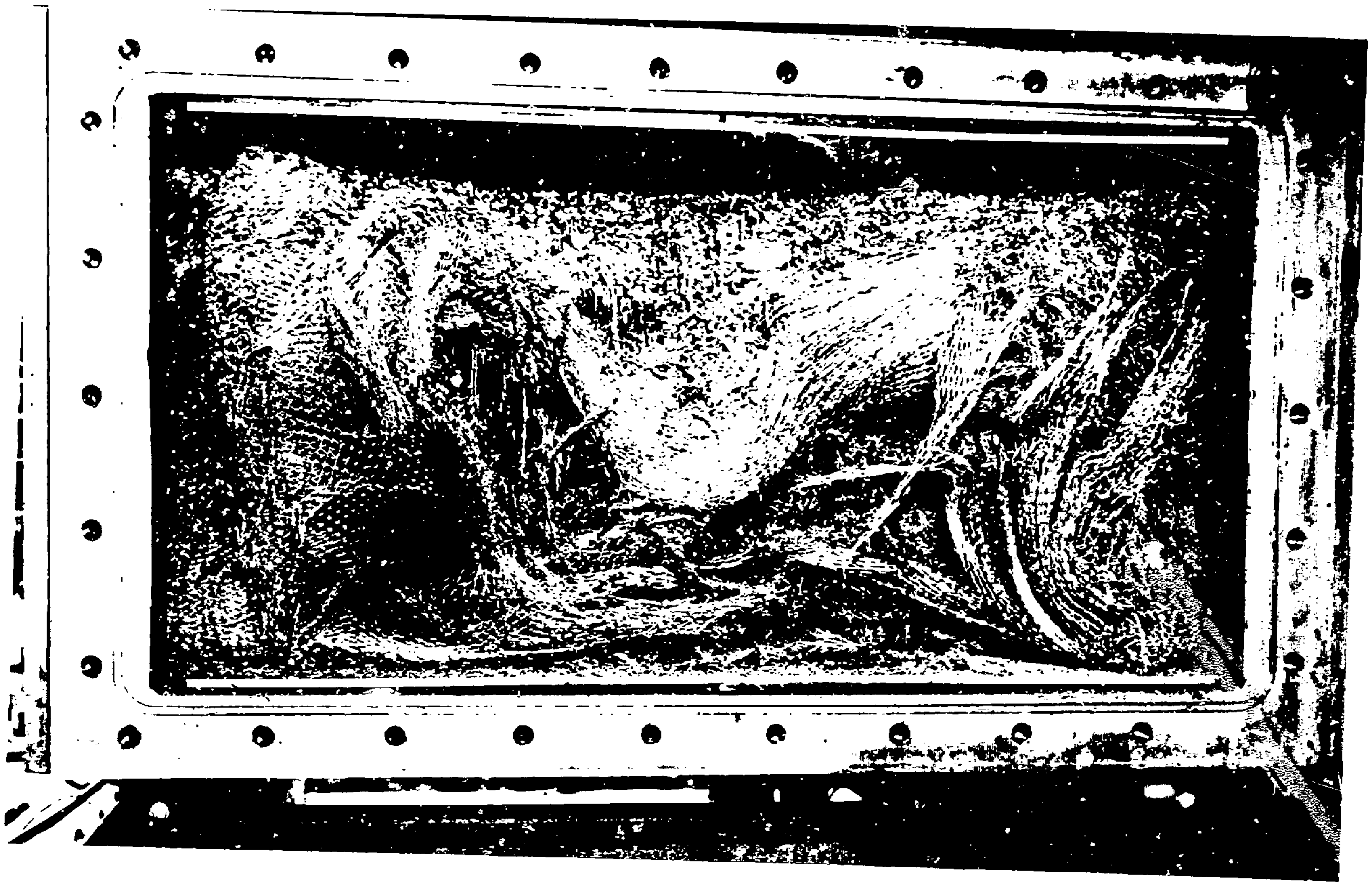

Figure 20. Damage Inflicted on 3.0 mil Explosafe Material by 23mm HEI-T

Figure 21. 2 mil Explosafe, Blue RPF, and 3 mil Explosafe (L to R)

TABLE 5. BALLISTIC TEST RESULTS SUMMARY - .30cal M-1

Tank Filler Material	Tank Volume (cu.ft.)	Installation Configuration	Average Peak Combustion Pressure
.002 in x 38 in Expansion 2.00 lb/ft^3 Density	15.55	Fully Packed	0 psig
	15.55	40% Void at Entry	37.3 psig
	15.55	40% Void at Rear	8.5 psig
	40.24	Fully Packed	0 psig
	40.24	40% Void at Entry	10.4 psig
	40.24	40% Void at Rear	11.0 psig
.0015 in x 38 in Expansion 1.80 lb/ft^3 Density	15.55	Fully Packed	0 psig
	15.55	40% Void at Entry	25.3 psig
	15.55	40% Void at Rear	6.0 psig
	40.24	Fully Packed	0 psig
	40.24	40% Void at Entry	10.3 psig
	40.24	40% Void at Rear	12.6 psig

The relationship of combustion overpressure to density demonstrated with the HEI-T projectile was less than clear in these tests. In fact, with the large volume tank the 1.5 mil material achieved similar attenuation to the 2 mil, and with the small tank the 1.5 mil achieved higher attenuation than the more dense 2 mil. This anomaly defies explanation at this point but may simply reflect the large degree of data scatter experienced with the gross voided configurations.

2.3 Procedure - External Wing Tank

Prior to the foregoing test program, a ballistic evaluation of two, 100 gallon wing tanks packed with Explosafe was made by the same agency at the request of the Naval Air Development Center. The wing tanks were manufactured by the Kellett Corporation and their installation with Explosafe is described in Appendix D 4. Briefly, the installation was made with the 2 mil material expanded to 38 inch web width, yielding a packing density of 2.15 lb/ft^3. Total void for components amounted to 5.6% of the tank volume.

The test concept was basically identical to that with the rigid tank program, i.e., fill the tank with a combustible fuel/air mixture, impact it with typical combat threats and measure the reaction with pressure transducers and high speed photography. The combustible fuel/air mixture used was targeted to be 1.4% JP-4 in air by volume and was achieved by circulating the ullage vapors from a JP-4 storage tank through the test article until a combustible condition was obtained, as illustrated in Figure 22. The vapor content was monitored with an MSA Lira Infrared Hydrocarbon Analyzer depicted in Figure 23.

Kulite model KHS pressure transducers were mounted in three locations - the sump drains at each end and a mounting eye adaptor modified to accept the transducer. The signals were recorded on a Sangamo Sabre VI magnetic tape recorded for subsequent analysis. Projectile impact time was recorded on the tape by a signal from electronic grid paper affixed to the tank. Two

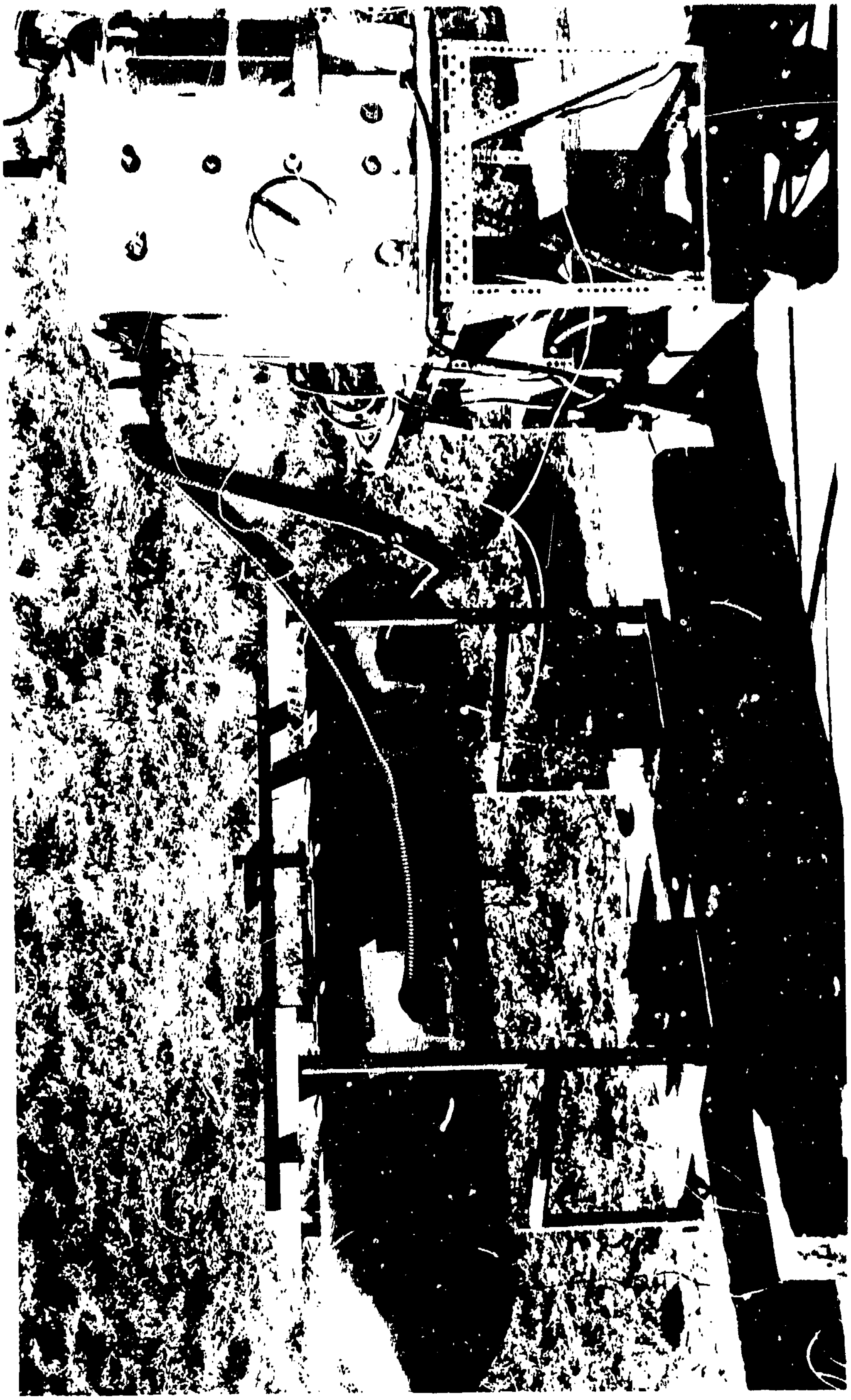

Figure 22. External Wing Tank being Prepared for Test

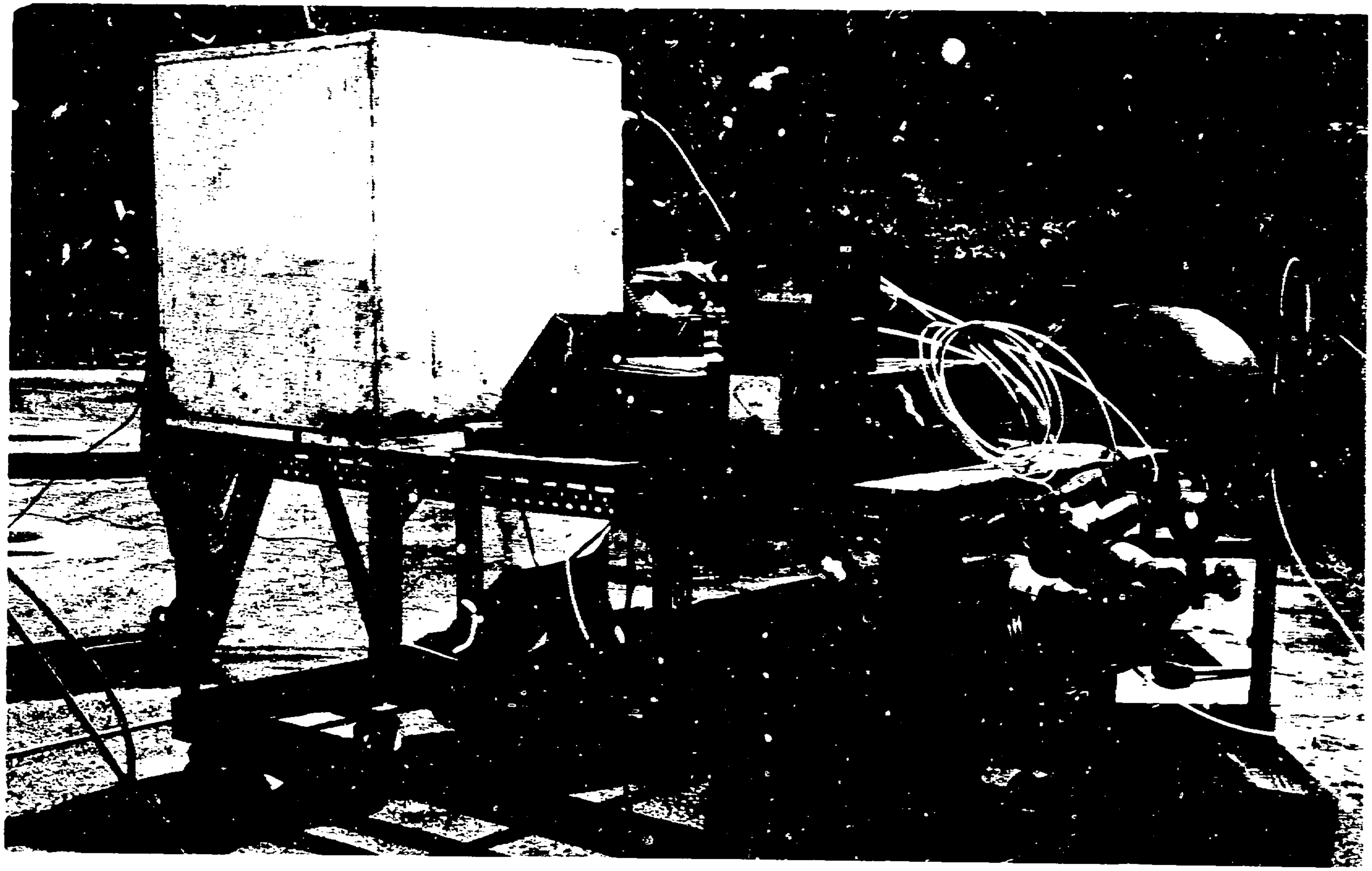

Figure 23. Vapor Generator and Monitoring Station

high speed cameras (600 frames/second) monitored the entrance and exit sides of the tank and photographic documentation was made with an Arriflex camera at 24 frames/second. A Hycam, operating at 200 frames/second, was also used during the HEI tests and still photographs were taken before, during and after each test.

Projectiles were fired by single shot Mann barrels and light screens measured the projectile velocity along its trajectory.

2.4 Results - External Wing Tank

Seven tests were conducted on the two 100 gallon wing tanks, 4 with the Explosafe material installed and 3 with it removed. The data is summarized in Table 6.

In Test #1, the 0.30 cal. MI incendiary projectile at 2000 ft/sec caused a slight pressure rise of about 3 psig and no damage to the tank, save the clean entry and exit holes. The high speed films showed internal incendiary activation at both entry and exit.

Test #2 was a repeat of #1 with the holes patched with heavy duty green tape. Substantially the same results were obtained with a pressure rise of 4 psig.

The second tank was prepared for test #3 and this was impacted with a 0.50 cal. API M-8 projectile at 90° yaw (i.e. tumbled) and 2000 ft/sec. Again, the only damage sustained was entry and exit holes with a pressure rise of 3 psig. High speed footage again showed incendiary activation.

Because these small caliber API impacts did not appear to present a severe threat, it was decided to use the Soviet 23 mm HEI-T with M9-25 (delay) fuses. Tank #2 was patched with tape and impacted at 2093 ft/sec with this projectile. The 5° and 40° cones of damage typical of this threat can be seen in Figure 24, taken from the exit side. Only a few fragments in the 150° cone penetrated the tank. Pressure rise was limited to about 5 psig and a

TABLE 6. BALLISTIC TEST RESULTS SUMMARY - 100 GALLON EXTERNAL WING TANK

	Tank #	Configuration	Vapor Content % JP-4 (vol)	Threat	Peak Pressure (psig)	Time to Peak (seconds)	Damage
1	1	With Explosafe	1.40	Cal .30 inc. M1	2.6	~.150	-Limited to entry and exit holes
2	1	With Explosafe	1.60	Cal .30 inc. M1	3.6	~.150	-Limited to entry and exit holes
3	2	With Explosafe	1.60	Cal .50 API M8	2.6	~.120	-Limited to entry and exit holes
4	2	With Explosafe	1.35	23mm HEI-T (delay fuze)	5.2	.010	-Entry hole, exit fragment damage
5	1	Without Explosafe	1.30	Cal .30 inc. M1	80.5	.100	-Limited to entry and exit holes
6	1	Without Explosafe	0.90	Cal .30 inc. M1	59.3	.080	-Limited to entry and exit holes
7	1	Without Explosafe	1.95	23mm HEI-T (delay fuze)	107.6	.003	-Catastrophic tank failure

Figure 24. Damage Inflicted on External Wing Tank with Explosafe by 23mm HEI-T (Exit Side)

small fire caused by residual fuel in the tank was extinguished with CO_2.

In order to gain some baseline knowledge of the vulnerability of this type of tank to an ullage explosion, it was decided to remove the Explosafe material from tank #1, which had only the 0.30 cal. damage, and impact it with the 0.30 cal. M1 projectile. The holes were covered with .040 inch aluminum plate. In test #5 a pressure rise of 80.5 psig was obtained, yet the tank sustained no damage Rapid venting was recorded on the high speed cameras at the wound sites and one of the bolted access plates. This test was repeated with substantially the same result and a 60 psig pressure rise. The suppression performance of the Explosafe material is worthy of note here. Attenuation ratios of between 15 and 26 were obtained with this threat.

Since the tank was still relatively undamaged, it was decided to test its ability to tolerate the 23 mm HEI-T without the Explosafe. All the damage areas were patched with 0.040 inch thick aluminum secured with sheet metal screws and sealed with RTV. In test #7 the tank was impacted with a 23 mm HEI-T (delay fuse) at 2000 ft/sec and the damage was catastrophic as shown in Figures 25, 26, and 27. The recorded pressure rise was over 100 psig. Compared to test #5 with Explosafe, this yields an attenuation greater than 20:1 and the comparative damage needs no comment.

This brief test program, although conducted prior to the optimization program, used the material which that program selected as optimum. The tests serve as confirmation of that selection and the combustion attenuation achieved was very close to that measured with the 15.55 cu ft test tank (116 gallons) - 7.6 psig in the optimization tests and 5 psig in the 100 gallon wing tank.

2.5. Conclusions.

The purpose of the ballistic test program was to evaluate the suppression performance of the Explosafe material in typical

Figure 25. Damage Inflicted on External Wing Tank without Explosafe by 23mm HEI-T

Figure 26. Damage Inflicted on External Wing Tank without Explosafe by 23mm HEI-T

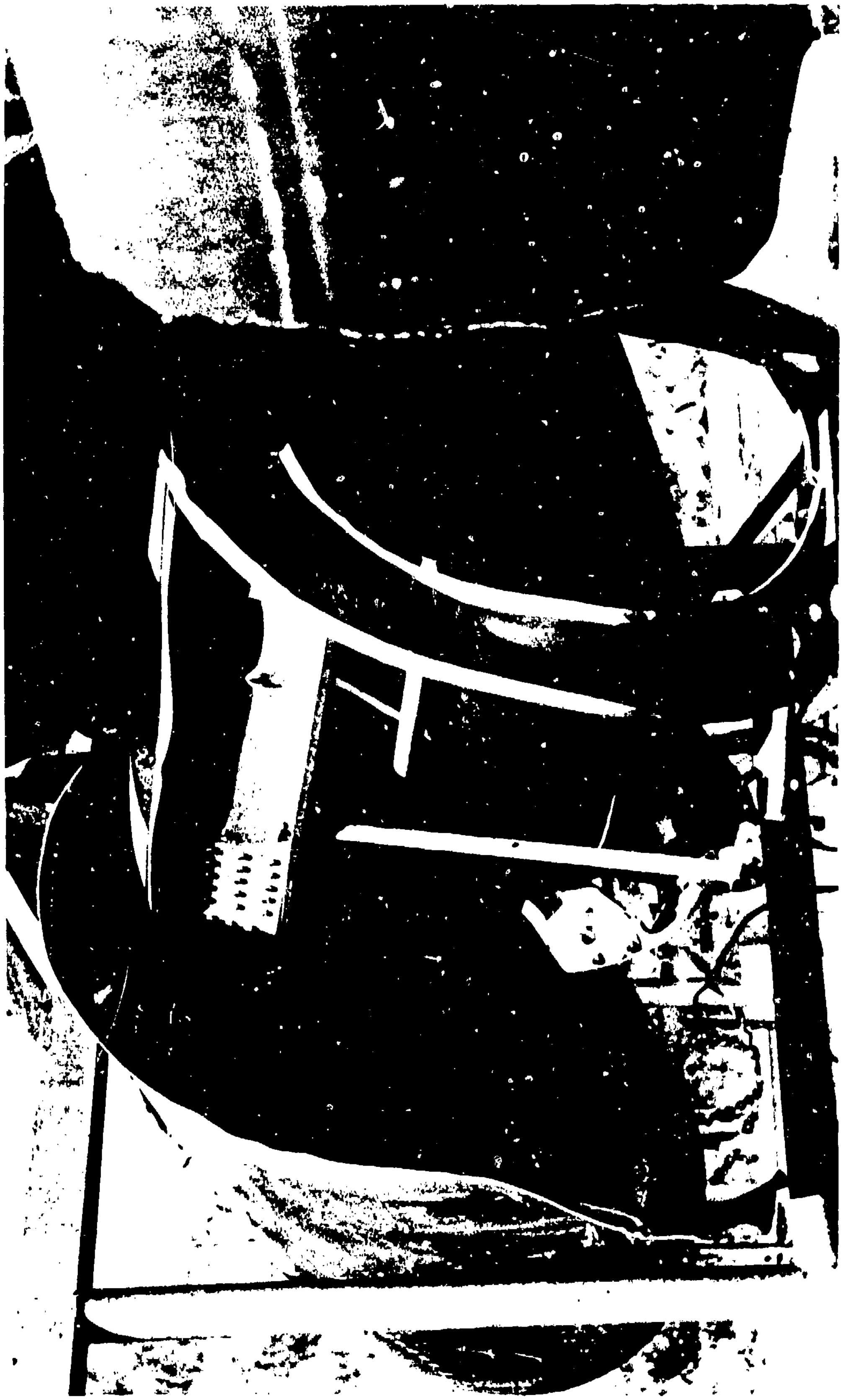

Figure 27. Damage Inflicted on External Wing Tank without Explosafe by 23mm HEI-T

environments with a restricted study of the effects of material density (as determined by foil gauge), tank volume, and combustion volume (void).

The tests with the 23 mm HEI-T projectile concurred with the flame tube testing in that similar combustion overpressures were obtained for all the materials in both void configurations. Inverse relationships between tank volume and combustion pressure and between material density and combustion pressure were demonstrated. A further dependence between projectile entry location with respect to voided areas and combustion pressure was revealed, particularly with the smaller volume tank.

The tests using the .030 cal. M-1 API ammunition generally achieved higher combustion attenuation than with the HEI-T. The dependencies of combustion pressure on threat entry to void location and on tank volume were confirmed. The effect of material density was confusing, however, at times contradicting the trend noted in the HEI-T and flame tube tests.

In comparing the three densities of material tested, the factors of weight, performance, durability during handling and susceptibility to projectile damage were considered. It was concluded that the 2 mil material was the optimum having acceptable performance in the fully packed to 15% void configurations with comparable damage from the projectile to the 3 mil but approximately two-thirds the weight of the 3 mil. Damage to the 1.5 mil material was excessive while the higher weight of the 3 mil could only be justified for performance critical applications.

The excellent performance of the selected material was dramatically demonstrated in earlier tests conducted on 100 gallon external tanks with the 23 mm HEI-T.

SECTION III

TASK II - MATERIAL PROPERTIES AND CHARACTERISTICS

1.0 PHYSICAL PROPERTIES

1.1 Procedure

Expansion Characteristics

As an aid in the optimized design and fabrication of Explosafe-protected systems, a series of tests were performed by VIPL to identify the following data as function of Final Expanded Web-width - (w):

a) AV - Surface area per unit volume of expanded foil.

b) Dp - Layers of expanded foil per inch of batt thickness.

c) P - Density, (Specific Weight) per unit volume of expanded foil.

Two studies were carried out on .055 inch strand width material, with the foil thickness being held at .003 inch and .002 inch, respectively. A further study centered around a .040 inch wide strand using .003 inch material thickness.

The sample preparation procedure followed throughout these series of tests consists of fanfolding a number of layers of material expanded to a range of web-widths from the raw foil web 14.0 inches wide.

Test samples were placed on a test bench, layers horizontal, with a load representing a constant pressure positioned centrally on the batt. Layer count and batt height (thickness), length, and width were measured and recorded. With the load removed, the batt weight was determined.

1.2 Results

The results of the studies are recorded in Appendix B 1 and B 2, the former covering the .003 inch material with both .055 inch and .040 inch strandwidths and the latter covering the .002 inch material with .055 inch strandwidth.

The results are summarized in tables 7A and 7B for the .003 inch and .002 inch foils respectively. All the values here are taken from the graphs drawn via a least squares fit of the experimental results. Individual samples of material may vary from these nominal values because of process and raw material deviations.

1.3 Recommendations

Promising results were reported in the previous section on the performance of the .040 inch strandwidth material. Those tests were conducted with material .003 inch thick.

In the event that tests with the .002 inch thick material are equally impressive, the expansion characteristics of the .002 inch thick x .040 inch strandwidth material should be established.

2.0 ENTRAINED SOLID CONTAMINATION

2.1 Procedure - Laboratory Method

Two cylindrical specimens of Explosafe material were tested for levels of entrained solid contamination to requirements outlined in section 4.6.15 of MIL-B-83054B (USAF). Gravimetric analyses to determine total contaminants were performed per procedure specified in ASTM D-2276-73 (Re-approved 1978), method A2, entitled "Determination of Particulate Contaminant by Laboratory Filtration". Each sample measured 8.25 inches in diameter by 8.00 inches high and was cut from a single, rectangular, fan-folded batt fresh off the production line. The finished sample dimensions correspond to a material volume of 0.25 cubic feet. Sample No. 1 weighed 239.4 grams, Sample No. 2 weighed 240.5 grams.

TABLE 7A. PHYSICAL PROPERTIES DATA - 3 MIL EXPLOSAFE EXPANSION CHARACTERISTICS

Sw Strand Width (in)	W Expanded Width (in)	AV Specific Surface Area (sq.ft./cu.ft.)	DP Layup (layers/in.)	P Expanded Foil Specific Weight (lb/cu.ft.)
.040	28	184	14.34	3.70
.040	29	180	14.37	3.64
.040	31	174	14.42	3.52
.040	33	167	14.47	3.40
.040	34	164	14.50	3.34
.040	37	154	14.58	3.16
.040	38	150	14.61	3.10
.040	39	147	14.64	3.05
.040	41	140	14.70	2.93
.040	44	130	14.81	2.76
.055	28	199	15.30	4.46
.055	29	190	15.05	4.24
.055	31	176	14.65	3.85
.055	33	163	14.20	3.51
.055	34	157	14.00	3.36
.055	37	141	13.40	2.98
.055	38	136	13.20	2.86
.055	39	132	13.05	2.75
.055	41	124	12.75	2.57
.055	44	113	12.35	2.31

TABLE 7B. PHYSICAL PROPERTIES DATA - 2 MIL EXPLOSAFE EXPANSION CHARACTERISTICS

Sw Strand Width (in)	w Expanded Width (in)	AV Specific Surface Area (sq. ft./cu.ft.)	DP Layup (layers/in.)	P Expanded Foil Specific Weight (lb/cu.ft.)
.055	28	188	14.9	2.69
.055	29	183	14.7	2.62
.055	31	174	14.5	2.50
.055	33	165	14.2	2.36
.055	34	160	14.0	2.30
.055	37	147	13.6	2.10
.055	38	142	13.5	2.04
.055	39	138	13.3	1.97
.055	41	129	13.1	1.84
.055	44	115	12.7	1.65

The following are the foil specifications:

Alloy:	Aluminum 3003
Temper:	H24
Thickness:	0.002 inch
Expansion:	38 inches
Stacking:	13.75 layers/inch (110 layers total)
Batch No:	1-51355-01, Reynolds Aluminum Co.

Preparation of Apparatus

All glassware and other equipment to be used was cleaned following the procedure outlined in "Preparation of Apparatus" (ASTM D2276-73). They were washed in warm water containing detergent, rinsed with warm water, then rinsed with deionized distilled water followed by rinsing with isopropyl alcohol, and finally with petroleum ether (boiling range 35-60°C). The petroleum ether used had been pre-filtered through 0.45μm cellulose acetate/nitrate membrane filters while 0.50μm teflon filters were used to pre-filter isopropyl alcohol as, in this case, the cellulose acetate/nitrate filters were not compatible.

The test and control membrane filters used were 47mm diameter MF-Millipore (cellulose acetate/nitrate), Type AA (0.8μm pore size). These were oven-dried for 30 minutes at 90°C and then cooled for 30 minutes to allow them to come to equilibrium with ambient air temperature and humidity prior to weighing on a 5 decimal place balance.

Experimental Procedure

Each specimen was placed in the center of the tumbler of a U.S. Testing Company model 6523 dry cleaning machine. About 4 liters of reagent grade iso-octane fluid was freshly filtered into a filtering flask through an MF Millipore, Type AA (47mm, 0.8μm) membrane filter. About 3 liters of this fluid was poured into the tumbler and the test cycle was run at 45 rpm for exactly 5 minutes. At the end of the test cycle, the specimen was raised above the fluid level in the tumbler and allowed to drain for 5 minutes. The test fluid was filtered through the pre-weighed test and control filters. The remaining 1 liter of pre-filtered iso-octane was used to rinse the particulate matter from the tumblers onto the filter. A solvent filtering dispenser was used at this stage to direct a hard jet of fluid into the tumbler and on the inner wall of the funnel to wash the particulate matter down onto the filter. The tests and control filters were removed from the filter base and placed in a covered, glass petri dish.

The above procedure was repeated for the second Explosafe sample. Prior to these runs, 2 blank runs had also been performed. All the filters were oven dried, cooled to ambient conditions, deionized, and weighed. First, total weights of all the matter collected were recorded. Then, a second weighing was taken after removing a flake of aluminum foil off one of the filters.

2.2. Results - Laboratory Method

The results are shown in Table 8. The weights of particulates were calculated as outlined in section 9, "Calculation and Report", Method A, of ASTM D2276-73. The initial weight, W_1, of the test membrane filter was subtracted from the final weight, W_2. Similarly, the initial weight of the control membrane filter was subtracted from the final weight. The weight of the contaminants is $(W_2-W_1)_{test} - (W_2-W_1)_{control}$ and is reported, after correction, in milligrams per cubic foot of material.

Visual inspection of the residue in the filters showed the contamination, for the most part, to be gray dirt interspersed with specks of fine aluminum dust.

The contaminant weights recorded were 13.9 and 12.2 milligrams per cubic foot for the two samples, respectively. The latter figure was lowered to 8.6 milligrams per cubic foot after removing a flake of aluminum foil off the filter. The average weight of the contaminants was 13.05mg when the foil flake was included and 11.25mg with the foil flake removed.

TABLE 8. ENTRAINED SOLID CONTAMINATION - LABORATORY METHOD

Test No.	Sample Description	Filter No.	Initial Weight of Filter (W_1) mg.	Final Weight of Filter (W_2) mg.	Difference in Weight ($W_2 - W_1$) mg.	Particulate Contamination $(W_2-W_1)_T-(W_2-W_1)_C$ (mg/run)	Particulate Contamination (mg/cu.ft.)**
1	Blank	2T	78.94	78.61	-0.33	0.20	-
		2C	78.72	79.19	0.53		
2	Batt No. 1 (0.25 cu.ft)	3T	77.41	80.72	3.31	3.67	13.9
		3C	78.21	77.85	-0.36		
3	Batt No. 2 (0.25 cu.ft)	4T	80.78	83.62,82.73*	2.84, 1.95*	3.24, 2.35*	12.2, 8.6*
		4C	80.93	82.53	-0.40		

T = Test Filter

C = Control Filter

* Value obtained after removing a flake of aluminum foil from the particulate matter collected.

** These values have been corrected for the blank value (0.20 mg) obtained in Test 1.

Discussion of Results

When the test fluid is poured out from the dry cleaning rig, it flows over the lip of the tumbler and into the groove behind the curled edge where it picks up dirt. On the first blank run, noticeable quantity of dirt was picked up and transferred onto the filter. Therefore, this blank run has been ignored. The groove behind the lip was difficult to reach and clean. After further attempts at cleaning, another blank run was performed and a minute quantity of dirt was once again noticed on the filter. The increase in weight of the filter was 0.20 milligrams and this value was used to correct the particulate weights in subsequent tests.

Upon initial over drying, the membrane filter curled noticeably and lost some weight. Since the filter material is reported to be hydrophilic, water is picked up again when it is cooled under room temperature and humidity conditions. The amount of water lost and picked up again was found to vary. This accounts for the negative weights which appear in Table 8. Less water had been re-absorbed after the second drying than after the first. The need for using a control filter is thus made apparent, and it is essential that this be weighed immediately after weighing the test filter.

2.3 Procedure - Field Fill and Drain Method

In conjunction with the dynamic slosh test described in Task III, the 200-gallon external pylon tank packed with Explosafe (see Appendix D 3 for Explosafe installation details) was subjected to three fill and drain cycles under supervision of AFWAL/POSH and ASD/ENFEF representatives. The tank was filled with JP-8 fuel from 55-gallon drums and a sample of fuel was taken at the inlet during each fueling. After a soak time of 30 minutes fuel samples were taken from the tank's jiffy drain during each defueling at the beginning, mid point and end of the drain cycle. Sample containers used were 1 quart bottles precleaned in accordance with ASTM procedure D2276-73. Determination of the increase in contamination level in the drain samples in relationship to the fill sample was done in accordance with ASTM procedure D2276-73, Appendix A 2.

To save defueling time, the fuel was evacuated via the fuel pick-up tube with the tank pressurized by air to about 9 psig. The defueling was stopped at the mid fuel level (as seen through the tank's observation windows) and once again, at the point of cavitation. Drain samples were taken at each stop after relieving the tank of air pressure.

2.4 Results - Field Fill and Drain Method

Although the test fuel had been clay treated, considerable amount of water was seen in the fill samples. Some particles of dirt were also observed in the first fill sample. It was for this reason that the fuel pick-up tube of the pump was raised a few inches from the bottom of the supply drums during fueling. In doing so, the supply of new fuel was exhausted halfway through the third fill as only enough fuel for three, 200-gallon fills was supplied. The remainder of the tank was, nevertheless, filled with contaminated fuel drained from the first and second fills, using fuel only from the top third of the barrel. This complete fill was necessary as fuel retention and displacement tests, which are described in para. 3.0 of this section were carried out simultaneously with the fuel contamination test.

Table 9 lists the contamination results of the first and second fills and drains. They average 1.33 milligrams of solids per gallon for the first drain, reducing to 0.52 milligrams per gallon for the second drain. The residue collected consisted of dirt, fiber, and aluminum dust.

The data for the third fill and drain is not listed in the table because contaminated fuel was used for this run. It is however, attached as Appendix B 3. It should be pointed out that the low baseline contamination level for fill 3 is misleading as this was derived from the inlet sample taken before the fresh fuel supply was exhausted.

TABLE 9. ENTRAINED SOLID CONTAMINATION - FIELD FILL AND DRAIN METHOD

WPAFB Sample No.	Fill No.	Fuelling Solids W_1 (mg/qt)	Defuel Cycle	Defuel Solids (mg/qt)	Defuel Avg. Solids W_2 (mg/qt)	Entrained Solids (W_2-W_1) (mg/qt)	Entrained Solids (mg/gal U.S.)
ASD - -	1	1.0*					
- 1			1 (Full)	0.9			
- 2			1 (Midway)	1.2			
- 3			1 (Empty)	1.9	1.33	0.33	1.33
- 4	2	1.0					
- 5			2 (Full)	0.9			
- 6			2 (Midway)	1.4			
- 7			2 (Empty)	1.1	1.13	0.13	0.52

* Value not made available. Assumed to be same as for Fill No. 2

2.5 Conclusions

2.5.1 Laboratory Method

The aluminum flake removed off the test filter was, in essence, a part of the explosion suppression material and is not considered to be a contaminant. When computations are made of contamination values, the weight of such foil flakes should be disregarded. The true contamination level, thus averaged, is 11.25 milligrams per cubic foot of Explosafe material. This figure is close to the 11.0 milligrams of entrained contaminants allowed per cubic foot for reticulated polyurethane suppression material, according to MIL-B-83054B.

2.5.2 Field Fill and Drain Method

The above mentioned USAF criteria requires fuel tanks equipped with explosion suppression material to be filled and drained a minimum of three times, or repeatedly, if necessary, until the increase in fuel contamination is not greater than 1 milligram per gallon. This criteria was met by Explosafe after just two fill and drain cycles.

2.5.3 General

The low levels of contamination recorded are, to some extent, tied to the development, by Explosafe Division, of a high-speed, continuous foil slitting machine equipped with a rotary slitter head. Shearing of foil with rotary slitters is cleaner when compared with conventional guillotine type shearing methods, resulting in generation of less free and partially attached slitter dust. When aggravated by slosh, both types of dust particles can be dislodged from the foil to contaminate the fuel.

Photomicrographs shown in Figures 28 and 29 dramatize the difference in the slit edges of foil cut by the two shearing methods.

Figure 28. Slit Edge of Aluminum Foil Cut by Rotary Shears (Magnification: 850x)

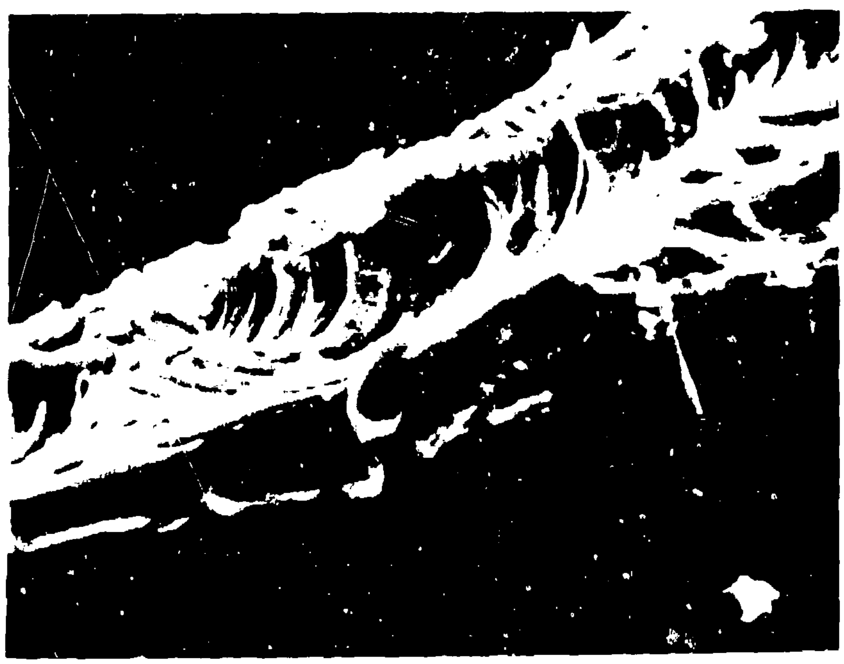

Figure 29. Slit Edge of Aluminum Foil Cut by Guillotine Shears (Magnification: 850X)

2.6 Recommendations

The fine specks of aluminum dust observed on the filter pads originate from the web slitting and batt shaping operations during manufacturing. Although low levels of entrained contaminants were recorded, the figures can still be reduced if dirt and slitter dust is removed by in-line installation of commercially available web cleaning equipment. If desired, further reduction in contamination level of finished batts can be accomplished by a combination of Freon vapor and distillate spray rinsing.

3.0 FUEL DISPLACEMENT AND RETENTION

3.1 Procedure - Laboratory Method

Fuel and water displacement and retention tests were performed on material of 2 different thicknesses, expanded to a range of densities. Procedural guidelines were taken from paragraphs 4.6.9, 4.6.9.1 and 4.6.10.1 of MIL-B-83054B. Deviations are incorporated below.

The test rig (Figure 30) consisted of the 7 x 7 x 10 inch galvanized sheet tank called out in paragraph 4.6.10.1 for retention testing. Approximately 6.5 inches above the bottom of one of the tank walls, an overflow hole was provided for displacement testing.

Jet A-1 fuel and distilled water were used as test fluids. Fluid temperatures and densities were recorded during the testing. All test fuels were filtered. In the water tests, only 2 runs were performed in each batch of distilled water. All water tests were run first. Tests were conducted at ambient conditions using foil cut into 6 x 6 x 6 inch cubes, weighed within 0.1 gm accuracy.

For displacement tests, the tank was filled with fluid past overflowing and allowed to drain through the overflow hole until the flow stopped. Each test specimen was slowly lowered into the test fluid onto stainless steel rods positioned on the bottom of the tank to support the specimen. Batts were oriented with layers horizontal to approximate a worse case condition. Displaced fluid

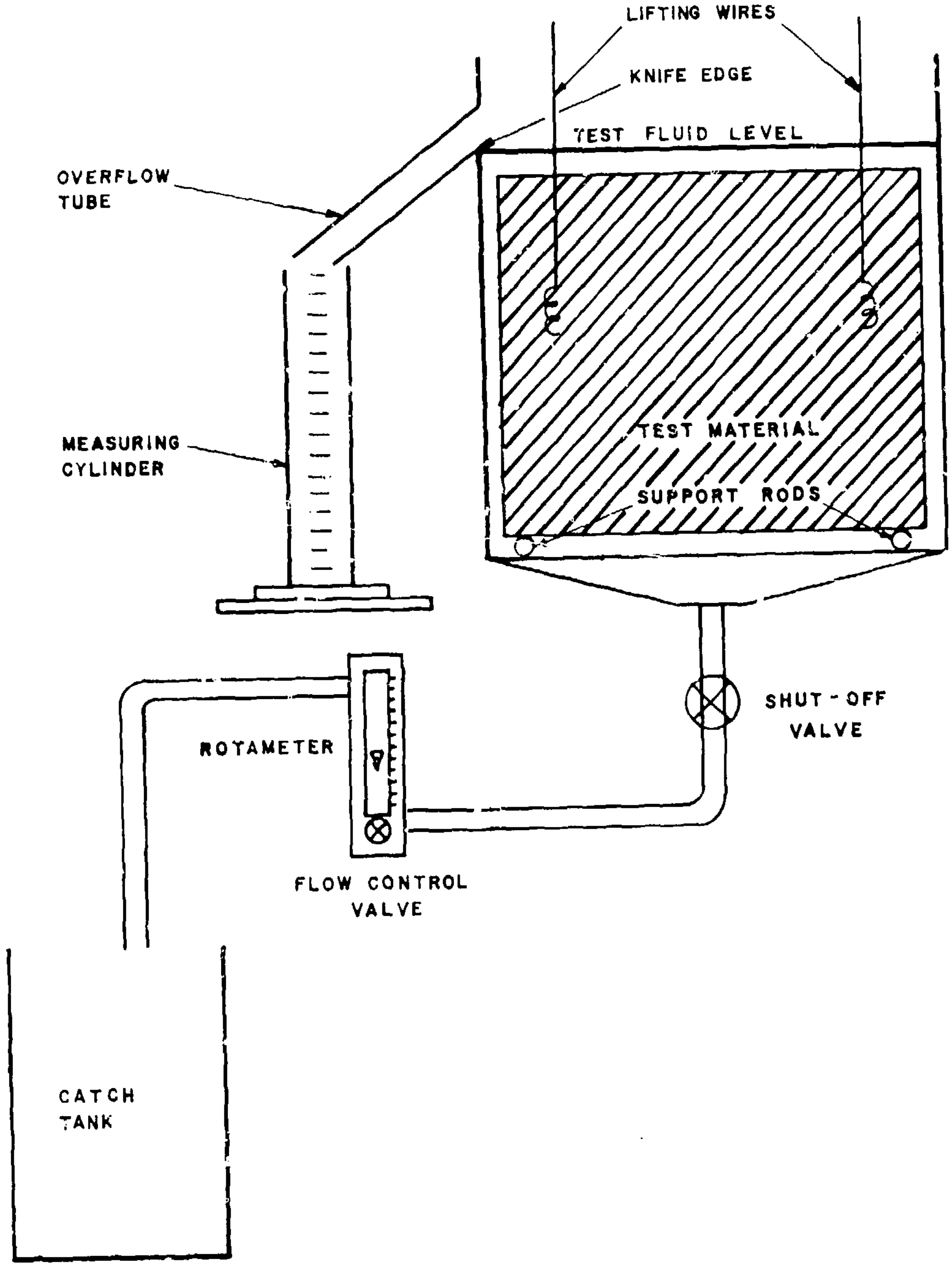

Figure 30. Retention and Displacement Test Rig

was collected in a dry, graduated cylinder and the volume of fluid was recorded for each specimen.

To obtain the retention values, the fluid in the rig was drained through the drain valve located in the bottom of the tank. Flow rate was monitored by a flow rotameter and held to 500 ± 50 cc/minute by continuous adjustment of an in-line flow valve, to compensate for head loss.

On completion of drainage, each sample was allowed to stand for an additional 2 minutes, then carefully removed from the test rig and weighed.

3.2. Results - Laboratory Method

The test results of water and fuel volumes displaced and retained by foil are shown in Table 10. Figures 31 and 32 show the plots of percent volume displacement versus material specific weight for the water and Jet A-1 fuel tests, respectively. Figures 33 and 34 show the plots of percent volume retention versus material specific weight for the water and Jet A-1 fuel tests, respectively. The raw data appears in Table B4-1 of Appendix B 4.

Percent of volume displaced was calculated using the following formula:

$$\text{Displacement (\% Volume)} = \frac{\text{Displaced Fluid Volume}}{\text{Specimen Volume}} \times 100$$

Fluid retention values were calculated using specimen weights obtained before and after wetting:

$$\text{Retention (\% Volume)} = \frac{\text{(Wet Specimen Wt. - Dry Specimen Wt.}}{\text{Sample Vol. x Density of Fuel}} \times 100$$

Displacement values obtained by the laboratory method are compared in Table 10 with values obtained by calculation.

TABLE 10. DENSITY, DISPLACEMENT AND RETENTION DATA

Foil Material			Laboratory Method				By Calculation	Field Method **	
Thickness (in.)	Expansion (in.)	Density (lb/ft^3)	Displacement (% Volume)		Retention (% Volume)		Displacement (% Volume)	Displacement (% Volume)	Retention (% Volume)
			Water	Jet A-1	Water	Jet A-1		JP-8	JP-8
.002	32.0	2.40*	1.52*	1.50*	1.49*	1.10*	1.43		
.002	34.0	2.28	1.30	1.32	1.39	1.06	1.35		
.002	-	2.13***	-	-	-	-	1.26	1.09	1.06
.002	36.5	1.99	1.03	1.14	1.02	0.84	1.18		
.002	40.5	1.92	0.98	1.10	0.83	0.65	1.14		
.003	32.0	3.52*	1.86	2.08*	1.65*	1.04*	2.09		
.003	34.5	3.20	1.56	-	1.49	-	1.90		
.003	35.5	3.01	-	1.83	-	0.82	1.79		
.003	38.0	2.75*	-	1.64	1.22	0.74*	1.64		
.003	40.0	2.66	-	-	1.13	-	1.58		
.003	42.3*	2.50*	1.41*	1.33	0.98	0.65*	1.48		

* Average of available data

** Field method described in 3.3

*** Packing density

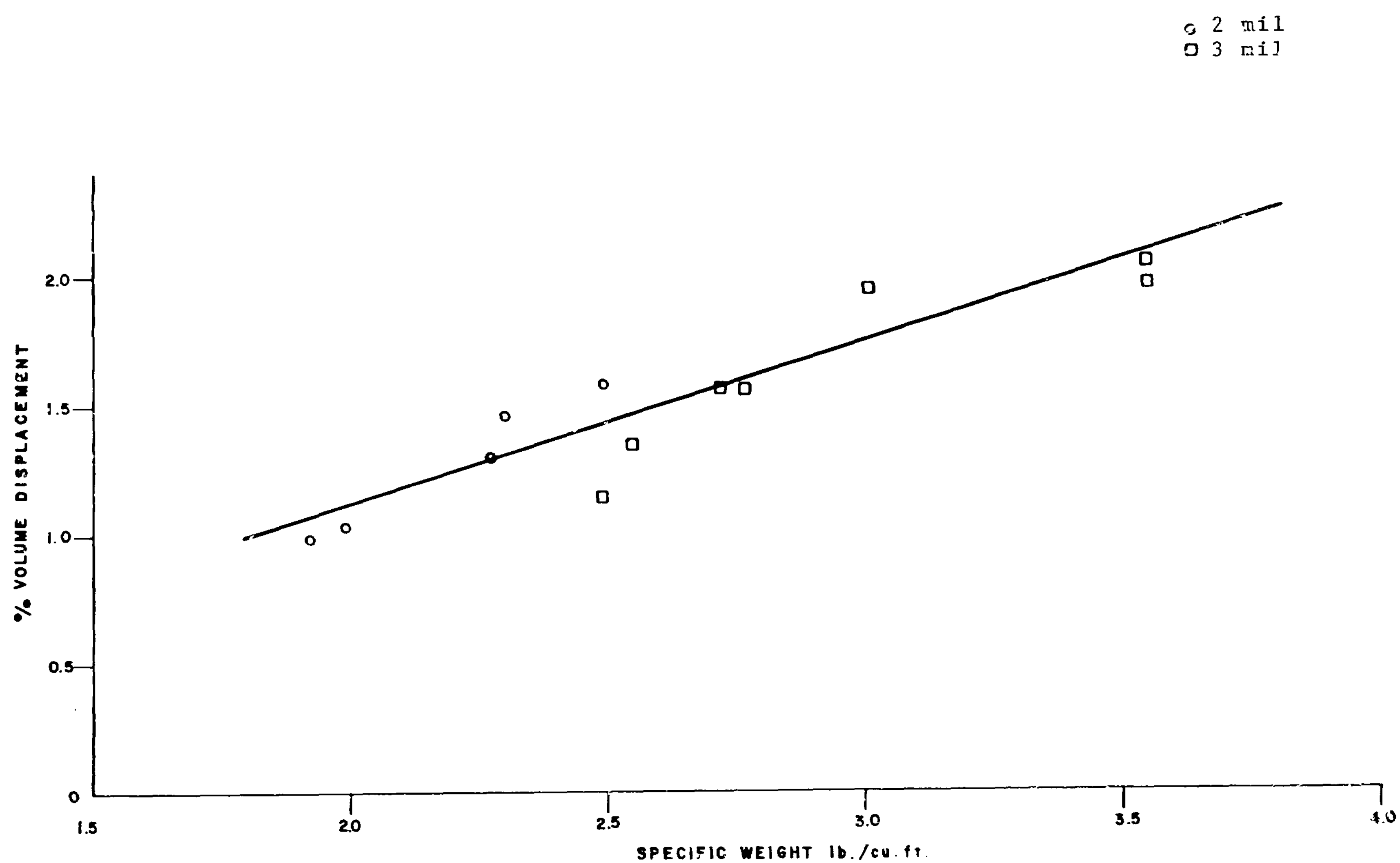

Figure 31. Displacement versus Foil Specific Weight - Water Tests

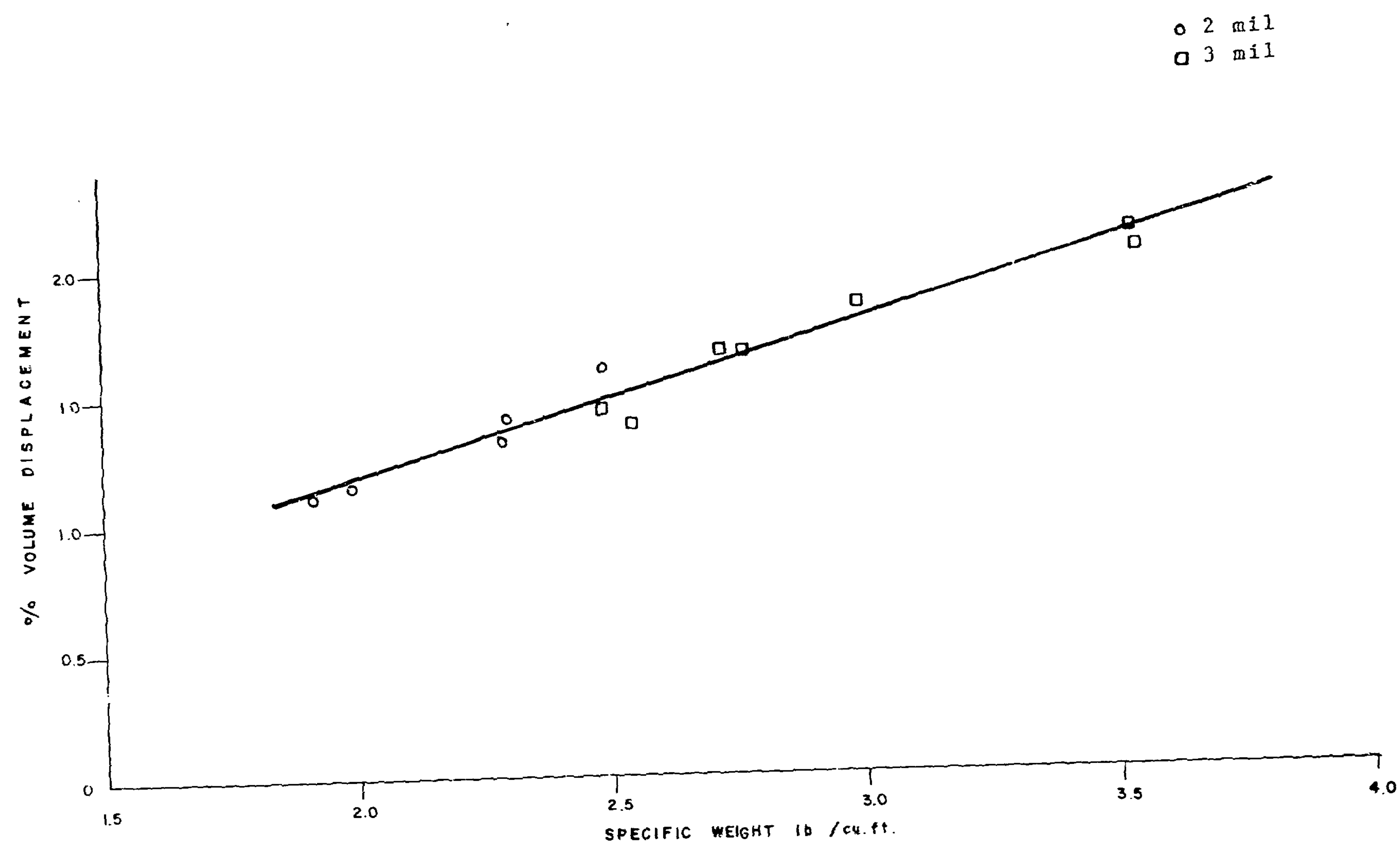

Figure 32. Displacement versus Foil Specific Weight - Jet A-1 Tests

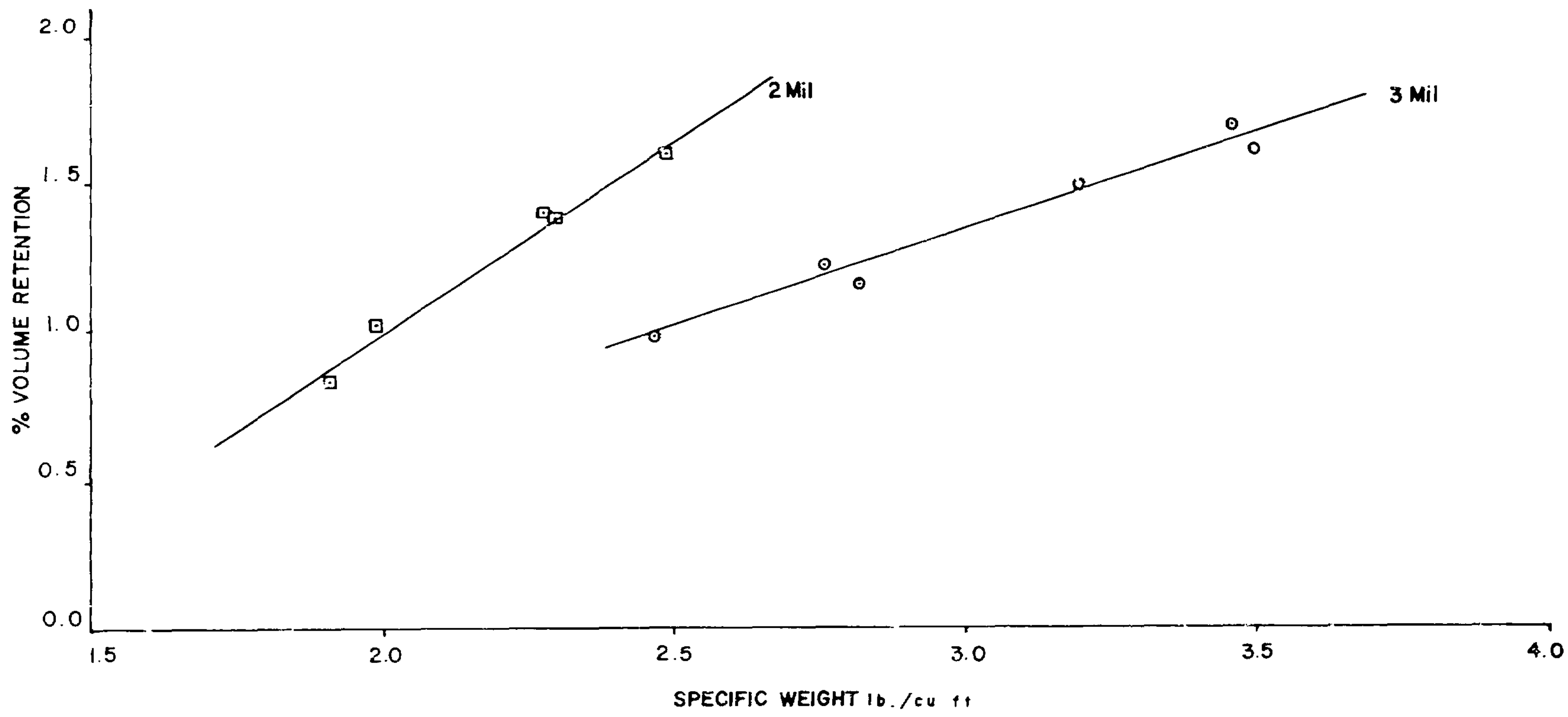

Figure 33. Retention versus Foil Specific Weight - Water Tests

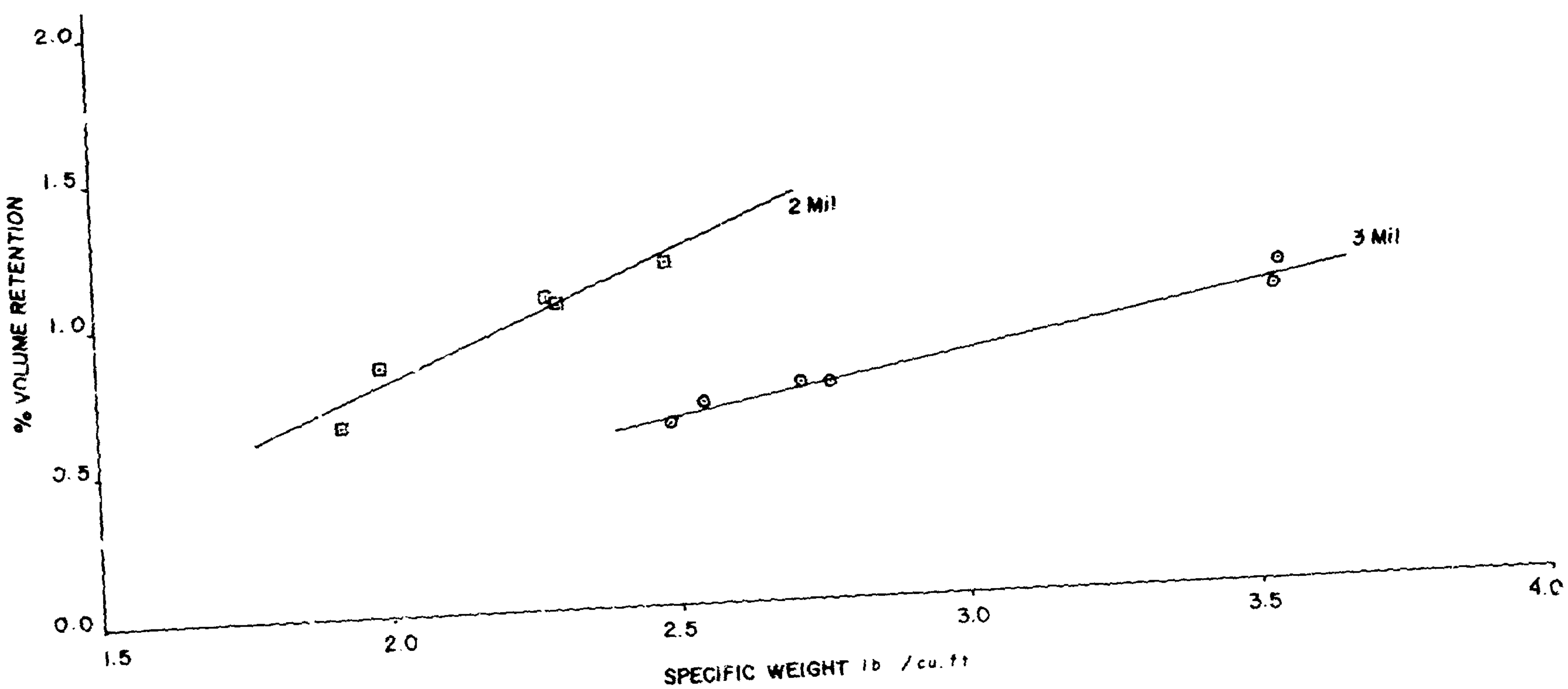

Figure 34. Retention versus Foil Specific Weight - Jet A-1 Tests

$$\text{Displacement by Calculation (\%)} = \frac{\text{Density of Explosafe}}{\text{Density of 3003 Al. Alloy}} \times 100$$

$$= \frac{\text{Density of Explosafe}}{168.4\#/ft^3} \times 100$$

3.3 Procedure - Field Method

Full scale fuel displacement and retention tests were conducted in conjunction with the dynamic slosh test No. 2 described in Section IV. The 200-gallon external pylon tank was 97% packed with 2 mil Explosafe having a material density of 2.2 lb/ft^3. The material packing density for this installation was 2.13 lb/ft^3 of tank volume. Appendix D 3 gives the pertinent installation data.

Prior to testing, the tank was leveled in both planes. The quantity of fuel in gallons, its temperature and density were recorded for each filling.

In order to calculate displacement and retention values, the total volume of the tank without Explosafe was first determined by filling it completely with JP-8 fuel and noting the quantity of the fuel (Fill 1). Fill 2 was performed to obtain the fuel displacement value. The dry tank, packed with dry Explosafe, was filled with clay treated JP-8 fuel. The quantity of fuel displaced by the foil was given by the difference between Fill 1 and Fill 2.

A soak time of 30 minutes was allowed before defueling the tank. To save time, the fuel was evacuated via the fuel pick-up tube instead of through the drain, with the tank pressurized to about 9 psig. Defueling was stopped at the point of cavitation. The fuel remaining in the sump was not drained. The tank was once again filled (Fill 3) with JP-8 fuel. The quantity of fuel recorded in this fill gave the systems' usable fuel with Explosafe.

The fuel was evacuated through the fuel pick-up tube, as before. At the point of cavitation, the defueling was stopped and the tank was relieved of air pressure. The fuel remaining in the sump was drained through the tank's jiffy drain and the quantity collected was measured. The sum of the usable fuel and the quantity collected from the sump gave the drainable fuel volume for the tank packed with foil. The difference between Fill 2 volume and the drainable fuel volume gave the quantity of fuel retained by the foil plus an indeterminate quantity of undrainable or trapped fuel. Fill 4 was conducted to verify the retention value obtained in Fill 3.

3.4 Results - Field Method

The results obtained are listed in Table 11.

The quantity of fuel displaced by Explosafe was calculated as follows:

$$\text{Displacement (\%)} = \frac{\text{Fill 1 Volume} - \text{Fill 2 Volume}}{\text{Fill 1 Volume}} \times 100$$

$$= \frac{201.4 - 199.2}{201.4} \times 100$$

$$= 1.09\% \text{ (or 2.2 gallons)}$$

Since the tank was 97% packed with foil, the extrapolated displacement value for a fully packed tank would be 2.27 gallons or 1.13%.

The quantity of fuel retained by Explosafe was calculated as follows:

Usable Fuel = Fill 3 Volume
= 196.45 gallons

Drainable Fuel = Usable Fuel + Fuel from Sump
= 196.45 + 0.67
= 197.12 gallons

Retention (%) (includes trapped fuel)

$$= \frac{\text{Fill 2 Vol. - Drainable Fuel}}{\text{Fill 1 Volume}} \times 100$$

$$= \frac{199.2 - 197.12}{201.4} \times 100$$

$$= 1.03\% \text{ (or 2.08 gallons)}$$

Verification of Retention:

Retention (%) (includes trapped fuel)

$$= \frac{\text{Fill 2 Vol. - Fill 4 Vol.}}{\text{Fill 1 Volume}} \times 100$$

$$= \frac{199.2 - 197.0}{201.4} \times 100$$

$$= 1.09\% \text{ (or 2.2 gallons)}$$

Average Fuel Retention (%) = 1.06% (or 2.14 gallons)

This figure is representative of a 97% packed tank. Extrapolation for a fully packed tank cannot be made as the retention figure includes an indeterminate, but constant quantity of trapped fuel.

3.5 Discussion

For Fill 1, the fuel pumped into the tank was weighed and the quantity in gallons was calculated. Fills 2 through 4 were performed at another facility where weighing facilities were not available. The fuel quantity in gallons was, therefore, read off directly from the fuel servicing meter.

The displacement value of 1.09% obtained in this test is 13% below the value of 1.26% obtained by calculation for Explosafe of similar density (see Table 10). This error may be attributed to the inconsistency in the fuel meter reading of Fill 2 with the weighed fuel reading of Fill 1.

The average retention value of 1.06% for the 2.3 lb/ft^3 packing density is also at variance with the laboratory value of 0.9%, extrapolated from Figure 34, for Explosafe of similar density and packing factor. Error in fuel quantity readings would probably have been consistent in this case and cancelled out as

TABLE 11. SUMMARY OF EXPLOSAFE FULL-SCALE FUEL DISPLACEMENT AND RETENTION TESTS

JP-8 Fuel	Fill 1 No Foil Dry Tank	Fill 2 Dry Foil Dry Tank	Fill 3 Wet Foil Wet Tank	Fill 4 Wet Foil Wet Tank	Average
Fill					
Temperature (°F)	58	72	72	69	
Density (lbs/gal)	6.7	6.6	6.68	6.68	
Weight (lbs)	1349.5				
Volume (gal)	201.4*	199.2	196.45	197.0	
Fuel from Sump (gal)	-	-	0.67	-	
Displacement					
Volume (gal)	-	2.20	2.20	2.20	2.20
Percent	-	1.09	1.09	1.09	1.09
Fuel Retention**					
Volume (gal)	-	-	2.08	2.20	2.14
Percent	-	-	1.03	1.09	1.06

* Calculated

** Values include an indeterminate quantity of trapped fuel

NOTE: Figures are for 97% packed tank
Explosafe Packing Density = 2.13 lb/ft^3

all fills for retention testing were gauged through the fuel meter. The higher retention value, therefore, must include a quantity of undrainable fuel trapped within the tank due to internal obstructions. This undrainable quantity is speculated to be approximately equal to the difference (0.16% or 0.32 gallons) between the observed and laboratory retention values.

3.6 System Weight Penalty and Usable Fuel

In order to evaluate the material's penalties imposed on an aircraft an analysis was made for various mission profiles by comparing the range of an aircraft at various gross weights with and without the explosion suppression material. For example, the objective of an aircraft mission may be for maximum range or it may be for maximum cargo or armament payload. The following discussion was provided by AFWAL/POSH and ASD/ENFEF in an attempt to correlate the material weight, fuel displacement and fuel retention penalty factors into realistic mission profiles and to compare the resultant range reduction to the baseline aircraft that has no explosion protection in the tanks.

The analysis used a typical cargo and fighter aircraft, that are presently modified with the Type IV coarse pore blue foam (Reference 3). The baseline aircraft parameters (maximum gross weight, empty weight, fuel tank volumes, and capacities in Table 12A) were taken from the applicable aircraft technical orders (T.O.) and the prototype foam installation reports.

The basic material densities for the various protection materials included 1.3#/ft^3 for the blue coarse and fine pore foams, 2.2#/ft^3 for the Explosafe, and 0.6#/ft^3 for the Promel (nylon).

The packing factor (P.F.) reference represents the ratio of material weight actually used in the kit to that required to completely fill the tank volume. The effective voiding is therefore the difference between 1.0 and the quoted packing factor,

TABLE 12: FUEL TANK SURVEY

Baseline Aircraft	Maximum Gross Weight (lbs)	Empty Weight (lbs)	Fuel Tank Volume (gallons)	Fuel Tank Volume (ft3)	Fuel Capacity Usable Fuel (gallons)	Fuel Capacity Usable Fuel (lbs)
Cargo	155,000	68,626	10,040	1,345	9,680	62,920
Fighter	55,000	30,335	1,316	176	1,277	8,301

Table 12A: Baseline Aircraft Parameters

Protection Material	Dry Kit (lbs)	Packing Factor	Maximum Usable Fuel (lbs)	Displacement (%)	Displacement (lbs)	Retention (%)	Retention (lbs)
Baseline	--	--	62,920	--	--	--	--
Coarse Foam (1.3#/ft3)	1,682	0.96	60,504	2.0	1,208	2.0	1,208
Explosafe (2.2#/ft3)	2,804	0.95	61,545	1.3	777	1.0	598
Promel (0.6#/ft3)	776	0.96	60,021	0.8	483	4.0	2,416
Fine Foam (1.3#/ft3)	874	0.50	61,033	2.0	629	4.0	1,258

Table 12B: Cargo Aircraft

Protection Material	Dry Kit (lbs)	Packing Factor	Maximum Usable Fuel[2] (lbs)	Displacement (%)	Displacement (lbs)	Retention (%)	Retention (lbs)
Baseline	--	--	8,301	--	--	--	--
Coarse Foam	186	0.82	8,029	2.0	136	2.0	136
Explosafe	323	0.84	8,140	1.3	91	1.0	70
Promel	87	0.82	7,975	0.8	54	4.0	272
Fine Pore	113	0.50	8,055	2.0	83	4.0	163

[1] Fuel density is 6.5 pounds/gallon.
[2] Quantities represent protected (fuselage) tanks only.

Table 12C: Fighter Aircraft

assuming the P.F. is 1.0 or less. Packing factors greater than 1.0 indicated that the packing material, when installed, is in a "compressed" condition.

The packing factors (Table 12B and 12C) for the blue foam were calculated from data provided during actual prototype installations and represent the average of all tanks. As an example the cargo aircraft foam kit was designed with a P.F. of 0.85 for the wing tanks, 1.08 for the auxiliary tanks and 1.04 for the external tanks, resulting in an average of .96 (Table 12B). For the fighter aircraft the fuselage tanks were the only tanks containing foam and the packing factors ranged from 0.46 to 1.12. The wing and external tanks were unprotected. The one cell in the fighter aircraft that was limited to a P.F. of 0.46 was maintained for all other candidate materials under study. The overall P.F. of the foam installation for the fighter was 0.82.

The values for the Explosafe were derived by limiting its P.F. at .90 in the tanks where the foam was less than 0.90, by maintaining the same P.F. where the foam was between 0.90 and 1.00 and by limiting its P.F. at 1.00 in the several cases where the foam exceeded 1.00. The P.F. limit of .90 for Explosafe is based on its suppression performance as noted in the combustion section of this report. These assumptions resulted in overall P.F. for the Explosafe of 0.95 for the cargo aircraft and 0.84 for the fighter aircraft.

The P.F. for the Promel was maintained the same as for the coarse pore foam. The fine pore (voided) foam configuration was maintained at a packing factor of 0.50. The explosion suppression performance of the fine pore foam permits the use of higher voiding levels over other materials with the same basic level of protection.

Once the material kit weight and packing factor values were established as shown in Tables 12B and 12C, the appropriate fuel displacement and retention penalty factors were calculated and the usable fuel volumes determined. It should be noted that the fuel displacement and retention penalty values were calculated using the baseline (unprotected) usable fuel volume as a basis and were further reduced by the overall packing factor that was established for each material kit.

As an example the fuel displacement was calculated as follows:

Fuel Displacement (pounds) = (baseline usable gallons) x (% displacement) x (packing factor) x (fuel density).

The maximum usable fuel volume for each suppression material was then calculated by reducing the baseline usable fuel volume by the sum of the displacement and fuel retention penalty factors.

In an attempt to determine the explosion suppression materials impact on the aircraft mission, several extreme cases of utilization were evaluated. When the suppression materials are added to the aircraft the effect is to increase the aircraft empty weight which results in a reduction of the amount of fuel and/or cargo (payload) that can be loaded onto the aircraft.

When the usable fuel is traded off to stay within the established gross weight limitation and the baseline cargo weight maintained this usable fuel is calculated as follows:

Available usable fuel = (gross weight) - (aircraft empty weight) - (cargo weight) - (unusable fuel weight) - (kit weight) - (fuel retention weight).

This formula can also be used to determine the maximum cargo weight when the maximum available fuel is maintained.

Study A and B utilized maximum available fuel and study C and D utilized available payloads (cargo). Realistically, these extremes show how the various materials' weight and fuel volume penalties directly impact the aircraft mission, since it is difficult to determine a material weight impact other than to assume a payload/fuel load tradeoff on a pound for pound basis. The resulting mission impact is expressed in terms of aircraft range and a range reduction from the baseline configuration without fuel tank protection.

The following mission conditions were examined for both study aircraft involved. Long range cruise missions at 20,000 ft for standard day conditions. Engine run up, taxi, takeoff, climb and cruise fuel usage estimates were made utilizing aircraft performance data located in the applicable aircraft T.O. Each aircraft was assumed to have landed with a 5% normal baseline fuel reserve in the tanks. The ranges for each mission were extrapolated from the appropriate charts in the aircraft T.O. that are based on the cruise and landing weights.

For the maximum fuel load studies A and B (Tables 13 and 14), the aircraft fuel volume is maintained at maximum as dictated by the protection material's fuel displacement/retention characteristics. Since the aircraft is gross weight limited for takeoff, two extreme but fixed payload (cargo) weights were examined. The two payload extremes chosen included no payload (Study A) and 75% of normal baseline payload (Study B), both of which resulted in aircraft gross weights that were below the maximum limits established (cargo 155,000#; fighter 55,000#).

For the maximum payload studies C and D (Tables 13 and 14) the baseline payload for each configuration was maximized, thus requiring that the usable fuel be reduced to accommodate the increase in aircraft weight resulting from the explosion suppression material's basic dry weight and fuel retention. This

TABLE 13: RANGE COMPARISON, CARGO AIRCRAFT

Range	Protection Material (Density)	Usable Fuel (lbs)	Range (Nautical Miles)	Penalty (%)	Takeoff[1] Weight (lbs)	Remarks
A	Baseline	62,920	4,080	0.0	132,326	Maximum Fuel Study: Cargo Load is 0# with maximum fuel load.
	Coarse Pore Foam	60,502	3,930	3.7	132,798	
	Explosafe	61,542	3,990	2.2	134,349	
	Promel	60,021	3,900	4.4	132,619	
	Fine Pore Foam	61,035	3,970	2.7	132,574	
B	Baseline	62,920	3,860	0.0	149,332	Maximum Fuel Study: Cargo load is 17,006# (75% Baseline Cargo Load) with maximum fuel load.
	Coarse Pore Foam	60,502	3,670	4.9	149,803	
	Explosafe	61,542	3,750	2.8	151,355	
	Promel	60,021	3,630	6.0	149,625	
	Fine Pore Foam	61,035	3,700	4.1	149,579	
C	Baseline	62,920	3,770	0.0	155,000	Maximum Payload Study: Cargo is 22,674# with baseline aircraft fully loaded with fuel.
	Coarse Pore Foam	60,028	3,550	5.8		
	Explosafe	59,521	3,490	7.4		
	Promel	59,729	3,530	6.4		
	Fine Pore Foam	60,788	3,600	4.5		
D	Baseline	47,190	2,680	0.0	155,000	Maximum Payload Study: Cargo is 38,404# with baseline aircraft at 75% full fuel load.
	Coarse Pore Foam	44,300	2,480	7.5		
	Explosafe	43,789	2,450	8.6		
	Promel	43,998	2,460	8.2		
	Fine Pore Foam	45,058	2,530	5.6		

[1]Takeoff weight = Empty weight + cargo + unusuable fuel + usable fuel + kit weight + retained fuel

TABLE 14: RANGE COMPARISON, FIGHTER AIRCRAFT

Range	Protection Material (Density)	Usable Fuel (lbs)	Range (Nautical Miles)	Penalty (%)	Takeoff[1] Weight (lbs)	Remarks
A	Baseline	17,206	951	0.0	47,937	Maximum Fuel Study: Armament Payload is 0# with maximum fuel load.
	Coarse Pore Foam	16,934	932	2.0	47,988	
	Explosafe	17,045	939	1.3	48,167	
	Promel	16,880	932	2.0	48,003	
	Fine Pore Foam	16,960	935	1.7	47,966	
B	Baseline	17,206	659	0.0	53,234	Maximum Fuel Study: Armament Payload is 5,297# (75% Baseline Armament Payload) with maximum fuel load.
	Coarse Pore Foam	16,934	643	2.0	53,285	
	Explosafe	17,045	647	1.8	53,373	
	Promel	16,880	645	2.1	53,300	
	Fine Pore Foam	16,960	646	2.0	53,263	
C	Baseline	17,206	590	0.0	55,000	Maximum Payload Study: Armament Payload is 7,063# with baseline aircraft fully loaded with fuel.
	Coarse Pore Foam	16,881	574	2.7		
	Explosafe	16,484	571	3.2		
	Promel	16,848	573	2.9		
	Fine Pore Foam	16,926	577	2.2		

[1] Fuel quantity is total in protected (8,301#) and unprotected tanks (8,905#).

reduction in fuel is required to maintain each aircraft within its maximum gross weight limitations. For Study C, the maximum payload is that which is obtained on the baseline aircraft when it is fully loaded with fuel. For study D (cargo aircraft only), the cargo is increased to a value that would be obtained on the baseline aircraft with a 75% fuel load. Both configurations assume maximum gross weights for both aircraft types.

The penalty values in Tables 13 and 14 represent the percentage of range that is lost from the baseline range value due to the material's combined weight and fuel volume penalties imposed on the aircraft. Notice that the range penalty of the Explosafe is less than the blue coarse pore foam under maximum fuel volume conditions but that it is greater under the maximum payload conditions.

When considering the range impact of the two extreme study conditions, one must remember in "real life" the tradeoff factors could likely involve both usable fuel and cargo weight depending on the mission, which could make the range values come closer together for each suppression material. The fighter aircraft penalties are much lower than the cargo aircraft presumably due to the limited use of the arrestor material in the fuselage tanks only which is approximately half the total aircraft fuel volume.

4.0 <u>EFFECT ON FUEL FLOW</u>

As part of the Environmental Type Exposures assessment requirements, tests were run to show the materials effect on fuel flow. These tests, performed by McDonnell Aircraft as part of the work on USAF PRAM Program, (Reference 4), consisted of two types of tests designed to determine the pressure drop through foil and to assess its response to a 1 g reversal with half full fuel tanks. Tests on the effect of fuel flow reported in USAF PRAM Program Final Report show the results included in the two following paragraphs. The reader is directed to this reference for comparison with performance tests on other suppression materials. Material supplied for these tests were specified as .003 inch thick foil.

4.1 Procedure - Pressure Drop

Using the test set-up shown in Figure 35, the pressure drop versus flow characteristics were determined. The test was initiated by pumping JP-4 fuel through a 7.5 inch diameter Lucite tube containing either 9 or 27 inch long pieces of the respective foil configurations. As the flow rate of the fuel was slowly increased, the foil was observed for signs of batt collapse. At each incremental flow rate, intermittent pressure measurements were recorded.

4.2 Results - Pressure Drop

The result of tests described in Paragraph 4.1 using flow rates ranging from 40 to 120 gpm is shown in Table 15. It should be noted that foil shows no signs of collapse nor any noticeable movement or distortion when subjected to this test.

TABLE 15. FUEL FLOW VERSUS PRESSURE DROP TEST DATA

Material Configuration	Batt Length (in)	JP-4 Flow Rate (gpm)	JP-4 Pressure Drop (in)	JP-4 Pressure Drop (psi)	
Foil sheets, perpendicular to direction of fuel flow	27	40	5.0	0.14	
	27	60	9.0	0.25	
	27	80	18.0	0.50	
	27	100	27.5	0.76	
	27	120	38.0	1.06	No noticeable movement
	9	40	1.5	0.042	
	9	60	3.5	0.10	
	9	80	7.0	0.19	
	9	100	9.5	0.26	
	9	120	14.5	0.40	No noticeable movement

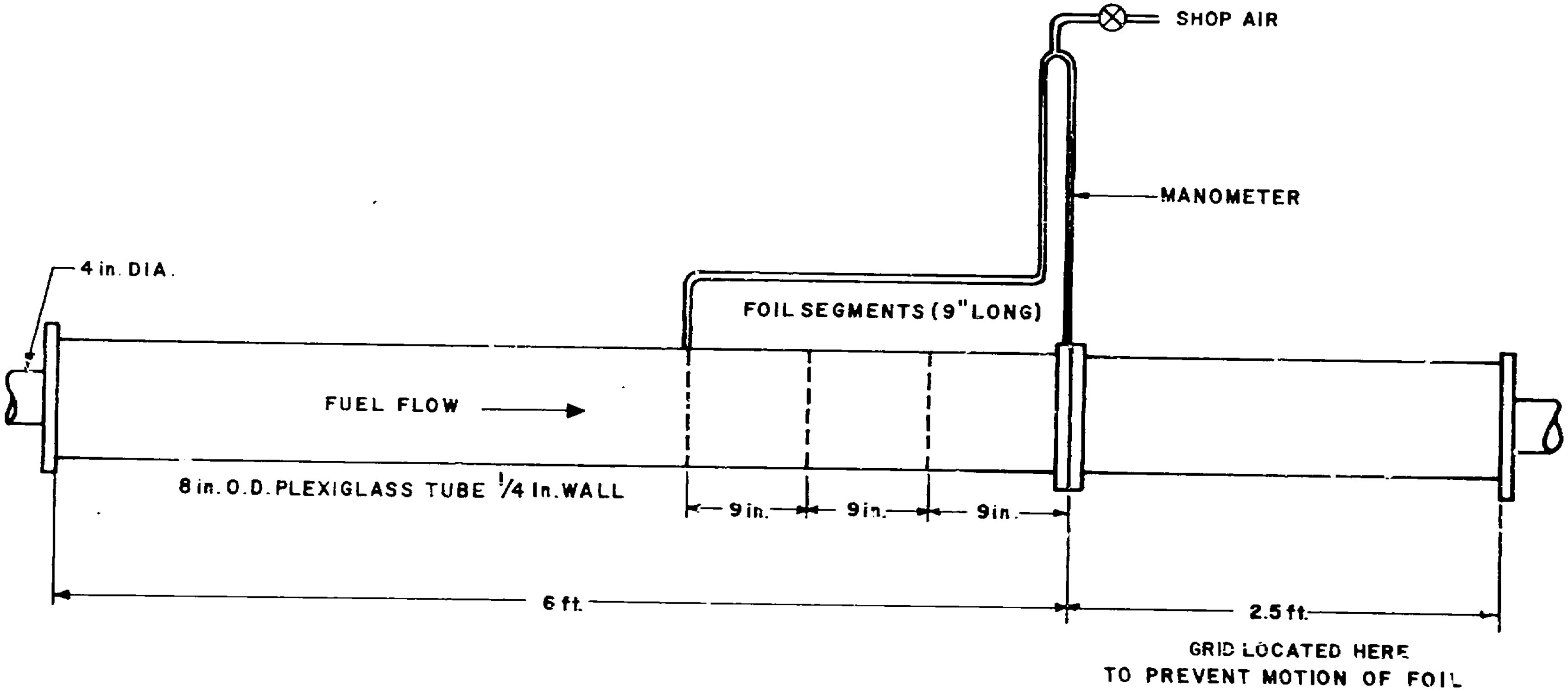

Figure 35. Test Set-Up for Fuel Flow versus Pressure Drop Tests

4.3 Procedure - Fuel Drop

The effect of fuel falling under a 1g drop condition through Explosafe expanded foil, was evaluated using the test set-up shown in Figure 36. This simulated an aircraft 1 g reversal with a half full fuel tank. The test fixture was divided into upper and lower halves by a .072 inch thick aluminum plate valve located at the mid-height of the test fixture.

With the plate (valve) inserted, JP-4 fuel was added to the upper half of the test fixture. The test was then initiated by allowing the weight attached to the valve to fall, thereby removing the plate and permitting the fuel to fall into the lower half of the fixture. The test was recorded by tank pressure transducers and motion picture coverage.

4.4 Results - Fuel Drop

Table 15 shows the data obtained in dropping fuel through a foil-filled container. Data obtained suggests no significant change on fuel system operation.

TABLE 16. ONE "G" DROP TEST DATA

Test Configuration	Time for Fuel to Impact Tank Bottom (sec)	Time for Top Tank to Empty (sec)	Average Velocity Thru Foil (ft/sec)
Solid batt, tank top removed. 3/4 in. dia. drain hole at tank bottom.	2.80	3.00	0.72

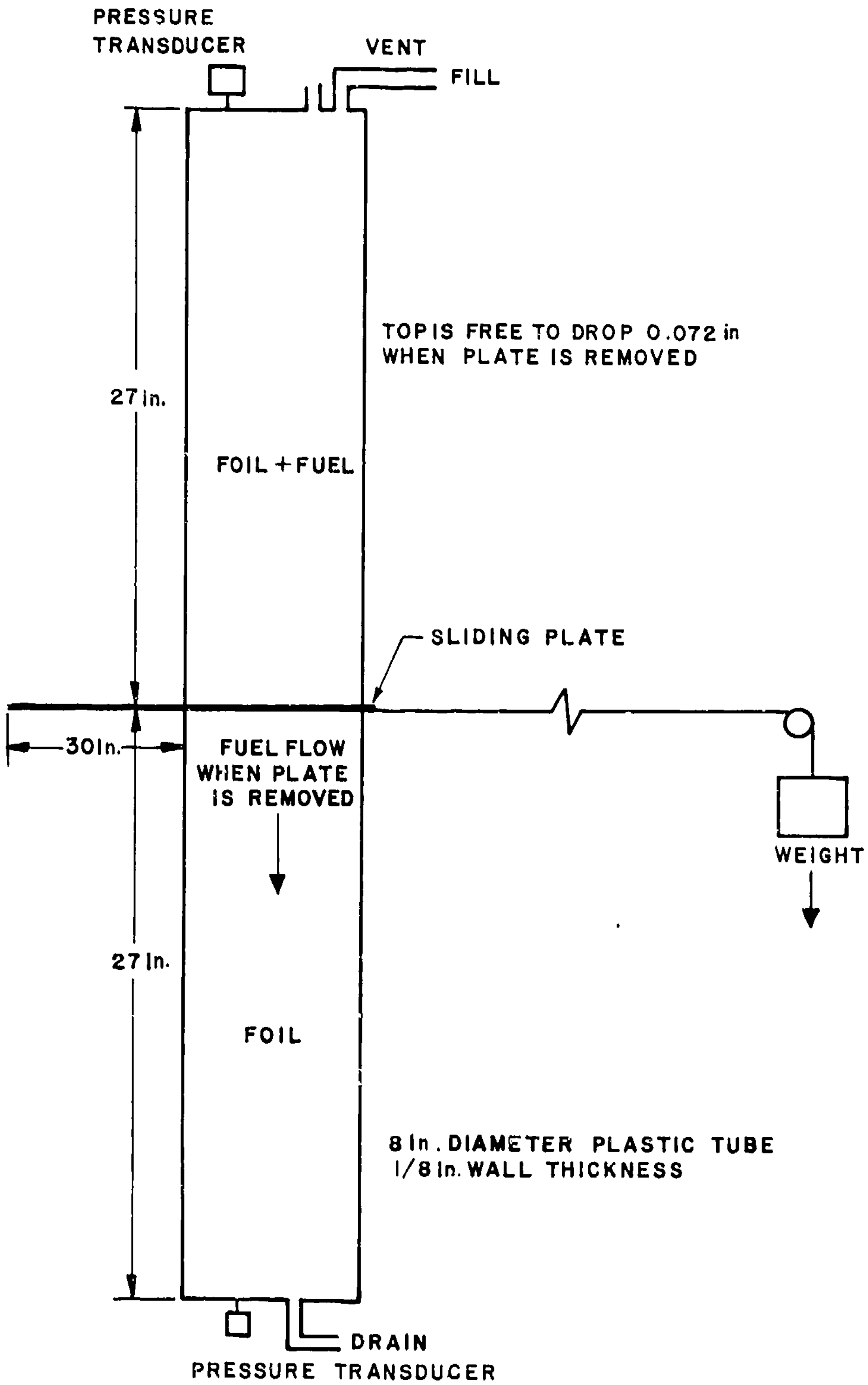

Figure 36. Test Set-Up for Fuel Drop Tests

4.5 Conclusions

The foil does not collapse, distort or move when subjected to a rapid pressure drop, nor does it have any significant effect on the fuel system operation.

5.0 VENT ICING

5.1 Procedure

Simulated Vent Icing tests were conducted by McDonnell Aircraft (Reference 4) to establish the material's susceptibility to icing using the test set-up shown in Figure 37. The test was conducted to show the relative icing susceptibility of expanded foil when subjected to worst case vent flow conditions. The foil test specimens were placed in a two-foot cube box equipped with a 2 inch diameter inlet and outlet, and a viewing window directly above the inlet.

The worst case icing conditions which were based on the test results presented in ASJ-TM-66-1, consisted of:

- Inlet air velocity of 50 fps (approximately 5 lb/min).
- Saturated inlet air, between 0°F and 25°F.
- Foil temperature same as air temperature

These conditions were achieved by cooling ambient air with cold gaseous nitrogen, then adding an air/water spray as required to obtain the desired inlet temperature and humidity, at a total flow rate of about 5 lb/min. The test was initiated when the average foil temperature was within 5°F of the inlet temperature and continued for specific time intervals.

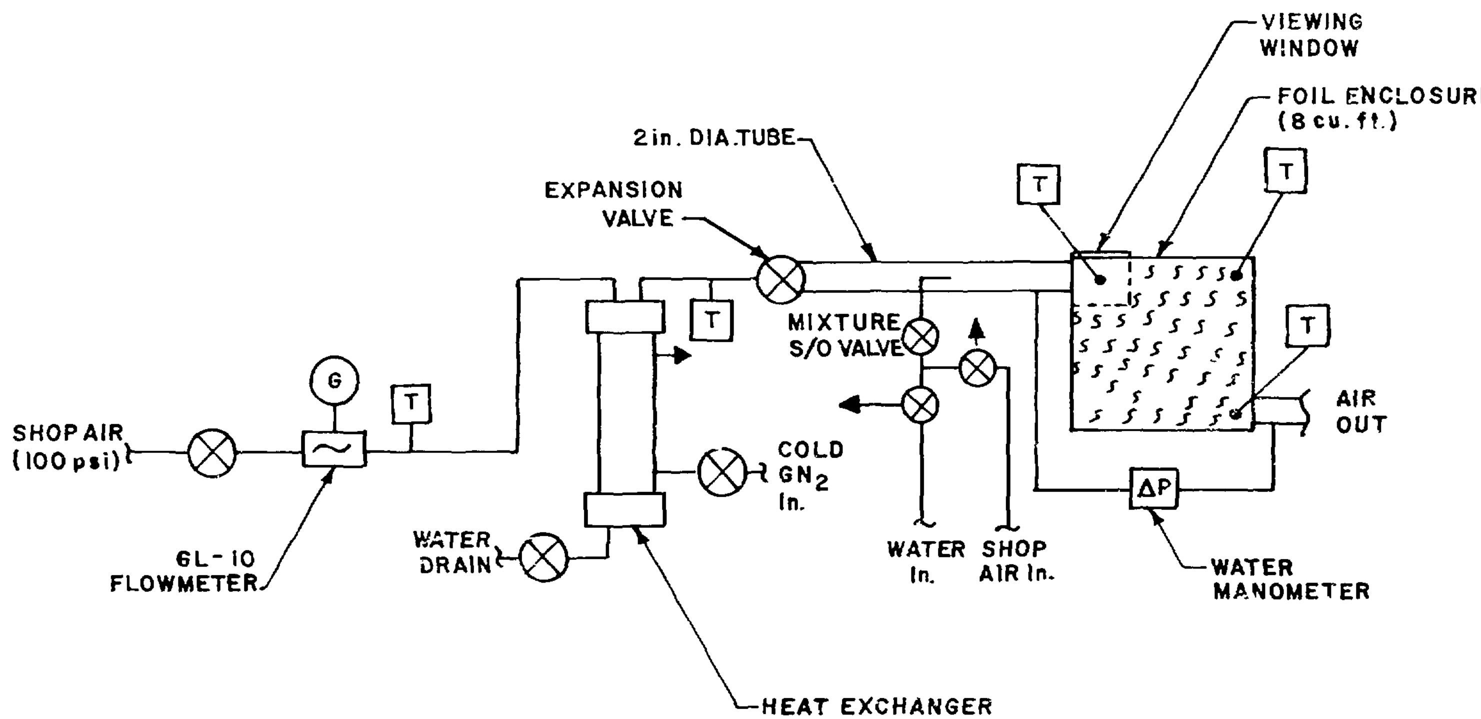

Figure 37. Vent Icing Test Arrangement

5.2 Results

The results of this test are shown in Table 17 and illustrated in Figure 38. The presented data was obtained from Reference 4. Conditions outlined in paragraph 4.0 apply. To obtain appreciable pressure drop, inlet void was deleted. The Explosafe material showed the lowest pressure drop of all the materials tested under the PRAM Program.

TABLE 17. VENT ICING TEST DATA

Test Configuration	Time min.	ΔP in. Water	Inlet Temp °F	Avg. Foil Temp °F	Airflow lb/min	
No void at inlet	0	3.2	23	18	5.35	Inlet pressure tap in inlet pipe.
	0.5	3.8	23	18		
	1.0	5.0	23	18		
	1.5	8.3	23	18		
	2.0	15.8	23	18		

5.3 Conclusions

The material should not present problems during rapid descent, and it is not essential to void the area local to a vent inlet. This practice is recommended, however, to ensure sustained performance in the event of foreign matter passing through the vent.

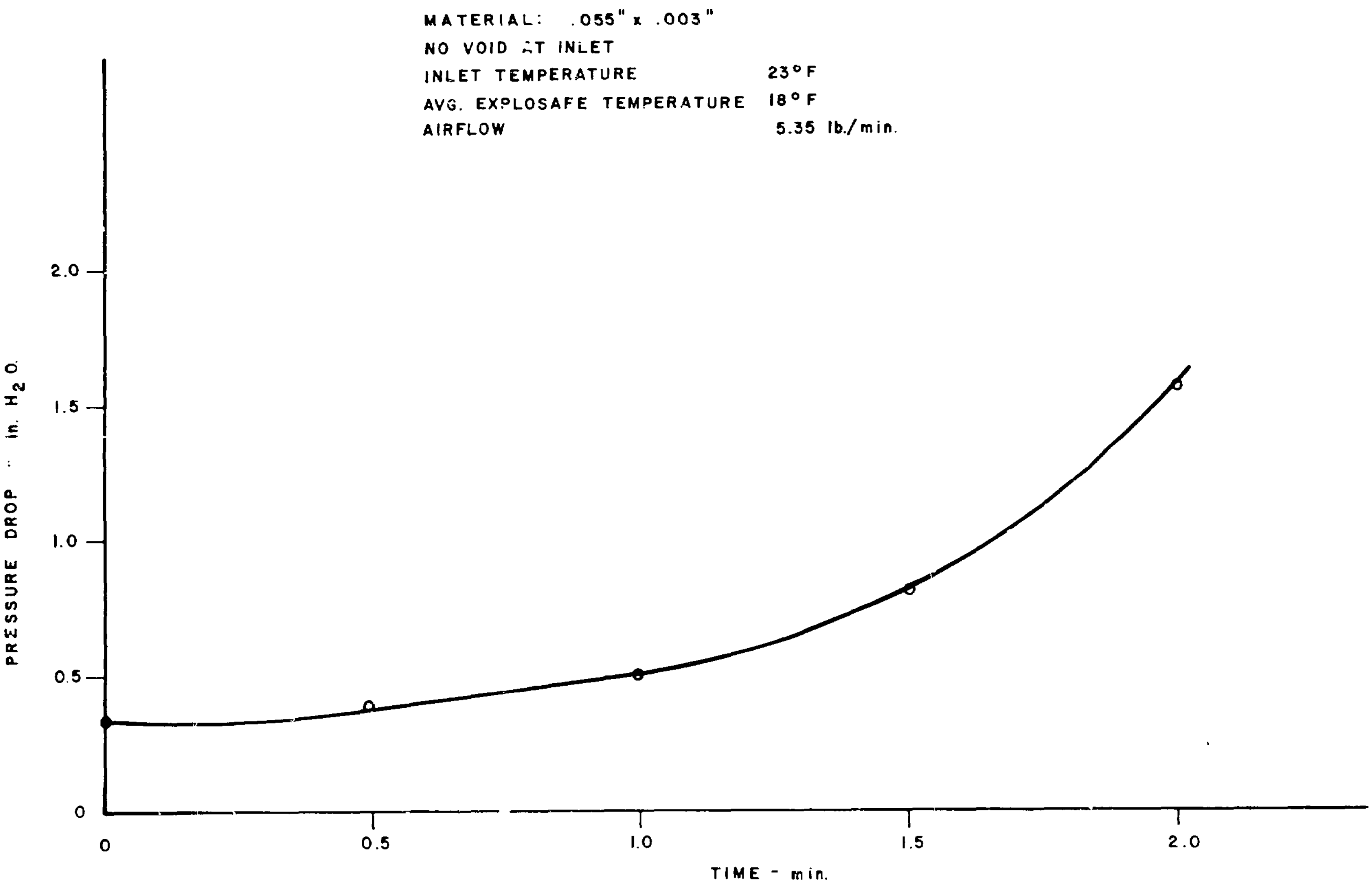

Figure 38. Vent Icing Characteristic

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6.0 SLOSH SUPPRESSION

An investigation of the effects of slosh on aircraft fuel system components is a standard military qualification test procedure. To our knowledge, however, no exercise has ever been undertaken to measure the forces exerted by sloshing fluid on a surface of interest, e.g., the end wall of a tank or internal baffles. The level of such forces is of particular interest to designers who must sometimes oversize components or joints and fasteners so that they are able to withstand the cyclic stresses imposed upon them.

The suppression of slosh is an additional feature of the Explosafe explosion suppression system and has in fact been the sole requirement of the customer in some instances. In concept with the AFWAL study of the effects of material orientation and density on explosion suppression performance, VIPL elected to carry out a quantitative study of the effects of these variables on slosh suppression.

6.1 Procedure

The test rig is depicted in Figure 39. A table is oscillated back and forth on tracks by an electric motor/gear/crank arrangement. The frequency of oscillation can be varied continuously, by means of an adjustable V-belt drive, between 20 and 62 oscillations per minute. A 17-5/8 x 7 x 7 inches open top tank is rigidly mounted to the table. Inside the tank, ½ inch from one end, there is mounted a transducer consisting of a vertical .050-inch gauge aluminum plate having a projected face of 6.6 inches wide x 6.5 inches high, with a 90° bend of 0.25 inch radius along one side in the vertical plane. At the end of the radius the plate is rigidly attached to one sidewall of the tank. Two strain-gauges are attached to each side of the bend and connected to form a strain-gauge bridge whose electrical response when energized is proportional to the stress in the bend. The transducer is protected by a wide-diamond rigid screen mounted to the tank sidewalls 0.5 inches distant to permit free

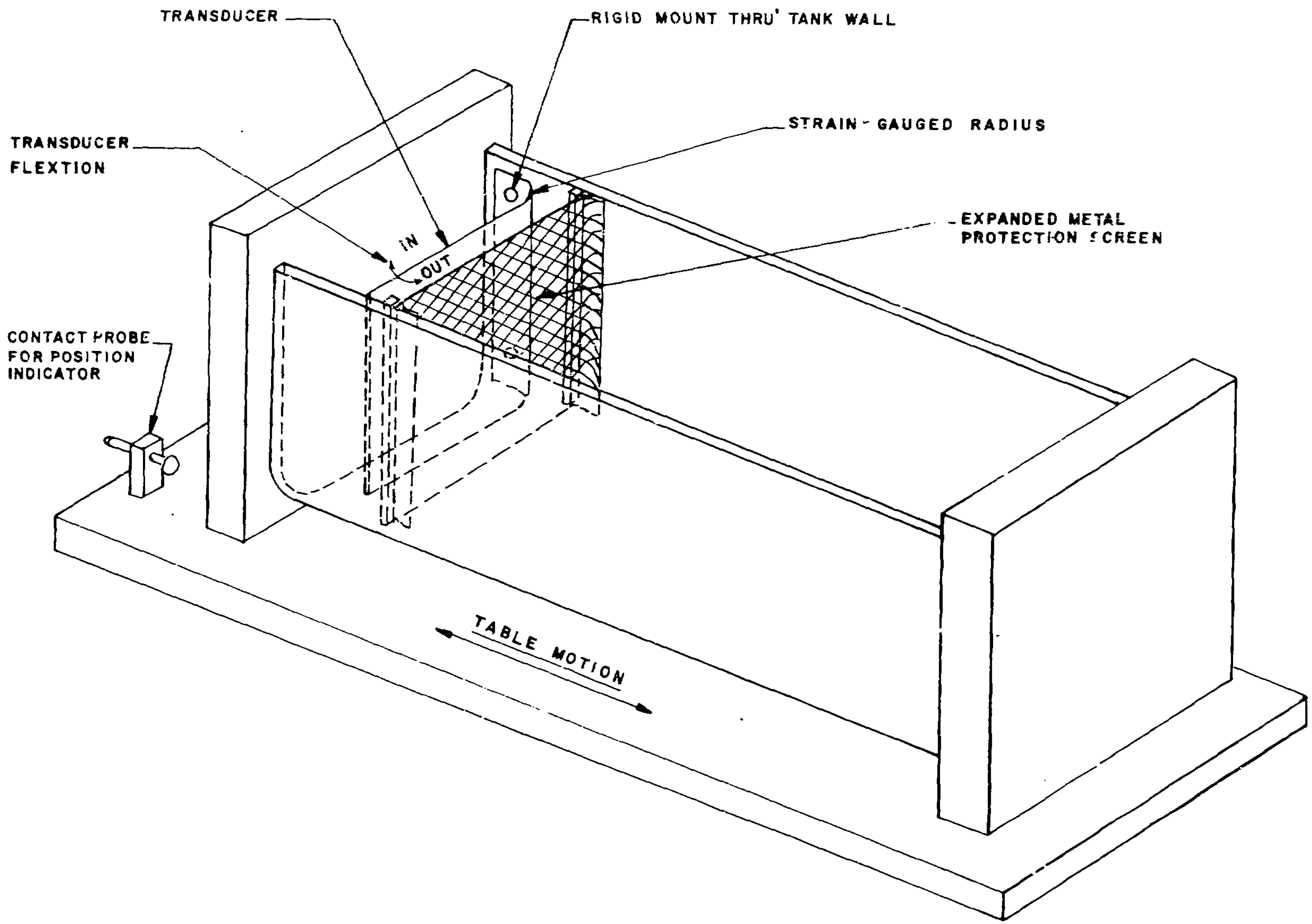


Figure 39. Slosh Reduction Measurement Rig

flexure of the plate. The remainder of the tank is the specimen section.

When the tank is partly filled with test fluid and oscillated, the resultant waves cause the plate to flex about the 90° bend. The strain gauge output (in millivolts) is proportional to the load on the plate as illustrated by the calibration shown in Table 18. The calibration factor is 200 gm/mv. The load is in turn a measure of the kinetic energy stored in the wave. The output is recorded on light sensitive paper via a Honeywell 1858 CRT visicorder and allows one system to be compared to another or to a datum obtained without a specimen of the Explosafe material. The frequency of oscillation is recorded with the transducer signal via a pulsed signal activated by a probe and microswitch on one end of the table.

Test procedure is as follows:

a) Activate recorder and record baseline transducer signal.
b) Oscillate tank at desired frequency and record the transducer response for 10 seconds. This is the signal due to the inertia of the plate and on which the signal due to the sloshing fluid will be superimposed.
c) Add test fluid to tank (0.89 Imperial gallons of water, dyed to improve visibility).
d) Insert test specimen into tank.
e) Activate recorder to record baseline transducer signal.
f) Oscillate the tank at the set frequency and record the transducer output for 10 seconds.

6.2 Results

The test program examined t e effects of material orientation, material density as determined by expansion, and frequency of oscillation. Material thickness (gauge) was held constant since this does not affect the geometry of the material. Six orientations were investigated and are illustrated in Figure 40. Orientations A, B, and C are those studied in the AFWAL work and were respectively designated S34, S32, and S33. Orientations A*, B*, and C* are simply the material of A, B and C rotated 90° relative to the axis of the tank to study the effect of the material geometry in the vertical plane while that in the horizontal plane is held constant. This was necessary because when a wave moves along a tank, there is fluid movement in the vertical plane as well as the horizontal. The vertical plane geometry of the material offers varying resistance to this motion.

With each of the material orientations, five frequencies of oscillation and a range of material densities were tested. In the datum tests without the Explosafe material, the frequency was limited to a maximum of 39 oscillations per minute by the height of the waves. Consequently, only four frequencies were studied in this case.

The transducer registers a quasi-sinusoidal response of which the positive portion is due to the approaching wave. The negative portion is the receding wave and is redundant. Figure 41 depicts a typical test recording.

As noted earlier, the transducer signal includes a response due to the inertia of the transducer itself and this must be subtracted from each particular result to obtain the response due to the wave alone.

Considering the positive half of the cycle only, the net maximum force on the transducer due to the wave was derived for each test in the following manner:

$$Fp = C\ ({}^{V}Af - {}^{V}Sf)$$

where F_p = net force on transducer due to wave -gm.

C = Transducer calibration factor -gm/mV.

V_{Af} = Positive peak transducer response (mV) at frequency f with test fluid (and specimen).

V_{Sf} = Positive peak transducer response (mV) at frequency f without test fluid.

These data are recorded in Tables 19, 20, and 21 and are graphically illustrated in Figures 42 through 48.

Figures 42, 43, and 44 illustrate the variation of the waveforce with different expansions of material at constant orientations and the lines connect data points for like frequencies. Orientation A (Figure 42) shows a mixed behavior with the upper and lower frequencies having a positive slope (force increasing with expansion) while the middle frequencies have overall negative slopes (force decreasing as expansion increases). Orientation B (Figure 43) shows little variation with respect to expansion for the lower frequencies but the slopes tend to negative for the upper frequencies, i.e., force reducing as expansion is increased. Orientation C (Figure 44) shows consistently positive slopes, i.e., force increasing as expansion is increased, with the slope increasing as the frequency is increased.

The relative suppressing effects of the different orientations become very clear when the waveforce is plotted against frequency for particular expansions. Figures 45, 46 and 47 illustrate this for expansions of 35-3/4, 40 and 44 inches with the lines connecting data points for like orientation. These graphs show that the slosh suppressing ability of the three orthogonal orientations is, in order of increasing ability: A, C, B. Consistently, orientation B is superior to the other two, and further, its relative superiority increases with increasing expansion.

The relative effect of all the orientations compared to the results obtained without the Explosafe material is depicted in Figure 48. Here the waveforce versus frequency is plotted for an expansion of 40 inches with the three orientations.

Two slosh suppressing mechanisms were suspected. Firstly, the density of the material was expected to directly affect the suppression ability - the more material in the tank, the more the slosh would be suppressed. Secondly, the degree of twist imparted to the strands of material by the expansion process was expected to directly affect the suppressing ability. The latter is directly proportional to expansion while the former is inversely proportional. These two predictions are obviously at odds with each other but the results indicate that they hold true.

With orientation C, the suppression mechanism is primarily density. Because of the layer and diamond orientation, there is a minimal amount of strand twist in the path of the advancing wave. The strands are almost parallel to the wave travel and increasing the expansion reinforces this condition. The change in waveforce as expansion is increased, portrayed in Figure 44, is due solely therefore to the change in material density. The increasingly positive slopes confirm the prediction that decreasing the expansion will reduce the waveforce.

With orientations A and B, the suppression mechanism is primarily the strand twist. The advancing wave meets the full projected area of the strand. While density decreases with expansion, the strand twist and hence the projected area of the strands increases. Figures 42 and 43 reveal somewhat inconsistent effects with expansion but in the majority of increments the waveforce decreases as expansion is increased. This indicates that the increasing strand twist outweighs the decreasing density and there is a net reduction in the waveforce as the expansion is increased.

Figure 48 reveals suppression ratios relative to the datum test without Explosafe material of 14 for orientation A, 40 for orientation B, and 20 for orientation C at a frequency of 39 oscillations per minute with a material expansion of 40 inches.

The data of Table 21 indicate no consistent or significant effect of rotating the material through 90° relative to the axis of the tank. It is concluded that the vertical motion of the wave is insignificant to the suppression mechanism.

6.3 Conclusions

The measurement of the waveforce in a sloshing situation revealed a number of important conclusions.

a) The material orientation giving the greatest slosh suppression was that where the maximum strand twist was placed in the path of the advancing wave.

b) The suppression ability with this orientation increases with decreasing density (increasing expansion).

c) Typically, at an expansion of 40 inches, material in this orientation reduced the measured waveforce relative to an undamped case by a factor of 55-40 dependent on and decreasing with oscillation rate.

d) While other orientations tested were less effective, reduction ratios of 15-25 were measured and are acceptable by any standards.

The foil orientation in most applications is determined by the manufacturing process and installation requirements. Figure 49 illustrates the remarkable reduction in slosh achieved with one of the less effective orientations in the dynamic slosh test.

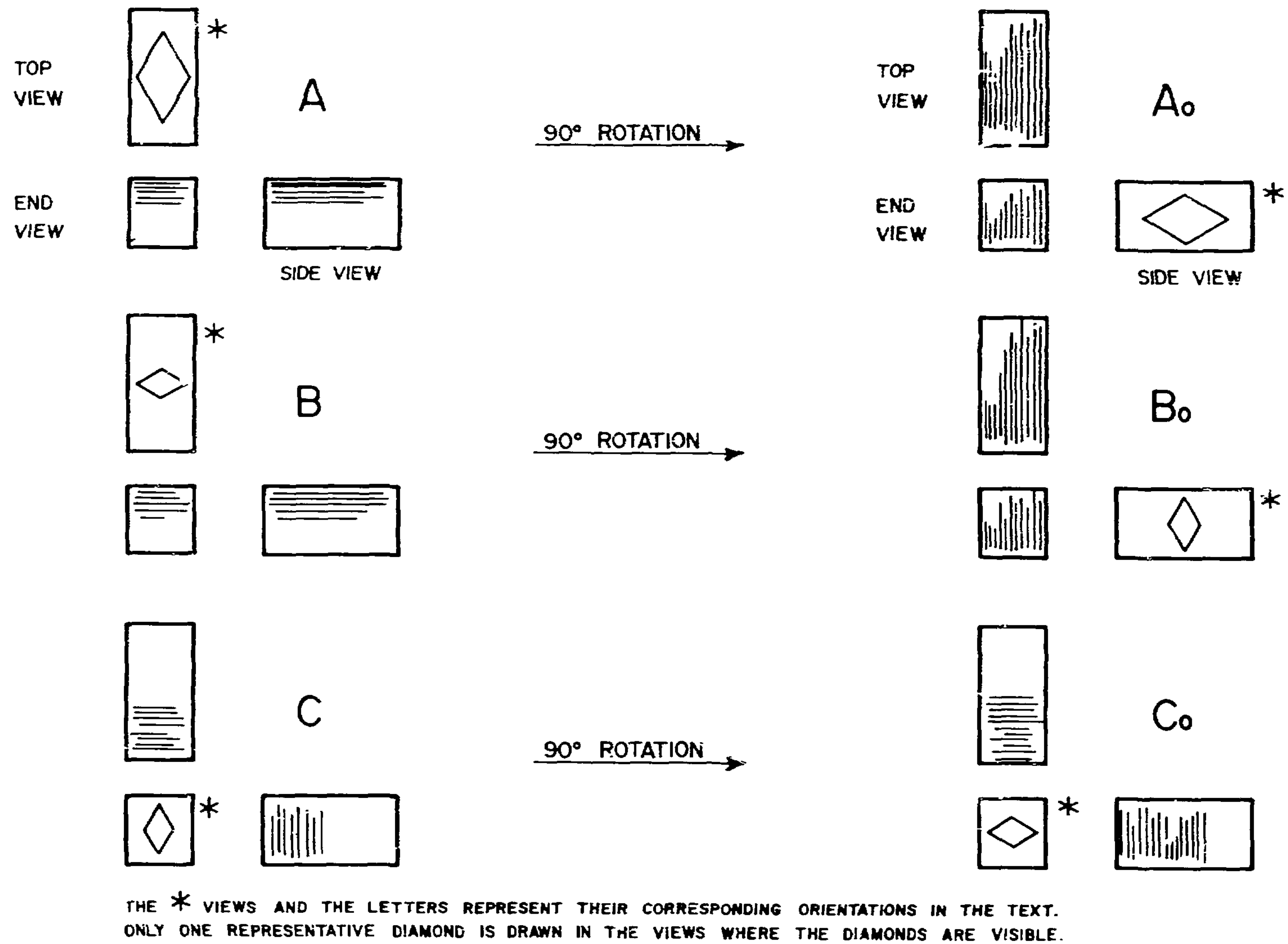


Figure 40. Foil Orientations in Slosh Reduction Tests

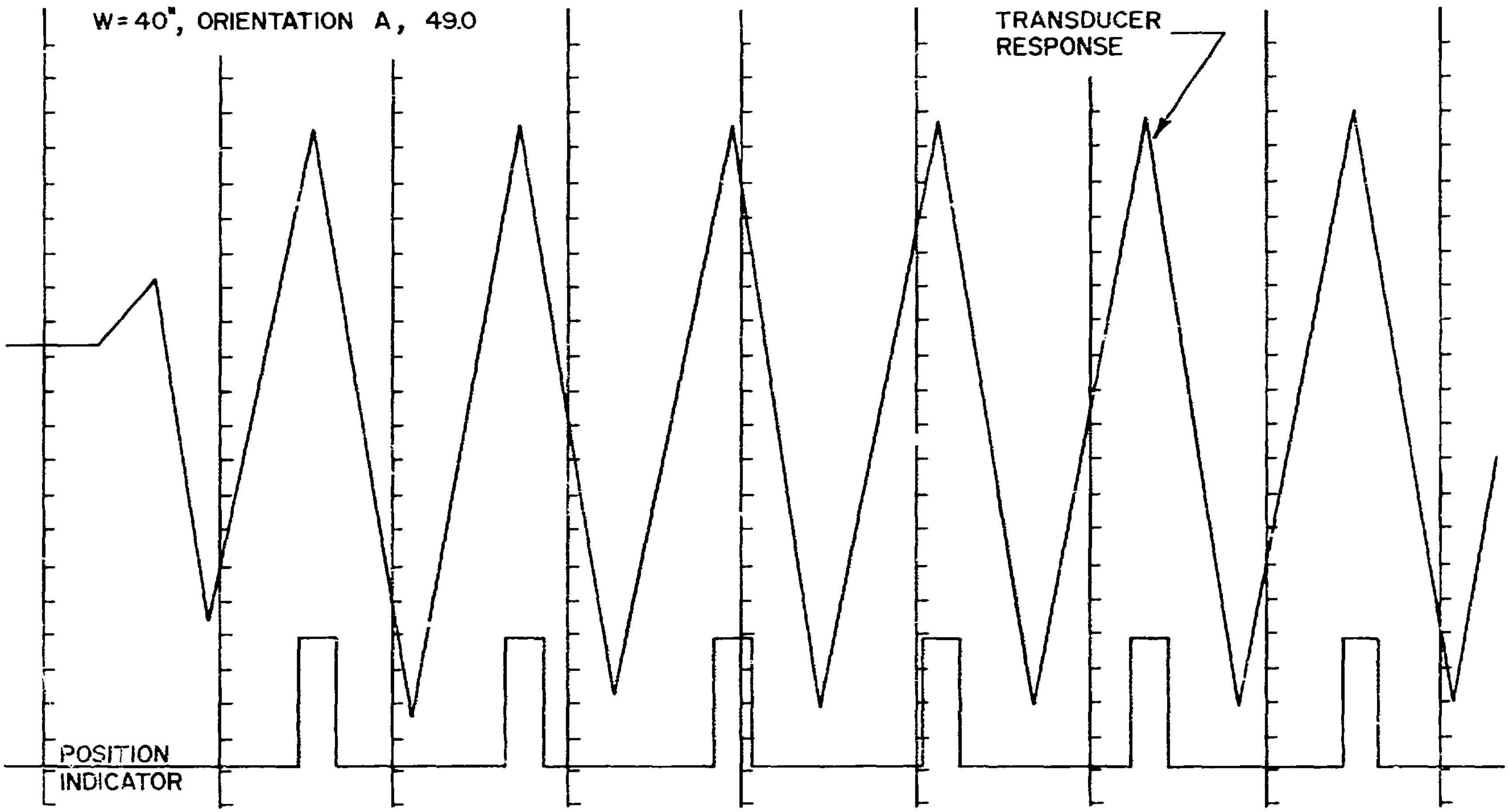


Figure 41. Typical Slosh Reduction Test Recorder Output

TABLE 18. SLOSH RIG TRANSDUCER CALIBRATION

Static Load (g)	Deflection (mV)
50	0.25
100	0.50
150	0.75
200	1.00
300	1.50
400	2.00
500	2.50
600	3.00
700	3.50

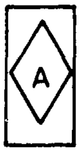
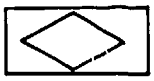
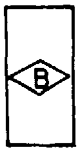
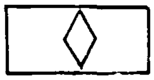
TABLE 19. SLOSH RIG TEST DATA - DRY RUN WITHOUT TEST FLUID

Frequency	Fp gm
30.43	10
35.80	14
38.40	16
45.76	24
49.00	26
51.40	30
53.74	42
61.60	46

TABLE 20. SLOSH RIG TEST DATA - NO EXPLOSAFE

Frequency	Fp gm
32.34	498
33.17	518
36.47	686
39.00	816

TABLE 21. SLOSH RIG TEST DATA
SUMMARY OF ALL EXPLOSAFE ORIENTATIONS

Orientation						
Material Expansion (in)			30.3 Oscillations/min.			
	Fpgm		Fpgm		Fpgm	
35.75	24	-	10	-	16	-
40.00	28	-	8	-	16	-
44.00	30	-	10	-	20	-
			39.3 Oscillations/min.			
	Fpgm	Fpgm	Fpgm	Fpgm	Fpgm	Fpgm
31.00	64	62	14	14	24	24
35.75	52	58	24	22	30	28
38.75	70	50	12	14	34	40
40.00	62	62	16	18	38	42
42.50	46	52	20	24	42	46
44.00	42	46	18	24	46	40
			48.96 Oscillations/min.			
	Fpgm	Fpgm	Fpgm	Fpgm	Fpgm	Fpgm
31.00	126	132	20	20	48	54
35.75	92	108	28	20	62	82
40.00	86	94	16	20	62	60
44.00	70	78	30	24	86	94
			53.74 Oscillations/min.			
	Fpgm		Fpgm		Fpgm	
35.75	118	-	74	-	88	-
40.00	132	-	48	-	118	-
44.00	120	-	72	-	132	-
			61.2 Oscillations/min.			
	Fpgm	Fpgm	Fpgm	Fpgm	Fpgm	Fpgm
35.75	156	208	130	98	132	132
40.00	178	200	100	104	136	154
44.00	188	190	86	76	178	192

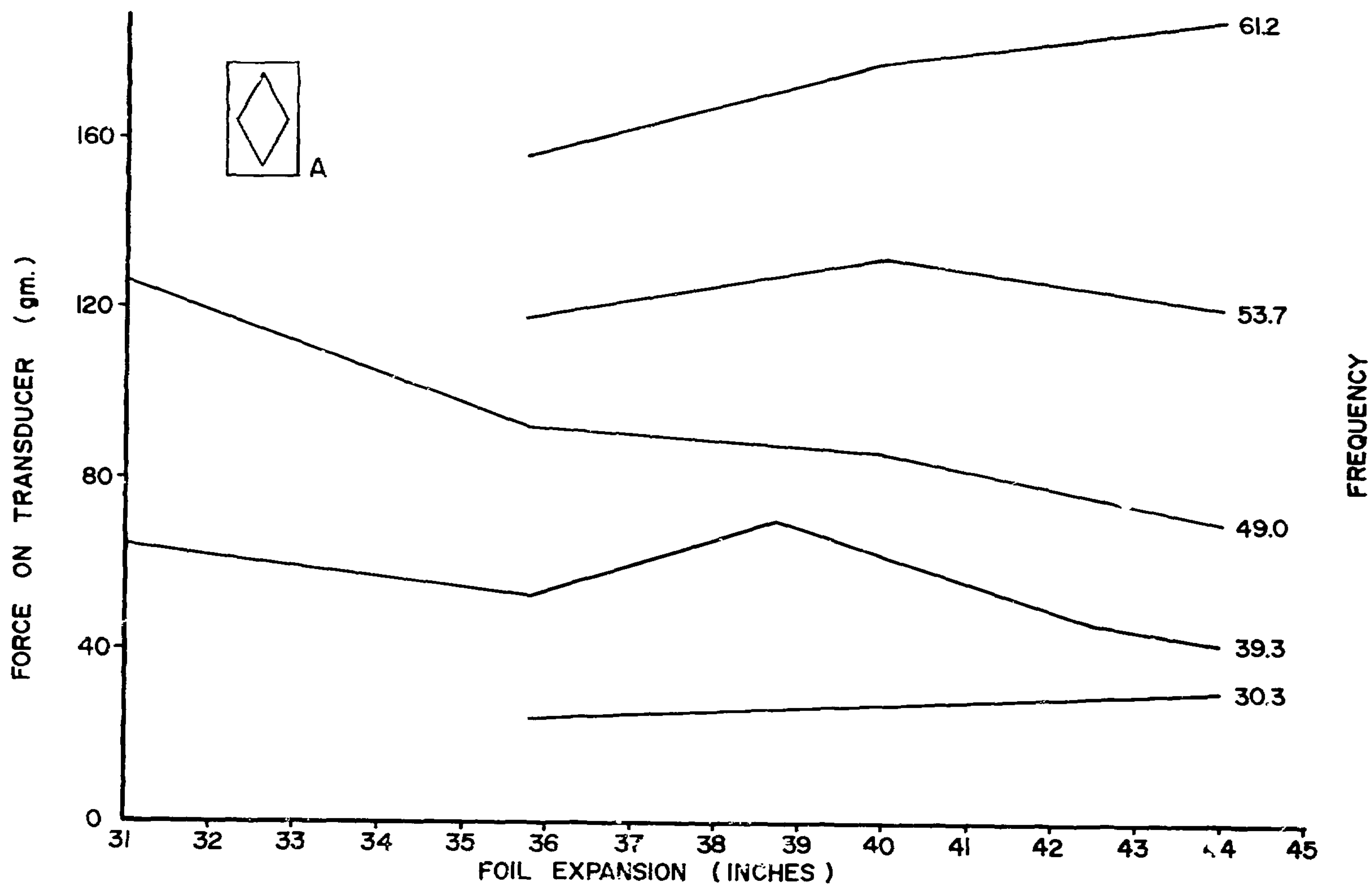


Figure 42. Effect of Expansion on Waveforce - Orientation (A)

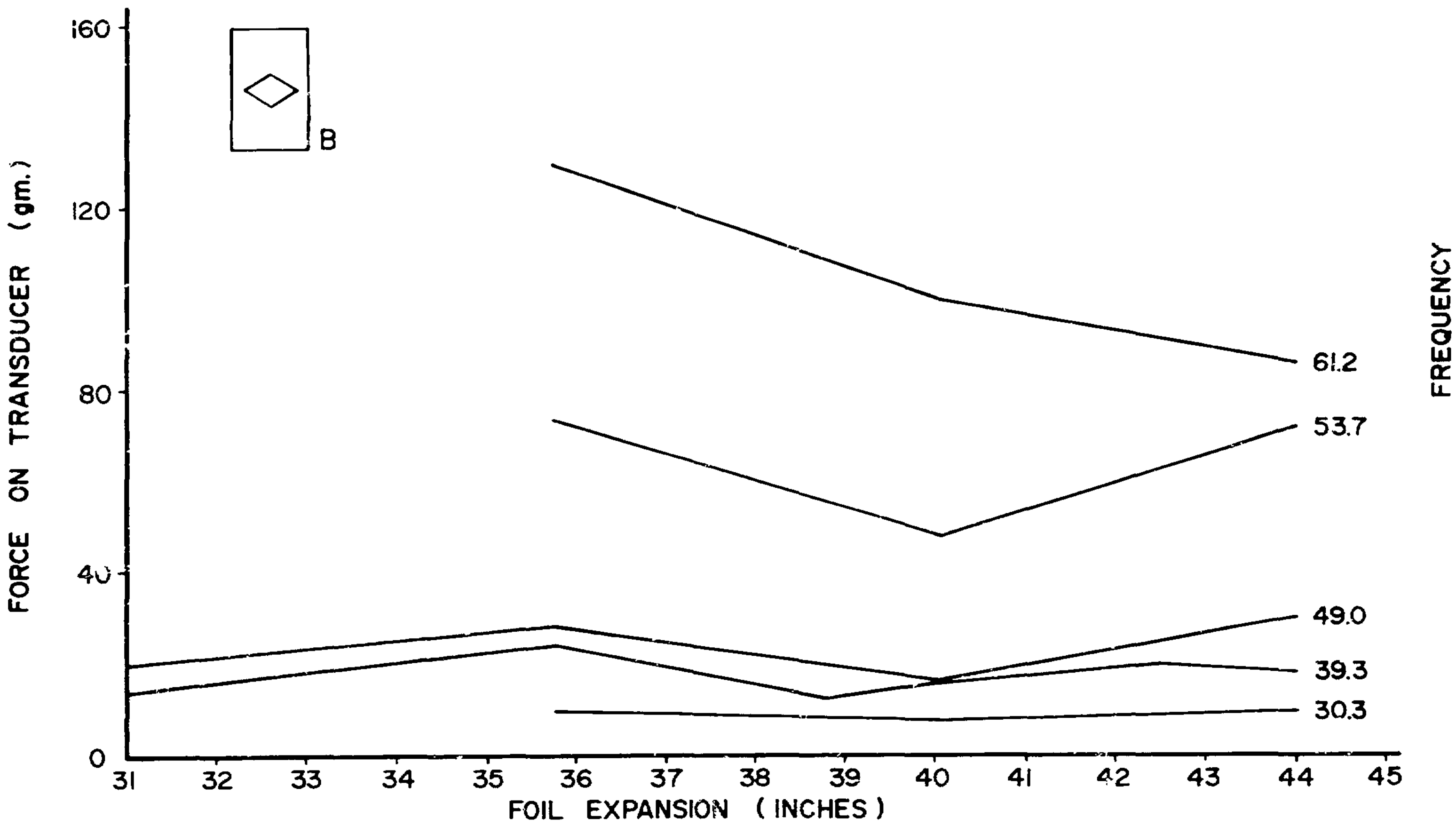


Figure 43. Effect of Expansion on Waveforce - Orientation (B)

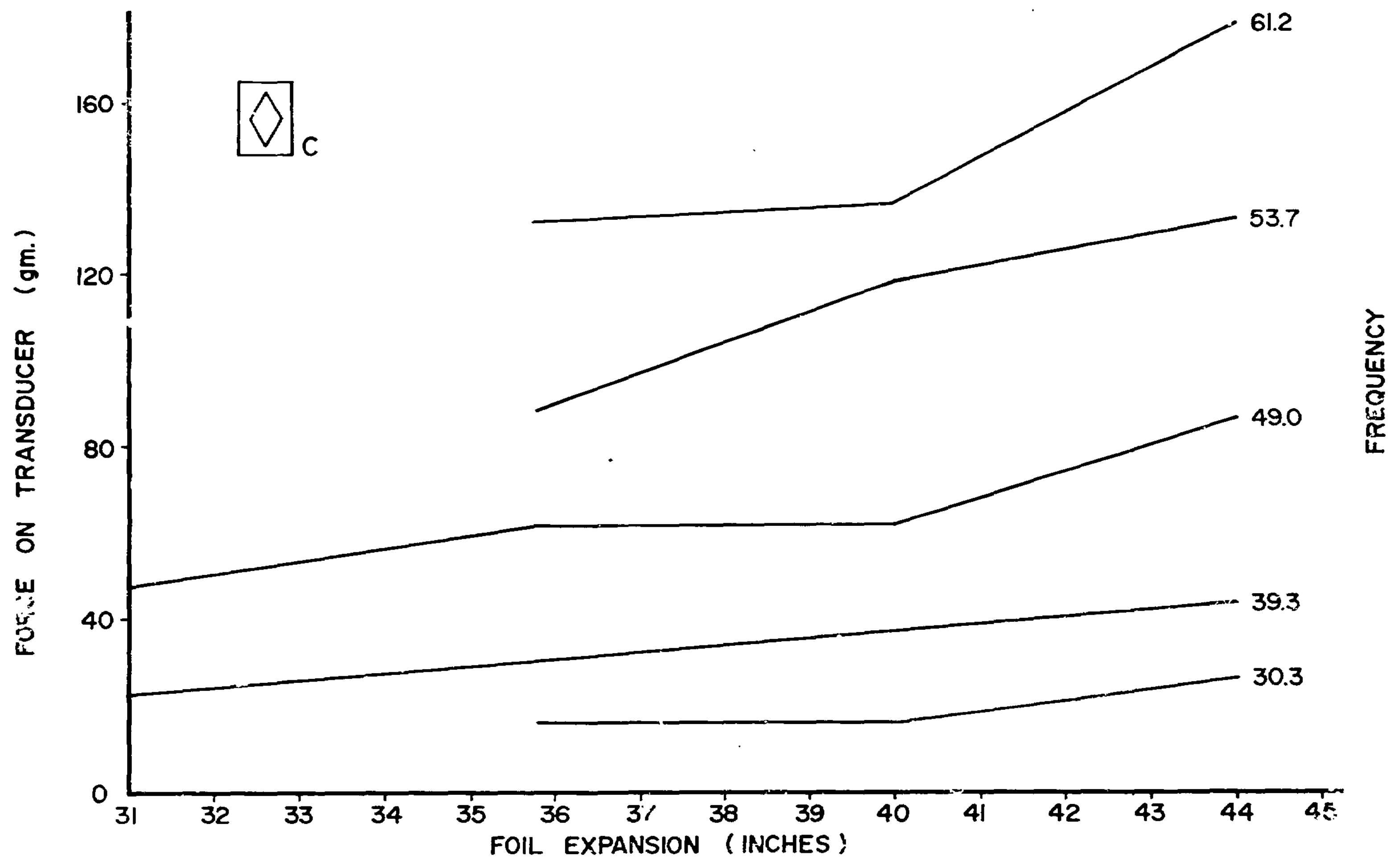


Figure 44. Effect of Expansion on Waveforce - Orientation (C)

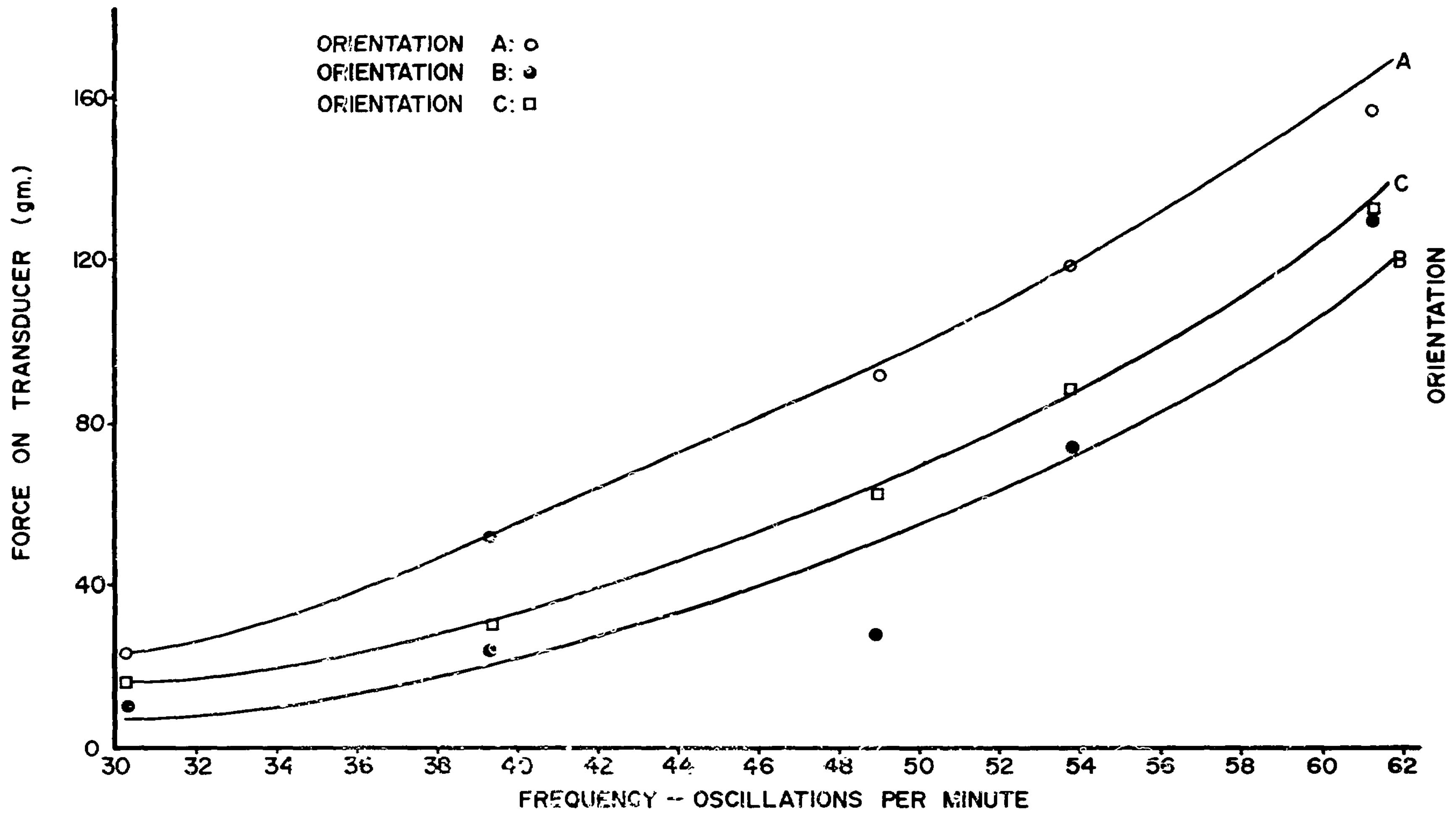


Figure 45. Effect of Orientation and Frequency on Waveforce

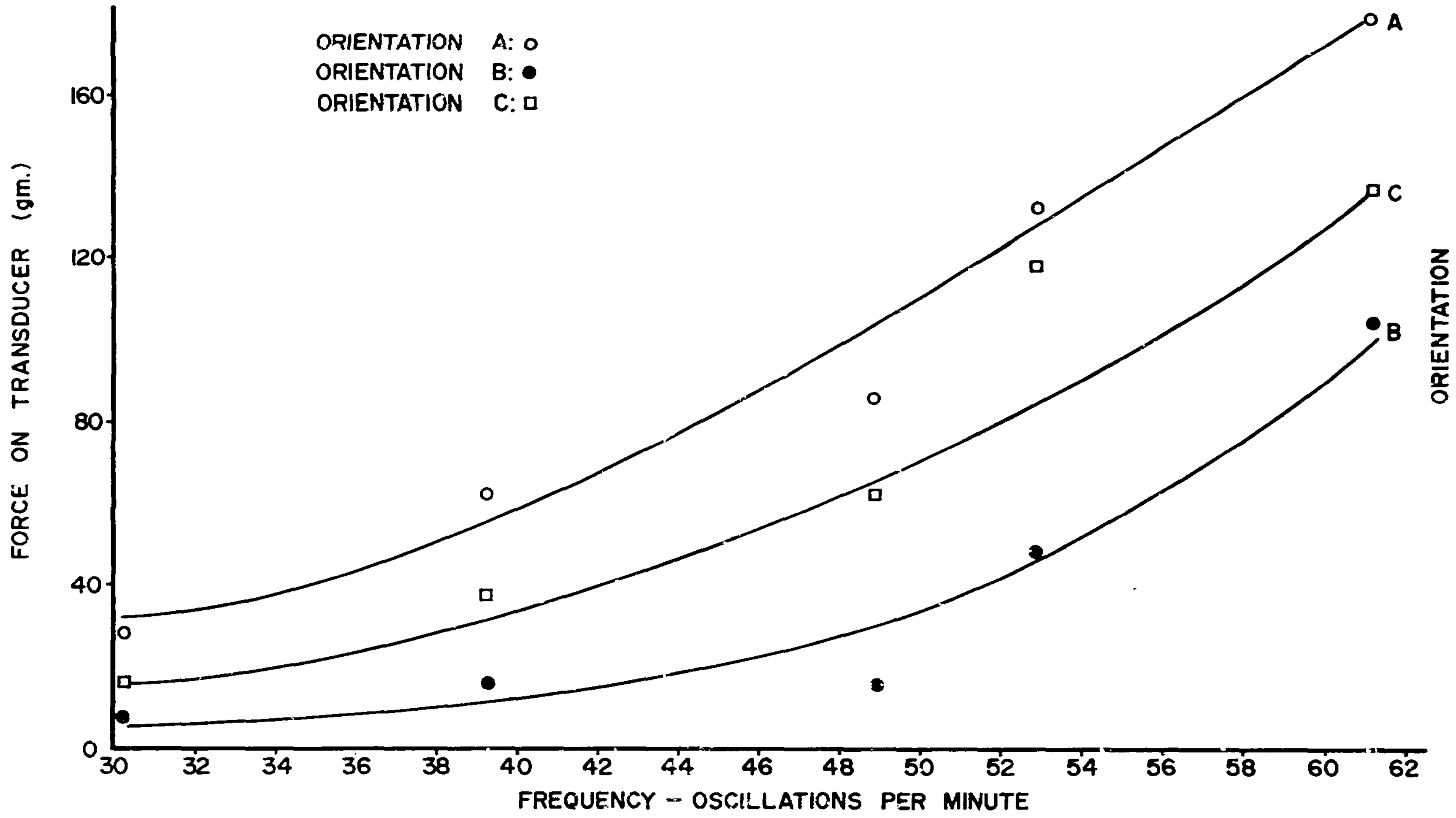


Figure 46. Effect of Orientation and Frequency on Waveforce

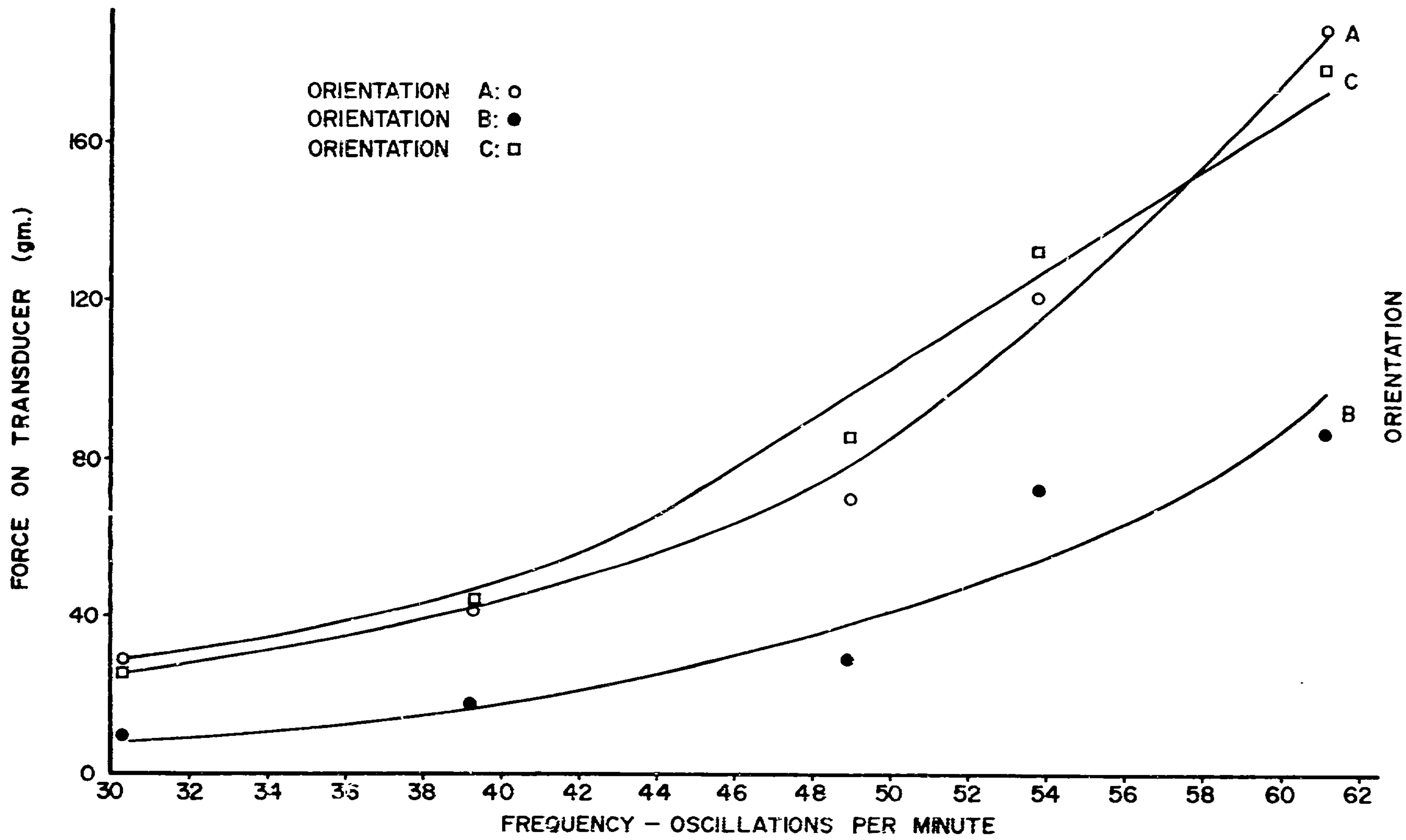


Figure 47. Effect of Orientation and Frequency on Waveforce

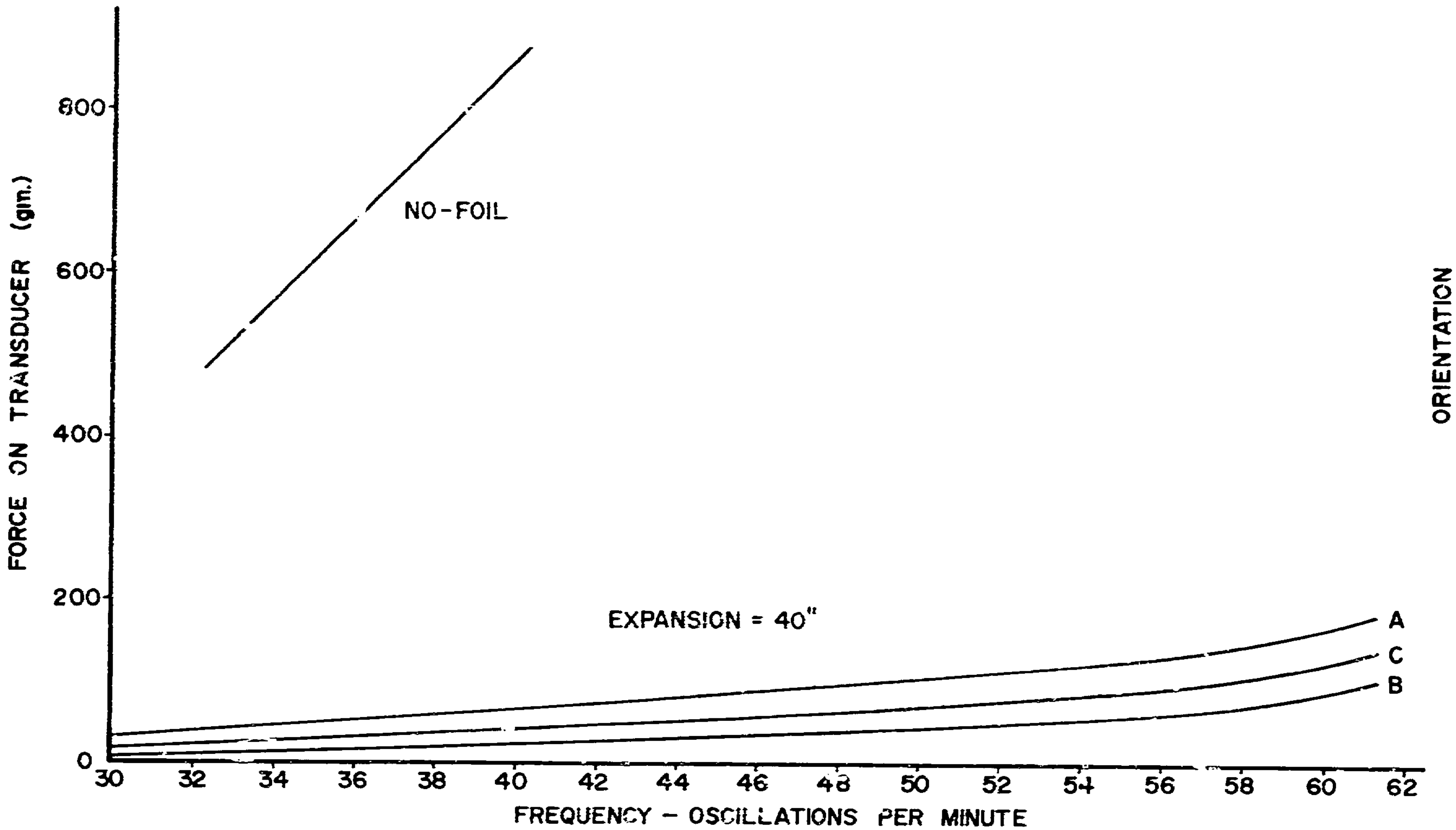


Figure 43. Waveforce Reduction by Explosafe

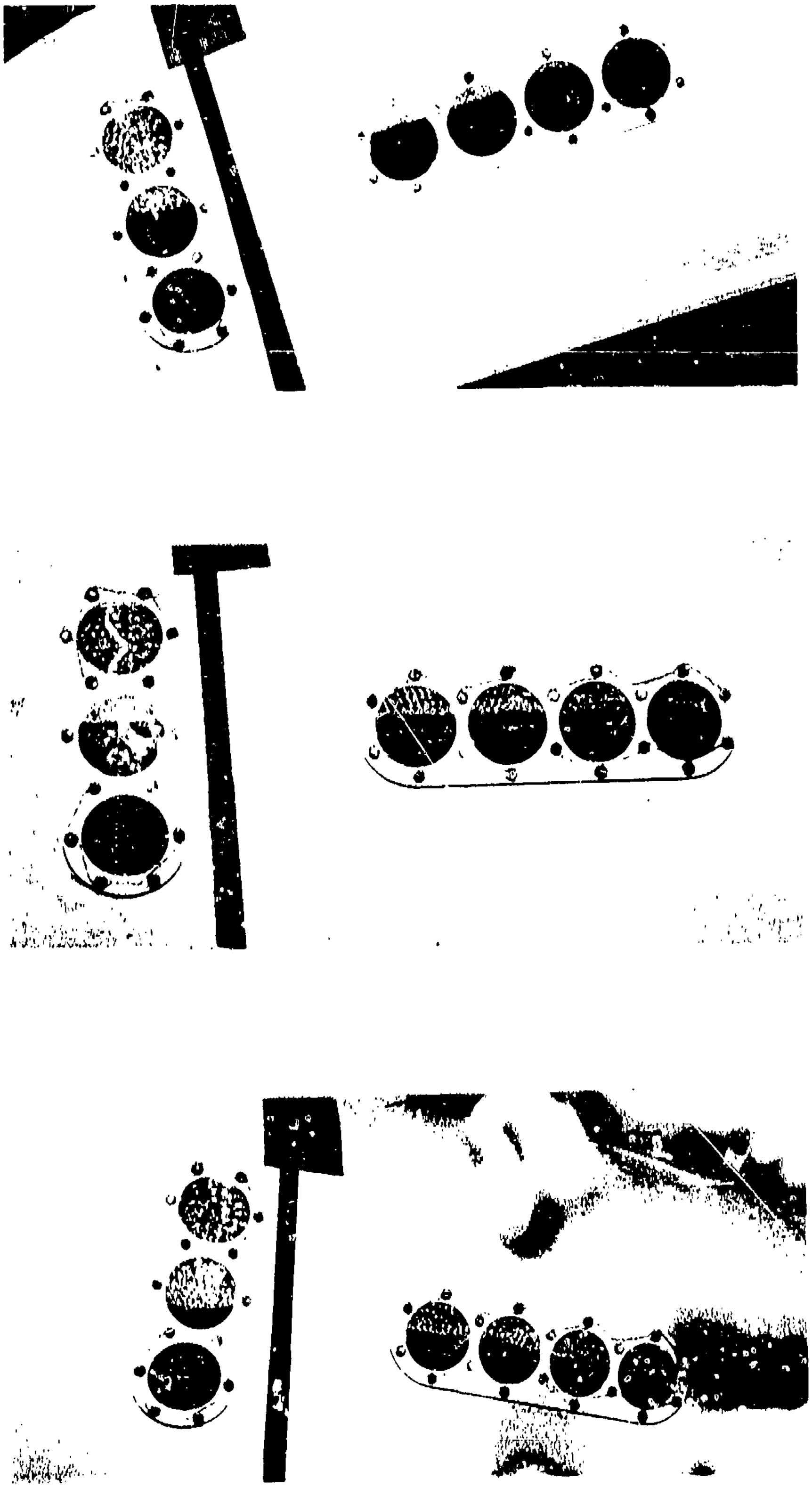


Figure 49. Slosh Reduction Demonstrated During External Wing Tank Slosh Test

7.0 ELECTROSTATIC CHARGE DISSIPATION

The hazards of static electricity in aircraft fuel systems have long been of concern to the US Air Force and the aircraft industry in general. Responsibility for a number of incidents involving the ignition of flammable vapors during aircraft fueling has been attributed to electrostatic spark discharge. In particular, eight recent examples involved military aircraft where bladder lined fuel tanks packed with reticulated polyurethane foam (RPF) were being fueled, generally with JP-4. Circumstances suggested that static charges were being generated and discharged within the RPF, and caused the USAF to support in-house and contract research on the subject.

Exxon Research and Engineering Company has considerable theoretical and experimental expertise in this field together with facilities designed to investigate the specific questions of charge generation and discharge. They participated in the USAF research program to study the role of RPF, bladder cells and fueling conditions in static generation and spark discharge.

At the outset of the Explosafe qualification program, the effects of the material on charge generation and dissipation were questioned. Exxon was therefore invited to include the Explosafe material in their test program. Reference 5 reports all the tests in that program - only the testing and the testing related to Explosafe will be described here.

7.1 Procedure

The test rig consisted of a 55 gallon drum serving as a test tank which could be supplied with either electrostatically charged or uncharged fuel. The schematic arrangement is depicted in Figure 50. Fuel from 55 gallon epoxy lined supply drums is pumped either through or around a Bendix Gage charge generator (filter-monitor), depending on the type of test being conducted, into the test drum and returns to the supply drums after test by gravity.

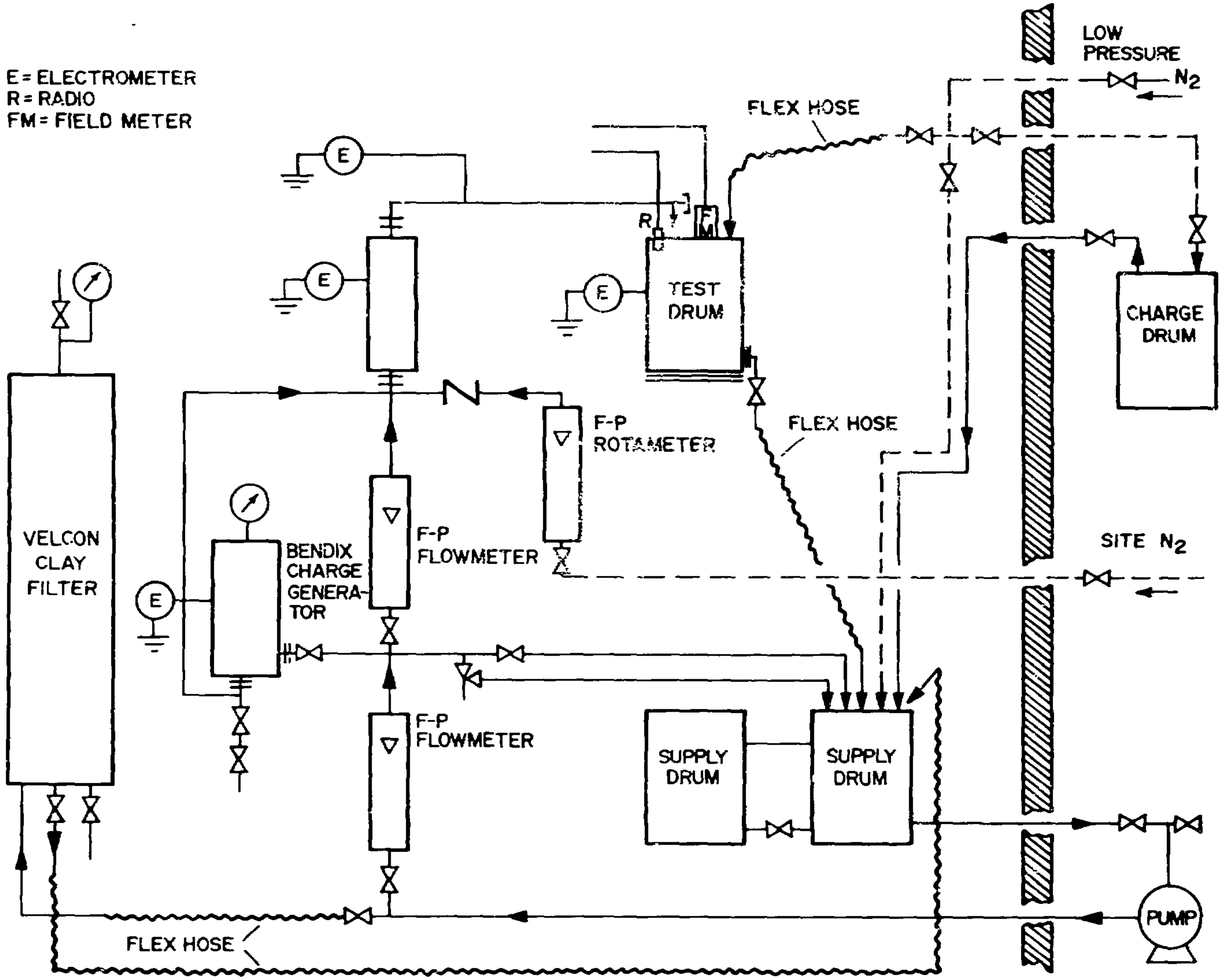


Figure 50. Electrostatic Charging Test Arrangement

Fuel level in the drum is monitored by the back pressure as nitrogen is bubbled through a tube extending to the bottom of the drum - this also serves to sustain an inert atmosphere in the vapor phase. A nitrogen purging system is also provided. A complete system by-pass is able to direct the fuel through a Velcon clay filter to maintain clean fuel and remove additives should they be used in particular tests.

Instrumentation monitors various parameters: Keithley electrometers (model 600B) measure the streaming currents from the electrically isolated charge generator, drum, and drum inlet pipe; an electrostatic voltmeter (Comstock & Wescott model # 12009) measures the field strength inside the drum; internal and external transistor radios are specially tuned to detect spark discharges - these are calibrated prior to each test sequence by discharging sparks of known energy inside the drum. The radios provide a rough measure of the energy content of a static discharge and the two allow discrimination between internal spark discharges and extraneous signals.

The signals from all the instrumentation are permanently recorded using a SOLTEC six point recorder.

7.2 Results

Tests were conducted in the drum lined with a bladder specially manufactured by Uniroyal from materials meeting MIL-T-6396 and MIL-T-5578. Two fuel inlet configurations were studied - one a high velocity single orifice type directed at the sidewall of the drum 0.8 inches above the bottom, and the other a multiple orifice piccolo tube type positioned on the bottom. Inlet velocities with each type are noted in the results.

Measurements were taken with both charged and uncharged fuel which was clay treated to ensure that no additives were present. The fuel used was Jet 'A' and a sample analysis is presented in Table 22.

The first series of tests were conducted on the lined drum packed with the Explosafe material. Figures 51 and 52 illustrate the packing arrangement of the horizontally layered, 2 mil thick aluminum alloy 3003/H24 foil expanded to a width of 35 inches from 14 inches. Total number of layers was 478 and the material density was 2.05 lb/ft^3.

The raw data for this series is presented in Appendix B5, Table B5-1. The second series of tests was conducted on the lined drum without the Explosafe material to give a basis for comparison. Table B5-2 lists the raw data of this series.

The most immediate observation was the absence of static discharge in the Explosafe series when flowing at maximum rate through either the high velocity inlet or the low velocity piccolo inlet with both charged and uncharged fuel.

TABLE 22. FUEL CHARACTERISTICS - ELECTROSTATIC CHARGING TESTS

Test Description	ASTM Test Method	Result
Gravity, °API	D-287	43.4
Distillation, °F	D-86	
IBP		314
10%		376
50%		428
FBP		521
Flash Point, °F	D-56	130
Freezing Point, °F	D-2386	-46
Saybolt Colour	D-156	28
Water Separometer Index (Modified)	D-2550	98

Figure 51. Batts of Explosafe Material Prior to Installation in Test Drum

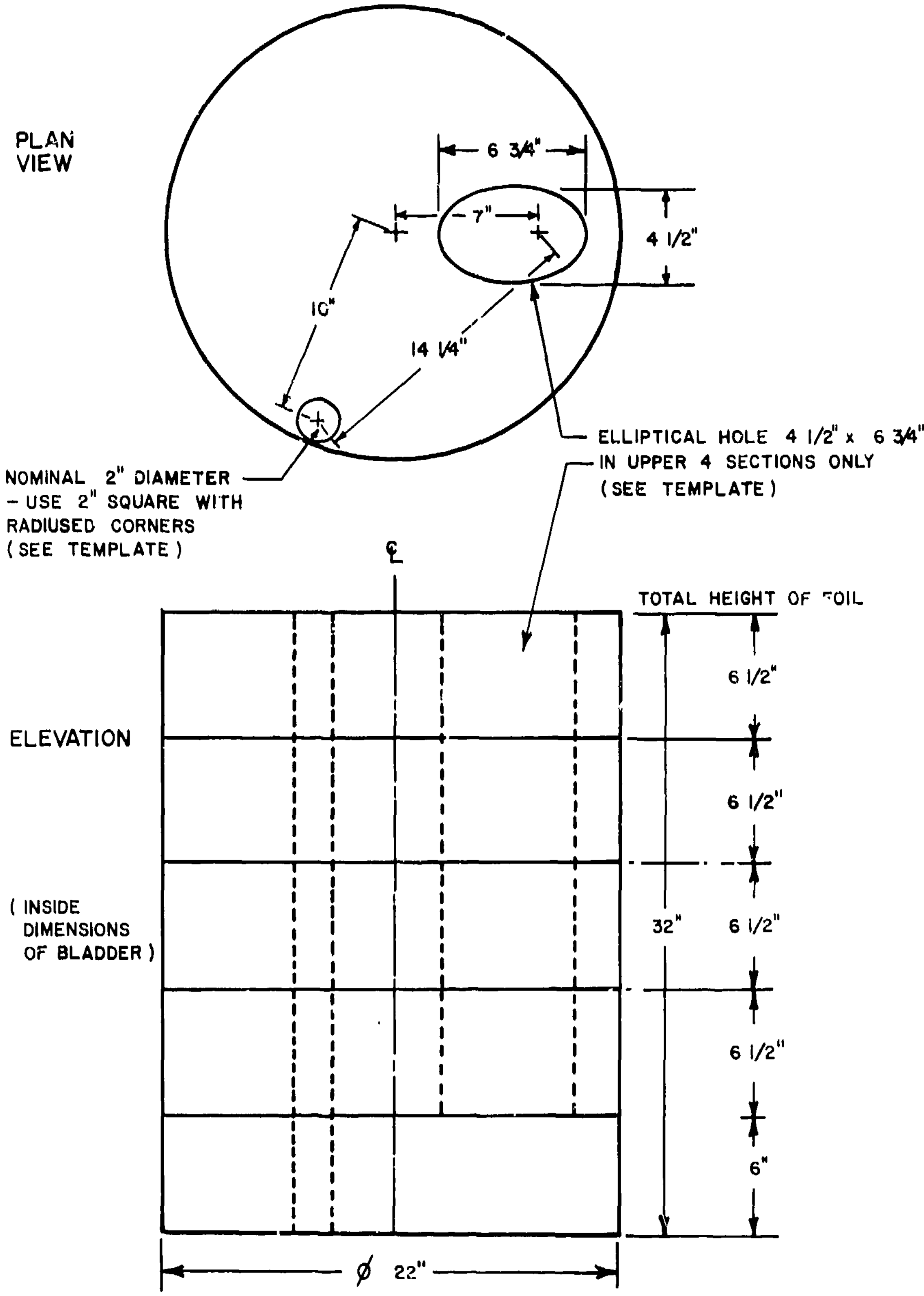


Figure 52. Detail Drawing of Explosafe Drum Installation

Unexpectedly, spark discharges were detected in a number of the subsequent tests without the Explosafe material with both charged and uncharged fuel and the high velocity single orifice inlet. These were later attributed to the presence of small aluminum particles which were broken off the Explosafe mesh during its removal and acted as unbonded metallic charge collectors.

The turbulence produced by the high velocity fuel apparently swept the particles from the bottom of the drum, and as they made contact with a grounded object such as the inlet, discharging occurred. After removal of the particles no further discharge was detected. It has been suggested that such particles, if occurring in service, might present a problem - not to the fuel tank but to a defueller into which they might be drawn. This is a rather far fetched argument and ignores one or two important points. Firstly, the tank would be defuelled prior to removal of the Explosafe material - it was the removal which generated the particles in this test series. Therefore, the only particles which would be in the tank prior to defuelling would be those resulting from breakdown of the material during service. Section IV of this report describes a simulated service testing which reveals that over the lifetime of a bladder fuel tank, the material breakdown was only 3 grams and the particles were large enough to preclude their entry into the fuel line past the strainer. Thus the probability of drawing significant quantities of particles into a defueller is obviously extremely low since there are filters in the line going to the defueller.

With the Explosafe material in the drum in contact with the inlet it was not possible to separate the electrometer signals from the drum and inlet. However, good balance between the fuel charge density (as it left the charge generator) and the inlet charge density was obtained. The field meter readings will, therefore, be compared to define the role of the material in charge generation.

During the initial Explosafe tests, it was noted that the field meter had no response until the last six seconds of the test when it increased to a maximum. This was because the meter was "looking" at grounded metal and so did not sense the charged fuel until it approached the top of the material, eventually peaking as the fuel covered the mesh. The field strength measurements therefore have to be compared at this fuel level where the peak occurred, i.e. 90% full.

A summary of these measurements is presented as Table 23. It is immediately apparent that in the charged fuel test with both inlet configurations the presence of the Explosafe reduces the field strength, strongly suggesting that the metal mesh conducts the charge to ground to a significant degree.

Unexpectedly, the field strength with uncharged fuel was higher with the Explosafe than without in the test with the single orifice,high velocity inlet. With the low velocity piccolo type inlet the trend reversed to that noted with the charged fuel. It has been suggested because of this that when using uncharged fuel and the high velocity inlet the Explosafe acts as a charge separator by presenting large surface area to the fuel. If so, then by the previous conclusion would it not simply be conducted to ground? It appears as though with the high velocity inlet there was some minimum field strength below which the charge could not be dissipated. Perhaps this was a function of the contact surface area between the material and the inlet. In the case of the piccolo inlet there certainly appeared to be no such limit - the charge was effectively totally dissipated by the mesh whether the fuel was charged or not. The tests are in fact somewhat inconclusive and further testing is required with more extensive study of the effect of contact area between the material and grounded objects, the fuel inlet configuration and velocity.

TABLE 23. ALUMINUM MESH VS DRUM TESTS (CLAY TREATED FUEL)

Inlet Type (**) / Inlet Velocity m/s	Max Field Strength (90% full) KV/m(*) Charged (Uncharged) Fuel		
	S / 22	S / 10	P-3 / 5
Empty Drum	>500 (45)	200 (11)	150 (26)
Al. Mesh	200 (180)		20 (5)

(*) All values in the table are negative. The field meter used for this study was limited in the maximum value it could sense (500 KV/m). Thus, a reading of 500 KV/m could indicate that the field strength was 500 KV/m or more.

(**) S = single orifice (High Velocity)

P = multiple orifice (Piccolo)

7.3. Conclusions

The restricted testing conducted to date has been inconclusive in determining the charge generating properties of the Explosafe material.

Charge dissipation qualities were positively demonstrated, however, and it seems logical to conclude that if the material will dissipate charge it will not generate high enough levels to cause spark discharges.

It must be borne in mind that this subject is not fully understood and measurement techniques are far from definitive. Compounding these problems is the difficulty of simulating actual fuelling operations.

7.4 Recommendations

The Explosafe material appears to have potential in eliminating the electrostatic problems encountered in aircraft fuelling operations. Further testing is required to gain definitive results on this, and must study the effect of:

- material/grounded object contact areas
- location, configuration, and velocity of fuel inlet
- scaling

Full scale testing in a non-inerted test rig is eventually recommended. A rig of such a scale does exist at the Fairchild-Republic factory in Farmingdale, New York. If smaller scale tests are positive, a test in this facility should be pursued.

SECTION IV

TASK III - ENVIRONMENTAL EFFECTS ON MATERIAL

1.0 OPERATIONAL - STATIC LOADING

The term static loading here refers to steady force applied to the Explosafe material, typically by itself during storage in a stacked arrangement or in aircraft applications during high 'g' maneuvers where the effective weight of material bearing upon other material may be increased many-fold. In the latter example, deformation of the material results in voids which could significantly affect the combustion overpressure attenuation if an ignition source were to be present. Should the deformation become permanent, then the addition of more material would be necessary to restore the suppression ability.

With this in mind, VIPL designed a test procedure and apparatus for measuring the deformation of a specimen of the Explosafe material under conditions of controlled uniformly distributed loading in the direction of the load. To simulate installed conditions the material was supported on all four sides thereby restricting deformation to the load direction only.

1.1 Procedure

The test procedure is described in Appendix C 1, together with the test rig.

1.2 Results

In devising a test program, it was determined that the strength of the material under compression would be influenced primarily by the orientation of the layers and cells and by the thickness of the foil used.

Specimens of the 2 and 3 mil foils were, therefore, studied in three orientations:

a) with the layers of material parallel to the loading plate - this orientation was designated "FLAT".

b) with the layers of material perpendicular to and the long dimension of the cells parallel to the loading plate - this orientation was designated "HORIZONTAL".

c) with both the layers of material and the long dimension of the cells perpendicular to the loading plate - this orientation was designated "VERTICAL".

The expansion of the material was held constant throughout the tests at 40 inches. Thus, the specimen densities were 1.90 and 2.71 lb/ft^3 for the 2 mil and 3 mil respectively. A variation in specimen height was experienced and to eliminate this inconsistency the results are best expressed in terms of percentage deflection, thus:

$$\% \text{ Deflection} = \frac{Q_o - Q_1}{Q_o} \times 100$$

Where Q_o = Measured height of specimen at first recorded pressure.

Q_1 = Measured height of specimen at a given loading.

The loading is expressed as loading plate pressure, thus:

$$P_p = \frac{P_g}{A_p} \times \frac{\pi D^2}{4}$$

where P_p = Loading Plate Pressure psi

P_g = Measured cylinder pressure psig

D = Piston diameter = 2.5 inches

A_p = Loading plate area = 10 x 10 = 100 sq. inches.

The results are summarized in this manner in Tables 24 and 25 for the 3 mil and 2 mil respectively. Figure 53 compares the results of both thicknesses at all three orientations.

The effect of the orientation is immediately apparent and both thicknesses have similar characteristics. The favored orientation is that designated "vertical", and with both material thicknesses, less than 5% deformation is experienced up to a loading of 0.8 psi. In the case of the 3 mil material this is equivalent to the load resulting from vertical stacking to a height of approximately 42 feet with the specimen density. With the lighter 2 mil material the stack could rise to a height of 60 feet for the same deflection.

An alternative way of expressing this capability is to relate it to the 'g' forces which with a given depth of material would result in the same deflection of the lower layers. Taking a four foot deep section of Explosafe material which might be the case in, for example, a fuselage tank, then the 3 mil foil would withstand approximately 14 'g' and the 2 mil up to 20 'g' without exceeding the 5% deflection.

The 2 mil material in this orientation eventually suffered a sudden increase and thereafter a more rapid rate of increase in deflection. This was found to be the result of the layers buckling and folding back on themselves rather than being simply compressed.

However, the load at which this occurred was well beyond any that might be experienced in normal use from either acceleration or storage. Within the load range tested the 3 mil remained below this critical point and deflection was a mere 10% at the maximum load of 3.8 psi - a load equivalent to a stacked specimen material

TABLE 24. STATIC LOADING TEST RESULTS - 3 MIL EXPLOSAFE

Foil Orientation

Vertical			Horizontal			Flat		
Plate Press. (psi)	Height (in)	% Deflection	Plate Press. (psi)	Height (in)	% Deflection	Plate Press. (psi)	Height (in)	% Deflection
0.1	5.62	0.00	0.15	5.06	0.00	0.15	6.75	0.00
0.15	5.56	1.07	0.25	5.06	0.00	0.25	6.72	0.44
0.25	5.50	2.14	0.34	5.03	0.59	0.34	6.66	1.33
0.44	5.44	3.20	0.49	5.00	1.19	0.49	6.53	3.26
0.74	5.38	4.27	0.69	4.94	2.37	0.69	6.41	5.04
0.98	5.31	5.52	0.79	4.88	3.56	0.79	6.34	6.07
1.23	5.31	5.52	0.88	4.84	4.35	0.88	6.25	7.41
1.47	5.31	5.52	0.98	4.78	5.53	0.98	6.22	7.85
1.72	5.31	5.52	1.18	4.65	7.91	1.18	6.06	10.22
1.96	5.28	6.05	1.37	4.56	9.88	1.37	5.88	12.89
2.21	5.25	6.58	1.47	4.47	11.66	1.47	5.81	13.93
2.46	5.22	7.12	1.57	4.41	12.85	1.57	5.72	15.26
2.70	5.22	7.12	1.77	4.22	16.60	1.77	5.38	20.30
2.95	5.19	7.65	1.87	4.13	18.38	1.87	5.28	21.78
3.19	5.16	8.19	1.96	4.03	20.36	1.96	5.22	22.67
3.44	5.13	8.72	2.21	3.75	25.89	2.21	4.81	28.74
3.78	5.06	9.96	2.46	3.38	33.20	2.46	4.56	32.44
			2.70	3.13	38.14	2.70	4.31	36.15
			2.95	2.94	41.90	2.95	4.09	39.41
			3.19	2.78	45.06	3.19	3.91	42.07
			3.44	2.66	47.43	3.44	3.78	44.00
			3.63	2.53	50.00	3.54	3.72	44.89
			3.73	2.50	50.59	3.63	3.66	45.78
			3.78	2.47	51.19	3.73	3.63	46.22
						3.78	3.53	47.70

TABLE 25. STATIC LOADING TEST RESULTS - 2 MIL EXPLOSAFE
Foil Orientation

Vertical			Horizontal			Flat		
Plate Press. (psi)	Height (in)	% Deflection	Plate Press. (psi)	Height (in)	% Deflection	Plate Press. (psi)	Height (in)	% Deflection
0.10	6.00	0	0.10	6.00	0	0.10	6.00	0
0.20	6.00	0	0.20	6.00	0	0.20	5.94	1.04
0.29	6.00	0	0.29	5.94	1.04	0.29	5.81	3.13
0.39	5.94	1.04	0.39	5.75	4.16	0.39	5.69	5.20
0.59	5.87	2.08	0.59	5.56	7.30	0.59	5.31	11.45
0.79	5.87	2.08	0.79	4.62	22.90	0.79	5.06	15.60
0.98	5.87	2.08	0.98	2.37	39.60	0.98	4.69	21.90
1.18	5.81	3.12	1.18	2.25	45.80	1.18	4.25	29.20
1.37	5.81	3.12	1.37	3.00	50.00	1.37	3.94	34.30
1.57	5.69	5.20	1.57	2.87	52.10	1.57	3.75	37.50
1.77	5.56	7.30	1.77	2.75	54.20	1.77	3.56	40.60
1.96	5.37	10.40	1.96	2.62	56.30	1.96	3.37	43.80
2.16	5.00	16.70	2.16	2.56	57.30	2.16	3.19	46.90
2.36	4.75	20.80	2.36	2.50	58.30	2.36	3.06	49.00
2.56	4.50	25.00	2.55	2.37	60.40	2.55	3.00	50.00
2.75	4.25	27.50	2.75	2.31	61.50	2.75	2.87	52.08
2.95	4.00	33.30	2.95	2.25	62.50	2.95	2.81	53.10
3.15	3.87	35.40	3.14	2.12	64.60	3.14	2.75	54.20
3.34	3.75	57.50	3.34	2.12	64.60	3.34	2.75	54.20
3.53	3.62	39.60	3.53	2.12	65.60	3.53	2.69	55.20
3.73	3.56	40.60	3.73	2.06	65.60	3.73	2.62	56.30

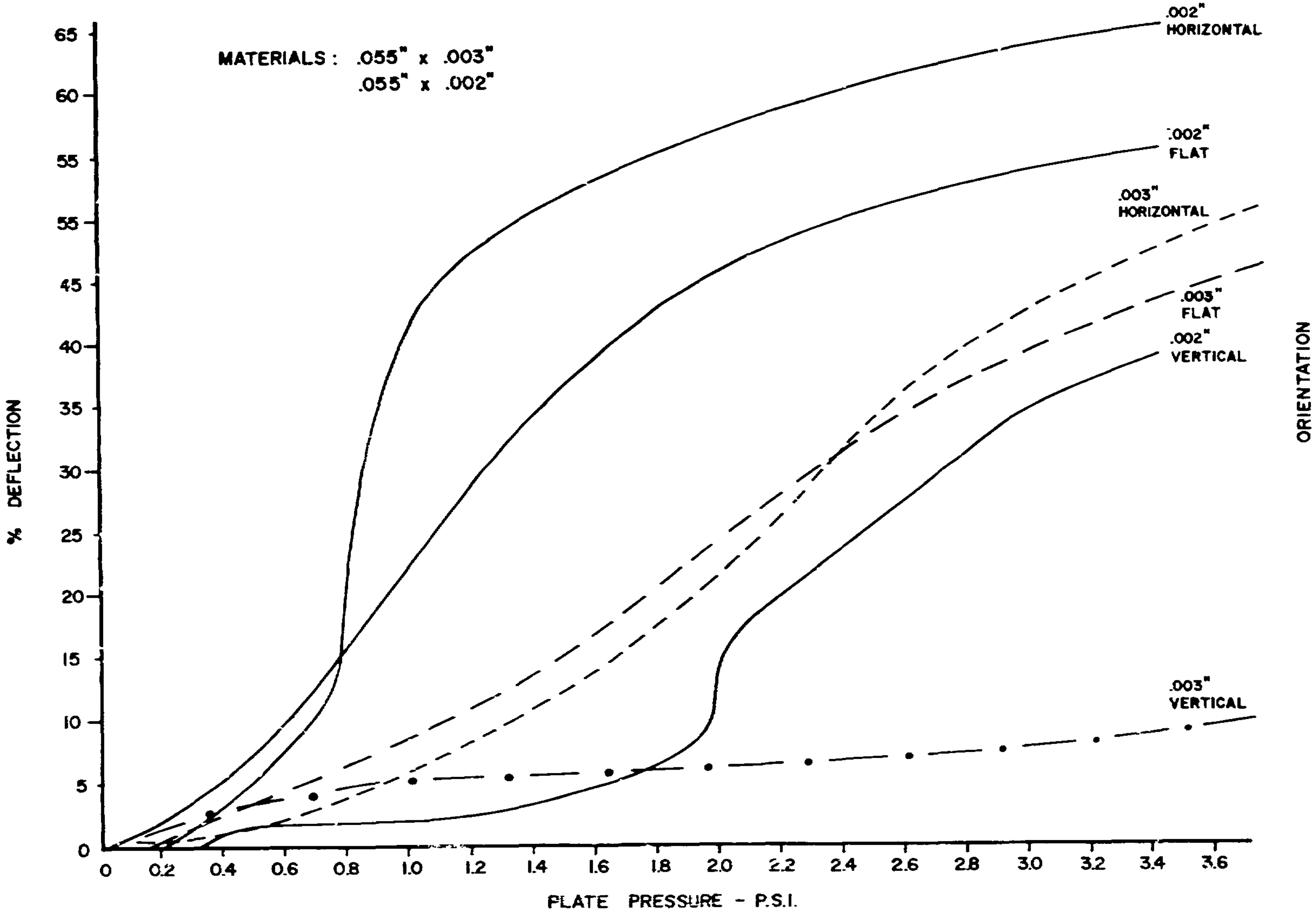


Figure 53. Static Loading Characteristics of Two Explosafe Materials in Different Orientations

height of 200 ft!

Both the 2 mil and 3 mil materials would be expected to return to their original dimensions after undergoing less than 5% deflection. This was not checked during the tests, however, and should be a part of future work.

The "horizontal" orientation by contrast exhibited rapid rise in deflection, the 2 mil in particular undergoing the buckling phenomenon at a very early stage. In this orientation the load is tending to reverse the expansion process. Consequently the twist of the strands decreases, the layers become thinner, and the side support for the layers is lost.

The "flat" orientation exhibits similar deflection to the "horizontal" but increases with load at a relatively steady rate. Inspection of the test specimen during the test suggested that the material is crushed in layers starting from the loaded surface and progressing down as the specimen was crushed.

The strengths of these two orientations are still impressive, however, and the 2 mil material in the example used previously with a four feet deep installation could withstand up to 10 'g' with less than 5% deflection. The 3 mil foil could similarly withstand up to 11 'g'.

Springback characteristics were not studied in depth during this test program but general observations suggested that the 'vertical' orientation would rapidly return after small deflections of up to 5%. The 'horizontal' and 'flat' orientations were more prone to permanent deformation.

After loading to the maximum rig capability the 'vertical' orientation sample sprang back to leave a permanent deformation of 6%, the 'horizontal' orientation 42%, and the 'flat' orientation 36%.

Further testing at the small loads which are more representative of in-service conditions are desirable to obtain springback data and also to study the effects of either prolonged or cyclic loading. Since expansion affects both the density of the material, the strand twist and the cell geometry, the next test series should be conducted with a range of expansions.

1.3 Conclusions

The primary conclusion of this test program was that the Explosafe material is best oriented such that its layers and the long dimension of the cell lie in the direction of the anticipated maximum load.

With this orientation the temporary deformation of both the 2 and 3 mil materials will be less than 5% under loads far in excess of those which might be imposed during service, storage, or transportation.

While the other two orientations are more likely to suffer permanent deformation with either prolonged or repeated loading, they also will withstand normal operating loads with less than 5% deformation.

1.4 Recommendations

Further testing is desirable in this area to define the characteristics of various densities of material under realistic static and cyclic loads (in the lower range of the tests reported here).

This requirement does not dilute or qualify the testing carried out to date. The information is necessary only to complete the data file for design purposes.

2.0 OPERATIONAL - DYNAMIC SLOSH

2.1 Procedure

Two slosh tests representing lifetime operating conditions were performed with the intention of evaluating the performance of both coiled and layered Explosafe material. Friability, measurable shrinkage or compacting of the foil, and shift in batt orientation were pertinent factors to be investigated. The influence of Explosafe, under dynamic slosh conditions, on typical sealant and corrosion preventive fuel tank coating was to be evaluated. Based on the results of this study, Explosafe design criteria was to be defined for aircraft applications of the foil.

Test No. 1

The first test was performed on a 200 gallon external pylon tank fully packed with a combination of coiled and layered Explosafe material. Layered foil was installed in the conical nose and tail sections and coiled foil in the cylindrical mid-section. See Appendix D 2 for material specifications, batt configurations and installation procedure.

Certain internal areas of the tank were coated in accordance with USAF T.O. 1-1-3 guidelines with: (a) specification MIL-C-27725 topcoating, which is a two part, translucent, polyurethane material which provides a corrosion preventive coating in integral tank interiors, and (b) specification MIL-S-8802, Class B sealant, which is a synthetic rubber based material generally used for prepack, injection, filleting and faying surface seals. Appendix C 2 gives full details of specifications and locations of the sealant and topcoating within the tank.

Test No. 2

The second slosh test was conducted on the same tank, but this time, all batts installed were manufactured from layered foil only. The batts were oversized by 2% in the short diamond and thickness dimensions. Voids were provided at the gravity filler port, sump drain area, level control valve (simulated) and pressure inlet fuel feed line. See Appendix D 3 for details.

In the nose cone, four strips of specification MIL-S-8802, Class B sealant were applied over selected areas in an experimental attempt to anchor batts voided at the gravity filler port. See Appendix C 3 for a detailed description. Other batts were not thus anchored.

MIL-C-27725 topcoating was reapplied over certain areas leaving portions of coating previously applied, intact. MIL-S-8802, Class A sealant, which is lighter than the Class B sealant previously used, was brush-coated over specially installed structural fasteners to present an uneven surface. The purpose was to record the degree of wear of the sealant material, as well as to identify leaks at the fasteners that could be directly attributed to the wearing of the sealant.

MIL-S-8802, Class B sealant strips were applied over selected areas in an attempt to minimize batt movement, thereby limiting abrasion to the corrosion preventive paint. Appendix C 3 gives details of all preparations described.

Slosh Machine

The slosh rig is essentially a table measuring 12 x 18 feet, pivoted about the center line of its short dimension. The rocking action is 15 degrees on either side of the horizontal position for a total of 30 degrees motion. The frequency of the rocking action is 12 cycles per minute. The load bearing capacity of the machine is 20,000 pounds.

Methodology

Testing was performed per MIL-T-6396D requirements for Type I metallic tanks, with some modifications in test procedure since the study was conducted for the purpose of evaluating the performance of the Explosafe material rather than that of the tank itself.

The pylon tank was placed on two wooden saddles, and the assembly was rigidly mounted on the rocker table (Figure 54).

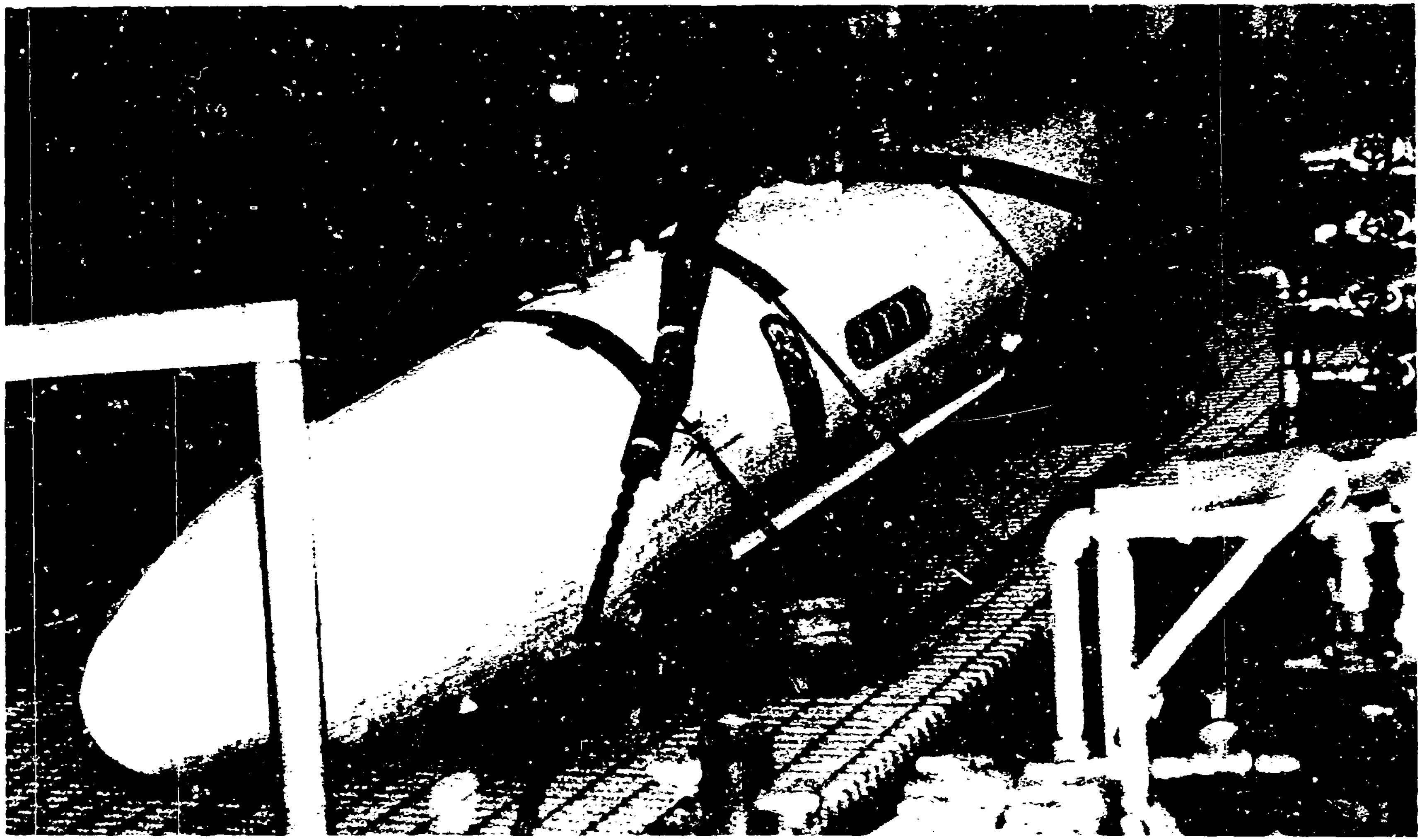


Figure 54. Test Tank Mounted on Siosh Table

For the first test, the tank was two-thirds filled (133 gallons U.S.) with specification TT-S-735, Type III test fluid containing a red dye. The second test was conducted with the tank two-thirds filled with filtered JP-8 fuel.

Testing was performed with the test fluid at ambient temperature and pressure. For each test, a total of 40 hours of sloshing, representing 28,800 slosh cycles, was accumulated on an intermittent basis.

The tank was examined periodically for leaks as the test progressed. Visual inspection of the contents of the tank was made via the observation windows to check for foil movement.

At the conclusion of the second test, samples of fuel were taken during draining. The set of samples consisted of fuel taken at the beginning, midpoint and end of the drain. The sample containers were 1 quart bottles precleaned in accordance with ASTM D2276-73 procedures.

For both the tests, after completion of the drain, approximately 2 gallons of fuel were added to flush the sump, and all drained fuel was collected in 1 quart bottles. Gravimetric analyses of the samples were performed per ASTM D2276-73 procedures to determine the quantity of particulate matter generated during the accelerated life-time operating conditions.

The tank was dismantled and the Explosafe material removed and examined for deformation, compacting and break-down. Where applicable, voids were examined for changes in dimensions and orientation.

2.2. Results

2.2.1 Effect on Material

There was no evidence of leakage from the tank in either test.

Test No. 1

The coiled batts in the mid-section were seen to move slightly with the slosh. There was no apparent damage to the fanfolded batts of the nose and tail cones (Figures 55 and 56). The foil of the coiled batts, all installed in the mid-section, was significantly fatigued such that it was seen to break off at the edges. The coil packed at the aft end of the mid-section was telescoped and visibly disintegrated around the edges (Figure 57). Some volume of foil debris was generated as a result. Additional foil debris was produced by the internally projected drain fitting scraping locally against the bottom of this coil (Figure 58). All the coils became fairly loose and lacked the firm body of the fanfolded batts. Figure 59 shows one such coiled batt after test. Fanfolded batts of the nose and tail cones had shrunk about 2 percent over their expanded dimension while no shrinkage was noticed in the direction perpendicular to the direction of expansion.

Test No. 2

The significantly voided batt located at the fuel pick-up tube (See Appendix D 3, Batt No. B4 shown in Figures D3-2, D3-12 and D3-16), was seen to flex with the slosh; at first slightly, and then, as sloshing progressed, gradually increasing to about 2 inches of total motion. The movement was actually the mass of the batt on either side of the void collapsing into the void due to the surge of the fuel, and moving back to its position of rest with the reversing of the surge. No damage to the batt occurred as a result of the flexing.

No movement of the foil was seen elsewhere in the tank during the first 14 hours of sloshing. The foil was observed to move slightly thereafter, and the motion towards the end of 40 hours of sloshing was about 1/2 inches total, indicating slight compaction in the thickness dimension. Separation between the batt perimeter and the tank wall was not apparent for most batts, signifying little or no shrinkage of the material in the expanded dimension.

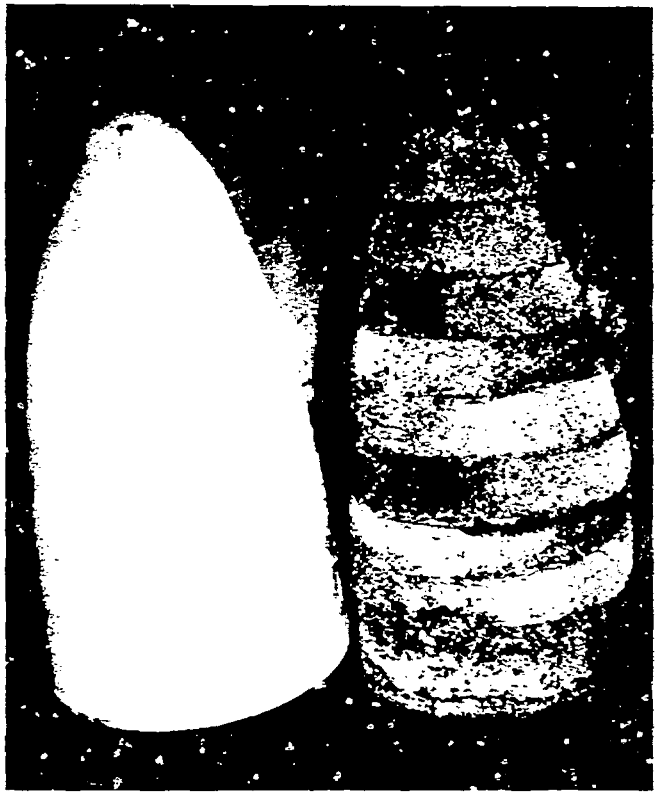


Figure 55. Test 1: Fanfolded Batts of Nose Cone

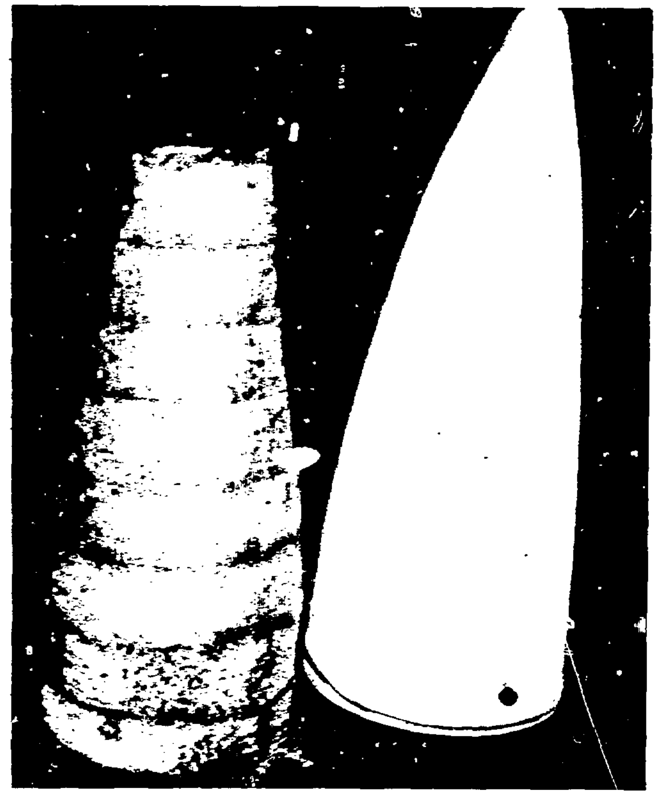


Figure 56. Test 1: Fanfolded Batts of Tail Cone

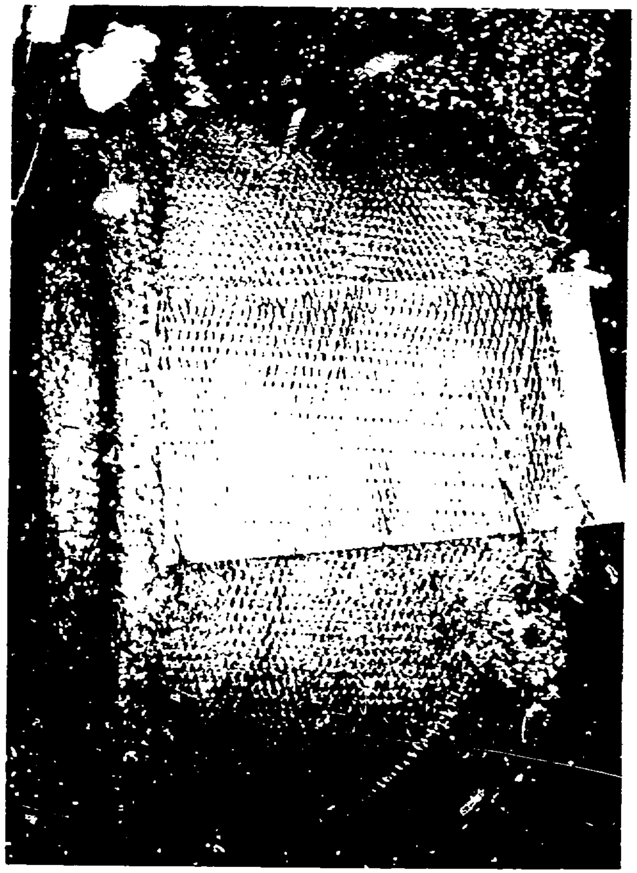


Figure 57. Test 1: Coil from Aft End of Midsection

Figure 58. Test 1: Foil Debris at Drain Fitting

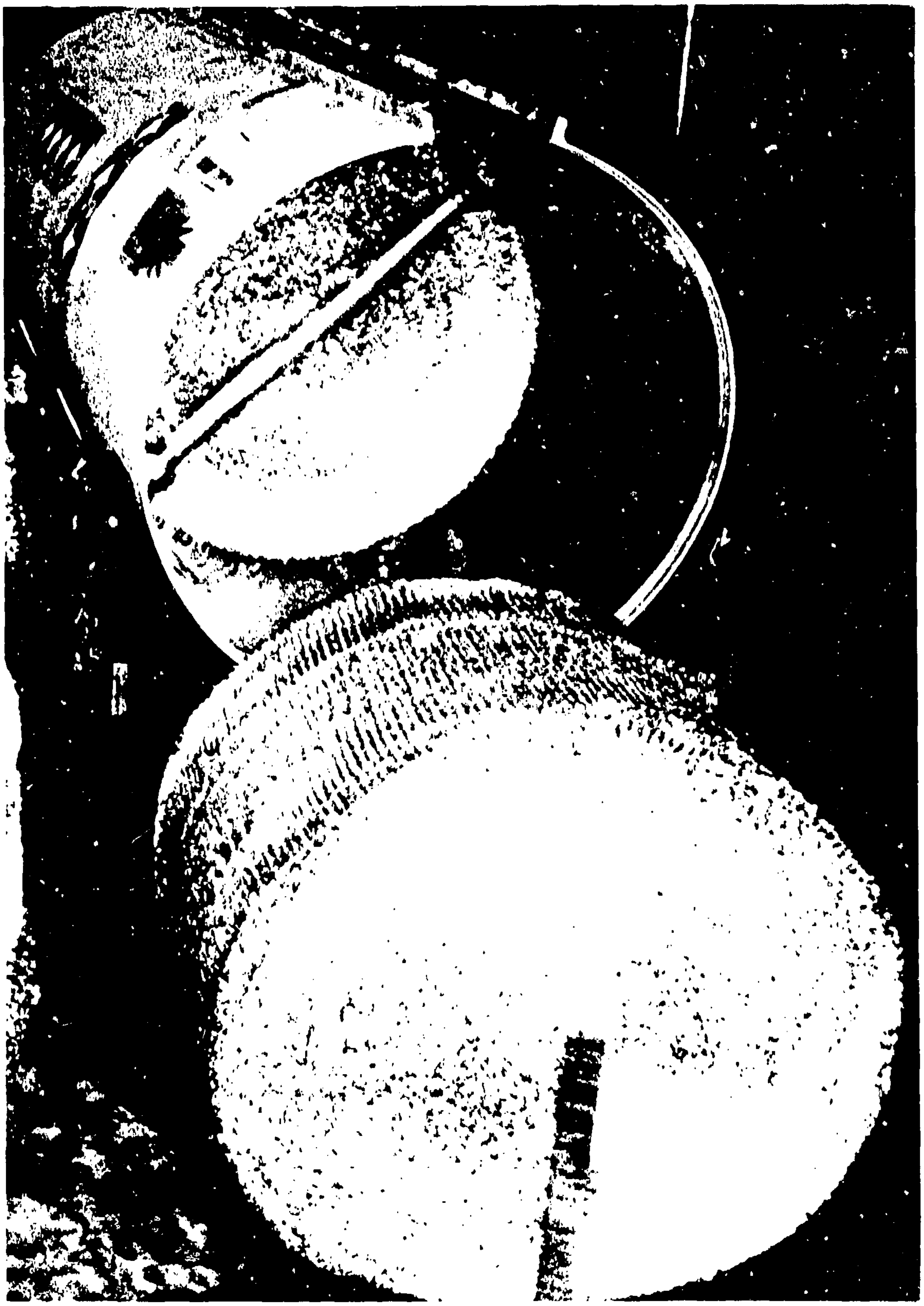


Figure 59. Test 1: Coil from Fwd End of Midsection

The tank is symmetrical with reference to its axis, except for the tail cone which is offset. There are, also, no obstructions within the tank, aside from the fuel pick-up tube and hardware between the baffles in the midsection. Most batts are, therefore, unrestricted and free to rotate around their own axis.

The batt at the aft end of the midsection had rotated about 4 degrees counter-clockwise (Figure 60). This batt lies adjacent to the aft baffle. The fwd face of the batt is voided to accommodate the sharp, protruding lip which lies asymmetrically on the baffle. When the batt rotated, the position of the void no longer coincided with that of the lip. Consequently, the lip cut into the foil causing damage around the voided area (Figure 61). All other batts remained intact and showed no evidence of damage. Figures 62 through 65 show after-test pictures of batts installed in the tank.

The batt at the mouth of the tail cone, which contained the void simulated for a level control valve component, had rotated about 3 degrees counter-clockwise (Figure 66).

The degree of rotation observed for these batts appeared to be in keeping with the maximum extent of rotation observed for other non-restricted batts.

The sealant strips in the nose cone served their intended function of anchoring the affected batts. No rotation of the anchored batts containing the critically located filler void was noticed (Figure 67).

In all cases, the dimensional integrity of the voids was maintained.

The overall quantity of foil debris generated was far less than that observed in the first test, as evidenced when post-test photographs are compared. The tail cone contained very little

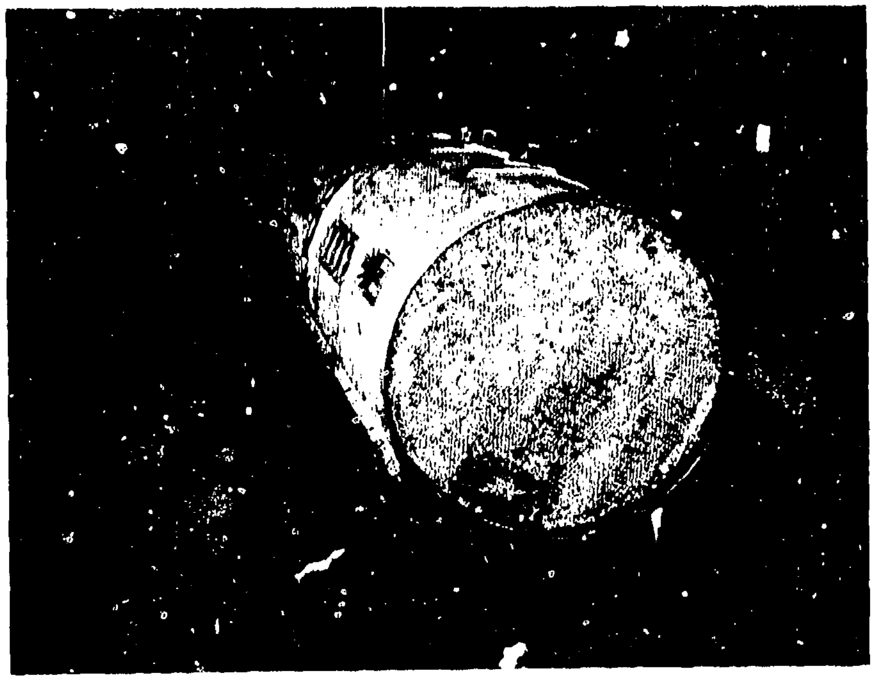


Figure 60. Test 2: Batt at Aft End of Midsection
Rotated 4 Degrees

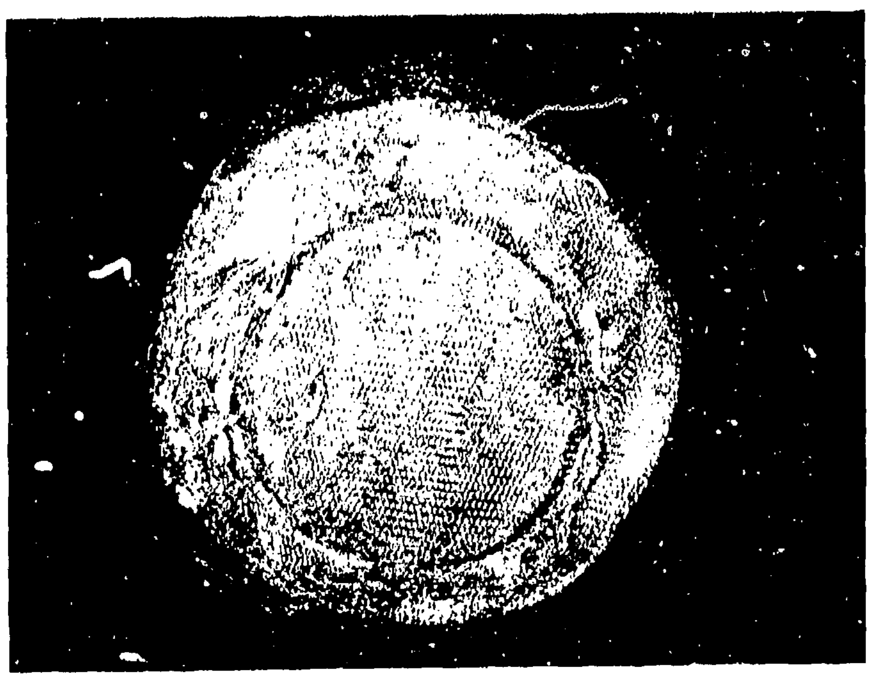


Figure 61. Test 2: Damaged Fwd Face of Batt
from Aft End of Midsection

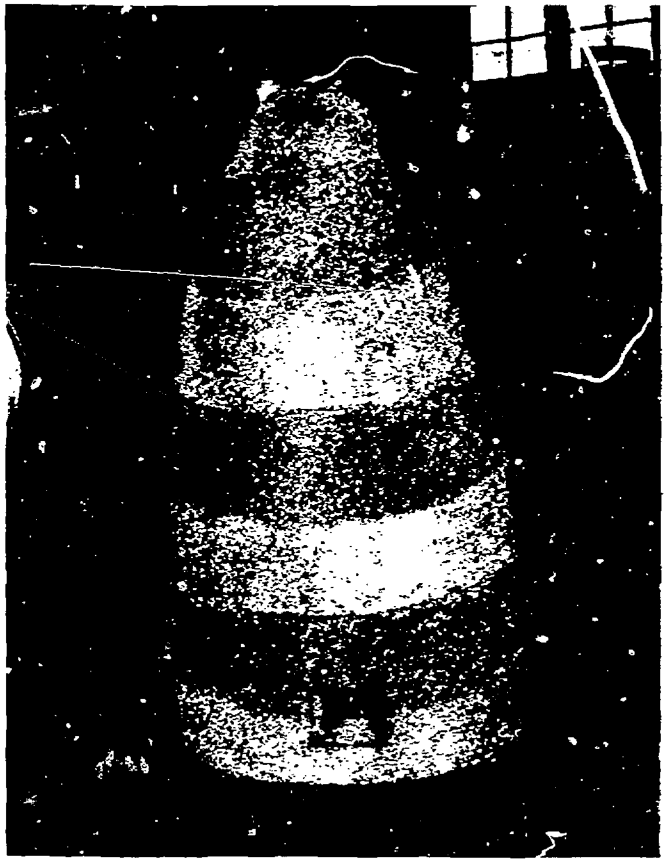


Figure 62. Test 2: Nose Cone Batts after Test

Figure 63. Test 2: Tail Cone Batts after Test

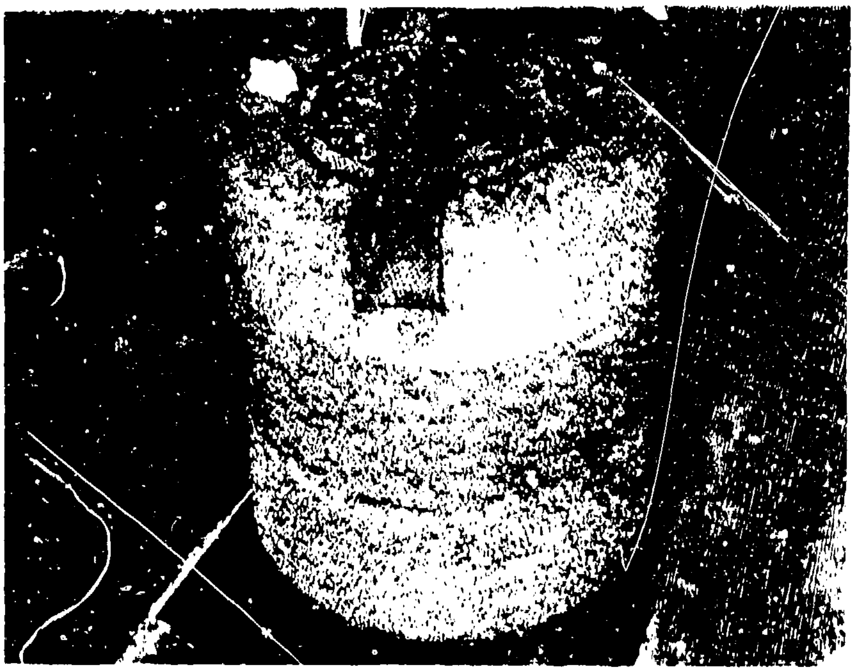


Figure 64. Test 2: Batts from Fwd End of Midsection after Test

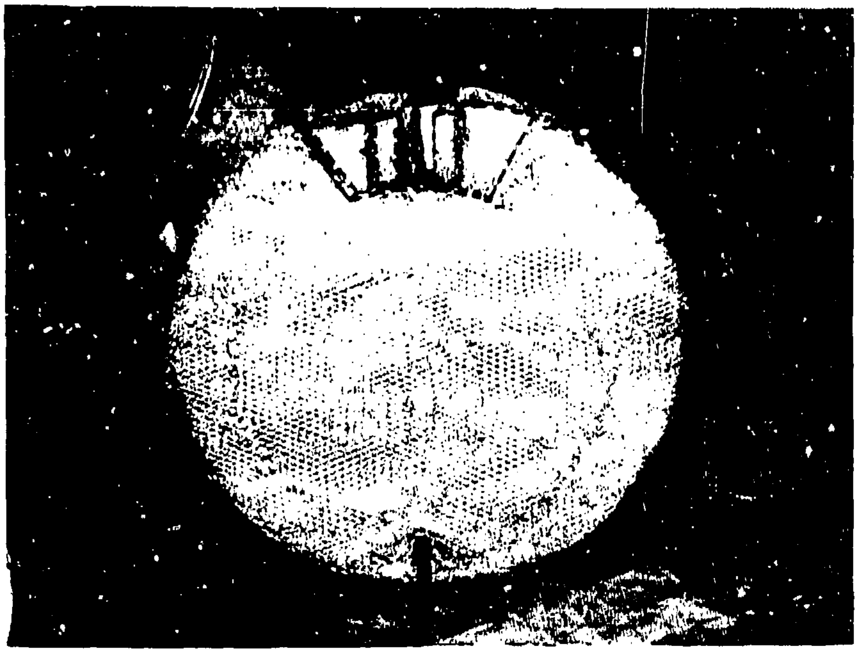


Figure 65. Test 2: Batts from between Baffles after Test

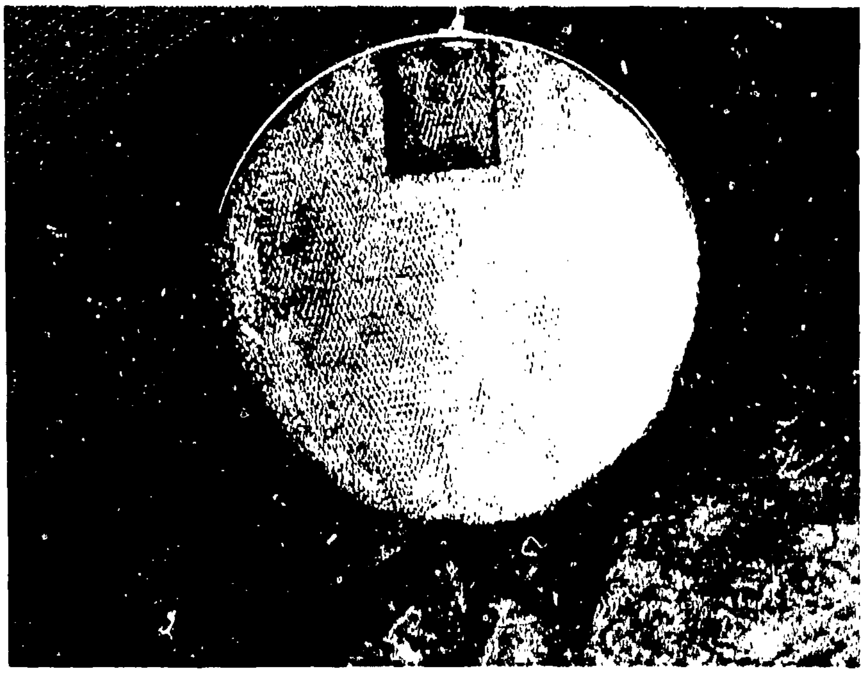


Figure 66. Test 2: Batts at Mouth of Tail Cone Rotated 3 Degrees

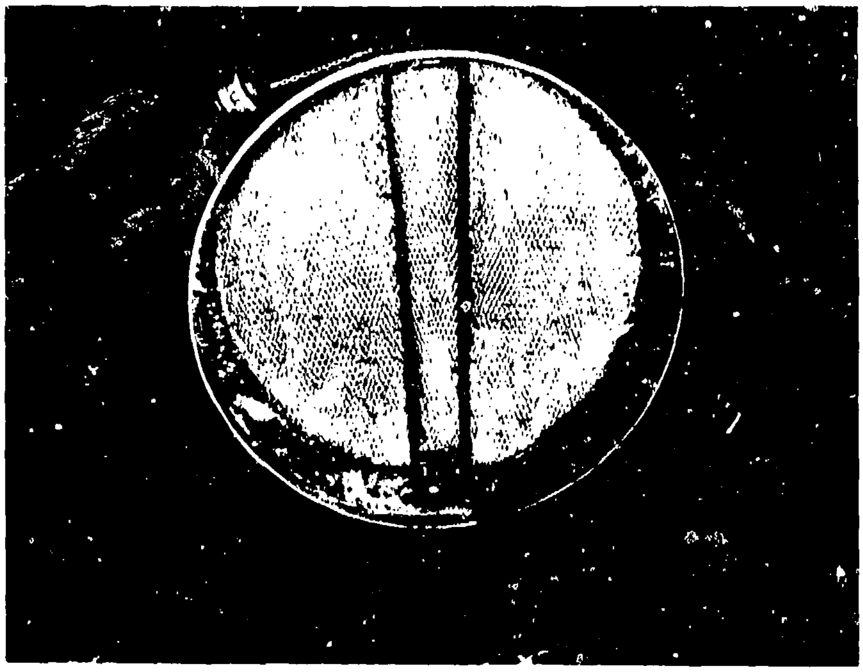


Figure 67. Test 2: No Rotation of Sealant-Anchored Batts in Nose Cone

debris (Figure 68) while the nose cone (Figures 69) contained more debris per unit length than the mid-section (Figures 70 and 71). The debris in the midsection was considerably less than that observed in the first test. Figure 72 shows samples of the foil debris from the nose cone and midsection. The total debris weighed 44.5 grams. When the batts were moved around, some more flakes fell out and this was collected and weighed at 4.7 grams. Total foil debris was 49.2 grams.

2.2.2 Effect on Sealant and Coating

Test No. 1

Varying degrees of wear were observed on the painted surface of the tank. In the nose and tail cones, where fanfolded batts were installed, the wear took the form of dense clusters (Figures 73, 74, and 75), while in the mid-section, where only coils were packed, the wear was considerably lighter, having a linear pattern in directional agreement with the slosh (Figures 76 and 77). There was a deposit of aluminum and aluminum oxide film over the wear areas which gave an appearance of excessive wear of the painted surface. However, when the film was removed by wiping with Metalprep solvent, there was, except for one noticeably worn patch at the mouth of the tail cone, no significant depth to the wear.

The wear on the surface of the Class B sealant patches was minimal. The sealant surfaces in contact with the fanfolded batts were slightly pitted. No disintegration of the sealant material was observed. Figure 78 shows typical sealant wear.

Test No. 2

The wear on both the old and new topcoating was similar to that observed in areas where fanfolded batts were installed in the first test. Here too, the aluminum oxide deposits could be easily removed with Metalprep solvent, revealing the underlying paint to be in very good condition (Figure 79).

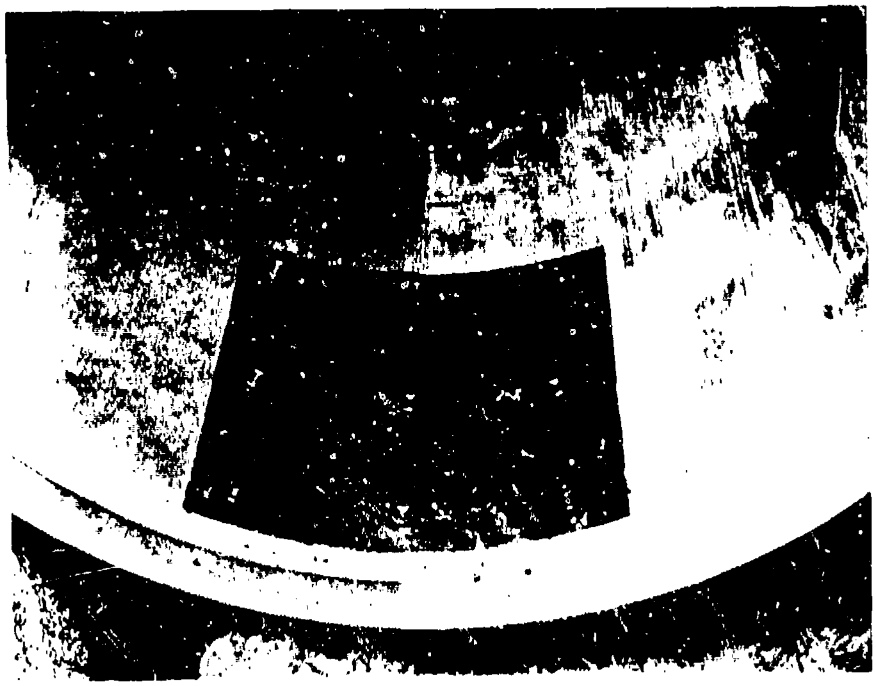


Figure 68. Test 2: Tail Cone after Test

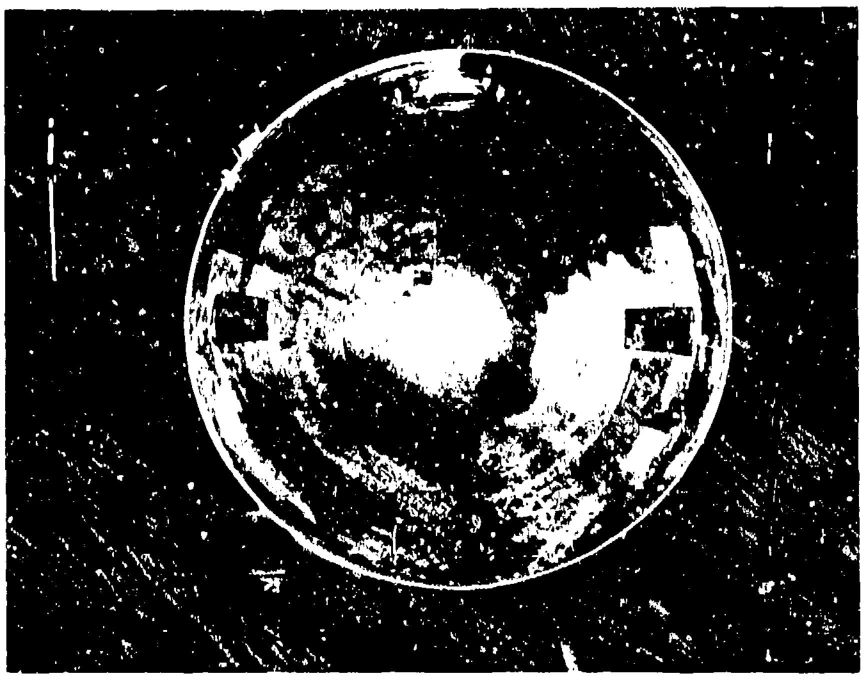


Figure 69. Test 2: Nose Cone after Test

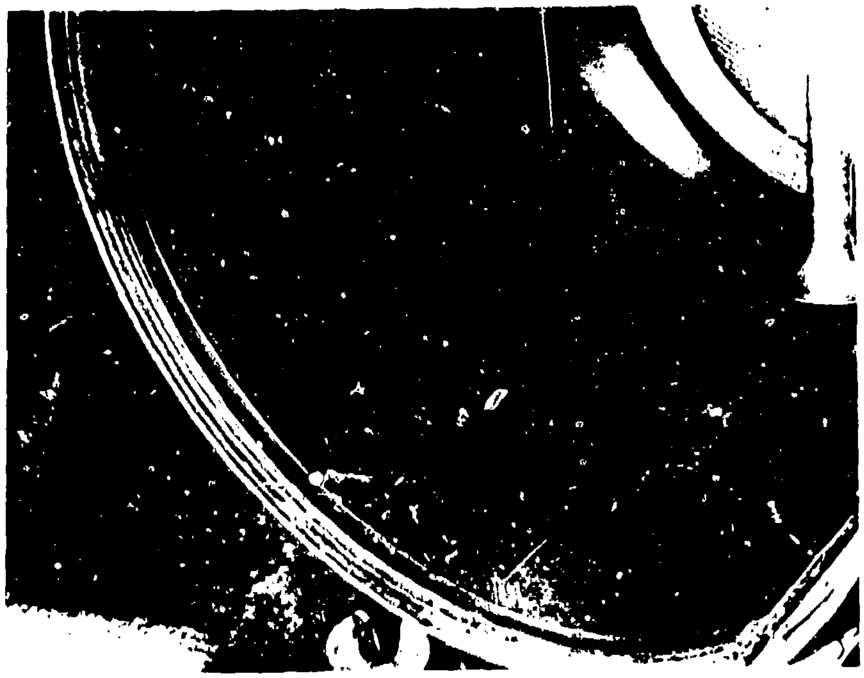


Figure 70. Test 2: Fwd End of Midsection after Test

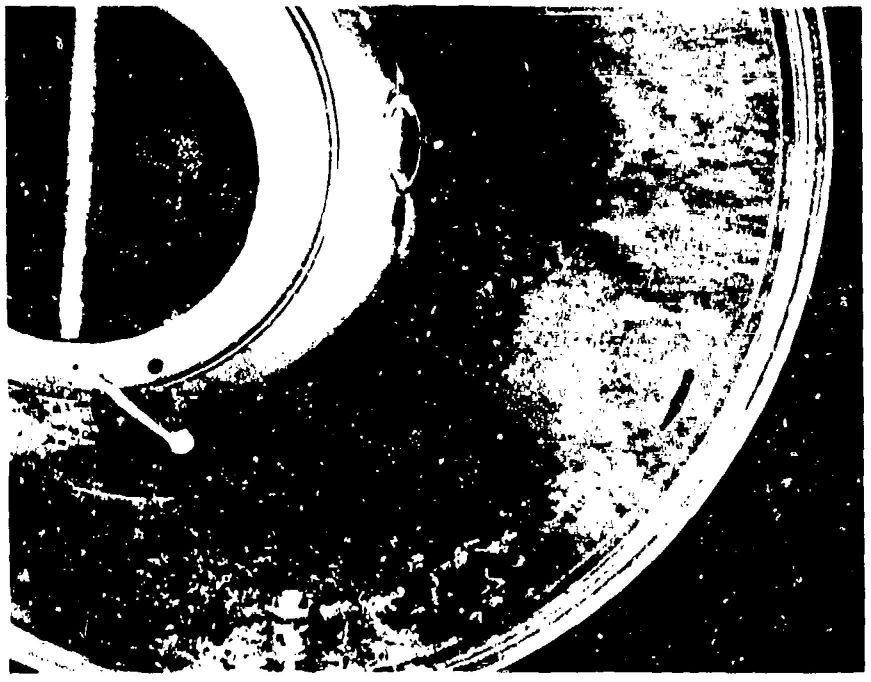


Figure 71. Test 2: Aft End of Midsection after Test

Figure 72. Samples of Foil Debris (Actual Size) Collected from Nose Cone (Top) and Midsection.

Figure 73. Test 1: Foil Caused Stains in Nose Cone

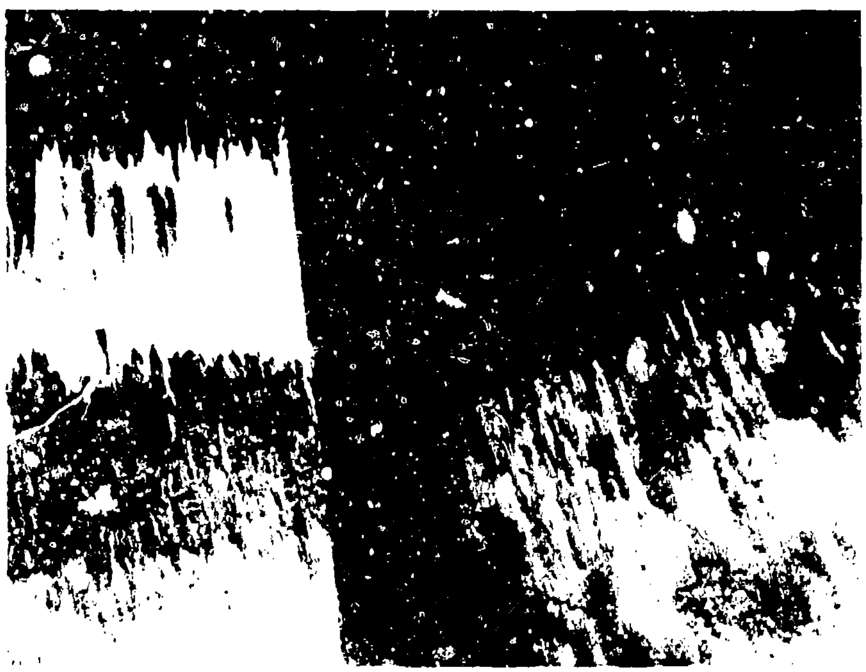


Figure 74. Test 1: Close-Up of Stains in Nose Cone

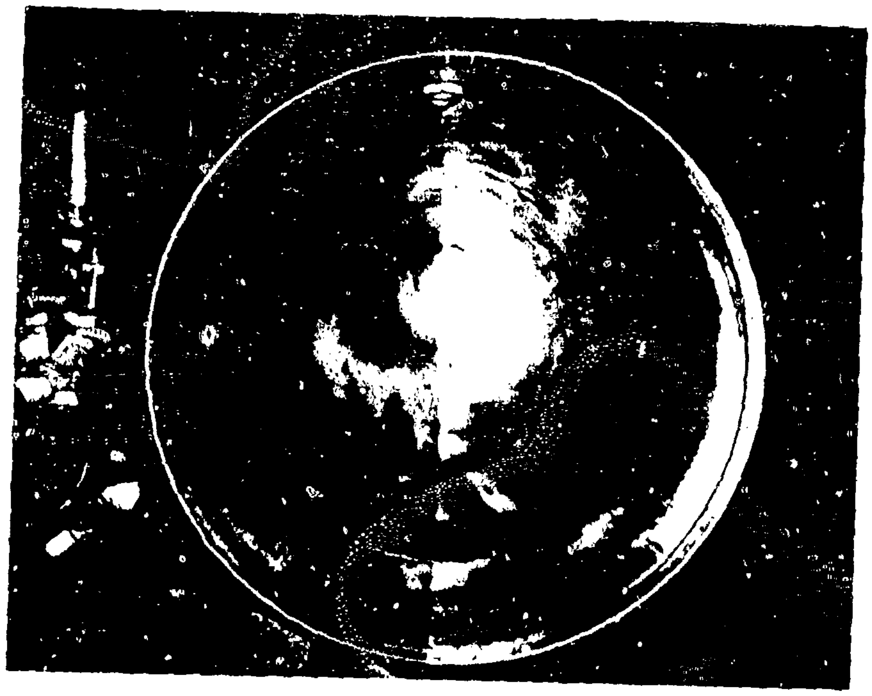


Figure 75. Test 1: Foil Caused Stains in Tail Cone

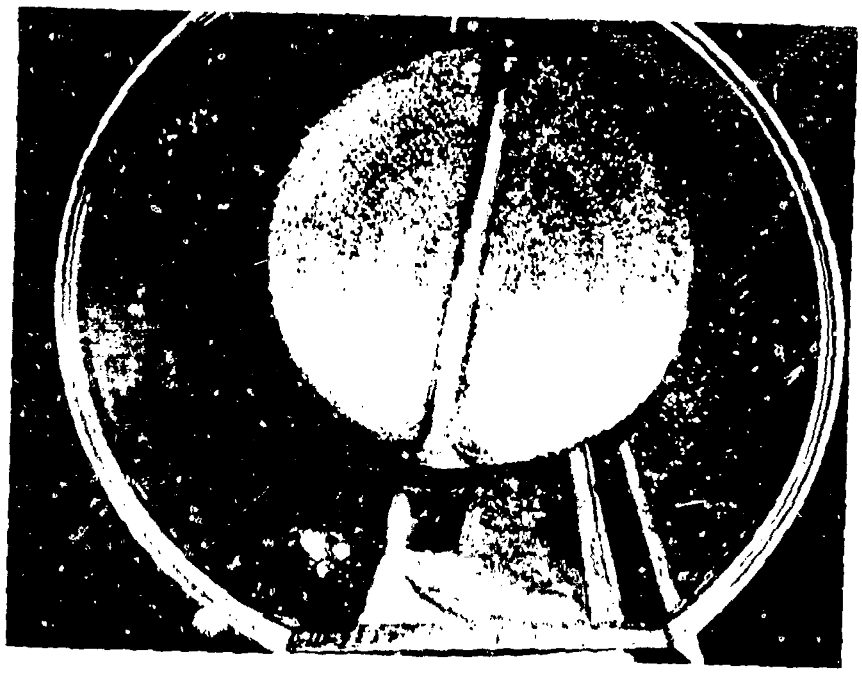


Figure 76. Test 1: Foil Caused Stains at Fwd End of Midsection

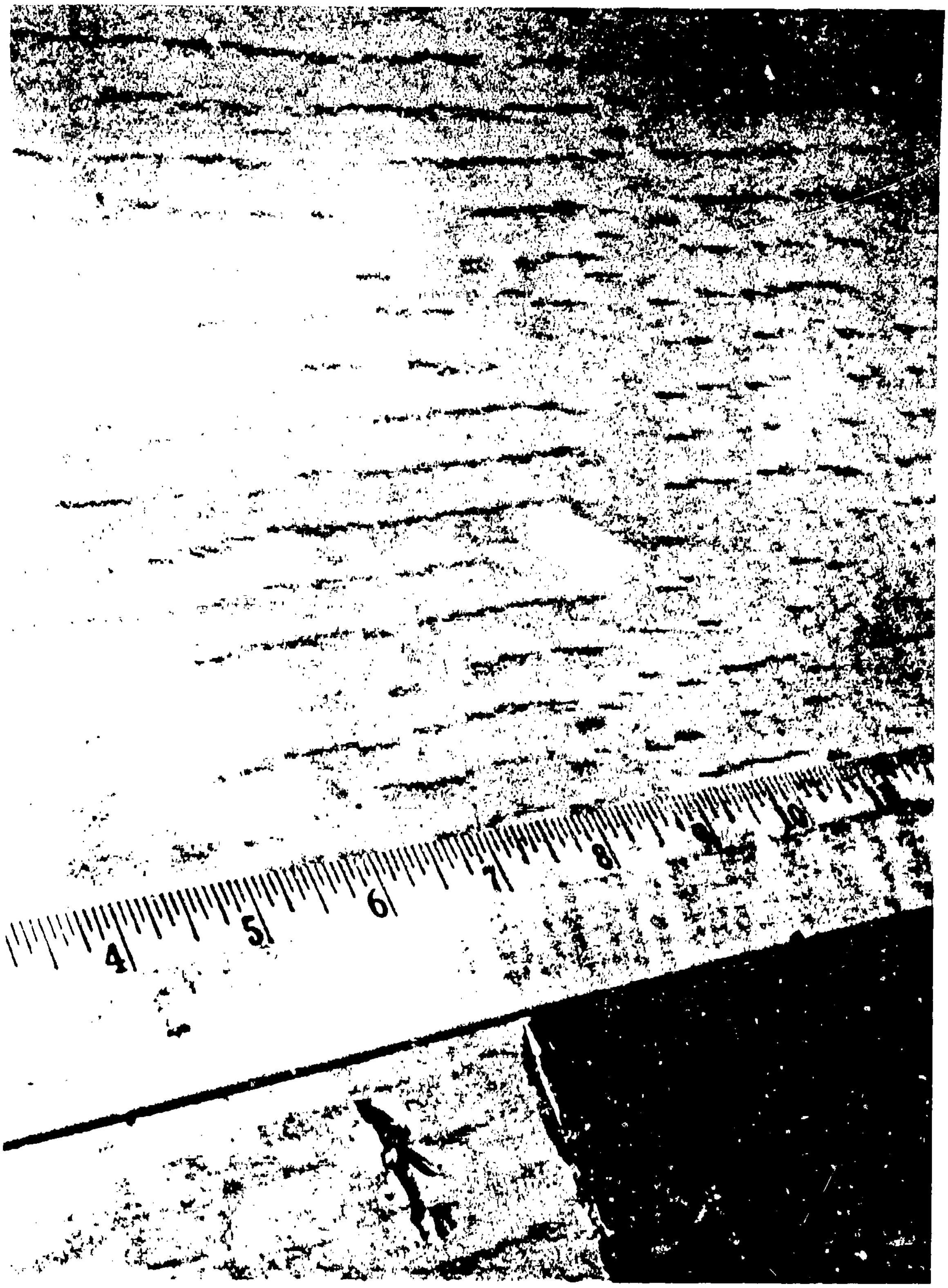


Figure 77. Test 1: Close-Up of Stains at Fwd End of Midsection

Figure 78. Test 1: Sealant Patch in Tail Cone shows Typical Wear

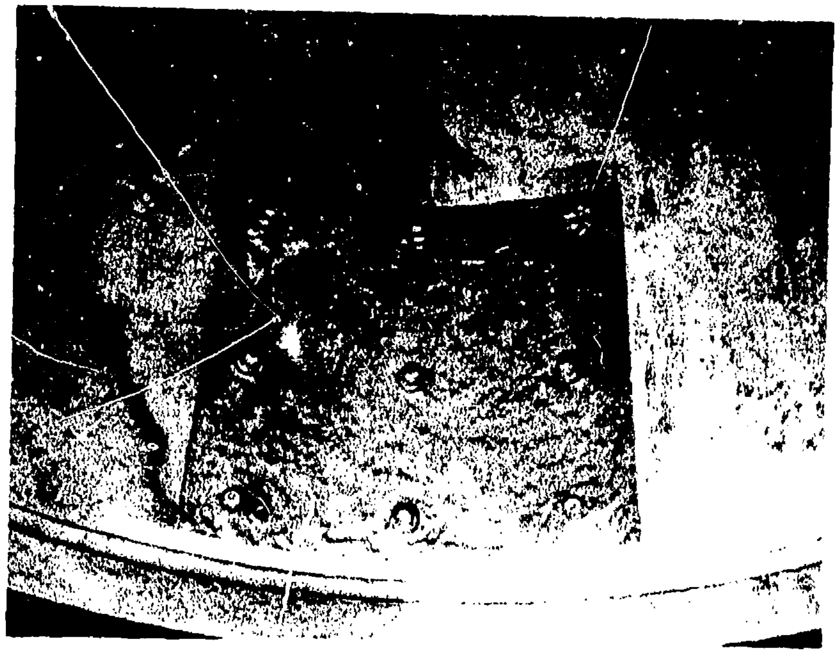


Figure 79. Test 2: Paint Surface in Tail Cone Before (top) and After Cleaning with Solvent

No difference in the wear pattern on the paint was observed around the MIL-S-8802, Class B sealant strips in the nose cone, indicating that the strips did not greatly limit the to and fro motion of the batts. They, however, prevented the batts from shifting orientation. The wear pattern over the sealant surface was like brush marks (Figure 80). No pitting or disintegration of the sealant material was observed.

The light, MIL-S-8802 Class A sealant had abraded off the domed heads of the fasteners creating fine sealant dust. There was some superficial wear of the sealant surface as well, but not deep enough to cause complete penetration of the material (Figures 68 and 70). A test for leakage showed no leaks at or around the fasteners.

2.3 Conclusions

2.3.1 Effect on Material

It was observed that the physical integrity of fanfolded batts was maintained while coiled batts, which to begin with are loose bodied, slackened further under slosh conditions. Because of the initial slack condition of the coiled batts, and partly because the direction of expansion of the foil for the coiled batts was parallel to the motion of the slosh, the diamonds, or cells, were allowed to flex by the to and fro motion of the fluid. This effect caused fatigue in the foil material that eventually resulted in its physical breakdown. Also, due to constant flexing, the twist of the strands tended to flatten out causing the foil to shrink back partially to its unexpanded form. This resulted in the entire coil shrinking in the direction opposite to which the foil was expanded. The flattening of the twist in the strands resulted in reduced contact between strands of adjoining layers of foil tending to further loosen the structure of the coil. This combination of a loose and shrunken batt allowed for greater movement of the foil during slosh which, in addition to causing fatigue and break-down of the material, resulted in the coil telescoping.

Figure 80. Test 2: Wear Pattern on Sealant Strip in Nose Cone

Layered foil, on the other hand, was not affected in this manner chiefly because of its firm construction which is reinforced with stitches, and partly because of the orientation of its cells in the tank. When the direction of slosh is perpendicular to the face of the diamonds, as was in this case, flexing of the foil in the direction of expansion is minimum. Stresses experienced by the foil, therefore, are far below the level at which fatigue caused failure of the material would occur.

Fanfolded batts tend to shrink across their short diamond dimension due to the residual spring-back forces existing in the foil acting opposite to the direction of expansion. Spring-back is further encouraged by the slosh motion of the fuel. The observed shrinkage was about 2 percent over the expanded dimension, as seen in the first test. If batts are oversized by 2 to 3 percent over the short diamond dimension, as was done in the second test, the shrinkage can be compensated for.

Although the free standing sealant strips proved effective in preventing reorientation of batts, this method of restricting batt movement is suspected to be the cause of other, possibly more serious problems. Abrasion of the sealant by the foil could add contaminants to the fuel. The sealant material also prevents free movement of the foil over its surface which could cause the foil ends in contact with the sealant to flex during sloshing causing local fatigue and break-down of the ends. In fact, the curled bits of foil found in the nose cone after the second test are suggestive of such an occurence. Here, it is important to stress that conventional application of sealant over spars, ribs, brackets, etc., should not have a detrimental effect on the foil as the hardware itself would be expected to obstruct foil movement and flexing.

The significant quantity of foil debris observed in the first test was largely due to the failure of the coiled material. Because of this phenomena coiled batts are no longer recommended for aircraft applications.

The foil bits generated during both tests were large enough to preclude their entry into the fuel line past the strainer. In the second test, the total quantity of foil debris weighed 49.2 grams. The installed weight of the foil was 57.4 pounds or 26,050 grams. This works out to a total material breakdown of just 0.19 percent over life-time operating conditions. Even though this amount is not considered significant, it is believed that foil breakdown can be yet reduced if heavy, free standing sealant strips are not used to anchor batts, and batts are restricted from shifting orientation by other means so that they are not damaged by uncatered-for components.

2.3.2 Effect on Sealant and Coating

Abrasion of the paint surface was relatively higher in areas where fanfolded batts were installed than where coiled batts were installed. The greater degree of wear in the former case can be attributed to the higher concentration per unit area of irregularly cut ends of the foil moving in contact with the paint surface. By comparison, for the coiled batts, the open face of the diamonds reduced the area of foil in contact with the paint surface to a minimum which resulted in less wear to the paint.

In the first test, the wear over the Class B sealant surface was observed as minute pit marks, indicating that the cut ends of the Explosafe material had anchored themselves by digging in fractionally into the sealant material. This effect was not seen in the second test. Instead, the brush-like marks on the sealant surface suggested that the material properties of this batch of sealant were in variance with the first. Therefore, the use of sealant strips as anchors for restricting batt movement cannot be consistently relied upon.

Analyses of the bare aluminum tank wall and topcoating were performed by the AFWAL Materials Laboratory. They have concluded (correspondence No. MXE/P. Tydings/55077, dated 8 January 1980) that "Areas of the bare aluminum appeared polished while areas of the urethane coating had gray streaks running across the surface. The black material on the cheese cloth (used to wipe the gray stains) was mainly aluminum and calcium. The abrasion of the bare aluminum and urethane fuel tank finishes was so slight as not to be measurable."

Further to that, the Mechanical Branch of USAF Flight Equipment Division have stated in their internal memo of 18 December, 1979, on the subject of fastener installation and material effects on sealant, that "The fasteners used appeared to hold up and no sign of leakage in or around the fasteners was evident. Chafing or scraping of the sealant top coat on top of the nut cages inside the tank was observed. However, (the wear) did not appear to be detrimental".

In conclusion, considering that the 40-hours slosh test is representative of slosh conditions generally encountered during the intended life of the test tank, even the most severe wear observed on the topcoating (some areas of which had been subjected to two, 40-hour slosh tests) and sealant materials cannot be deemed significant.

2.4 Recommendations

It is suggested that only batts made of layered foil be installed in aircraft fuel tanks, with the foil so oriented that the direction of slosh, which for the most part is governed by the pitching of the aircraft, would be through the face of the diamonds.

Adequate clearance should be left between any sharp or substantially protruding component and the foil to prevent disintegration of the foil by scraping.

Batts should be oversized across their short diamond dimension by 2 to 3 percent to compensate for the tendency of the finished batts to shrink in that direction during handling and under severe operation conditions. Also, the batt thickness should be oversized by 2 percent to provide tighter packing for minimizing foil movement.

To prevent batts containing critical voids from shifting orientation, mesh cages or void guards of compatible dimensions should be fixed to the tank walls such that the void encompasses the cage when the batt is put into position. The void guard may be removable for facilitating installation and removal of other in-line batts.

Flexing or collapsing of highly voided batts can be minimized if these are given added support by unitizing them with adjacent batts.

3.0 OPERATIONAL - DYNAMIC SLOSH/VIBRATION - BLADDER TANK

3.1 Procedure

A 25 hour dynamic slosh and vibration test was performed on a 90-gallon, flexible rubber test tank in which Explosafe material had been installed. Disintegration, settling or compacting of the Explosafe material, as well as interaction of the foil with the inner surface of the tank were to be pertinent points of assessment.

Testing was conducted at Uniroyal's Mishawaka (Indiana) test facilities. Basic slosh/vibration procedure of MIL-T-6936D was used. Certain requirements, such as fluid temperature which is pertinent to flexible rubber tank performance, were modified since the emphasis was on performance of Explosafe rather than the container in which it was installed.

Test Tank

The tank was of Uniroyal manufacture, fabricated of US 180 material which is a light weight, flexible, rubber impregnated fabric having self-sealing characteristics. The tank measured 30 x 30 x 24 inches and is classified as Type II, Class A under MIL-T-5578C specifications (Figure 81).

Test Material

The Explosafe material was of 0.002 inch thick 3003/H24 alloy aluminum, expanded to 38 inch web width and stacked at 16 layers of foil per inch height. The design of the installed kit is described in Appendix D 1. The resultant material density was approximately 2.6 pounds per cubic foot (Figure 82).

Slosh/Vibration Machine

The slosh/vibration machine is essentially a platform 5 feet wide and 9 feet long which is pivoted about the center line perpendicular to the length dimension. Rotating eccentric weights are mounted on the table and provide the required vibration independent of the oscillation mode.

The machine is designed to provide a 30° total motion, which is 15° either side of the horizontal position. The rocking mode is fixed at 20 cycles per minute.

The vibration frequency is 1960 cpm with a double amplitude of 0.032". Capacity of the machine is 4000 lbs. Provisions are made external to the machine to provide for fuel circulation. Simultaneous slosh and vibration is characteristic of this machine.

Methodology

Prior to conducting any test operations, the tank was placed on soak test using TT-S-735, Type III test fluid at ambient temperature. The tank was allowed to remain on stand for 35 days, after which it was drained and examined for leakage as would be evidenced by sealant swelling. Also, the liner was examined for superficial marks or appearance items so that pre-test conditions would not be attributed to the test procedures (Figure 83). The tank did not show any evidence of leakage.

The tank was mounted in a wooden test box having a 30 x 30 x 24 inch inside dimension. It was necessary to add ½" thick wood shims on two adjacent sides because of an undersize condition in

Figure 81. Bladder Test Tank

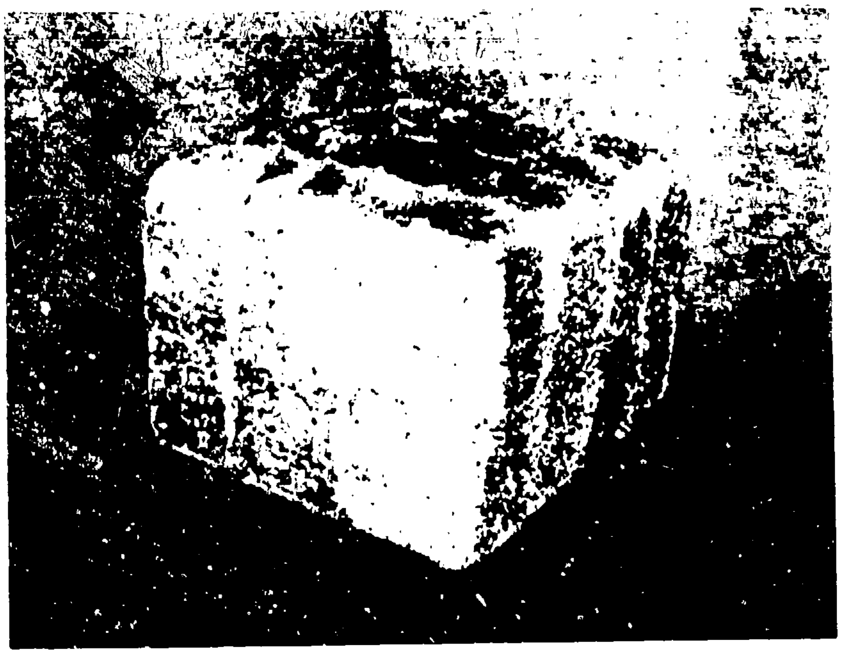


Figure 82. Explosafe Kit before Test

Figure 83. Typical Inner Wall Surface of Tank before Test

the tank. This undersize condition required additional compression of the Explosafe material.

The Explosafe material was installed using the sequence and batt sizes given in the installation study attached as Appendix D 1. A vent opening was added to the transparent access cover and the cover was bolted to the top panel access fitting.

The tank/container assembly was mounted on the slosh/vibration machine with the access door facing up and aligned with the long axis of the access at right angles to the machine axis of rotation (Figure 84).

Sixty gallons of Type III fluid at ambient temperature were added to the tank. Slosh/vibration was initiated on 29/01/79 pm and was completed 01/02/79 am. Slosh/vibration periods were intermittent. Slosh frequency was 20 cpm and 15° either side of the horizontal. Vibration frequency was 1960 cpm in conjunction with a 0.030" double amplitude.

Upon completion of 25 hours of slosh/vibration, the tank was removed from the test structure and the Explosafe material was removed for analysis.

The tank was sectioned to permit detailed examination of the inner liner. Photo-micrographs were obtained of several randomly selected areas.

3.2 Results

3.2.1 Effect on Material

No appreciable settling or compacting of the Explosafe material was seen at the conclusion of the test. Figure 85 shows the position of the foil, as seen around the access, at about the same level as at the start of the test.

The foil did not show any signs of damage or deformation that could

Figure 84. Test Tank Mounted on Slosh/Vibration Machine

be directly identified as having occurred during testing. The top and bottom batt layers, as they appeared after testing, are shown in Figures 86 and 87, respectively.

Fine aluminum dust and numerous small flakes of foil, totally weighing 3 grams, were noted on the bottom of the test tank (Figure 88). A few small pieces of foil were seen adhered to the tank walls.

3.2.2. Effect on Bladder Wall

No failure or leakage of any type was experienced during the testing of the Explosafe packed test cube.

The inner liner ply of the test tank consists of a tightly woven square weave of 0.005 inch thick nylon fabric lightly coated on both sides with 0.002 inch thick buna rubber coating (Figure 89). Post-test examination of the liner revealed clusters of small, variously shaped scuff marks. Most of these had a maximum dimension of 0.15 inches. Figures 90 through 95 show the wear on the six panels of the tank. Except for 12 of these scuff marks in which broken strands were seen on the nylon liner, the wear was limited to the depth of the buna rubber coating. At no instance was the nylon liner penetrated by the Explosafe material. No wear was observed on the inner liner of the tank's bottom panel.

Photomicrographs presented in Figures 96 and 97, show the degree of abrasion experienced in areas which were judged to be of typical severity.

3.3 Conclusions

3.3.1 Effect on Material

Severe settling and compacting of any explosion suppression material, under operating conditions, could be detrimental to its intended function. Explosafe, when subjected to intense slosh and vibration, does not appreciably settle or compact, reducing

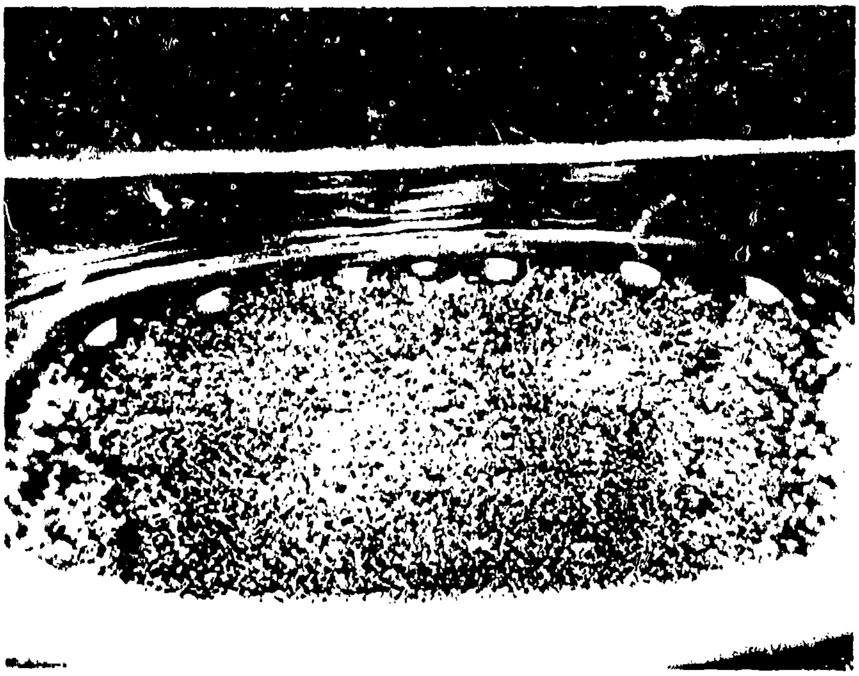


Figure 85. Level of Foil after Test Showing Almost No Settling

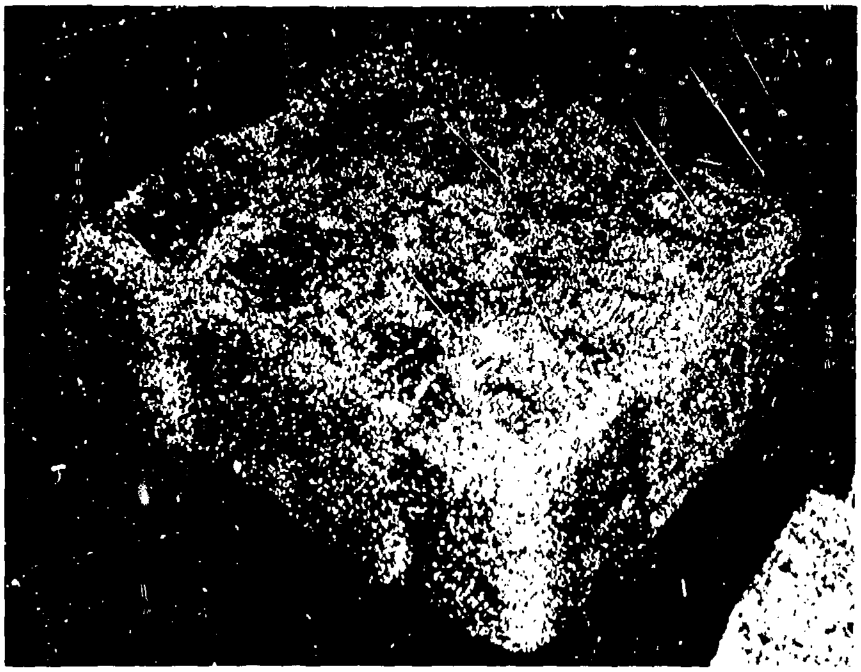


Figure 86. Top Layer of Batts after Test

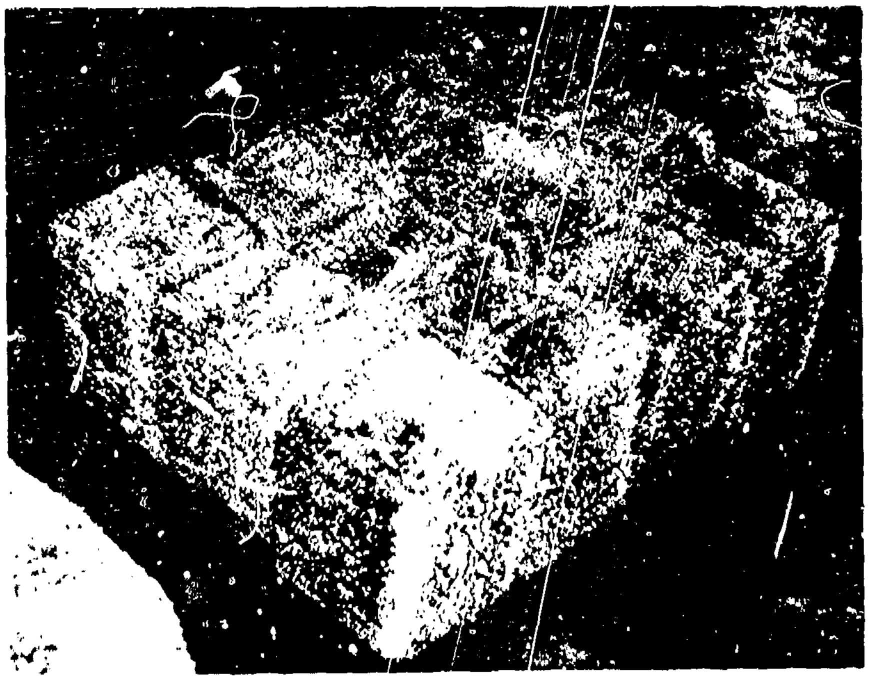


Figure 87. Bottom Layer of Batts after Test

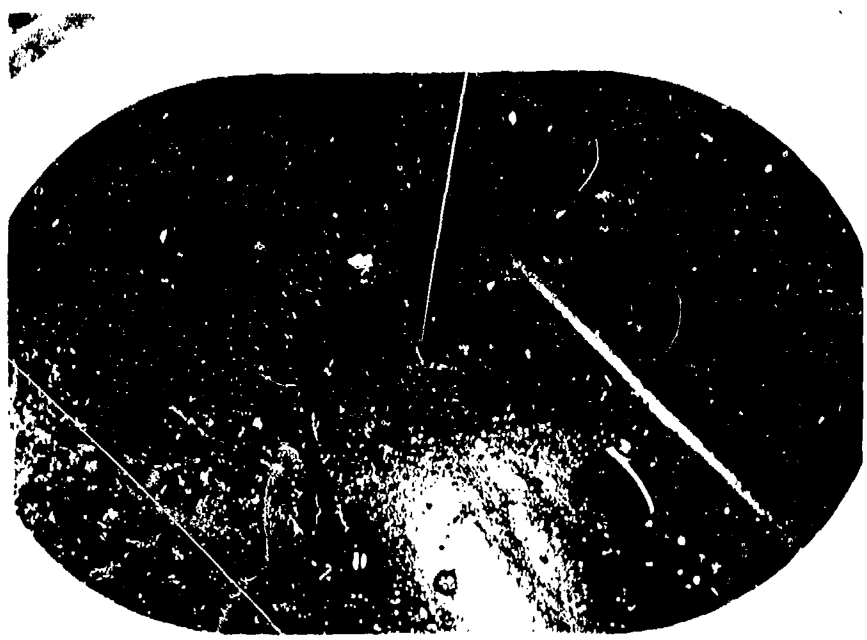
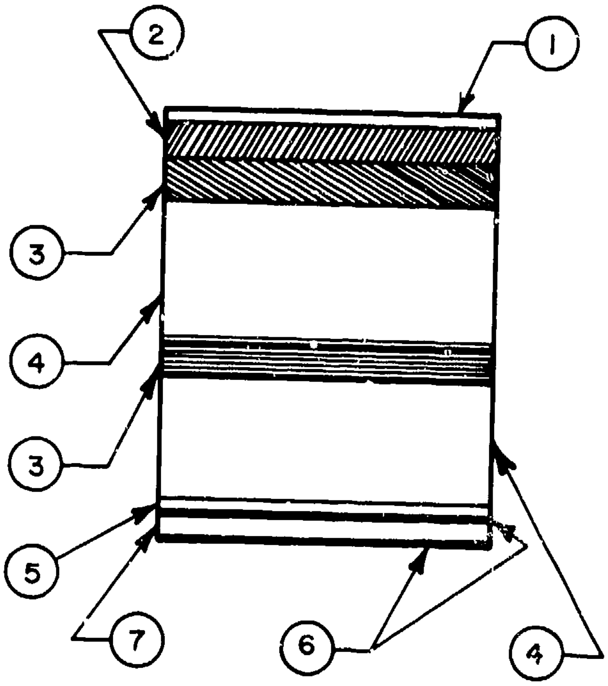
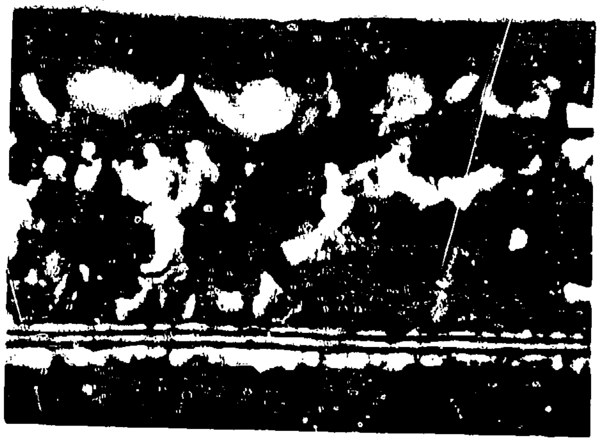


Figure 88. Foil Debris on Bottom of Tank





MAGNIFICATION - 25x

1 OUTER BUNA VINYLITE LACQUER
2 CORD, RUBBER COATED
3 CORD, RUBBER COATED
4 SEALANT
3 CORD, RUBBER COATED
4 SEALANT
5 0.002" NYLON FILM BARRIER
6 0.002" BUNA COATING
7 0.005" NYLON FABRIC LINER
6 0.002" BUNA COATING

Figure 89. Sketch and Actual Photomicrograph of Cross Section of Tank Wall Material

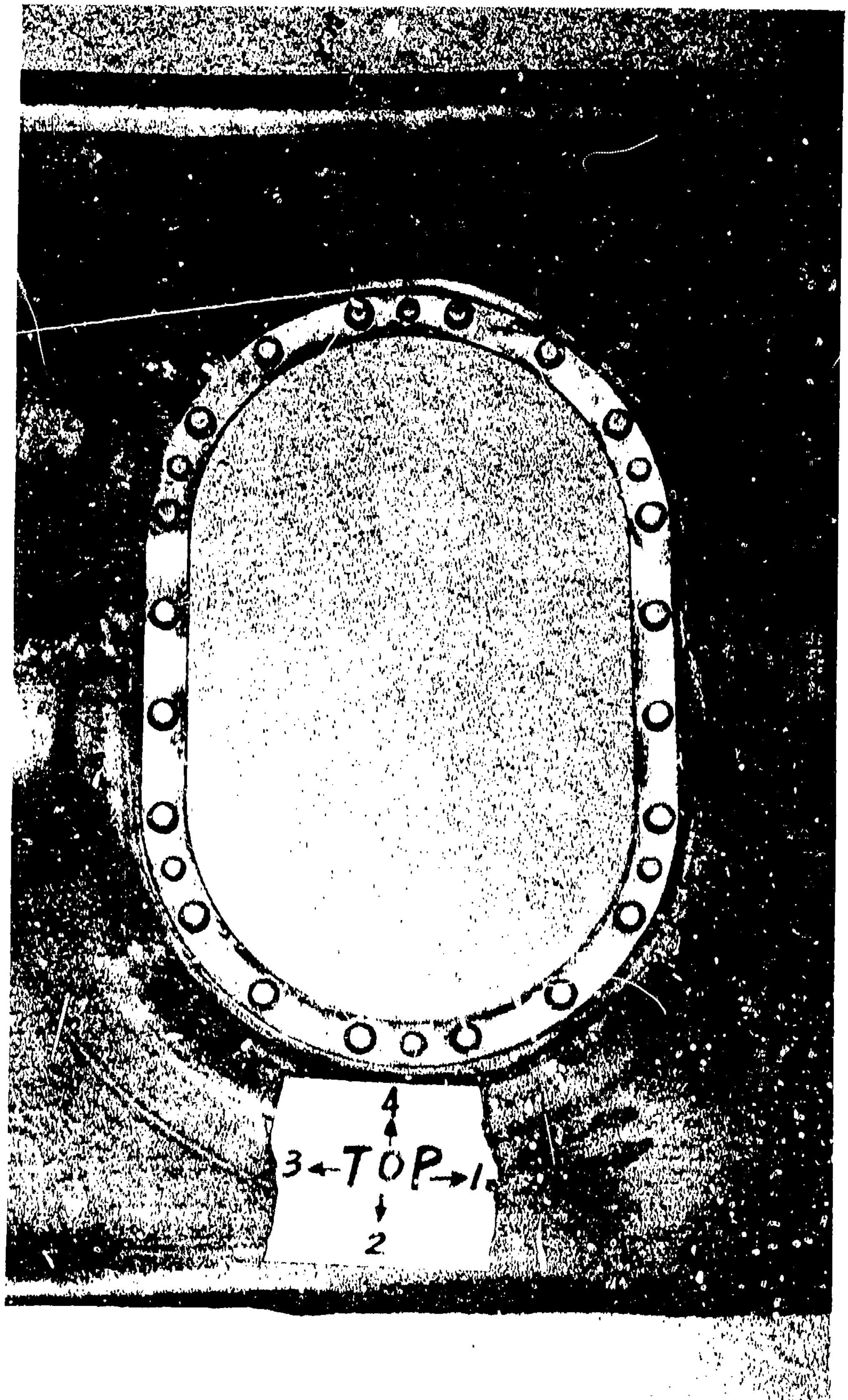


Figure 90. Top Panel cf Tank after Test Showing Almost No Wear

Figure 91. Bottom Panel of Tank after Test Showing Almost No Wear

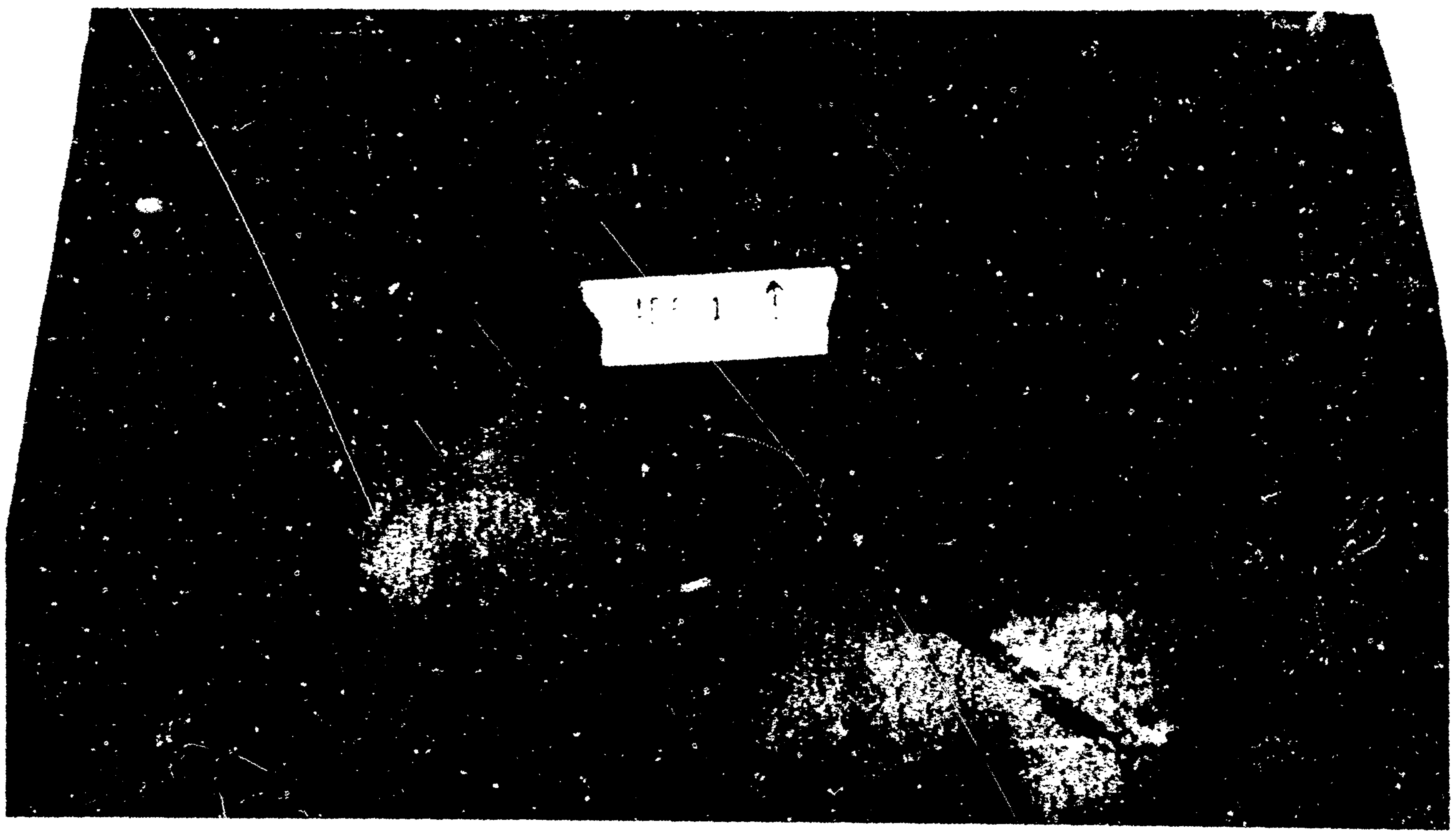


Figure 92. Side Panel 1 Showing Clusters of Minute Scuff Marks

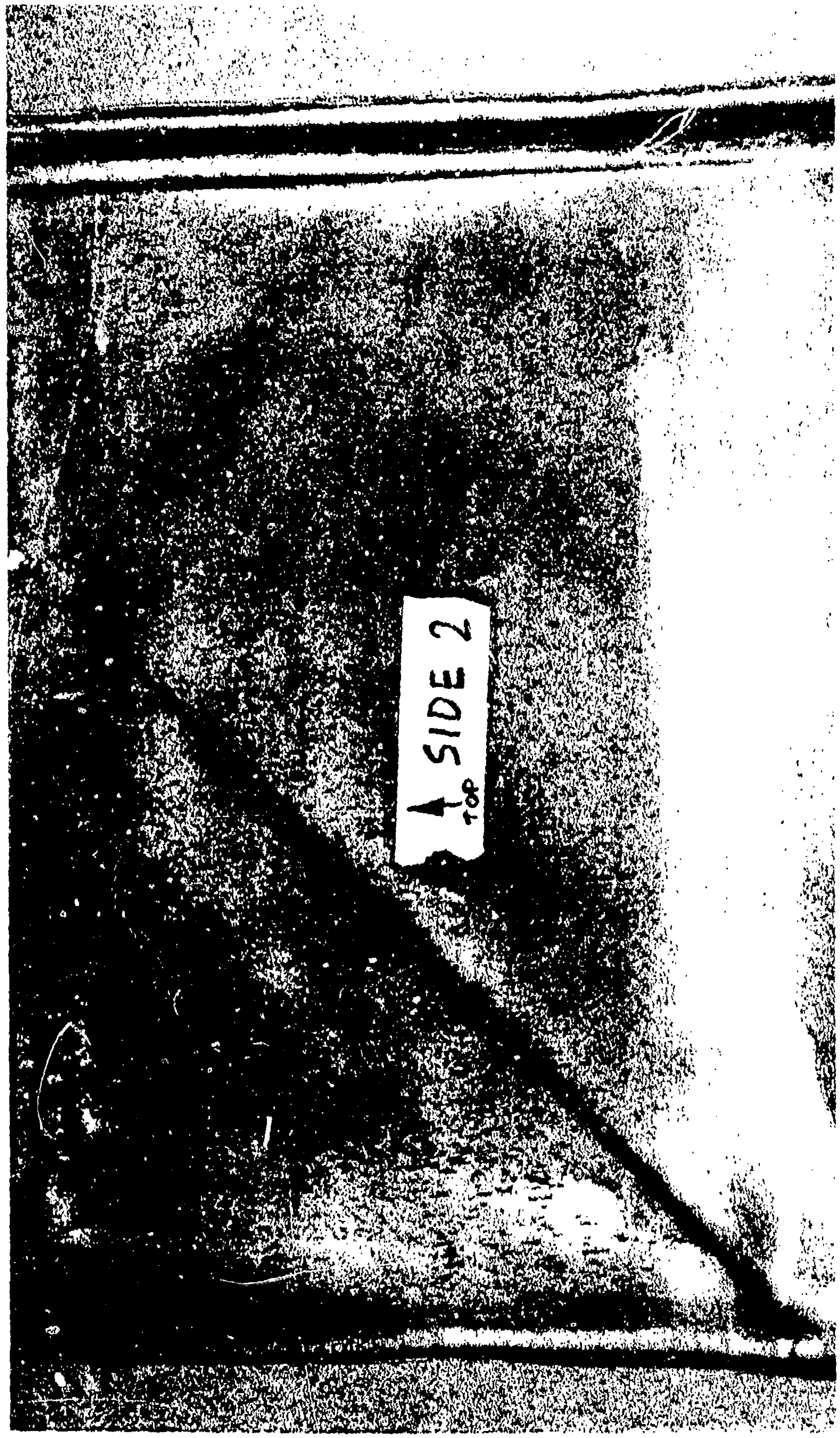


Figure 93. Side Panel 2 Showing Clusters of Minute Scuff Marks

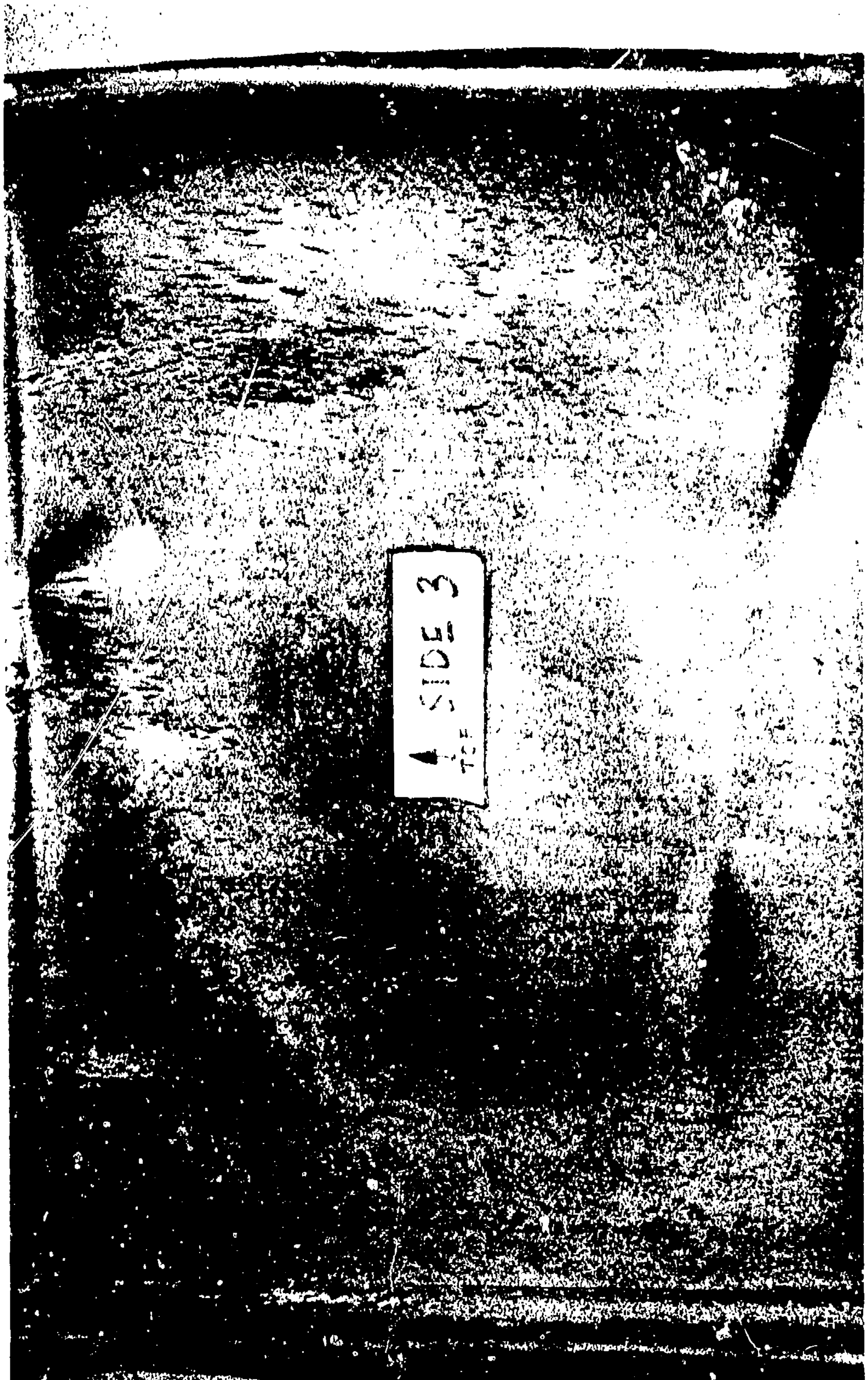


Figure 94. Side Panel 3 Showing Clusters of Minute Scuff Marks

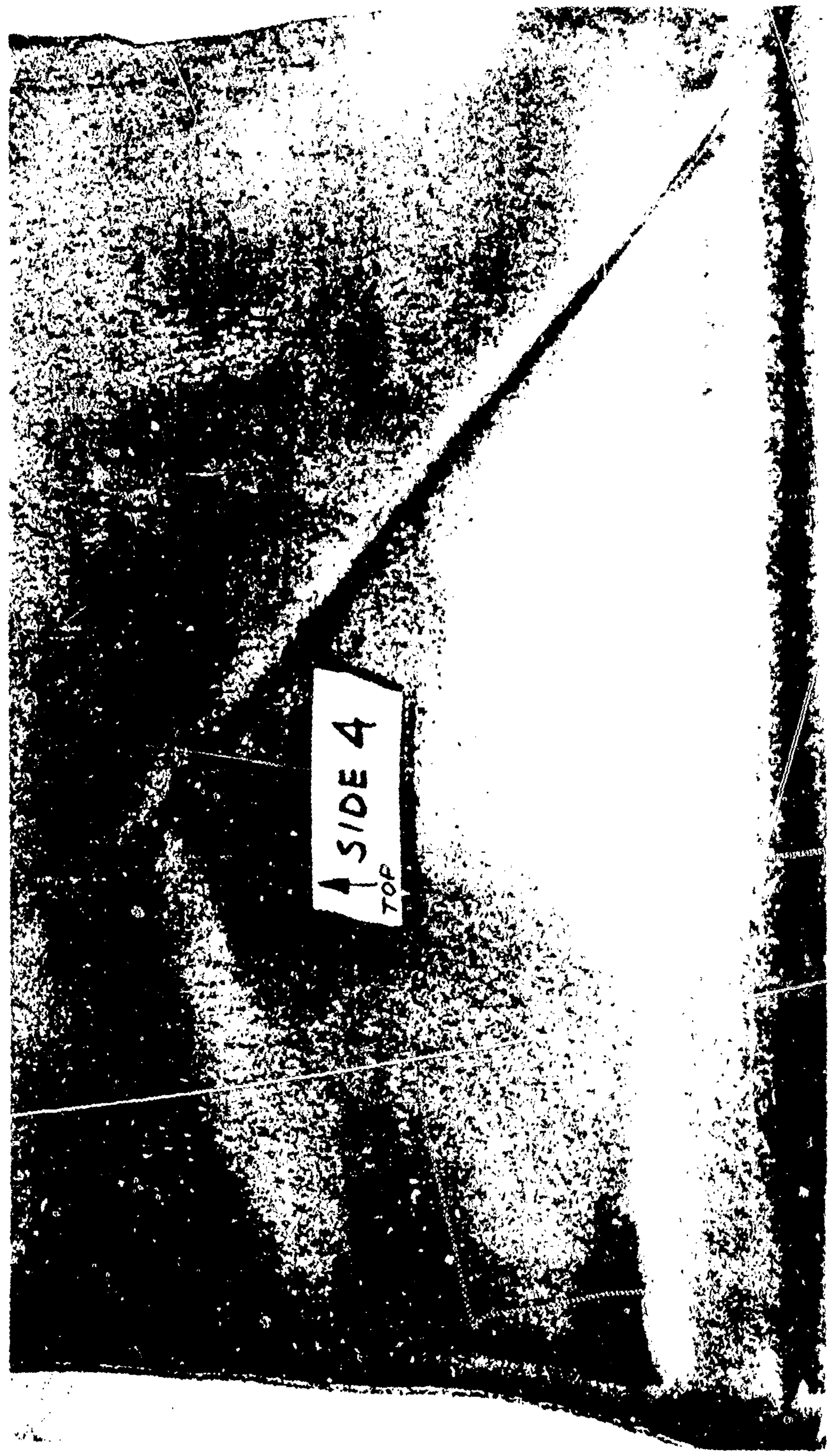
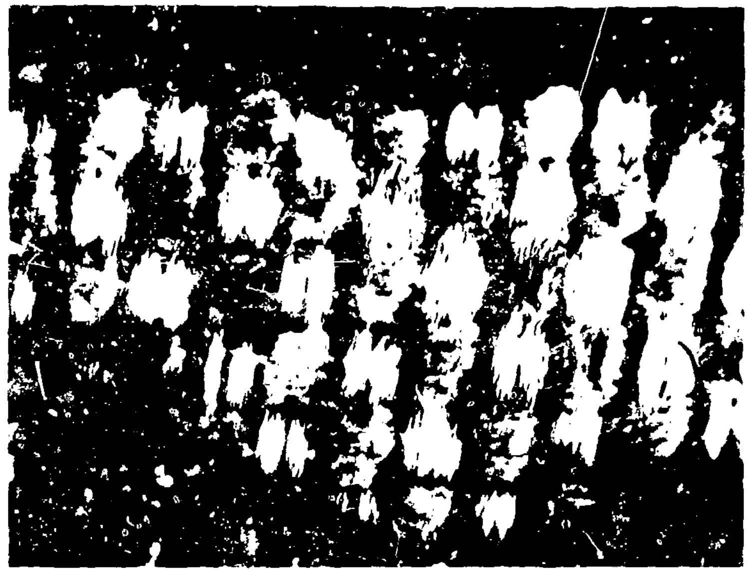


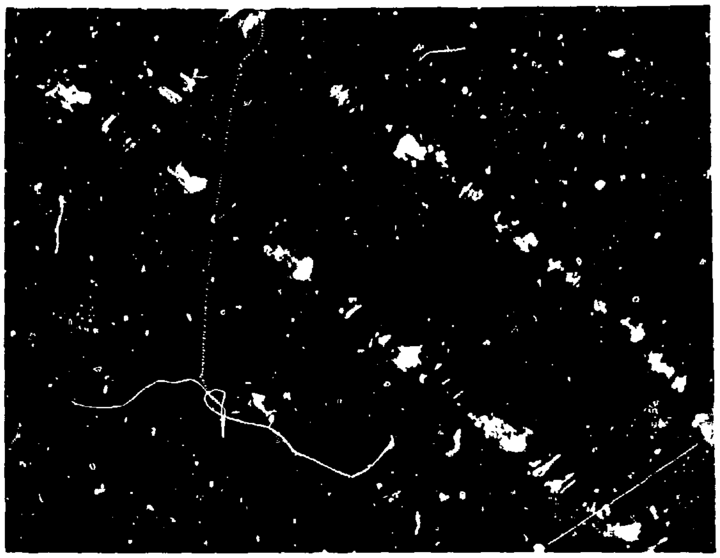
Figure 95. Side Panel 4 Showing Clusters of Minute Scuff Marks



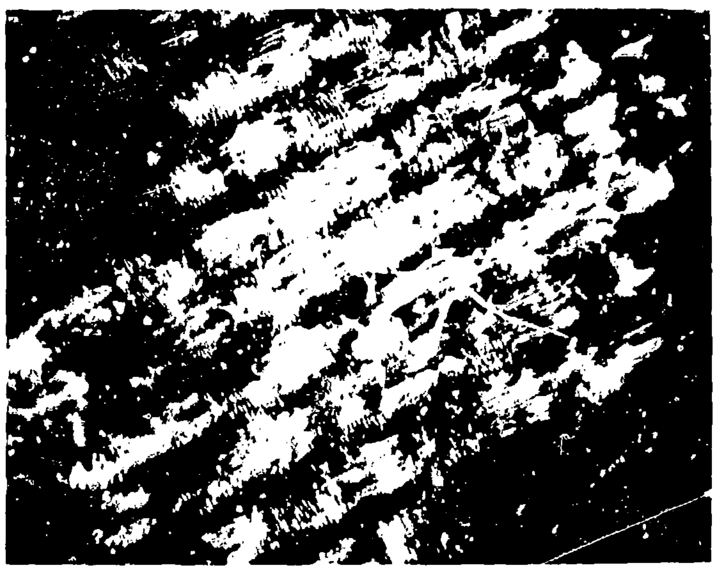
Magnification 50X

Magnification 58X

Figure 96. Photomicrographs of Randomly Selected Abraded Areas



Magnification 58X



Magnification 58X

Figure 97. Photomicrographs of Randomly Selected Abraded Areas

the chances of a compromise in its expected performance.

It is believed that a portion of the debris consisted of small flakes of foil that were entrapped in the Explosafe matrix during its manufacture, and shaken free during testing. The flakes of foil seen adhered to the tank walls suggest some breaking off of the foil ends due to a fretting action against the rubber coated tank walls. The foil pieces were large enough to prevent their entry into the fuel line past the strainer.

The 3 grams of foil break-down is considered insignificant when seen that this quantity represents only 0.02 percent of the 32 lbs 15 oz of foil installed in the tank.

3.3.2 Effect on Bladder Wall

While the side walls of the test tank in contact with the cut ends of the foil showed some wear, no wear was observed on the bottom panel which was in contact with the expanded surface of the foil although this area, by virtue of its location, would be expected to experience maximum abuse. This indicates that the expanded surface of the foil is relatively less abrasive than the irregularly cut ends.

Uniroyal, Inc., who were the performing organization and also the manufacturer of this specific test tank, have concluded in their report, No. FC 1726-79 dated March 1979, that "The degree of observed damage is not considered to have influenced the tank's performance to any significant degree. It should not be concluded that additional sloshing would cause significantly more damage. The 25 hours slosh and vibration test is generally considered to represent conditions experienced over the intended life of the tank."

3.4 Recommendations

Wear to the tank walls can be minimized if batts are so oriented that all, or most of the wall areas are in contact with the expanded surface of the foil rather than with the cut ends.

4.0 OPERATIONAL - DYNAMIC SLOSH/VIBRATION - METAL TANK

4.1 Procedure

A 25 hour simultaneous slosh and vibration test was conducted on an Explosafe packed 100 gallon auxiliary fuel tank of Kellett Corporation (Willow Grove, Pa.) manufacture. Detailed fuel tank description, as well as Explosafe design and installation specifics are described in Appendix D 4. The test was conducted for Kellett Corporation by East-West Technology Corporation, W. Babylon, N.Y.

Test Set-Up

The tank and pylon assembly was fixed to an inclination table and then mounted on a vibration table. The complete assembly was set up so that it could be rocked on an axis parallel to the axis of the fuselage while being vibrated. The tank was filled to two-thirds capacity with MIL-H-3136 calibration fluid.

Methodology

The slosh and vibration tests were performed simultaneously. The set-up was vibrated at 2000, +0, -60 rpm with a double amplitude of 0.032", + 0.010", -0.000". While undergoing the specified vibration, the tank was rocked at 16-20 cycles per minute through a total angle of 30°; 15° on either side of the horizontal position. The test was conducted for 12½ hours in pitch and 12½ hours in the roll condition for a total test time of 25 hours. After testing, the test fluid was pumped out of the tank and passed through two in-line filters. Two samples of the out-going fluid were taken. Fluid sample No. 1 was taken of fluid going into Filter No. 1 and fluid sample No. 2 was taken of fluid exiting from filter No. 1 and going into filter No. 2. The tank was visually inspected and then delivered to Kellett Corporation for detailed inspection. The two in-line filters along with the two fluid samples were sent to an independent laboratory (W.B. Coleman Co., Philadelphia, Pa) for particulate analysis.

4.2 Results

Test report submitted by East-West Technology Corporation (Report No. 10612-9, 3 December, 1979) states that:

> "There was no visual evidence of damage and/or deterioration noted during or after completion of testing".

Test report submitted by Kellett Corporation (Report No.382T60-2, 2 January, 1980) had the following comments:

> "A leakage test was accomplished by pressurizing the tank to 50 psig with shop air and then applying a soap solution to the tank exterior. All joints were found to be tight and free from leaks.
>
> The access door was then removed for an internal inspection. All structure was found to be tight and free from damage. The walls of the tank were examined for signs of scouring from the Explosafe. No scouring was found".

W.B. Coleman's figures on particulate analysis of fluid and filter samples is presented in Table 26.

TABLE 26. PARTICULATE QUANTITY AND SIZE DISTRIBUTION

Sample I.D. No.	Sample	Total Solids	Particle Size (largest dimension)
967265	Flask 1	0.23 mg.	<0.0005"
967266	Flask 2	0.45 mg.	Most <0.0005" Some 0.001" - 0.006"
967267	Filter 1	31.80 mg.	Most 0.0007" - 0.005" Few as large as 0.02"
967268	Filter 2	2.54 mg.	<0.0005"

4.3. Conclusions

Explosafe did not have any detrimental effect on the structure or internal components of the metal tank as a result of 25 hours of simultaneous slosh and vibration.

A very small quantity of particulate matter was collected in the in-line filters. Most of it was caught by the first filter. In this regard, Kellett Corporation have stated in their test report that:

> " A few particles were found ranging from 0.0005" to 0.020" in the fluid and on the filters. Some of this could have been material caught under bulkheads and castings during (tank) manufacture. It is our opinion that this is a harmless, acceptable condition and probably will not reoccur (sic)."

5.0 OPERATIONAL - DYNAMIC VIBRATION

5.1 Procedure

Product Assessment Laboratories of Hampshire, Great Britain, performed a vibration test on a 9-inch cube of Explosafe material of 0.003 inch foil thickness. The material was installed in a rectangular aluminum tank internally coated with cabin sealant material and corrosion preventive topcoating. See Appendix C 4 for details of test set-up.

The tank was placed in a vibration jig and vibrated in JP-1 fuel medium for 24 hours in each of the following three modes:

25 Hz at ± 0.03 in. amplitude (±2g)
100 Hz at ± 0.0065 in. amplitude (±7g)
500 Hz at ± 0.0008 in. amplitude (±20g)

At the end of each 24-hour test period, the foil was removed from the test tank and examined for deformation and break-down. The sealant and topcoating were examined for wear.

5.2 Results

5.2.1 Effect on Material

Product Assessment Laboratories have concluded in their report, which is attached as Appendix C 4, that "A considerable degree of success is considered to have been achieved in this experiment. There were no tag-ends broken away from the mesh and no other debris in the tank at the conclusion of any of the three test periods. At the completion of 3 x 24 hour vibration periods, the Explosafe pack was opened for detailed examination. One area of mesh was torn and some folds were distorted, both could have occurred during handling and folding in the manufacturing process."

5.2.2. Effect on Sealant and Coating

Product Assessment Laboratories have stated in their report that "There were slight scratch marks apparent on the tank walls (sealant and topcoating), mainly caused by insertion and removal of the CFAM (Explosafe) pack after each 24 hour (vibration) period. There were also smear deposits of aluminum oxides on the walls."

5.3 Conclusions

The Explosafe material was not affected by the 72 hours vibration test. No breakdown or vibration-caused deformation of the foil occurred.

No significant wear was observed on the sealant material and top-coating.

6.0 ENVIRONMENTAL - FUELS AND ADDITIVES

The purpose of this area of study was to determine if the Explosafe material caused any degradation to typical aircraft fuels under prolonged exposure.

6.1 Procedure

Several weighed samples of the material were inserted into two litre glass beakers containing one litre of pre-filtered fuel and various additive packages for a three month soak period. Two types of jet fuel were to be evaluated - JP-4 and JP-8 with and without an additive package made up of Dupont's DCI-4A (4#/KBBL) and Fuel System Icing Inhibitor (0.15 vol%). Distilled and medium hard (Type "B") water bottoms were to be added up to the beakers containing the additive package in the amount of 1% by volume, (this amount was increased to 5% midway through the test program). The effect of temperature was also to be determined by keeping the JP-4 samples at ambient temperature and the JP-8 samples at 135°F.

Detailed procedure was as follows:

a) Sample fuels were clay-treated according to D3602, Appendix A 2 or better and then filtered through a 0.45 micron Millipore filter membrane.

b) 1000 ml of the appropriate fuel was added to each of the 17.5 cm high x 12.5 cm diameter 2000 ml glass beakers resulting in an 8.0 cm depth of fuel.

c) An aliquot of the additive package was pipetted into the appropriate beakers.

d) The Explosafe material samples were pre-weighed on a Mettler P200 top loading balance. Note that the samples were touched only by poly-gloves from the time of being unpackaged.

e) The sample material was inserted into the beakers and the appropriate water bottom, if any, poured over the top.

f) Aluminum foil was tightly creased over the beakers and the samples stored in their assigned environment.

g) Samples were inspected periodically for signs of fuel discoloration or precipitant.

h) At the end of the three month soak the material samples were removed, shaken of excess fuel, washed repeatedly in succeeding chambers of 50/50 reagent grade acetone/isopropyl alcohol then reagent grade petroleum ether, and permitted to air dry.

i) The samples were then reweighed and any change recorded.

j) The fuel in the beakers was submitted for a standard JFTOT analysis according to ASTM D3241, to determine whether or not the material had released sufficient metal and/or oxides to eventually degrade the fuel quality.

6.2 Results

Table 27, lists the results of the JFTOT analysis of the post-test fuel samples. The temperature at which the analyses were conducted was determined by the "breakpoint" of the particular fuel + additive used in each test. These were determined from unexposed samples of the fuels. That of the JP-4 + additives was determined to be 270°F, hence the analyses were run at 265°F. That of the JP-8 + additives was found to be 285°F, hence the analyses were run at 275°F.

All the samples were acceptable and it was concluded that the Explosafe material would not degrade typical aircraft fuels.

Storage at the two different temperatures apparently had no significance.

The test fuels did not affect the samples of Explosafe material in any way.

TABLE 27. FUEL SAMPLE ANALYSIS AFTER EXPOSURE TO EXPLOSAFE MATERIAL

Sample Composition	ΔAL WT(gms)	Test Temp	JFTOT Visual Rating*	Test Comments
JP-4 + ADD	-	265°F	1	no pressure drop exceeding 25 mm HG was observed for any of the runs at the temperatures listed in this table; no abnormal or peacock type deposits were observed, no large increase in AL mesh weight (>1%) was found either.
JP-4 + AL	+0.001	265°F	1	
JP-4 + AL + ADD	-0.002	265°F	2	
JP-4 + AL + ADD + DW	-0.001	265°F	1+	
JP-4 + AL + ADD + HW	-0.001	265°F	1+	
JP-8	-	275°F	2+	
JP-8 + AL	+0.004	275°F	1+	
JP-8 + AL + ADD	+0.013	275°F	1+	
JP-8 + AL + ADD + DW	+0.583	275°F	1+	
JP-8 + AL + ADD + HW	+0.002	275°F	1+	

NOTE: ADD = additives
AL = aluminum
DW = distilled water
HW = hard water

* A rating of less than '3' without abnormal (A) or "peacock" type (P) deposits and a differential pressure drop of less than 25mm Hg is considered passing.

6.3 Conclusions

The following conclusions have been drawn from the fuel immersion tests:

- The Explosafe material will not degrade aircraft jet-type fuels irrespective of temperature
- Jet type fuels will not corrode the Explosafe material
- Fuel System Icing Inhibitor does not adversely affect the material.

7.0 ENVIRONMENTAL - ELECTRO-GALVANIC

The Explosafe material is manufactured from an aluminum/manganese alloy designated 3003 by the Aluminum Association. In aircraft service the material is expected to come into good contact with various metals, typically other aluminum alloys and steels. A survey of the compatibility of these materials was therefore necessary in order to predict the durability of the Explosafe in electrically conductive environments.

7.1 Conclusions

The available literature and experience indicates that the Explosafe material will not be subject to electro-galvanic corrosion in the fuel environment with any of the typical aircraft fuel tank and system construction materials. Some problems may be encountered, however, in sump/drain areas where the water bottom may be contaminated with chlorides. In such locations where the aluminum is in contact with steel, some corrosion may be expected.

Coatings are available which could inhibit such action and local application to the Explosafe material would be prudent.

Alternatively, contact between the aluminum and steel can be avoided by locally excluding the Explosafe, i.e., voiding, from such areas. This is, in fact, already the common practice to aid in installation and/or avoid interference with system components.

7.2 Recommendations

In-service installations of the Explosafe material should be continually monitored for local incidence of corrosion in areas where the material is in contact with steel. When sufficient information is available, design rules for selectively coating the material or locally voiding the installation can be set down.

8.0 ENVIRONMENTAL - CORROSION

Bacteriological (microbial) activity at the interface of the fuel and water bottoms generally present in aircraft fuel tanks has in the past caused problems with some materials, particularly aluminum. These led to the specification of protective coatings for various materials, defined in MIL-C27725.

Since that time, use of a Fuel System Icing Inhibitor (FSII) additive (MIL-1-27686E, Amend. 2) has become virtually universal for military fuels and this acts as a biocide by preferentially partitioning to the water bottom. As a result of this and the frequent draining of fuel tanks, microbial growth is practically non-existent. The question then becomes one of compatibility between the water bottom with its FSII content and the subject material. Analysis of typical water drains had determined that this solution can contain 20-30% by weight FSII in all types of water, including sea water.

8.1 Procedure

Two series of tests were conducted to determine the effect of such solutions on the Explosafe material. The first was judged to set up unrealistic conditions by the inclusion of glacial acetic acid in the solution (intended to simulate the by-products of the microbial activity). That test method was therefore discontinued. The second series more closely modelled actual conditions in military aircraft fuel tanks and is considered to be a valid projection of in-service effects. The tests were conducted in accordance with ASTM G31-72, Preparing, Cleaning and Evaluating Corrosion Test Specimens, by the Systems Support Division of Materials Laboratory, AFWAL.

Pre-weighed 3 x 3 x 3 inch cubes of the as-received Explosafe material were immersed in the following solutions for short-term tests of 30 days and long-term tests of up to 6 months. The former were conducted at a temperature of 140°F and the latter at ambient temperatures.

a) Tap water + 10% FSII
b) Tap water + 20% FSII
c) Tap water + 30% FSII
d) Salt water (3.5% NaCl by weight) + 10% FSII
e) Salt water + 20% FSII
f) Salt water + 30% FSII

Figure 98 illustrates a typical test set up. Periodic evaluations were made during the tests, and on completion the samples were removed and allowed to dry prior to being re-weighed. Half of the samples were then cleaned with a chromic acid/phosphoric acid mixture (20g chromic acid/35 ml phosphoric acid in one litre of water) for 5 minutes at 212°F. They were then reweighed to determine the net weight loss due to corrosion.

8.2 Results

The results of the short-term (30 day) immersion tests prior to sample cleaning are presented in Table 28. Each of the specimens became coated with a dull gray film during the test period and the consequent weight increases are noted in the table. Increasing the concentration of the FSII inhibited this action in both

Figure 98. Explosafe Immersion Arrangement
- Corrosion Testing

TABLE 28. RESULTS OF 30 DAY EXPLOSAFE IMMERSION TESTS

Fluid	Sample No.	Initial Weight Grams	Final Weight Grams	Change in Weight Grams	Percentage Weight Change	Observations
Tap Water 10% FSII	1A	16.4402	18.8093	+2.3691	14.4	Precipitate in bottom of beakers Powder fallout on drying and shaking Flocculent precipitate
	1B	16.6110	18.8400	+2.2290	13.8	
Tap Water 20% FSII	2A	14.8464	16.2953	+1.4489	9.8	Precipitate in bottom of beaker Powder fallout on drying and shaking Flocculent precipitate
	2B	15.0990	16.9706	+1.8776	12.5	
Tap Water 30% FSII	3A	16.2285	17.5486	+1.3201	8.1	Precipitate in bottom of beakers
	3B	17.0479	17.8343	+0.7864	4.6	
Salt Water (3.5% by weight NaCl) - 10% FSII	4A	15.9138	17.7386	+1.8246	11.5	Precipitate in bottom of beakers
	4B	16.7474	18.9010	+2.1536	12.9	
Salt Water 20% FSII	5A	16.2385	17.3489	+1.1104	6.8	Precipitate in bottom of beakers
	5B	17.3475	18.6424	+1.2949	7.5	
Salt Water 30% FSII	6A	15.8740	16.5272	+0.6532	4.1	Precipitate in bottom of beakers
	6B	16.7532	17.4608	+0.7076	4.2	

the tap water and salt water solutions as illustrated in Figure 99. Interestingly, the rates of weight increase were greater with the tap water solution than the salt water solution.

The effect of cleaning in the chromic acid/phosphoric acid solution on one half of the samples is recorded in Table 29. Here, the net change from the original weight also appears to be related to the FSII concentration, i.e., the more FSII, the lesser the rate of corrosion. Again, the weight changes overall were greater in the tap water solutions than in the salt water solutions. The final weights in the latter were, in fact, fairly close to the original weights.

Before commenting on the results, it should be noted that the experimental conditions duplicate an accelerated worst case situation in actual service. If an aircraft is properly serviced, the water bottoms would be drained frequently, minimizing potential corrosion. Explosafe material exposed only to the fuel in a tank would not measurably corrode as demonstrated in the tests reported in section 6.3.

While a fairly substantial loss of weight due to corrosion occurred in these accelerated tests, no apparent pitting or perforation of the foil resulted. The results of the long-term (6 month) immersion tests are presented in Table 30. The samples were those used in the 30-day test but the test fluids were modified by diluting with JP-4 fuel (50% by volume) to more closely simulate a fuel tank environment. The beakers containing the fluids all had varying amounts of flocculant precipitate subsequent to exposure. The Explosafe material samples were cleaned in hot chromic/phosphoric acid solution (20g chromic acid/35ml phosphoric acid in one litre of water) prior to the final weighing. Visual and optical examination of the material revealed that general surface etching (corrosion) had occurred. A few isolated areas of severe corrosion attack were noted and some are depicted in Figures 100 to 103.

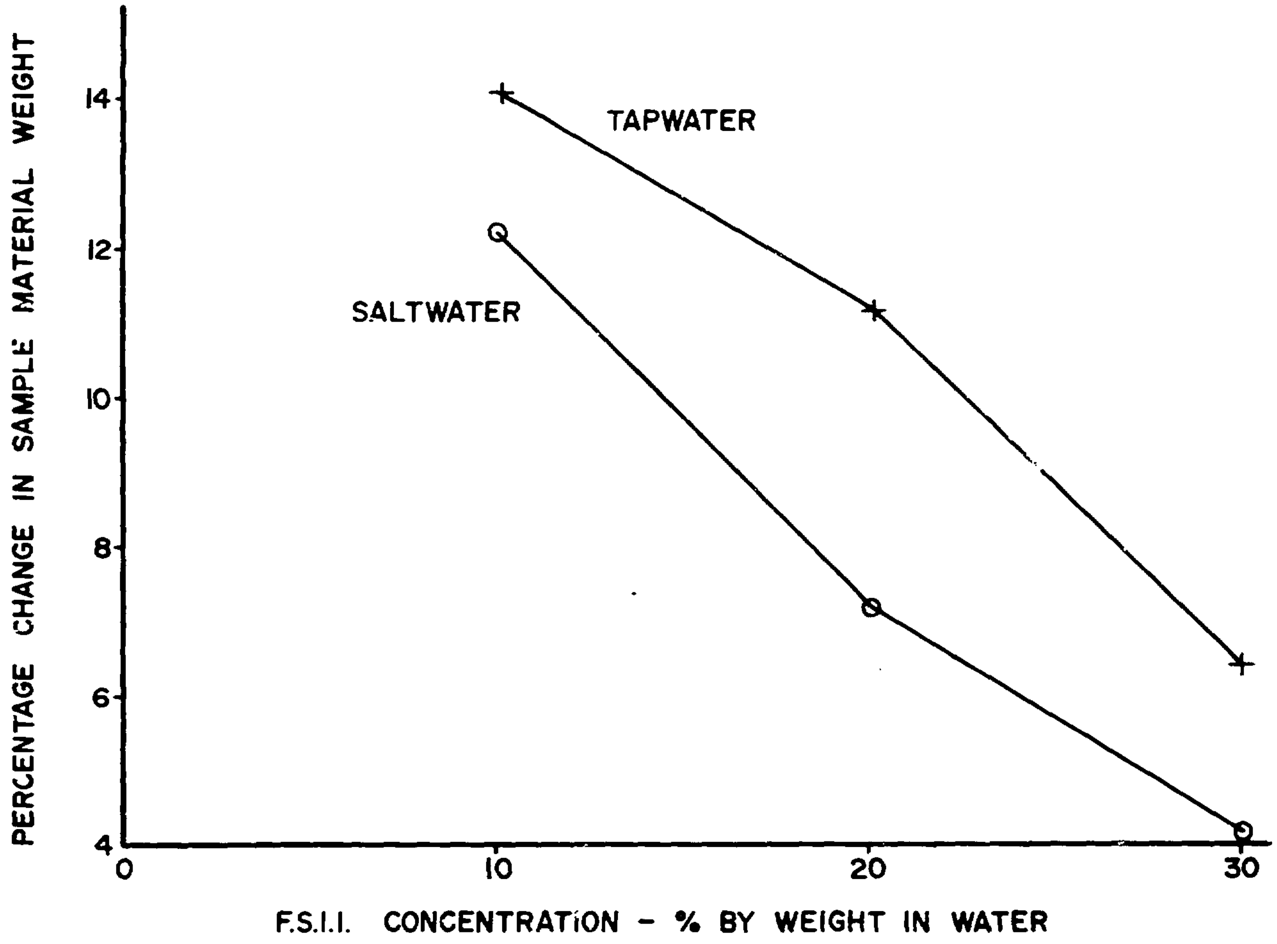


Figure 99. Effect of FSII Concentration on Weight Increase due to Corrosion

TABLE 29. RESULTS OF 30 DAY EXPLOSAFE IMMERSION TESTS - AFTER SAMPLE CLEANING

Fluid	Sample No.	Initial Weight Grams	Final Weight Grams	Change in Weight Grams	Percent Weight Change	Total Weight Loss Due to Cleaning Corroded Sample
Tap Water 10% FSII*	1A	16.4402	15.2042	-1.2360	-7.5	3.6051
	1B	16.6110	-	-	-	-
Tap Water 20% FSII	2A	14.8464	14.1436	-0.7028	-4.7	2.1517
	2B	15.0990	-	-	-	-
Tap Water 30% FSII	3A	16.2285	15.5429	-0.6856	-4.2	2.0057
	3B	17.0479	-	-	-	-
Salt Water (3.5%) 10% FSII	4A	15.9138	-	-	-	-
	4B	16.7474	16.9411	+0.1937	+1.2	1.9599
Salt Water 20% FSII	5A	15.2385	-	-	-	-
	5B	17.3475	17.4073	+0.0598	+0.3	1.2351
Salt Water 30% FSII	6A	15.8740	-	-	-	-
	6B	16.7532	16.3517	-0.4015	-2.4	1.1091

*FSII - Fuel System Icing Inhibitor, MIL-1-27686E

TABLE 30. RESULTS OF 6 MONTH EXPLOSAFE IMMERSION TESTS

Fluid	Sample No.	Initial Weight Grams	Final Weight Grams	Change in Weight Grams	Percent Weight Change	Percentage Weight Change at 30 Days
Tap Water 10% FSII*	1A	16.4402	15.1885	-1.2517	-7.6	-7.5
	1B	16.6110	16.1602	-0.4508	-2.7	-
Tap Water 20% FSII	2A	14.8464	14.1368	-0.7096	-4.8	-4.7
	2B	15.0990	14.9810	-0.1180	-0.8	-
Tap Water 30% FSII	3A	16.2285	15.5367	-0.6918	-4.2	-4.2
	3B	17.0479	16.6251	-0.4228	-2.4	-
Salt Water (3.5%) 10% FSII	4A	15.9138	16.1568	+0.2256	+1.4	-
	4B	16.7474	16.5738	-0.1736	-1.0	+1.2
Salt Water 20% FSII	5A	16.2385	16.6548	+0.4163	+2.5	-
	5B	17.3475	17.0370	-0.3105	-1.8	+0.3
Salt Water 30% FSII	6A	15.8740	15.7776	-0.1064	-0.7	-
	6B	16.7532	16.3262	-0.4270	-2.5	-2.4

*FSII - Fuel System Icing Inhibitor, MIL-1-27686E

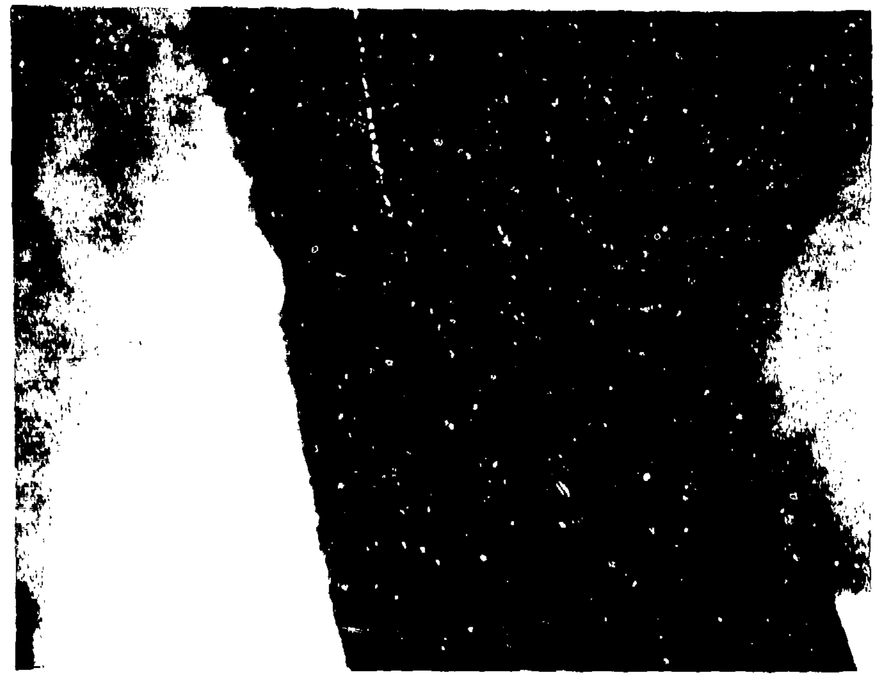


Figure 100. Corrosion of Explosafe in Tap Water 10% FSII/50% JP-4 Mixture

Figure 101. Corrosion of Explosafe in Tap Water 10% FSII/50% JP-4 Mixture

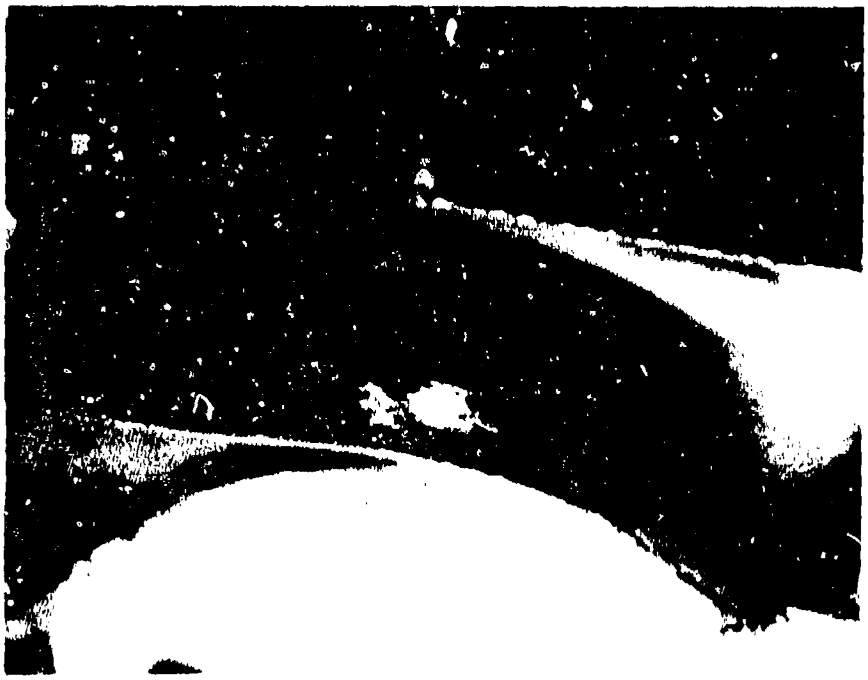


Figure 102. Corrosion of Explosafe in Tap Water
20% FSII/50% JP-4 Mixture

Figure 103. Corrosion of Explosafe in 3.5% Salt Water
20% FSII/50% JP-4 Mixture

The changes in sample weights after the 30-day exposure are included in Table 30 for those samples which were cleaned at that time (samples A in the tap water solutions and samples B in the sea water solutions). It will be noted that with samples 1A, 2A, 3A, and 6B the additional 5-month exposure had virtually no effect on weight loss, while with samples 4B and 5B there is an apparent net weight gain. This suggests that samples 4B and 5B were not thoroughly cleaned after the 6-month exposure. It also suggests that the bulk of any changes took place during the 30-day exposure at elevated temperature with concentrated solutions. In fact, no firm conclusions can be drawn from the weight loss data though it again appears that FSII more effectively reduced weight loss in salt water than tap water.

8.3 Conclusions

Some corrosion would occur on the bare Explosafe material in the water bottoms of aircraft fuel tanks in service. As noted earlier, the water bottoms in the fuel tanks are drained frequently during routine servicing which minimizes corrosion of the foil. If water bottoms were allowed to remain in the fuel tanks for long periods of time, the degree of corrosion could be related to prevailing temperature - continuous operation at temperatures of 140°F and above in highly concentrated drain solutions apparently being far more arduous than at 70°F with the more typical dilute solutions. Fuel screens around fuel pick-up lines and fuel pumps would preclude the entry of large corroded particles into the fuel lines. Smaller particles (in the order of microns) would be picked up by the in-line filters. Routine filter maintenance would ensure that the contaminants are removed.

8.4 Recommendations

In areas of a fuel tank where corrosion causing contaminants might accumulate, as mentioned in 8.3, an approved chromate conversion coating such as MIL-C-5541 should be used on the Explosafe material.

SECTION V

TASK IV - INSTALLATION STUDY

1.0 PROCEDURE

Installation studies were conducted on aircraft fuel tanks to determine the feasibility of designing the Explosafe material for installation into tanks of various complexity, and to evaluate techniques associated with shaping and bundling the material to accomplish these installations.

The study was performed in three phases. Successive phases dealt with techniques required to design, fabricate and install the material into tanks of increasing complexity, culminating in installation for a fighter type wing tank complete with all associated integral plumbing.

Fuel Tanks

Installation studies were conducted on the following fuel tanks:

Phase-I

- 90 gallon flexible rubber test cube (Appendix D 1).

Phase-II

- 200 gallon external pylon tank (2 studies, Appendix D 2 and D 3).
- Kellett Corp. 100 gallon helicopter drop tank (Appendix D 4).

Phase-III

- CF-104 ammunition compartment tank (Appendix D 5).
- A-10 wing tank (Appendix D 6).

Explosafe Material Specifications

The Explosafe material used was 0.002 inch thick 3003/H24 alloy aluminum foil, slit for 0.055 inch strand width and expanded to 38 inch web width. The expanded foil was either coiled or layered, and shaped to the desired configurations. For most

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installations, the foil was stacked at 13.8 layers per inch height to provide a material density, after oversizing, of about 2.2 pounds per cubic foot. Each batt was unitized by stitching or pinning together the layers of foil or, in the case of coiled batts, stapling the tail end of the foil to the coil body.

1.1 Design

Optimizing Batt Sizes and Quantities

Batt dimensions were selected so that an optimum number of batts per kit would be needed to pack any given tank. The batt sizes were contingent upon the available space within the tank and the size of the access to the interior of the tank. Other considerations that governed batt sizes were configurations that would permit easy handling and installation with minimum damage to the foil.

In no case were the dimensions of any batt allowed to be such that its free passage through the access would be restricted by its size. Furthermore, the batts were sized and shaped to allow normal maintenance and inspection operations to be accomplished within a reasonable time.

Oversizing and Optimum Cell Orientation

Shrinkage, settling and movement of the foil were investigated under simulated operating conditions (Task III : Dynamic Slosh, and Dynamic Slosh/Vibration). The observations made and data derived from these tests helped to determine oversizing criteria to compensate for shrinking or settling of the material.

An evaluation of the optimum cell orientation that would minimize compaction of the material was also made.

Batt Configuration

For all installations, the design of the batts was kept as simple as possible. Where tank internal plumbing or fittings called for a complex batt configuration, the batt was subdivided into a series of smaller, simpler batts.

Voiding

Voiding techniques to preclude interference with system components such as vents, level control valves, pumps, quantity gauge probes and other critical components were incorporated into the design study.

1.2 Fabrication

Raw fanfolded batts were marked to indicate the locations of stitches and cuts. Before cutting, each marked batt was stitched either temporarily or permanently, depending upon the intended complexity of the finished product. Excess foil was trimmed off on a tilting-head band saw. The batts were shaped either with portable electric shears or with the band saw, or both; the choice of cutting tool depending upon the shape and configuration required (Figures 104 and 105). Here, templates were used to obtain better dimensional accuracy. After all shaping was completed, the batts were permanently stitched, if not already done so at the raw stage, and temporary stitches, if any, were removed. The finished batts were tagged and installed into fuel tanks or suitably packaged for storage.

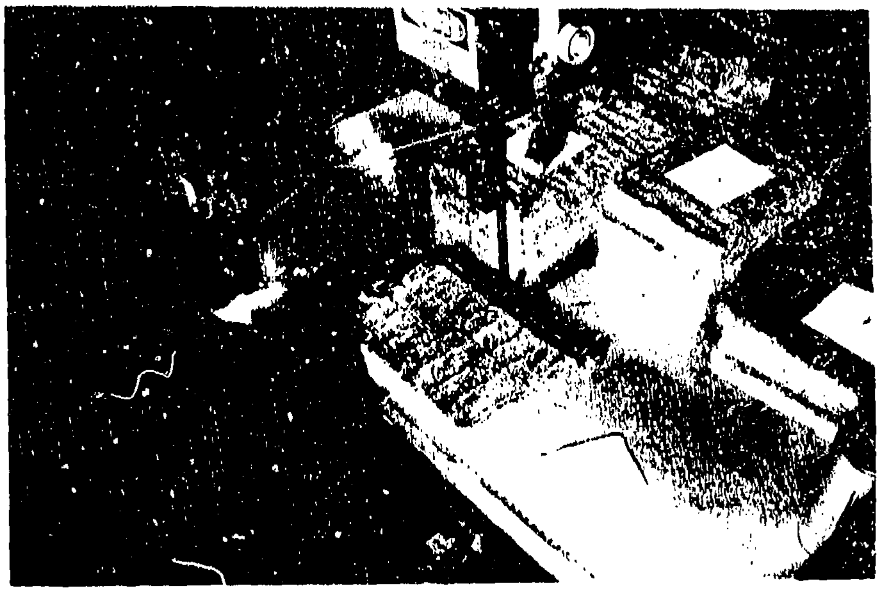

Figure 104. Cutting Foil with Band Saw

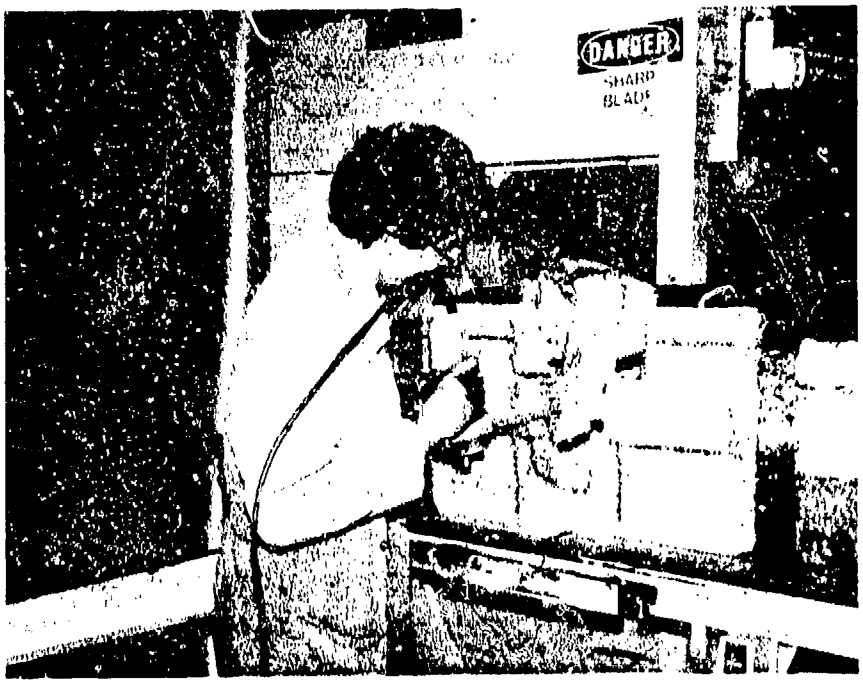

Figure 105. Shaping with Portable Shears

Cleanliness

Explosion suppression material intended for aircraft applications are subject to stringent qualification criteria that, for one, limits the level of entrained contaminants in the material.

In order to comply with such requirements, it was considered imperative to maintain a clean production environment and observe good house-keeping practices.

The work area was kept clean at all times and the floor swept of foil debris regularly. All manufacturing machinery and equipment, including stitching and assembly benches, were kept free of dirt. In addition, foil debris and dust were swept off the band saw and hand saw tables after each cut to ensure against adding contaminants to the foil.

Prior to storage, the entrapped foil debris was gently shaken off each batt. Foil was never placed directly on the floor where it could collect contaminants or be subject to damage by scuffing. Batts were placed either on clean tables, or on skids topped with a clean sheet of cardboard.

At no time were batts left unprotected from the surrounding work environment. Instead, they were stored under sheets of clean plastic film. Extended storage requires the foil to be packaged in 4 mil plastic bags and stored in corrugated cardboard boxes.

1.3 Installation

Special care was exercised to minimize contamination of the fuel tank and foil during installation. Prior to installing Explosafe, each tank was thoroughly cleaned by first, vacuuming, and then, if necessary, wiping with a suitable solvent. Thereafter, the tank was periodically vacuumed to pick up any loose foil debris that ensued while installation was in progress.

Before installation, the batts were shaken thoroughly, but gently, to remove bits of foil that could still be entrapped within its matrix. The foil was handled with extreme care as rough handling can damage the material and alter critical batt dimensions.

2.0 RESULTS

2.1 Design

Oversizing and Optimum Foil Orientation

Batts were observed to shrink approximately 1 percent in the short diamond and thickness dimensions when handled during manufacturing and another 1 to 2 percent in the same dimensions when subjected to severe operating conditions.

Wherever installation made it possible, oversizing by 2 to 3 percent across these dimensions was seen to be the desired remedial measure. Oversizing, also, provided for a tighter fit which aided in restricting movement of the foil in operation.

An intensive, full scale dynamic slosh test, described in Task III, showed that coiled foil (see installation, Appendix D 2), because of its fairly slack body, was prone to fatigue caused failure. By comparison, layered foil presented a firmer body and managed to keep its physical integrity under the same conditions. In light of these findings, use of only layered foil in favor of coiled foil was considered for subsequent installations.

To minimize slosh-caused flexing of the foil, the foil was so oriented that the direction of fluid slosh, for the most part, would be through the face of the diamonds. This generally called for the face of the cells to be aligned perpendicular to the fwd-aft axis of the tank. Here too, it was considered desirable to align the long dimension of the cells vertically, as compressive strength of Explosafe when top loaded, as by g forces, is maximum for this orientation.

Batt Configurations

Batts of less than 2 inch thickness were too delicate to handle and were easily subject to deformation during installation. On the other hand, batts having thickness of over 15 inches tended to be cumbersome to work with and install. An ideal range of batt thickness seemed to be from 2 to 12 inches.

Installation studies showed that frictional resistance offered by contacting batt surfaces hindered the placement of batts into their designated final positions. To solve this problem, the adjoining batt surfaces were simply, obliquely cut such that adjacent batts would mate completely only when fully in position. Frictional resistance and damage to the foil was thus minimized.

An example of such a design is shown in Figure 106 and a detailed comparative installation study of batts vertically cut versus batts obliquely cut appears in Appendix D 6 (A-10 wing tank).

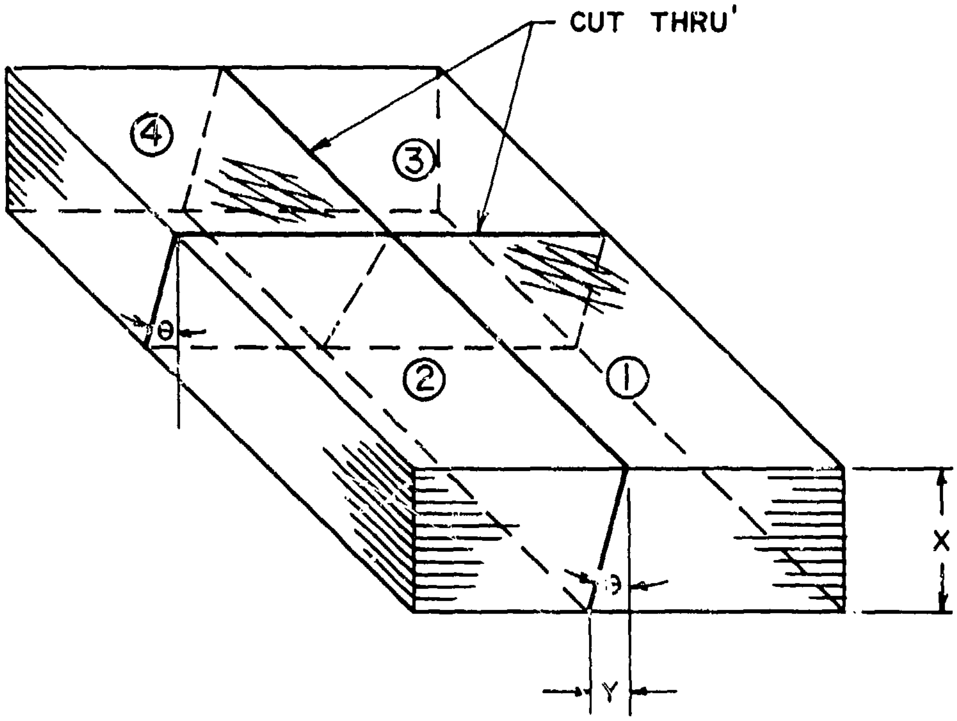

Figure 106. Obliquely Cut Batt System

The illustration above shows four batts, numbered in their sequence of installation, that could be packed with reduced frictional resistance into an open-top rectangular container.

There is a limit to the slant, θ, that can be cut over the stacked dimension, x. Batts are usually vertical stitched with stitches located about an inch away from the edge of the batt. An oblique cut would generate an overhang, y, that would leave the layers of foil, extending from the stitch to the edge of the overhang, unsecured. In practice, it has been observed that an overhang of 2 inches over a batt thickness of up to 8 inches does not seriously violate the integrity of batt extremities, and at the same time yields a sufficient slant to promote easy installation.

As the batt thickness is increased, its rigidity is reduced so that flexing of the batt may occur during handling. Such flexing might cause premature contact between adjacent batt surfaces during installation, making their positioning difficult. Thus, for batt thicknesses in the 8 to 12 inch range, a 2 inch overhang may not be sufficient to allow near contact-free installation, especially, when nearing the upper thickness limit. In such cases, the overhang may be increased to 3 to 4 inches and a corrective slant may be given to the stitches to maintain the unsecured portion at about 3 inches.

When a slanted cut is required to transverse the expanded surface of the batt, particularly in end installations such as shown in Figure 107, the cutting angle may be varied as desired depending on that particular installation. In practice, the effective cutting angle has been observed to be about 15 degrees.

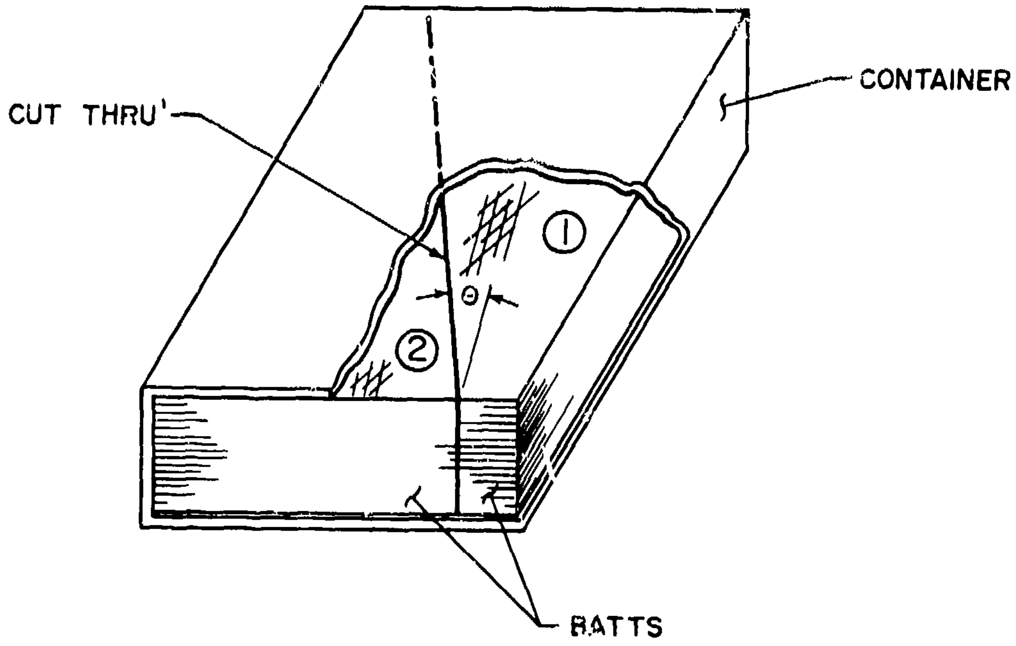

Figure 107. Slanted Cut across Expanded Surface

Voiding

For each installation, total voiding not exceeding 10% by volume was strived for. This limit was exceeded only in the CF-104 ammunition compartment study where a void level of 12.4% was reached. The need for voiding around a large number of internal components in a small volume tank was the cause. Table 31 lists the various void levels obtained.

The following suggested criteria for Explosafe voiding are based on existing USAF criteria, ENJIF-EC-71-1 (Rev. 6, 1973), for foam voiding, and on observations made during installation studies and slosh testing of Explosafe. Some void dimensions are reduced because, unlike foam, Explosafe does not swell in the presence of fuel to partially close up the voids.

A void is necessary in the Explosafe material around all float-type components and other components that function by moving through the tank. For instance, fuel quantity gauges that operate by a vertical sliding float or swing arm type float would require a void to be cut in the foil around the float to permit it to move without obstruction. Such a void should extend at least one inch in all directions from all moving or stationary components of the fuel gauge assembly. The foil should then be retained by a stiff mesh cage such that the cage surrounds the fuel gauge assembly. The cage should be anchored in place by riveting, soldering, or tack welding it to the tank body or to another suitable immovable component. The mesh cage, or guard, should protect the moving member of the component at all points through which it sweeps.

Most electrical capacitance gauges will operate normally in an Explosafe environment without the need for precautionary voiding around the components. However, some gauge sensors have an outer sheath on the probe which is at an electric potential greater than that of the tank. In this event, the foil must be insulated from the sheath.

For all installations, care must be taken to ensure that the foil does not contact any live electrical components. Conversely, all live electrical components and terminals that would come in contact with the foil, must be insulated.

To prevent loading of components such as pumps, quantity gauge probes and fuel pick-up tubes that are supported only at one end, about an inch of clearance between the component and foil should be maintained in all directions.

The foil should fit snugly around supported tubing. All drains should have a minimum of 2.5 inches of clearance in all directions. Sump areas for drainage, where water would usually collect, should not be filled with foil.

A 3.5 to 4 inch diameter void should be provided vertically to the bottom of the tank at each gravity filler port to allo for suction defuelling.

Open vents should have a void of rectilinear shape so as to provide 2.5 inches of standoff from the vent opening to the foil.

At least one inch clearance should be provided in all directions between any small protruding component and the foil to prevent disintegration of the foil by scraping.

Large voids should be avoided since they tend to weaken the batt structure which could possibly lead to crushing of the batt during severe flight maneuvers. If it becomes absolutely necessary to provide large voids, the batts containing such voids should be supported by unitizing them with adjacent batts or by the use of supporting mesh cages similar to those used for supporting foil around fuel gauges.

<u>Material Density</u>

Explosafe material used for the installation study is classified as Type II, Class B foil. This has a material density ranging between 1.8 to 2.3 pounds per cubic foot, depending upon the foil expansion and stacking used. The lower and upper density limits are obtained at expansion of 42 inches with stacking at 13 layers per inch, and expansion of 34 inches with stacking at 14 layers per inch, respectively.

With oversizing, the density of material used for the study fell just within this range, except for the cube tank where the density of Explosafe installed was 2.64 pounds per cubic foot. The higher density is attributed to the higher layer count of 16 layers per inch. Table 31 lists the material and packing densities for each installation. Data for the first 200 gallon pylon tank study (Appendix D 2) is not listed as it was partially packed with coiled foil, the use of which is now discontinued.

TABLE 31. INSTALLATION STUDY DATA

Fuel Tank	Appendix	Volume of Tank (cu.ft.)	Percent Void (%)	Weight of Explosafe Kit (lbs)	Foil Density Installed (lbs/ft^3)	Packing Density (lb/ft^3)
Test Cube	D-1	12.50	0	32.9	2.64	2.64
External Pylon	D-3	26.92	3.0	57.4	2.20	2.13
Kellett	D-4	14.44	5.6	31.1	2.28	2.15
CF-104	D-5	8.04	12.4	15.5	2.20	1.93
A-10 Wing*	D-6	36.83	5.5	73.1	2.23	1.99

* Two of eight compartments

2.2 Fabrication

Bundling Techniques

Three techniques were tried. All were performed manually.

They were:

1) Pinning the layers of foil with lengths of 16 gauge aluminum wire pushed through the foil and bent at both ends. (Appendix D 4: Kellett 100-gallon tank).

2) Stitching with 24 gauge stainless steel wire (Appendix D 3: 200-gallon pylon tank; Appendix D 5: CF-104 ammunition compartment tank; Appendix D 6: A-10 wing tank).

3) Stitching with nylon spun yarn (Appendix D 1: 90-gallon flexible rubber tank) and Dupont Kevlar-29 spun yarn (Appendix D 2: 200-gallon pylon tank).

Bundling with 16 gauge aluminum wires gave best results for batts of average complexity; a design situation common to most installations. The wires were either: (a) elbow bent at both ends or, (b) double bent to form ½ inch square Us with the turned around end of the U imbedded in the foil (Figure 108).

The latter technique proved more effective in holding the batt together because of the positive grip of the wires on the foil.

Where complex batt shapes were involved, such as those seen in the A-10 wing tank study, stitching uniformly with stainless steel wire around irregular sections, voids and perimeters of the batts, held together even the most precarious configurations with little or no apparent damage to the foil. Here, stitching across the short diamond direction of the foil was avoided because weaker compressive strength of the Explosafe material in that direction allowed excessive local compaction of the foil due to the pinching effect of the stitches. This effect was not evident when stitches were placed along the long diamond direction.

Intricate batt structures were well supported by stitches 2 to 3 inches long, with 2 to 4 inches spacing between stitches, and placed about an inch away from the perimeter of the batt or voided areas needing support.

Nylon and Kevlar yarn stitches performed well even under arduous slosh and vibration conditions. Aside from some stretching of the yarns which tended to slightly loosen the structure of the batts, no significant problems were encountered.

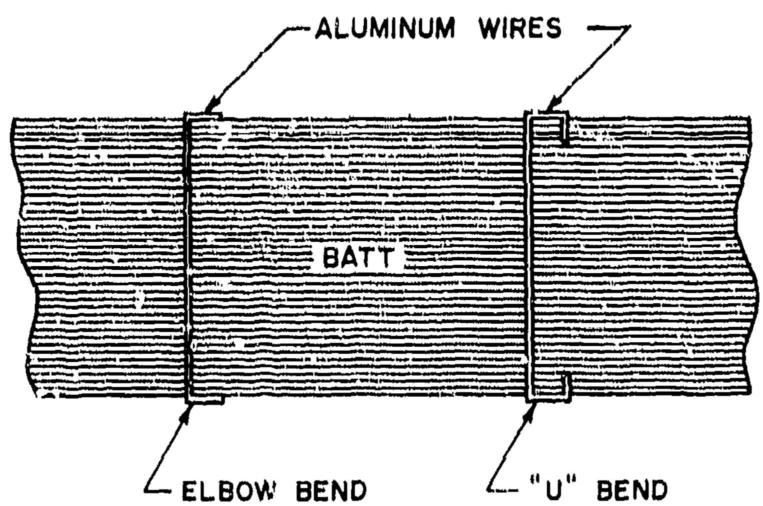

Figure 108. Methods of Pinning with Aluminum Wire

When comparisons are made, the use of Kevlar yarn is preferred over nylon because of Kevlar's self extinguishing characteristic and its ability to maintain its useful properties within a wide temperature range (-420°F to 500°F).

To sum up, pinning the batts with aluminum wire is preferable for batts of average complexity. Adequate structural strength is afforded to the batts while time related costs are kept down to a minimum.

For batts of intricate construction, stitching with stainless steel wire or Kevlar yarn in the long diamond direction is preferred. Manufacturing costs are high for this method when compared to pinning with aluminum wire as the manual stitching process is tedious and time consuming.

Because of its inherent stiffness, stainless steel wire, while being harder to work with, furnishes a stronger stitch and a firmer body to the batt than Kevlar yarn. Stainless steel wire, however, is more costly.

Handle

At the bundling stage, a handle, which is essentially a loop of the stitching material, can be stitched on to the batts to facilitate their removal from the tank during maintenance operations.

Cutting and Shaping

Prior to cutting, the batts were marked with a felt tip marker to indicate the locations of the cuts and stitches. Next, they were stitched permanently by one of the various methods described, or held together temporarily by pinning with lengths of 16 gauge aluminum wire. The stitches were placed at strategic locations so that they would not interfere with the blade during the cutting operations.

Cutting the foil with the bandsaw generated significantly lesser quantities of large particle foil debris than with the portable electric shears. Instead, small quantities of fine aluminum dust were seen on the cutting table. The dust and foil debris needed to be swept away after each cut as a precaution against adding contaminants to the foil.

The bandsaw was best for trimming excess foil or when making vertical or angled cuts straight down the batt. For cutting more complex configurations, the portable electric shears did the job admirably well, although, much more foil debris was generated when using this tool. Some of the debris tended to get entrapped in the foil matrix in the immediate vicinity of the cut and needed to be shaken or patted out.

The vibration and pressure of the blades caused some compacting of the foil at the cut surfaces. This, when combined with loss of material during cutting, resulted in a dimensional loss averaging 1/16 inch per cut across the long diamond dimension and as much as 1/8 inch per cut over the short diamond dimension. The problem was easily remedied by corrective oversizing, which was in addition to designed oversizing, or, alternatively, placing the batts in proper jigs while cutting.

Masonite or cardboard templates defining batt perimeters were generally affixed to individual batts with pins and used as guides during cutting. With a little care, dimensional accuracy thus obtained was adequate for all practical purposes. For production runs, however, past experience has shown that consistent dimensional control can be exercised if the batts are shaped in specially designed cutting jigs.

Batt Identification

Each batt was tagged with its batt number and orientation embossed on a 2 x 2 inch square of aluminum foil. The numbers were assigned such that their order of ascension would also serve as the sequence of installation. The tags were slipped in between the first two layers of foil of each batt and secured in place with stainless steel staples. As far as possible, the tags were located on the side of the batt that would face the installer.

This method of batt identification was not considered satisfactory as the embossed figures were difficult to read. Numbering with marking pens yielded legible figures sufficient for first time installation, but the ink was prone to be washed off during use making identification impossible at the time of maintenance. Paints investigated were ruled out because they too were apt to dissolve in use and had the added disadvantage of being a source of fuel contamination.

2.3 Installation

Forcing the batts into place was avoided. Often, inter-surface contact between batts gave some resistance to proper batt placement. In such instances, stiff cardboard sheets were inserted between contacting batt surfaces to reduce excessive frictional resistance. These sheets were removed immediately after the affected batts were in place. It was sometimes necessary to slip in such sheets between contacting batt surfaces when removing batts, as well.

For production installation jobs, sized 18 gauge aluminum plates or acrylic plastic sheets can be substituted for cardboard for their better strength and wear characteristics.

Installation times varied from tank to tank, often depending upon the need for dismantling and reassembling internal components and plumbing to effect installation. Table 32 shows actual kit installation times for the various tanks studied. The times do not reflect dismantling to open up the tanks or final assembly of major structural sections to complete the tanks.

TABLE 32. INSTALLATION TIMES

Fuel Tank	Appendix	Installation Time (mins)	No. of Batts	Average Time per Batt (mins)
Test Cube	D-1	22	25	0.88
External Pylon	D-3	69	21	3.29
Kellett	D-4	96	24	4.00
CF-104	D-5	80	39	2.05
A-10 Wing*	D-6	209	135	1.55

* Two of eight compartments

3.0 CONCLUSIONS

No problems were experienced during the design, fabrication and installation of Explosafe kits for any of the tanks considered under Phase I and Phase II of the study. The tanks did not demand elaborate engineering or manufacturing attention as their geometry allowed non-complex kit designs. Installation of the batts was made simple due to the freer access afforded to the tanks' interiors. In addition, plumbing and obstructing components could generally be dismantled to easily negotiate otherwise difficult installation situations.

By comparion, much design consideration was necessary in the Phase III study. The small accesses and cluttered tank interiors did not permit much latitude. As a consequence, the kit designs were more detailed - becoming somewhat intricate in the case of the A-10 wing tank - and the batts small and numerous.

The need for complex voiding and cutting of Explosafe to circumvent high concentrations of internal obstructions presents some engineering and fabrication problems. Careful thought to design is required to overcome inherent limitations of the foil, particularly its restricted ability to sustain highly voided configurations. While the solutions may involve high penalties in terms of both engineering and labor times expended, the problems are generally not insurmountable.

4.0 RECOMMENDATIONS

4.1 Fuel Tank Re-design

Design, fabrication and installation problems, such as those experienced while retrofitting complex fuel tanks, can be avoided if new aircraft fuel tanks are designed with characteristics of Explosafe in mind. For instance, internal plumbing and conduits can be routed and components positioned so that they lie close to the tank walls. Accesses to tank interiors can be maximized to allow installation of larger batts. Structural considerations are necessary to eliminate the need for, or minimize the frequency of baffles, ribs and other obstructions.

4.2 Improvements in Manufacturing

Two major areas in manufacturing need refining:

a) Manual bundling methods are labor intensive and do not lend themselves to the concept of mass production. In most situations, they contribute to bottlenecks in an otherwise speedy manufacturing process. The development of automatic or semi-automatic stitching or pinning machinery is essential if manufacturing costs are to be kept down to a reasonable level.

b) Some effort should be directed towards developing a more legible numbering method for batts. One method worth investigating further is stencilling identification with paint that is fast curing and impervious to fuels and additives commonly used in aircraft fuel tanks.

5.0 FIELD EXPERIENCE

Explosafe was first introduced in volume to the market place in the form of 1, 2½ and 5 gallon gas cans in the spring of 1977. Up to the end of 1st quarter, 1980, approximately 140,000 units had been distributed to North American and overseas markets in Scandinavia, Hong Kong, Australia and South Africa.

A 5 gallon marine tote tank, added to the consumer product line in July 1979, is now being distributed to North American and overseas markets through distributors and licensed representatives.

Current high priority markets include security vehicles, both private and military, aircraft, industrial storage/transport and marine applications. Major installations include: Nuclear Escort Vehicles, Navairsyscom External Helicopter Tanks, USAF Armored Response Convoy Vehicles, and a wide variety of private security vehicles and work/utility/harbor patrol boats. Table 33 provides specifics of some installations mentioned above.

Studies to date indicate that the cost of raw material in bulk form is comparable to foam with superior performance indicated with respect to total cost over the life cycle of aircraft/ surface vehicles.

TABLE 33. FIELD EXPERIENCE - APPLICATION DATA

Product	Contractor/Client	Material Thickness (in)	Material Expansion (in)	Tank Volume (gal)	Weight of Kit (lbs)
Commando Ranger Armored Response Vehicle	Cadillac Gage/USAF Security Police	.003	38	38 U.S.	13.4
Nuclear Escort Vehicle	Sandia Laboratories	.003 .003	38 38	40 U.S. 50 U.S.	
Armored Communication Vehicle	Intersect Corp./ Foreign Government	.002	38	120 U.S.	37.2
External Helicopter Pylon Tank	Kellet Corp./(test) NAVAIRSYSCOM	.002	38	108 U.S.	31.1
In-Plant Storage/Mixing	Black & Decker Corp.	.002 .002	38 38	100 Imp. 200 Imp.	33.6 65.0
Motorcycle Auxiliary	Snow Products/Motorcycle Safety Equipment Company	.002	38	1.5 U.S.	0.5
Private Security Vehicles	Protection Development International Corp.				
Jeep Cherokee	Protective Devices Corp.	.003	38	20 U.S.	
Cadillac Seville (armored)	NAECO Associates/ Foreign Government	.003	38	22 U.S.	9.8
Harbour Patrol Boat	Orange Co. Sheriff's Dept.	.003		110 U.S.	
Hydroplanes	Snow Products			30 U.S.	
Nuclear E.V. - Series II	Prototype/Sandia Labs.	.002 .002		22 U.S. 18 U.S.	
Zero Trainer	By-Air Corp.				

APPENDIX A

VIPL FLAME TUBE TEST PROCEDURE AND RESULTS

VIPL Combustion Test Equipment

The VIPL flame tube is depicted in Figure A-1 and is a steel chamber capable of withstanding pressures up to 370 psig. Both ends can be removed for access and the chamber can be dismantled into two sections. Plexiglas windows are set into one side of the chamber to allow observation of the ignition and flame propagation. Internal dimensions are 11 x 11 x 84 inches yielding a volume of 5.392 cubic feet and a cross-sectional area of 121 square inches. Ports are provided as indicated for air and gas injection, venting, evacuation, sampling and purging. Ignition is effected by a spark igniter located in the center of one end plate.

To confirm the gas mixture strength and consistency a 9 inch diameter spherical test bomb is provided in which the overpressure of a gas sample when ignited by a centrally located igniter, identical to that in the flame tube, can be determined. Figure A-2 illustrates the results of testing two gas samples from the flame tube in this chamber.

The instrumentation is depicted in Figure A-3. Usually only one transducer location was employed, this being the one closest to the igniter. Various transducers were used during the course of the testing, all being the straingauge bridge type. All were electrically isolated from the test chamber by insulating interconnectors to prevent high voltage pick up from the ignition system. The signals were recorded on light sensitive paper by a Honeywell model 1858 CRT visicorder equipped with the required straingauge amplifiers and signal conditioning models. A typical recording is shown in Figure A-4.

The manometer, vacuum and one of the pressure transducer tappings are used in setting up the 5% mixture of propane in air at the desired pressure level. The photocells are located externally in the center of some of the viewing ports and are constructed with a confined field of view to monitor the advance of the flame

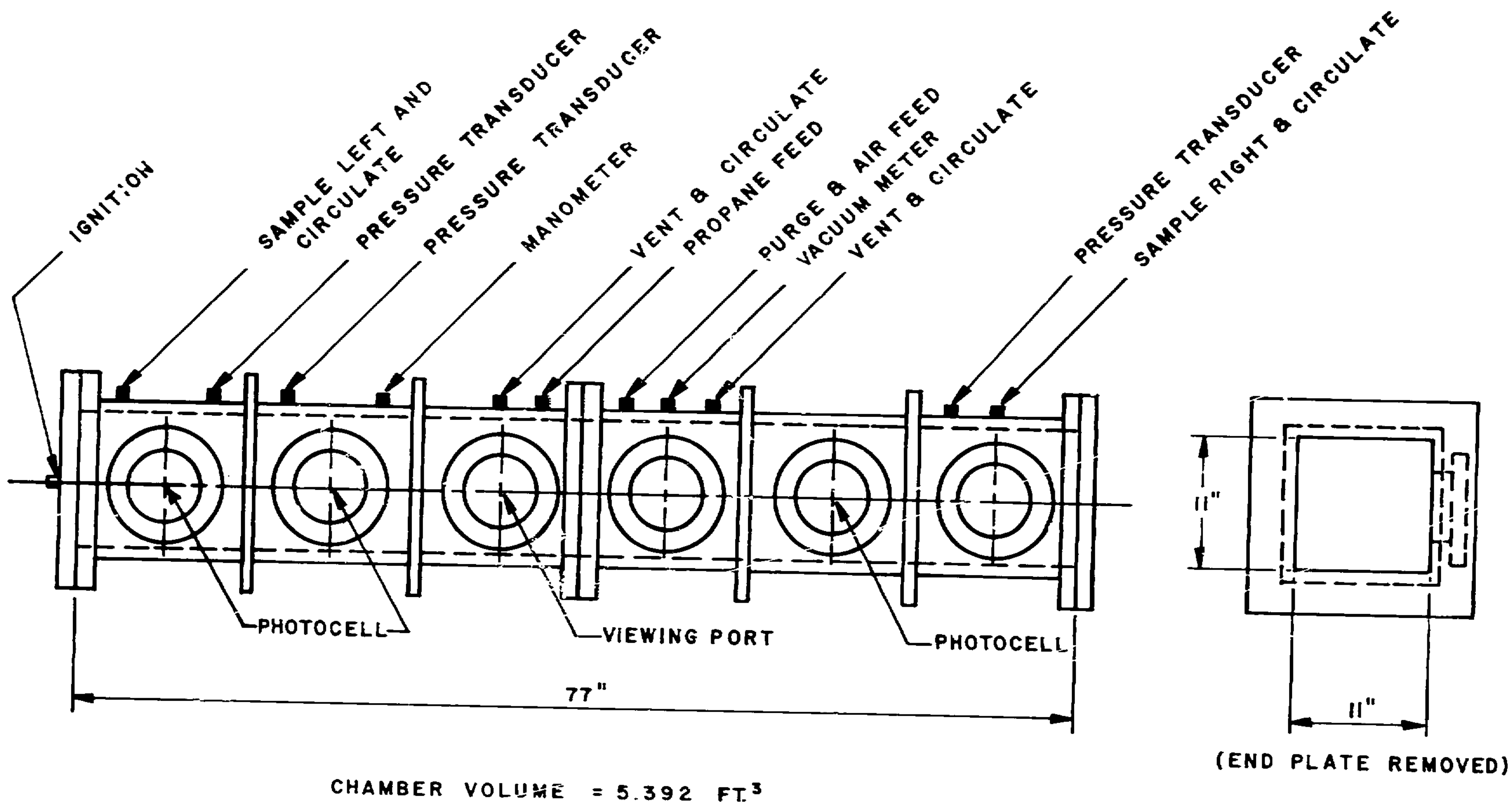

Figure A-1. VIPL Flame Tube Dimensions and Features

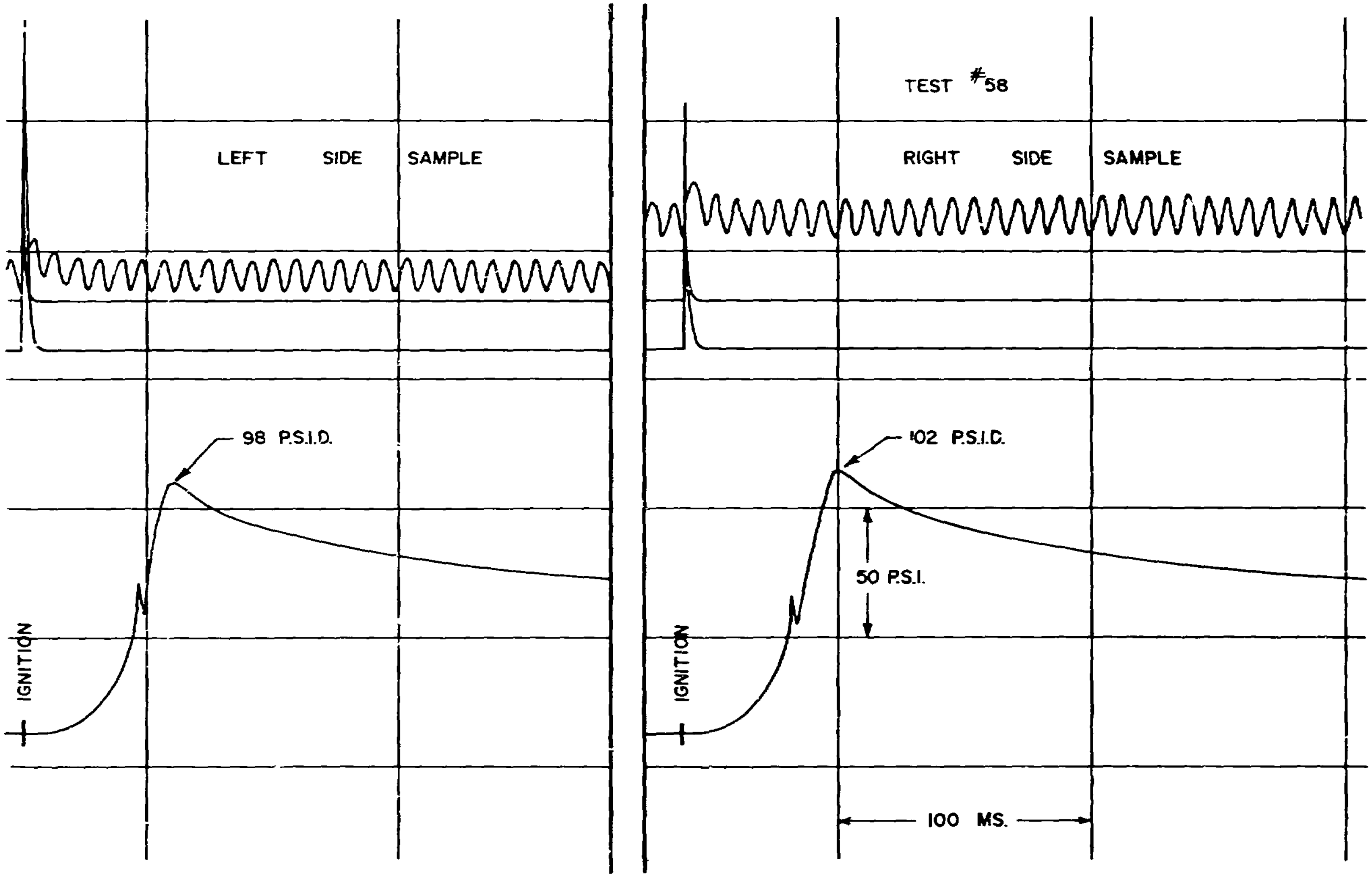

Figure A-2. Overpressure Tests on Gas Samples from Flame Tube

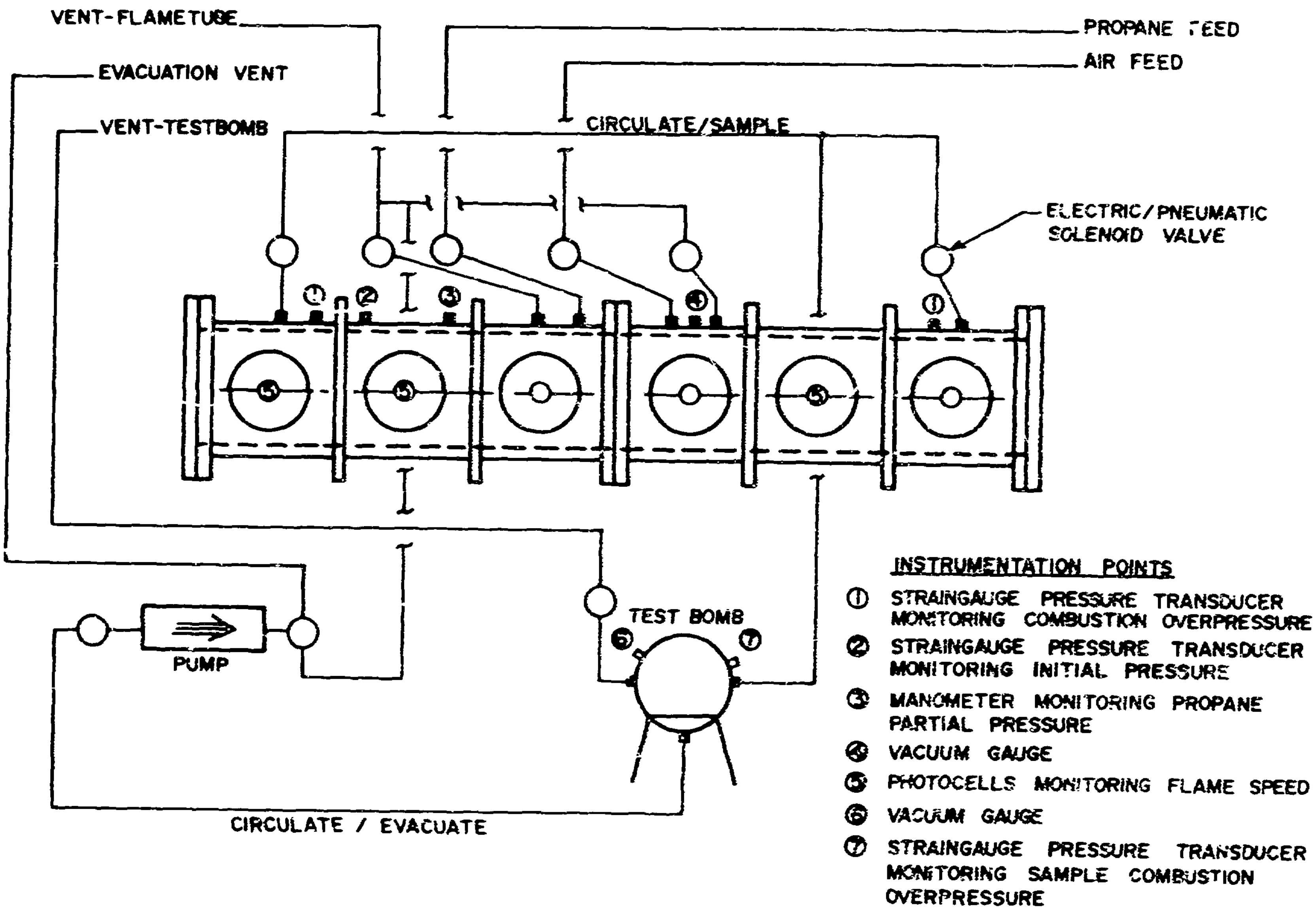

Figure A-3. VIPL Combustion Test Rig Schematic and Instrumentation

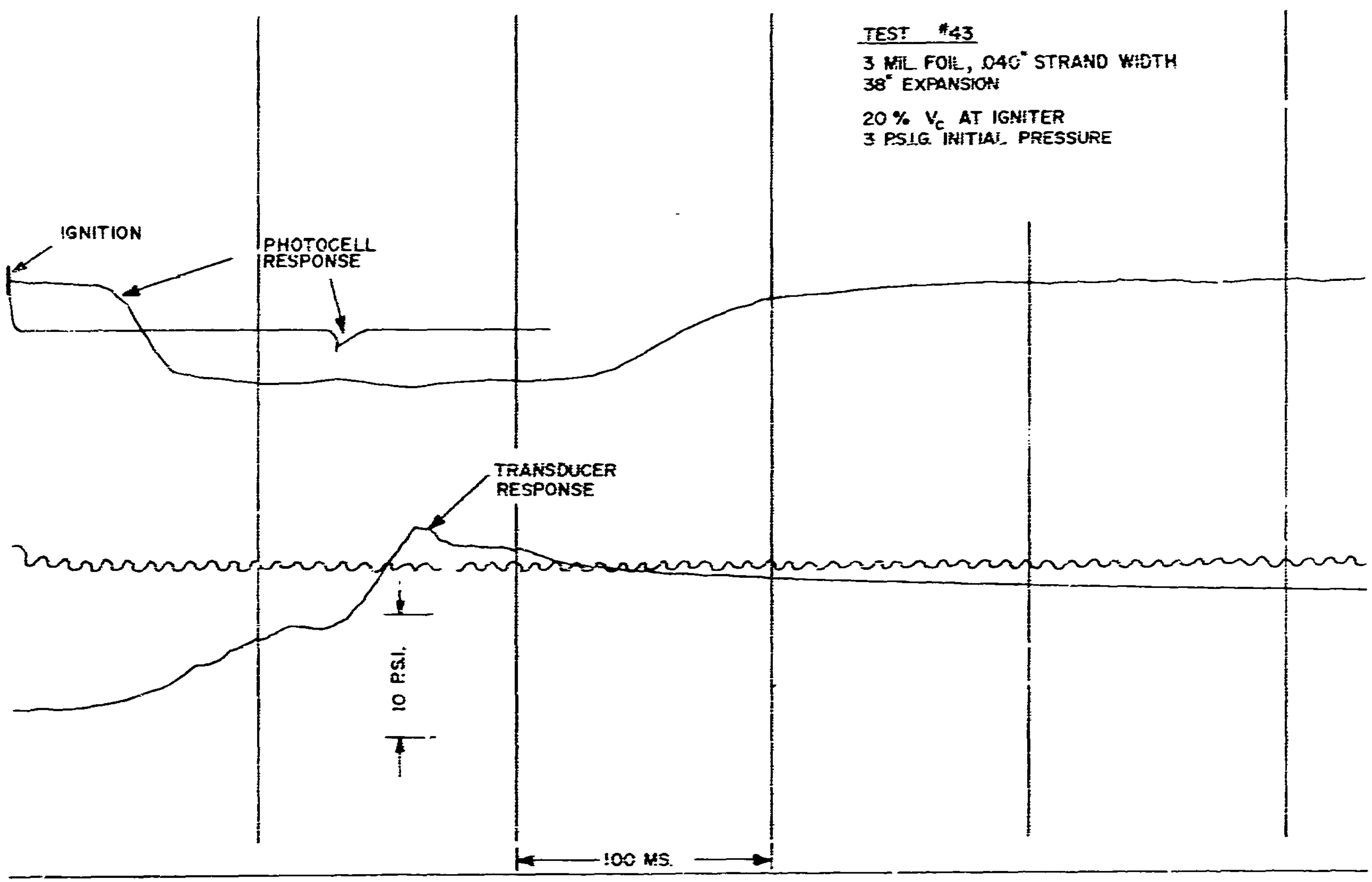

Figure A-4. Typical Combustion Test Recording front. Their sequential response is recorded with the transducer signal(s) and is used to derive the flame propagation speed.

Igniters are champion RN9Y automobile spark plugs with a .075 inch electrode gap located as shown in Figure A-1. Energy sources available are either a single capacitor charged to 15,000 volts (11.25 millijoules) or a continuous AC discharge at 10,000 volts delivered from a transformer. The selected source can be directed to either the flame tube or the test bomb by high voltage solenoids.

<u>VIPL Combustion Test Procedure</u>

All procedures in the testing are accomplished remotely from a separate control room by the use of solenoid operated valves, selection switches, solenoids, remote gauges and the ignition-interconnected recorder. Figure A-5 depicts the test control station and the Honeywell recorder.

Test procedure is as follows:

a) Install specimen suppression system as required.

b) Close end plates and pressure-test chamber and system at 5 psig.

c) Checkout all instrumentation and solenoid matrix board (a 20 x 20 diode array enabling the selection of all the solenoids required for any function by one switch).

d) Evacuate chamber to 26" Hg vacuum and purge three (3) times with air.

e) With test chamber at atmospheric pressure add the required amount of propane to give a 5% propane in air mixture at the required pressure level as

Figure A-5. VIPL Combustion Test Control Station and Recorder determined by partial pressures e.g. if the test is to be conducted at atmospheric pressure (14.7 psig) the test chamber will be set up at 3 psig, requiring 17.7/20 psig of propane to be added.

TABLE A-1. RAW DATA FOR .040" STRAND COMBUSTION TESTS

Date	Run	Foil	V_c	Pr	ΔP	Δt	Remarks	$\frac{\Delta P + Pr}{\Delta P}$	V_F	P_A	T_A	R_H
27-3-78	30	British foil 0.0016" thick fanfolded 1.75 #/ft^3 S-33	20%	atmos.	8.8	256	no comp.	1.60	40	29.8	67	34
27-3-78	31	British foil 0.0016" thick fanfolded 1.83 #/ft^3 S-34	20%	atmos.	8.8	231	no comp.	1.60	31	29.8	67	34
28-3-78	32	British foil 0.0016" thick fanfolded 1.83 #/ft^3 S-34	20%	3 psig	12.3	250	3" comp.	1.84	30	29.8	65	35.5
31-3-78	33	British foil 0.0016" thick fanfolded 1.92 #/ft^3 S-34	20%	3 psig	12.5	252	3" comp.	1.85	29	30.06	67	35
04-4-78	34	Alcan 0.0018 x .055 new alloy 34" exp. 2.54 #/ft^3 S-34	20%	3 psig	17.0	280	8" comp.	1.96	27.[illegible]	29.8	70	38
05-7-78	35	Alcan 0.003 x .04 35" exp. 3.57 #/ft^3 S-34	0	3 psig	3.7	208	no comp.	1.207	29	30.16	74	58
06-7-78	36	Alcan 0.003 x .04 35" exp. 3.57 #/ft^3 S-34	0	atmos.	2.1	453	no comp.	1.14	17.9	30.17	80	60
07-7-78	37	Alcan 0.003 x .04 35" exp. 3.57 #/ft^3 S-34	20%	3 psig	7.5	272	no comp.	1.42	20	30.09	80	59
07-7-78	38	Alcan 0.003 x .04 35" exp. 3.57 #/ft^3 S-34	20%	atmos.	5.8	377	no comp.	1.39	20	30.06	84	61.5
10-7-78	39	Alcan 0.003 x .04 35" exp. 3.57 #/ft^3 S-34	40%	3 psig	20.5	263	4" comp.	2.16	43	29.95	78	46
10-7-78	40	Alcan 0.003 x .04 35" exp. 3.57 #/ft^3 S-34	40%	atmos.	10.5	183	no comp.	1.71	37	29.96	80	45
11-7-78	41	Alcan 0.003 x .04 38" exp. 3.0 #/ft^3 S-34	0	3 psig	5.0	272	no comp.	1.28	33	30.12	76	42
12-7-78	42	Alcan 0.003 x .04 38" exp. 3.0 #/ft^3 S-34	0	atmos.	3.8	370	no comp.	1.26	21	30.22	74	47
12-7-78	43	Alcan 0.003 x .04 38" exp. 3.0 #/ft^3 S-34	20%	3 psig	14.5	162	½" comp.	1.81	4[illegible]	30.24	76	46
13-7-78	44	Alcan 0.003 x .04 38" exp. 3.0 #/ft^3 S-34	20%	atmos.	7.1	306	no comp.	1.48	26	29.96	77	54
17-7-78	45	Alcan 0.003 x .04 38" exp. 3.0 #/ft^3 S-34	40%	3 psig	22.2	134	7" comp. (extra foil)	2.25	47	30.01	78	50
17-7-78	46	Alcan 0.003 x .04 38" exp. 3.0 #/ft^3 S-34	40%	atmos.	12.0	177	no comp.	1.81	-	30.01	78	47
18-7-78	47	Alcan 0.003 x .04 42" exp. 2.78 #/ft^3 S-34	0	3 psig	4.8	243	no comp.	1.27	39	30.12	77	50
18-7-	48	Alcan 0.003 x .04 42" exp. 2.78 #/ft^3 S-34	0	atmos.	2.5	350	no comp.	1.17	22	30.14	78	49
18-7-78	49	Alcan 0.003 x .04 42" exp. 2.78 #/ft^3 S-34	20%	3 psig	12.8	158	no comp.	1.72	37	30.12	80	50
19-7-78	50	Alcan 0.003 x .04 42" exp. 2.78 #/ft^3 S-34	20%	atmos.	6.0	302	no comp.	1.41	22	30.02	76	5.
20-7-78	51	Alcan 0.003 x .04 42" exp. 2.78 #/ft^3 S-34	40%	3 psig	16.8	155	4½" comp.	1.95	43	30.08	84	56
24-7-78	52	Alcan 0.003 x .04 42" exp. 2.78 #/ft^3 S-34	40%	atmos.	15.5	273	3" comp.	2.04	[illegible]	30.25	79	55
24-7-78	53	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	0	3 psig	4.6	200	no comp.	1.26	37	30.23	81	46
25-7-78	54	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	0	atmos.	2.2	293	no comp.	1.15	29	30.07	78	58
25-7-78	55	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	20%	3 psig	9.1	171	no comp.	1.51	39.7	30.04	80	57
25-7-78	56	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	20%	3 psig	9.3	181	½" comp.	1.92	35.[illegible]	30.01	81	57
26-7-78	57	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	20%	atmos.	5.7	259	3" comp.	1.38	28	29.96	80	63
26-7-78	58	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	40%	3 psig	20.3	166	1" comp.	2.15	44.3	29.76	82	64
26-7-78	59	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	40%	atmos.	11.7	145	2" comp.	1.80	41.7	29.74	83	65
31 8-78	60	Alcan 0.003 x .04 33½" exp. 3.49 #/ft^3 S-34	40%	3 psig	23.3	117	no comp.	2.33	46.3	29.74	73	65
06-4-78	70	No foil	100%	atmos.	10.5	595	-	8.13	18.0	30.07	68	34

APPENDIX B 1

EXPANSION CHARACTERISTICS-EXPERIMENTAL DATA
.003 INCH THICK X .055 INCH STRAND
AND
.003 INCH THICK X .040 INCH STRAND
EXPLOSAFE MATERIAL

LIST OF SYMBOLS

Expanded

WA - Expanded width at arms

W - Final expanded width

L - Expanded length (total linear feet in a batt) = lf x n

lf - Length between folds (preset on fanfold control i.e. 24")

H - Batt height

V - Volume of the batt = W x H x lf

n - No. of layers in a batt height H

Dp - Lay up of a batt (layers/inch) = $\frac{n}{H}$

Fae - Area expansion factor = $\frac{A}{a} = \frac{W \times lf}{ws \times ls} = \frac{W \times lf \times n}{ws \times Lo}$

Fve - Volume expansion factor = $\frac{W \times H \times lf}{Wr \times Lo \times t}$

A - Surface area of one expanded layer = W x lf

P - Specific weight of expanded foil = $\frac{vp}{V} = \frac{wt.}{V}$

wt. - Theoretically calculated weight of a batt = vp

K - Surface area per unit volume = $\frac{24Dp}{Fae}$

d - % displacement of the batt = $\frac{1}{(Fve)} \times 100$

Z - wt per ft^2 layered surface area = wt. x $\frac{1}{nA}$ x 144

Unexpanded

wr - Raw width (14")

ws - Slit width (14.38")

lo - Unexpanded length

ls - Length of slit foil required to achieve lf - $\frac{Lo}{n}$

v - Volume of raw foil required to achieve v = wr x Lo x t

a - Surface area of slit foil required to achieve A = ws x ls = $\frac{ws \times Lo}{n}$

p - Density of raw foil (as supplied by AA) .099 for 3003 alloy

t - Thickness of raw foil (as supplied by Reynolds)

TABLE B1-1. FORMULATION DATA

W (in)	Fae	Fve	Dp (layers/in)	K (ft^2/ft^3)	P (lb/ft^3)	d	$Z \times 10^{-2}$ (lb/ft^2)
26.38	1.72	38.21	15.26	212.93	4.49	2.62	2.425
29.63	1.90	45.02	14.46	182.65	3.80	2.22	2.190
32.00	2.03	47.73	14.54	171.90	3.58	2.10	2.055
32.50	2.08	46.70	15.27	176.19	3.66	2.14	2.000
33.50	2.13	50.79	14.35	161.69	3.37	1.97	1.956
35.63	2.29	53.85	14.58	182.80	3.18	1.86	1.815
36.25	2.34	56.89	14.06	144.21	3.01	1.76	1.783
37.00	2.34	57.79	13.88	142.36	2.96	1.73	1.777
37.00	2.32	60.71	13.10	135.52	2.82	1.65	1.793
37.00	2.29	60.79	12.91	135.30	2.81	1.65	1.817
39.00	2.44	62.07	13.47	132.49	2.76	1.61	1.705
39.75	2.49	64.96	13.10	126.27	2.63	1.54	1.676
40.63	2.39	63.75	12.86	129.14	2.68	1.57	1.739
41.00	2.44	64.73	12.90	126.89	2.64	1.54	1.708
41.50	2.47	65.87	12.85	124.86	2.60	1.52	1.684
41.88	2.50	67.59	12.67	121.63	2.53	1.48	1.665
42.25	2.49	68.52	12.45	120.00	2.50	1.46	1.670
43.38	2.53	72.88	11.90	112.89	2.35	1.37	1.643
44.50	2.64	77.34	11.68	106.18	2.21	1.29	1.578

Material: 3003 H24 - .003 x .055

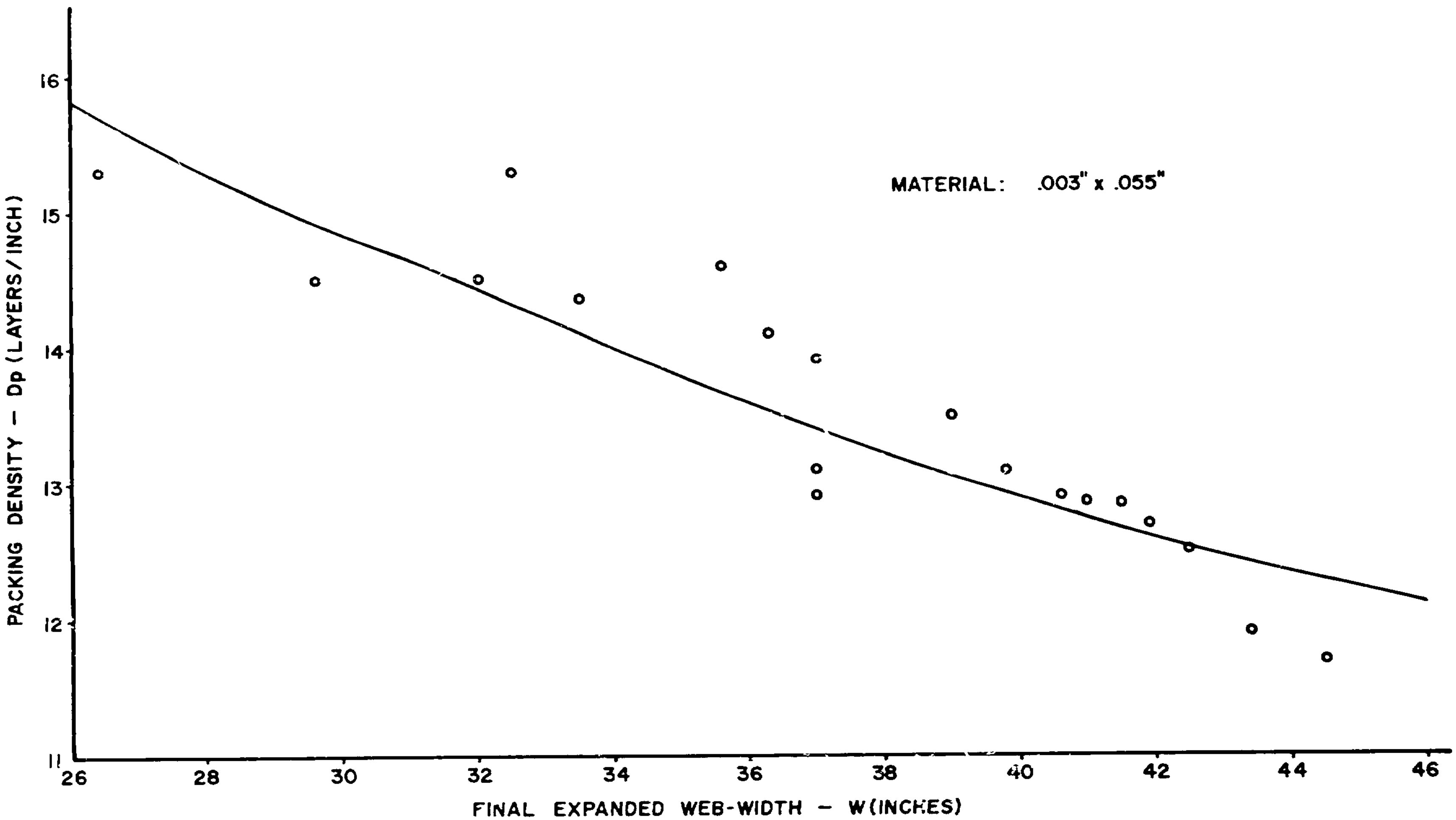

Figure B1-1. Effect of Expansion on Packing Density

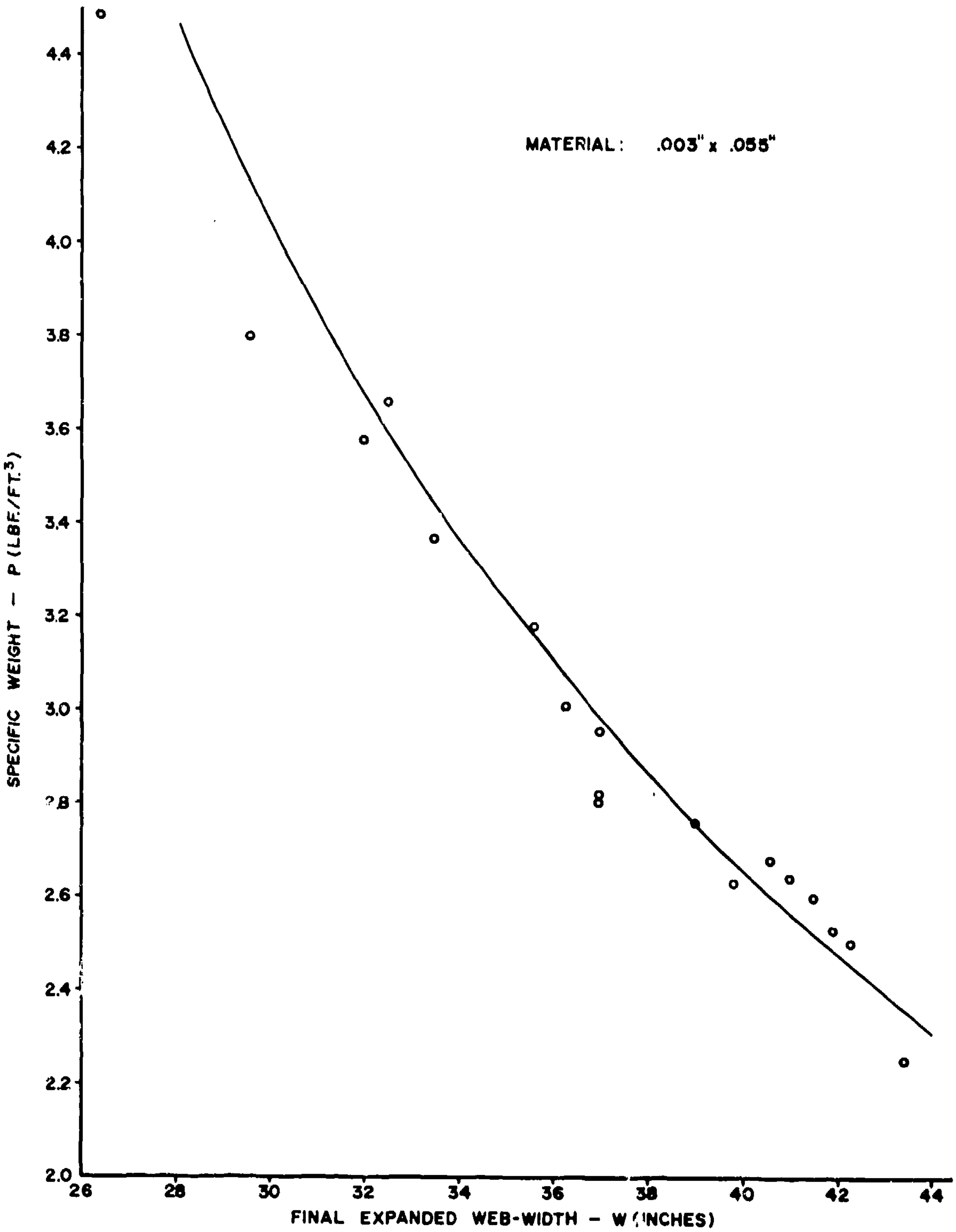

Figure B1-2. Effect of Expansion on Specific Weight

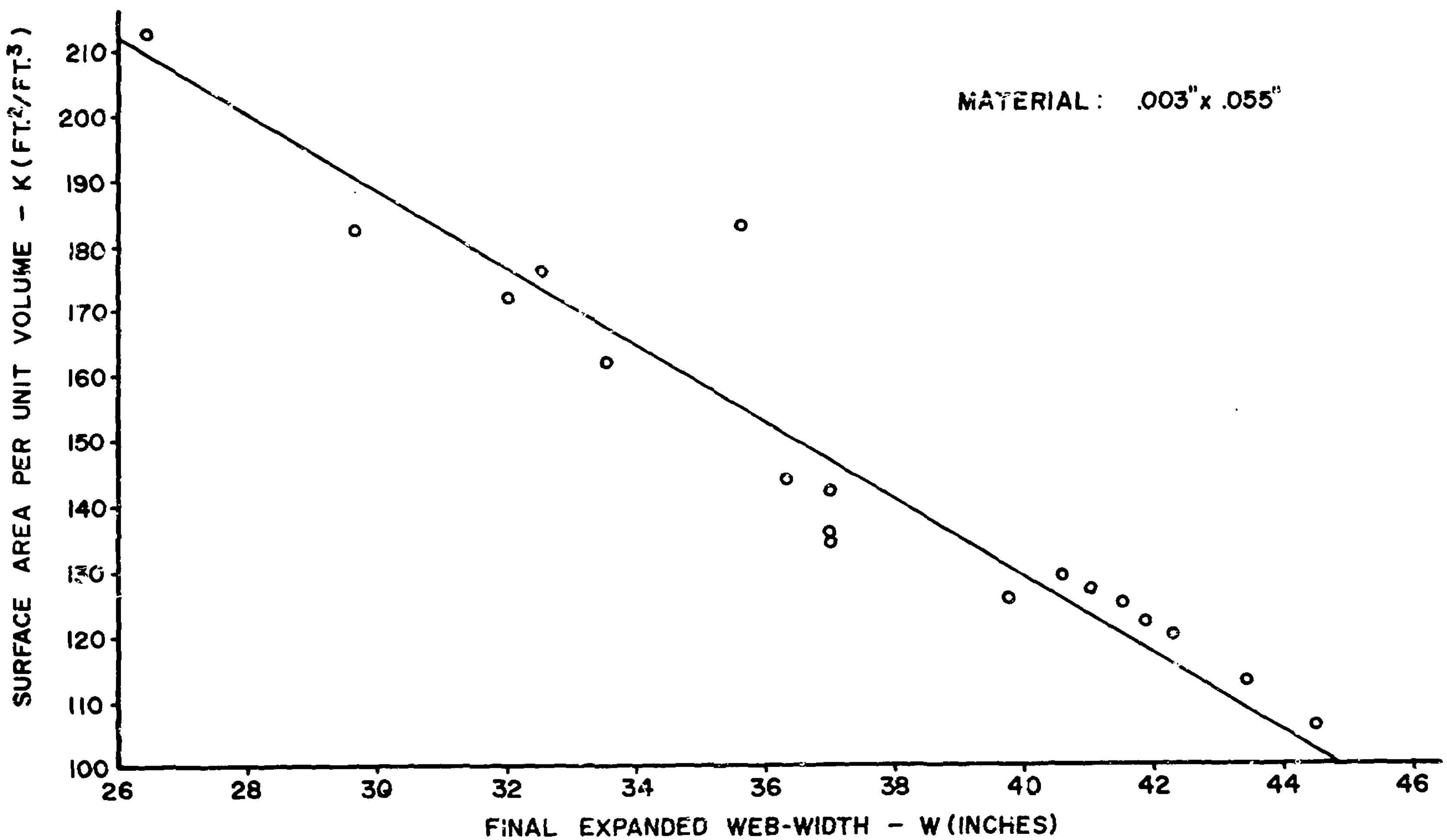

Figure B1-3. Effect of Expansion on Specific Surface Area

TABLE B1-2. EXPERIMENTAL DATA

Arm Set	W (in)	Wa (in)	H (in)	n	Lo (ft)
-14	31.50	35.25	14.86	212	469.5
-10	33.38	37.38	9.50	138	308.0
-10	34.50	38.63	13.38	181	410.0
- 7	35.25	39.50	12.63	182	403.5
- 2	38.50	42.75	14.63	216	477.5
- 1	42.00	45.00	14.00	202	467.0

Material: Aluminum 3003 H24 - .003" x .040"

wr = 14"
ws = 14.563"
t = .003"
p = 171.072 lbf/ft^3
lf = 24"

TABLE B1-3. DERIVED DATA .003" x .040" FOIL

W (in)	L (ft)	ls (in)	a (ft^2)	A (ft^2)	v (ft^3)	V (ft^3)	Dp (layers/in)	wt (lbf)
31.5	424	26.58	2.688	5.25	.1369	6.508	14.25	23.43
33.38	276	26.78	2.708	5.563	.0098	4.404	14.53	15.37
34.5	362	27.18	2.749	5.75	.1197	6.409	13.5	20.46
35.25	364	26.6	2.69	5.875	.1177	6.181	14.42	20.1[illegible]
38.5	432	26.53	2.683	6.417	.1393	7.82	14.77	23.83
42.0	404	27.74	2.805	7.0	.1362	8.167	14.4	23.3

TABLE B1-4. FORMULATION DATA .003" x .040" FOIL

W (in)	Fae	Fve	K (ft^2/ft^3)	P (lbf/ft^3)	d (%)	Z x 10^2 (lbf/ft^2)
31.5	1.953	47.52	175.1	3.6	2.1	2.105
33.38	2.054	49.02	169.76	3.49	2.04	2.0
34.5	2.092	53.59	155.27	3.19	1.[illegible]7	1.966
35.25	2.184	52.52	158.44	3.26	1.9	1.883
38.5	2.392	56.15	148.2	3.05	1.78	1.719
42.0	2.495	59.96	138.79	2.85	1.67	1.648

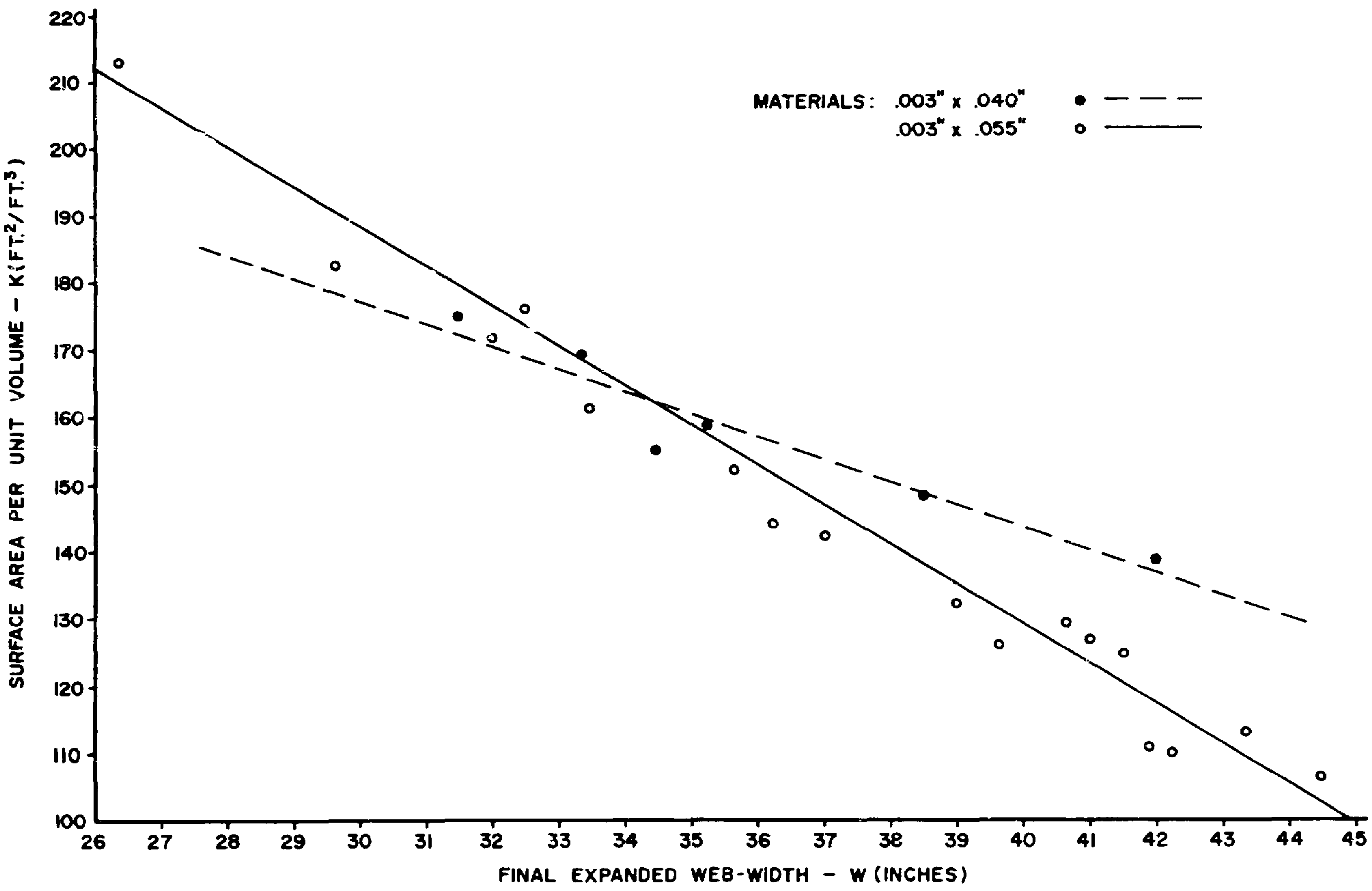

Figure B1-4. Effect of Expansion on Specific Surface Area

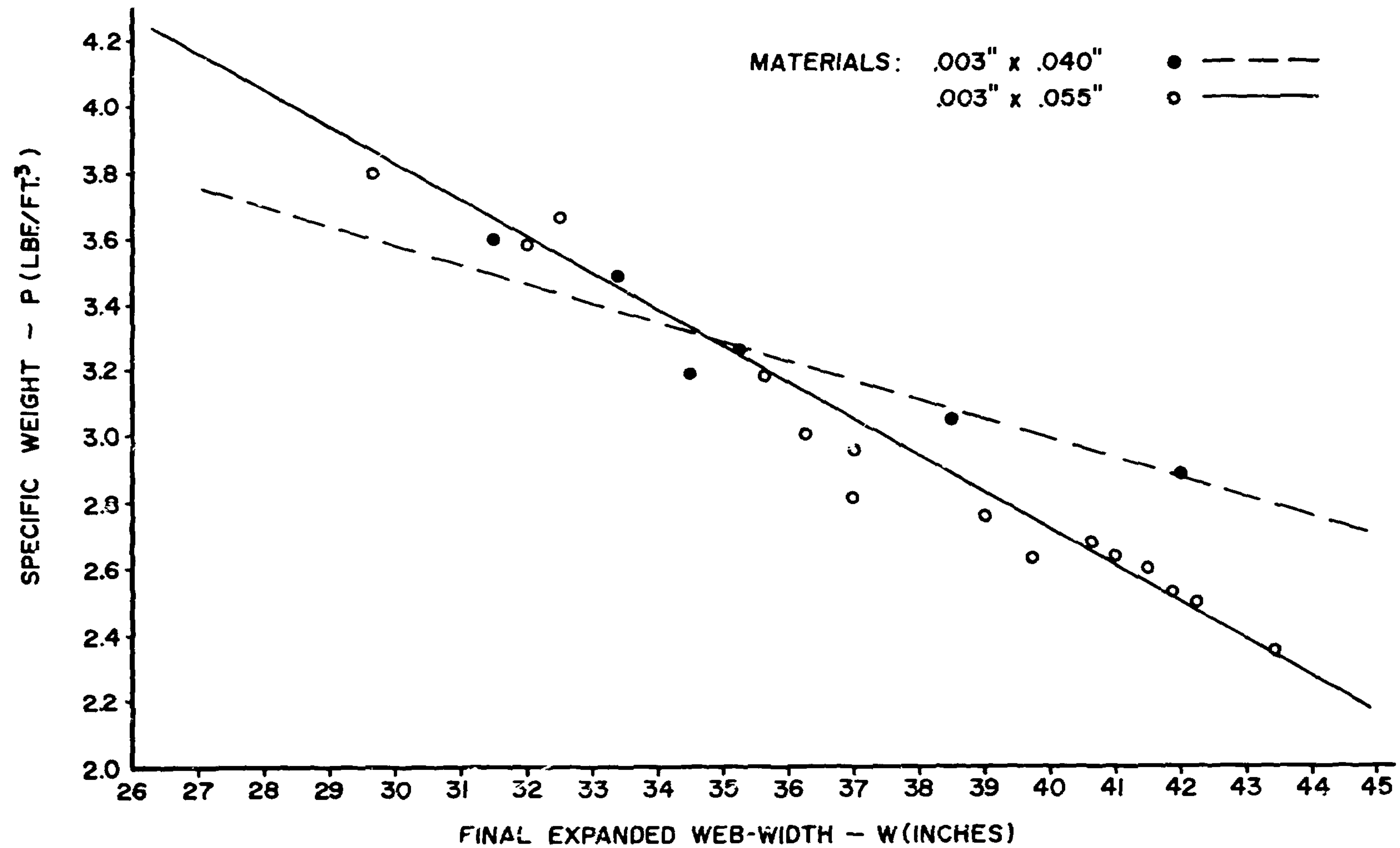

Figure B1-5. Effect of Expansion on Specific Weight

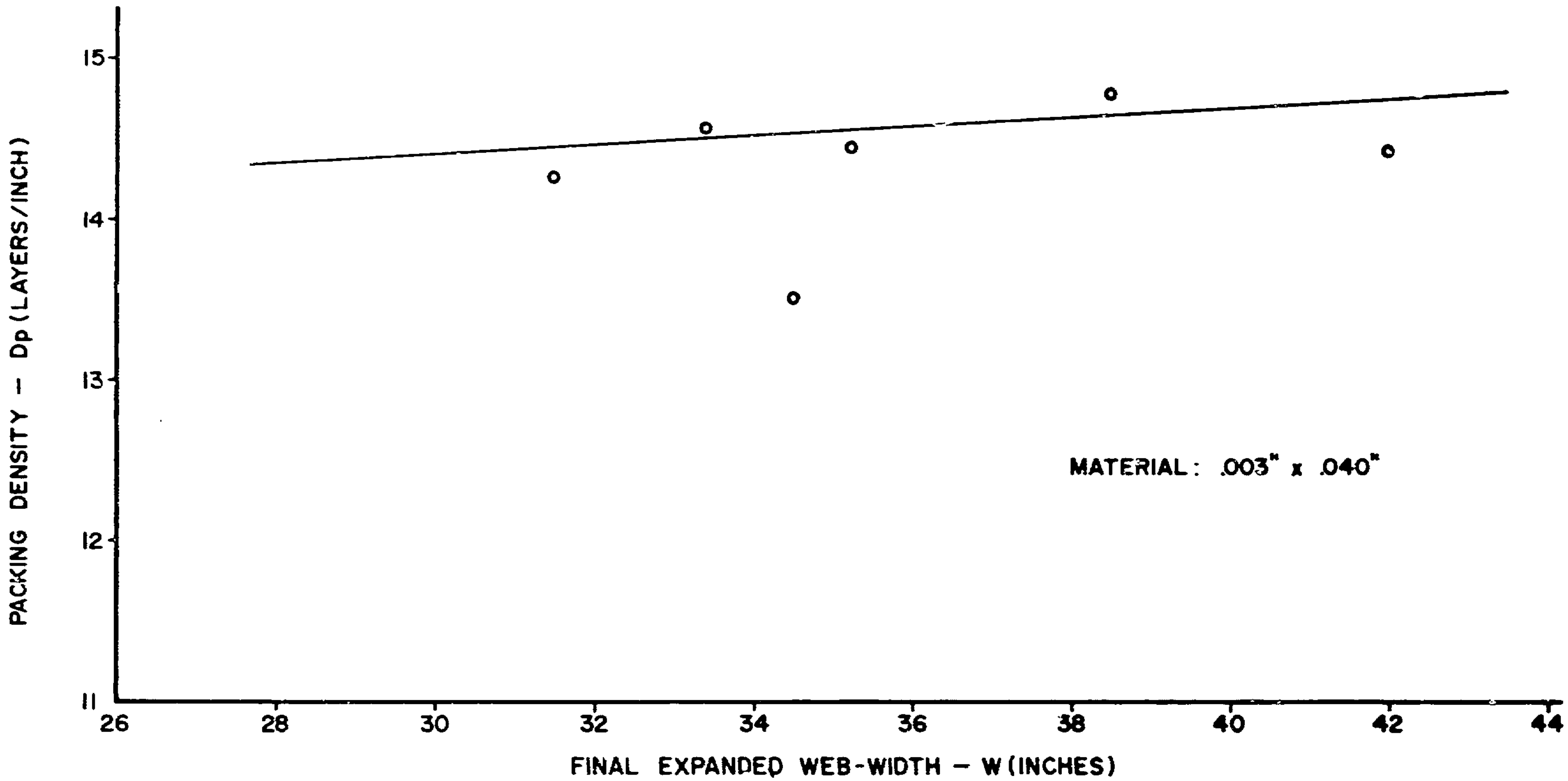

Figure B1-6. Effect of Expansion on Packing Density

APPENDIX B 2

EXPANSION CHARACTERISTICS-EXPERIMENTAL DATA
.002 INCH THICK X .055 INCH STRAND
EXPLOSAFE MATERIAL

LIST OF SYMBOLS

wr	Raw foil width.
ws	Slit foil width.
t	Foil thickness or gauge.
p	Specific weight of raw foil (171.072 lbf/ft^3).
lf	Length between folds.
W	Final expanded web-width, foil expansion.
Wa	Web-width at fanfolder.
Lo	Length of slit foil in a batt.
n	Number of layers in a batt.
load	Gives pressure of .025 psi on a batt: load = .025 x lf x W
H	Height of a batt with load applied.
wt	Weight of batt.
V	Volume of batt: V = lf x W x H
P	Specific weight of batt: $P = \frac{wt}{V}$
v	Volume of unslit foil used to make a batt: v = wr x t x Lo
d%	Displacement of a batt: $d = \frac{v}{V} \times 100$.
Dp	Packing density: $Dp = \frac{n}{H}$
L	Length of expanded foil in a batt: L = n x lf
FL	Length factor: length of expanded foil per unit length of unexpanded foil: $FL = \frac{L}{Lo}$
FA	Area factor: area of expanded foil per unit area of unexpanded foil: $FA = \frac{L \times W}{wr \times Lo}$
FV	Volume factor: volume of expanded foil per unit volume of unexpanded foil: $FV = \frac{V}{v}$
AA	Surface area per unit area of expanded foil: $AA = \frac{ws \times Lo \times 2}{W \times L}$
AV	Surface area per unit volume of expanded foil: $AV = \frac{ws \times Lo \times 2}{V}$

TABLE B2-1. EXPERIMENTAL DATA

Arm Set	W (in)	Wa (in)	Lo (in)	n	load (lbf)	H (in)	wt (lbf)
-12	28.50	32.25	261.5	183	11.4	12.25	8.56
-10	29.00	33.50	275.5	191	11.6	13.38	8.25
-[illegible].5	31.25	34.50	260.5	180	12.5	12.13	8.75
-6	33.25	37.00	268.5	184	13.3	13.00	10.25
-4	34.50	38.25	268.5	182	13.8	13.13	9.00
0	37.00	40.75	267.5	177	14.8	13.50	9.00
+2	38.00	42.00	282.0	185	15.2	13.88	9.50
+4	39.50	42.50	285.0	184	15.8	13.63	9.63
+6	41.25	44.00	271.0	173	16.5	13.00	9.13
+8	42.50	44.50	268.0	169	17.0	13.00	9.00

Material: Aluminum 3003 H24 - .055 x .002

wr = 14"
ws = 14.38"
t = .002"
p = 171.072 lbf/ft^3
lf = 16"
load: gives .025 psi

TABLE B2-2. DERIVED DATA

W (in)	V (ft^3)	vx10^2 (ft^3)	L (ft)	Dp (layers / foot)	P (lbf / ft^3)	AA (ft^2/ft^2)	AV (ft^2/ft^3)	FL (ft/ft)	FA (ft^2/ft^2)	FV (ft^3/ft^3)	d (%)	lbf/gal (Can)	lbf/gal (US)	grams/litre
28.5	3.233	5.08	244.0	179.2	2.648	1.01	193.8	.9331	1.900	63.6	1.57	.425	.354	42.4
29.0	3.524	5.36	254.7	174.6	2.625	.991	187.3	.9245	1.915	65.7	1.52	.421	.351	42.0
31.25	3.508	5.07	240.0	178.1	2.494	.998	173.3	.9213	2.073	69.3	1.44	.400	.333	40.0
33.25	4.002	5.22	245.3	169.8	2.561	.865	160.7	.9136	2.170	76.7	1.30	.411	.342	41.0
34.5	4.193	5.22	242.7	166.4	2.149	.833	153.4	.9039	2.227	80.3	1.25	.345	.287	34.4
37.0	4.625	5.20	236.0	157.3	1.946	.777	138.6	.8822	2.332	88.9	1.12	.312	.260	31.2
38.0	4.882	5.48	246.7	160.0	1.946	.757	138.4	.8748	2.374	89.1	1.12	.312	.260	31.2
39.5	4.983	5.54	245.3	162.1	1.933	.728	137.0	.8607	2.428	89.9	1.11	.310	.258	31.0
41.25	4.965	5.27	230.6	159.7	1.839	.697	130.8	.8509	2.507	94.2	1.06	.295	.246	29.5
42.5	5.116	5.21	225.3	156.0	1.759	.676	125.5	.8407	2.552	98.2	1.02	.282	.235	28.2

Material: A13003 H24 - .055 x .002

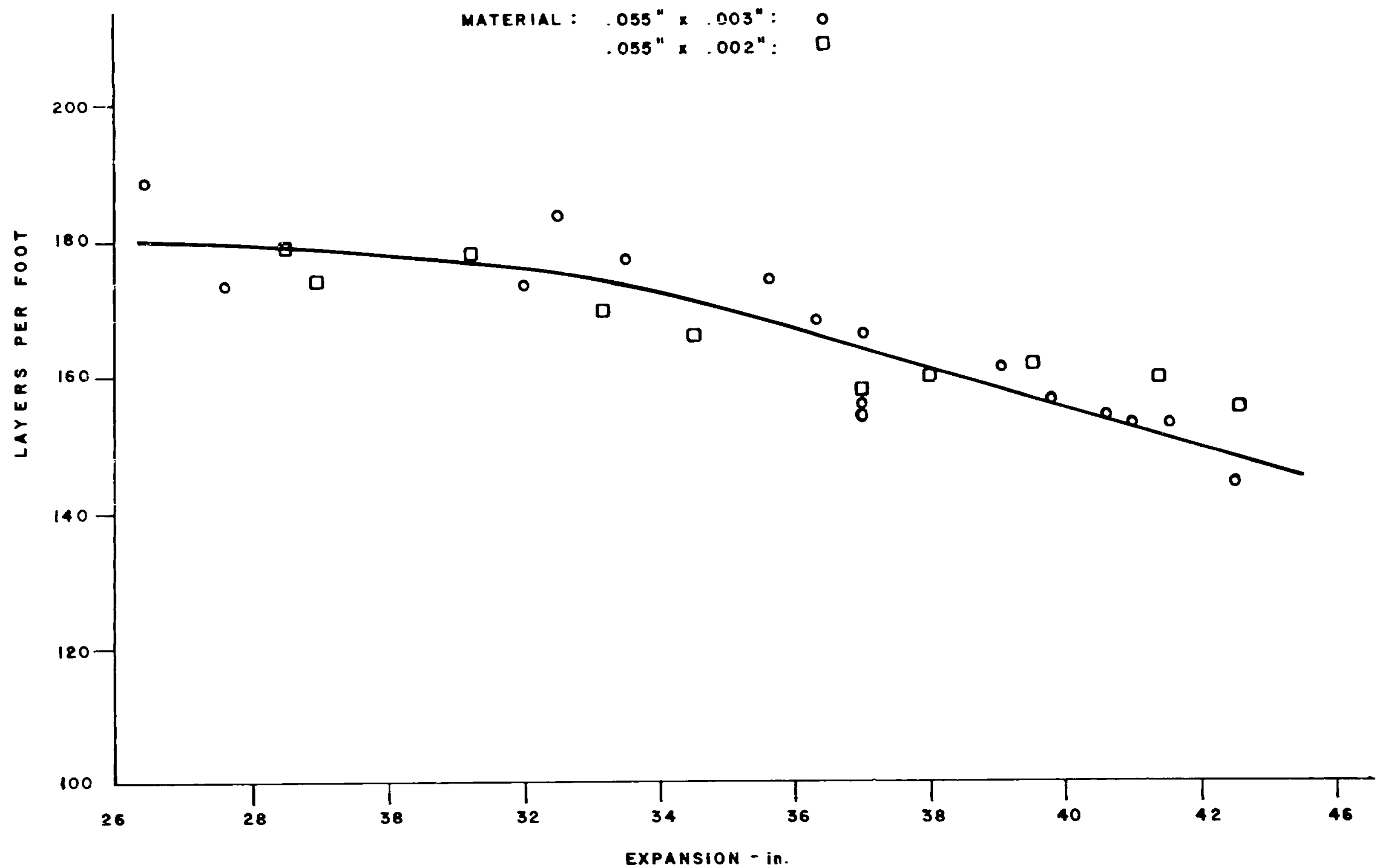

Figure B2-1. Effect of Expansion on Packing Density

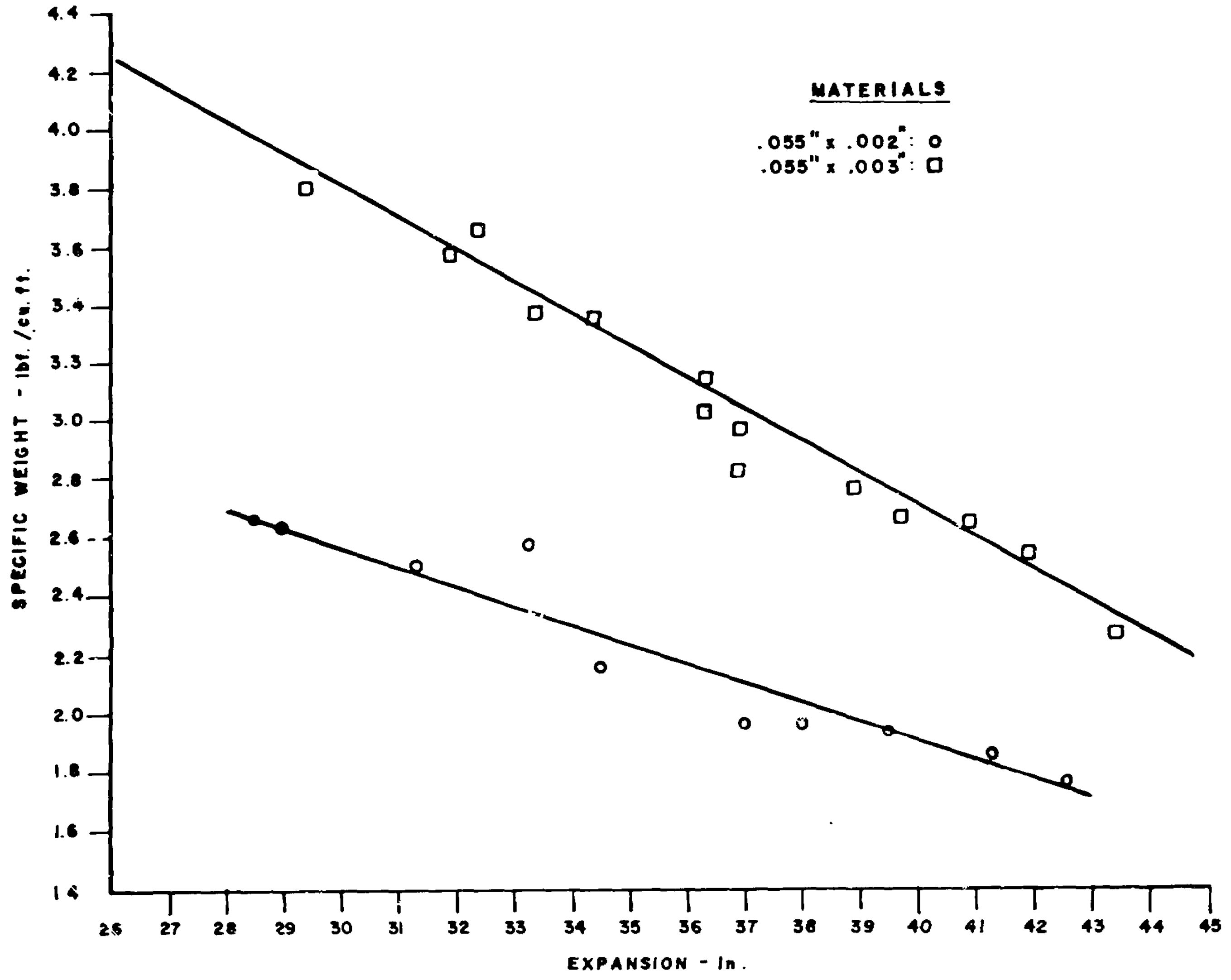

Figure B2-2. Effect of Expansion on Specific Weight

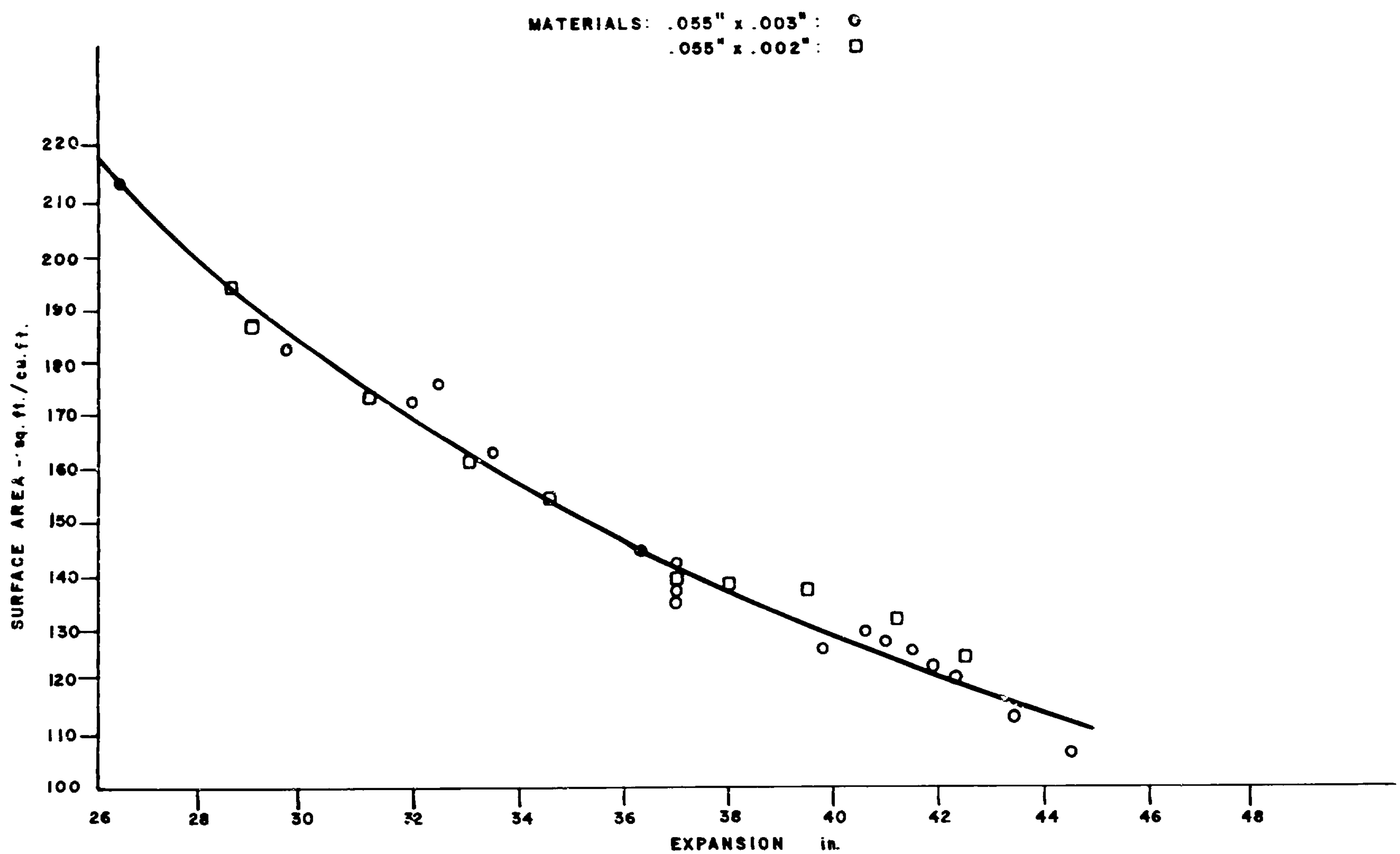

Figure B2-3. Effect of Expansion on Specific Surface Area

APPENDIX B 3

CONTAMINATION TEST DATA
FIELD FILL AND DRAIN METHOD

AEROSPACE FUELS LABORATORY TEST REPORT	Item To Be Tested MIL-T-83133 JP-8

Test Laboratory And Location

?CT 13, SAN ANTONIO ALC/S?QLA, WRIGHT-PATT AFB OH 45433

Sample Number	Date Sample Received	Date Sample Tested
SEE BELOW	24 Aug 1979	27 Aug 1979

Submitted By	Sample Marked
T.O. Reed ASD/ENFEF	SEE BELOW

Test Results

SUBMITTED IN ACCORDANCE WITH T.O. 42B1-1, para 5-23

SFQLA SAMPLE NUMBER	BASE SAMPLE NUMBER	SOURCE	TOTAL SOLIDS	FSII
79-F-1718	ASD-1	Defuel #1 (Full)	0.9 mg/qt	
79-F-1719	-2	Defuel #1 (Midway)	1.2 "	
79-F-1720	-3	Defuel #1 (Empty)	1.9 "	
79-F-1721	-4	Defuel #2 (Inlet)	1.0 "	
79-F-1722	-5	Defuel #2 (Full)	0.9 "	
79-F-1723	-6	Defuel #2 (Midway)	1.4 "	
79-F-1724	-7	Defuel #2 (Empty)	1.1 "	
79-F-1725	-8	Defuel #3 (Inlet)	0.6 "	
79-F-1726	-9	Defuel #3 (Full)	1.4 "	
79-F-1727	-10	Defuel #3 (Midway)	0.6 "	
79-F-1728	-11	Defuel #3 (Empty)	2.8 "	
79-F-1729	-12	Defuel #3 (After Sump Flush)	0.2 "	

NOTE. Samples were taken from an external fuel tank packed with explosafe metal mesh prior to slosh testing.

Remarks

Tested as per request.

Reviewed By		Approved By
JOHN H. YOUNT	30 Aug 79	THOMAS J. O'SHAUGHNESSY Chief, Aerospace Fuels Laboratory Directorate of Energy Management

APPENDIX B 4

DISPLACEMENT/RETENTION
LABORATORY TEST DATA

TABLE B4-1. DISPLACEMENT AND RETENTION LABORATORY TEST DATA

Run	Liquid Temp. (°F)	Foil Thick. (mil)	Exp. (in.)	Dry Weight (gm.)	Box Weight (gm.)	Total Tare Weight (gm.)	Dry Density (lb/ft^3)	Volume (cc.)	Wet Weight (gm.)	Fluid Retained (gm.)	Fluid Density (gm/cm^3)	Vol. Retained (%)	Average Flowrate (cm^3/min)	Displaced Fluid (ml.)	Vol. Displaced (%)
								Tested with Water							
8	70.7	2	32	135.0	9.1	144.1	2.49	3371.9	197.8	53.7	.9979	1.59	500	53	1.57
9	70.5	2	32	131.0	9.1	140.1	2.30	3557.4	189.2	49.1	.9979	1.38	500	52	1.46
10	71.6	2	34	126.7	9.1	135.8	2.28	3465.75	184.2	48.4	.9978	1.39	500	45	1.30
11	71.6	2	36.5	117.3	9.1	126.4	1.99	3675.8	163.8	37.4	.9978	1.02	500	38	1.03
12	70.5	2	40.5	106.2	9.1	115.3	1.92	3441.6	143.9	28.6	.9979	0.83	500	34	0.98
30	70	3	32	170.5	9.1	179.6	3.46	3081.4	231.8	52.2	.9980	1.69	500		
29	70	3	32	184.3	9.1	193.4	3.51	3274.86	245.8	52.4	.9980	1.60	500	61	1.86
28	70	3	34.5	164.8	9.1	173.9	3.20	3210.48	221.9	48.0	.9980	1.49	500	50	1.56
27	70	3	38	161.8	9.1	170.9	2.76	3645.6	215.3	44.4	.9980	1.22	500		
26	72	3	40	141.8	9.1	150.9	2.66	3326.3	188.7	37.8	.9378	1.13	500		
31	70	3	42	124.5	9.1	133.6	2.47	3150.0	164.3	30.7	.9980	0.98	500	42	1.33
								Tested with Jet A-1							
8	74	2	32	135.0	9.1	144.1	2.49	3371.9	175.5	31.4	.7989	1.16	500	54	1.60
9	74	2	32	131.0	9.1	140.1	2.30	3557.4	169.7	29.6	.7989	1.04	500	50	1.40
10		2	34	126.7	9.1	135.8	2.28	3465.75	165.3	29.5	.7989	1.06	500	46	1.32
11	69	2	36.5	117.3	9.1	126.4	1.99	3675.8	151.2	24.8	.7995	0.84	500	42	1.14
12		2	40.5	106.2	9.1	115.3	1.92	3441.6	133.3	18.	.7989	0.65	500	38	1.10
13A	74	3	32	203.9	9.1	213.0	3.55	3580.2	243.9	30.9	.7989	1.08	500	73	2.04
13B	71	3	32	199.3	9.1	208.4	3.54	3511.35	236.5	28.1	.7989	1.00	500	74	2.11
14		3	35.5	171.1	9.1	180.2	3.00	3556.3	203.4	23.2	.7989	0.82	500	65	1.83
15	70	3	38	154.1	9.1	163.2	2.77	3464.5	183.3	20.1	.7995	0.73	500	67	1.64
16		3	38	159.1	9.1	168.2	2.72	3533.4	189.2	21.0	.7995	0.74		58	1.64
17	70	3	42.5	141.6	9.1	150.7	2.55	3465.0	170.0	19.3	.7595	0.69	500	48	1.38
18	71	3	42.5	138.4	9.1	147.5	2.49	3464.8	164.4	16.9	.7995	0.61	500	50	1.44

APPENDIX B 5

ELECTRO-STATIC CHARGING TEST RESULTS
(EXXON RESEARCH AND ENGINEERING COMPANY)

TABLE B5-1. DRUM CHARGING/SPARKING TESTS - ALUMINUM MESH

Test Fuel: Jet A (Clay Treated) (Cu = 1.6 pS/m @ 2^0C)

Run No.	Element Set	Flow Rate $m^3/s \times 10^{-3}$	Fuel Charge (1) Density $\mu C/m^3$	Inlet Charge (2) Density $\mu C/m^3$	Drum Charge (2) Density $\mu C/m^3$	Field (3) Strength KV/m	Total No. Radio Disch. Signals	Remarks: Temp ^0C (4) A	Remarks: Temp ^0C (4) L
Test Inlet: High Velocity Ell									
Removed Explosafe from Drum - Empty Drum Runs for Comparison									
707	4	3.34	-329	-144	-135	-500	6 [5]	0	2
708	4	3.34	-240	-270	↑	-200	6	0.5	2
709	4	3.34	-240	-270	Inlet	-500	7	0.5	2
710	4	3.34	-	-	Touching	Splashing	5	0.5	2
711	4	1.89	-	-	Drum	-3.9	-	0.5	1.5
712	4	1.89	-	-	↓	-11	-	0.5	3
713	4	1.89	-317	-26	-260	-200	-	0.5	4
714	4	1.89	-260	-26	-260	-200	-	0.5	5
Conductivity Check = 1.72 @ 5^0C									
Installed Piccolo #3 (5 m/s velocity)									
715	4	3.66	-219	-49	-137	-150	2	0.5	-2.5
716	4	3.66	-164	-33	-109	-150	-	1	-2
717	4	3.78	-	+5.3	-13.2	-26	-	1	-1
718	4	3.78	-	+4.8	-10.6	-20	-	1.5	-0.5
Conductivity Check = 2.07 @ 0^0C									

(1) Fuel charge represents current density measured from the filter but of opposite polarity. Where the value is blank, the filter was bypassed.

(2) All current readings were made about 8 seconds after flow started.

(3) Field strength observed at about 90% full, when fuel reached the top of the aluminum mesh. The field meter used for this study was limited in the maximum value it could sense (500 KV/m) Thus, a reading of 500 KV/m could indicate that the field strength was 500 KV/m or more.

(4) A = ambient temperature; L = liquid (fuel) temperature.

(5) Aluminum chips which broke off from the main mesh body were left behind upon removal. These acted as unbonded charge collectors floating in the tank.

TABLE B5-2. DRUM CHARGING/SPARKING TESTS - ALUMINUM MESH

Test Fuel: Jet A (Clay Treated) (Cu = .98 pS/m @ -1^0C)

Run No.	Element Set	Flow Rate $m^3/s \times 10^{-3}$	Fuel Charge (1) Density $\mu C/m^3$	Inlet Charge (2) Density $\mu C/m^3$	Drum Charge (2) Density $\mu C/m^3$	Field (3) Strength KV/m	Total No. Radio Disch. Signals	Remarks Temp ^0C(4) A	L
Test Inlet: Piccolo #3 (4.8 m/s velocity)									
700	4	3.66	-410	-410	-	-6	-	-2	-1
Conductivity Check = 1.84 @ -1^0C									
701	4	3.66	-301	-328	-	-20	-	-1.5	-0.5
702	4	3.78	-	-16	-	-5	-	-1.5	-0.5
Removed Piccolo Inlet - Installed High Velocity Ell									
703	4	3.34	-359	-359	-	-130	-	-0.5	0
704	4	3.34	-270	-270	-	-200	-	-0.5	+0.5
705	4	3.34	-239	-270	-	-200	-	0	+1.5
706	4	3.34	-	-18	-	-180	-	0	+1.5
Conductivity Check = 1.6 @ 2^0C									

(1) Fuel charge represents current density measured from the filter but of opposite polarity. Where the value is blank, the filter was bypassed.
(2) All current readings were made about 8 seconds after flow started.
(3) Field strength observed at about 90% full, when fuel reached the top of the aluminum mesh.
(4) A = ambient temperature; L = liquid (fuel) temperature.

APPENDIX C 1

STATIC LOADING TESTS

Static Loading Test Rig and Procedure

The test rig is depicted in Figure C1-1. It consists of a steel table on which are mounted two vertical steel columns forming the supports for a channel section crossbeam. A pneumatic cylinder is mounted to the crossbeam with its piston rod travelling through a clearance hole therein. This cylinder has a 2½-inch diameter piston and a maximum stroke of 6 inches. Attached to the end of the 5/8-inch diameter piston rod on the underside of the crossbeam is a 10 inch square, one inch thick particle board loading plate which transforms the concentrated load of the piston rod into a uniformly distributed load over an area of 100 square inches. The pneumatic cylinder is driven by air fed through a pressure regulator and directed by a lever-operated three way valve. Rate of travel of the piston in both directions is controlled by adjustable mufflers in the valve exhaust ports. Cylinder pressure is monitored by a calibration standard 0-200 psig bronze movement Bourdon pressure gauge with 1½% F.S. accuracy.

The test specimen is contained in an open top wooden box having inside dimensions of 10 inches square by 8 inches high with smooth sidewalls to minimize specimen/box friction. The loading plate is a close sliding fit inside the box. In the side of the box closest to the operation is a 1-inch wide observation slot through which can be seen a scale set flush into the inside surface of the opposite side. The scale is used to measure the specimen deformation under the selected load. Procedure is as follows:

a) Check that the cylinder is depressurized and the valve lever is in the retract position.

b) With the specimen inside, place the box on the table directly below and aligned with the retracted loading plate. Note the scale reading corresponding to the upper surface of the specimen.

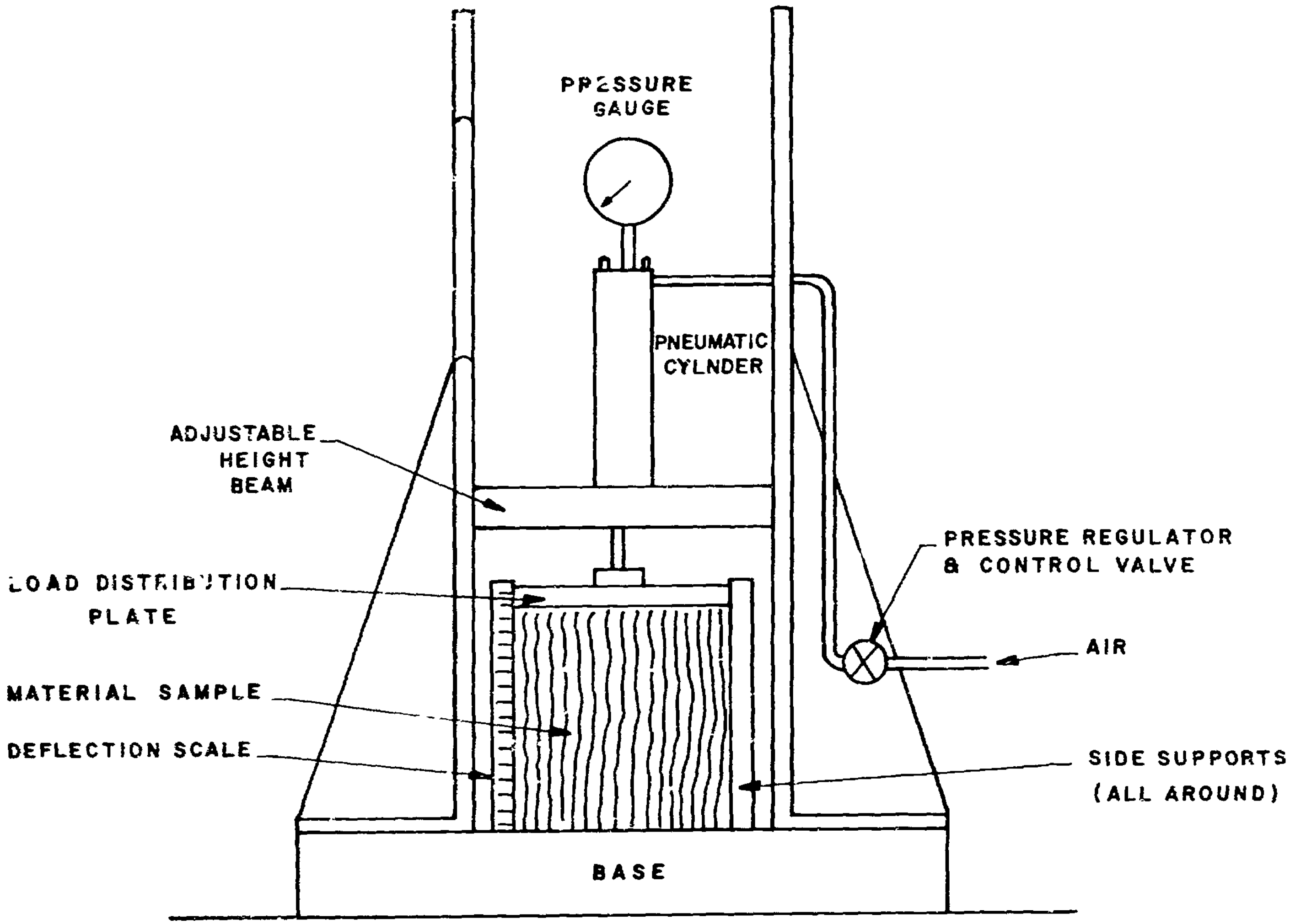

Figure C1-1. Static Loading Test Rig

c) Set the valve lever to the "piston extended position" and with the mufflers set to give extremely slow piston travel open the air supply valve until a pressure of 2 psig registers on the Bourdon gauge.

d) When the piston has come to a complete stop note the scale reading corresponding to the top of the loading plate. Subtract one inch to account for the loading plate thickness.

e) Increase the cylinder pressure by a small amount not exceeding 5 psig, repeat (d) noting cylinder pressure.

f) Continue repeating (e) until a maximum cylinder pressure of 78 psig is attained.

g) Retract the piston and after the specimen has ceased moving note the scale measurement corresponding to the top of the specimen. This records "the spring back" of the material.

APPENDIX C 2

PREPARATION OF 200 GALLON PYLON TANK
FOR SLOSH TEST NO. 1

Introduction

A 200 gallon external pylon tank was specifically prepared to observe the slosh reduction characteristics of the Explosafe explosion suppression material, and to evaluate the influence of Explosafe, under dynamic slosh conditions, on untreated aluminum tank wall surfaces and on typical sealant and corrosion prevention fuel tank coatings.

General Description of Preparations

The tank was fitted with 3-inch diameter plexiglas observation windows to facilitate the documentation of foil movement and to photographically record the slosh-reduction characteristics of the foil.

Certain internal areas of the tank were coated in accordance with USAF T.O. 1-1-3 guidelines with:

a) Specification MIL-C-27725 topcoating, which is a two part, translucent, polyurethane material which provides a corrosion preventive coating in integral tank interiors. The maximum thickness of the coating is 1.2 mils.

b) Specification MIL-S-8802, Class B sealant, which is a synthetic rubber based material generally used for prepack, injection, filleting and faying surface seals.

Locations of Observation Windows

A total of ten observation windows were installed in the midsection of the tank as follows:

A set of three windows arranged vertically and a set of four windows arranged horizontally were installed on the port side of the midsection (Figures C2-1, C2-2, C2-3). Two windows were set side by side on the starboard side (Figure C2-4 and C2-5) and one window was placed on the fwd top side of the mid-section (Figure C2-6 and C2-7).

Preparation of Nose Cone

The entire starboard half portion of the nose cone, extending from the mouth to the tip of the cone, was coated internally with specification MIL-C-27725 corrosion preventive paint.

A patch of specification MIL-S-8802, Class B sealant, measuring 6 x 6 inches and approximately 1/16 inch thick, was applied on the bottom of the nose cone, near its mouth (Figure C2-8).

Preparation of Midsection

The entire starboard half portion of the midsection was coated internally with the specified corrosion preventive paint.

A patch of sealant, measuring 6 x 6 inches and approximately 1/16 inch thick, was applied on the bottom of the midsection near its fwd end (Figure C2-9).

Another patch of sealant, 1/16 inch thick, was applied on the aft baffle of the midsection, covering the bolts holding the baffle (Figure C2-10). The approximate dimensions of this patch were 11 inches at the top edge, 7½ inches at the bottom edge and 3½ inches in width.

Preparation of Tail Cone

The entire starboard half portion of the tail cone, extending from the mouth to the tip of the cone, was coated internally with the corrosion preventive paint.

A patch of sealant, measuring 6 x 6 inches and approximately 1/16 inch thick, was applied on the bottom of the tail cone, near its mouth (Figure C2-11).

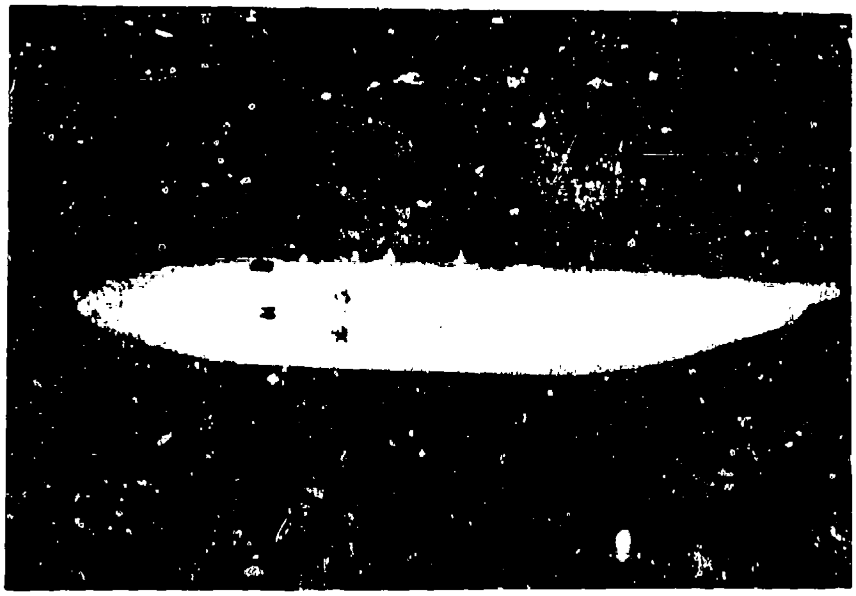

Figure C2-1. Observation Window Arrangement on Port Side

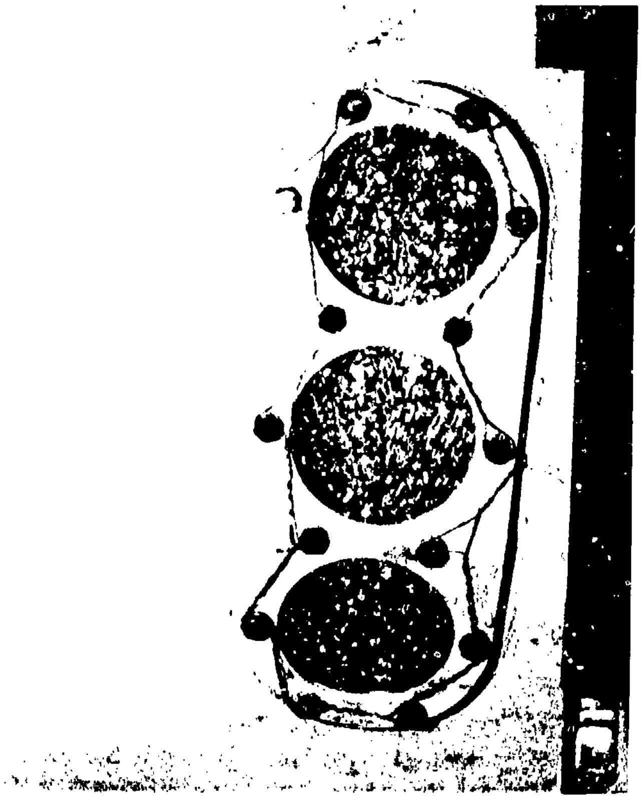

Figure C2-2. Close-Up of Vertical Window Arrangement on Port Side

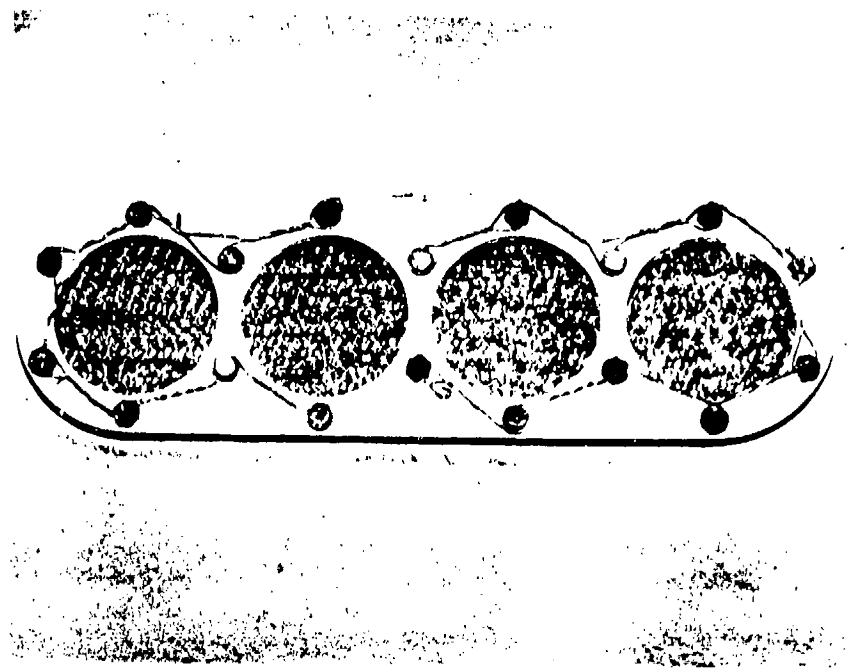

Figure C2-3. Close-Up of Horizontal Window Arrangement on Port Side

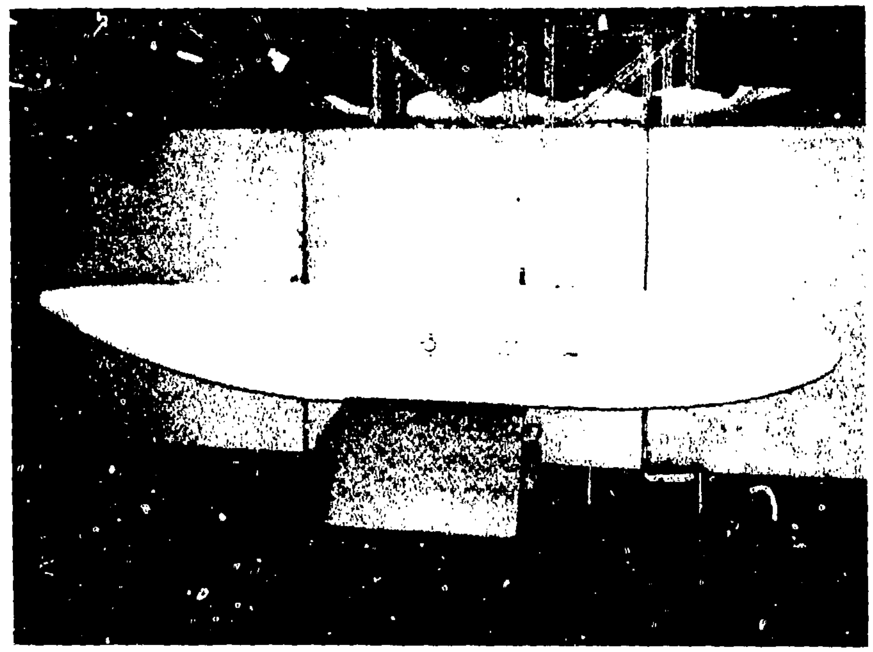

Figure C2-4. Observation Window Arrangement on Starboard Side

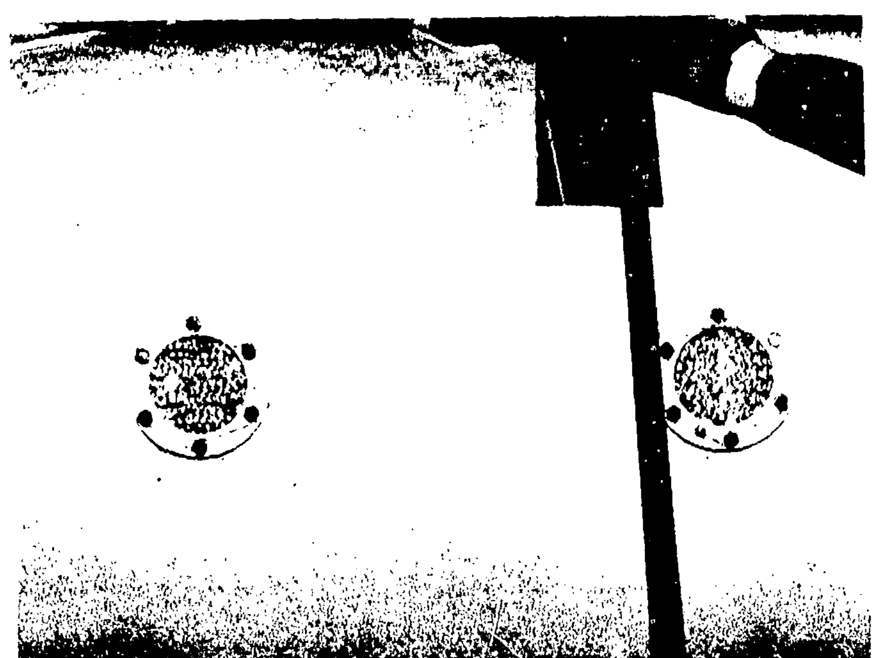

Figure C2-5. Close-Up of Window Arrangement on Starboard Side

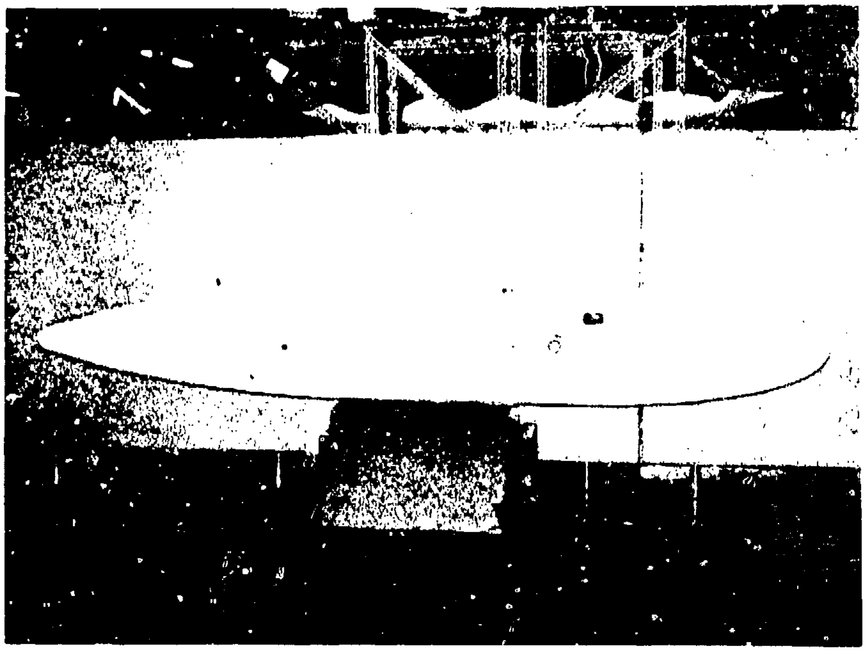

Figure C2-6. Observation Window on Top Side

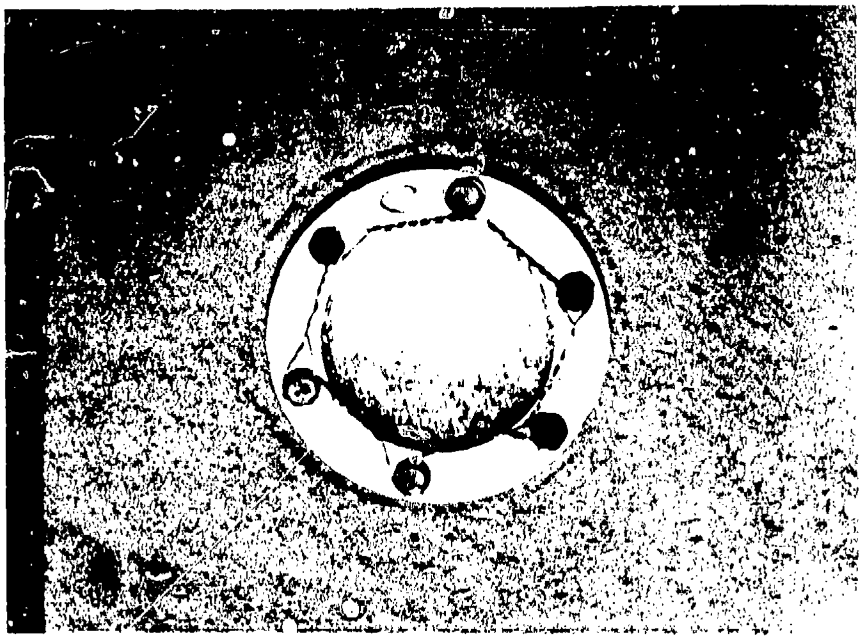

Figure C2-7. Close-Up of Window on Top Side

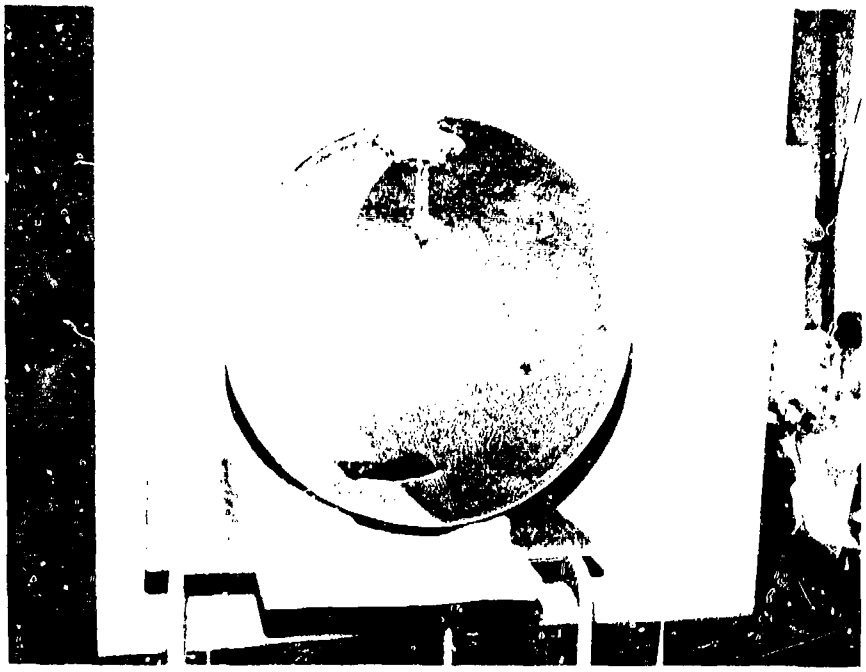

Figure C2-8. Nose Cone: Location of Paint and Sealant Patch

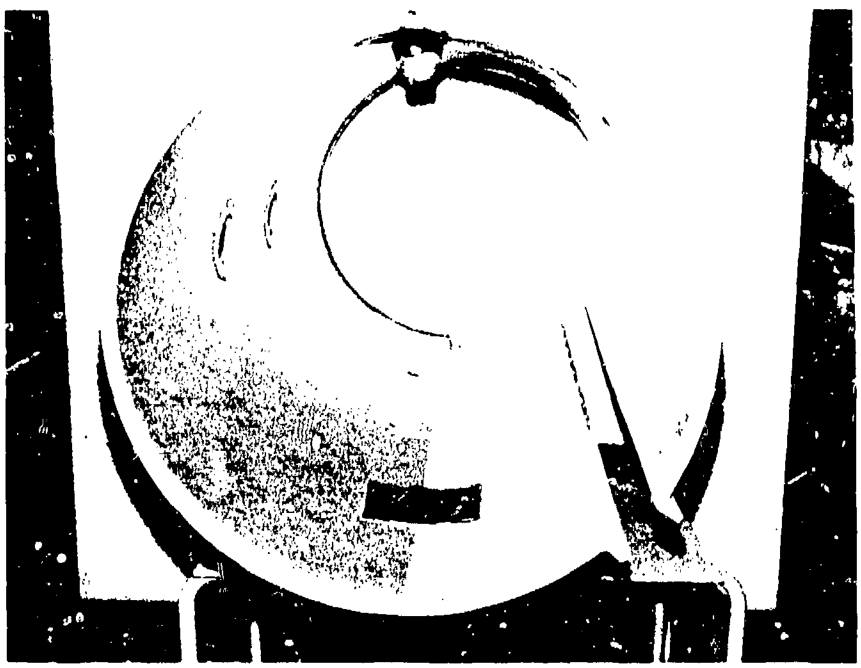

Figure C2-9. Midsection: Location of Paint and Sealant Patch

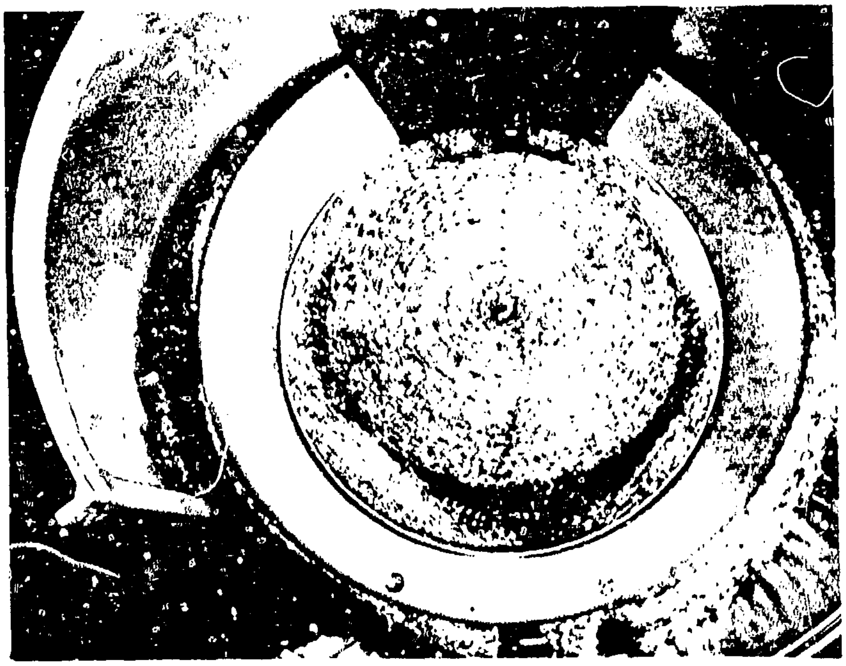

Figure C2-10. Location of Sealant Patch on Aft Baffle

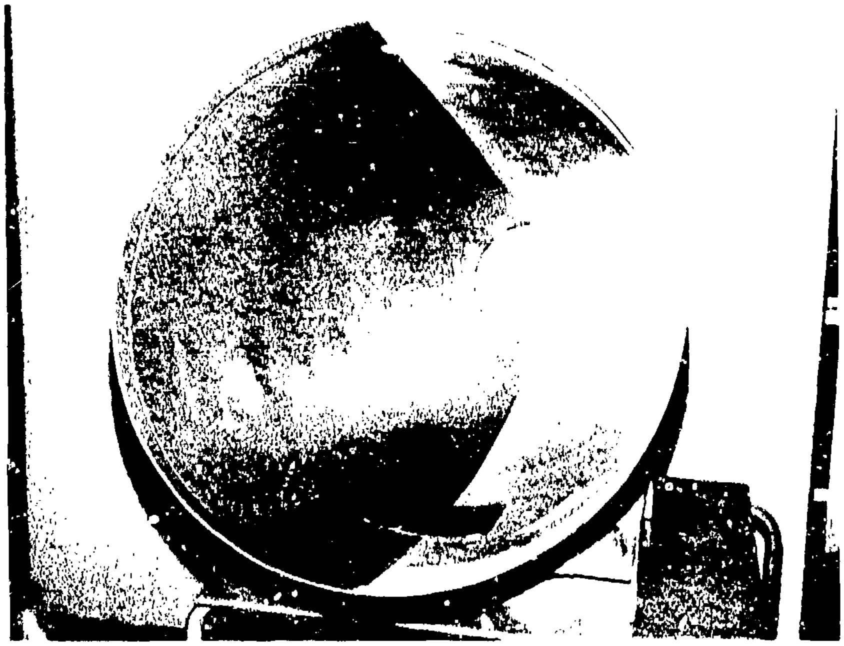

Figure C2-11. Tail Cone: Location of Paint and Sealant Patch

APPENDIX C 3

PREPARATION OF 200 GALLON PYLON TANK FOR SLOSH TEST NO. 2

Introduction

A 200 gallon external pylon tank was specifically prepared to evaluate the influence of the Explosafe explosion suppression material, under dynamic slosh conditions, on typical sealant and corrosion prevention fuel tank coatings.

Guidelines for Preparing Tank

Certain internal areas of the tank were coated in accordance with USAF T.O. 1-1-3 guidelines with:

a) Specification MIL-C-27725 topcoating, which is a two part, translucent, polyurethane material which provides a corrosion preventive coating in integral tank interiors. The maximum thickness of the coating is 1.2 mils.

b) Specification MIL-S-8802, Class A sealant, which is a synthetic rubber based material generally applied as a precoating around fasteners.

   Two types of structural fasteners were supplied by USAF for installation on the inside surface of the tank.

   These fasteners, when coated with MIL-S-8802, Class A sealant, were to simulate uneven sealant surface conditions for evaluation of Explosafe caused wear.

   The fasteners supplied were:

   (i) Deutsch self-sealing type floating dome nuts (PN SFNL 6010-10-B) having BUNA-N sealing gaskets.

   These were installed with the dome and sealing surfaces on the inside of the tank.

The domes were cleaned with MIL-C-38736 cleaner and overcoated with a brush coat of Class A sealant after installation. The applied sealant thickness was 0.01 in. minimum and spread a minimum of 0.5 in. in all directions around the fasteners.

(ii) HI-SHEAR (HL 374-18) Hi Lok sealing collars and pins, having teflon sealing inserts.

The pins provided required the use of about 0.30 in. shims for proper installation and torquing. The sealing collars were installed on the inside wall of the tank with the pins inserted from the outside. The collars were cleaned with MIL-C-38736 cleaner and overcoated with a brush coat of Class A sealant according to guidelines described for coating Deutsch dome nuts.

(iii) Specification MIL-S-8802, Class B sealant, which is also synthetic rubber based and used for pre-pack, injection, filleting and faying surface seals. For the purpose of this test, however, the sealant was applied over selected areas in the nose cone to act as anchors for the Explosafe batts. The intent was to prevent reorientation and excessive movement of the foil, thereby limiting abrasion to the paint.

Location of fasteners, sealant, and corrosion prevention coating for the nose cone, midsection, and tail cone of the tank are detailed below.

Preparation of Nose Cone

The entire starboard half portion of the nose cone, extending from the mouth to the tip of the cone, was coated internally with specification MIL-C-27725 corrosion preventive paint (Figure C3-1).

Four strips of MIL-S-8802, Class B sealant measuring 2 in. wide by 12 in. deep and approximately 0.06 in. thick were applied at a uniform distance of 6 inches from the mouth of the cone and located equidistant from one another on the top, bottom, port and starboard sides (Figures C3-1 and C3-2). The sealant strips were intended to act as anchors for batts A5 and A6 (see Explosafe Installation Study - Appendix D3 for batt details).

Figure C3-3 shows batt A5 in place. The diamond orientation of the foil is highlighted with the aid of a sheet of card paper inserted between the first two layers of foil.

Preparation of Midsection

Two bands of MIL-C-27725 corrosion preventive coating, each about 6 inches wide and 6 inches apart, were painted on the port half of the midsection at its fwd end.

At the aft edge of the first band, and continuing around the entire circumference of the midsection, Deutsch and Hi Lok fasteners were attached alternately about 5.5 inches apart. A total of 7 Deutsch and 6 Hi Lok fasteners were installed in this fashion.

A band of MIL-S-8802, Class A sealant approximately 1.75 inch wide and 0.01 inch thick was brush coated over the fasteners (see Figure C3-4 and C3-5).

Another band of MIL-C-27725 corrosion preventive coating, 18 inches wide, was painted on the port half of the midsection at its fwd end (Figure C3-6).

Preparation of Tail Cone

A band of MIL-C-27725 corrosion preventive coating, 18 inches wide, was painted on the starboard half of the tail cone at its mouth.

A grid of 9 fasteners (7 Deutsch, 2 Hi Lok) was attached three across and three deep on the bottom of the tail cone near its mouth. Each fastener was placed 4 inches apart from its neighboring fastener. The two Hi Lok fasteners were attached nearest to the mouth of the tail cone on either side of the forward Deutsch fastener.

A brush coating of MIL-S-8802, Class A sealant, covering a 10 inch by 10 inch area, was applied over the fasteners (see Figures C3-7 and C3-8).

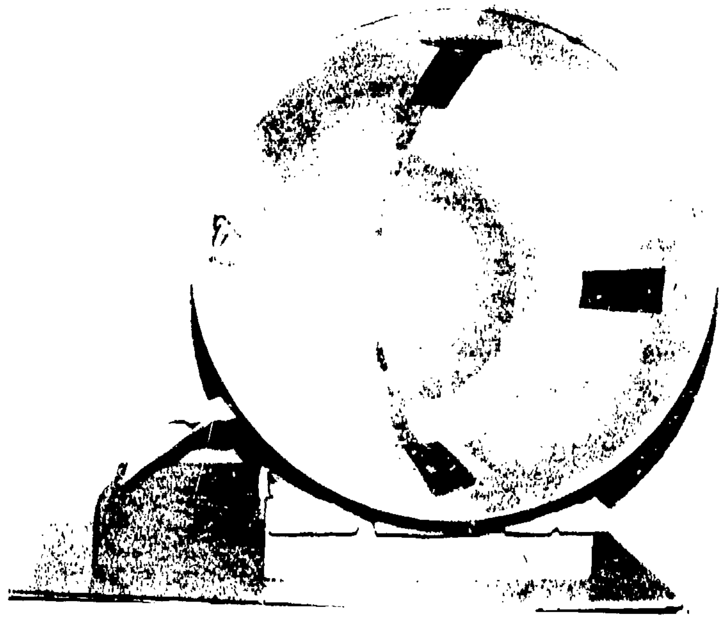

Figure C3-1. Nose Cone: Location of Paint and Sealant B Strips

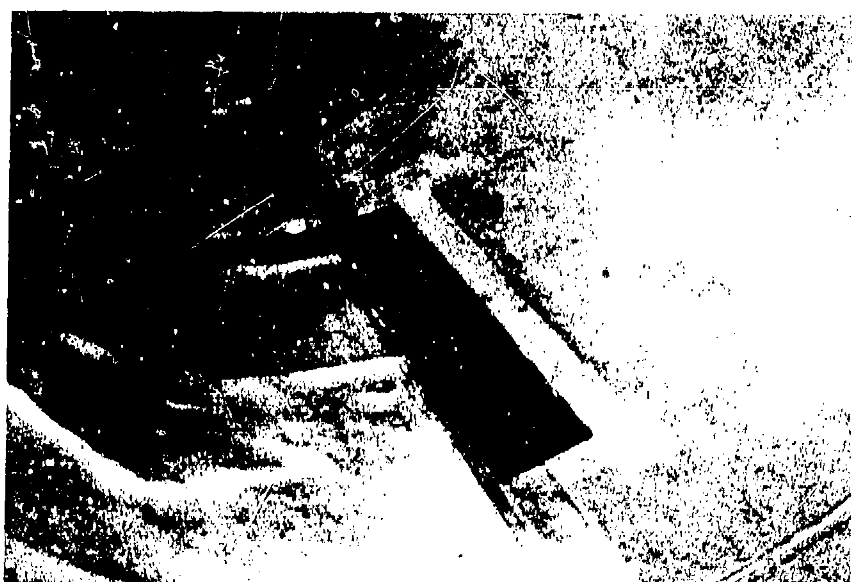

Figure C3-2. Nose Cone: Close-Up of Sealant Strip

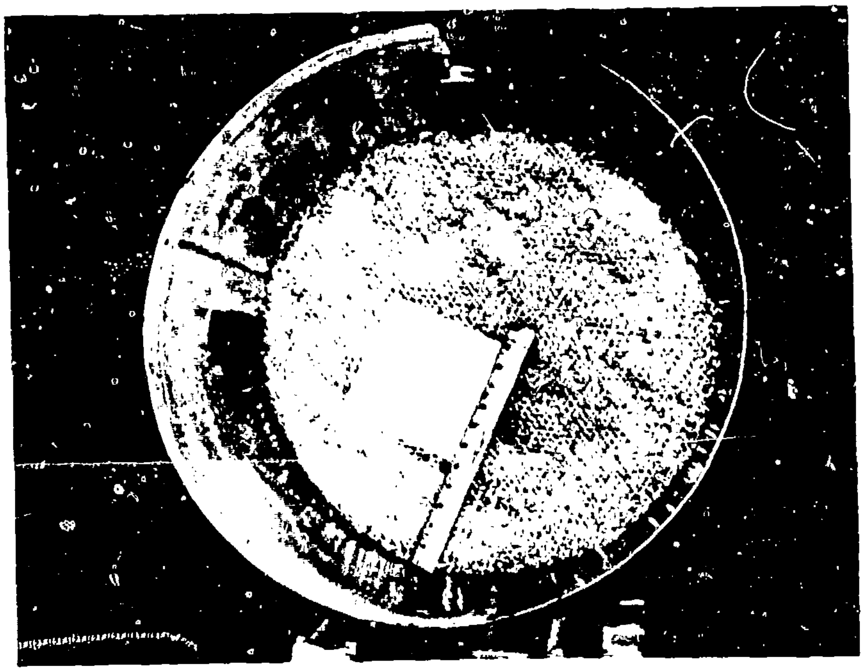

Figure C3-3. Nose Cone: Batt A5 in Place

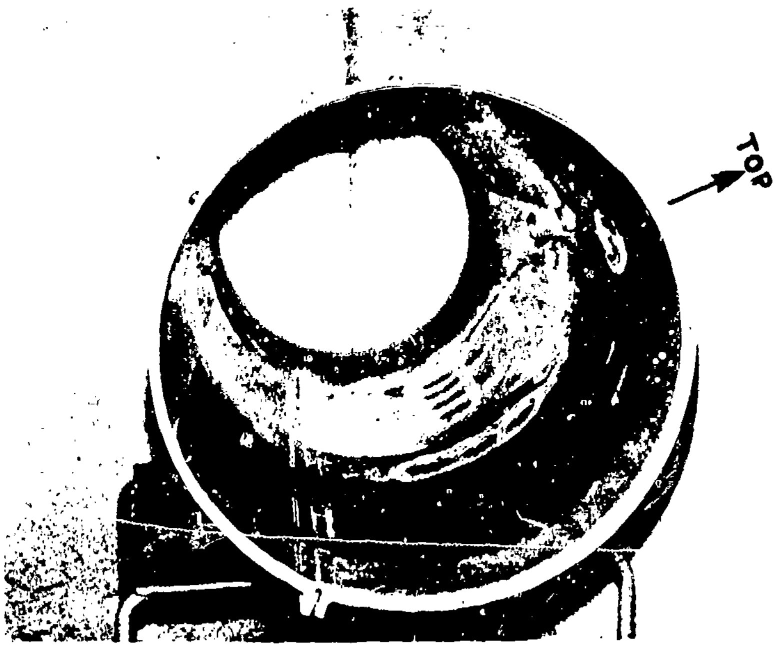

Figure C3-4. Midsection: Paint, Fastener and Sealant A Location at Fwd End

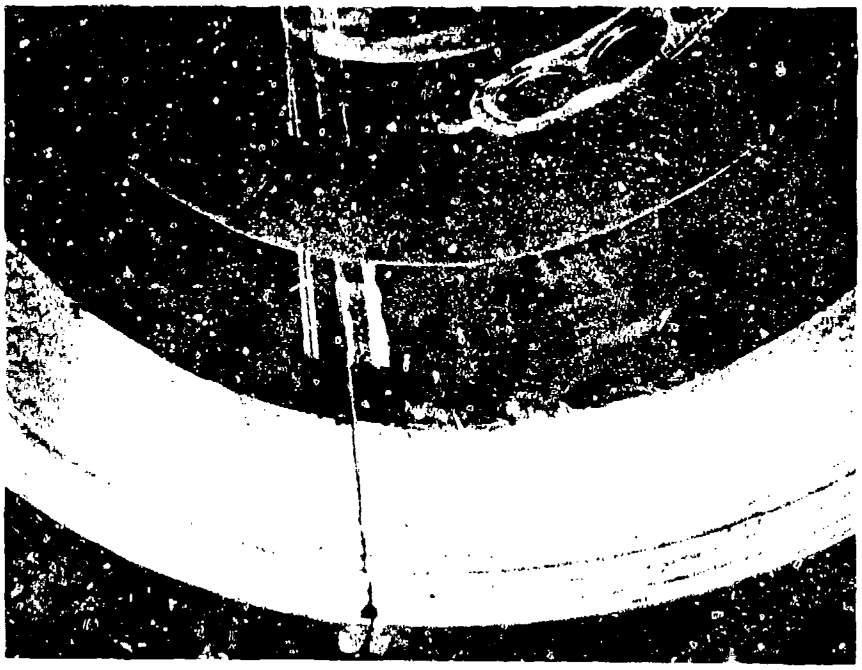

Figure C3-5. Midsection: Detail of Paint Bands, Fasteners and Sealant A Overcoating at Fwd End

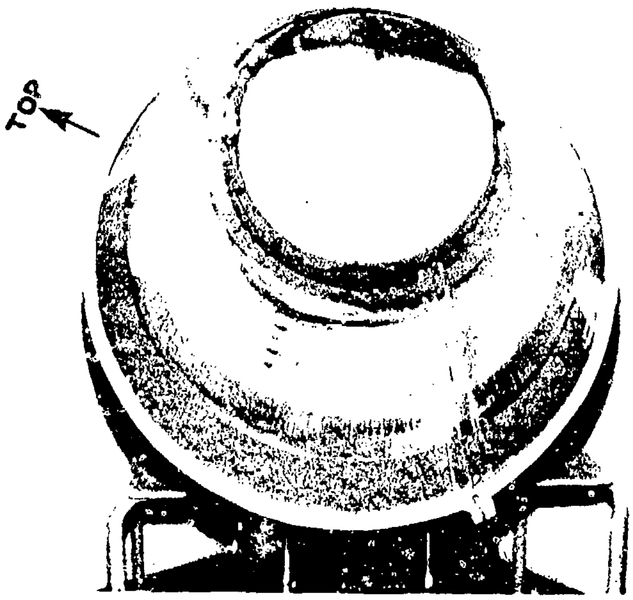

Figure C3-6. Midsection: Paint Band at Aft End

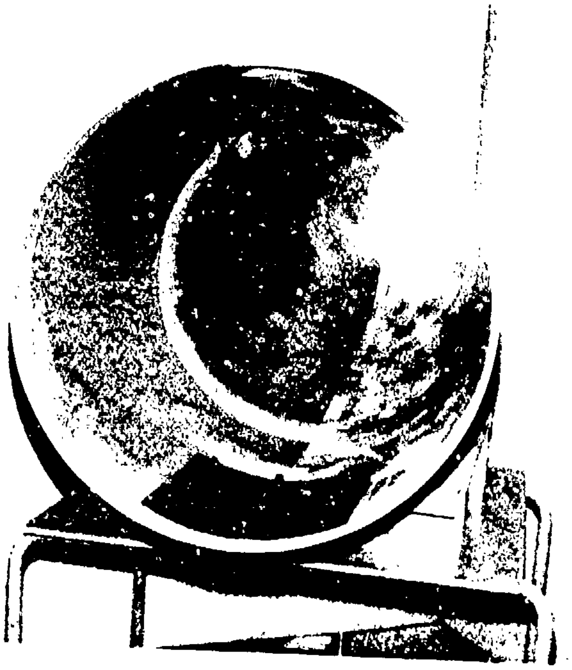

Figure C3-7. Tail Cone: Paint Band, Fastener and Sealant A Locations

Figure C3-8. Tail Cone: Detail of Fasteners and Sealant A Overcoating

APPENDIX C 4

VIBRATION TEST OF EXPLOSAFE
(PRODUCT ASSESSMENT LABORATORIES)

TRUE COPY

PRODUCT ASSESSMENT LABORATORIES

PLESSEY COMPONENTS LIMITED, TITCHFIELD, HAMPSHIRE

DQAB Part III Approval No. 30778
CAA Approval No. A1/7480/65
BS9000 Approval 3013/T
BCS Approval No. 0078

REPORT ON

VIBRATION TESTS OF EXPLOSAFE CFAM FILLINGS

May 1977

CONTENTS

DISTRIBUTION

APPROVED: Sd. A.M. Matthews
Manager

Mr. K.C. Fryer
Expamet Explosafe Limited
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London SW1H 0RA 10 copies

File 2 copies

Report No. 171499

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STATUS

1.	MANUFACTURING DESCRIPTION	Explosafe Fillings.
2.	OBJECTIVE OF TEST	To determine whether defined vibration levels affect Explosafe fillings and tank linings or produce any dangerous debris.
3.	MANUFACTURER	Expamet Industrial Products Limited.
4.	MANUFACTURER'S TYPE OR MODEL NUMBER	Canadian Folded Aluminium Mesh (CFAM).
5.	SERIAL NUMBER	-
6.	DRAWING NUMBER	-
	ISSUE	
	DATE	
7.	SPECIFICATION NUMBER	As instructed by Customer.
	ISSUE	
	DATE	
8.	QUANTITY OF ITEMS TESTED	One pack.
9.	SECURITY CLASSIFICATION OF ITEMS	Unclassified.
10.	INCOMING RELEASE	Not released.
	DATE	-
11.	DISPOSAL	Returned to Customer.
	REFERENCE	
	DATE	23.3.77
12.	ORDER NUMBER	G4080
	DATE	13th May 1977.
13.	START OF TEST	March 1977.
	FINISH OF TEST	March 1977.

BRIEF SUMMARY OF RESULTS

Test Clause No.	DESCRIPTION	RESULTS
1	RAE Aluminium Tank with cabin sealant, and aircraft epoxy primer paint linings. (Filled with one pack of Canadian Folded Aluminium Mesh.)	Very slight damage to tank liners and mesh. No debris. Slight contamination of filters.

Gravimetric analysis, particle totals and physical aspects of detectable solids on filters performed by:

Thermal Control Company Limited
Filtration Laboratories
Brighton.

Their results are presented in the Appendix to this report.

OBSERVATIONS

A considerable degree of success is considered to have been achieved in this experiment. There were no tag-ends broken away from the mesh and no other debris in the tank at the conclusion of any of the three test periods. Levels of contamination were approximately 1mg after 25Hz period, 3mg after the 100Hz period and 0.5mg after the final period.

There were slight scratch marks apparent on the tank walls, mainly caused by insertion and removal of the CFAM pack after each 24 hour period. There were also smear deposits of aluminium oxide on the walls.

At the completion of 3 x 24 hour vibration periods the pack was opened for detailed examination. One area of mesh was torn and some folds were distorted, both could have occurred during handling and folding in the manufacturing process.

TABLE C4-1. EQUIPMENT USED FOR VIBRATION TEST

Instrument	Maker	Type	TD. No.	Uncertainty	Last Calibration		Remarks
					Authority	Date	
Vibrator	Derritron	VP100		±10% (shared by Vibrator, Vibrator Controller, Accelerometer, Conditioning Amplifier)	PAL	Mar.77	Calibrated before use with Foepel triangle.
Vibrator Controller	Bruel and Kjaer	1019	PA1079C		PAL	25.11.76	
Accelerometer	Environmental	AQ40			PAL		
Conditioning Amplifier	Bruel and Kjaer	2626	12941/4		PAL	15.2.77	
Flushing Rig	Thermal Control Limited	-	-	-	-	-	Using fuel AVTUR DERD 2453 + FS11. Cleanliness standard measured by Thermal Control Company Filtration Laboratories.

TEST CONFIGURATION

(1) Vibration Jig:

Jig proven to be resonance free at the frequencies of interest.

Figure C4-1. RAE Aluminium Tank in Vibration Jig

(2) Filter Rig:

Field Filter monitors used in 'S' for preparation work. (Measurements and observation at PAL.) Tare filter monitor to be used for absolute measurements. (Measurements and observations at Thermal Controls Limited.)

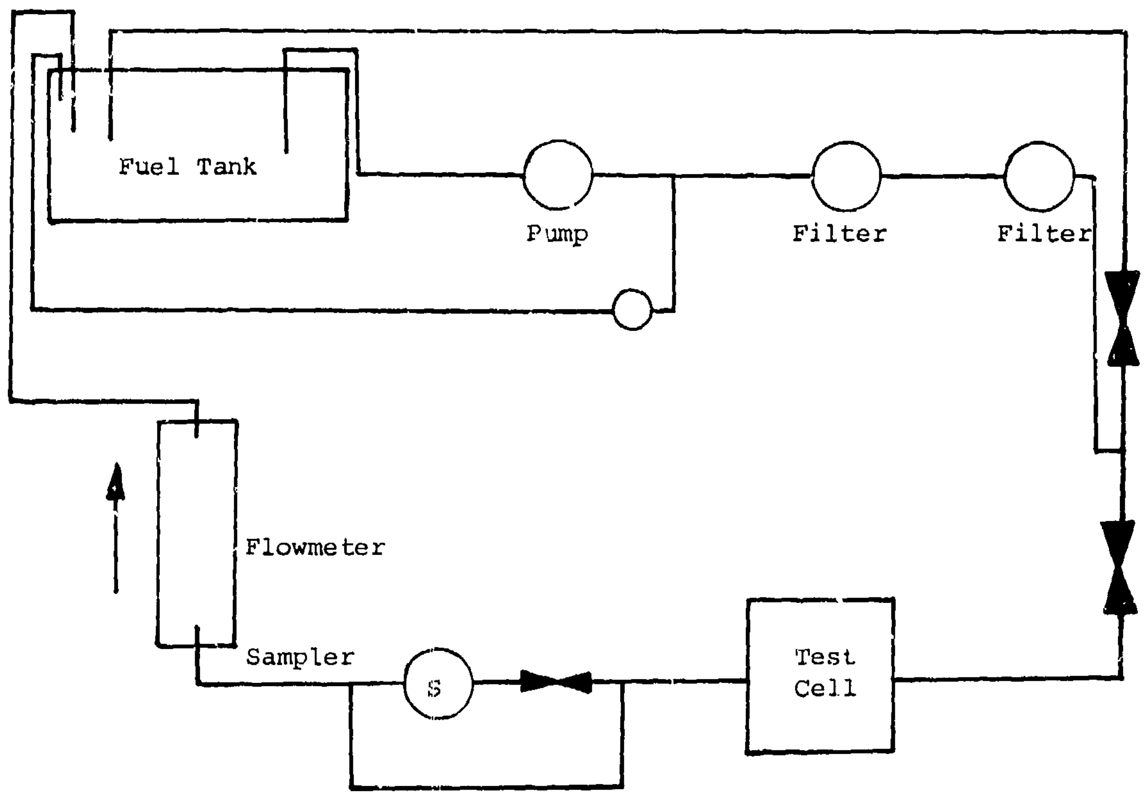


Figure C4-2. Test Rig Schematic Diagram

Supplied by Thermal
Controls Limited, Brighton
(Ref. TW56007)

TABLE C4-2. VIBRATION TEST SCHEDULE AND RESULTS

Product Test Spec. Clause	Test Description	Test Conditions	Method Spec. Clause	Result
1	RAE fabricated Aluminium Tank treated with cabin sealant materials as wall liners. CFAM mesh. Sealants: 1732 / 1733 + FR1720 Black 1422 BT2 - Brown Epoxy Primer - Yellow	Vibration for 24 hours in each of three conditions: 25Hz at ±0.03 ins. (±2g) 100Hz at ±0.0065 ins. (±7g) 500Hz at ±0.0008 ins. (±20g) Measure contamination levels and inspect for damage prior to and after each condition. Flow rate of flushing system to be nominal 2 litres/min. Flush continuously until fuel has circulated twice.	Customer instructions	No positive damage to mesh observed. No tag-ends present at conclusion of each of the three 24 hour periods. Tare filter samples taken prior to first and third periods and after each period. Prior to 24 hours at 25Hz. Ref. CAN 3, Ref. CAN 4. After 24 hours at 25Hz. Ref. CAN 5. After 24 hours at 100Hz. Ref. CAN 6. Prior to 24 hours at 500Hz. Ref. CAN 7. After 24 hours at 500Hz. Ref. CAN 8. Contamination level satisfactory Full characteristics shown in Appendix. Slight markings of the tank walls and some aluminium oxide deposits. See photographs 1 to 4 for comparisons before and after. Final visual inspection (first time the pack of CFAM was unfolded for inspection) showed one slight tear in material. (See photo 5). Typical sharp crease distortion shown in photo 6.

RECORD PHOTOGRAPHS

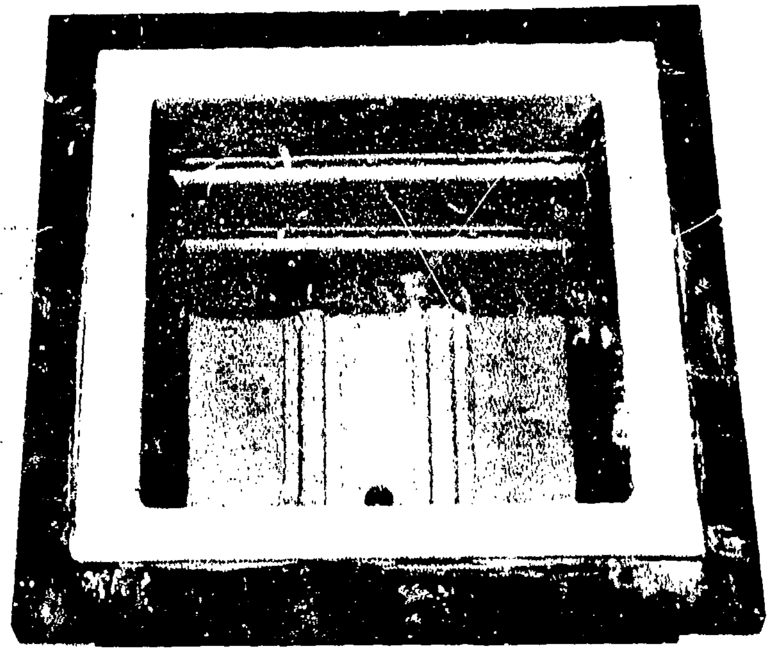


Figure C4-3. Photograph 1: Interior of Test Tank showing Lining of Aircraft Epoxy Primer Paint (Before Tests)

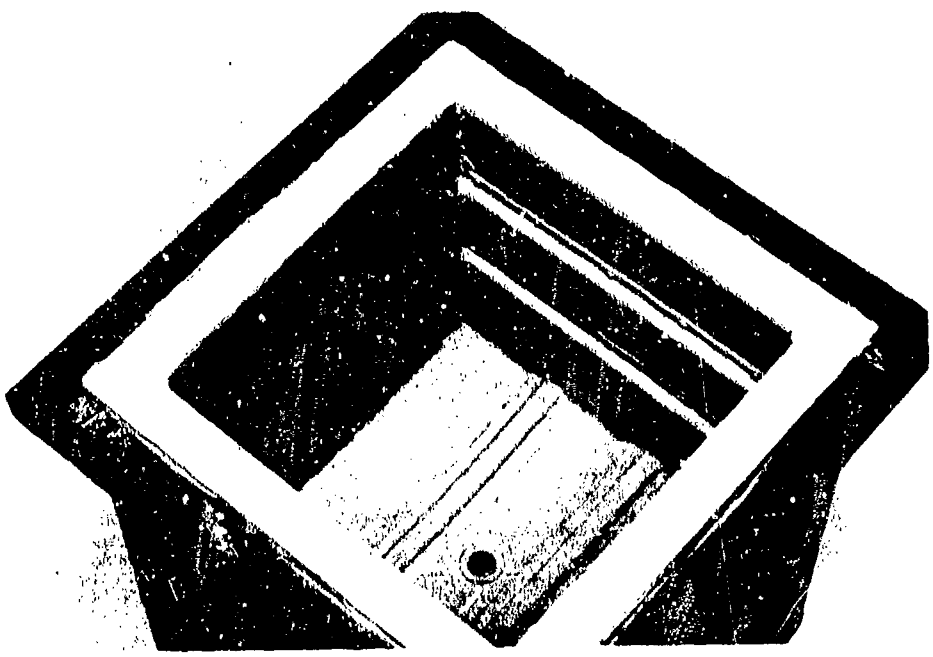


Figure C4-4. Photograph 2: Interior of Test Tank Showing Lining of Cabin Sealant (Before Tests)

RECORD PHOTOGRAPHS (continued)

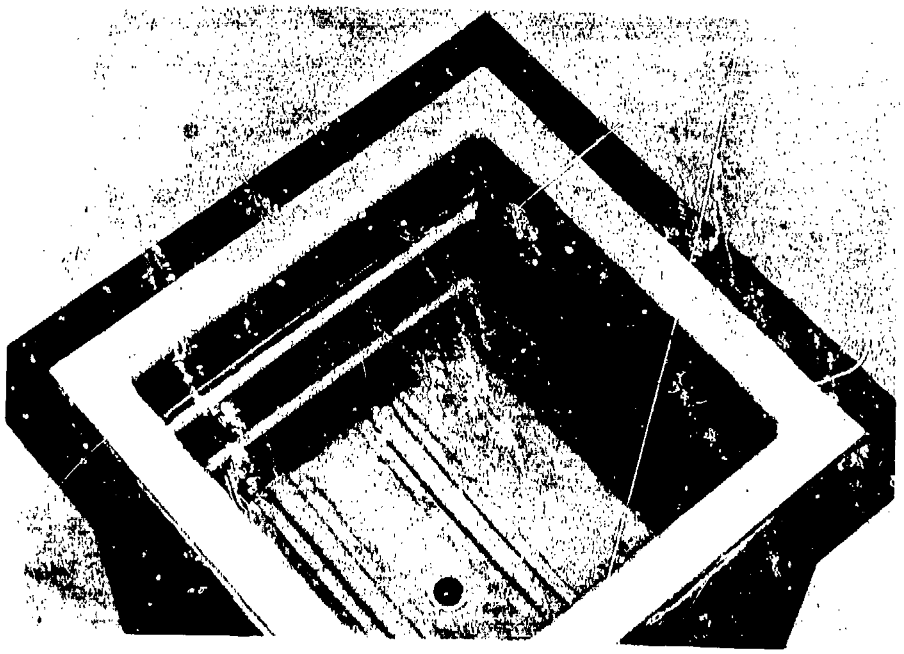


Figure C4-5. Photograph 3: Interior of Test Tanks showing Lining of Cabin Sealant (Before Tests)

Figure C4-6. Photograph 4: Interior of Test Tank showing Scratch Marks on Primer Paint Lining (After Tests)

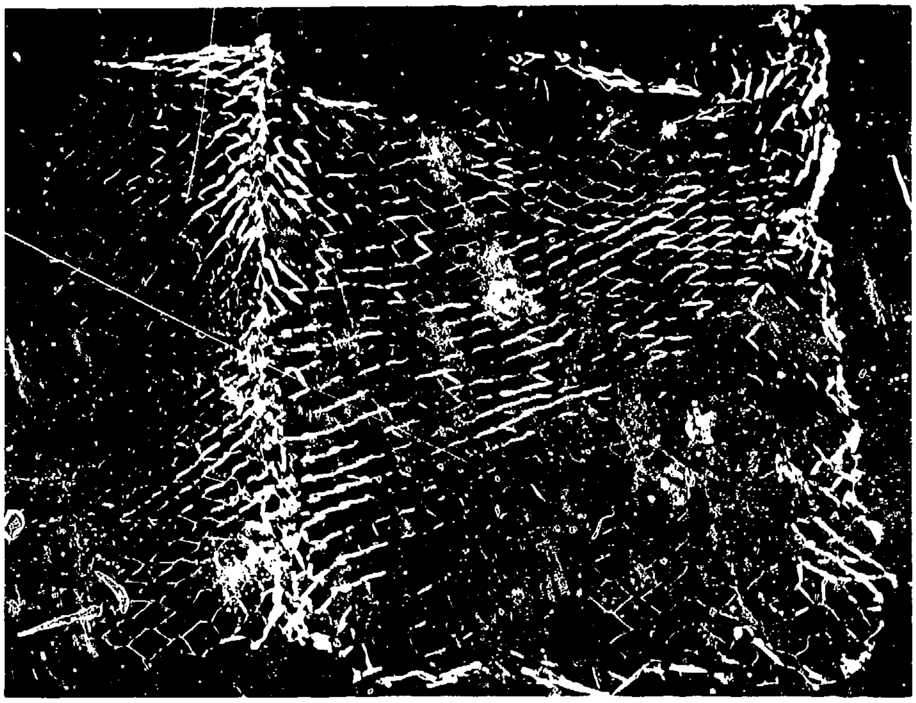


Figure C4-7. Photograph 5: Portion of Mesh from Top of Pack (After Tests)

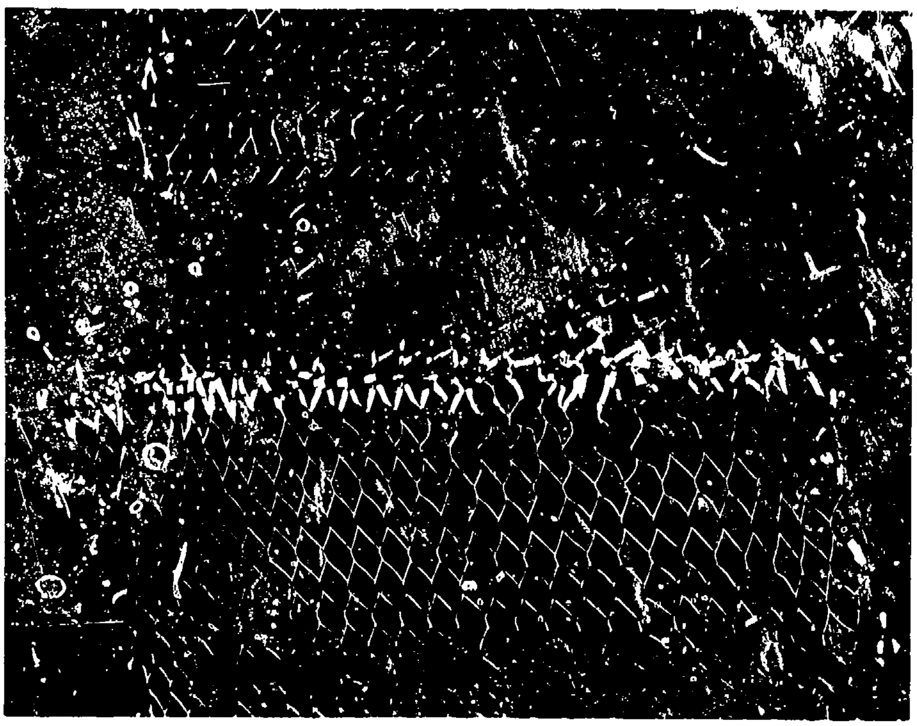


Figure C4-8. Photograph 6: Portion of Mesh from Middle of Pack (After Tests)

TABLE C4-3. SOLID PARTICULATE ANALYSES
Report No. HFA 1920

Client		Plessey Components Ltd. Product Assessment Labs, Titchfield, Hampshire	
Title		The particle size and count analysis and gravimetric analysis of the particulate matter retained from membrane samples.	
Contract Nos.		G 4418	T.W. 56007
Description of Samples		Monitor Samples	
Sampling Methods		Thermal Control Sampling Set	
No. Received			No. Analysed
No. Rejected and Why		Refer to Comments	
Sampling Data		Location or other Information	
Client	Lab		
	3/5699	CAN 3 10.3.77	
	3/5700	CAN 4 11.3.77	
	3/5701	CAN 5 14.3.77	
	3/5702	CAN 6 17.3.77	
	3/5703	CAN 7 17.3.77	
	3/5704	CAN 8 21.3.77	

TABLE C4-4. PARTICULATE COUNT AND SIZE DISTRIBUTION

Particle Size Range Micrometers	Sample Reference		
	CAN 3 3/5699	CAN 4 3/5700	CAN 7 3/5703
Fibres	0	55	0
≥100	35	55	50
≥50 <100	155	205	170
≥25 < 50	990	685	2,150
≥15 < 25	1,310	1,530	5,420
≥10 < 15	3,850	3,545	21,430
≥ 5 < 10	16,660	14,685	122,625
≥ 1 < 5	221,575	902,460	U.C.

Notes: (1) Totals represent statistically, the particles per membrane.

(2) Symbol U.C. = particle density is too heavy to permit counting.

(3) Sample CAN 6 was too heavily contaminated for a particle size and count analysis to be performed.

(4) Due to agglomeration of fibers and silicous particles on samples CAN 5 and CAN 8, it was not possible to perform a particle size and count analysis.

TABLE C4-5. GRAVIMETRIC ANALYSES OF CONTAMINANTS

Thermal Control Company Limited
Filtration Laboratories
Report Number HFA 1920
Gravimetrical Analysis Total Weight

Sample No.	CAN 3	Sample No.	CAN 4
Wt: A mgm	49.45	Wt: A mgm	49.22
Wt: B mgm	47.99	Wt: B mgm	47.73
Wt: C mgm	1.46	Wt: C mgm	1.49
Sample No.	CAN 5	Sample No.	CAN 6
Wt: A mgm	48.10	Wt: A mgm	50.12
Wt: B mgm	45.72	Wt: B mgm	45.66
Wt: C mgm	2.38	Wt: C mgm	4.46
Sample No.	CAN 7	Sample No.	CAN 8
Wt: A mgm	50.00	Wt: A mgm	46.66
Wt: B mgm	48.19	Wt: B mgm	44.43
Wt: C mgm	1.81	Wt: C mgm	2.23

Wt: A = Weight of Membrane + Weight of Contaminant

Wt: B = Weight of Membrane

Wt: C = Weight of Combustionable and Non-Combustionable Contaminant

A - B = C = Total Weight

PHYSICAL ASPECTS OF THE DETECTABLE SOLID PARTICULATES

Each specimen is examined for indications of the chemical, metallurgical or other characteristics of the particulate on the membrane. Use is made of microscopes equipped with light sources allowing either a combination of reflected, transmitted and polarised light techniques or the individual application of either illuminating mode.

The information supplied is indicative of the probable identity of the particulate observed, but does not have the precision value of the more specialised procedures available if specifically requested.

TABLE C4-6. COMPOSITION OF CONTAMINANTS

Characteristics of Particles Given as % Totals for Each Sample Classified											
Client	Laboratory	fe_2O_3	fe O	fe	si	cu	al	f	fs	pp	rubber
CAN 3	3/5699				45		40			5	10
CAN 4	3/5700				55		30			10	5
CAN 5	3/5701	2			8		40			10	40
CAN 6	3/5702				10		30			10	50
CAN 7	3/5703	7			25		40			3	25

Symbols: fe_2O_3 ferric oxide: fe O ferrous oxide: si silica:
fe ferrous: cu cuprous: al aluminium: f organic fibres:
s synthetic fibres: p plastics & paints:

APPENDIX D 1

INSTALLATION STUDY

RUBBER BLADDER TANK

Objective

To fully pack a 30 x 30 x 24 inch, Type II, Class A, standard nitrile bladder tank (Figure D1-1) with Explosafe.

Material Used

Explofoil: 0.002 inch thick 3003 alloy aluminum foil of 0.055 inch strandwidth, expanded to 38 inch web-width.

Batt Manufacturing Procedure

The Explofoil is creased at 35 inches and fanfolded to a height of 12 inches, at 16 layers of foil per inch, to form a 38 x 35 x 12 inch batt. Two such batts are produced; one to form the top section and the other the bottom section of the cube to be packed.

The batts are secured temporarily with lengths of 16 gauge aluminum wire pushed through the foil at strategic locations so as not to intefere with the bandsaw blade during the cutting operation.

Both batts are then sized down on the bandsaw to produce two 30 x 30 x 12 inch batts.

One inch radius cuts are made with a hand held electric saw on the top four corners of the top section, the bottom four corners of the bottom section, and the four side corners of both the top and bottom sections.

Next, the batts are cut on the bandsaw into smaller batts, as shown in Figure D1-2, to dimensions listed in Table D1-1. Note the diamond orientation in the drawing.

TABLE D1-1. BATT DIMENSIONS

Batt Numbers	Length (in)	Width (in)	Height (in)
Batts 1 through 22	10	7.5	12
Batts 23 through 25	10	5.0	12

Batt dimensions selected are optimum with consideration to the size of the access opening in the cube and for providing greatest ease of installation with minimum damage to the foil.

The finished batts are individually stitched with spun nylon yarn and the aluminum wires are removed. Each batt is provided with a handle stitched on with the same yarn to facilitate the removal of the batts from the fuel cell for maintenance purposes.

Each batt is tagged with a batt number embossed on a disc of 0.003 inch thick aluminum foil. These numbers are assigned to indicate the sequence of batt installation. The tags are slipped in between the bottom two layers of foil in the case of batts comprising the top section, and between the top two layers of foil for batts comprising the bottom section. It is necessary to position the tags in this manner in order that abrasive contact between the staples and inner tank wall material may be avoided.

Batt Installation/Removal Technique

Batts are installed in their order of numerical ascension as indicated by the tags.

Wherever inter-surface contact between batts prevents easy installation, stiff cardboard should be inserted between adjacent batts to reduce excessive friction. The cardboard should be removed immediately after the batt is properly installed.

For production installation jobs it is recommended that sized sheet metal or acrylic plastic sheets of 0.03 inch thickness be substituted for cardboard. It should be noted that to facilitate easy removal of the batts, it could be necessary to slip in such sheets between contacting batt surfaces before batt removal.

Weight Analysis

Weight of untrimmed foil = 48.06 lbs.
Weight of Completed Batts = 32.94 lbs.

Packing Density

Volume of Tank = (2.5 x 2.5 x 2.0) cu. ft.
= 12.50 cu. ft.

$$\text{Packing Density} = \frac{32.94}{12.50}\ \frac{\text{lbs.}}{\text{cu.ft.}}$$

$$= 2.64\ \text{lbs./cu.ft.}$$

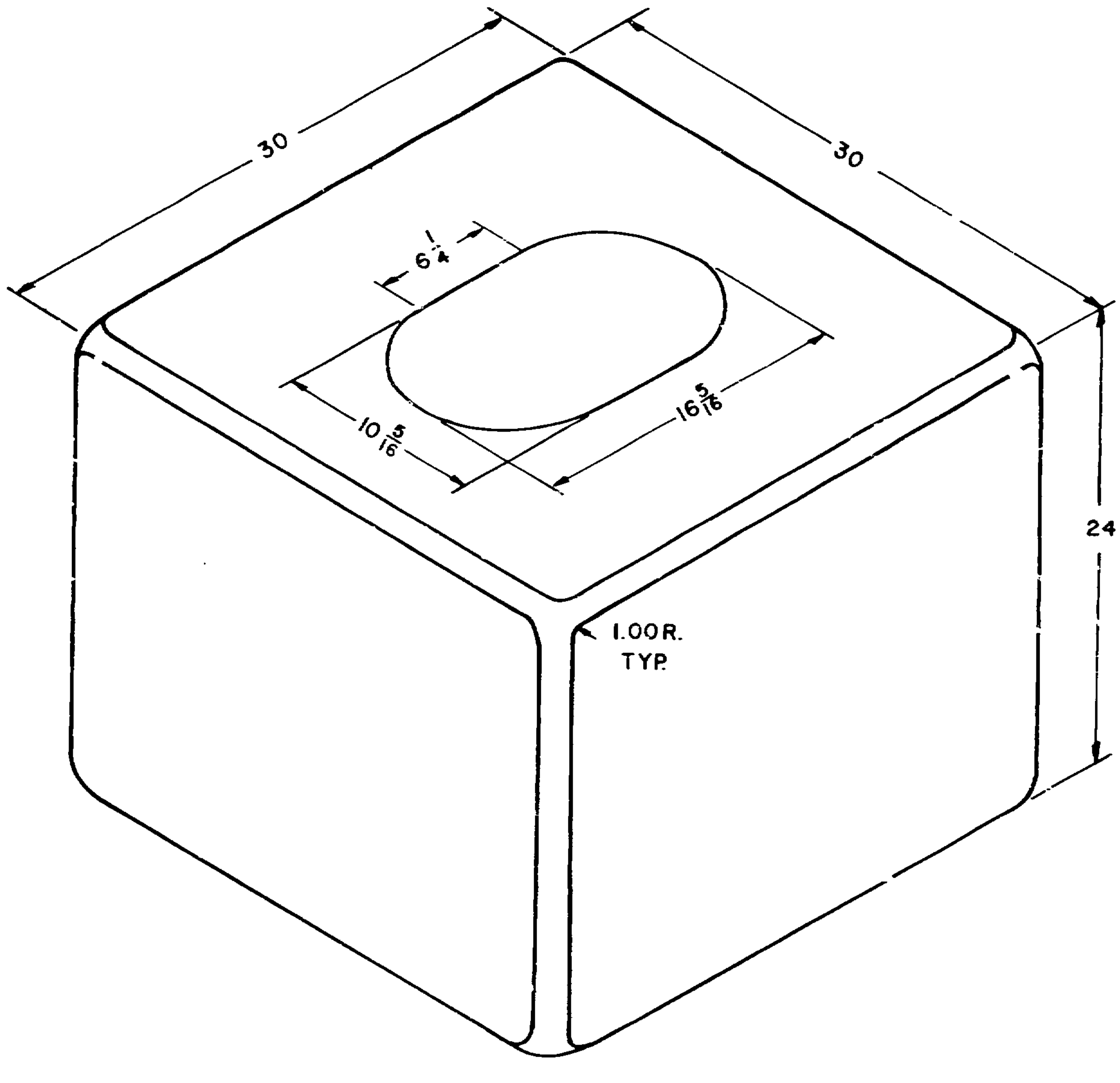


Figure D1-1. Type II, Class A Rubber Bladder Test Tank

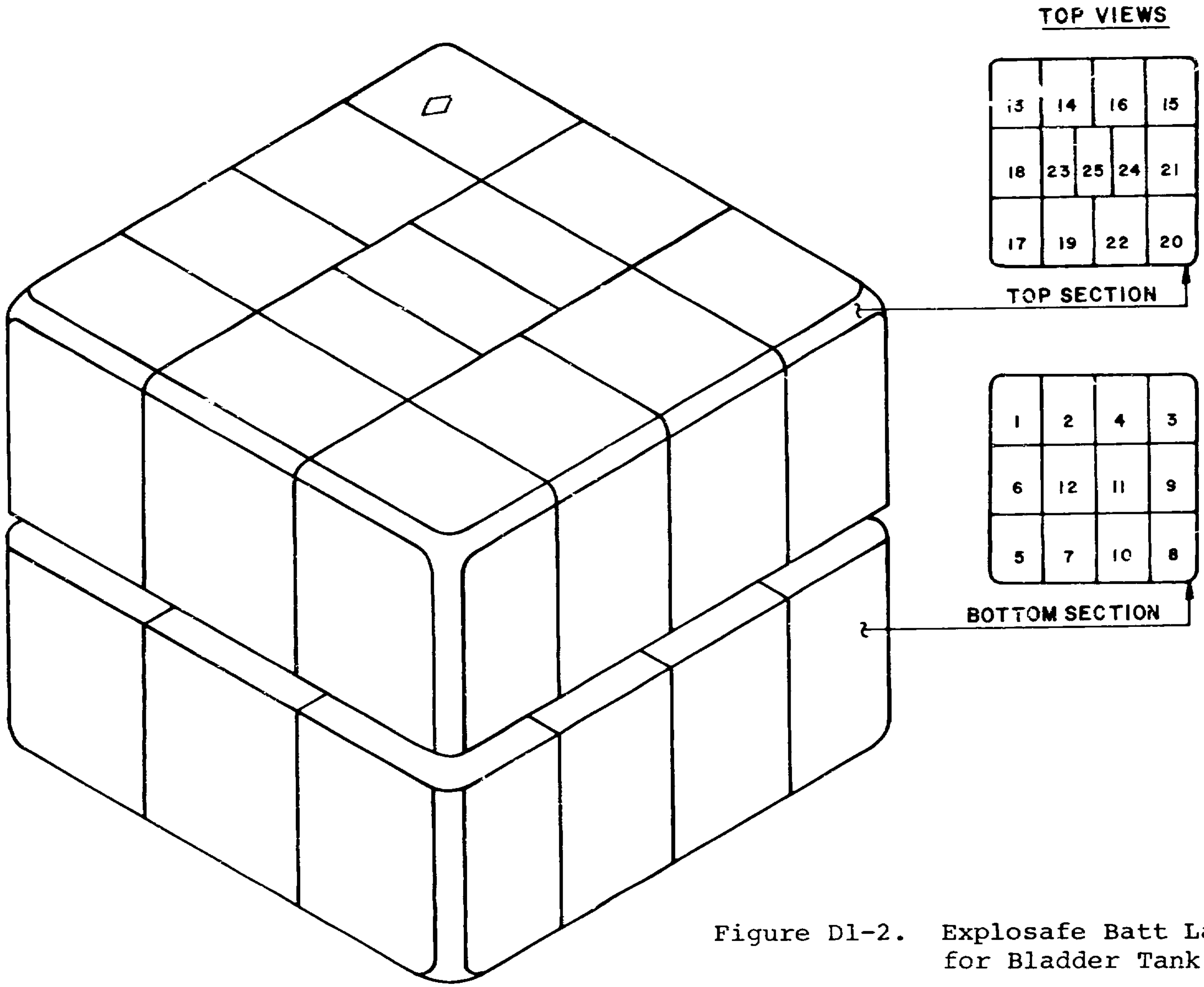


Figure D1-2. Explosafe Batt Layout for Bladder Tank

APPENDIX D 2

INSTALLATION STUDY NO. 1
200 GALLON EXTERNAL PYLON TANK

Fuel Tank Description

The 200 gallon external pylon tank consists of three main components; a conical nose section, a cylindrical midsection, and an offset, cone shaped tail section (Figures D2-1 and D2-2). The midsection houses a baffle assembly.

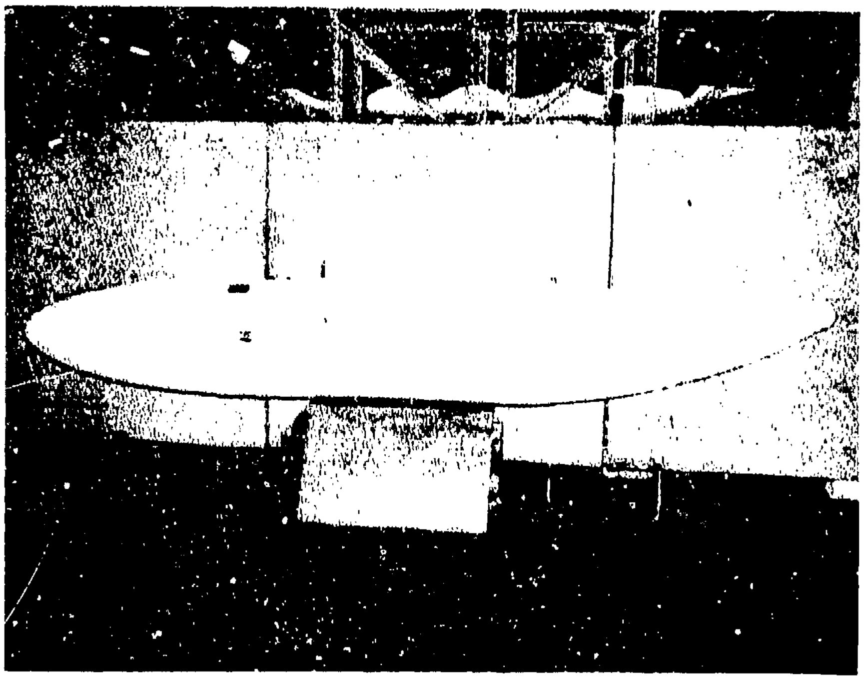


Figure D2-1. 200 Gallon External Pylon Tank

Objective

To fully pack the tank with Explosafe explosion suppression material.

Explosafe Material Used

0.002 inch thick 3003 alloy aluminum foil of 0.055 inch strand width is expanded to 38 inch web width. All batts are formed by coiling foil or cutting the required shapes from fanfolded batts. The approximate material density is 2.5 pounds per cubic foot.

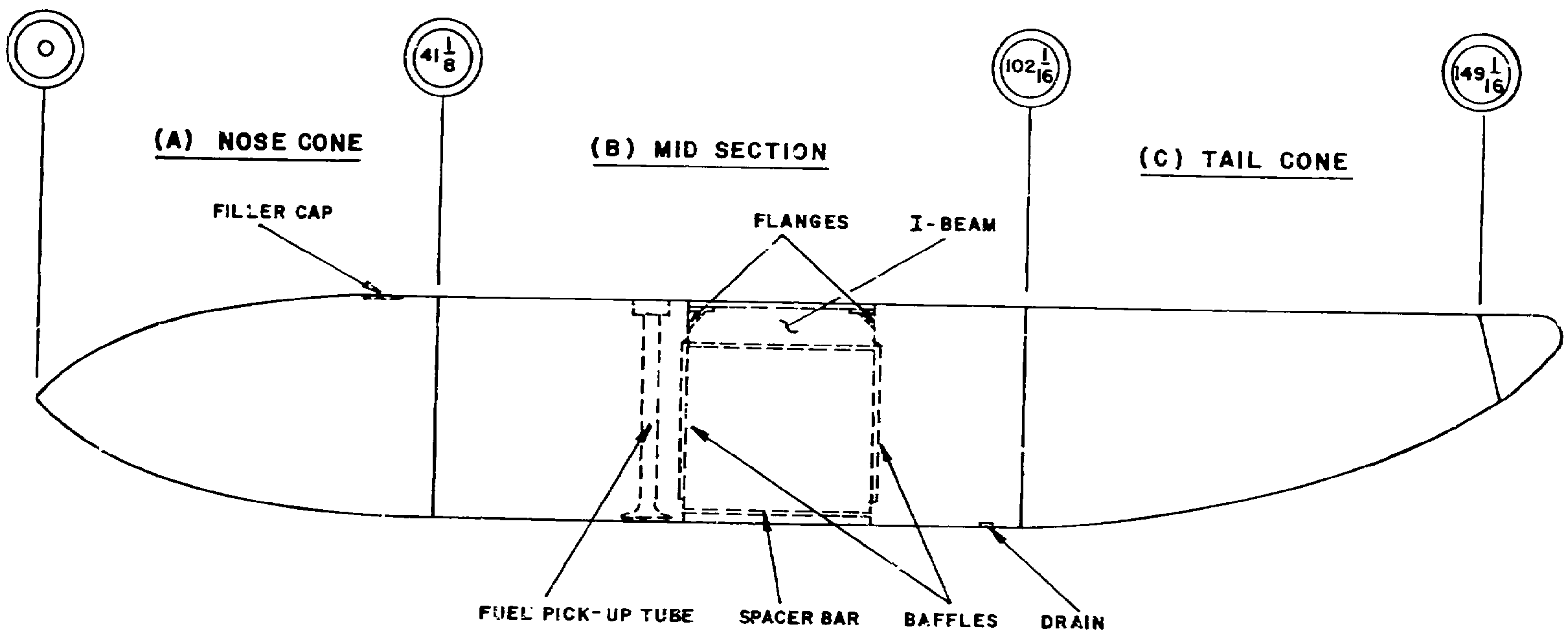


Figure D2-2. 200 Gallon External Pylon Fuel Tank

Batts for Nose Cone (Section A)

Fanfolded batts are shaped to produce a series of frustums using circular templates of diameters specified in Table D2-1. Templates are placed on the top and bottom of the untrimmed batts such that they are coaxial. Each template is fixed to the batt by means of four, 2 inch nails pushed through the template and into the batt. The bandsaw is tilted to the desired angle of the cut, specified in Table D2-1, and the batt is shaped by rotating it around its axis against the bandsaw blade. The templates are removed and the finished batt is stitched using Dupont Kevlar 29 spun yarn. In this method of batt production, the bottom template of one batt becomes the top template for the next. See Figures D2-3 and D2-4, for nose cone batt details.

Figure D2-3. Batt Assembly for Nose Cone

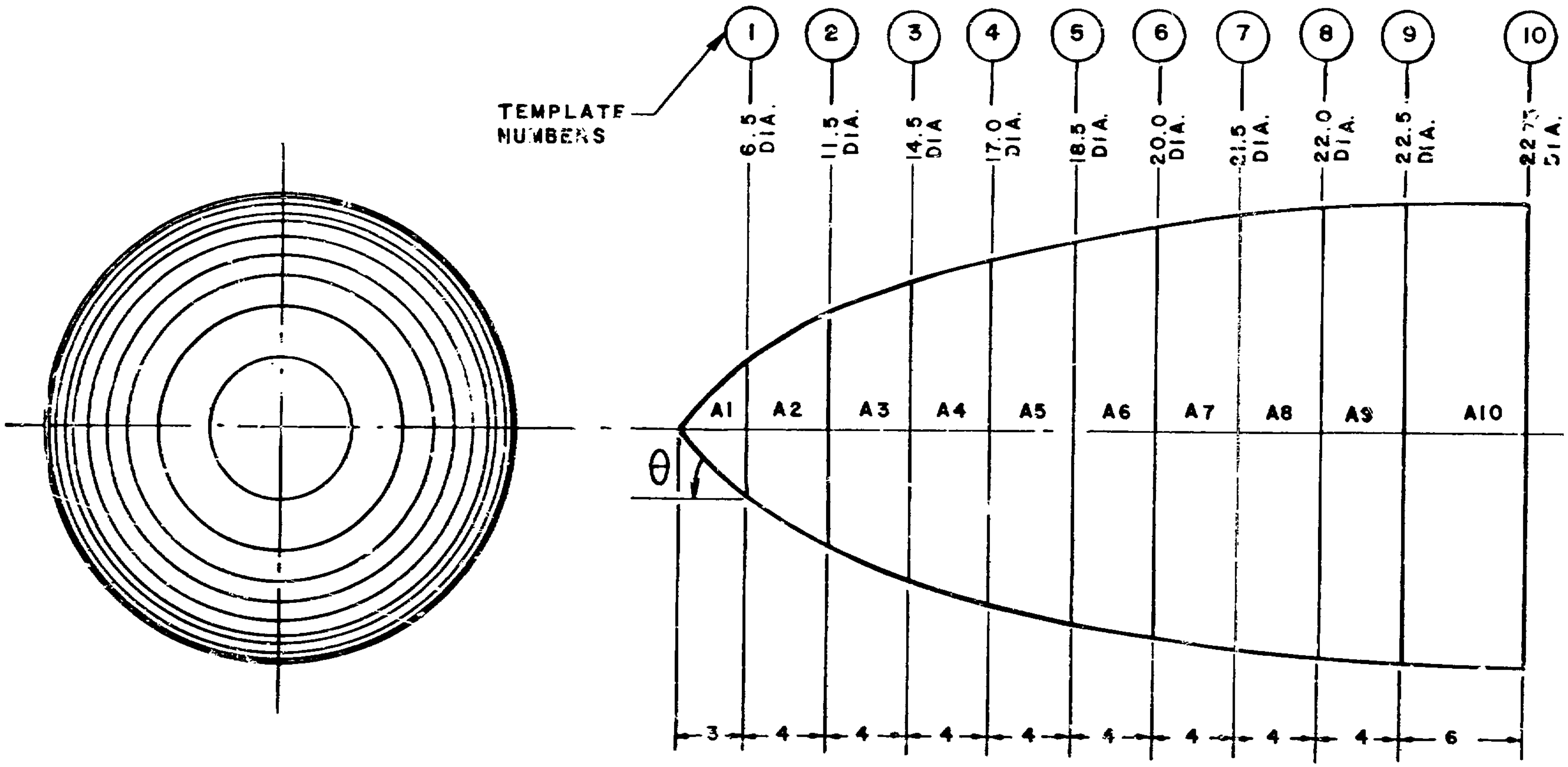


Figure D2-4. Explosafe Batt Assembly for Nose Cone

TABLE D2-1. BATT DIMENSIONS: NOSE CONE

Batt Number	Batt Thickness (in)	Template Number	Template Diameter (in)	Angle of Cut (θ^0)
A1	3.00	1	6.50	45
A2	4.00	2	11.50	30
A3	4.00	3	14.50	22
A4	4.00	4	17.00	15
A5	4.00	5	18.50	13
A6	4.00	6	20.00	9
A7	4.00	7	21.50	8
A8	4.00	8	22.00	5
A9	4.00	9	22.50	3
A10	6.00	10	22.75	0

Batts for Midsection (Section B)

The midsection is formed of four coils of dimensions specified in Table D2-2. Coil B1 is a plain, unvoided, cylindrical coil (Figure D2-5). Coil B2, which goes between the baffles, is a three piece assembly formed from a single coil of 23 inch diameter by cutting two diametrically opposite 5 inch deep slits along the entire length of the coil so as to form a 13 inch diameter coil B2c, and two contoured batts B2a and B2b (See Figures D2-6 and D2-7). Since these are blind cuts, provisions for ensuring clean cuts are made during the coiling operation. This is done by stopping the coiling when a diameter of 13 inches is reached and then wrapping a sheet of card paper around the entire cylindrical surface of the coil. The coiling operation is continued until the desired 23 inch coil diameter is reached. Now, when cuts are made in the coil, the card paper acts as a guide for the cutting blade of the saw at a uniform depth of 5 inches. The card paper is discarded after the cuts are made.

Batts B2a and B2b are stitched and coil B2c, as all other coils, is secured with stainless steel staples. Edges (i), (ii), (iii) and (iv) of the batts are trimmed to accomodate the flanges.

Coils B3 and B4 are voided at their interface to accommodate the centrally located fuel pick-up tube (Figure D2-8). Figure D2-9 shows the dimensions of the void for the fuel pick-up tube.

TABLE D2-2. BATT DIMENSIONS: MIDSECTION

Coil Number	Diameter (in)	Batt Thickness (in)
B1	23	14.31
B2	23	19.50
B3	23	4.00
B4	23	21.06

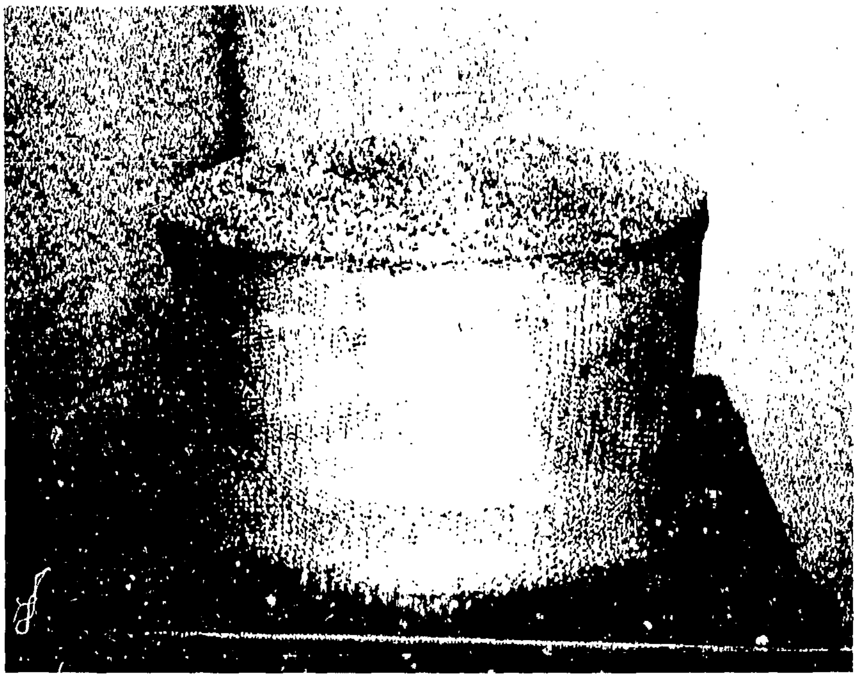


Figure D2-5. Coil B1 of Midsection

Figure D2-6. Coil Assembly B2 of Midsection

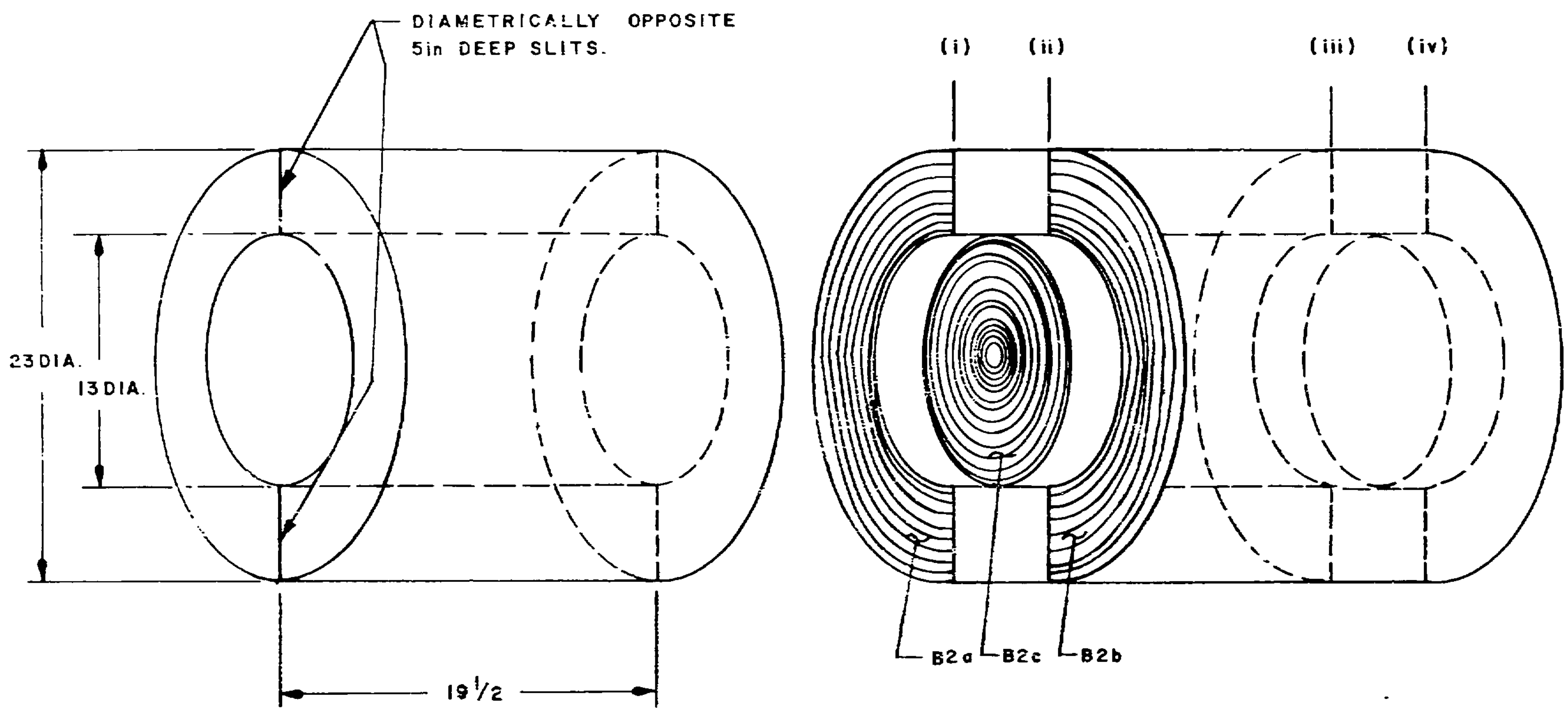


Figure D2-7. Batt Assembly B2 for Midsection

Figure D2-8. Coils B3 (top) and B4 Voided for Fuel Pick-Up Tube

Batts for Tail Cone (Section C)

Fanfolded batts are shaped to form a series of offset frustums in a way similar to the method used to form batts for the nose cone, except, in this case, instead of placing the templates coaxially they are placed with one edge lined up with the vertical (Figures D2-10 and D2-11). A hand held electric saw is used to shape the batts. The templates are removed and the finished batts are stitched with DuPont Kevlar 29 spun yarn. Table D2-3 lists batt and template dimensions.

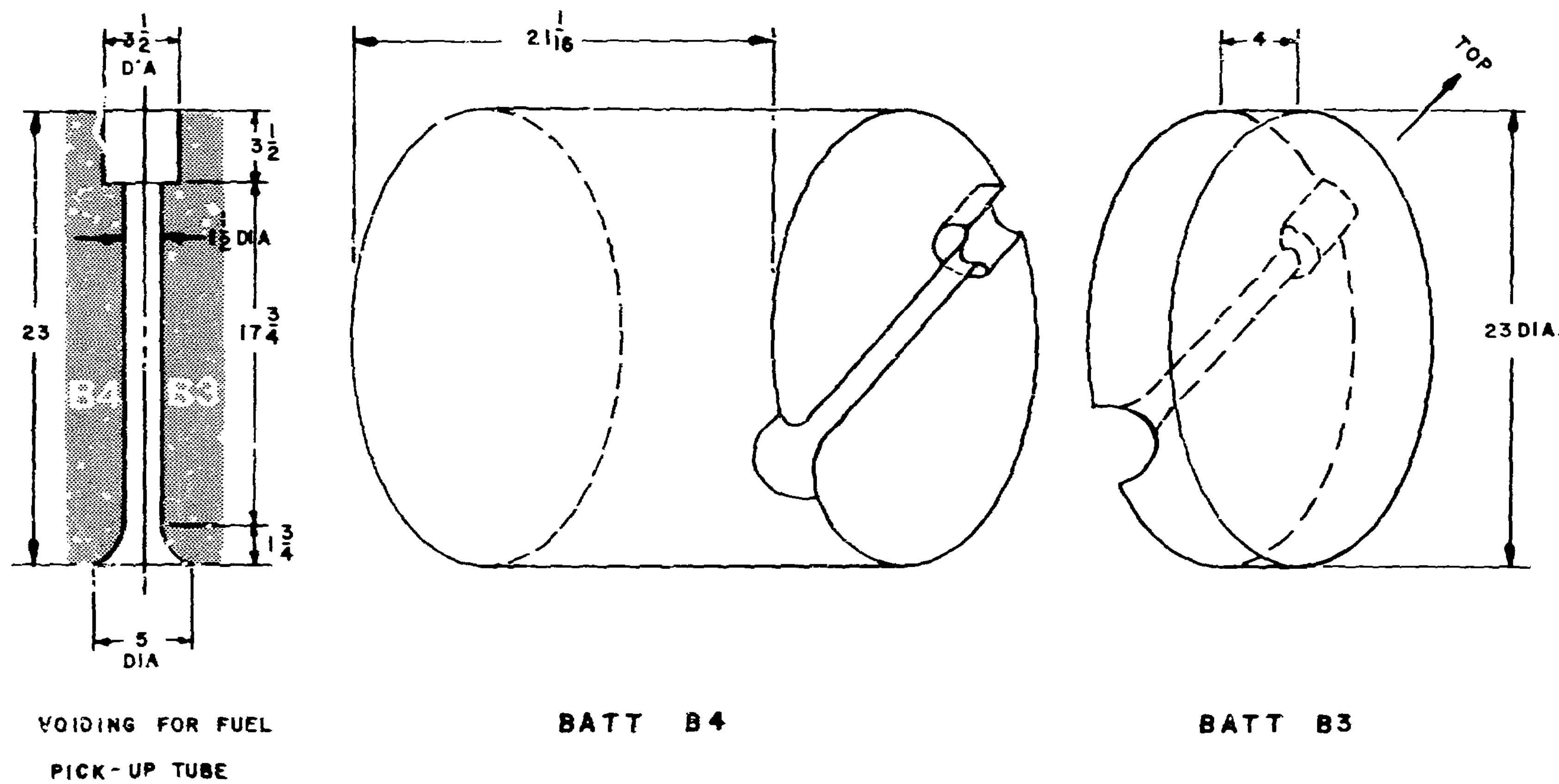


Figure D2-9. Batts B3 and B4 for Midsection

Figure D2-10. Batt Assembly for Tail Cone

TABLE D2-3. BATT DIMENSIONS: TAIL CONE

Batt Number	Batt Thickness (in)	Template Number	Template Diameter (in)
-	-	11	10.75
C1	6.00	12	13.00
C2	6.00	13	15.25
C3	6.00	14	17.25
C4	6.00	15	19.00
C5	6.00	16	20.25
C6	6.00	17	21.50
C7	6.00	18	22.25
C8	6.00	19	22.75

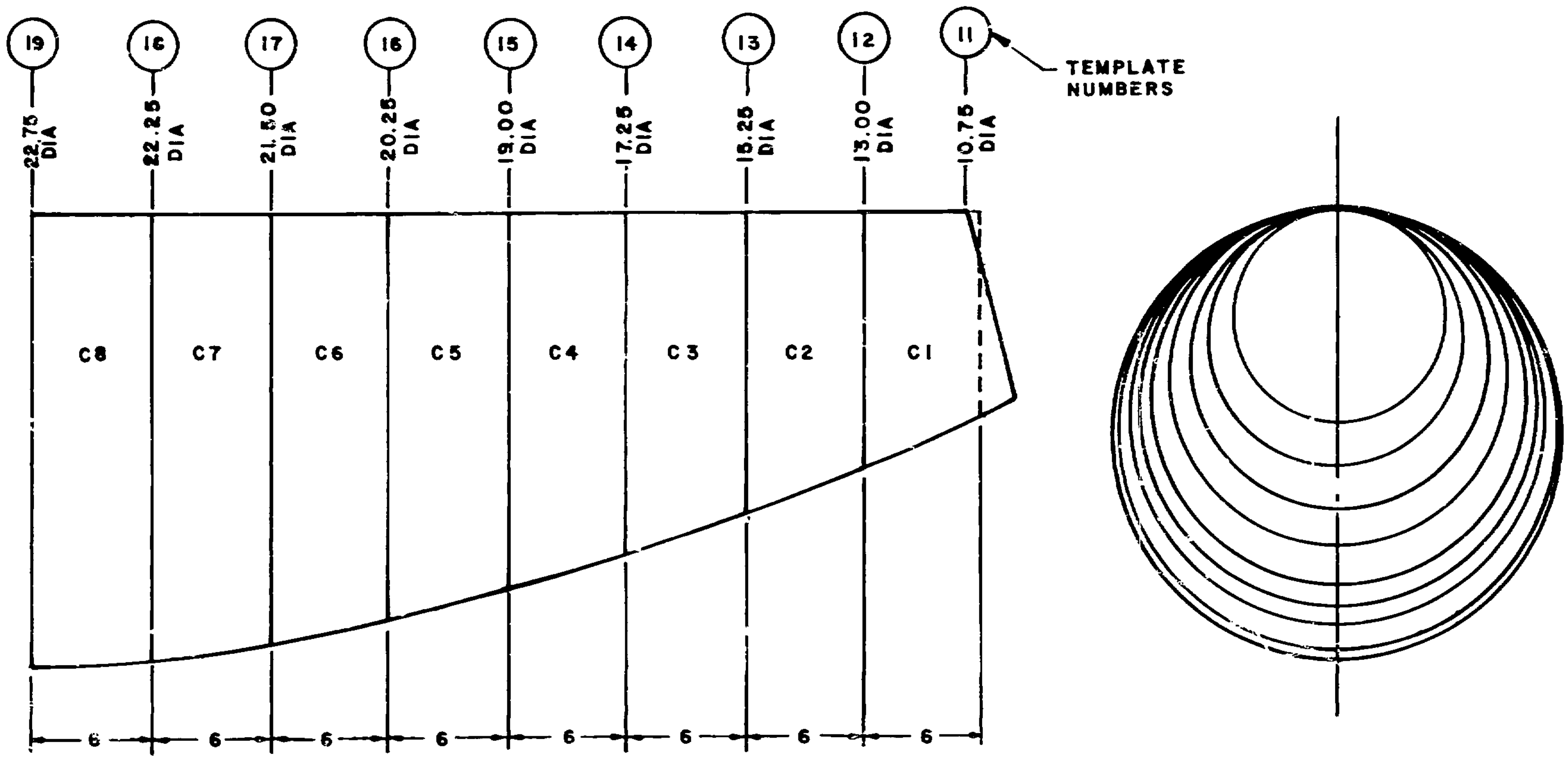


Figure D2-11. Batt Assembly for Tail Cone

Explosafe Installation Procedure

The nose cone, the midsection and the tail cone are packed independently and reassembled.

Batts for the nose and tail cones are installed in ascending order of their assigned batt numbers. Figure D2-12 shows the nose and tail sections fully packed with Explosafe.

Before installing the batts for the midsection, it is necessary to remove the bolts along its seam to open up the section. The fuel pick-up tube and the fwd baffle are removed. Batt B1 is installed at the aft end of the midsection. The contoured batts B2a and B2b are installed around the I beam and the spacer bar between the baffles. Coil B2c is inserted in the void between the two batts and the fwd baffle is reinstalled (Figure D2-13). Next, coil B3 is installed, the fuel pick-up tube is replaced and coil B4 is put into position. See Figures D2-14 and D2-15 for midsection batt layout.

The bolts along the seam of the midsection are fastened to close up the section. During fastening of the bolts, the following precaution should be taken to prevent the foil from getting entrapped in the seam. A sheet of thin gauge aluminum is inserted between the Explosafe and the inner tank wall at the seam. The bolts are tightened until the seam is almost closed. At this point, the aluminum sheet is pulled out. The nose and tail sections are positioned on their respective ends of the midsection and the bolts fully tightened to secure the entire assembly.

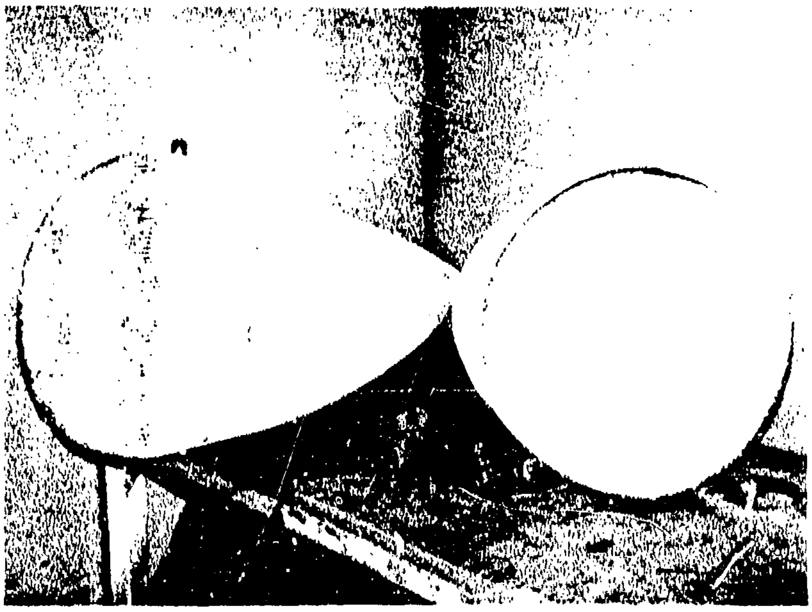


Figure D2-12. Tail and Nose Cones Fully Packed with Explosafe

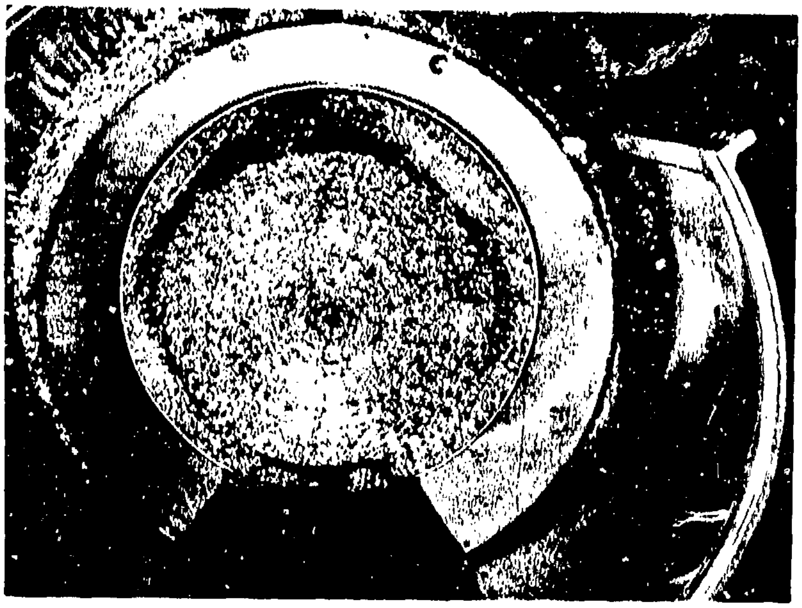


Figure D2-13. Batt Assembly B2 Installed between Baffles

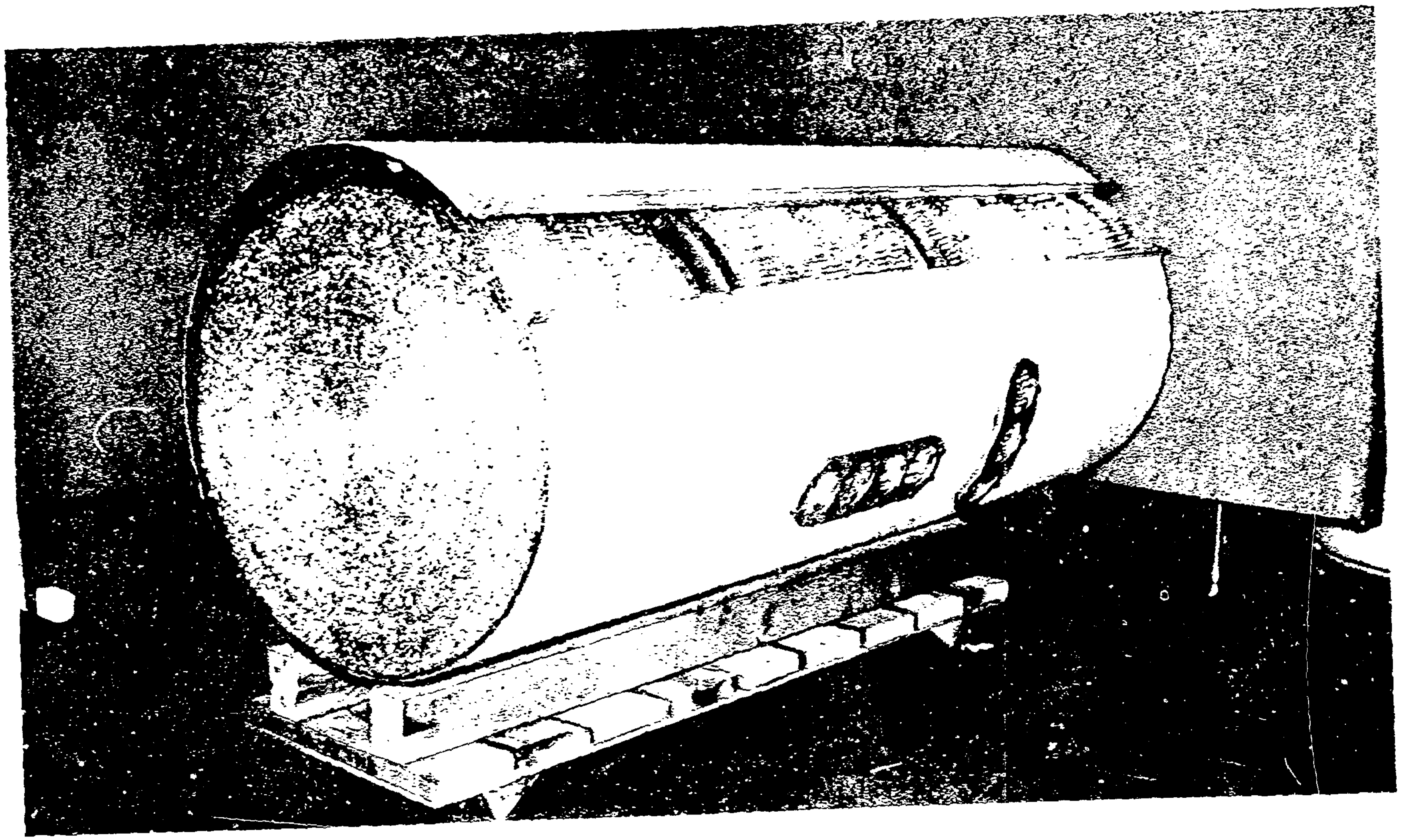


Figure D2-14. Batt Layout for Midsection

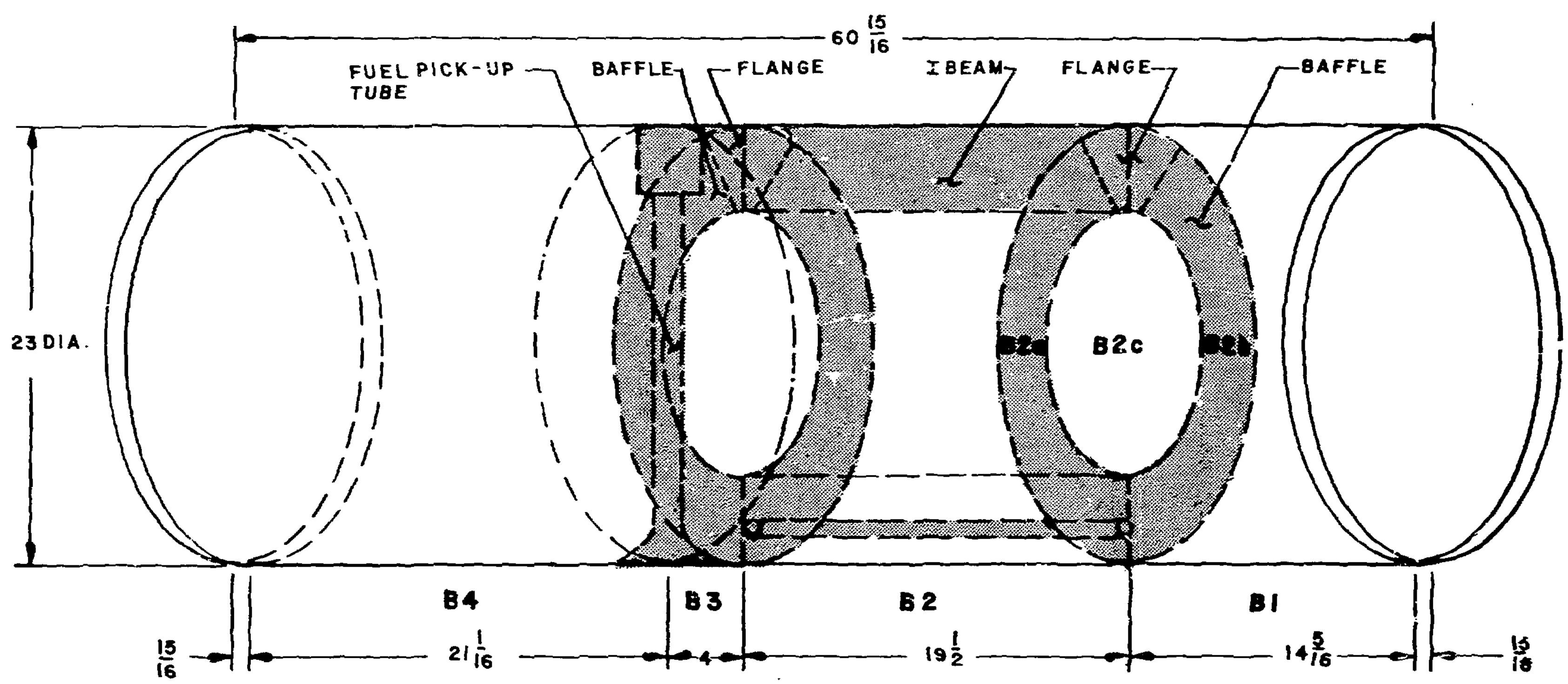


Figure D2-15. Explosafe Batt Layout for Midsection

Weight Analysis

Weight of Explosafe batts for:

a) nose cone	14.8 lbs
b) midsection	34.5 lbs
c) tail cone	19.1 lbs
Total weight of Explosafe material	68.4 lbs
Weight of empty tank	100.6 lbs

Percent increases in weight of dry tank with Explosafe installed:

$$= \frac{68.4}{100.6} \times 100$$

$$= 68\%$$

Packing Density

Volume of tank = 201.35 gallons (U.S.) = 26.92 cu.ft.

$$\text{Packing Density} = \frac{\text{Weight of Explosafe}}{\text{Volume of Tank}}$$

$$= \frac{68.4}{26.92} \text{ lbs/cu. ft.}$$

$$= 2.54 \text{ lbs/cu. ft.}$$

APPENDIX D 3

INSTALLATION STUDY NO. 2
200 GALLON EXTERNAL PYLON TANK

Fuel Tank Description

The 200 gallon pylon tank consists of three main components: a conical nose section, a cylindrical midsection, and an off-set, cone shaped tail section (Figure D3-1).

Objective

To pack the tank with Explosafe providing voids at the gravity filler port, sump drain area, level control valve, and around the pressure inlet fuel feed line. The void dimensions and locations are as follows:

a) Gravity Filler Port: The cross-section of this void is 4 x 4 inches and extends from the filler opening to the bottom of the tank.

b) Sump Drain Area: A 7 x 7 x 3 inches void is provided at the tank jiffy drain.

c) Level Control Valve: A void measuring 6 x 6 x 6 inches is provided at the upper area near the mouth of the tail cone, to simulate voiding for a level control valve component.

d) Fuel Pressure Feed and Pick-up Tube: The area around the fuel feed - pick-up tube is voided to provide a minimum of 1 inch clearance around the outside surface of the tube, except for the aft surface of the tube where the void extends to the fwd baffle.

Explosafe Material Used

0.002 inch thick 3003 alloy aluminum foil of 0.055 inch strand width is expanded to 38 inch web width and fanfolded at 13.8 layers per inch height. The resultant material density is approximately 2.2 pounds per cubic foot.

Batt Manufacturing Procedure

All batts are cut to the required shapes from fanfolded Explosafe material with the aid of templates. The templates are oversized by 2% in the Short Diamond direction of the foil to compensate for the tendency of the finished batts to shrink in that direction. Also, the batt thickness is oversized by 2% to provide tighter packing and to compensate for any compacting.

Each template is fixed to the batt to be cut by means of four or five 3 inch long nails pushed through the template and into the batt.

The shaped batts are stitched with 0.025 inch stainless steel wire only along the Long Diamond direction of the foil.

Table D3-1 lists the dimensions of templates and batt thicknesses, and indicates the diamond orientation of each batt. Figures D3-2 and D3-3 show the batt layout for the tank.

Section A: Nose Cone

Batt Numbers A1 through A7:

Fanfolded batts are shaped to produce a series of frustums, as illustrated by Figures D3-4 through D3-6, using circular templates of diameters specified in Table D3-1. The templates are placed on the top and bottom of the untrimmed batt such that they are coaxial. The bandsaw is tilted to the desired angle of the cut and the batt is shaped by rotating it around its axis against the bandsaw blade. In this method of batt production the bottom template of one batt becomes the top template for the next. Figure D3-7 shows the finished batts for the nose cone.

Voids for the gravity filler port are cut into batts A6 and A7 (Figure D3-8).

Section B: Midsection

Batt Numbers B1 through B6:

The dimensions of the batts that make up the midsection are specified in Table D3-1 and illustrated in Figures D3-9 through D3-13. Batts B1 and B2 go between the baffle assembly and are appropriately voided to accommodate the flanges, I-beam and the spacer bar (Figure D3-14). Batt B3 is installed in the aft portion of the midsection and is voided on its fwd face to accommodate the circular lip on the baffle, and on its bottom aft side at the tank's jiffy drain (Figure D3-15). Batt B4 is voided on its aft side to accommodate the fuel feed pick-up tube and the circular lip on the fwd baffle (Figure D3-16). Batts B5 and B6 are unvoided, fanfolded cyclindrical batts.

Section C: Tail Cone

Batt Numbers C1 through C8:

Fanfolded batts are shaped to form a series of offset frustums in a way similar to the method used to form batts for the nose cone, except, in this case, instead of placing the templates coaxially they are placed with one edge lined up with the vertical. A hand held electric saw is used to shape the batts. The batt dimensions and diamond orientation are shown in Table D3-1 and illustrated in Figures D3-17 and D3-18. Figure D3-19 shows the finished batts for the tail cone.

A void is cut into the top portion of batt C8 to simulate voiding for a level control valve component (Figure D3-20).

Explosafe Installation Procedure

The nose cone, the midsection and the tail cone are packed independently and reassembled. Batts for all sections are installed in ascending order of their assigned batt numbers.

Before installing the batts for the midsection, it is necessary to remove the bolts along its seam to open up the section. The aft baffle must be removed before batts B1 and B2 can be installed.

When all three sections are packed, the nose and tail cones are positioned on their respective ends of the midsection and the bolts along the seam fully tightened to secure the entire assembly. Figures D3-21 through D3-29 show the various stages of Explosafe installation.

Weight Analysis (Actual)

Weight of Explosafe batts for:

a) nose cone	12.9 lbs.
b) midsection	29.1 lbs.
c) tail cone	15.4 lbs.
TOTAL weight of Explosafe material	57.4 lbs.
Weight of empty tank	100.6 lbs.

Void Analysis

Voids at:

a) gravity filler port	359 cu. in.
b) fuel pick-up tube	449 cu. in.
c) lip of fwd baffle	43 cu. in.
d) flanges and I-beam	340 cu. in.
e) spacer bar	13 cu. in.
f) lip of aft baffle	50 cu. in.
g) jiffy drain	131 cu. in.
h) level control valve	204 cu. in.
TOTAL cut void	1589 cu. in.

Volume occupied by fittings at voids:

a)	flanges	78 cu. in.
b)	I-beam	81 cu. in.
c)	spacer bar	9 cu. in.
d)	fuel pick-up tube	22 cu. in.
e)	miscellaneous	25 cu. in.
	TOTAL volume occupied by fittings	215 cu. in.

Effective void = (total void-volume of fittings)

= (1589-215) = 1374 cu. in.

= 0.80 cu. ft.

Percent void $= \frac{\text{affective void}}{\text{volume of tank}} \times 100$

$= \frac{0.80}{26.92} \times 100$

= 3%

Packing Density (Actual)

Volume of tank = 201.35 gallons (U.S.) = 26.92 cu.ft.

Packing Density $= \frac{\text{Weight of Explosafe}}{\text{Volume of Tank}}$

$= \frac{57.4}{26.92}$ lbs./cu. ft.

= 2.13 lbs./cu. ft.

Specific Weight of Explosafe (Actual)

Volume of Explosafe = Volume of Tank - Effective Void

= (26.92 - 0.80 cu. ft.)

= 26.12 cu. ft.

Specific Weight $= \frac{\text{Weight of Explosafe}}{\text{Volume of Explosafe}}$

$= \frac{57.4}{26.12}$ lbs./cu. ft.

= 2.20 lbs./cu. ft.

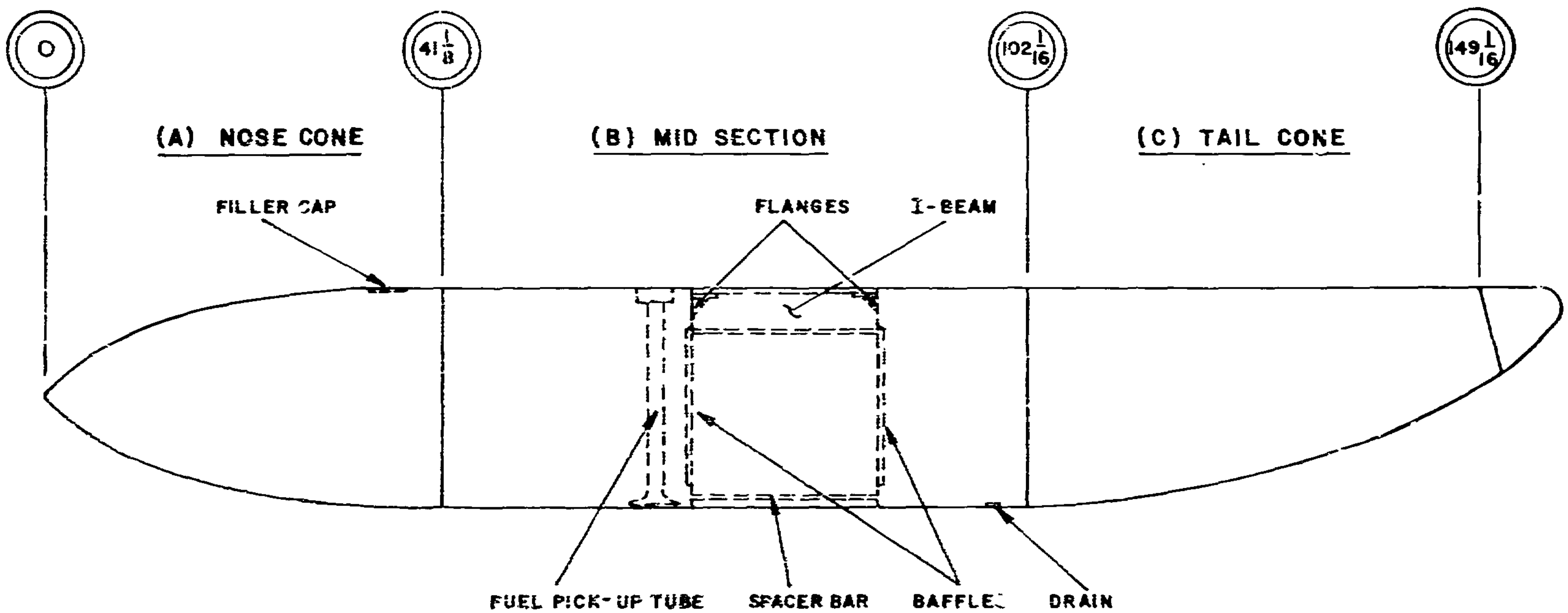


Figure D3-1. 200 Gallon External Pylon Fuel Tank

TABLE D3-1. OVERALL BATT DIMENSIONS

Batt No.	Diamond Orientation	Batt Thickness (Oversized 2%) (in)	Template Number	D_{ld}* (in)	D_{sd}** (in)
			1	2.00	2.00
A1	horizontal	5.12	2	9.00	9.19
A2	vertical	6.12	3	14.75	15.00
A3	horizontal	6.12	4	18.00	18.37
A4	vertical	6.12	5	20.25	20.62
A5	horizontal	6.12	6	21.50	22.00
A6	vertical	6.12	7	22.75	23.19
A7	horizontal	6.12	8	22.75	23.19
			9	23.25	23.75
B1	horizontal	10.00	9	23.25	23.75
B2	vertical	10.00	9	23.25	23.75
B3	vertical	14.62	9	23.25	23.75
B4	vertical	8.50	9	23.25	23.75
B5	horizontal	8.50	9	23.25	23.75
B6	vertical	8.50	9	23.25	23.75
			10	10.75	11.00
C1	vertical	6.12	11	13.00	13.25
C2	horizontal	6.12	12	15.25	15.62
C3	vertical	6.12	13	17.25	17.62
C4	horizontal	6.12	14	19.00	19.37
C5	vertical	6.12	15	20.25	20.62
C6	horizontal	6.12	16	21.50	22.00
C7	vertical	6.12	17	22.25	22.69
C8	horizontal	6.12	18	22.75	23.19

* Template diameter in Long Diamond direction
** Template diameter in Short Diamond direction (oversized 2%)

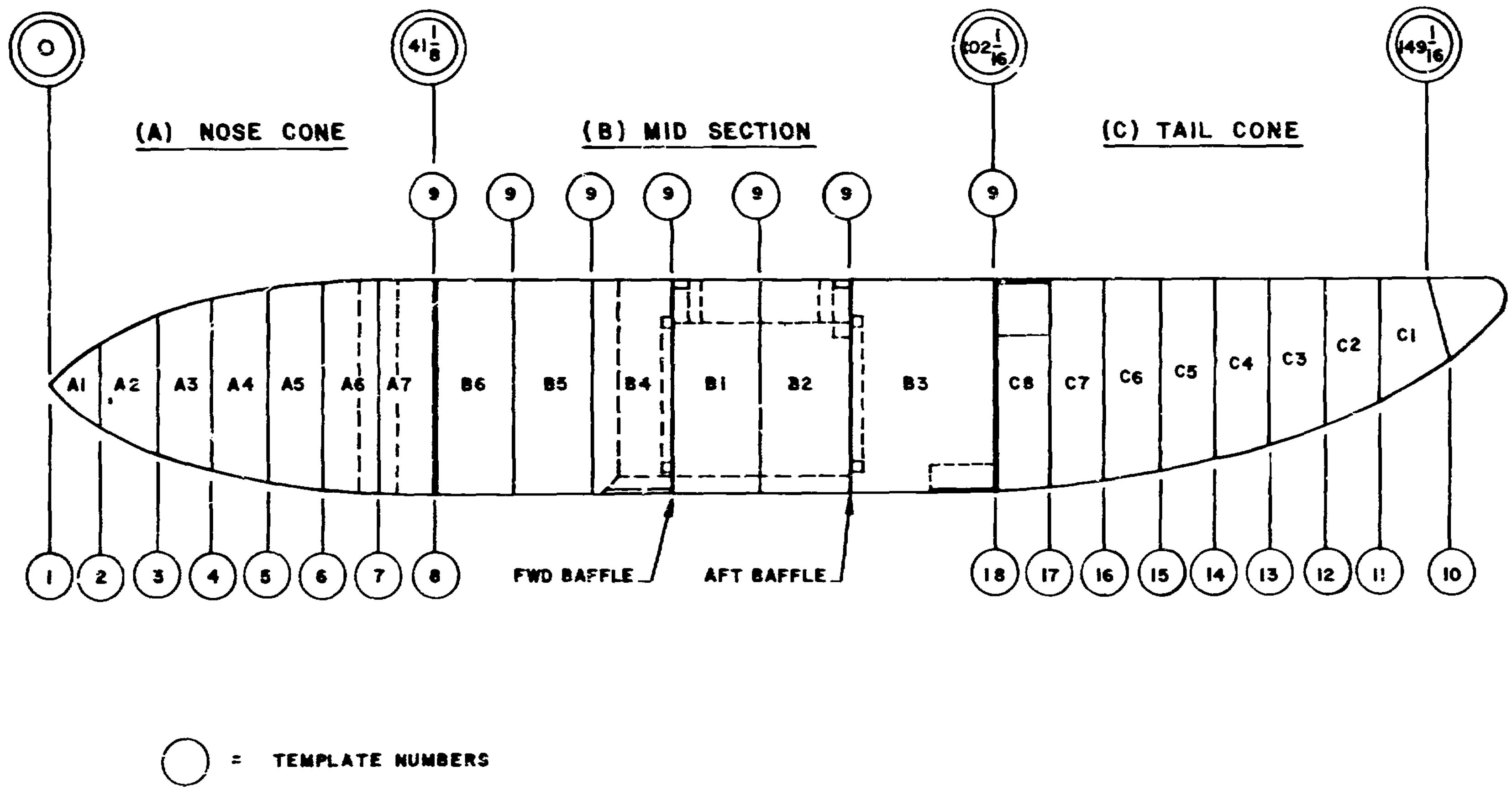


Figure D3-2. Explosafe Batt Layout: Installation 2

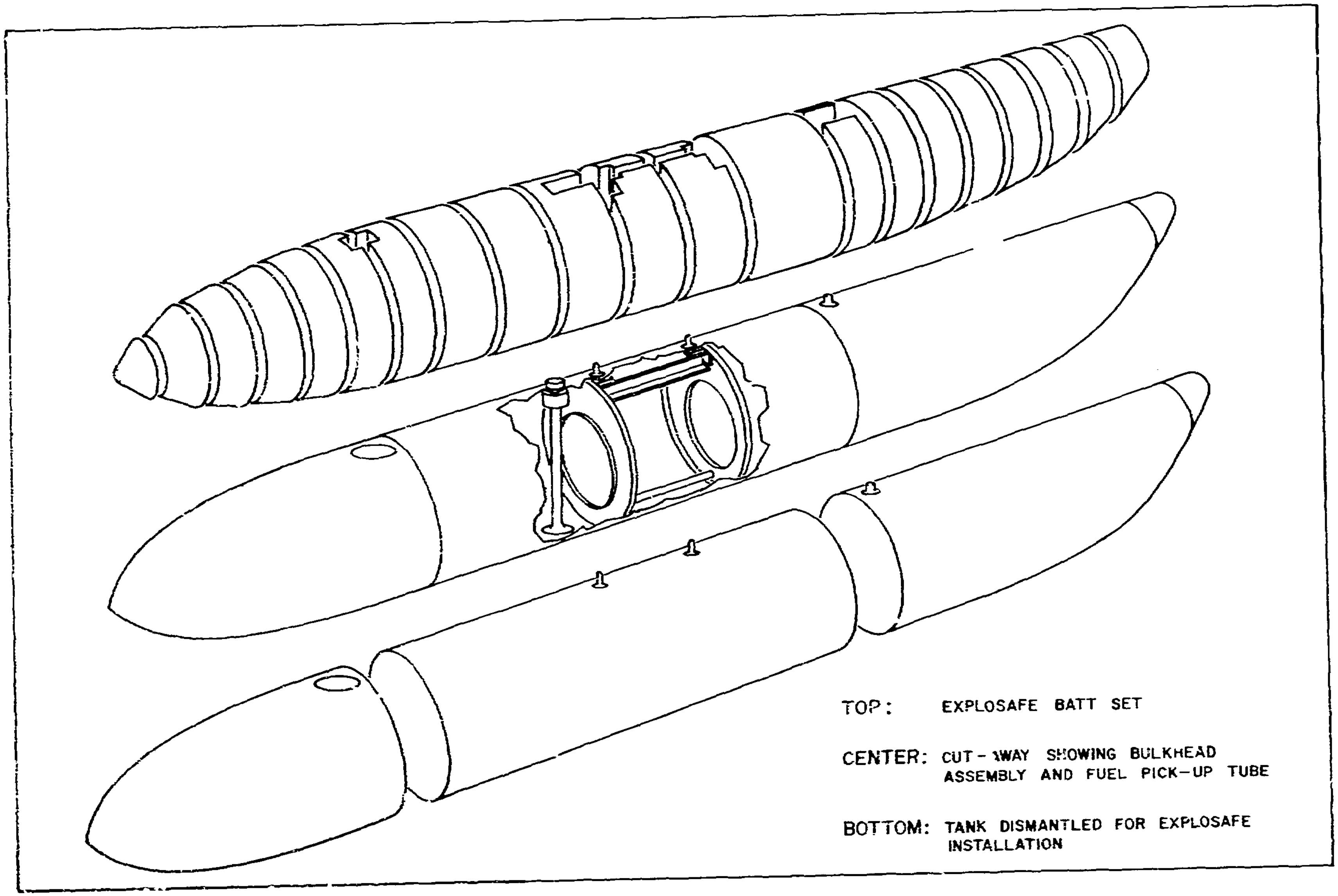


Figure D3-3. Explosafe Batt Layout, and Internal Components of 200 Gallon Pylon Tank

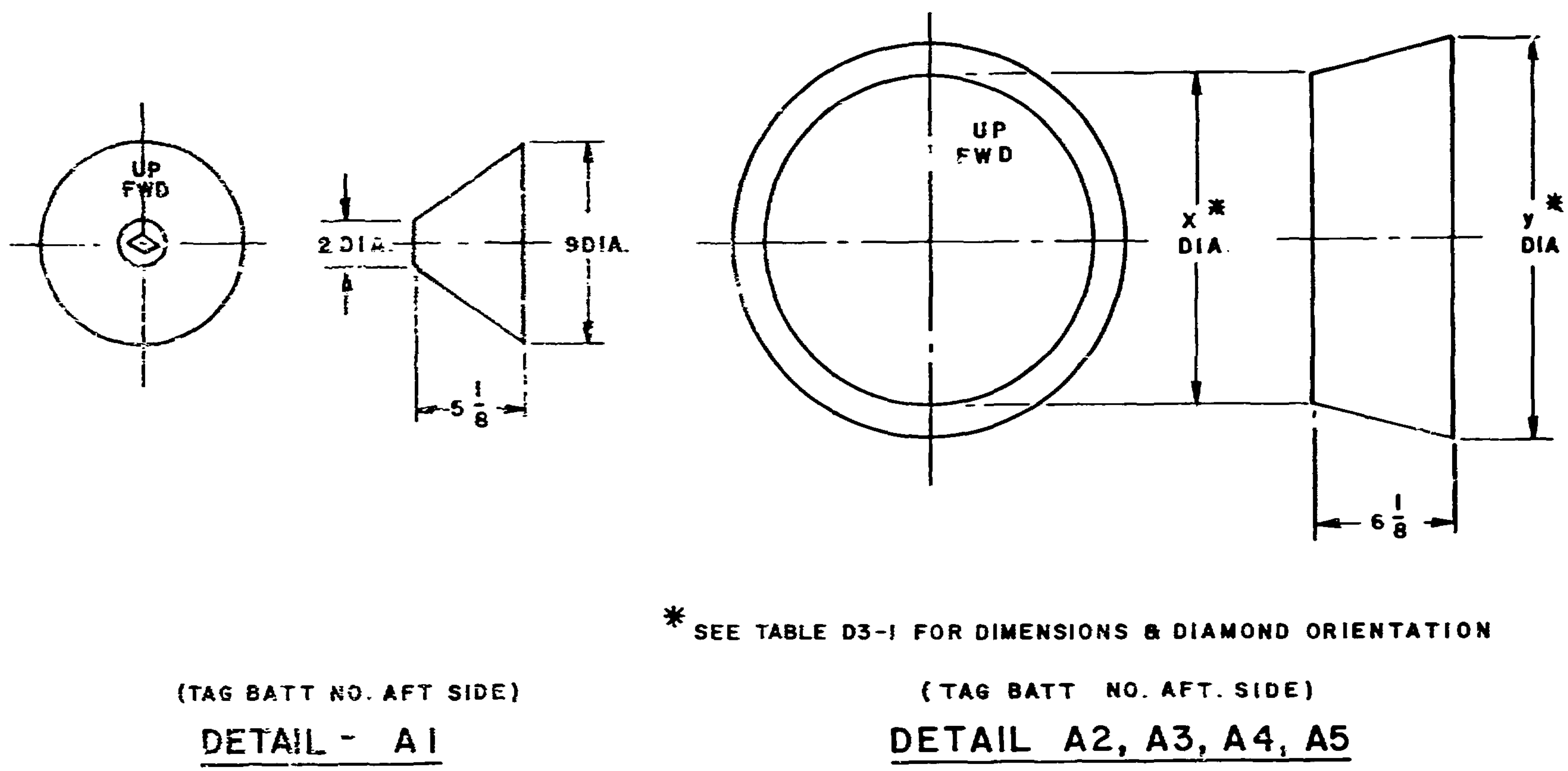


Figure D3-4. Nose Cone Batt Details

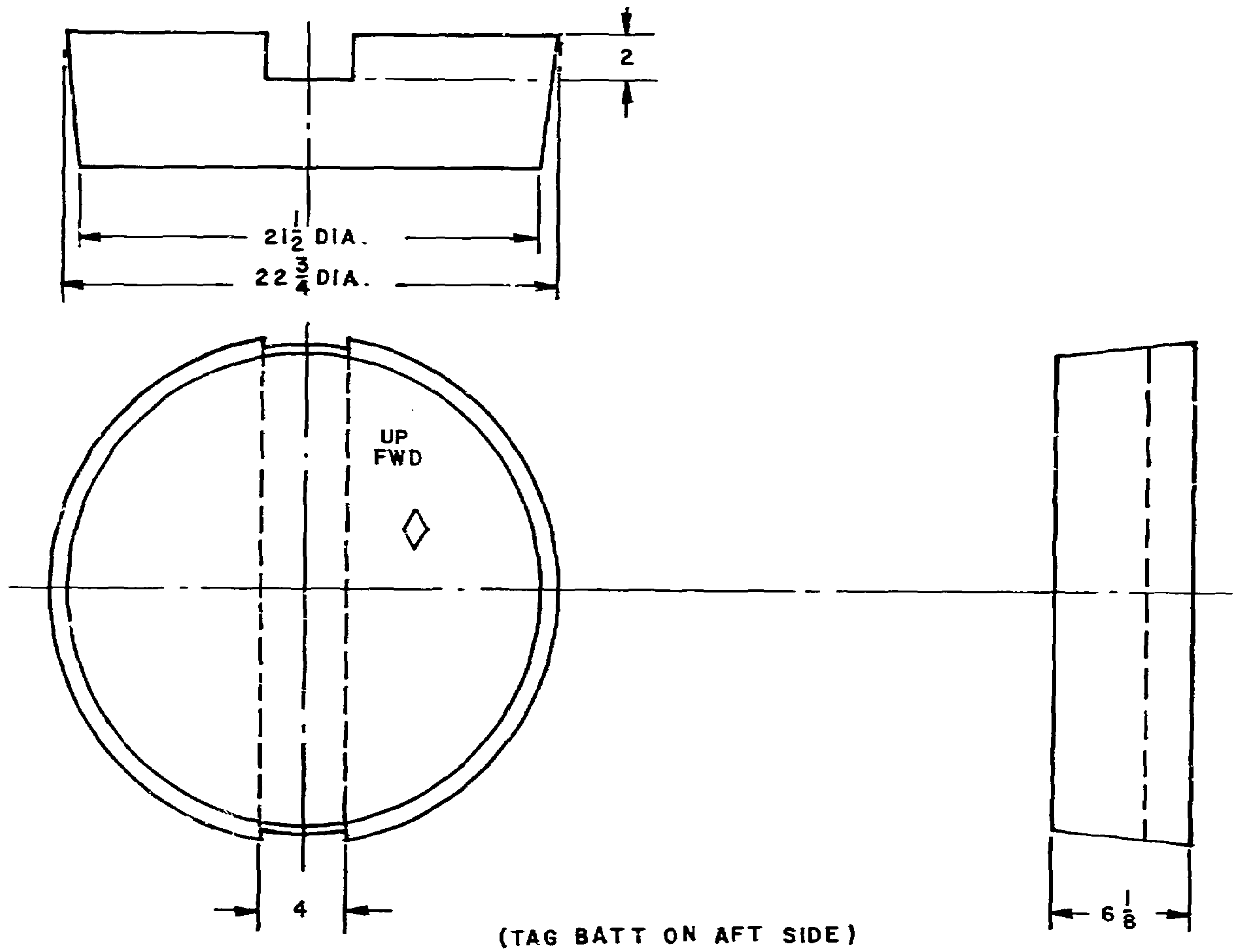


Figure D3-5. Nose Cone Batt A6 Detail

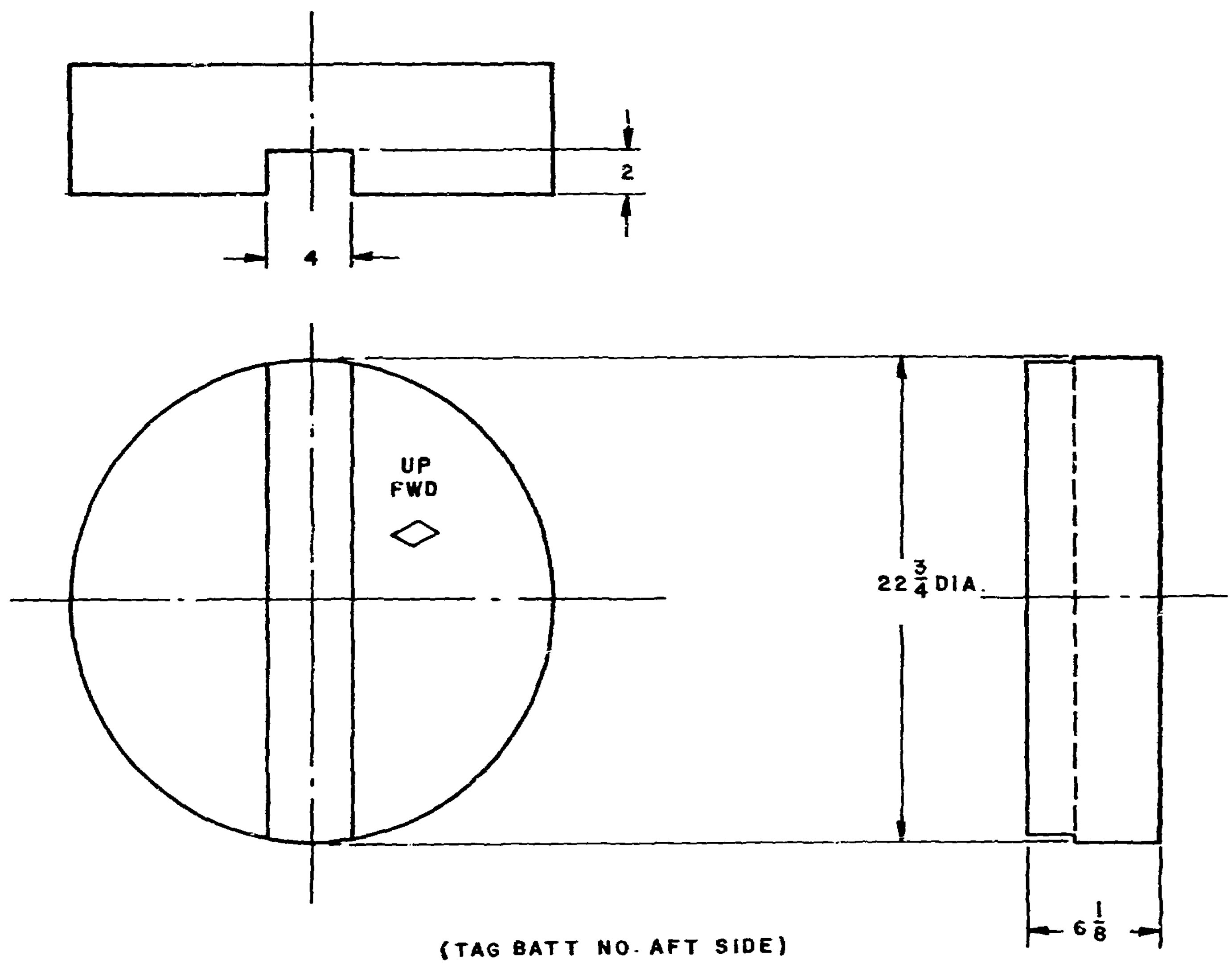


Figure D3-6. Nose Cone Batt A7 Detail

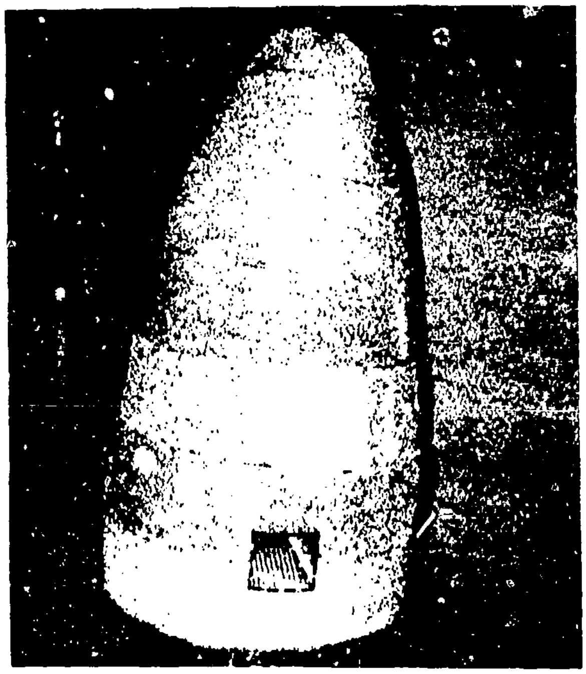


Figure D3-7. Batts for Nose Cone

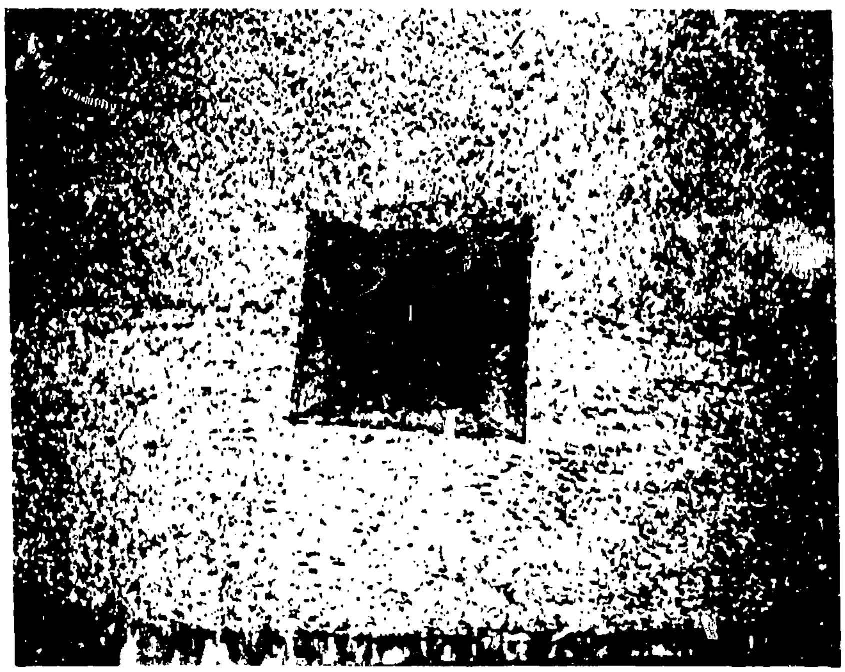


Figure D3-8. Void Below Filler Port

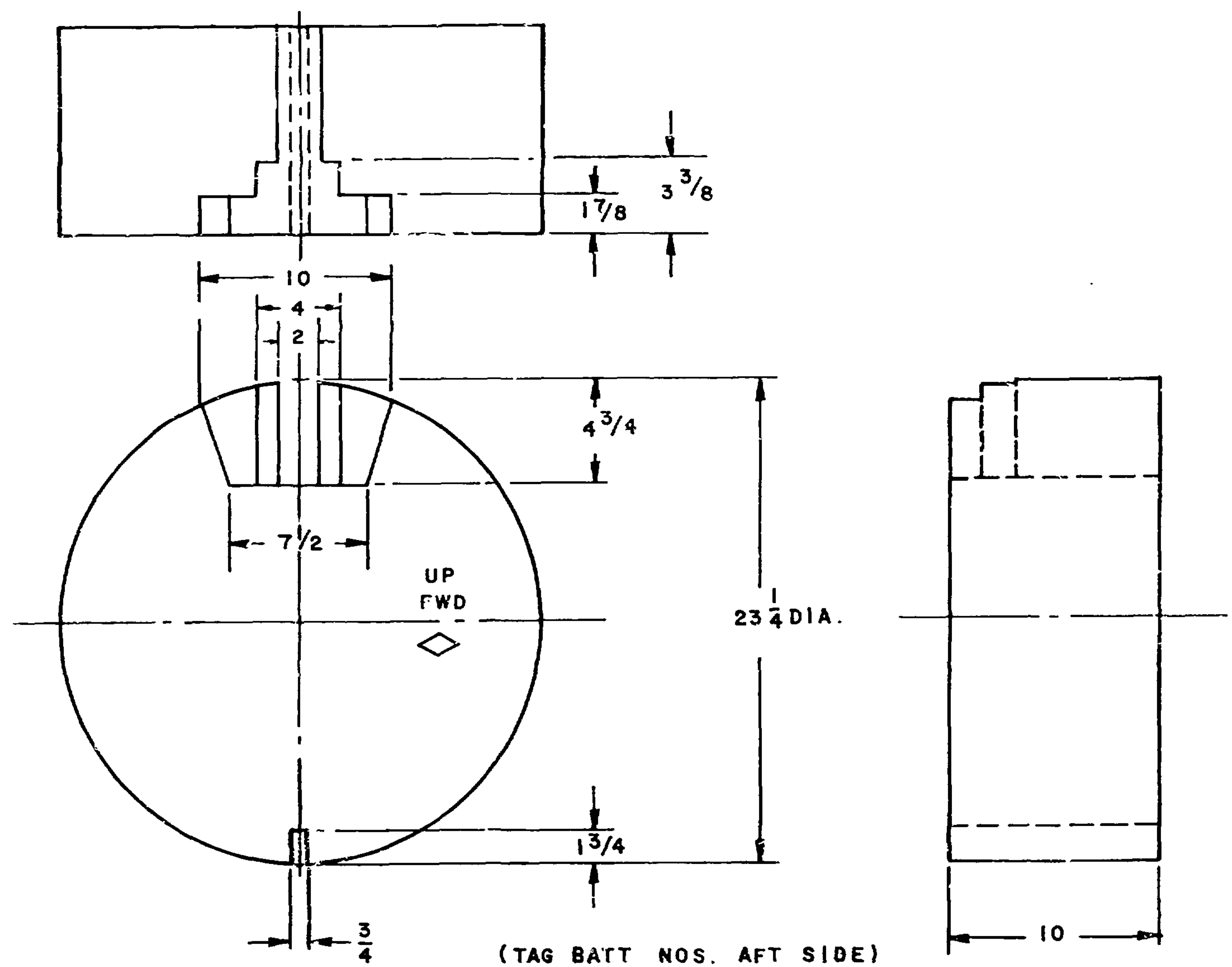
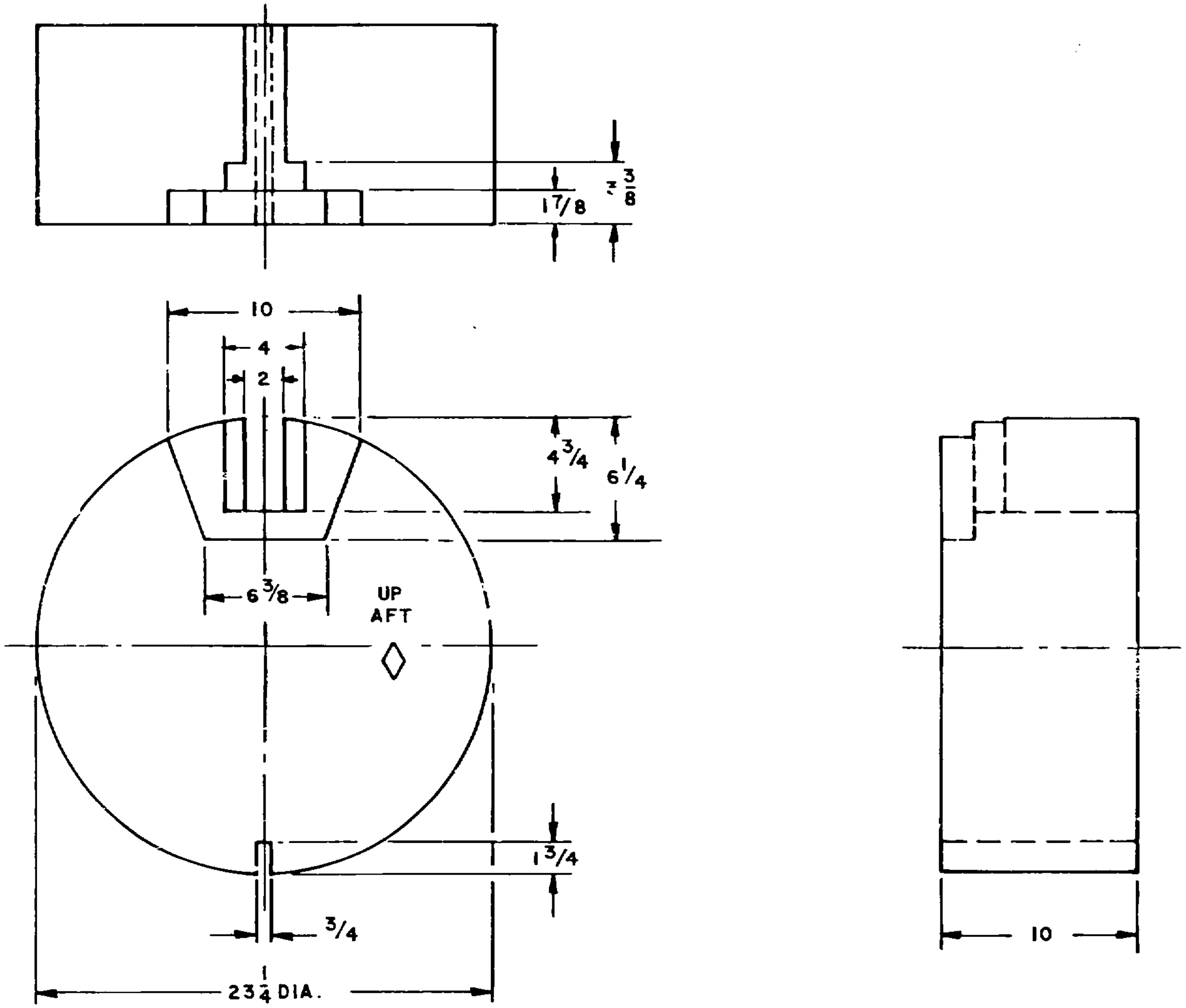
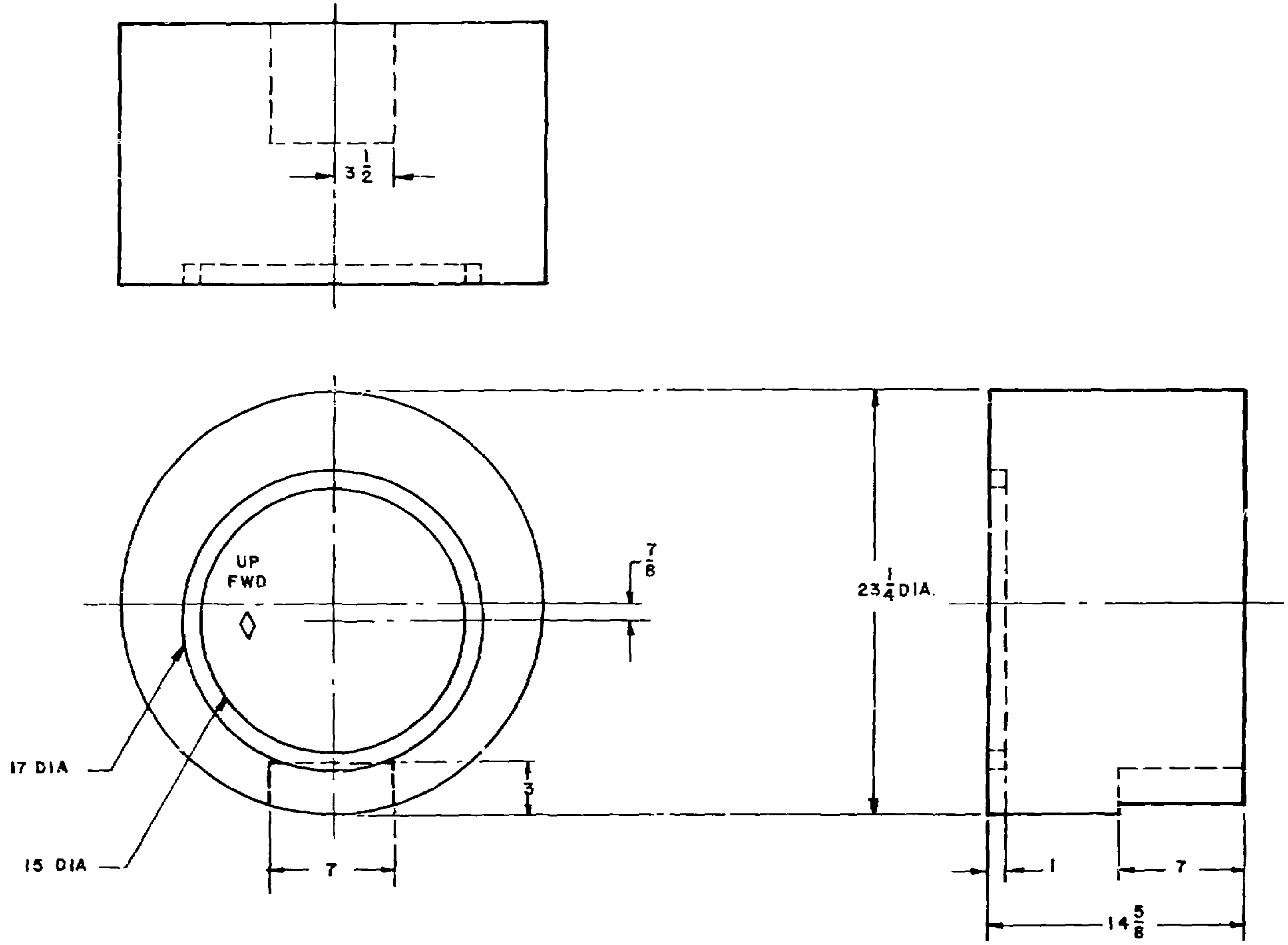


Figure D3-9. Midsection Batt B1 Detail



(TAG BATT ON AFT SIDE)

Figure D3-10. Midsection Batt B2 Detail



(TAG BATT NO. AFT SIDE)

Figure D3-11. Midsection Batt B3 Detail

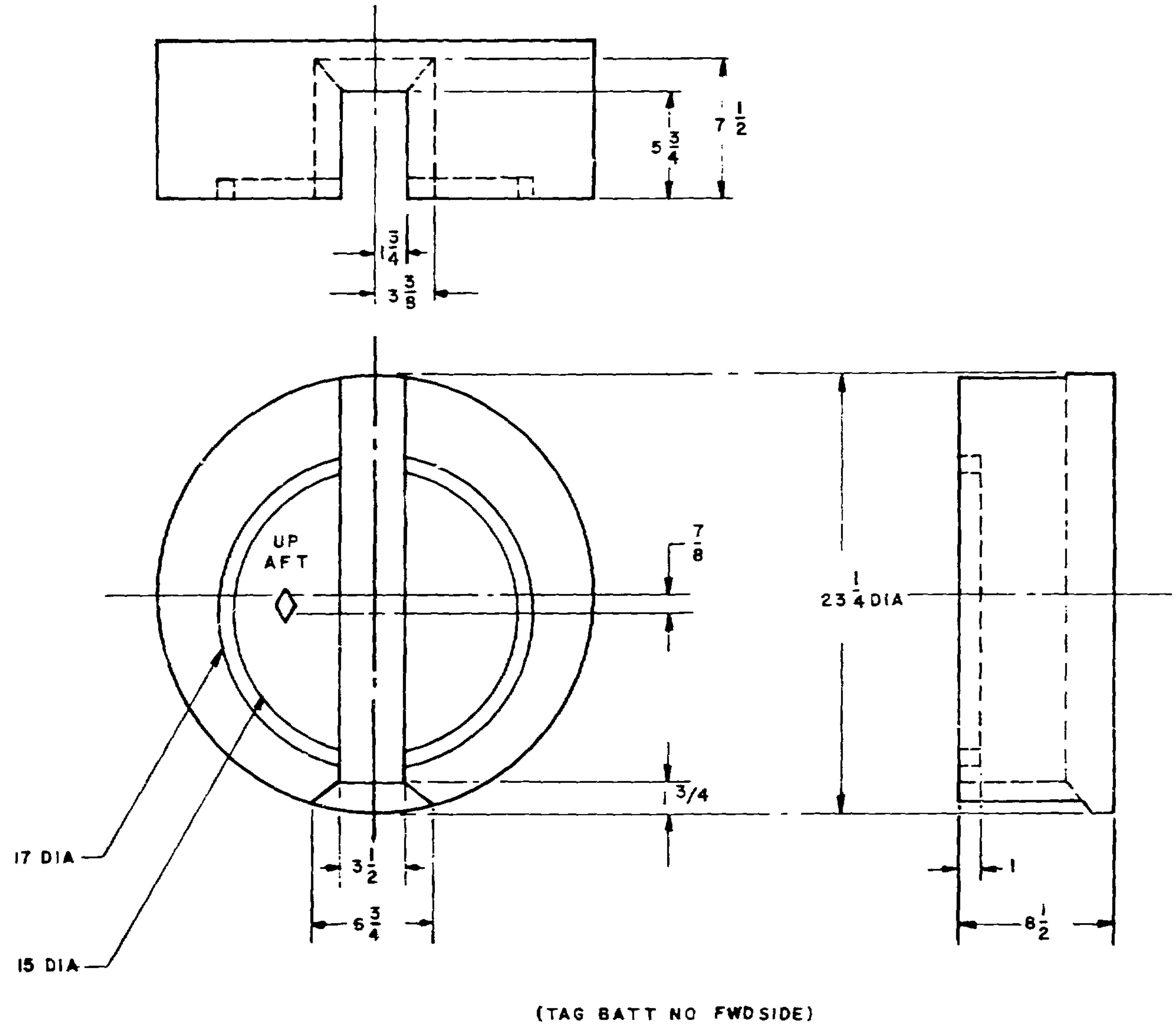
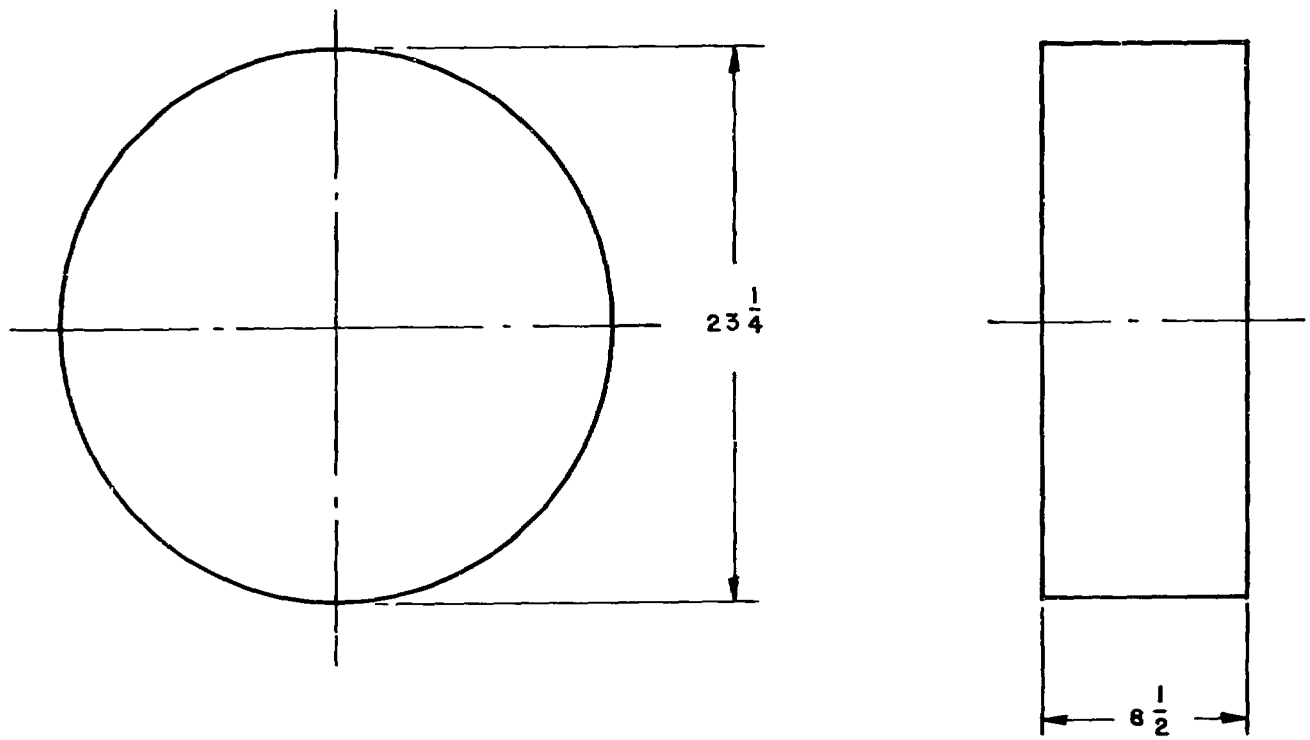


Figure D3-12. Midsection Batt B4 Detail



FOR DIAMOND ORIENTATION SEE TABLE D3-I

(TAG BATT NOS. FWD. SIDE)

Figure D3-13. Midsection Batts B5/B6 Detail

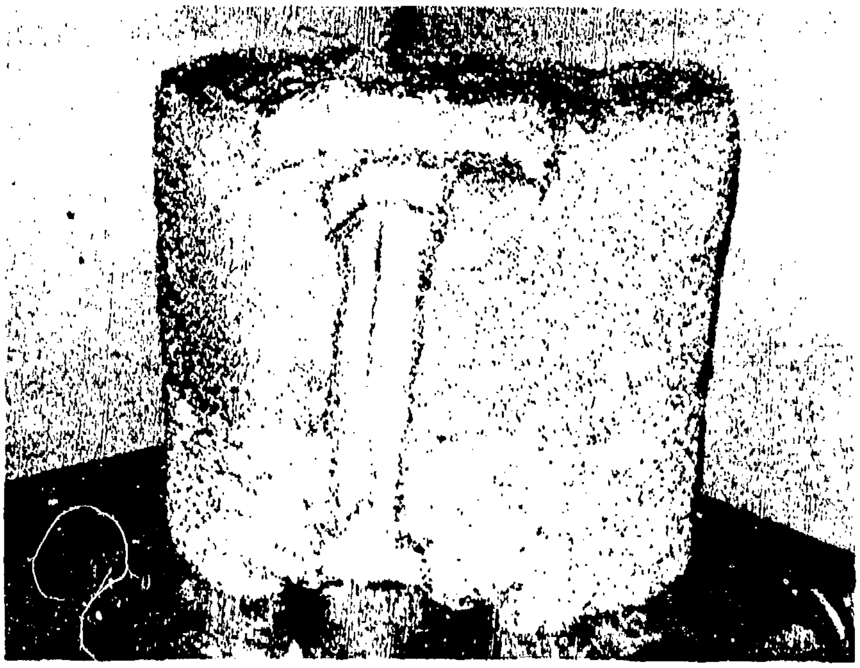


Figure D3-14. Batts B1 and B2 for Baffle Assembly

Figure D3-15. Batt B3 shows Voiding at Jiffy Drain

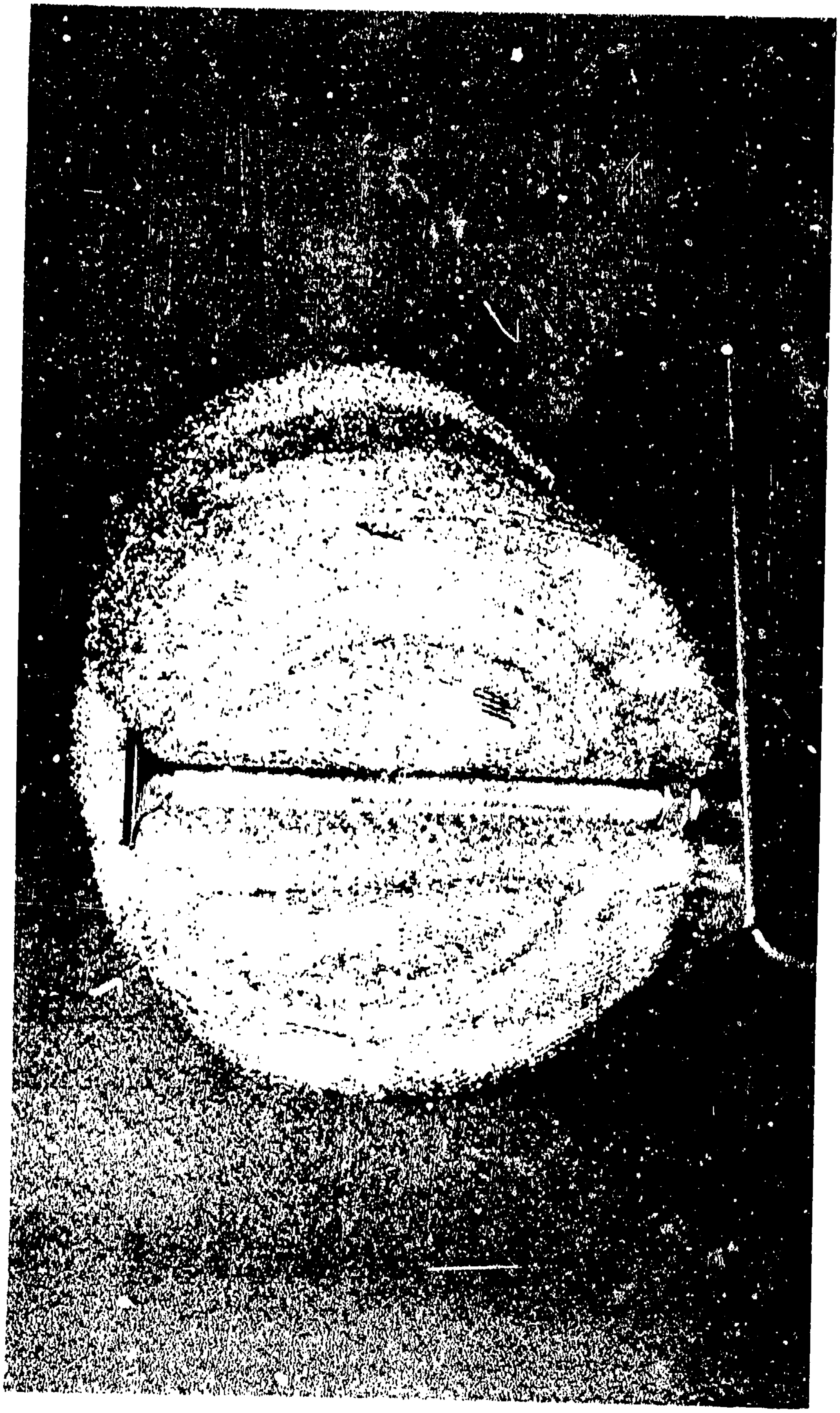
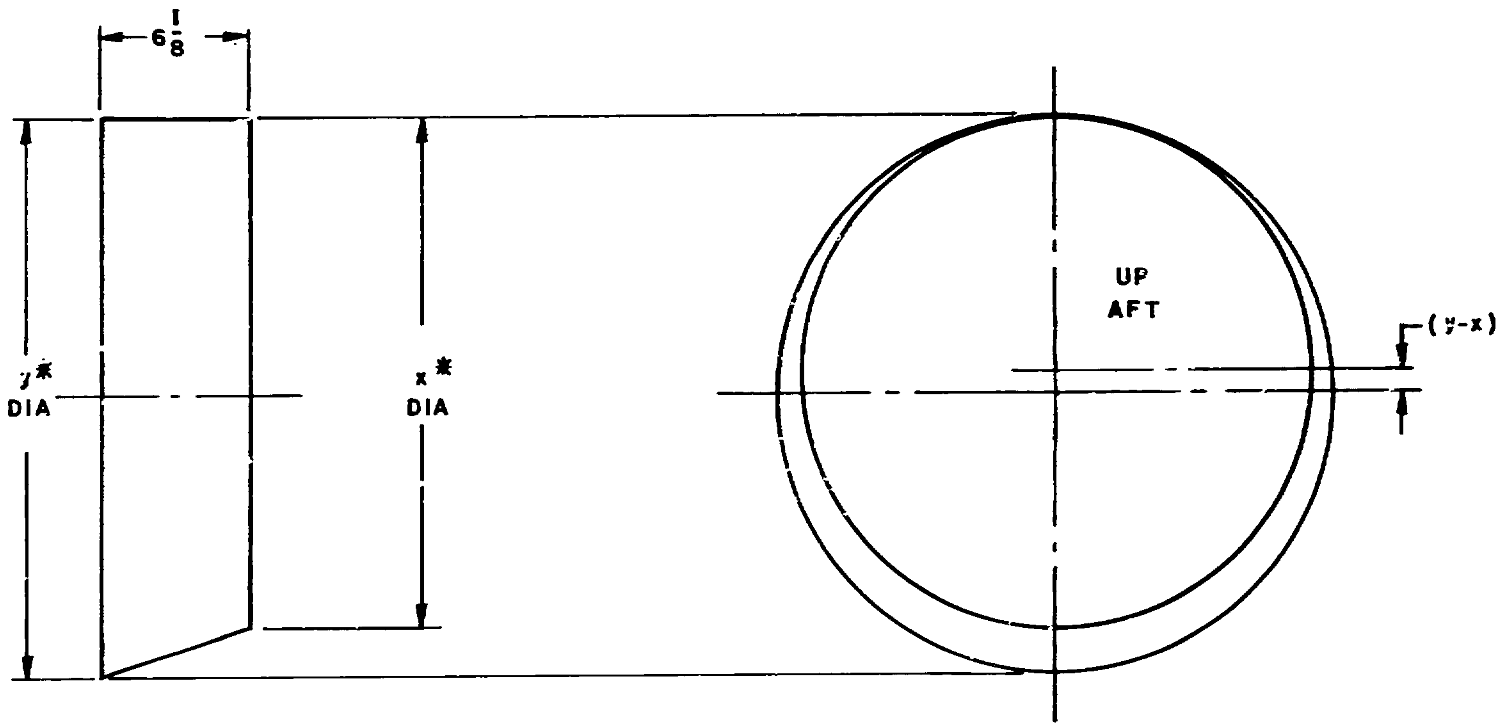


Figure D3-16. Batt B4 shows Voiding for Fuel Pick-Up Tube (shown top-side down)

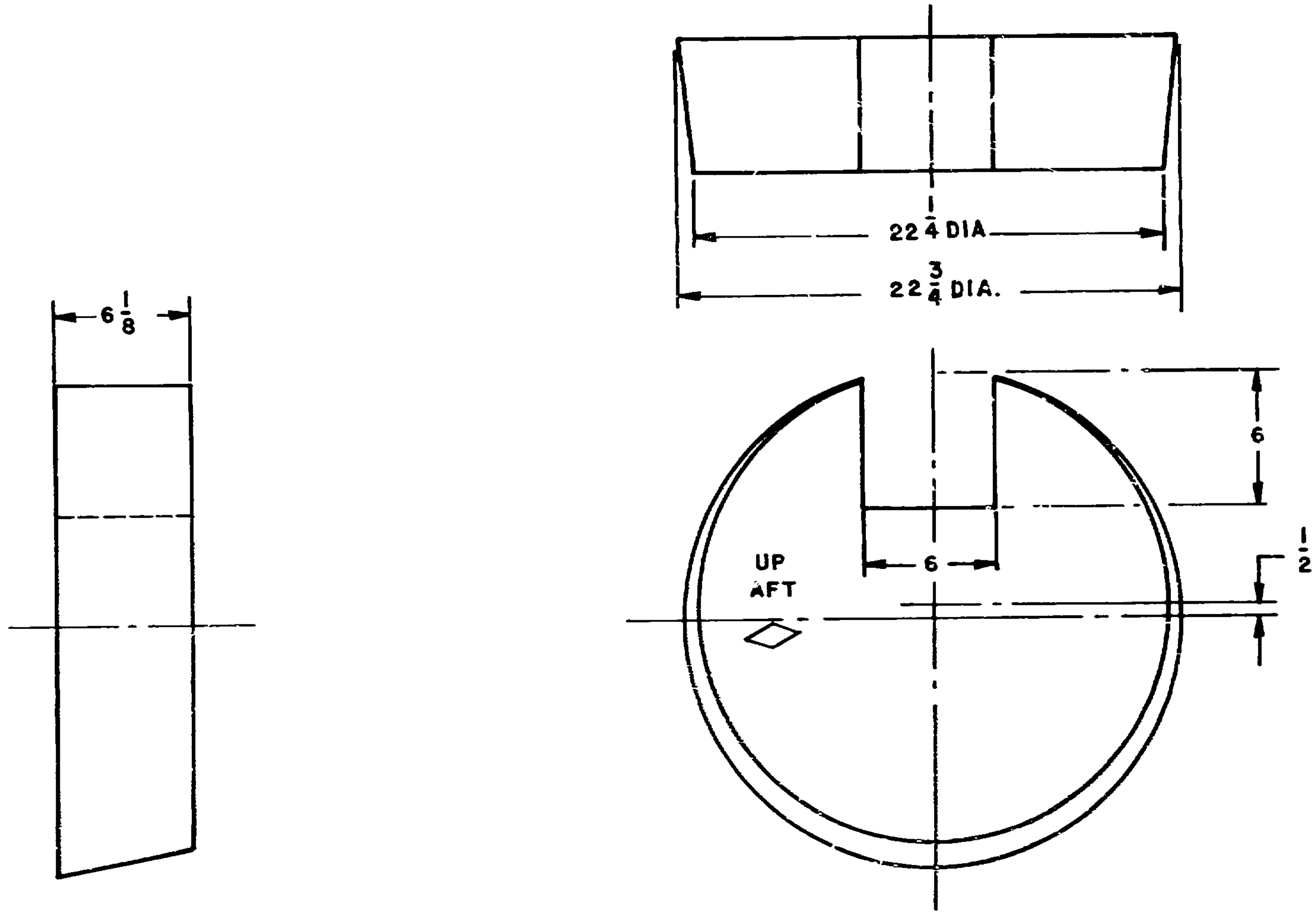


*SEE TABLE D3-1 FOR DIMENSIONS AND DIAMOND ORIENTATION

(TAG BATT NOS. FWD. SIDE)

DETAIL - C1,C2,C3,C4,C5,C6,C7

Figure D3-17. Tail Cone Batt Details



(TAG BATT NO. FWD SIDE)

Figure D3-18. Tail Cone Batt C8 Detail

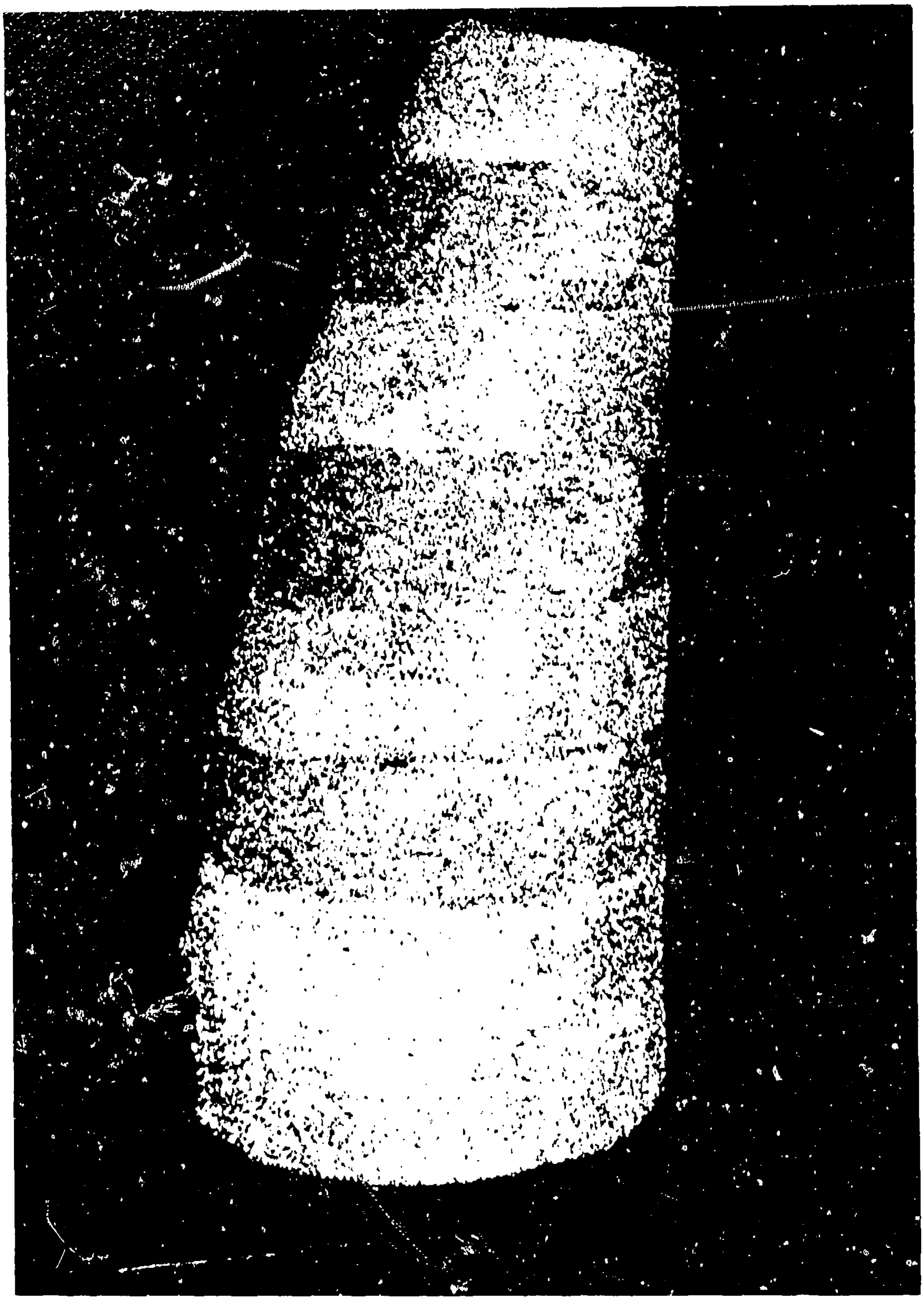


Figure D3-19. Batts for Tail Cone

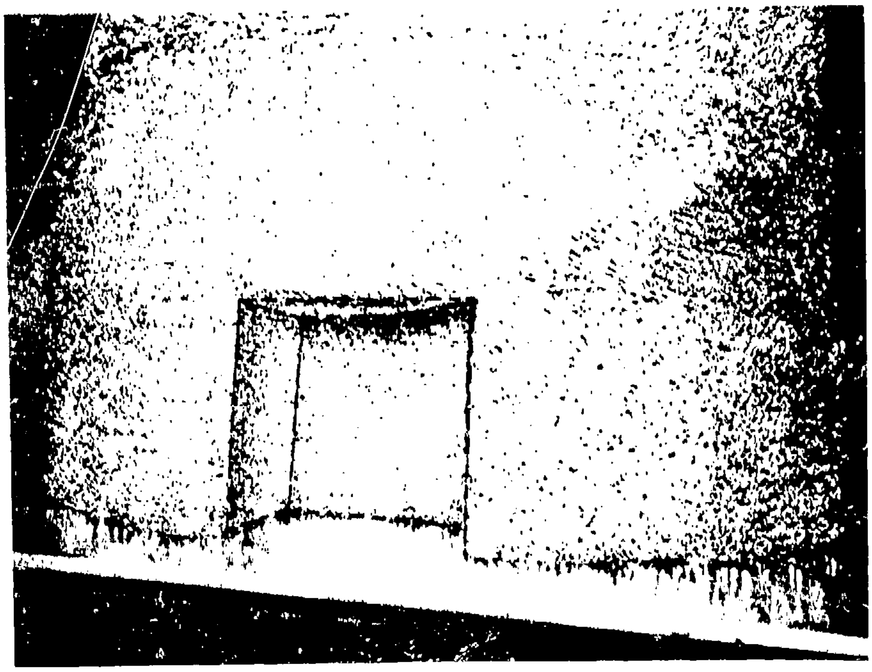


Figure D3-20. Batt C8 shows Voiding Simulated for Level Control Valve

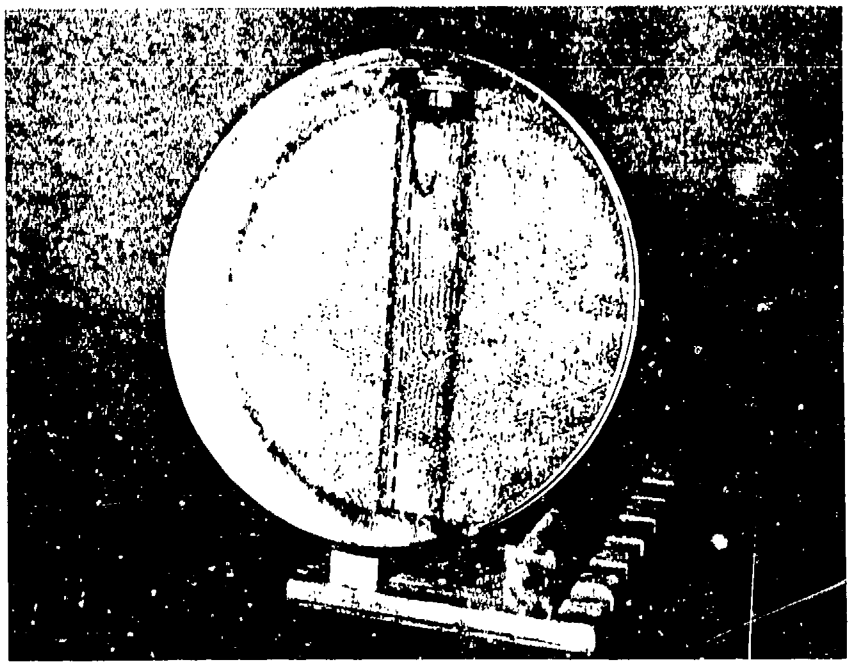


Figure D3-21. Nose Cone: Batt A6 in Place Showing Half of Void below Filler Port

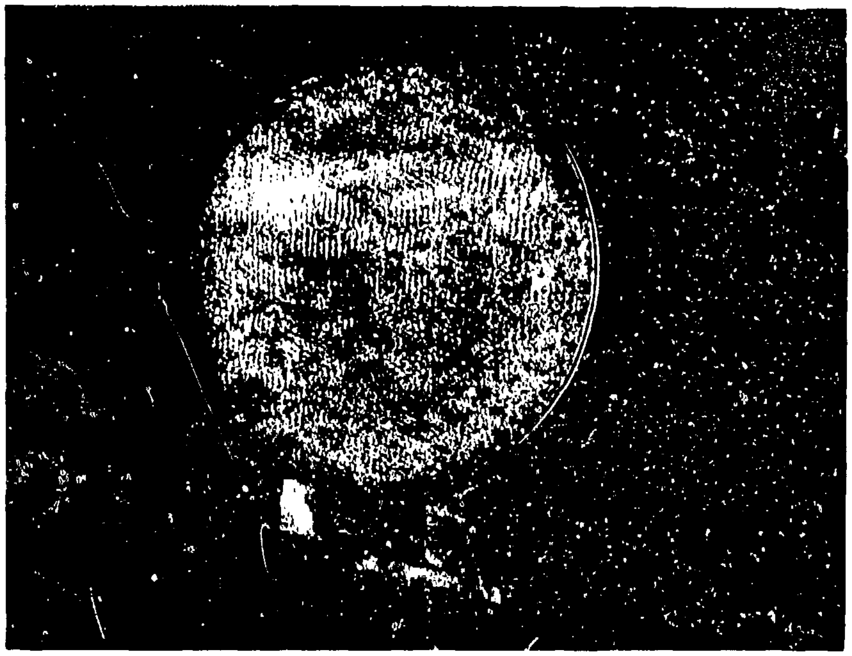


Figure D3-22. Nose Cone: Fully Packed

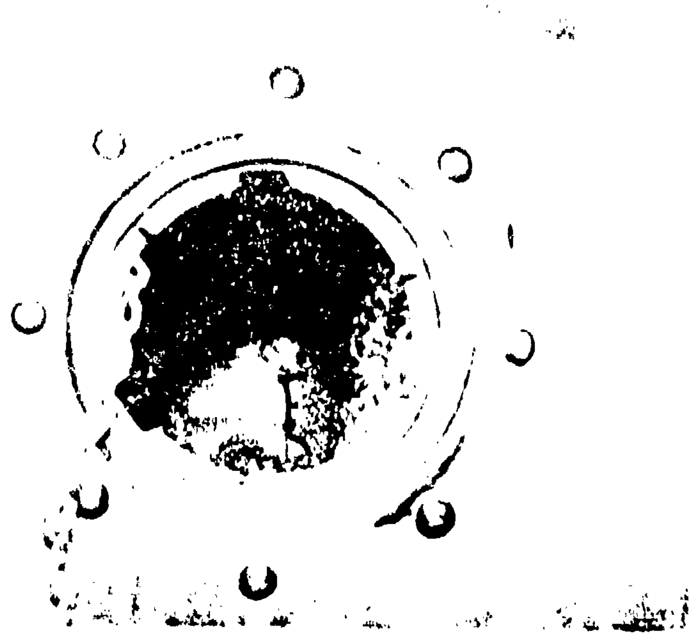


Figure D3-23. Nose Cone: Void Below Filler Port

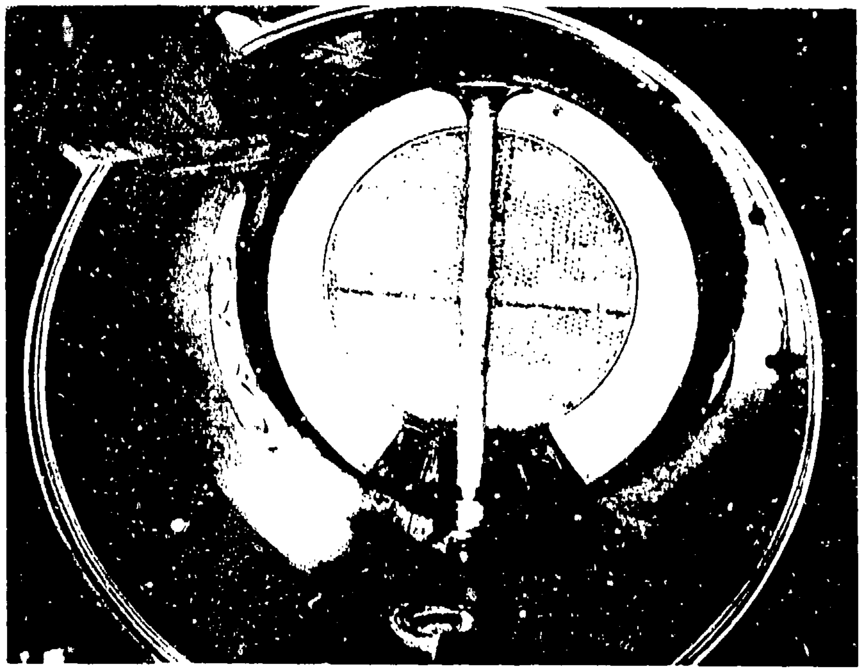


Figure D3-24. Midsection: Batt B1 in Place between Baffles

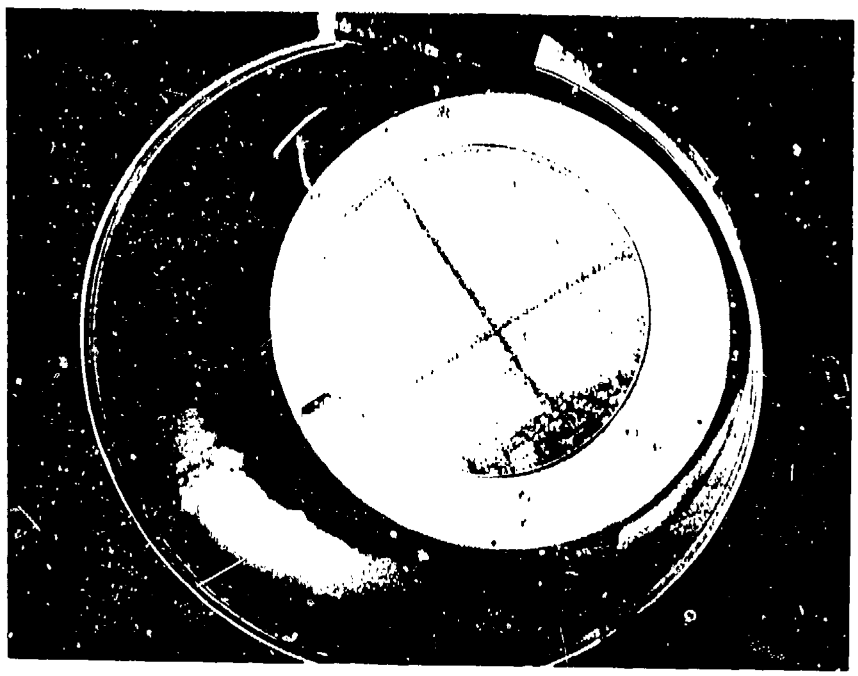


Figure D3-25. Midsection: Batt B2 in Place between Baffles

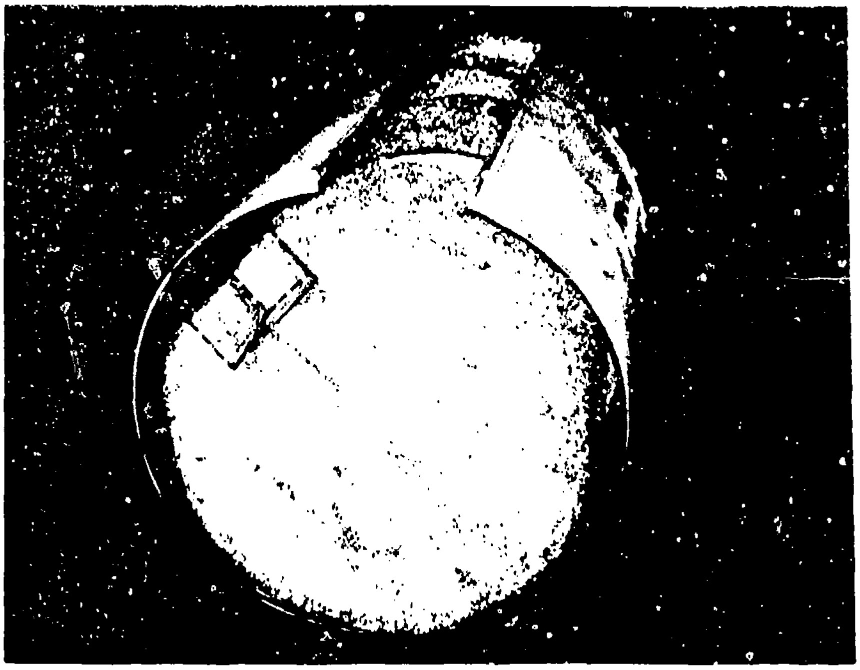


Figure D3-26. Midsection: Batt Layout

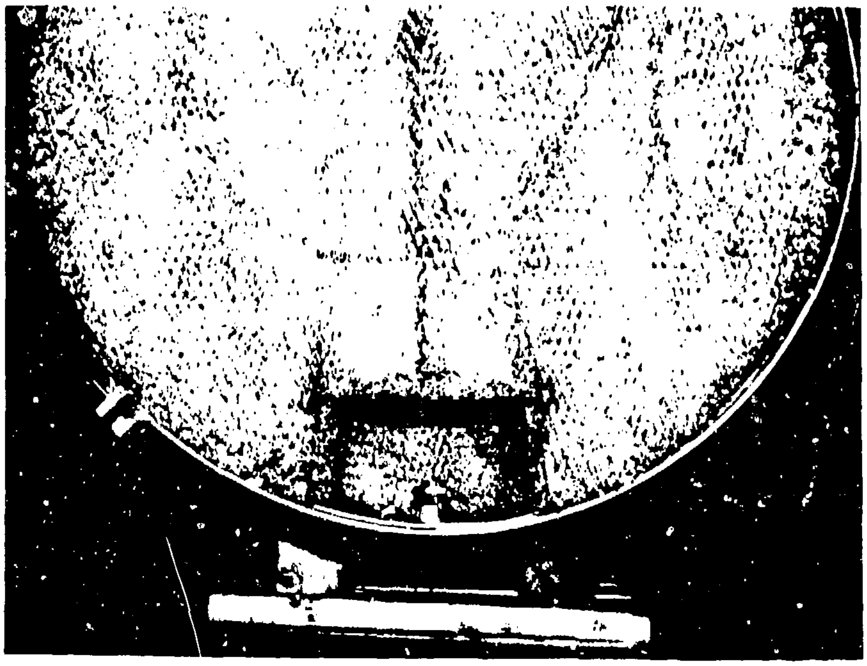


Figure D3-27. Midsection: Void in Batt B3 at Jiffy Drain

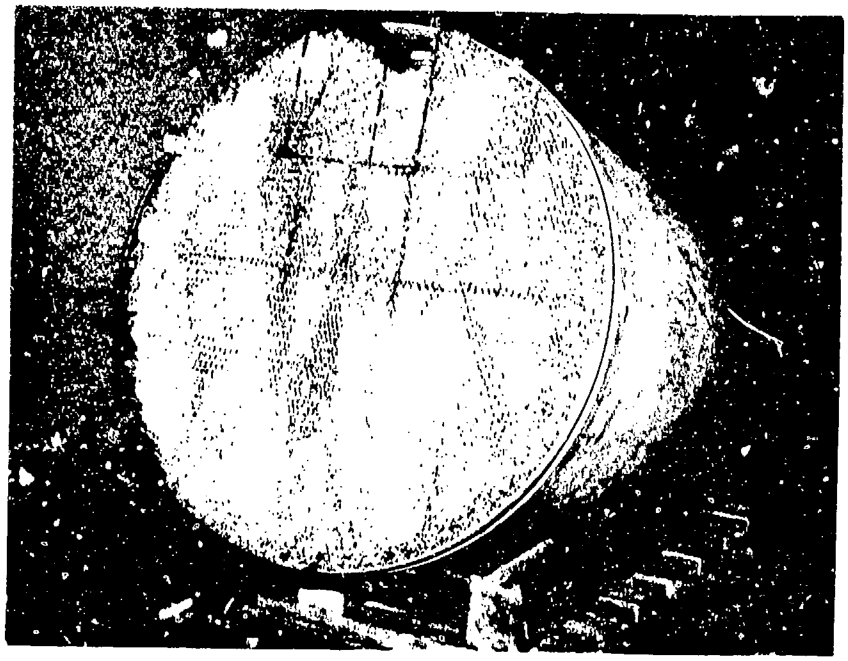


Figure D3-28. Tail Cone: Fully Packed

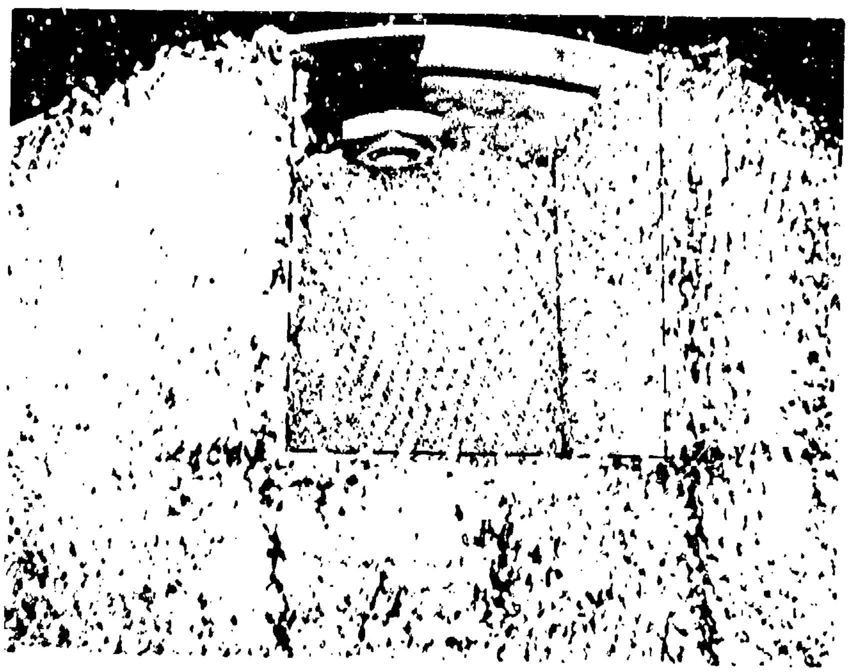


Figure D3-29. Tail Cone: Void for Level Control Valve in Batt C8

APPENDIX D 4

INSTALLATION STUDY

KELLETT 100 GALLON AUXILIARY FUEL TANK

Fuel Tank Description

The Kellett 100 gallon auxiliary fuel tank comes in three basic pieces: A forward domed section, an aft conical section and a cylindrical midsection containing a central bulk-head assembly. The volume of the tank, including the expansion area, is 14.44 cubic feet. Diagrammatic representation of the tank is shown in Figure D4-1.

Objective

The tank is to be packed with Explosafe, leaving voids at the side access window, below the fuel filler port (Figures D4-2 and D4-3) and at the drain.

Explosafe Material Used

0.002 inch thick 3003/H24 alloy aluminum foil, slit for 0.055 inch strand width, is expanded to 38 inch web-width and acked at 13.8 layers per inch height. The material expansion and stacking corresponds to a specific weight of about 2.2 pounds per cubic foot.

Manufacturing Procedure

All batts are cut to the required shapes with the aid of templates. The templates are essentially sets of masonite sheets with cut-outs to represent the fwd and aft face geometries of each batt. These are positioned on either side of a batt and held in place with 3 inch nails or pins pushed into the batt through pre-located holes.

Each batt is tagged with its batt number, orientation and position embossed on a 2 x 2 inch square of aluminum foil. The order of ascension of the numbers is also the sequence of installation. The tag is slipped in between the first two layers of foil of each batt and secured in place with stainless steel staples. The tags are located on the side of the batt that would face the installer. Figure D4-4 illustrates the complete set of tags.

The foil layers of the completed batts are held together with lengths of 16 gauge aluminum wire pushed through the batt and double bent at both ends.

Design

Batts are oversized by 2% in the Short Diamond direction to compensate for the tendency of the finished batts to shrink marginally in that direction. Also, the batt thickness is oversized by 2% to provide tighter packing and to compensate for any compacting. Table D4-1 lists the batt dimensions and Figure D4-5 shows the batt locations in the tank. Figures D4-6 through D4-18 illustrate the configurations and orientations of batts 1 through 14. The stitch locations are shown by x marks.

All batts, except batts 3 and 4, are designed so that their installation may be accomplished with all internal plumbing and fittings in place. Because of the nature of the plumbing in the midsection, and the need for substantial voiding below the filler port, it would not be possible to adequately maintain the physical integrity of batt 4 and, to some extent, batt 3 if these were sectioned and voided for installation around pre-installed plumbing.

Batts 5 (b) and 6 (a), both of which are voided to provide clearance at the access window are, by themselves, non self-supporting when positioned as shown in Figures D4-11 and D4-13. To give these batts support, batt 5 (b) is unitized with batt 5 (a) to give a single batt 5 (a+b), and batt 6 (a) is unitized with batt 6 (b) to give a single batt 6 (a+b).

Installation Procedure

Midsection

Batts 1 (a), 1 (b) and 1 (c) which are identical batts, each consisting of 2 outer sections and an inner section (Figure D4-6), are to be packed between the fwd and aft bulkheads.

Entering from the aft end of the midsection, the outer sections of batts 1 (a), 1 (b) and 1 (c) are placed against the walls of the tank between the bulkheads. Once all the outer sections are in place, the inner sections are inserted between them. For ease of installation, it is necessary to separate the contacting foil surfaces of the inner and outer sections with sized cardboard sheets before the inner sections are inserted. The cardboard sheets are removed once the inner sections are in place.

Batts 2 (a), 2 (b) and 2 (c) can now be installed behind the aft bulkhead.

The electrical conduit, the air line and the fuel line should be removed before installing batts in front of the fwd bulkhead. Once batt 3 is in place, the electrical conduit and air line are installed. Next, batt 4 is installed. The fuel line is refitted and the remaining batts 5 (a+b) and 6 (a+b) are installed. During installation the foil should be protected from the securing nut rings of the access panel and filler area by sheets of cardboard. The cardboard should be removed after the affected batts are in place.

Nose and Tail Sections

Batts for the nose and tail sections are installed in ascending order of their assigned batt numbers.

TABLE D4-1. BATT DIMENSIONS

Batt Nos.	Batt Thickness (z) (Oversized 2%)	Template Nos. Fwd.	Aft.	Long Diamond Diameter Fwd (x)	Aft (y)	Short Diamond Diameter (Oversized 2%) Fwd (x)	Aft (y)
1(a)	6.12	1	1	18.31	18.31	18.62	18.62
1(b)	6.12	1	1	18.31	18.31	18.62	18.62
1(c)	6.12	1	1	18.31	18.31	18.62	18.62
2(a)	10.12	2	2	18.31	18.31	18.62	18.62
2(b)	10.12	2	2	18.31	18.31	18.62	18.62
2(c)	10.12	2	2	18.31	18.31	18.62	18.62
3	6.50	2	2	18.31	18.31	18.62	18.62
4	6.50	3	4	18.31	18.31	18.62	18.62
5(a)	8.00	5	6	18.31	18.31	18.62	18.62
5(b)	3.37	7	7	18.31	18.31	18.62	18.62
6(a)	3.37	8	8	18.31	18.31	18.62	18.62
6(b)	4.25	9	9	18.31	18.31	18.62	18.62
7	3.00	10	11	3.00	11.37	3.12	11.62
8	3.00	11	12	11.37	14.87	11.62	15.19
9	4.00	12	13	14.87	17.37	15.19	17.75
10	4.00	13	2	17.37	18.31	17.75	18.62
11	4.50	14	15	6.69	2.00	6.87	2.00
12	7.12	16	14	14.75	6.69	15.00	6.87
13	3.06	17	16	16.87	14.75	17.25	15.00
14	6.06	18	19	18.31	16.87	18.62	17.25

Void Analysis

Capacity of Tank
(including 8% expansion area) = 108 gallons U.S.
= 14.44 cu.ft.

Batt No.	Void (cu.in.)
1 (a)	52
1 (b)	52
1 (c)	52
4	416
5 (a)	158
5 (b)	312
6 (a)	306
6 (b)	27
14	26

Total Gross Void: 1401 cu. in. = 0.81 cu.ft.

Percent Gross Void:

$$= \frac{\text{Gross Void}}{\text{Capacity of Tank}} \times 100$$

$$= \frac{0.81}{14.44} \times 100$$

$$= 5.6 \%$$

Explosafe Material Density (actual)

Weight of Explosafe kit: 31.1 lbs.

Volume of Explosafe: = Capacity of Tank-Gross Void
= (14.44 - 0.81) cu. ft.
= 13.63 cu.ft.

Material Density $= \dfrac{\text{Weight of Explosafe}}{\text{Volume of Explosafe}}$

$= \dfrac{31.1}{13.63} \; \dfrac{\text{lbs}}{\text{cu.ft.}}$

$= 2.28$ lbs/cu.ft.

Packing Density

Packing Density $= \dfrac{\text{Weight of Explosafe}}{\text{Capacity of Tank}}$

$= \dfrac{31.1}{14.44} \; \dfrac{\text{lbs}}{\text{cu.ft.}}$

$= 2.15$ lbs/cu.ft.

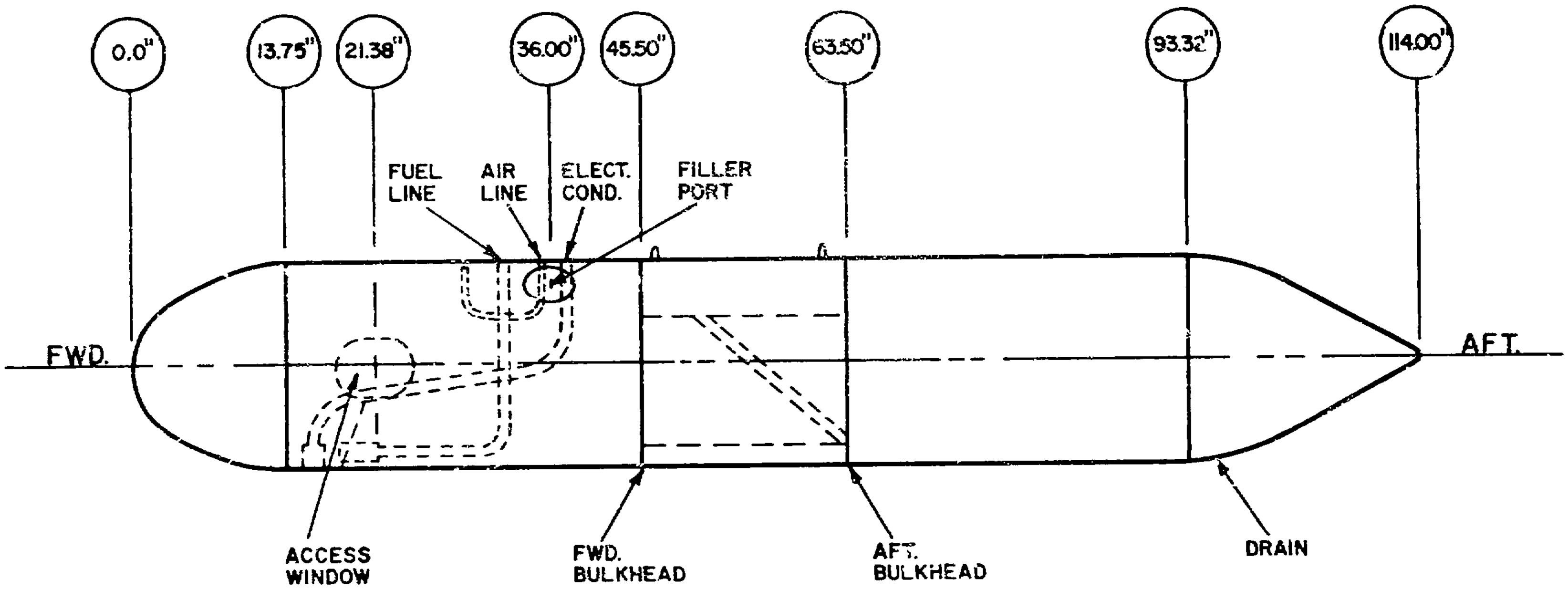


Figure D4-1. Kellett 100 Gallon Auxiliary Fuel Tank

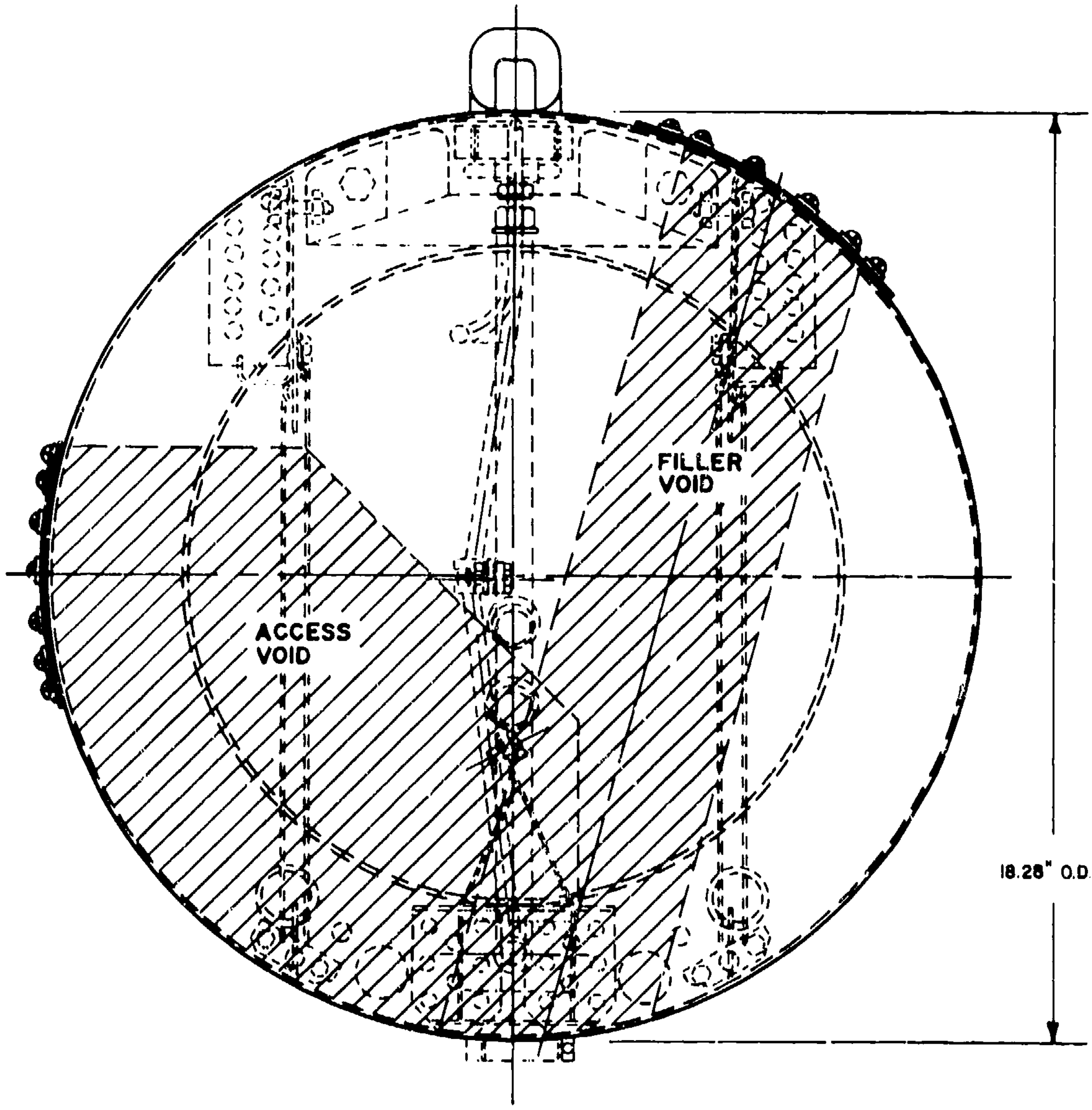


Figure D4-2. Cross Section of Kellett Tank showing Locations of Filler and Access Voids

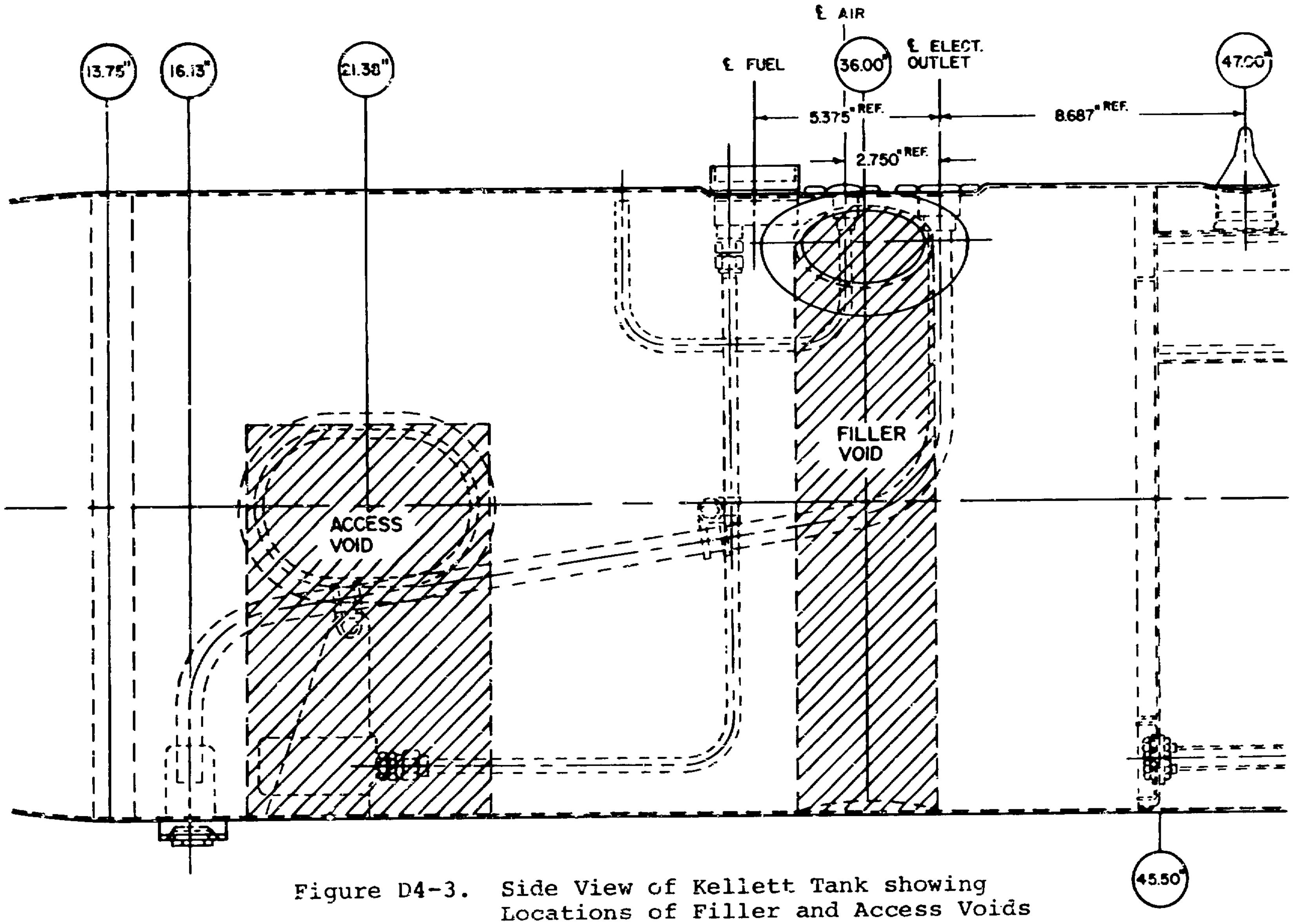


Figure D4-3. Side View of Kellett Tank showing Locations of Filler and Access Voids

BATT 1 (a) UP/AFT KELLETT 385-68500	BATT 1 (b) UP/AFT KELLETT 385-68500	BATT 1 (c) UP/AFT KELLETT 385-68500	BATT 2 (a) UP/AFT KELLETT 385-68500	BATT 2 (b) UP/AFT KELLETT 385-68500
BATT 2 (c) UP/AFT KELLETT 385-68500	BATT 3 UP/FWD KELLETT 385-68500	BATT 4 UP/FWD KELLETT 385-68500	BATT 5 (a+b) UP/FWD KELLETT 385-68500	BATT 6 (a+b) UP/FWD KELLETT 385-68500
BATT 7 UP/AFT KELLETT 385-68500	BATT 8 UP/AFT KELLETT 385-68500	BATT 9 UP/AFT KELLETT 385-68500	BATT 10 UP/AFT KELLETT 385-68500	BATT 11 UP/FWD KELLETT 385-68500
BATT 12 UP/FWD KELLETT 385-68500	BATT 13 UP/FWD KELLETT 385-68500	BATT 14 UP/FWD KELLETT 385-68500		

Figure D4-4. List of Batt Identification Tags

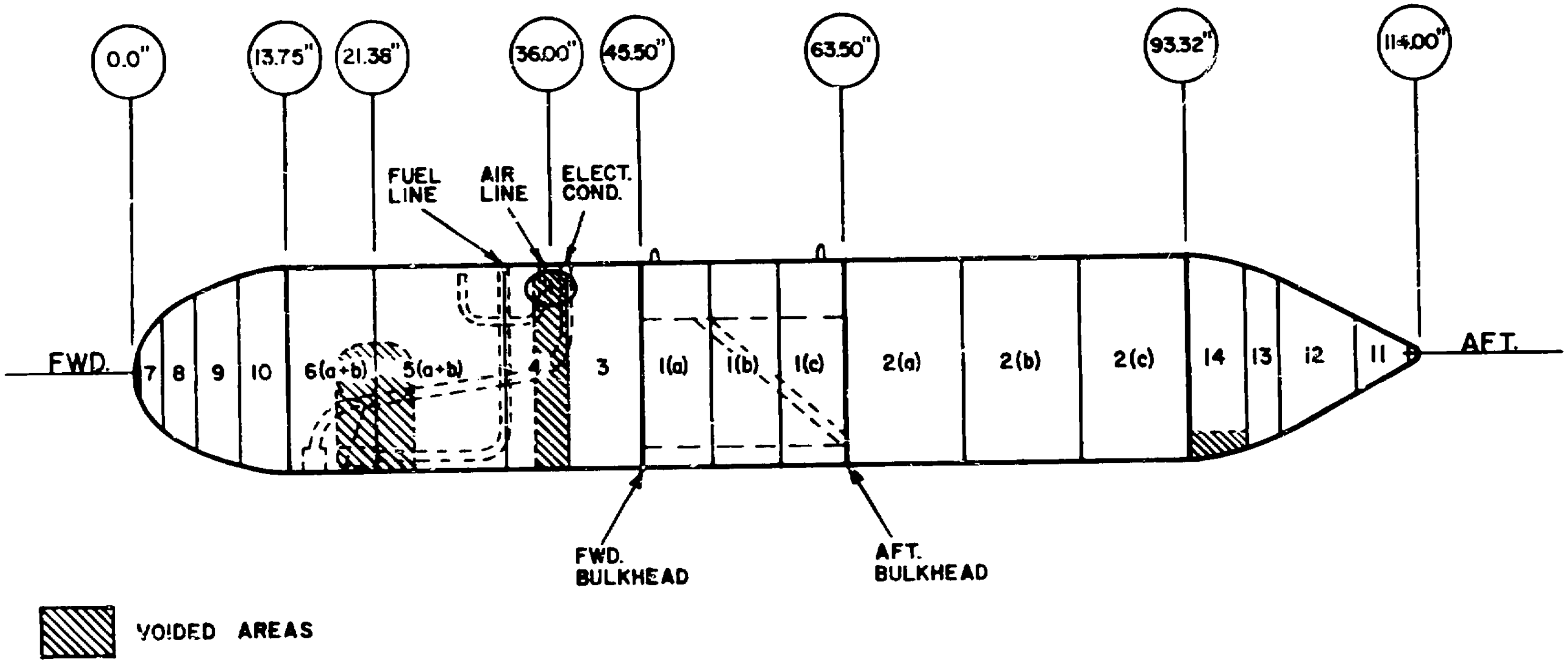


Figure D4-5. Batt Layout for Kellett 100 Gallon Auxiliary Fuel Tank

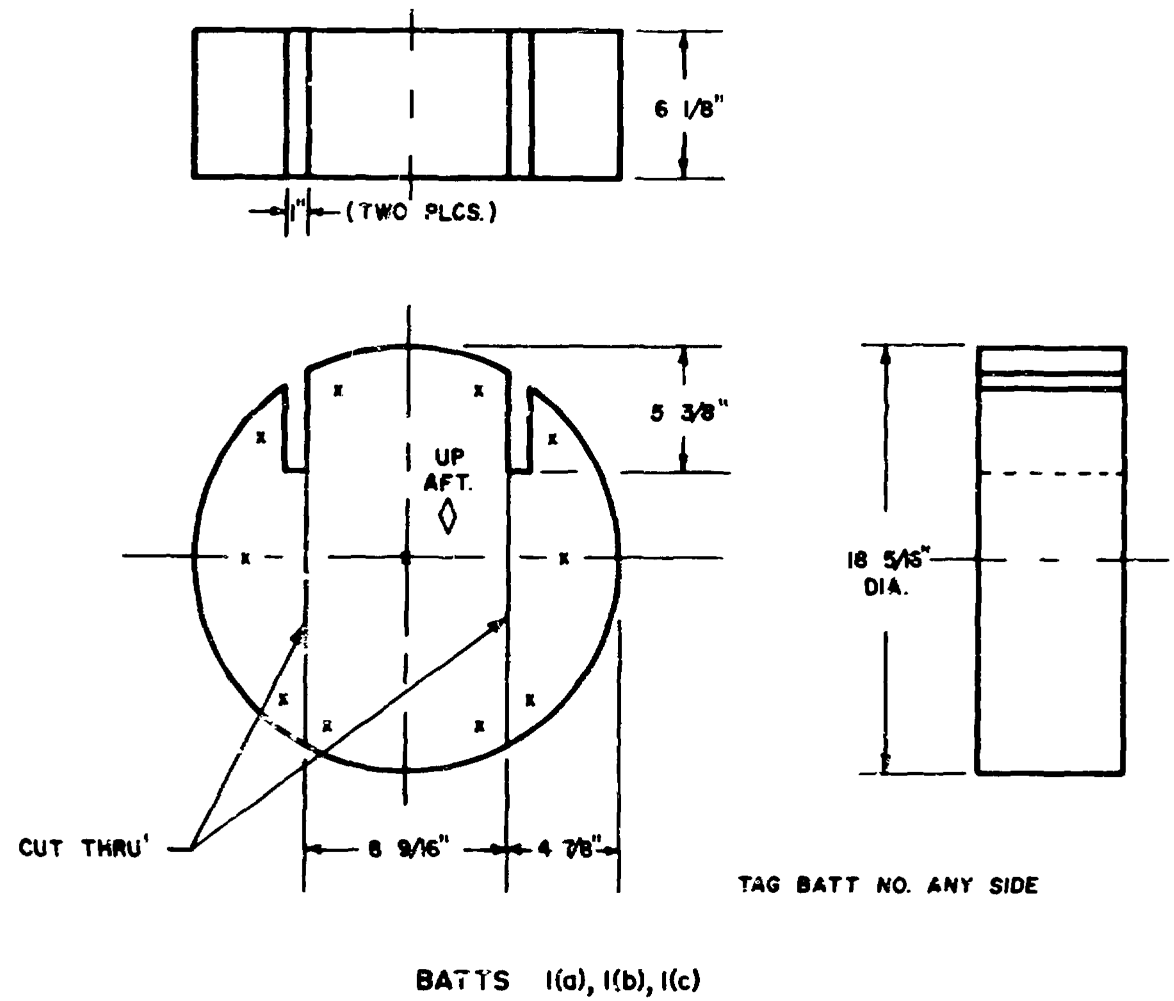


Figure D4-6. Batt Detail, Kellett 100 Gallon Tank

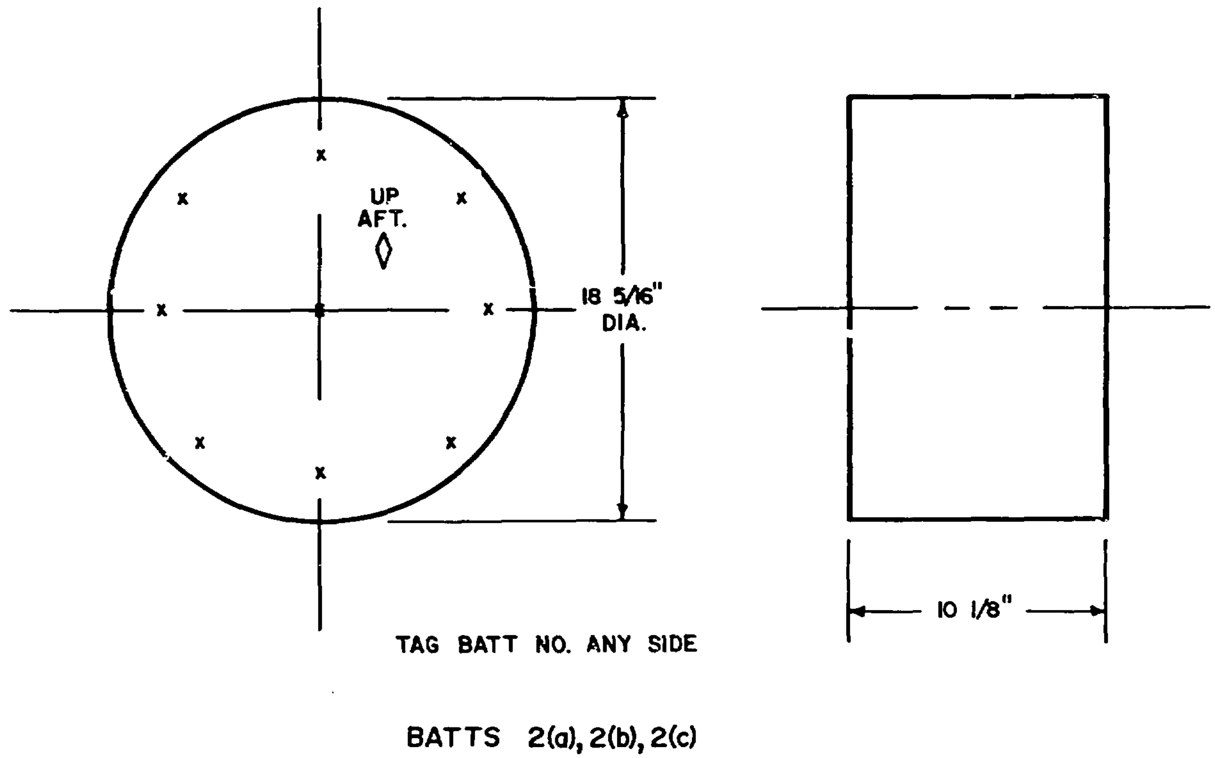
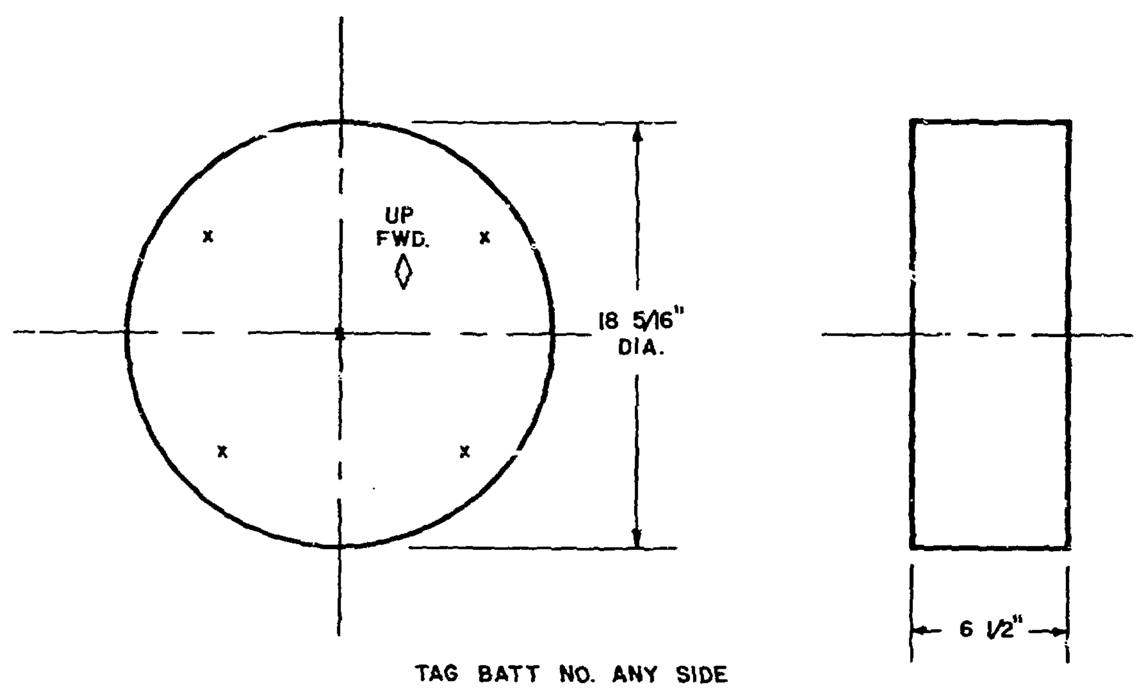


Figure D4-7. Batt Detail, Kellett 100 Gallon Tank



BATT 3

Figure D4-8. Batt Detail, Kellett 100 Gallon Tank

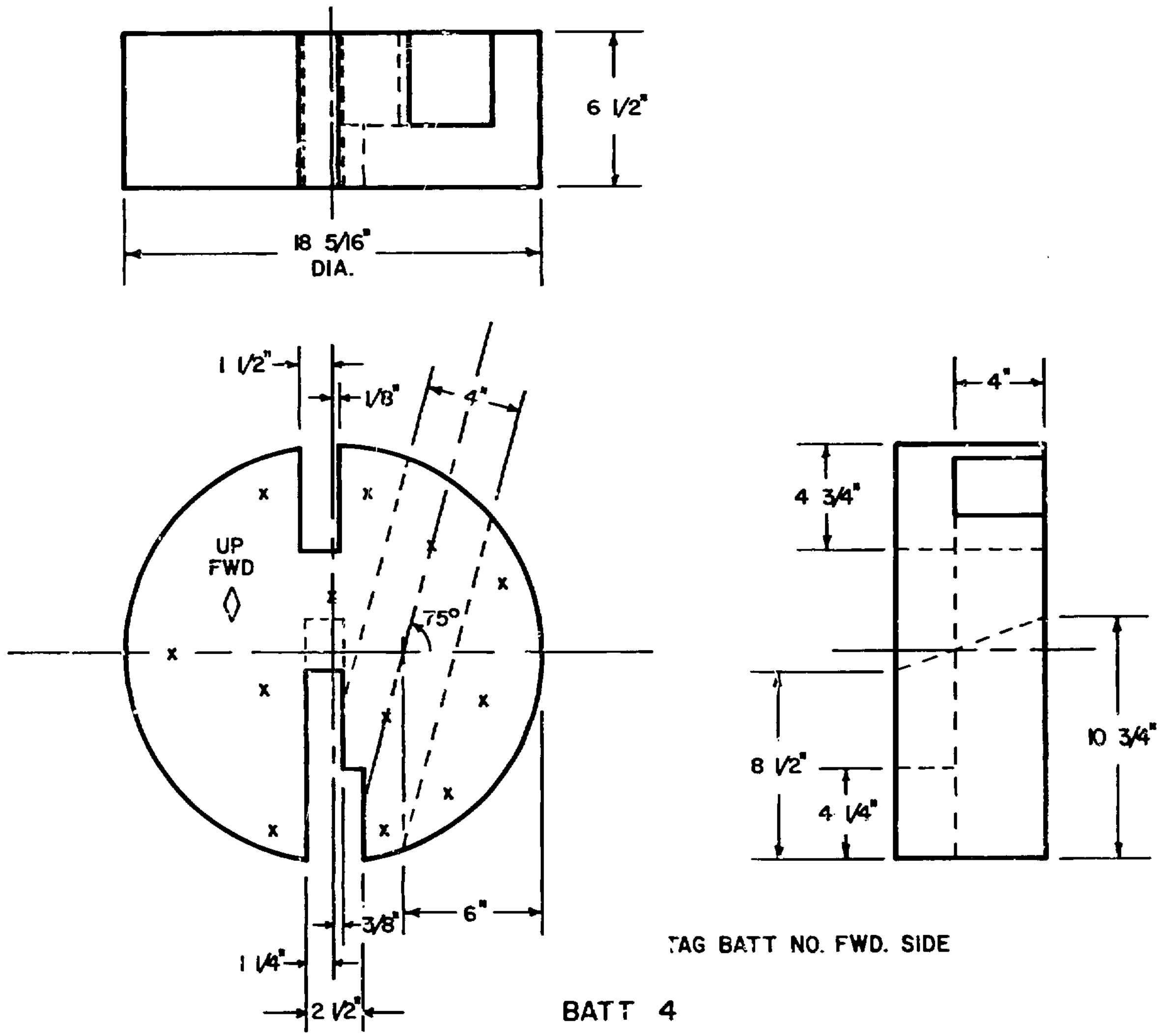


Figure D4-9. Batt Detail, Kellett 100 Gallon Tank

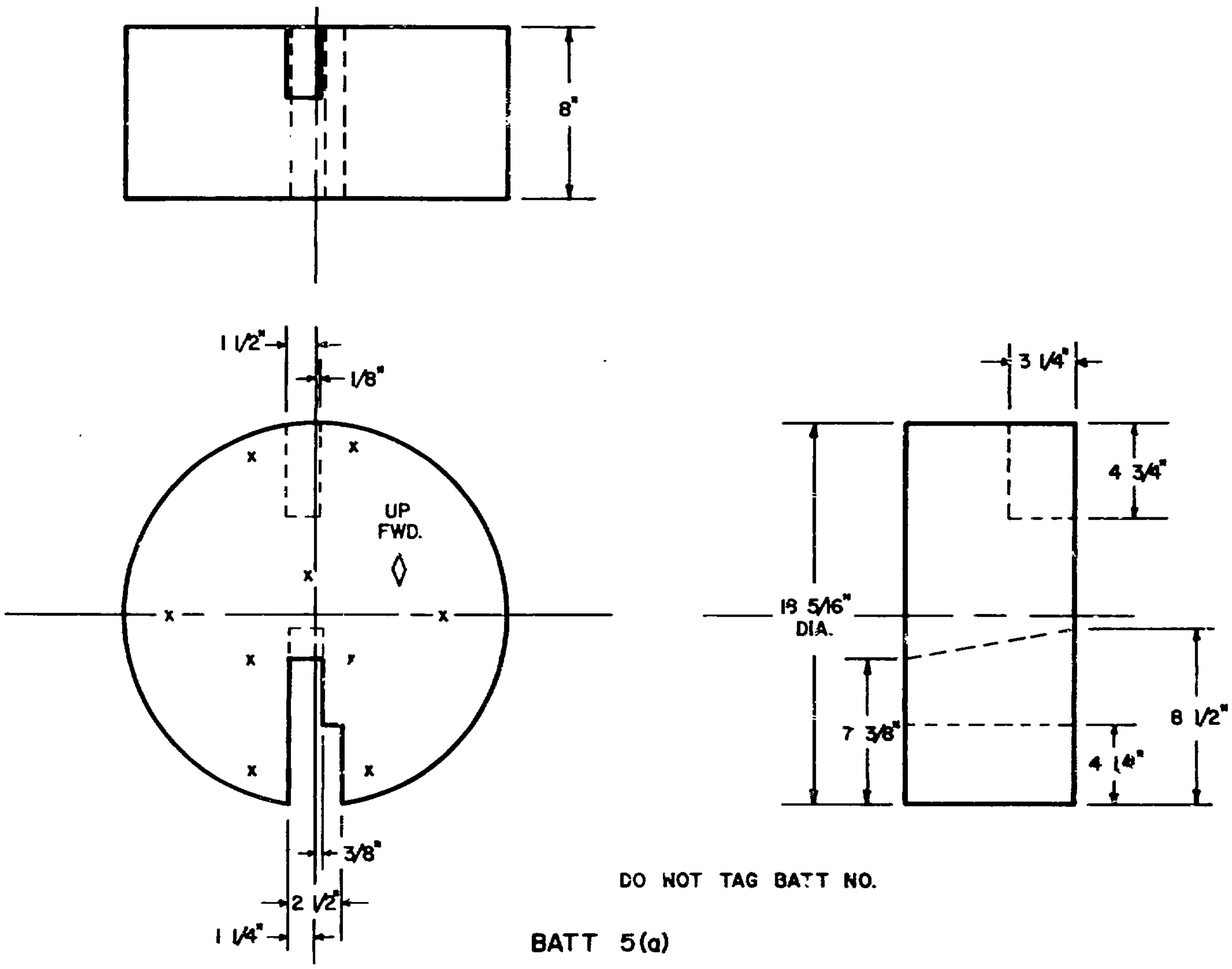
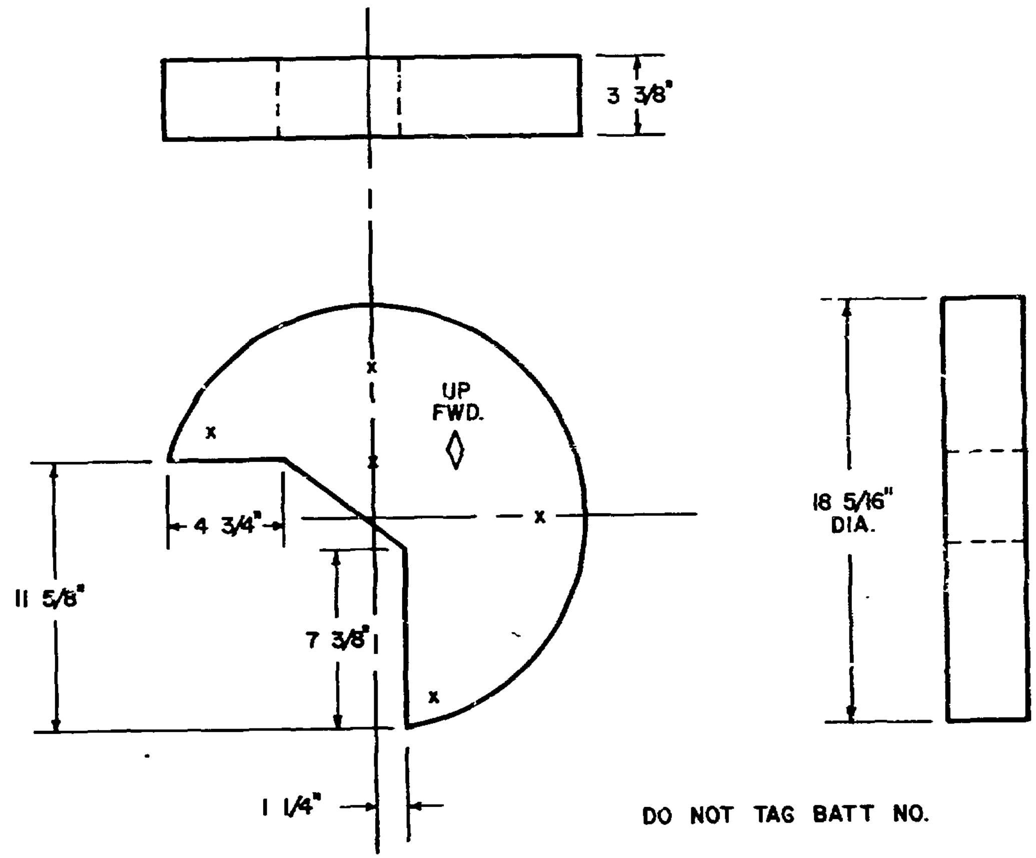


Figure D4-10. Batt Detail, Kellett 100 Gallon Tank



BATT 5(b)

Figure D4-11. Batt Detail, Kellett 100 Gallon Tank

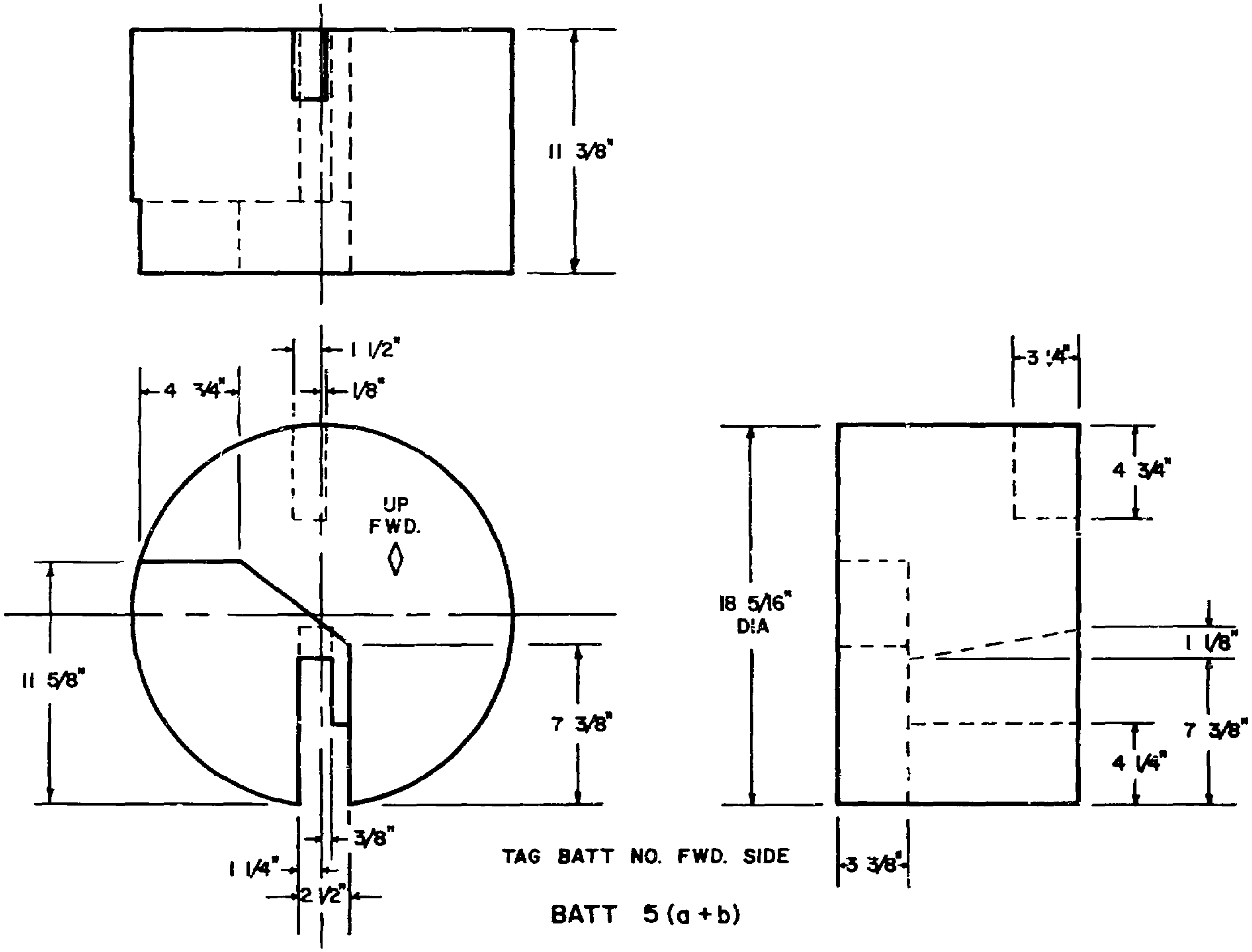
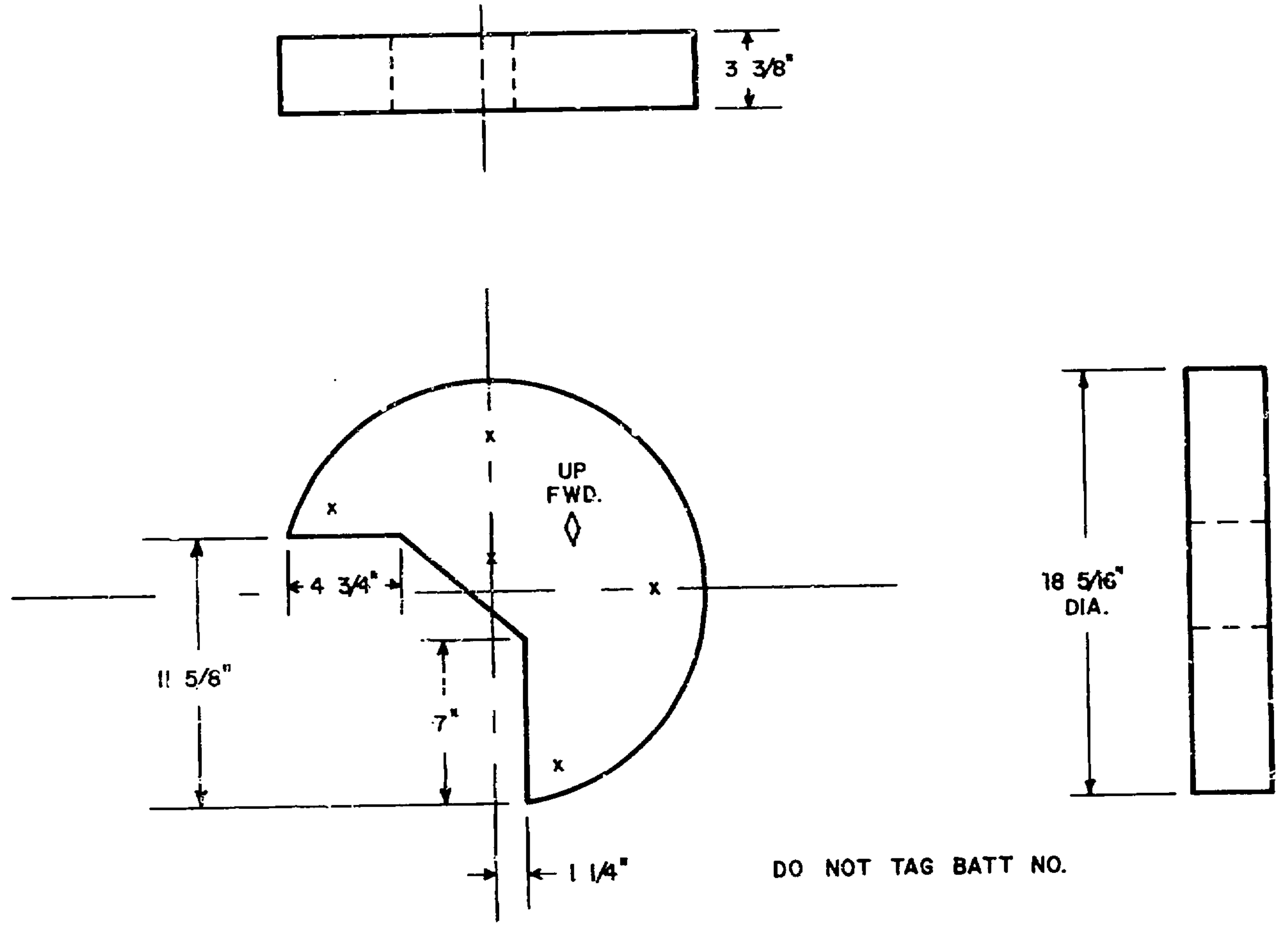


Figure D4-12. Batt Detail, Kellett 100 Gallon Tank



BATT 6(a)

Figure D4-13. Batt Detail, Kellett 100 Gallon Tank

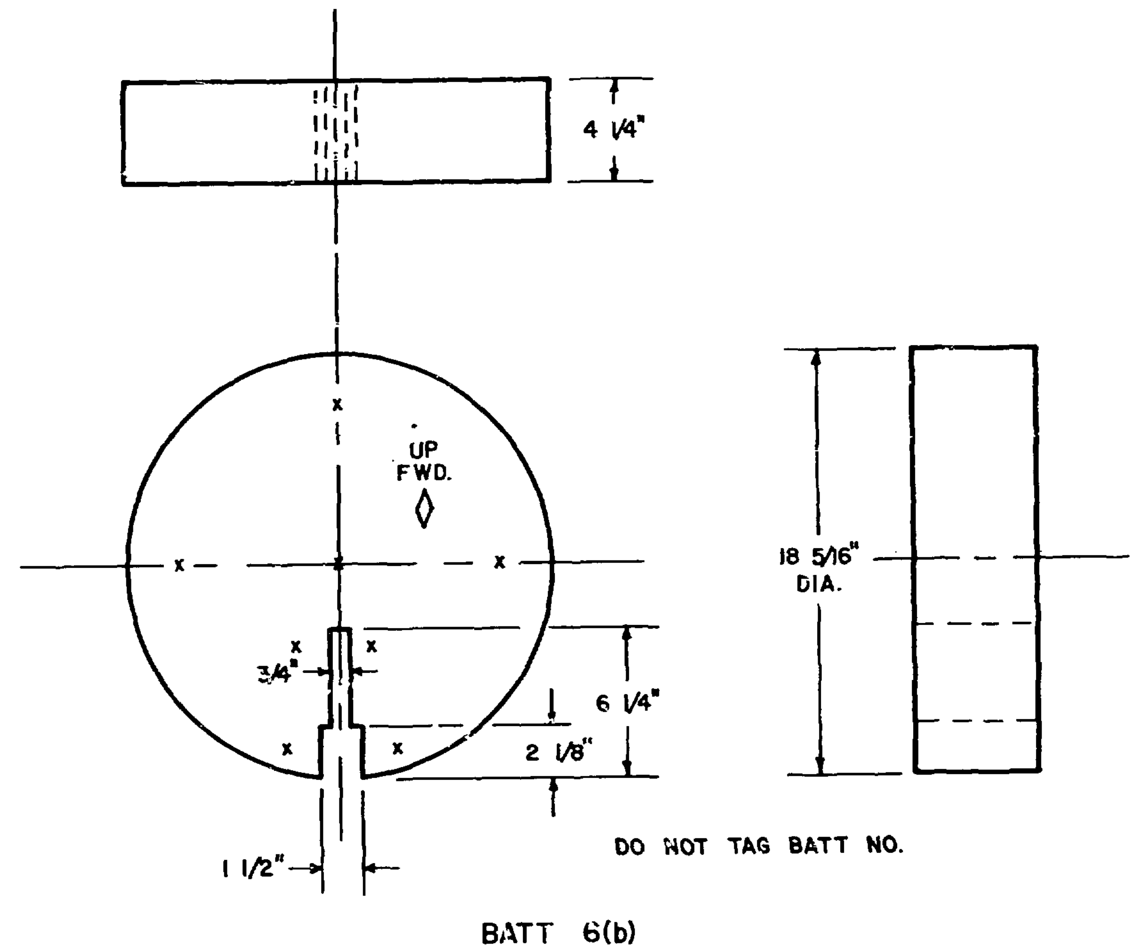


Figure D4-14. Batt Detail, Kellett 100 Gallon Tank

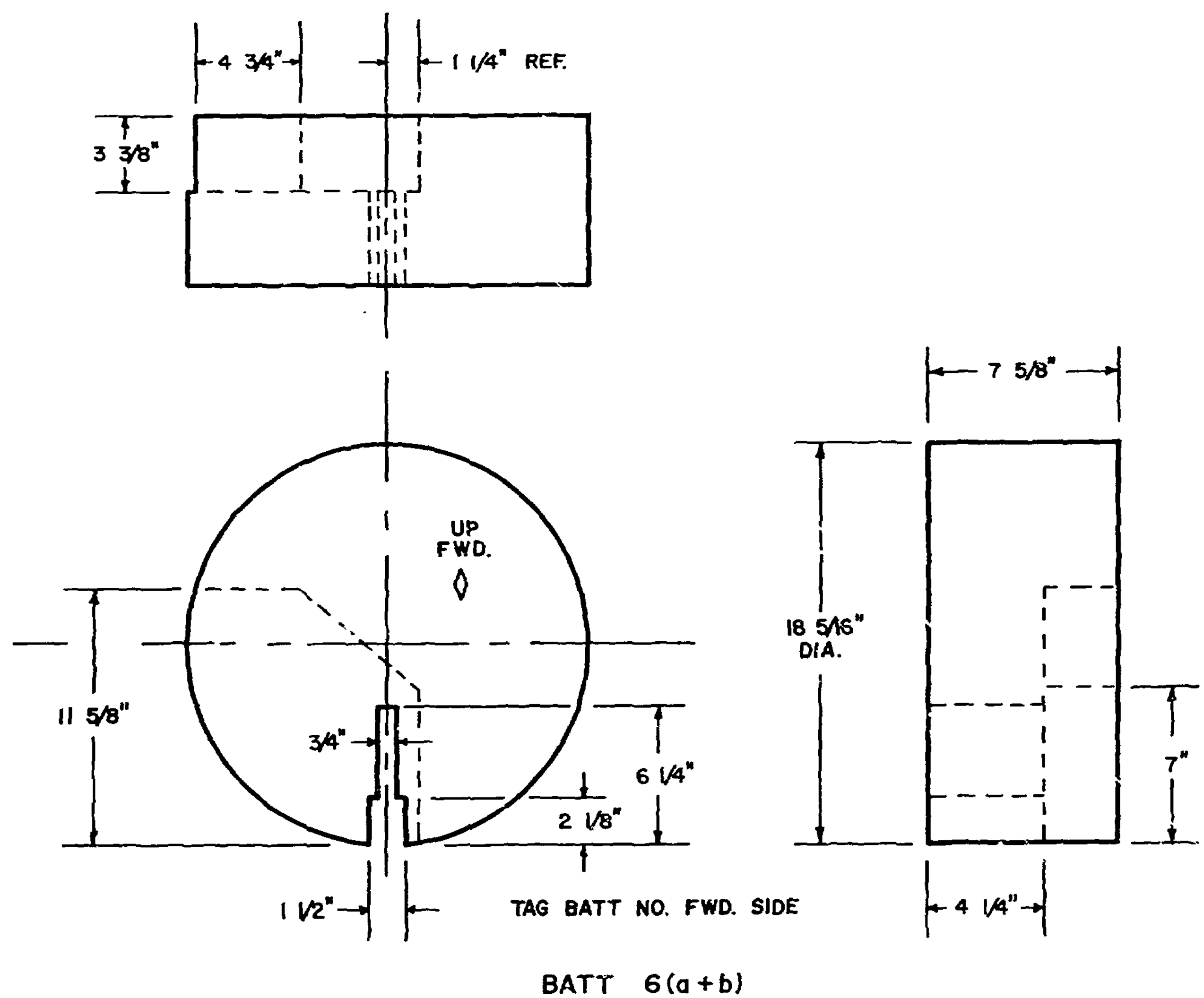
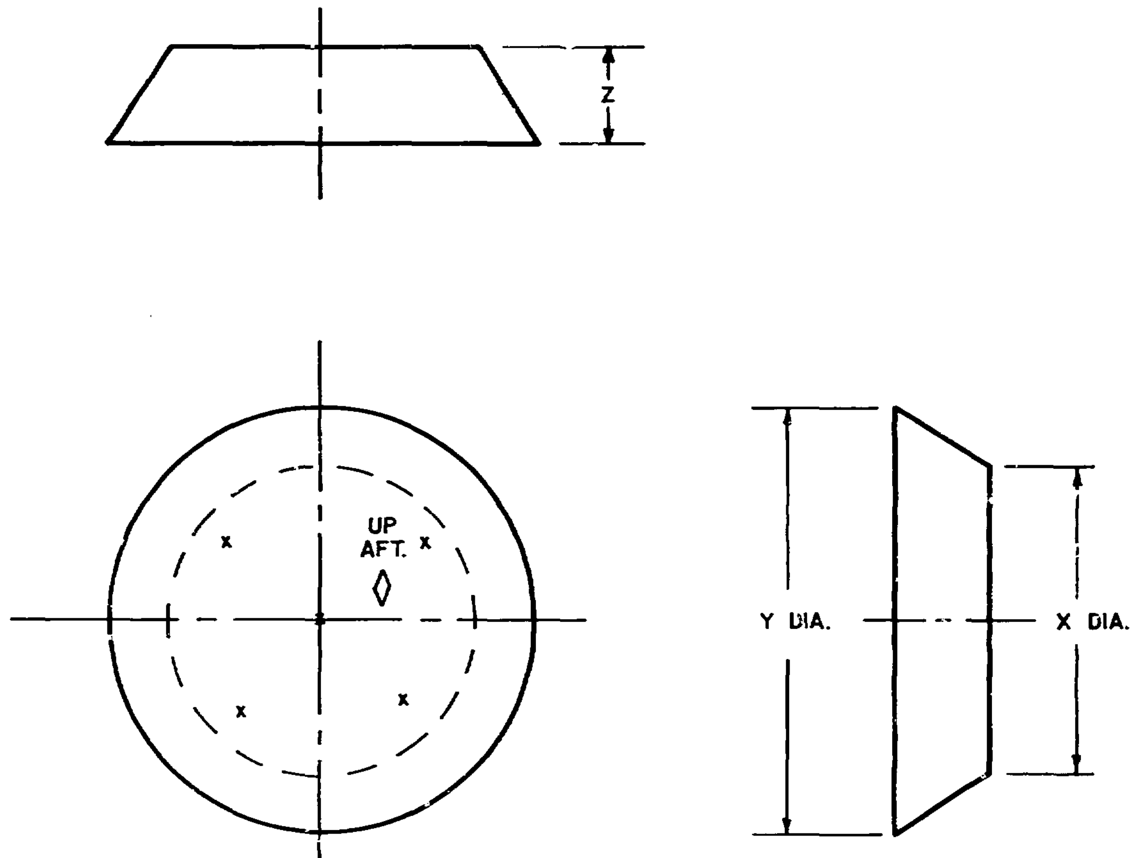


Figure D4-15. Batt Detail, Kellett 100 Gallon Tank



SEE TABLE D4-I FOR DIMENSIONS

TAG BATT NO. AFT. SIDE

BATTS 7,8,9,10

Figure D4-16. Batt Detail, Kellett 100 Gallon Tank

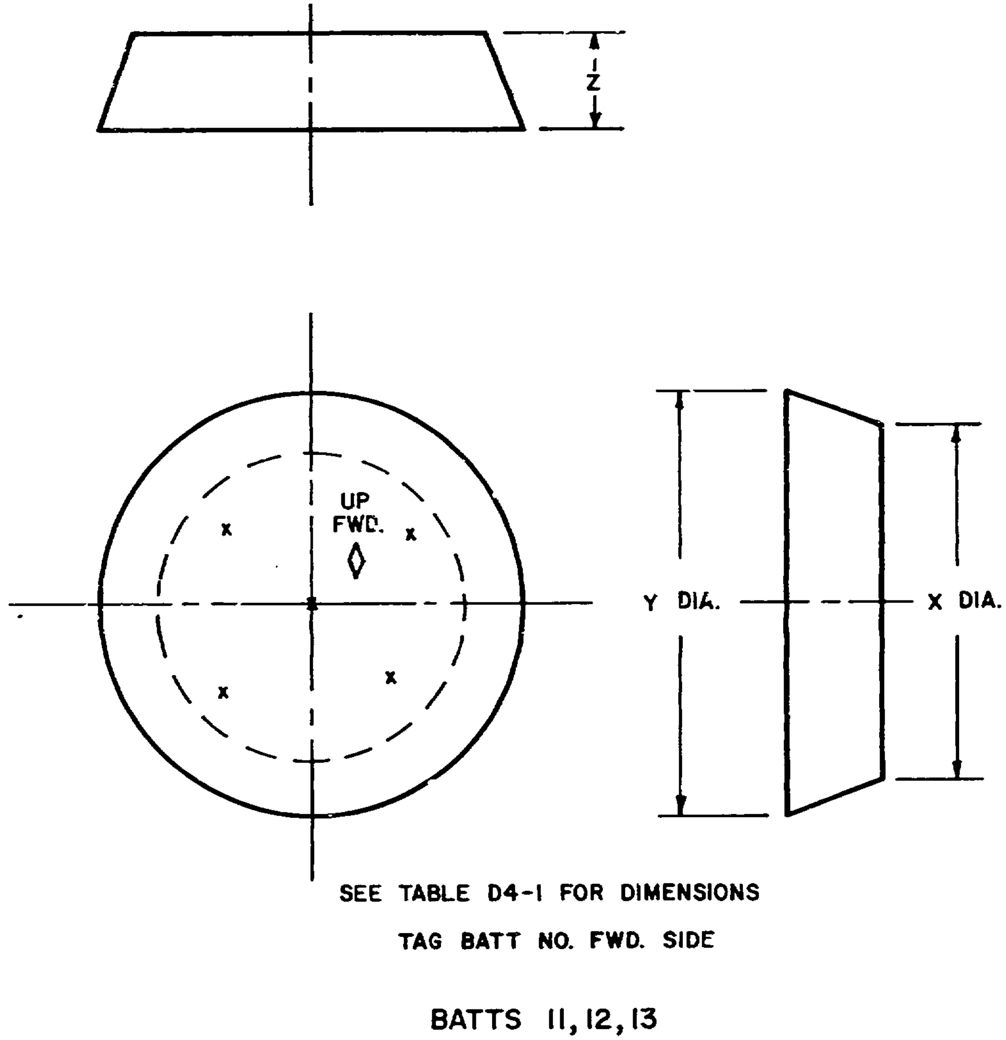


Figure D4-17. Batt Detail, Kellett 100 Gallon Tank

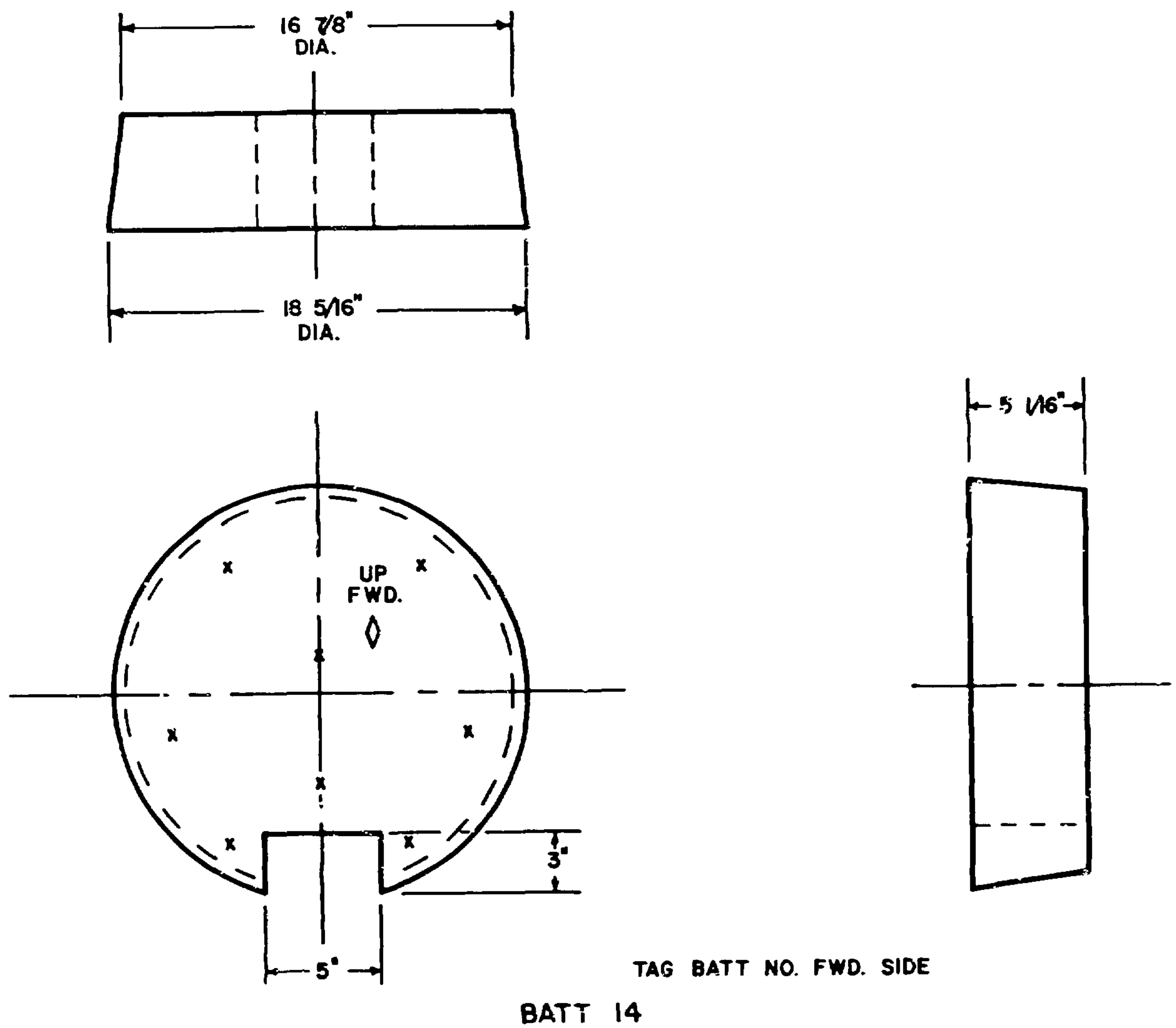


Figure D4-18. Batt Detail, Kellett 100 Gallon Tank

APPENDIX D 5

INSTALLATION STUDY
CF-104 AMMUNITION COMPARTMENT TANK

Fuel Tank Description

The CF-104 Ammunition Compartment Tank measures 28.25 x 23 x 24.75 inches and has a nominal fuel capacity of 60 U.S. gallons. A cover plate with pump, fuel level control valve and quantity gage probe attached to it fits over an 8 1/8 x 10 1/8 inch oval access window on top of the tank (Figures D5-1 and D5-2).

The tank also has a valve assembly, complete with flexible plumbing, installed internally at the top corner, left of the small side window. Three baffles line the inside of the tank. A 3 inch diameter drain hole is located on the tank bottom (Figure D5-3).

Objective

To pack the tank with Explosafe, leaving appropriate voids to accommodate the cover plate attachments, plumbing, valve assembly, baffles and drain (Figure D5-4).

Explosion Suppression Material Used

Explosafe material used was 0.002 inch thick, 3003/H24 alloy aluminum foil of 0.055 inch strand width, expanded to 38 inch web-width and fanfolded at 13.8 layers per inch height. The resultant Explosafe material density is approximately 2.2 pounds per cubic foot.

Batt Manufacturing Procedure

Rectangular batts are cut from fanfolded foil to dimensions specified in Table D5-1. The diamond orientation is shown in Figure D5-5. Each batt is secured temporarily with lengths of 16 gauge aluminum wire pushed through the batt and bent at both ends. These wires are removed once the batts are properly stitched.

Next, the location of the cuts required to shape the batts are marked out with a felt tip marker pen. Figures D5-6 through

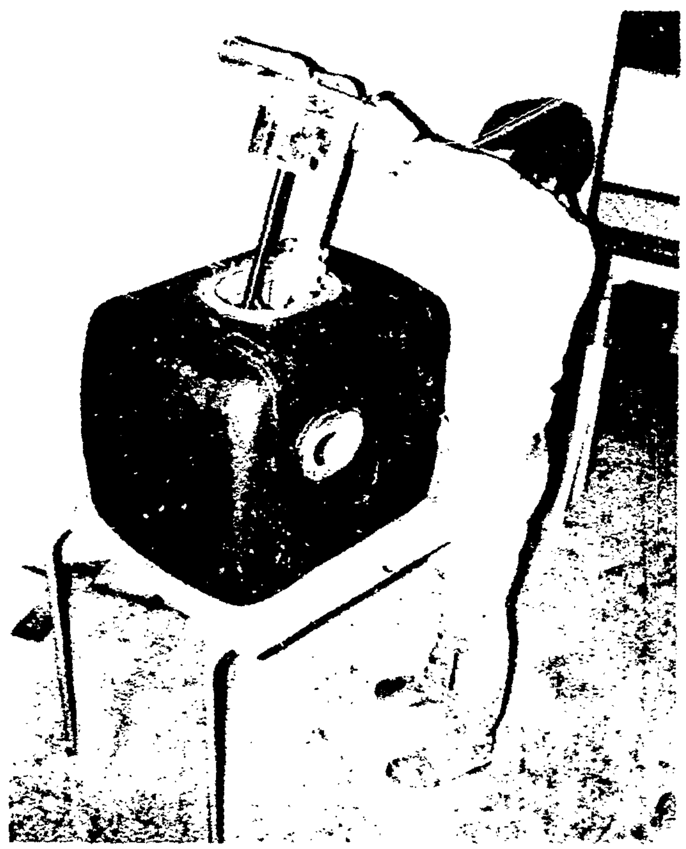


Figure D5-1. CF-104 Ammunition Compartment Tank

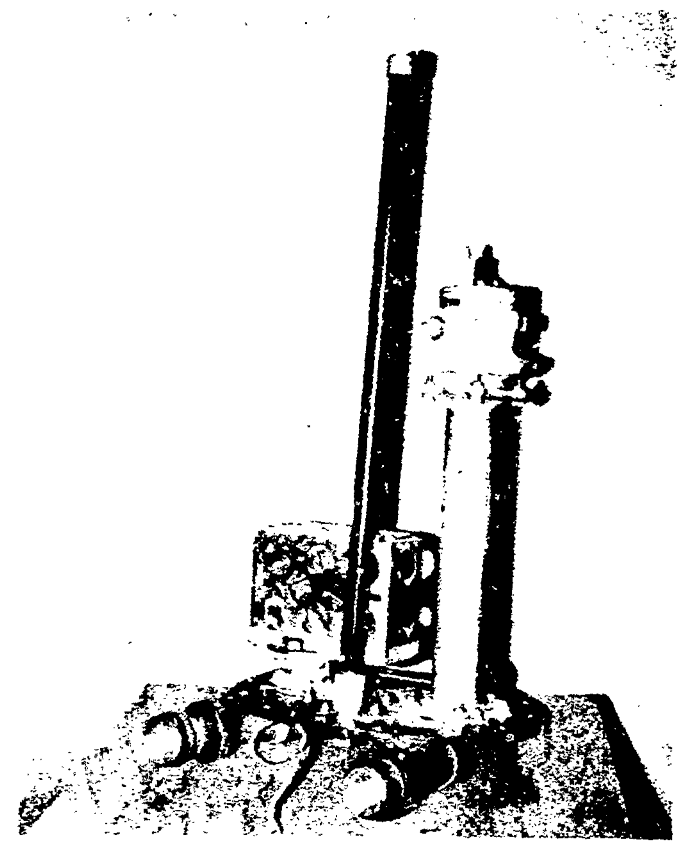


Figure D5-2. Cover Plate with Attachments

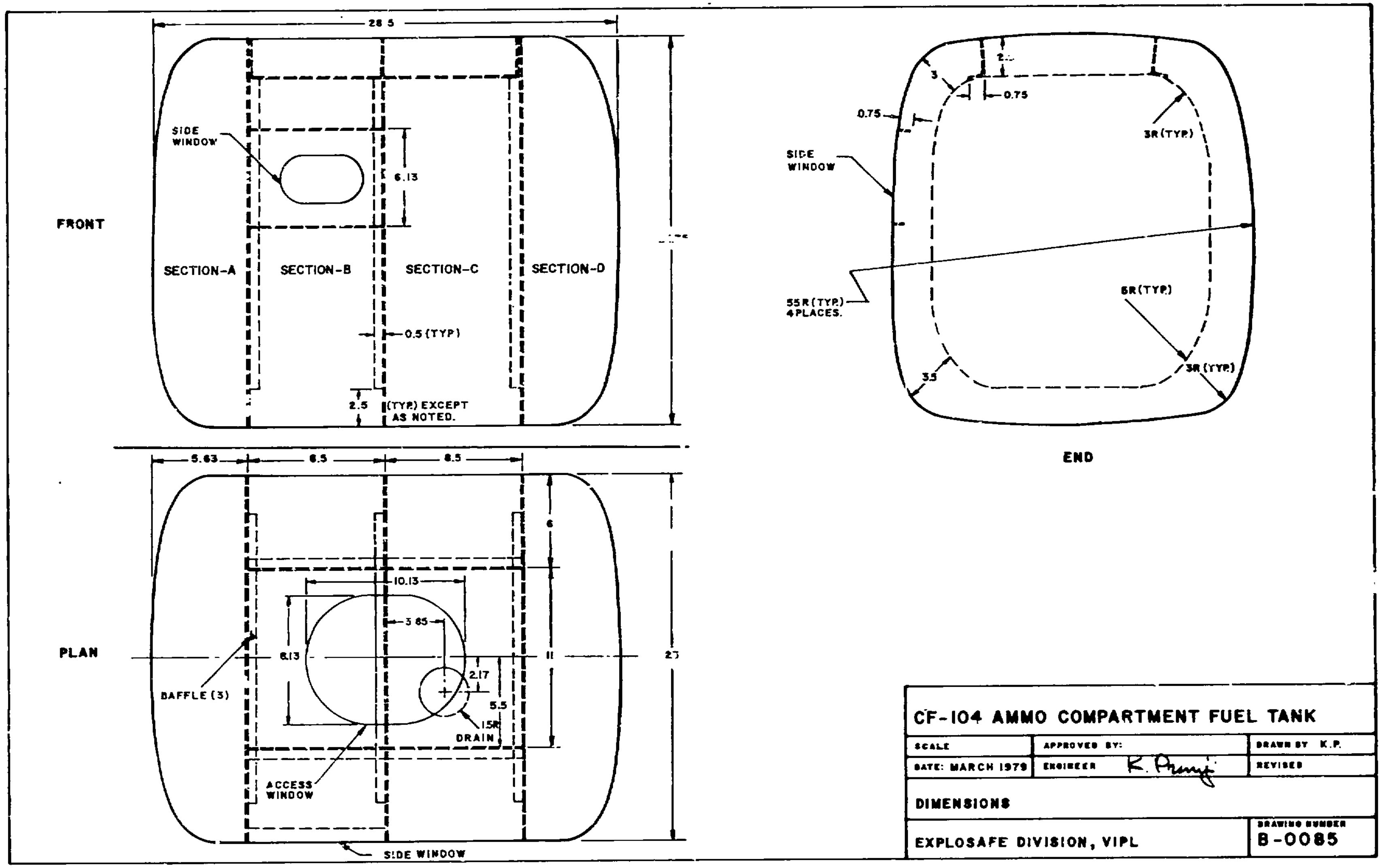


Figure D5-3. Dimensions, CF-104 Ammunition Compartment Tank

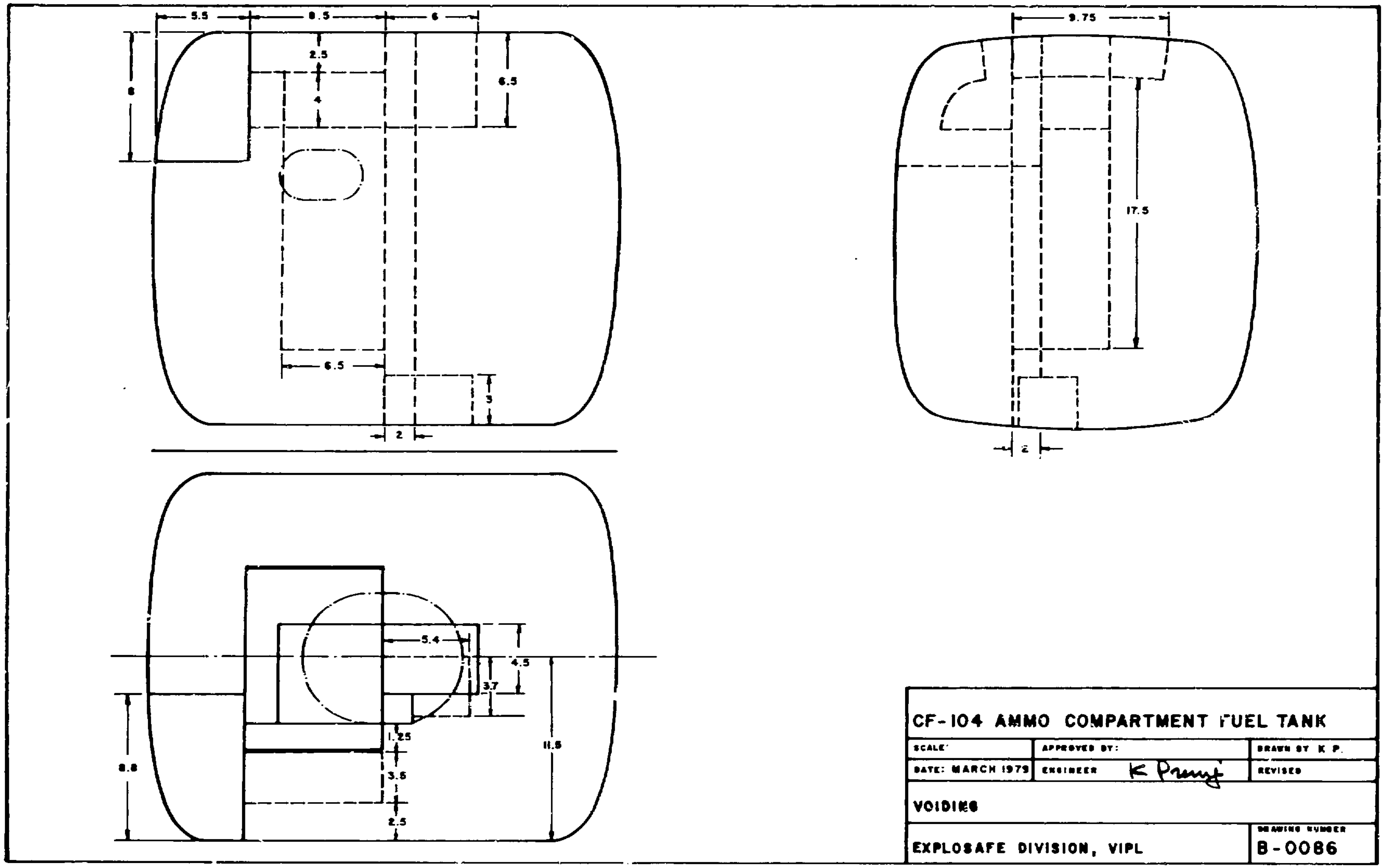


Figure D5-4. Void Dimensions

D5-12 illustrate the various batt configurations. The marked batts are stitched with 23 gage stainless steel or aluminum wire, with the stitches placed so as not to interfere with the cutting operation. A hand held electric saw is used to shape the batts.

Each batt is tagged with its batt number embossed on a 2 x 2 inch square of aluminum foil. The tags are slipped in between the top two layers of foil and secured in place with stainless steel staples.

TABLE D5-1. EXPLOSAFE BATT DIMENSIONS

Quantity	Batt Number(s)	Dimensions (in) (a) x (b) x (c)
12	A1,A2,A3,A4,A8,D1,D2,D3 D4,D6,D8,D9	8.0 x 5.5 x 7.4
1	A7	8.0 x 5.5 x 6.0
4	A5, A6, D5, D7	7.4 x 5.5 x 8.0
1	B1	9.5 x 8.0 x 2.0
2	B2, B3	9.25 x 7.0 x 8.5
9	B4,B5,B6,C1,C2,C3,C4,C5,C6	8.1 x 6.0 x 8.5
2	B7, B8	8.5 x 5.0 x 4.75
1	B9	17.5 x 8.5 x 3.5
1	B10	6.5 x 17.5 x 2.25
4	C7, C8, C9, C10	8.5 x 9.0 x 5.5
2	C11, C12	8.5 x 7.25 x 6.5

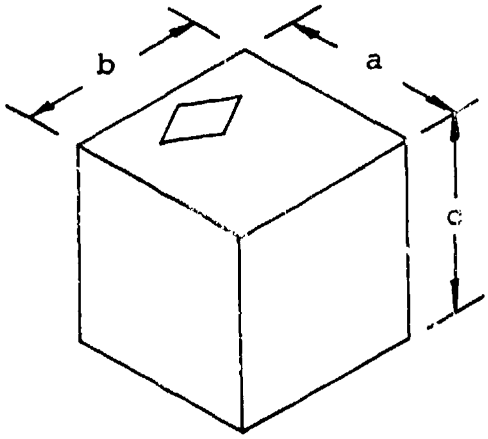


Figure D5-5. Diamond Orientation

Explosafe Installation Technique

To clarify illustrations, the tank is divided into four sections: A, B, C, and D. Each section is packed with a series of Explosafe batts whose batt numbers are prefixed with the appropriate section letter. Figures D5-13 through D5-16 show the designated batt locations for each section.

Before installing the batts, the top cover plate, along with its attachments, is unbolted and lifted out. All flexible plumbing from the internal valve assembly to the attachments on the cover plate is disconnected and the cover plate set aside.

The completed batts are installed through the top access window, in the sequence shown in Table D5-2.

TABLE D5-2. SEQUENCE OF INSTALLATION

A1, A2, A3, A4, A5, A6, A7, A8, D1, D2, D3, D4, D5, D6, D7, D8, D9, B1, B2, B3, B4, B5, B6, C1, C2, C3, C4, C5, C6, B7, B8, C7, C8, B9, B10, C9, C10, C11, C12.

Wherever inter-surface contact between batts prevents easy installation, stiff cardboard sheets should be inserted between the batts to reduce excessive friction. The cardboard must be removed immediately after each batt is properly installed.

For production installation jobs, it is recommended that sized sheet metal or acrylic plastic sheets of about 0.03 inch thickness be substituted for cardboard for their better strength and wear characteristics. It should be noted that to facilitate easy removal of the batts, it could be necessary to slip in such sheets between contacting batt surfaces before batt removal.

To reinstall the cover plate, the quantity gage probe is first removed from the plate. The flexible plumbing from the tank's internal valve assembly is reconnected and the entire cover plate assembly is bolted down over the access window. The quantity gage probe is then reinserted into the tank through its opening in the cover plate and bolted in place.

Void Analysis

(A) Volume of Tank (Valve Assembly Installed) 14116 cu.in.

(B) Void Created

void for quantity gage probe	99	
void for fuel level control valve	175	
void for pump	940	
void for drain	51	
void below cover plate	224	
void around valve assembly	167	
void for flexible plumbing	71	
void to accommodate baffles	253	
Gross Void		1980 cu.in.

(C) Volume Occupied by Plumbing

quantity gage probe	20	
fuel level control valve	122	
pump	71	
flexible plumbing	11	
Total Volume Occupied by Plumbing		224 cu.in.

(D) Actual Void = (B-C) = (1980-224) cu.in = 1756 cu.in.

(E) $\% \text{ Void} = \frac{D}{A} \times 100 = \frac{1756}{14116} \times 100$

$\% \text{ Void} = 12.4\ \%$

<u>Weight Analysis (Theoretical)</u>

(F) Theoretical Density of Explosafe = 2.2 lbs/cu.ft.

(G) Usable Volume of Tank = (A-C) = 13892.0 cu.in.

(H) Volume of Explosafe = (G-D) = 12136.0 cu.in.

(I) Theoretical Weight of Explosafe

$\frac{H}{1728} \times F \text{ lbs} = \frac{12136}{1728} \times 2.2 \text{ lbs} = 15.45 \text{ lbs}$

<u>Weight Analysis (Actual)</u>

(J) Weight of Empty Tank = 28.0 lbs

(K) Weight of Tank Packed w/Explosafe = 43.5 lbs

(L) Weight of Explosafe = (K-J) = 15.5 lbs

(M) Actual Density of Explosafe

$= \frac{L}{H} \times 1728$ lbs/cu. ft.

$= \frac{15.5}{12136} \times 1728$ lbs/cu. ft. = 2.2 lbs/cu. ft.

(N) Packing Density (actual)

$= \frac{L}{G} \times 1728$ lbs/cu. ft.

$= \frac{15.5}{13892} \times 1728$ lbs/cu. ft. = 1.9 lbs/cu. ft.

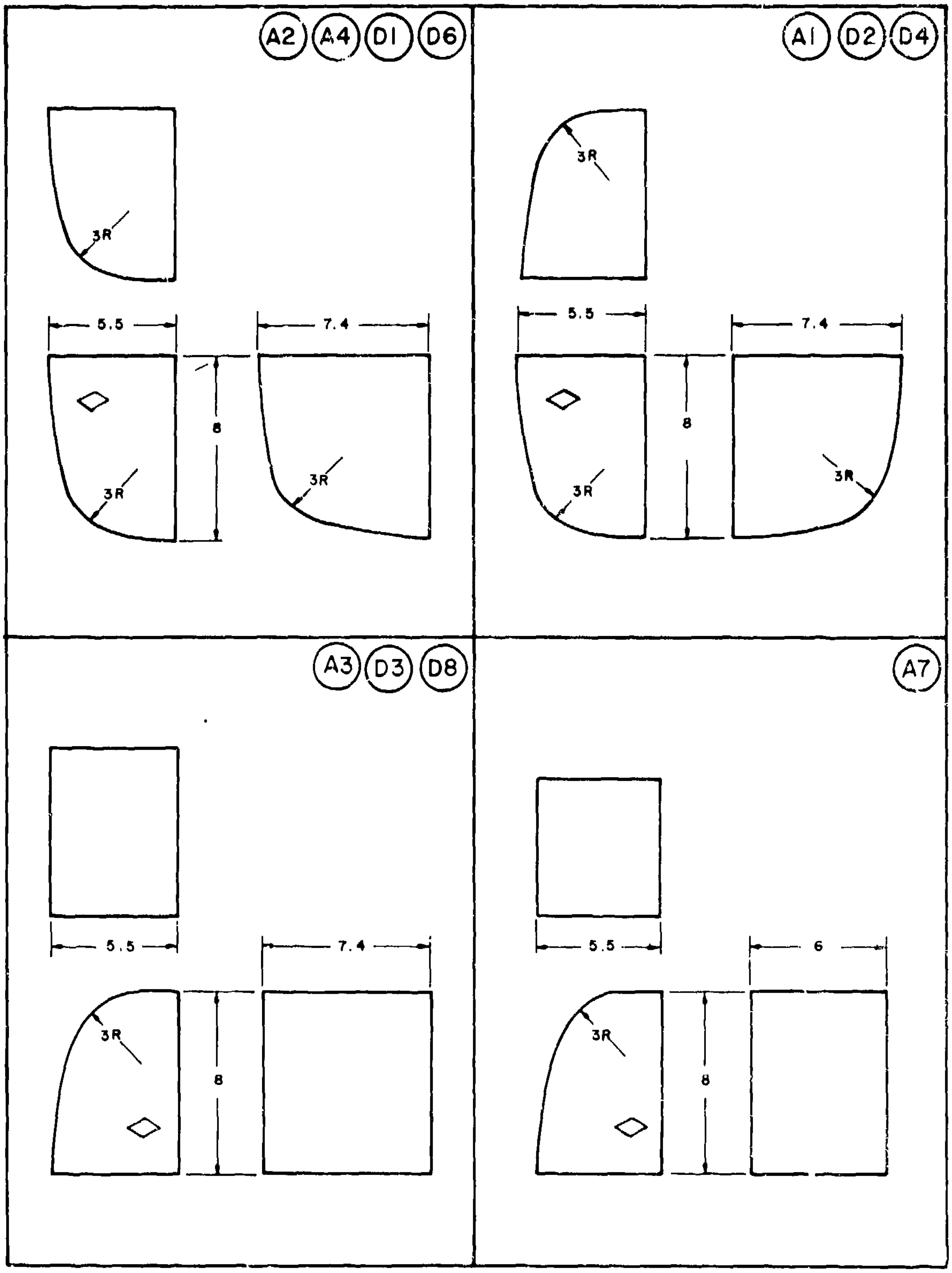


Figure D5-6. Batt Details, CF-104 Ammunition Compartment Tank

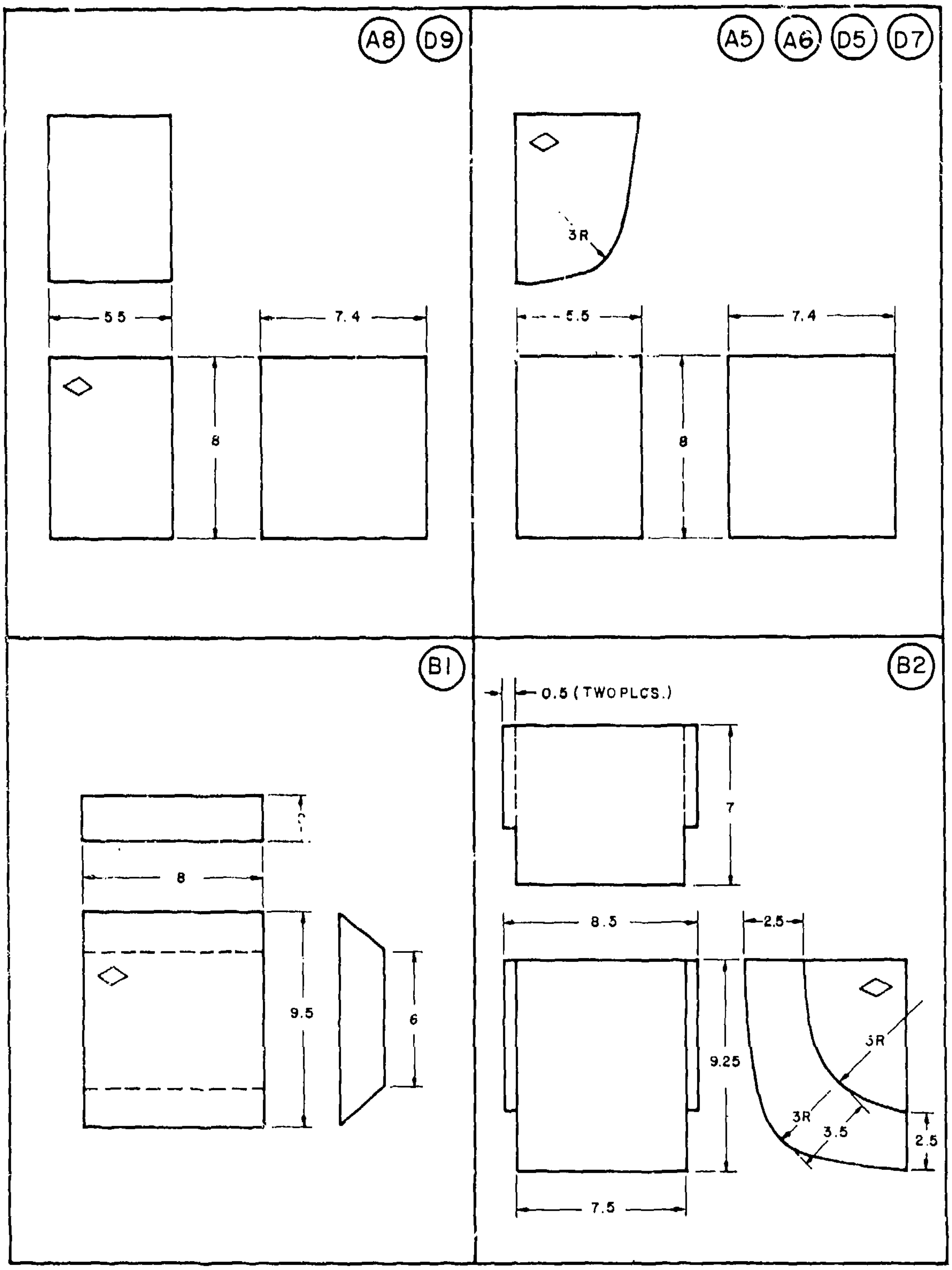


Figure D5-7. Batt Details, CF-104 Ammunition Compartment Tank

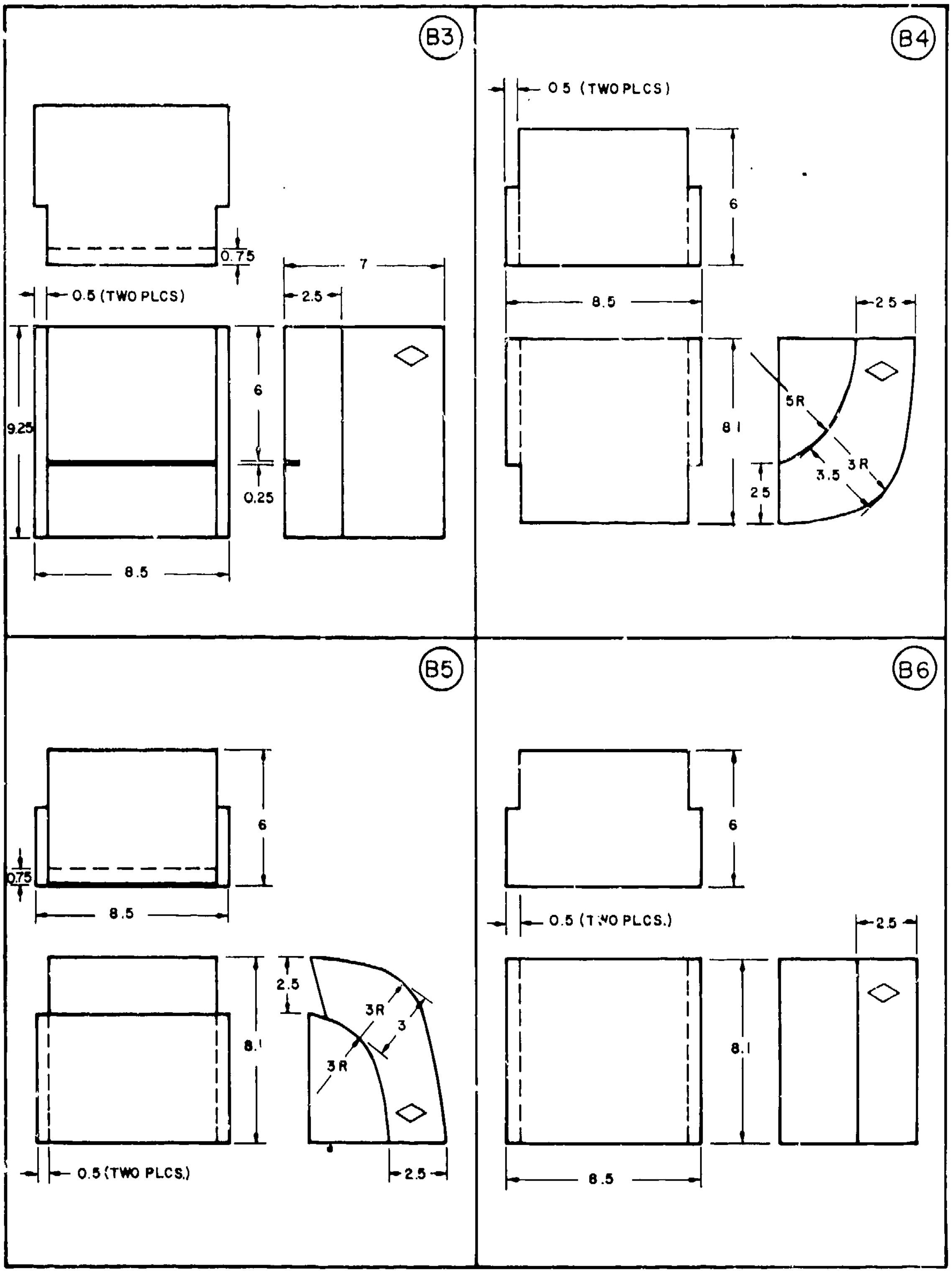


Figure D5-8. Batt Details, CF-104 Ammunition Compartment Tank

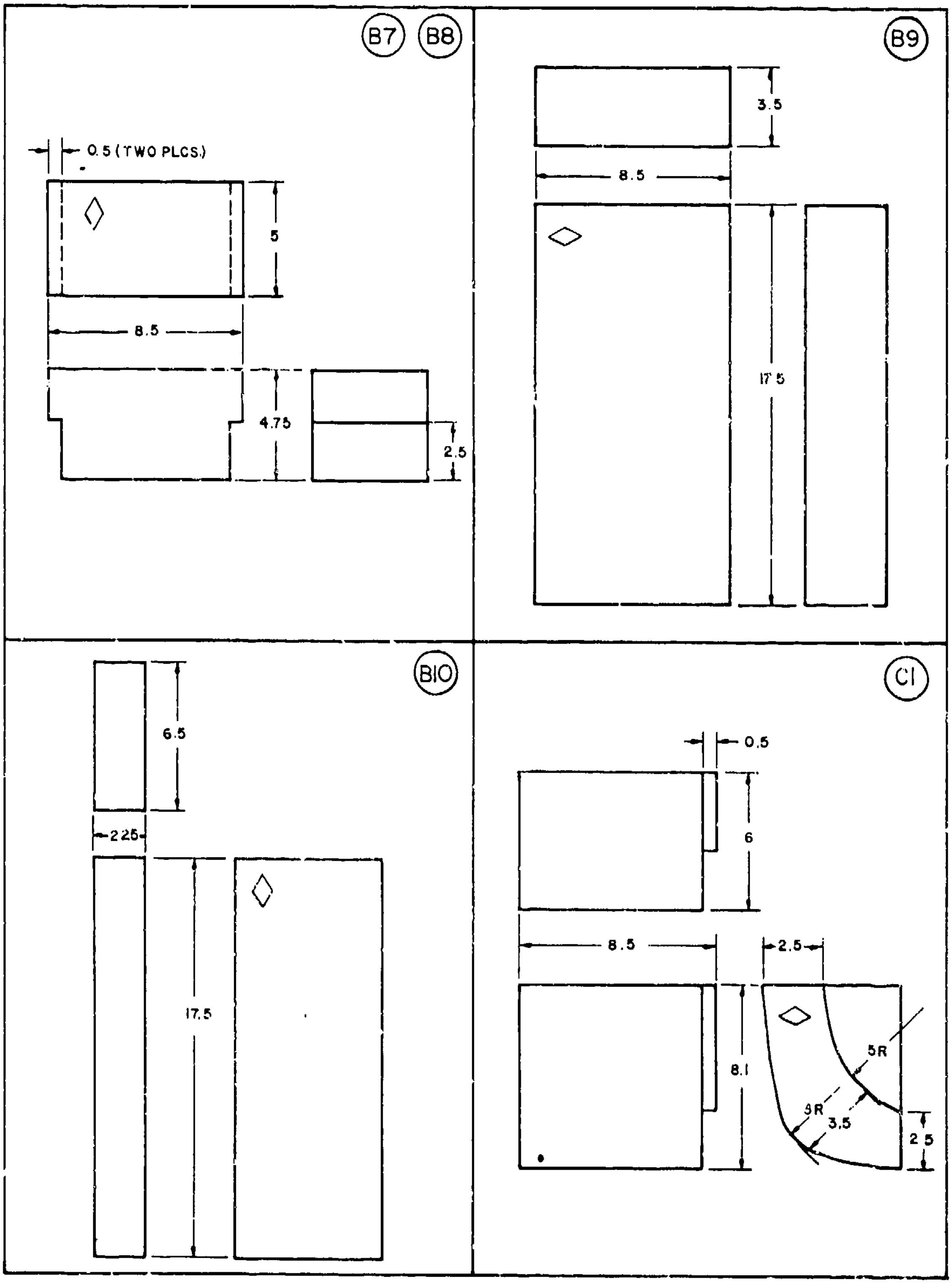


Figure D5-9. Batt Details, CF-104 Ammunition Compartment Tank

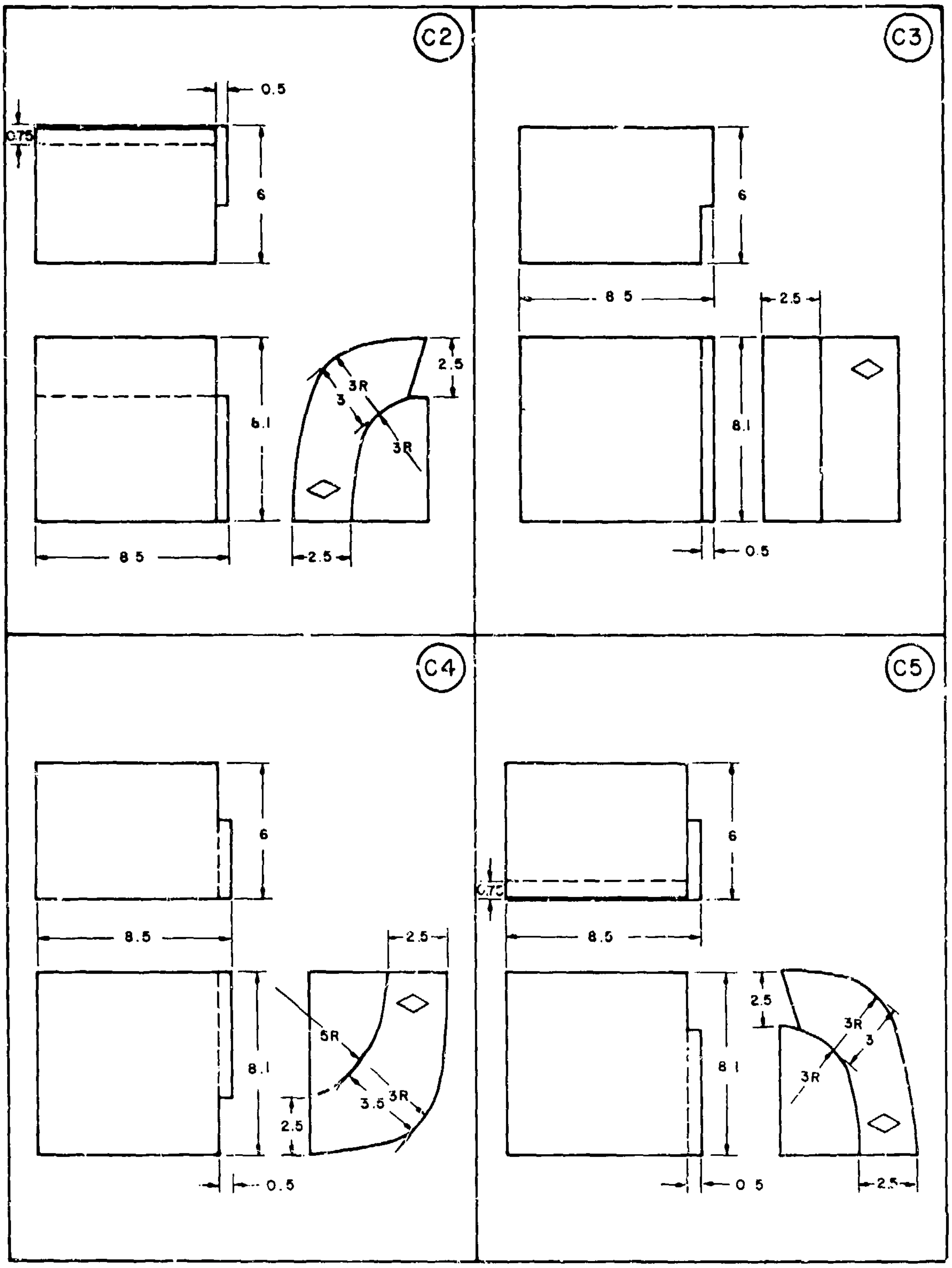


Figure D5-10. Batt Details, CF-104 Ammunition Compartment Tank

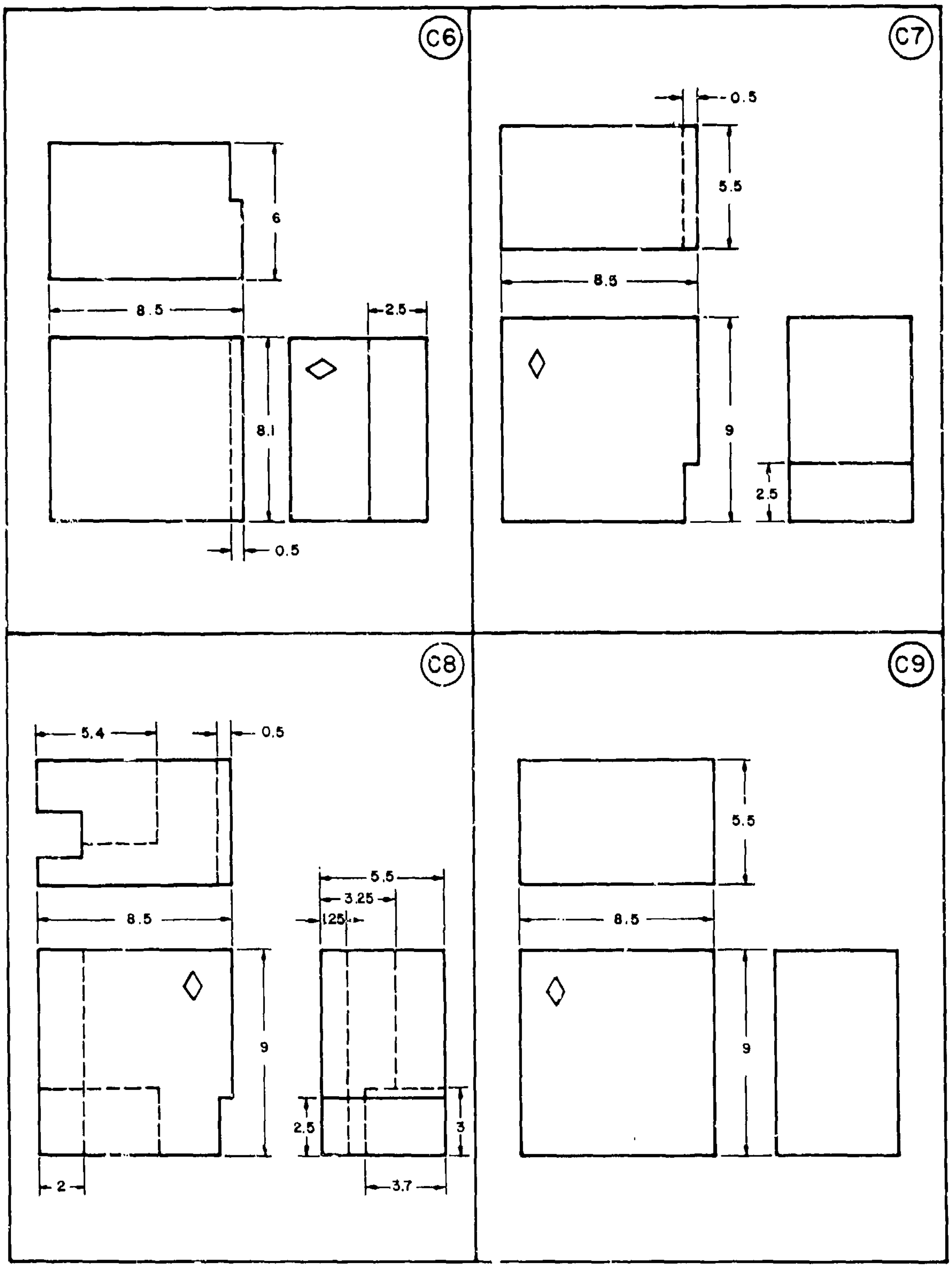


Figure D5-11. Batt Details, CF-104 Ammunition Compartment Tank

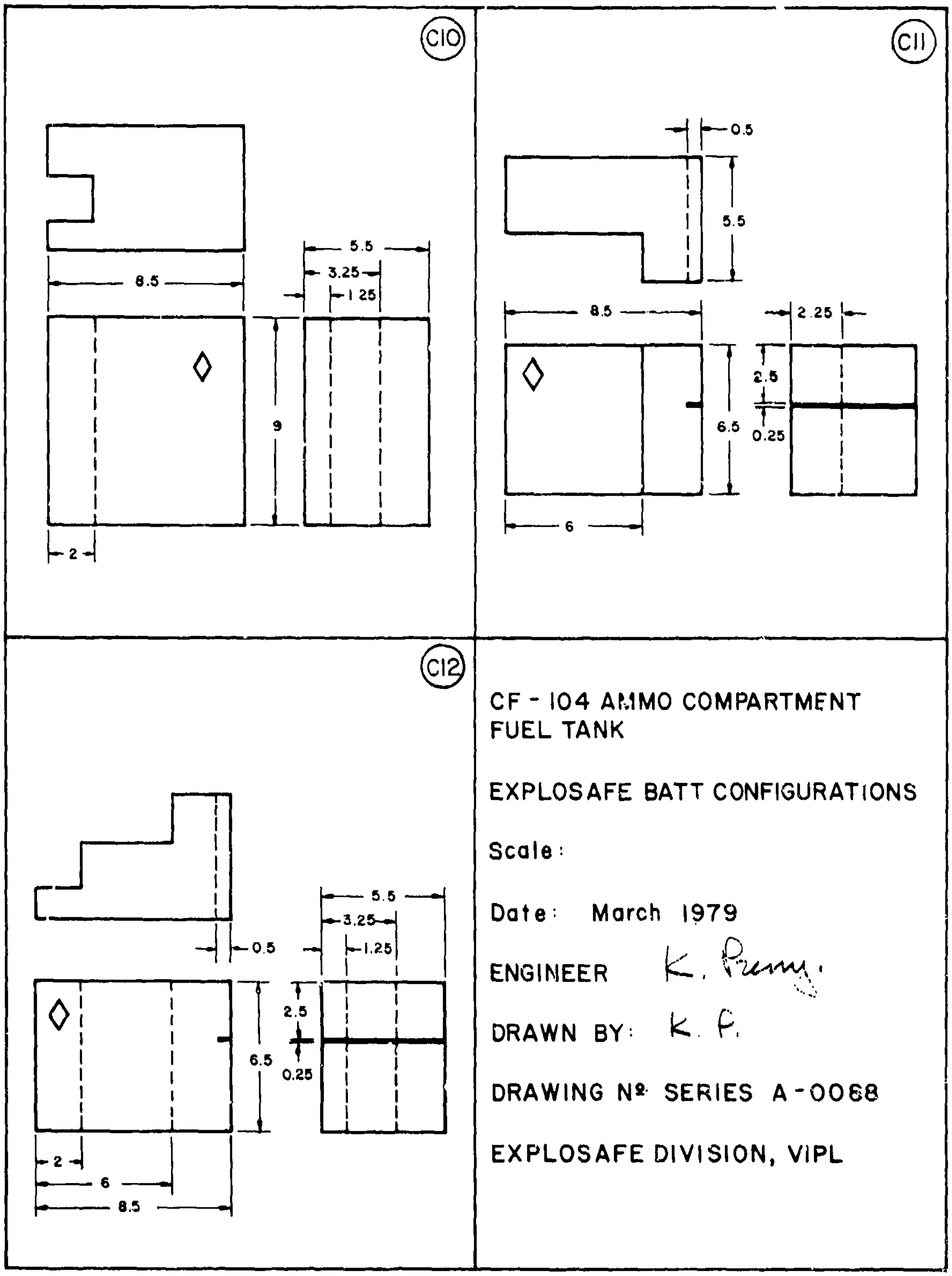


Figure D5-12. Batt Details, CF-104 Ammunition Compartment Tank

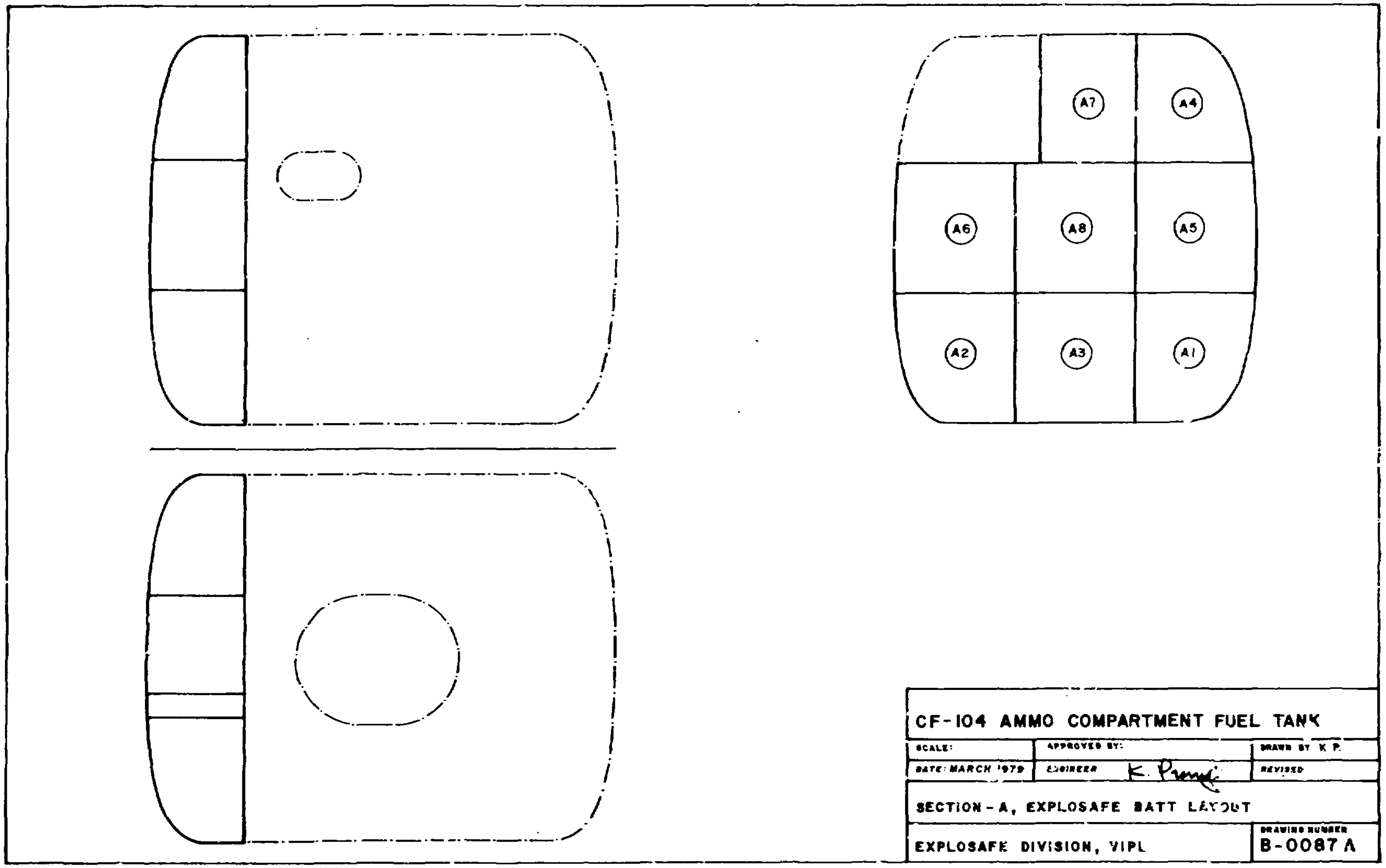


Figure D5-13. Batt Layout for Section A

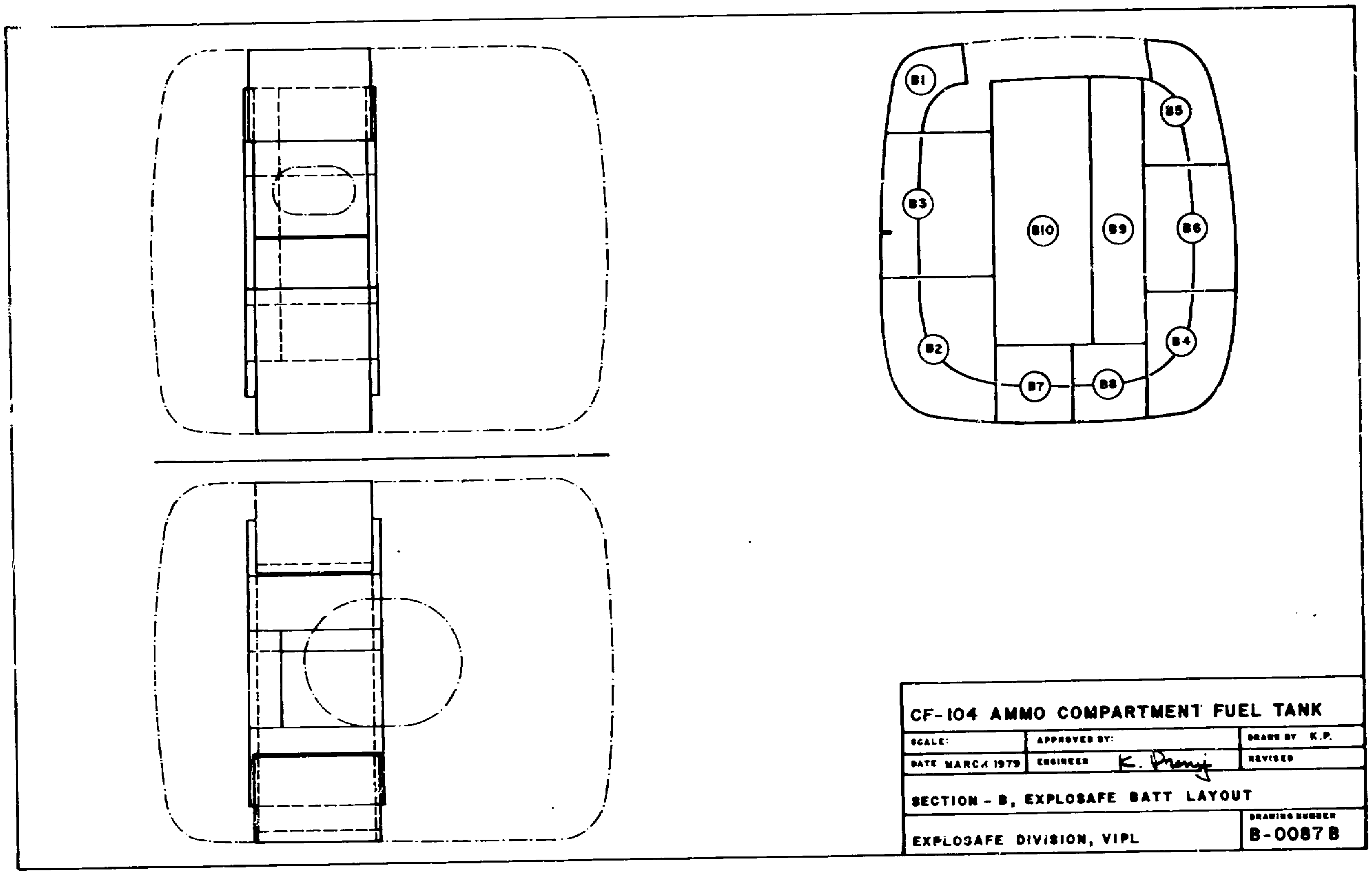


Figure D5-14. Batt Layout for Section B

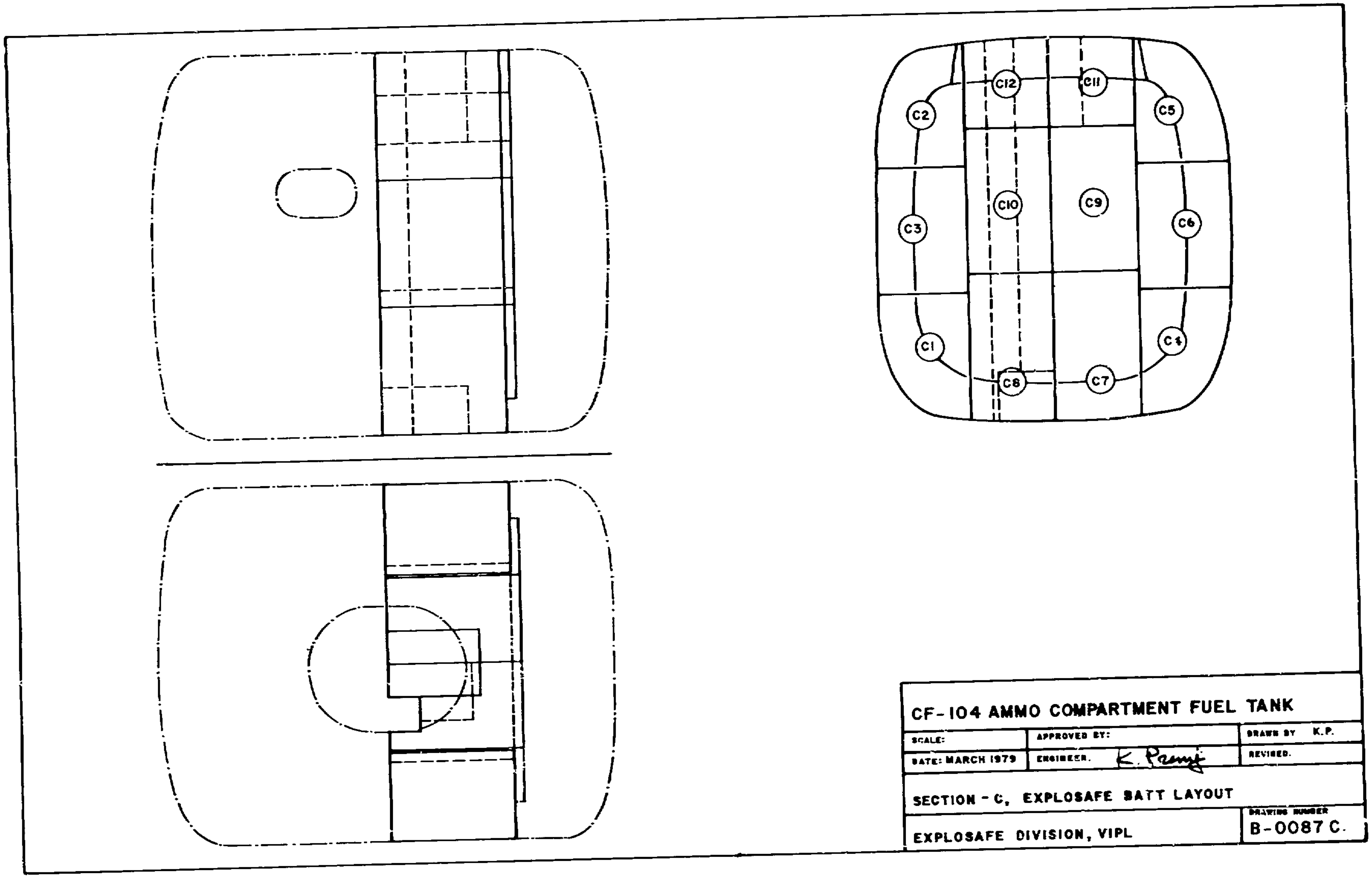


Figure D5-15. Batt Layout for Section C

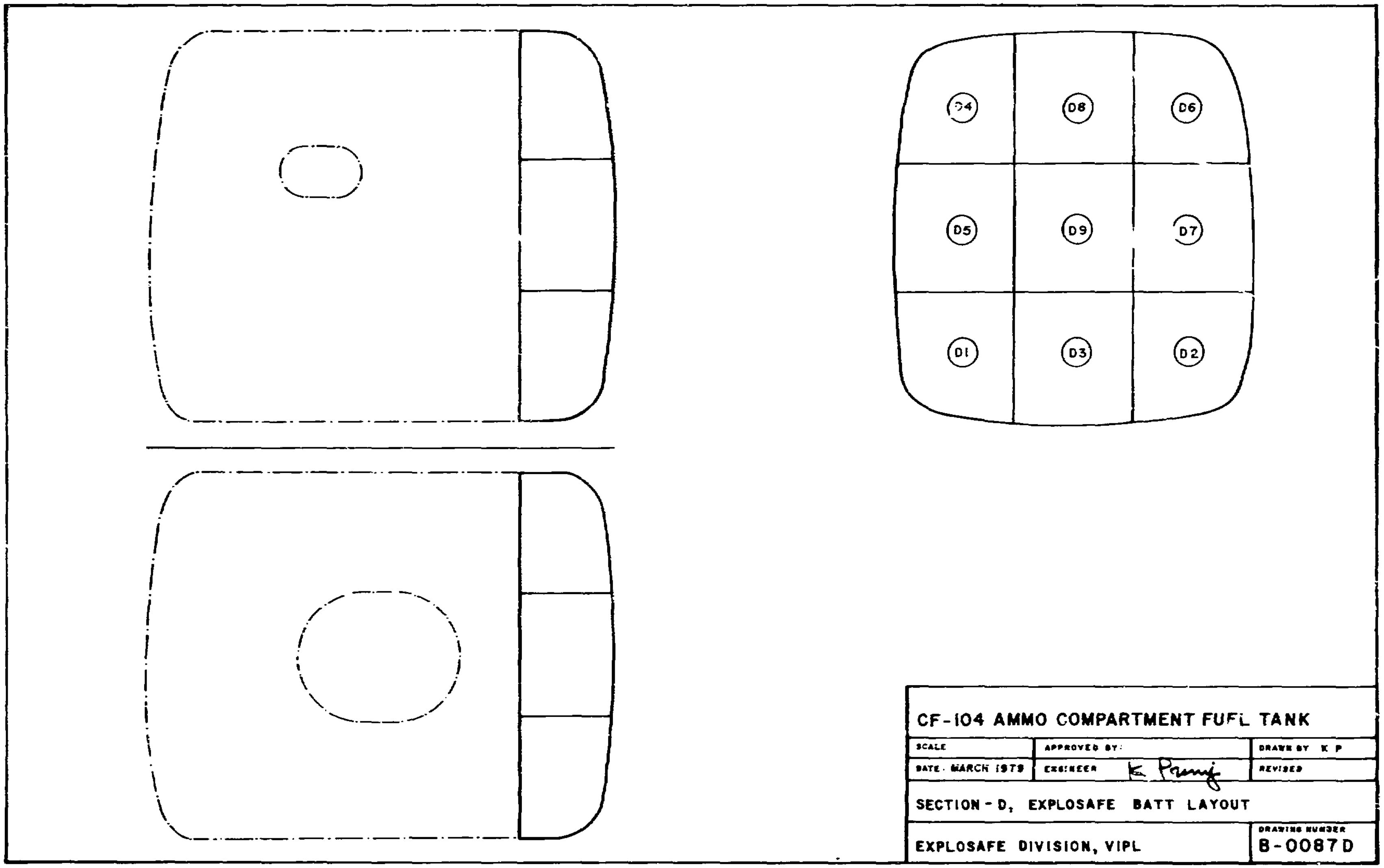


Figure D5-16. Batt Layout for Section D

APPENDIX D 6

INSTALLATION STUDY
A-10 WING BOX TANK

Fuel Tank Description

The A-10 aircraft wing box tank incorporates a structural isolation design where the structure offers natural compartmentization with intercommunicating openings between compartments. Eight such compartments exist. The compartments are again, segmented by a mid-spar that divides them into fwd and aft sections of approximately equal internal volume. The total volume of the tank, including the fuel expansion area, is 146 cubic feet. Access ports exist on the underside and mid-spar of each compartment. Numerous ribs run the length of the tank. Associated integral plumbing and components are situated at various locations. Figure D6-1 shows an overall view of the tank.

Objective

To pack the tank with Explosafe so that the foil fits snugly around all static internal components and supported plumbing. Voids of 3.5 x 3.5 inches cross-section are to be left below the filler ports.

Explosafe Material Used

Explosafe material used was of 0.002 inch thick 3003/H24 alloy aluminum foil, slit for 0.055 inch strand width, expanded to 38 inch web-width and fanfolded at 13.8 layers per inch height. The resultant material density was approximately 2.2 pounds per cubic foot.

Batt Manufacturing Procedure

Rectangular batts were cut to size from raw, fanfolded foil. Each batt was secured temporarily with lengths of 16 gauge aluminum wire pushed through the batt and bent at both ends. These wires were removed once the batts were properly stitched. The locations of the cuts required to shape the batts were marked out with a marking pen. Stitches of 24 gauge stainless steel wire were placed about an inch away from the perimeter of the batt or voided areas needing support. The stitches were about 2 inches long with about 2 inches of spacing between stitches. Some stitches were placed centrally within large unsecured masses of the foil for added structural support. Typical stitch locations are shown in Figure D6-2. The sized batts were trimmed to required dimensions on a bandsaw and shaped to their final configurations with a portable electric saw. Each finished batt was tagged with its batt number and orientation embossed on a 2 x 2 inch square of aluminum foil. The tags were slipped in between the top two layers of the foil and secured in place with stainless steel staples. The tags were located on the side of the batt that would face the installer.

Discussion

Batts were oversized by 2 percent in all dimensions to provide tighter packing and to compensate for any shrinkage or compacting during handling and use. The open faces of the cells, or diamonds, were aligned perpendicular to the fwd-aft axis of the tank, with the long dimension of the cells aligned vertically.

Initially, 5 of the 8 compartments were packed with Explosafe to fully experience the range of complexity existing within the tank. Of these, batt configurations for the most complex compartment, No. 1, and a relatively simpler compartment, No. 3, are presented in this study. See Figure D6-3 for batt layouts for the five compartments.

Each batt was subdivided into smaller components to allow its entry in the fuel tank through the small access ports (Figure D6-4). Figures D6-5 through D6-20 illustrate the configurations of batts for compartment 1, and Figures D6-21 through D6-35 for compartment 3. The void below the filler port in compartment 1 is shown in Figures D6-9 and D6-10. Two types of cuts for subdividing batts are studied here. Batts installed in compartment 1 were subdivided with vertical cuts. To reduce inter-surface friction during installation between contacting batt components, batts for compartment 3 were subdivided with oblique cuts such that adjacent batt components would mate completely only when fully in position. An attempt was made to reduce the quantity of batts in compartment 3 by combining two or more batt sets. Because of the internal obstructions present in the tank and the limited access available, it was only possible to combine two batt sets. These were located directly behind the main access. Figure D6-25 shows batt No.3.15 which is a combination of previously designed batts 3.15 and 3.16 (not illustrated).

Table D6-1 gives the sequence of batt installation for compartments 1 and 3. Table D6-2 lists pertinent weight, void and density data for the Explosafe material installed. Figure D6-37 through D6-41, and Figures D6-42 through D6-46 show compartments 1 and 3, respectively, as viewed through the access, at various stages of packing. Figure D6-47 shows foil installed in the five compartments with some of the compartments fully packed.

TABLE D6-1. SEQUENCE OF INSTALLATION

Compartment 1		Compartment 3	
Batt Sequence	Component Sequence	Batt Sequence	Component Sequence
1.01	D, C, B, A	3.01	D, C, B, A
1.02	B. D, C, A	3.02	A, B, C, D
1.03	B, D, C, A	3.03	A, B, C, D
1.04	B, D, C, A	3.04	B, D, A, C
1.05	A, C, B, D	3.05	B, D, A, C
1.06	C, A, B, D	3.06	A, B, C, D
1.07	C, D, A, B	3.07	A, B, C, D
1.08	H,D,A,E,C,G,B,F	3.08	A,C,B,D,F,E
1.09	A, C, B, D	3.09(a)	A, B, C, D
1.10	A, B, C, D	3.09(b)	A, B
1.11	A, C, B, D	3.10	C, A, B, D, E
1.12	A, C, B, D	3.11	B, A, D, C
1.13	A, B, C, D	3.12	A, B, C, D
1.14	A, B, C, D	3.13	B, A, D, C
1.15 }	15A, 16B, 15C, 16E	3.14	A, B, C, D
1.16 }	15B,16A,15D,16C,16D	3.15	A, B, C, E, D
Total Components:	69	Total Components:	66

TABLE D6-2. *EXPLOSAFE MATERIAL DATA*

Compartment	(A) Volume (US gals)	(B) Volume (cu.ft.)	(C) Weight of Explosafe (lbs)	(D) Gross Void (percent)	(E) Net Void (percent) (approx.)	(F) $= \frac{100 \times C}{(100-D)B}$ Material Density (lbs/cu.ft.)	(G) = C/B Packing Density (lbs/cu.ft.)
1	145.3	19.42	38.0	12.6	6	2.24	1.96
3	130.2	17.41	35.1	9.2	5	2.22	2.02

D = Total (Gross) void cut in foil

E = (D) - (Volume occupied by plumbing and brackets)

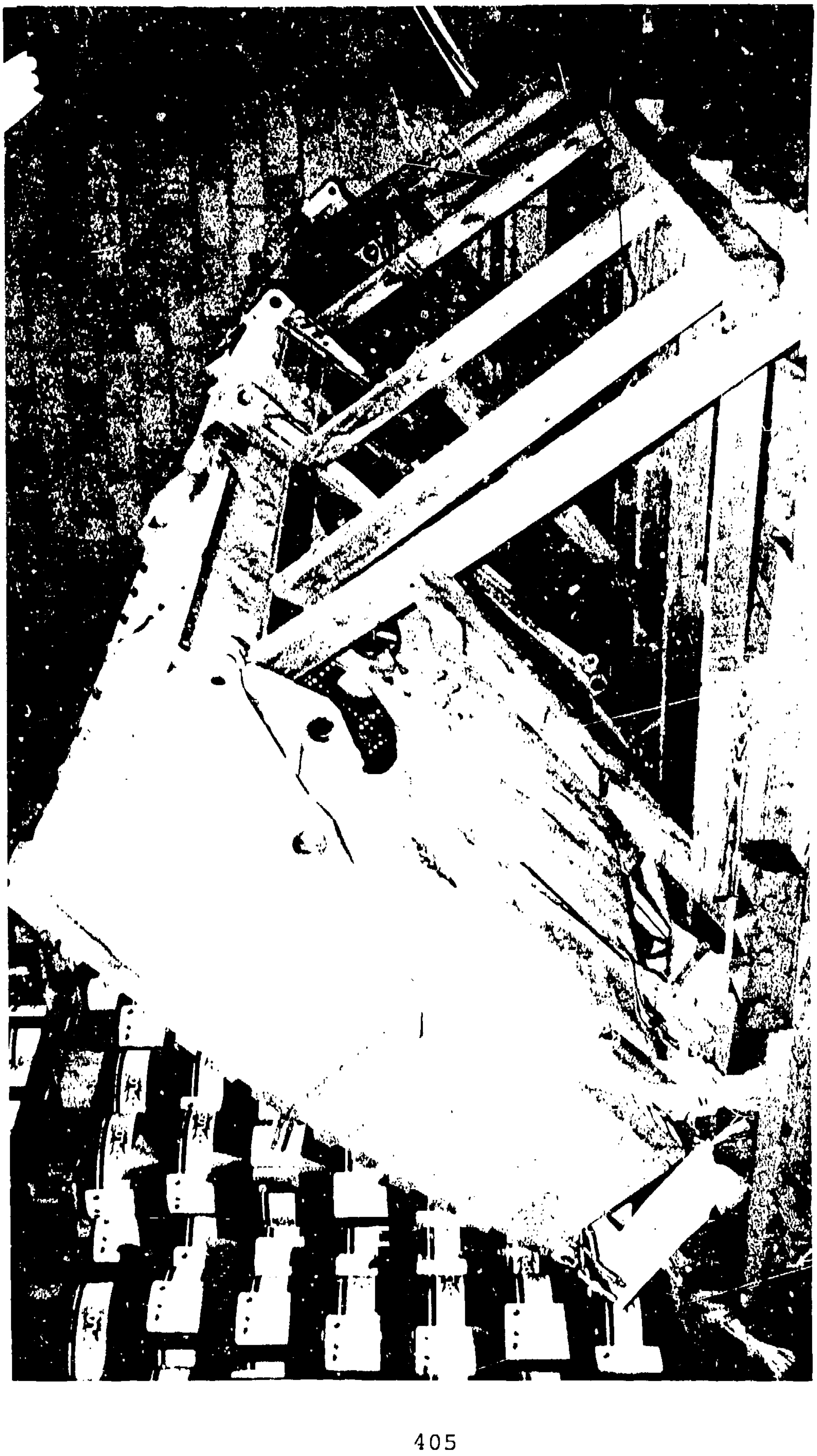
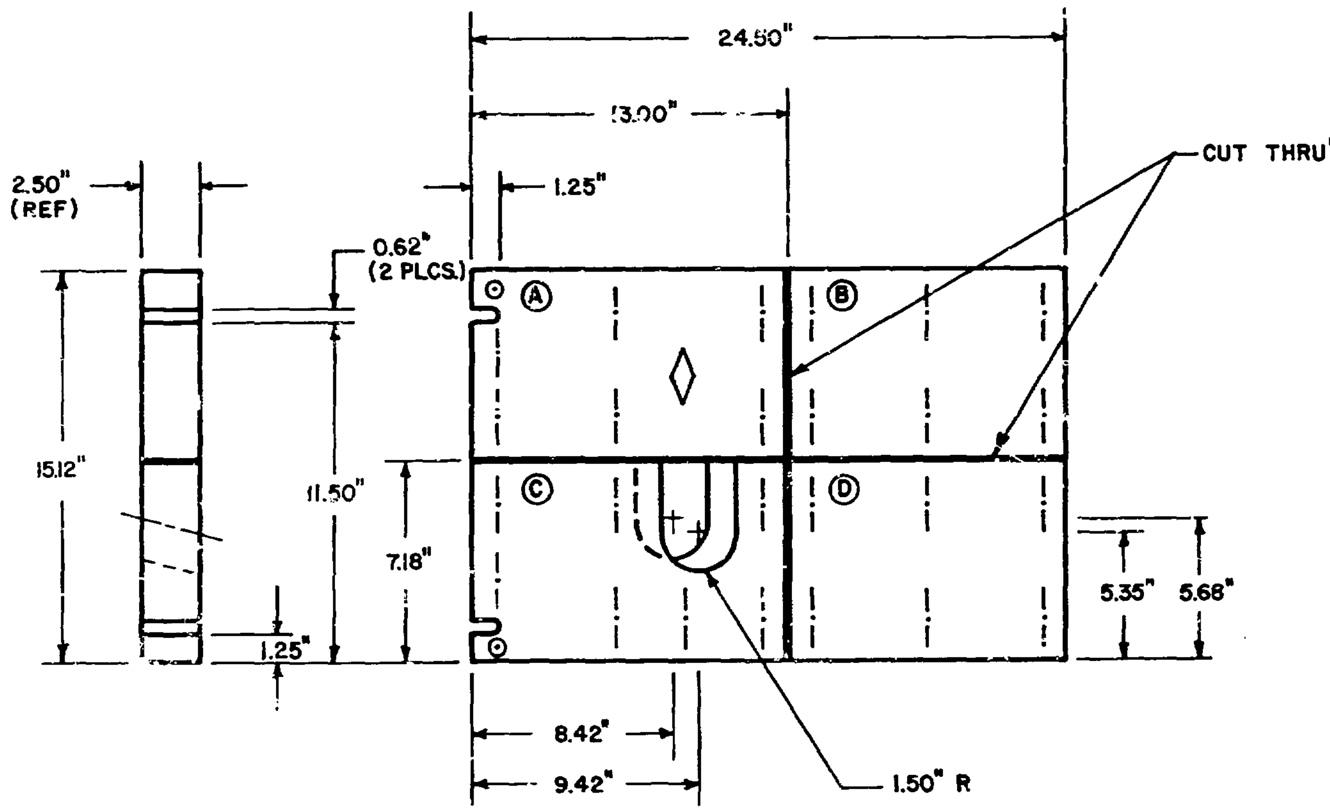


Figure D6-1. A-10 Wing Box Tank



= 24 GAUGE STAINLESS STEEL WIRE STITCHES

⊙ = 16 GAUGE ALUMINUM WIRE PINS

Figure D6-2. Typical Stitch Locations

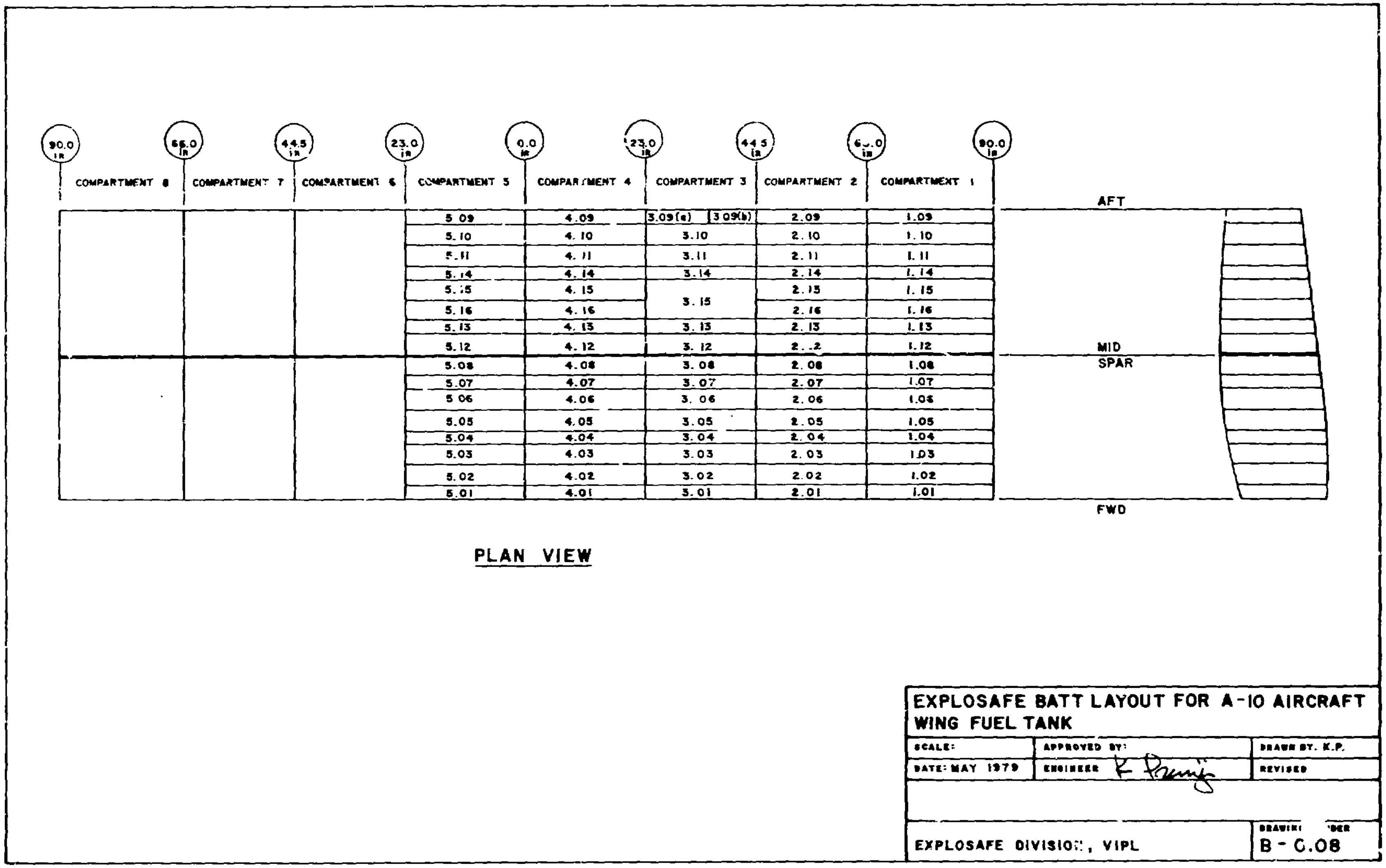


Figure D6-3. Batt Layout for A-10 Aircraft Wing Tank

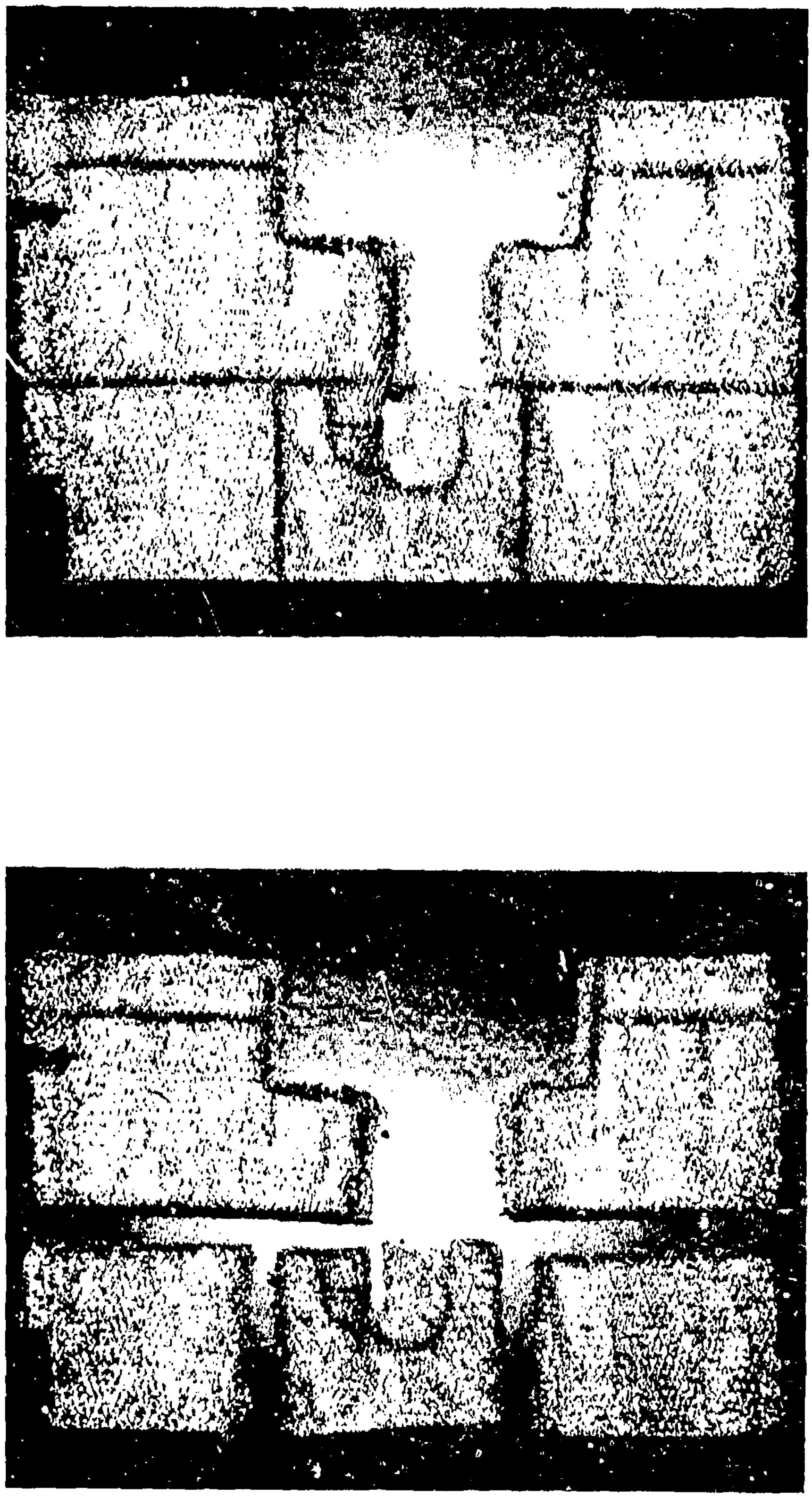
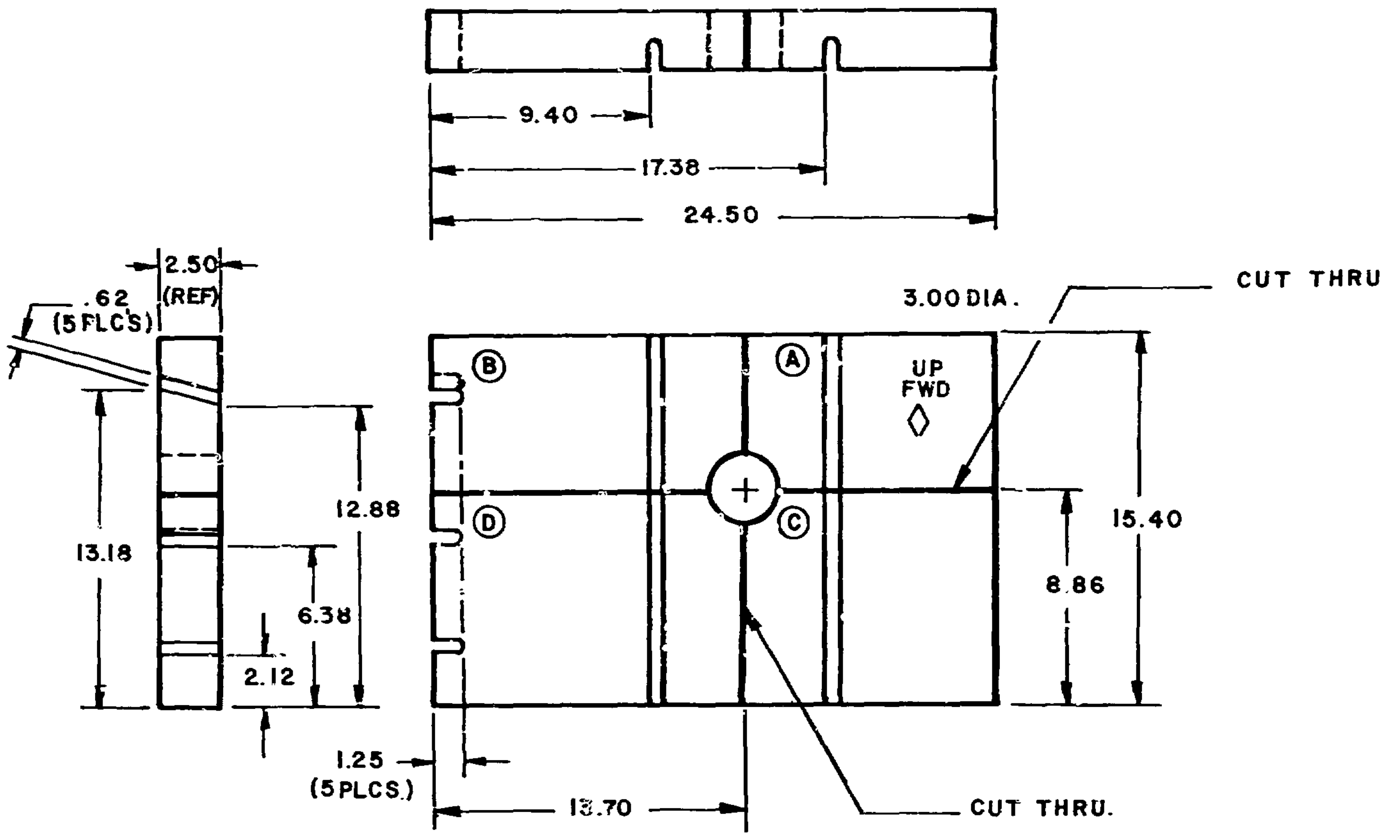
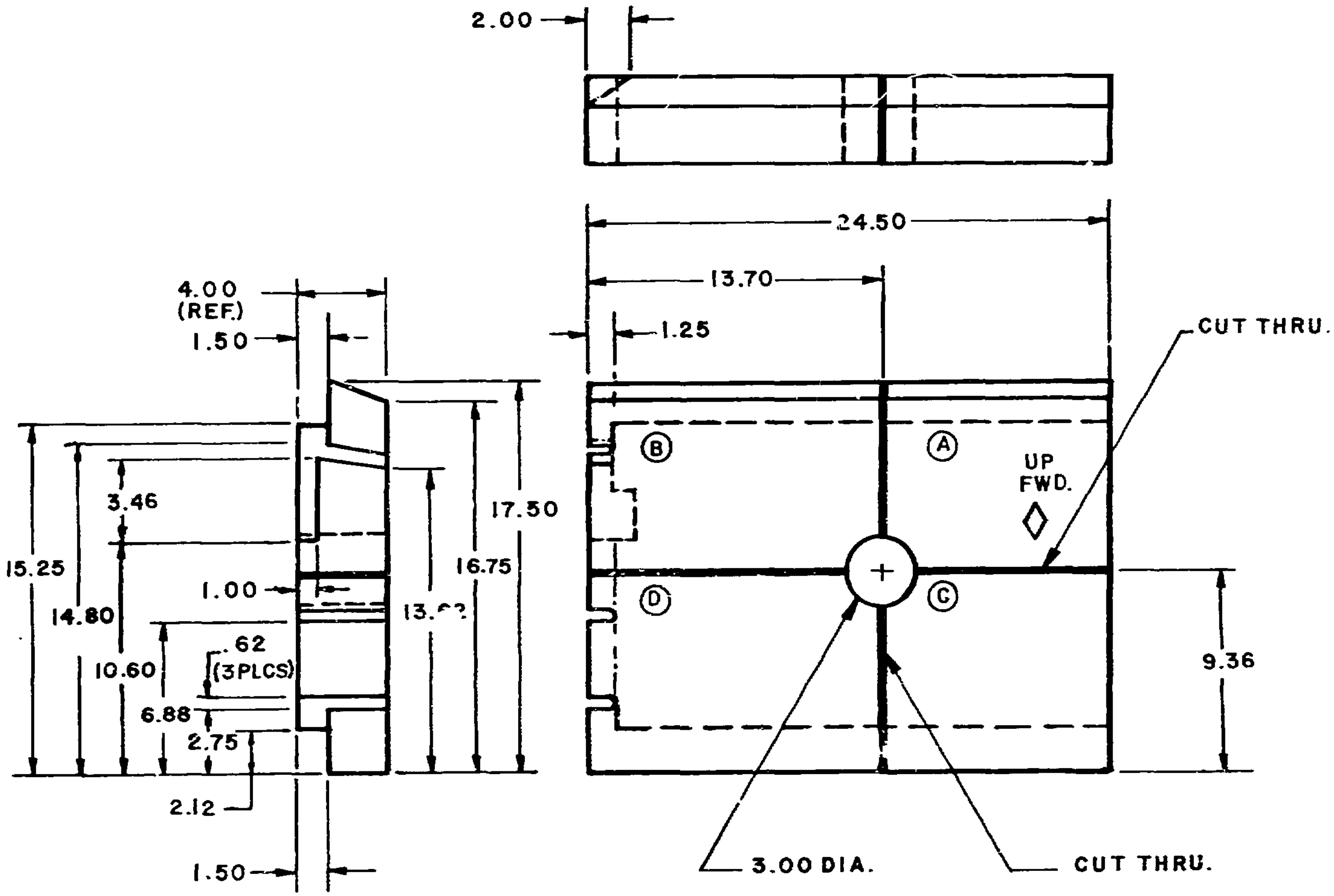


Figure D6-4. Typical Batt Before and After Subdivision



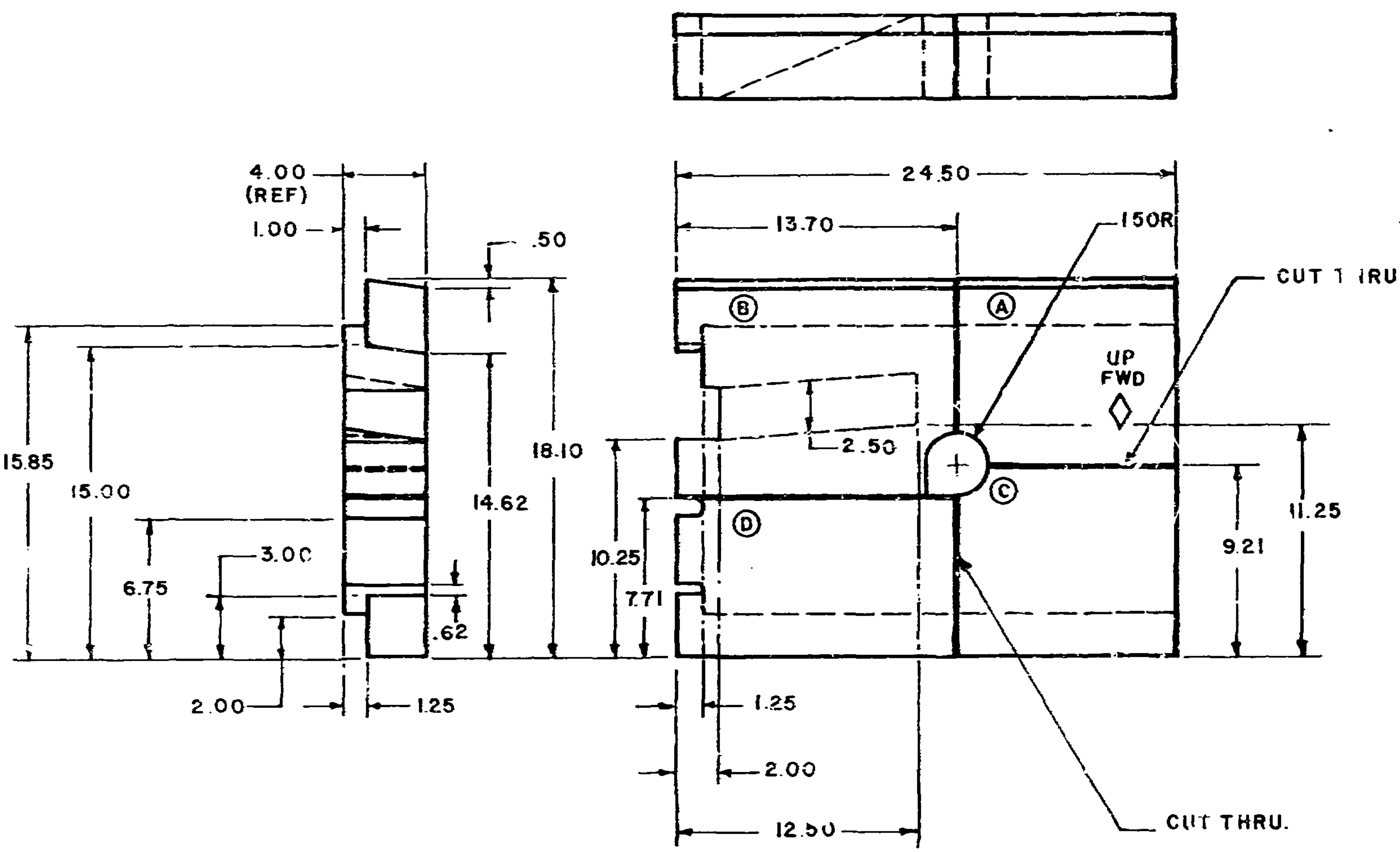
(TAG BATT NOS. AFT SIDE)

Figure D6-5. Batt 1.01 Detail Compartment 1



(TAG BATT NOS. AFT SIDE)

Figure D6-6. Batt 1.02 Detail Compartment 1



(TAG BATT NOS. AFT SIDE)

Figure D6-7. Batt 1.03 Detail Compartment 1

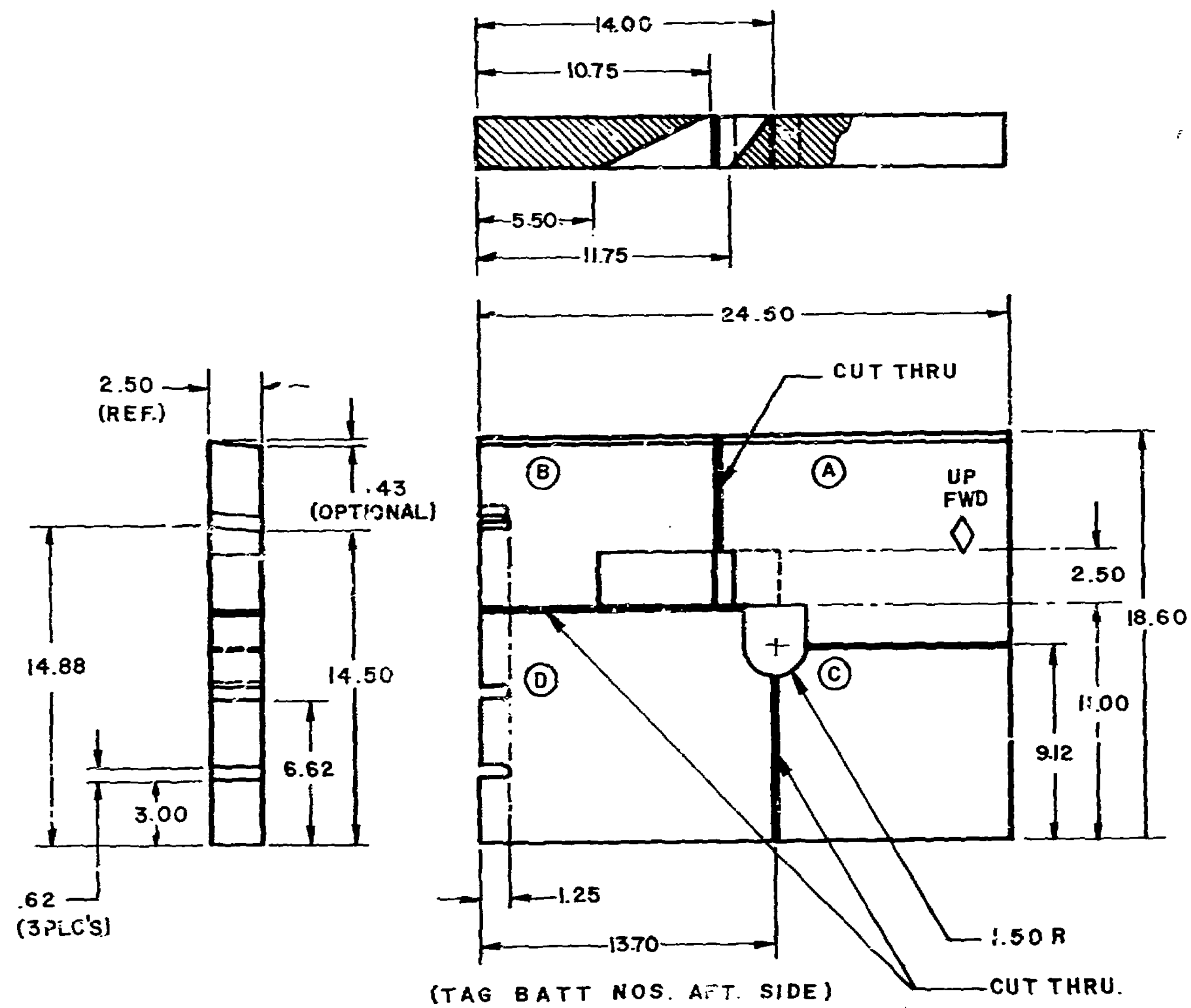


Figure D6-8. Batt 1.04 Detail Compartment 1

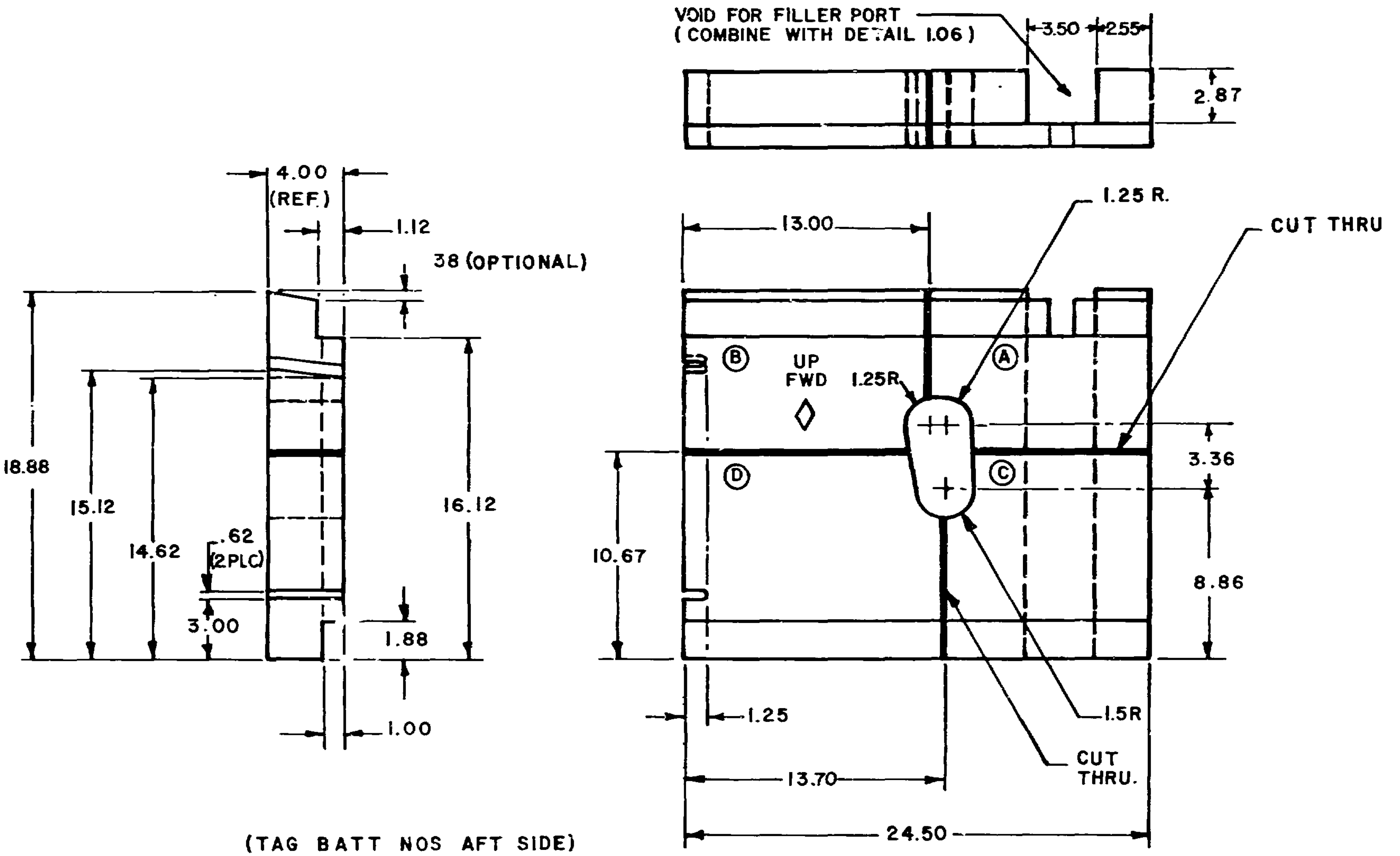


Figure D6-9. Batt 1.05 Detail Compartment 1

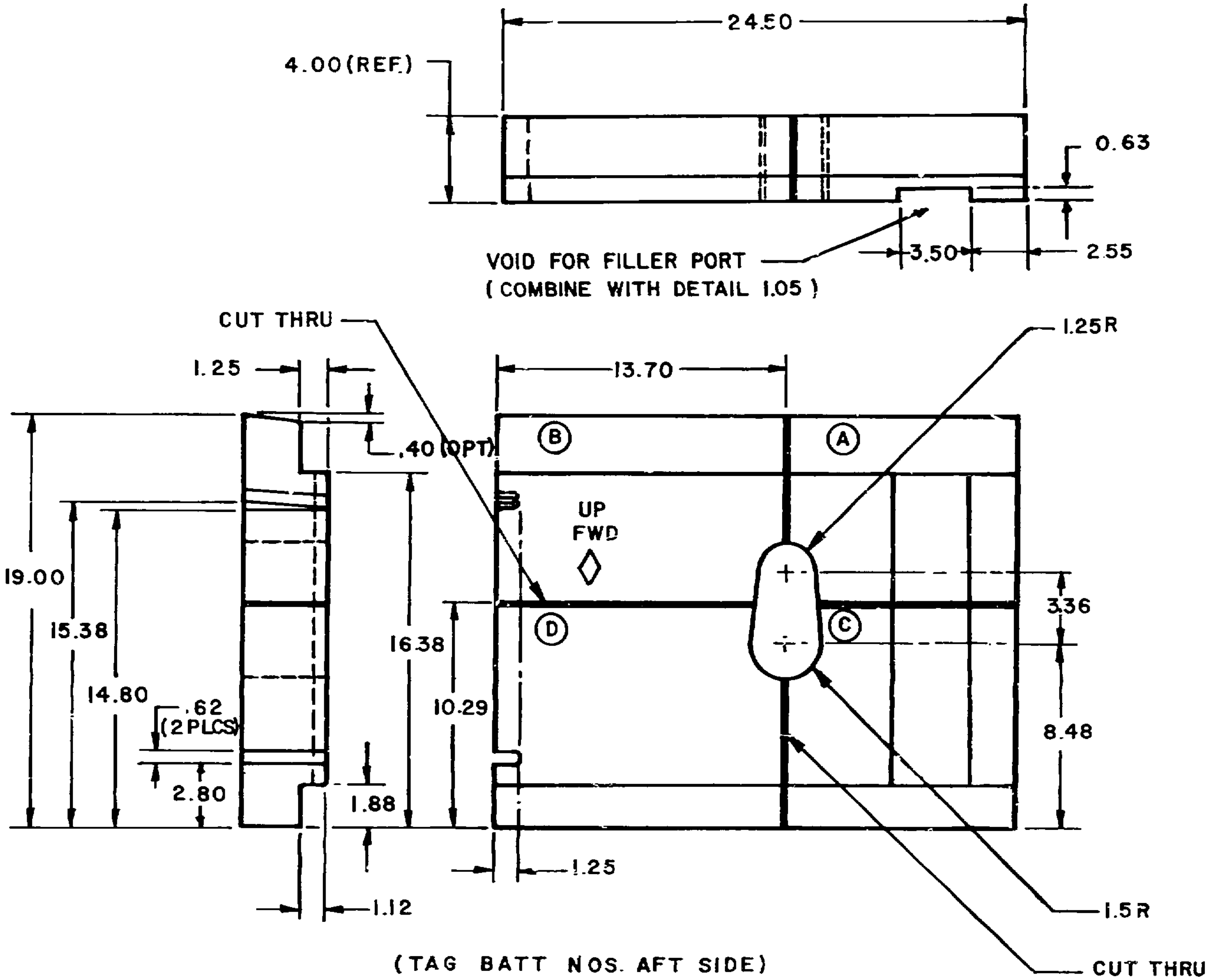
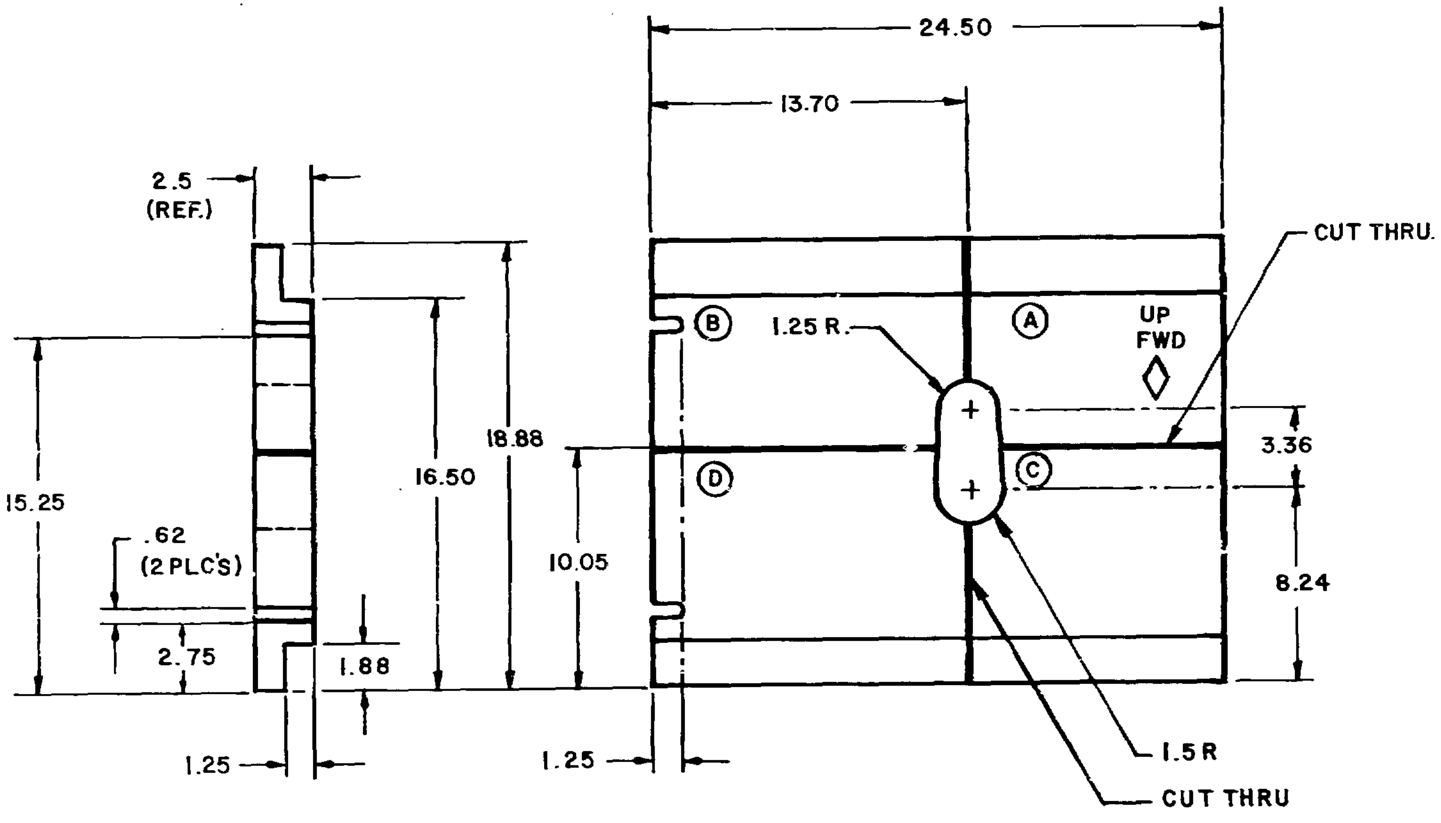


Figure D6-10. Batt 1.06 Detail Compartment 1



(TAG BATT NOS. AFT SIDE)

Figure D6-11. Batt 1.07 Detail Compartment 1

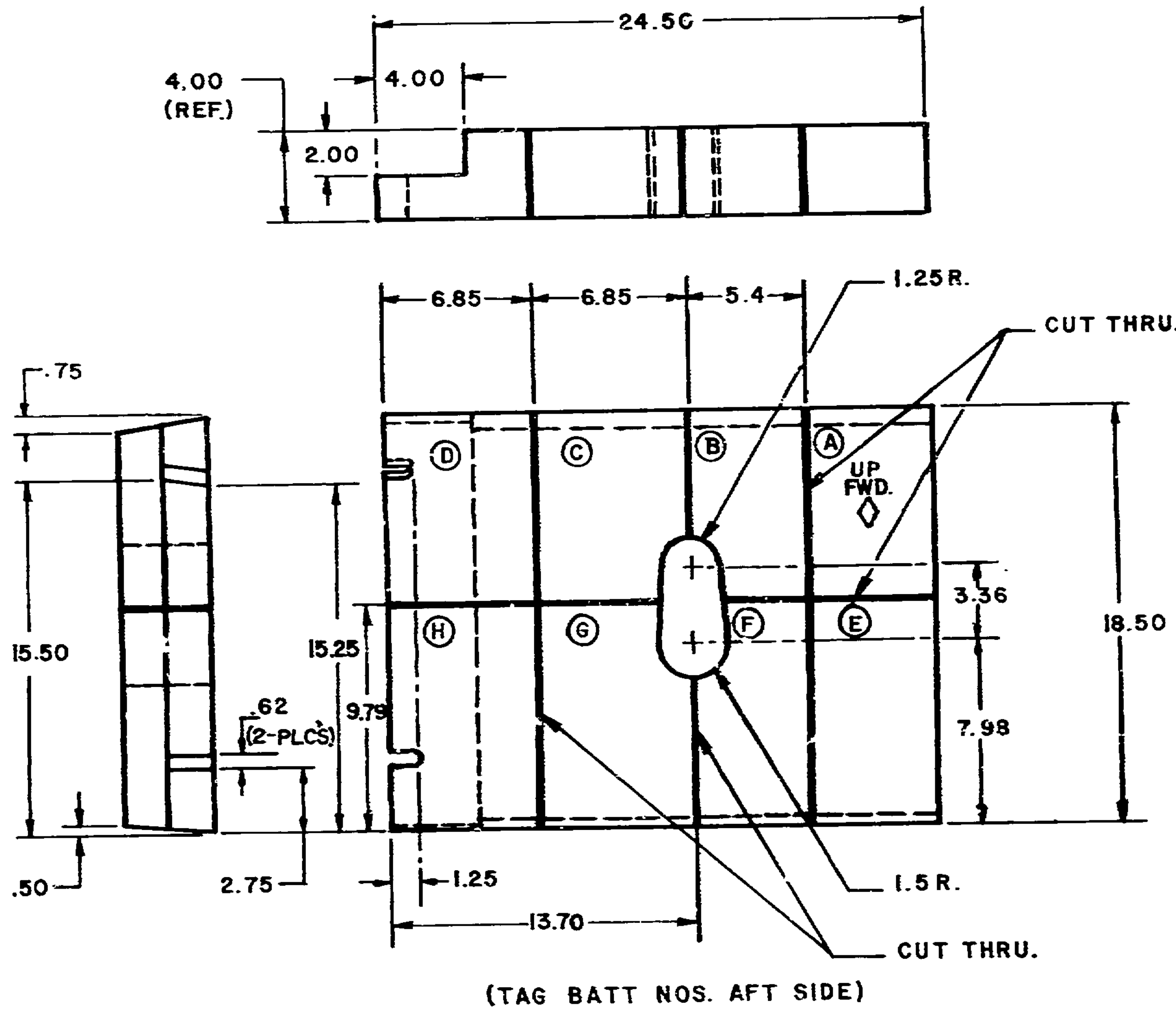
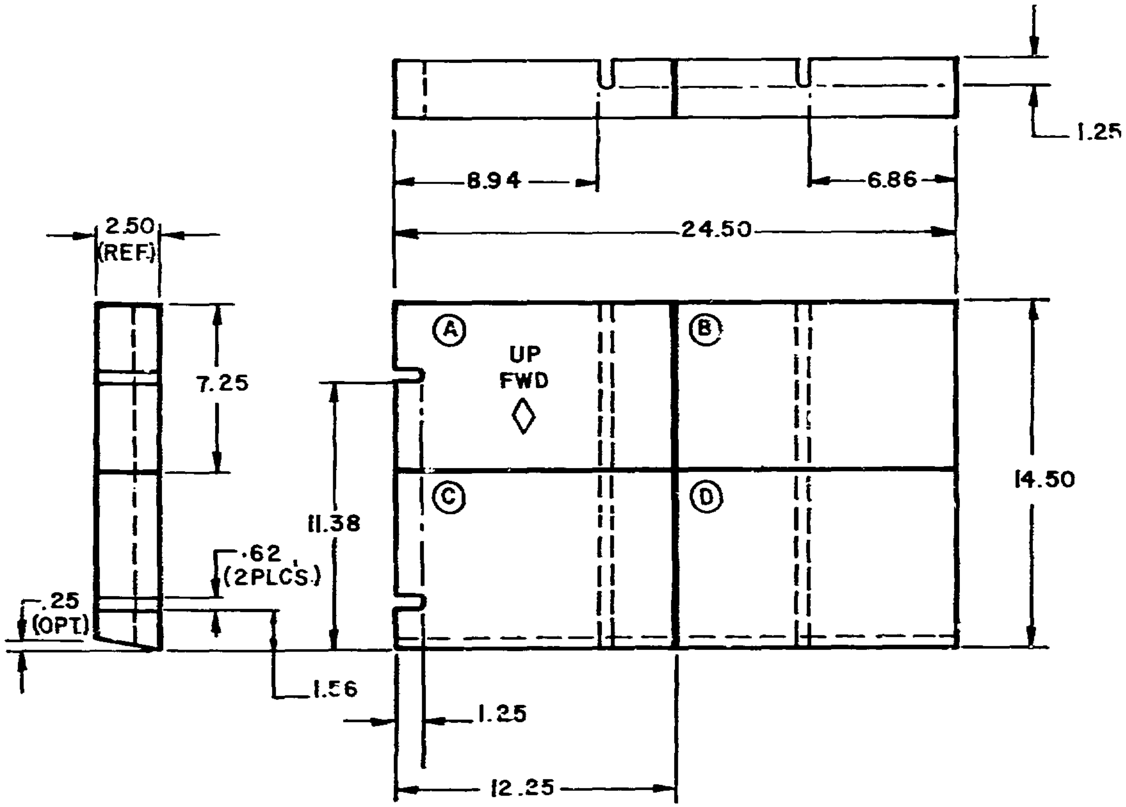
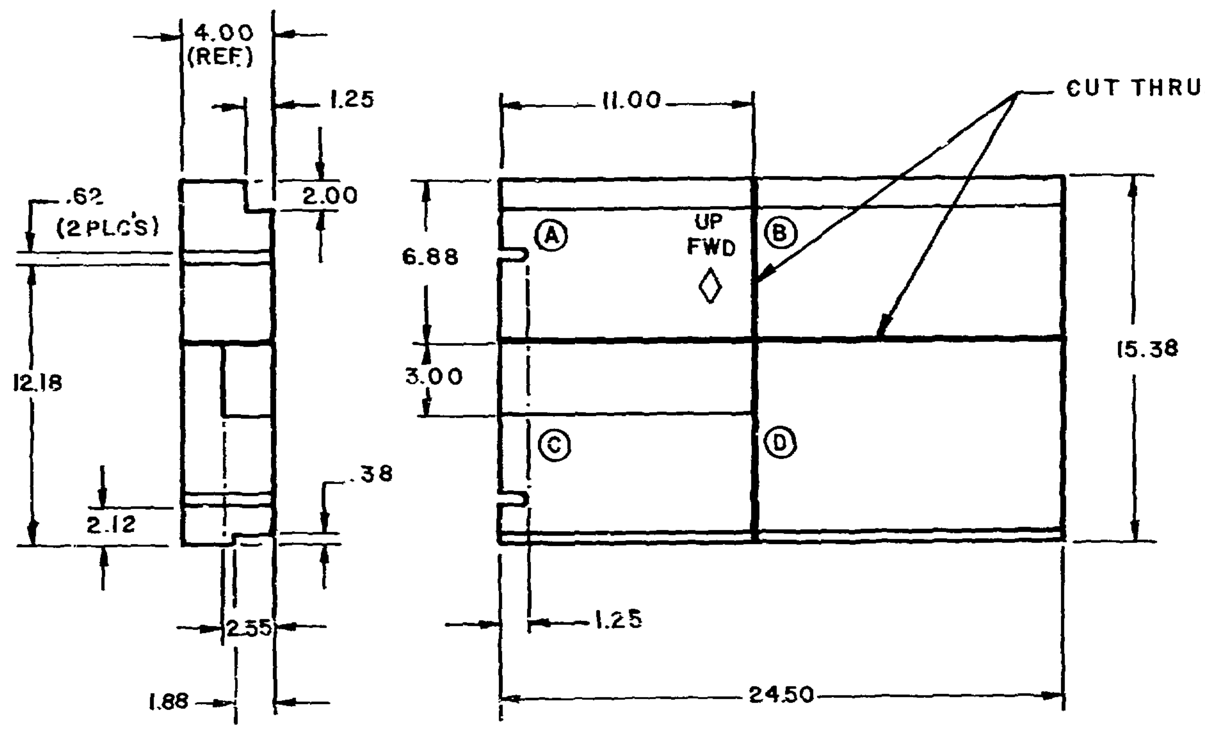


Figure D6-12. Batt 1.08 Detail Compartment 1



(TAG BATT NOS. FWD. SIDE)

Figure D6-13. Batt 1.09 Detail Compartment 1



(TAG BATT NOS. FWD. SIDE)

Figure D6-14. Batt 1.10 Detail Compartment 1

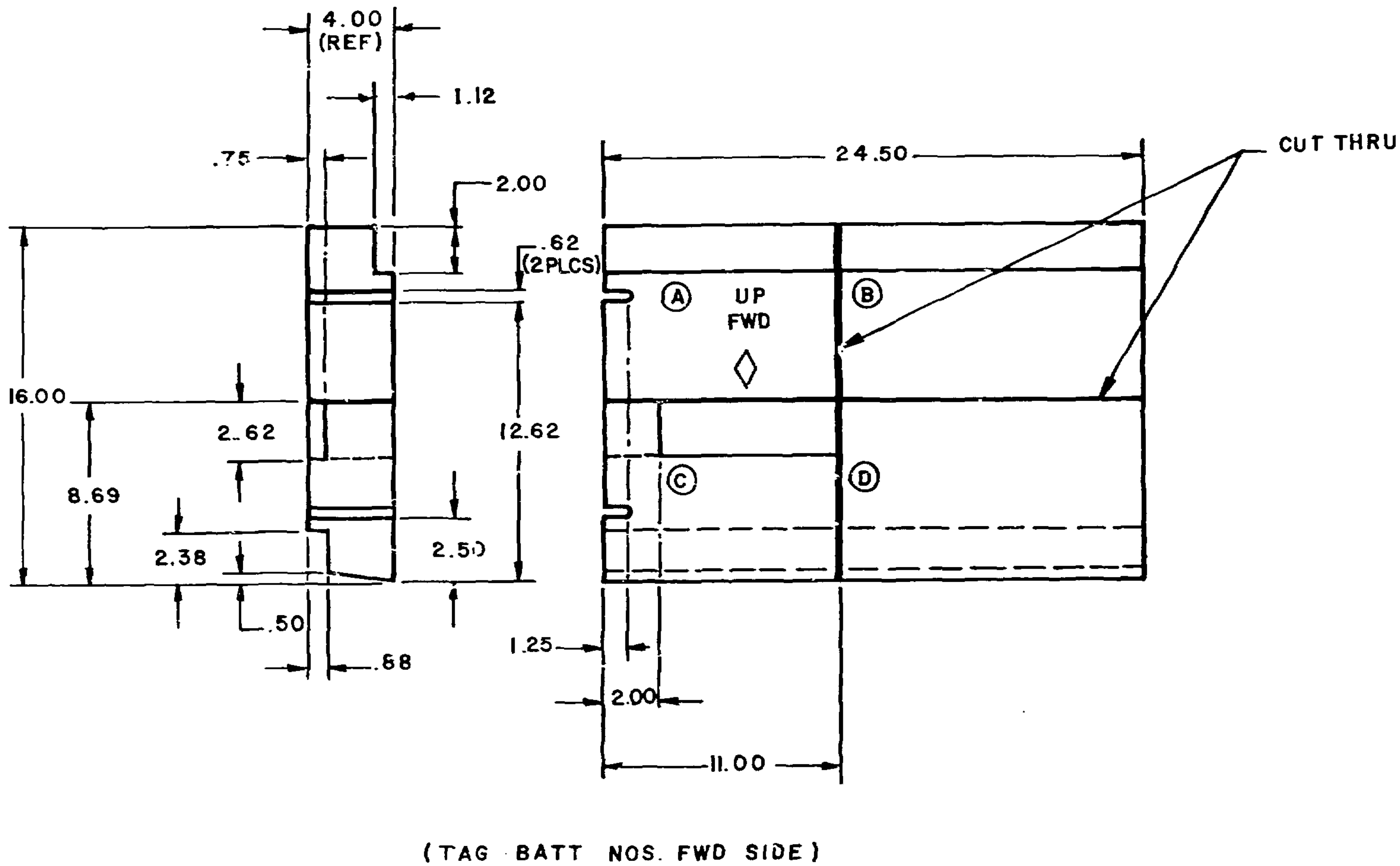


Figure D6-15. Batt 1.11 Detail Compartment 1

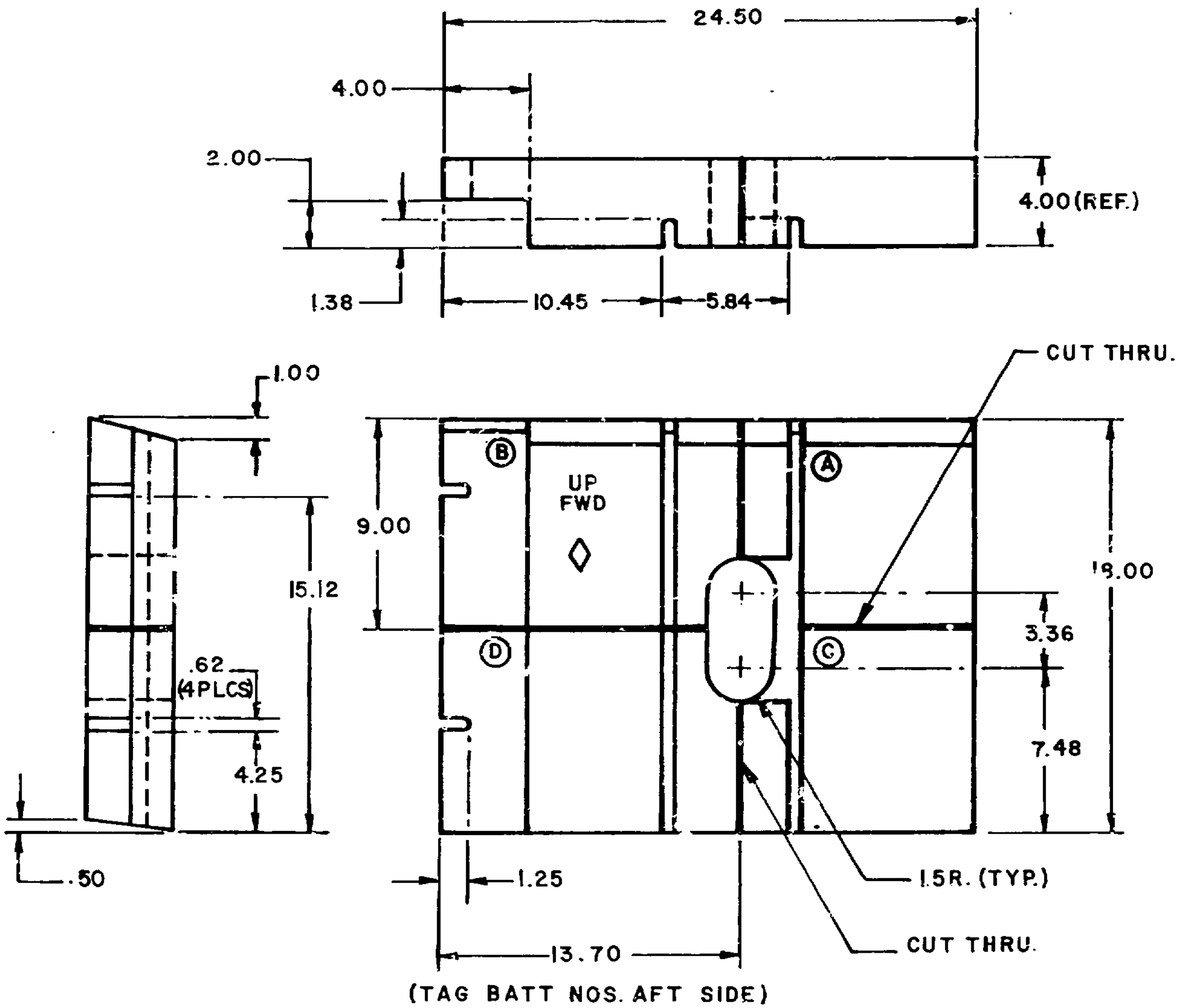
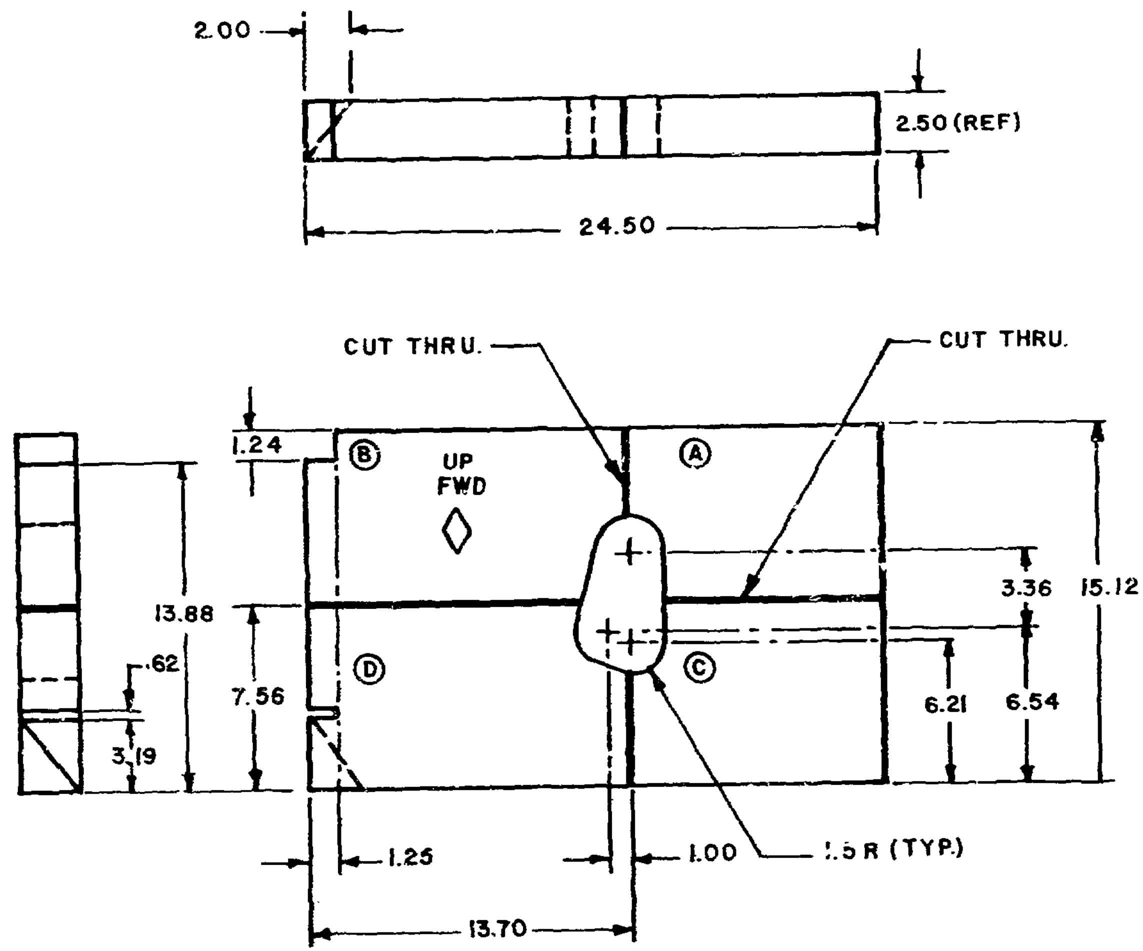
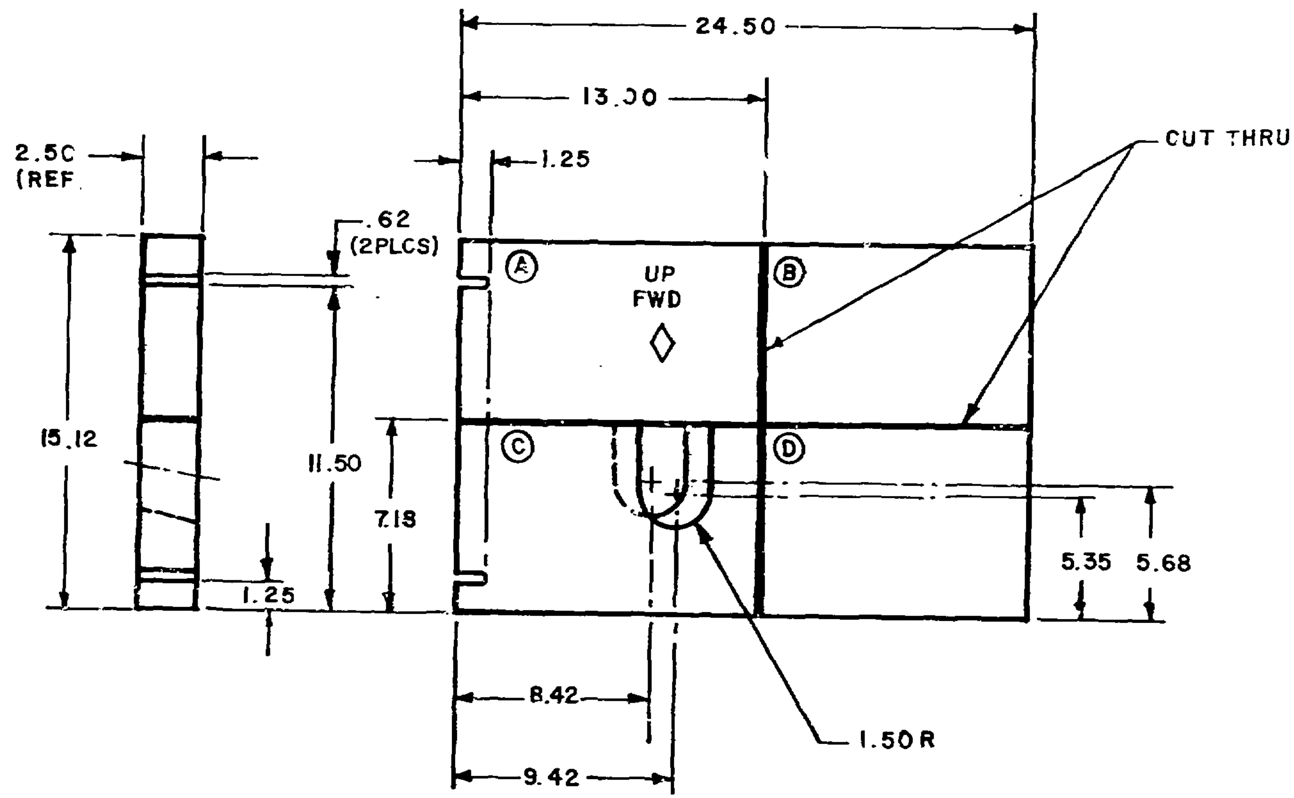


Figure D6-16. Batt 1.12 Detail Compartment 1



(TAG BATT NOS. AFT SIDE)

Figure D6-17. Batt 1.13 Detail Compartment 1



(TAG BATT NOS. FWD. SIDE)

Figure D6-18. Batt 1.14 Detail Compartment 1

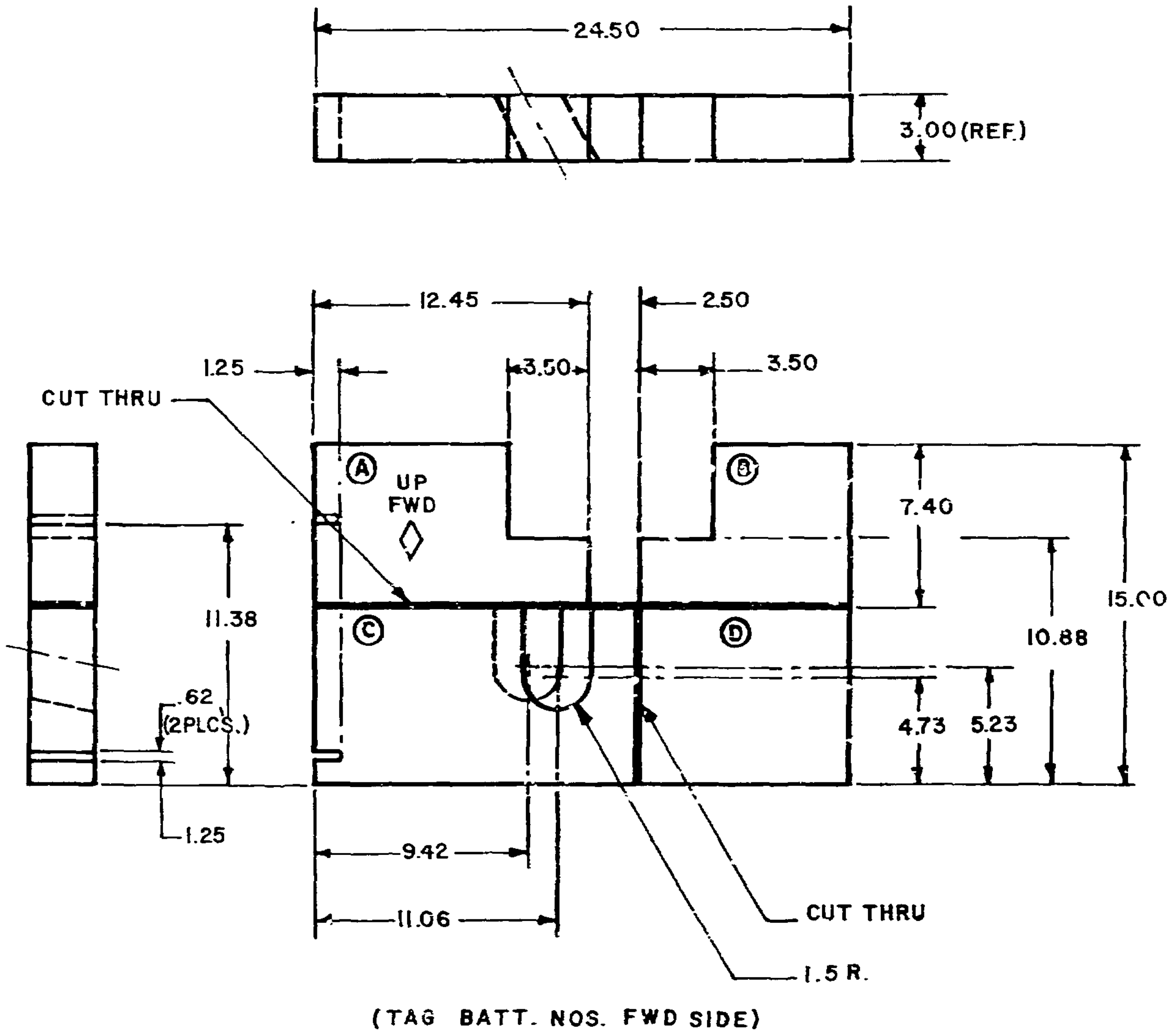


Figure D6-19. Batt 1.15 Detail Compartment 1

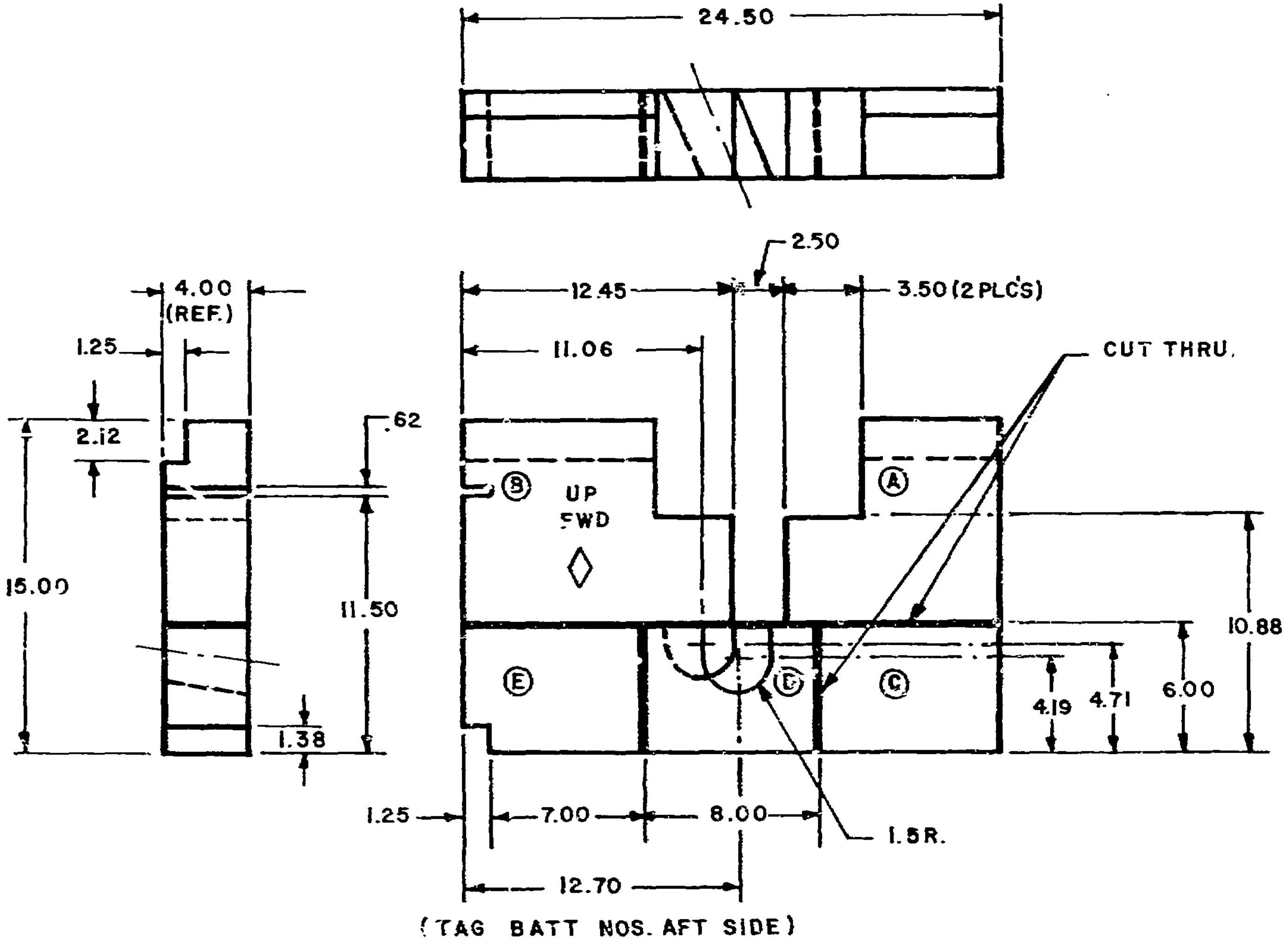
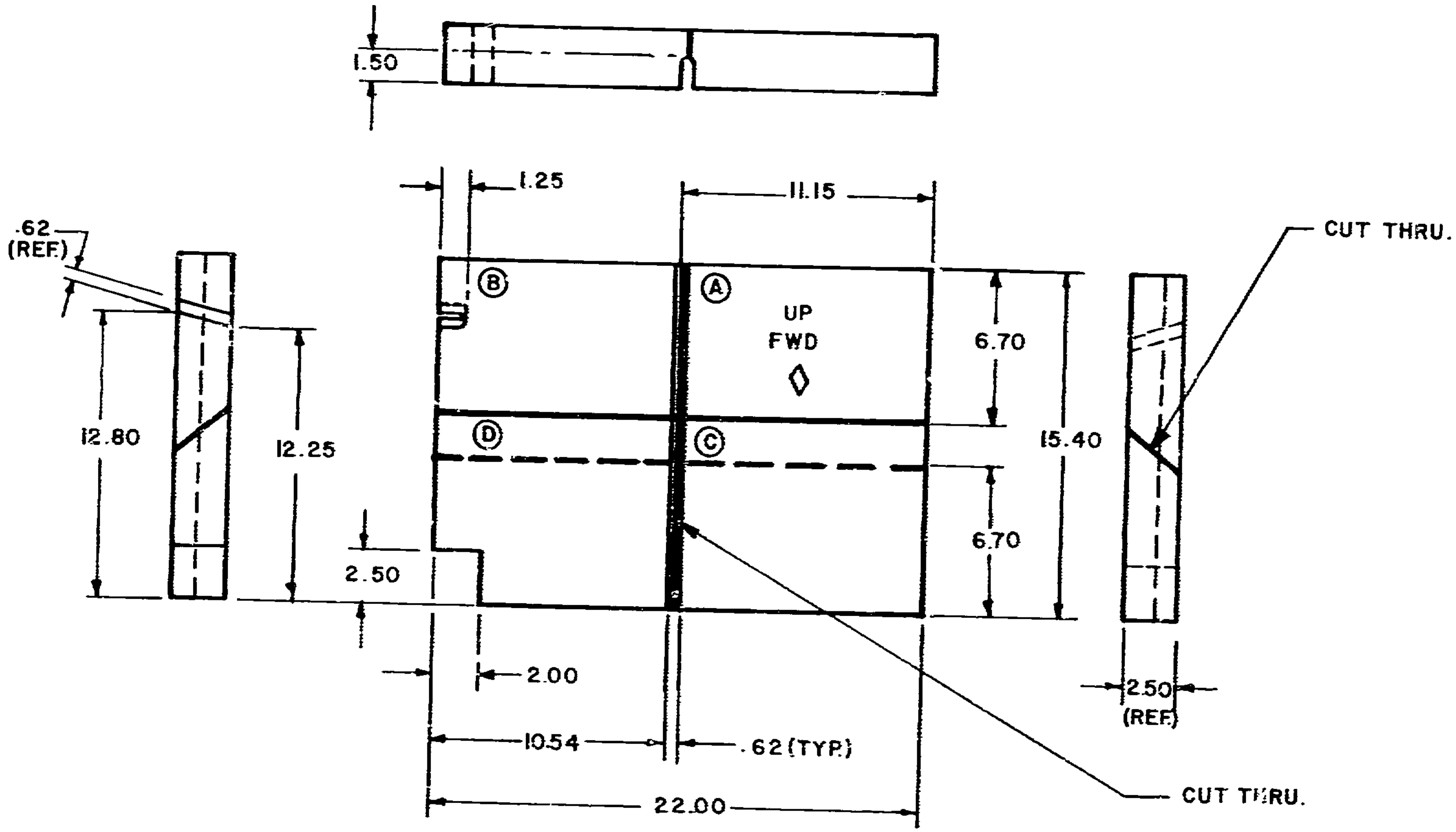


Figure D6-20. Batt 1.16 Detail Compartment 1



(TAG BATT NOS. AFT SIDE.)

Figure D6-21. Batt 3.01 Detail Compartment 3

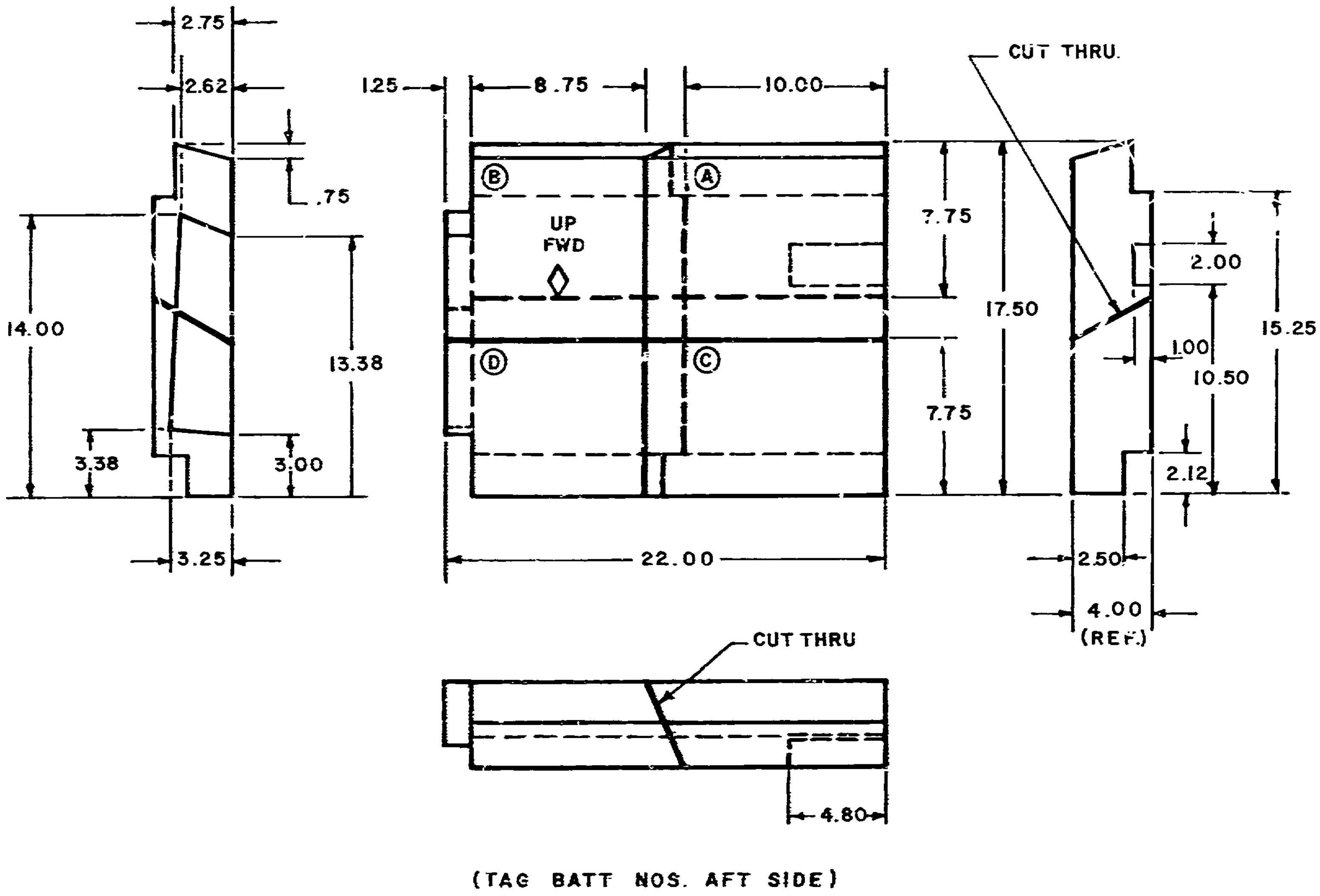
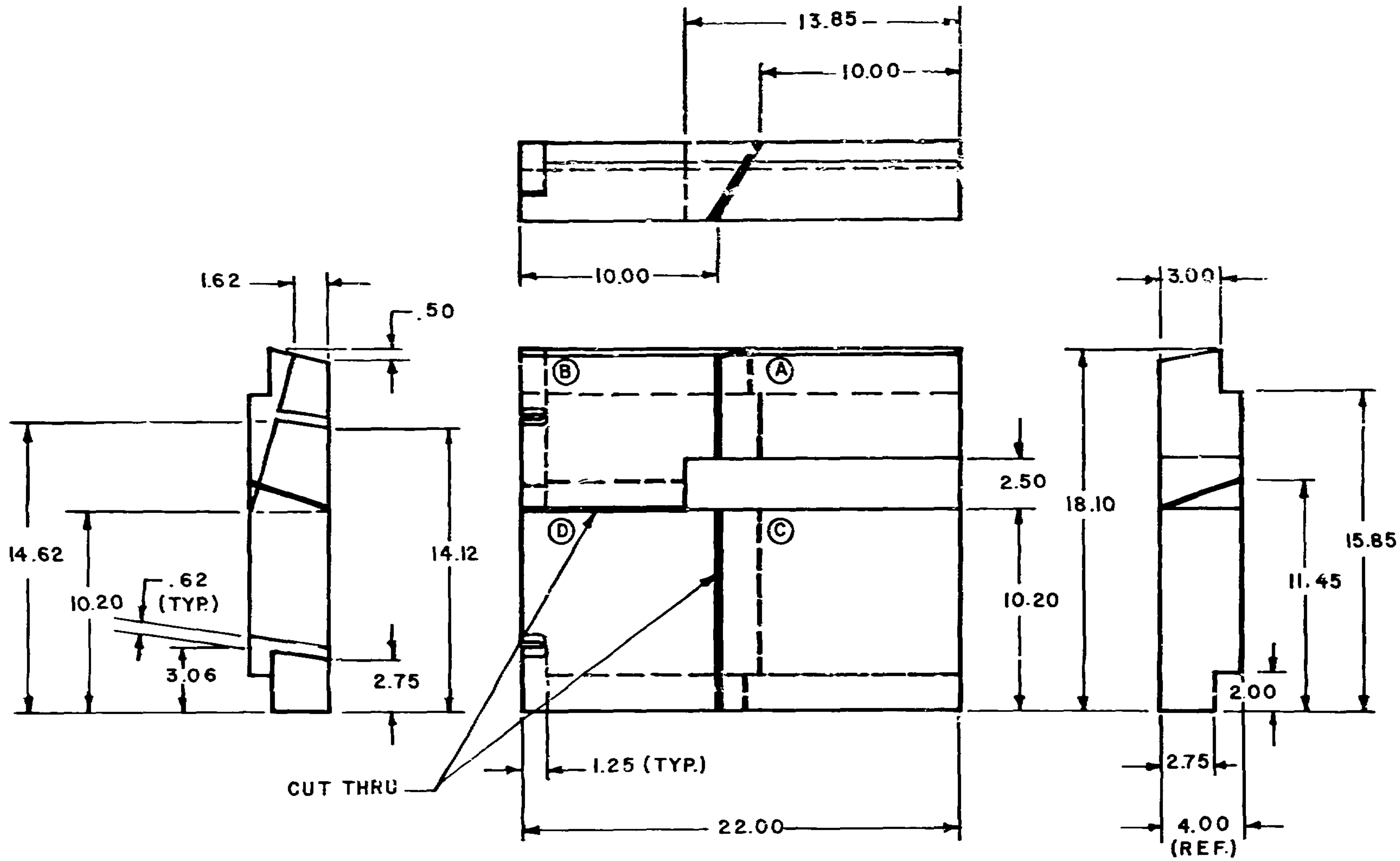


Figure D6-22. Batt 3.02 Detail Compartment 3



(TAG BATT NOS. AFT SIDE)

Figure D6-23. Batt 3.03 Detail Compartment 3

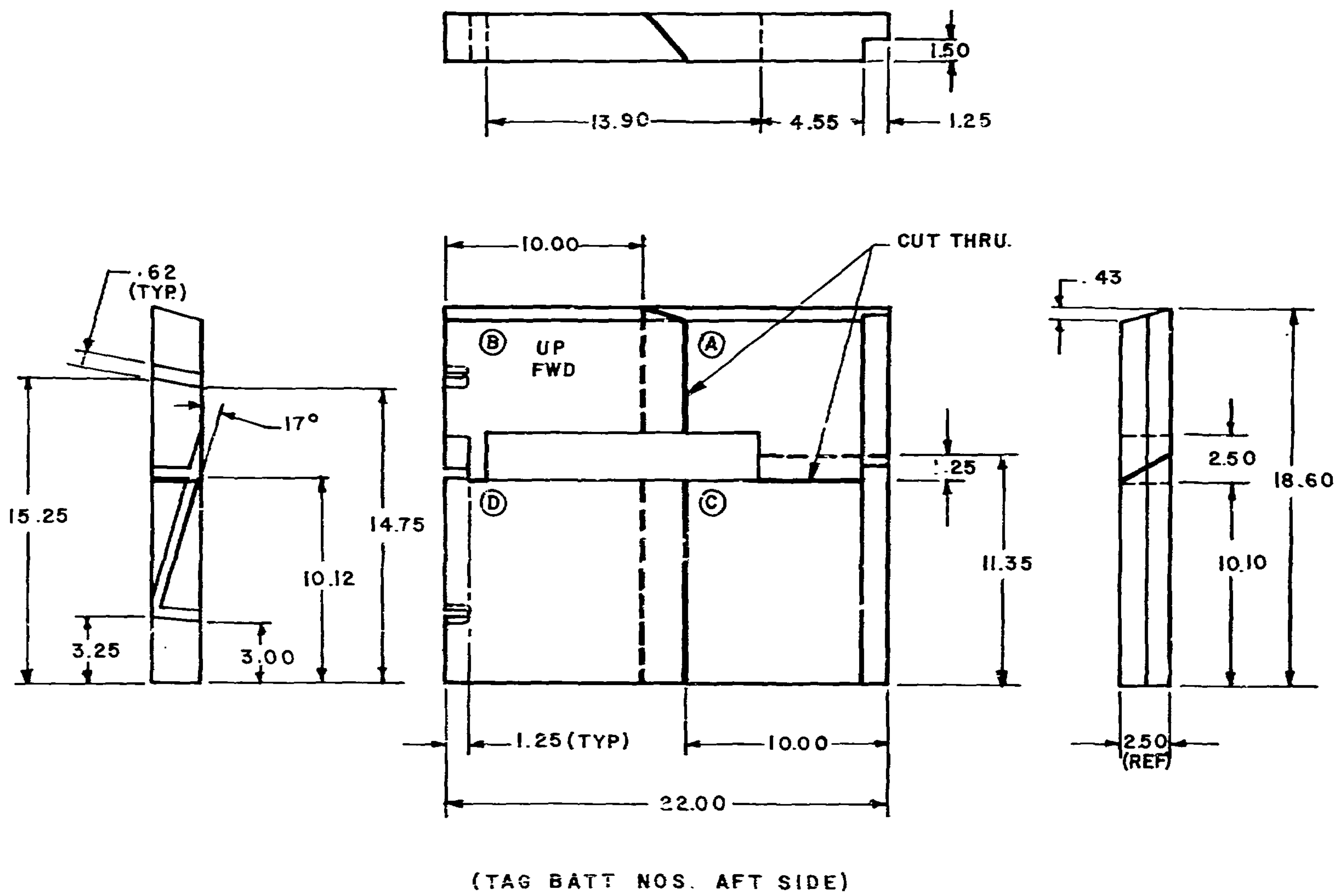


Figure D6-24. Batt 3.04 Detail Compartment 3

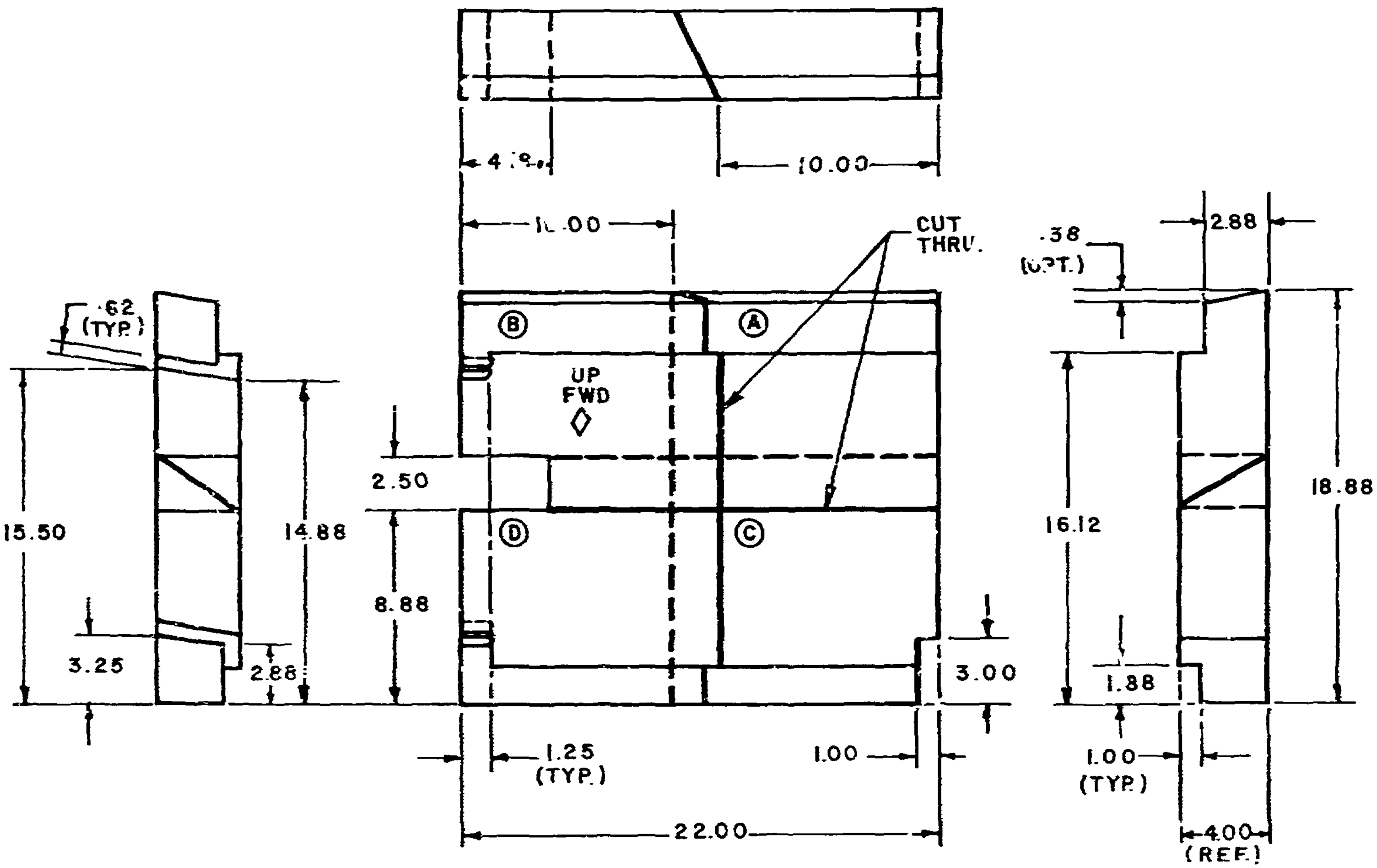


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Figure D6-25. Batt 3.05 Detail Compartment 3

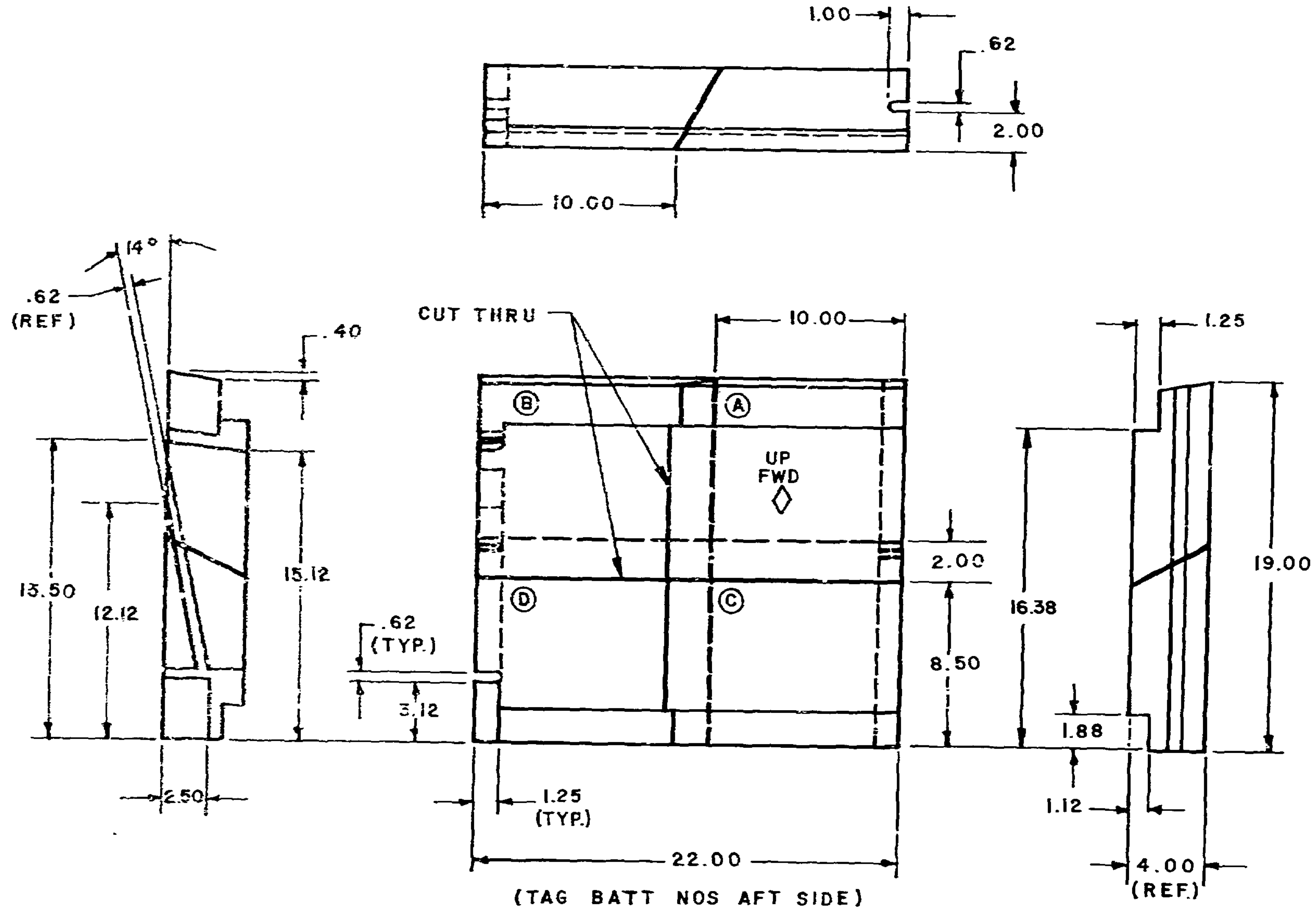
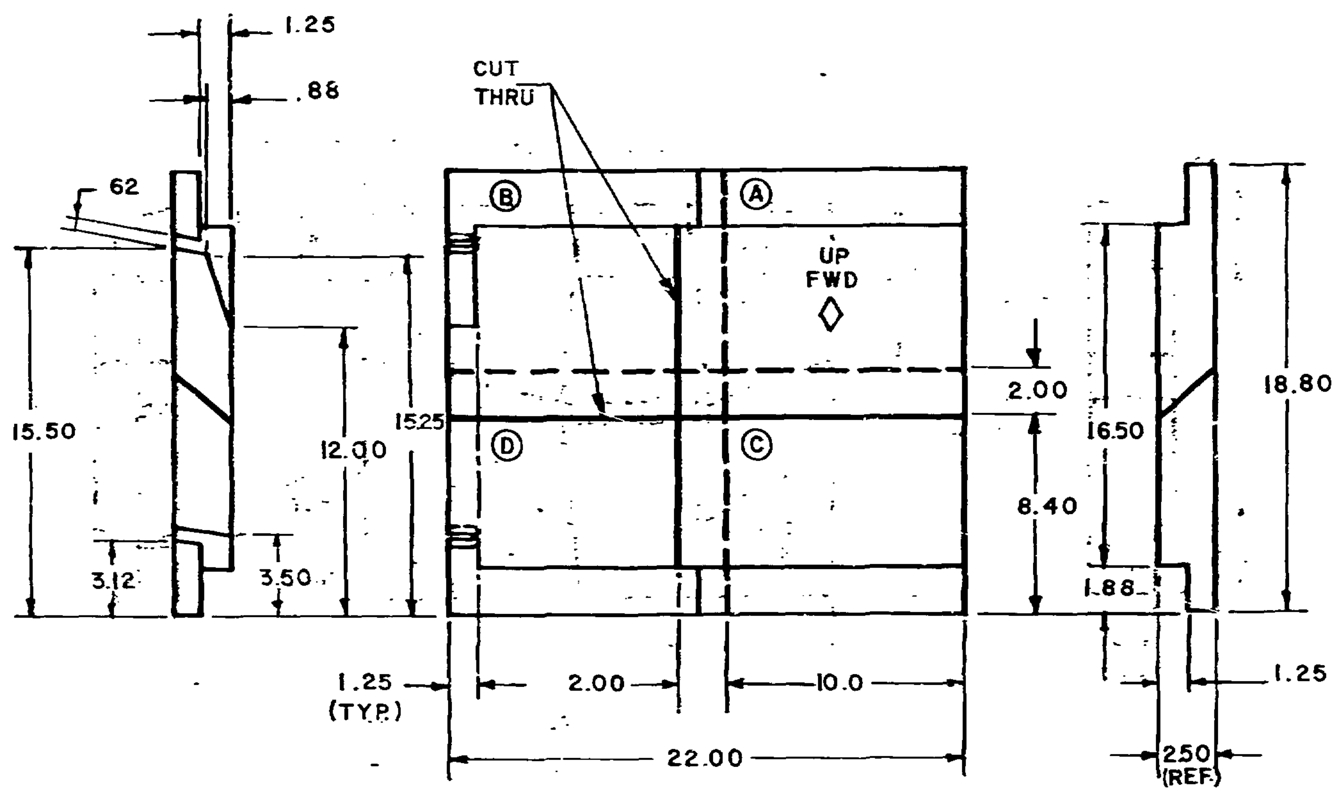


Figure D6-26. Batt 3.06 Detail Compartment 3



(TAG BATT NOS. AFT SIDE)

Figure D6-27. Batt 3.07 Detail Compartment 3

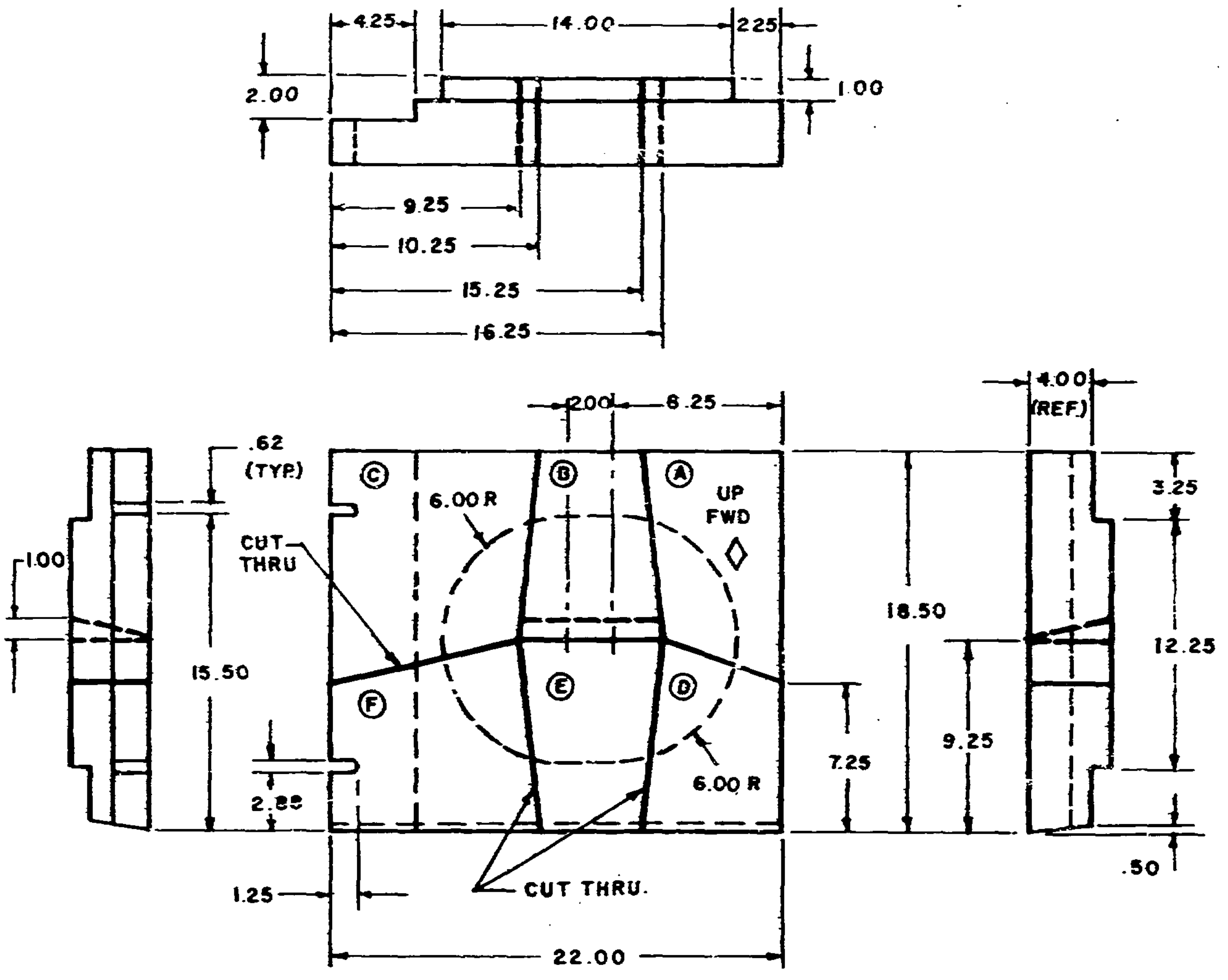


Figure D6-28. Batt 3.08 Detail Compartment 3

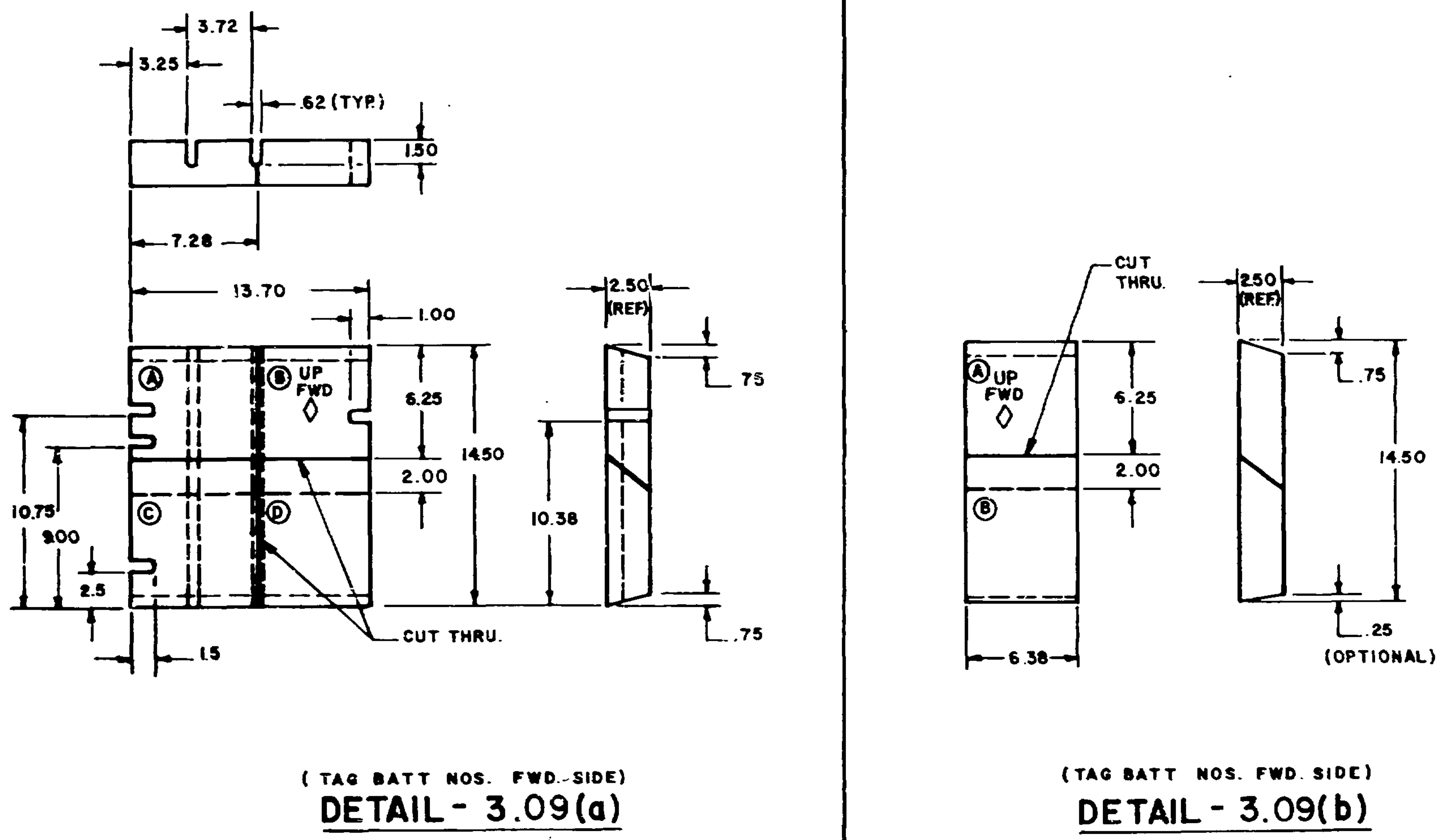
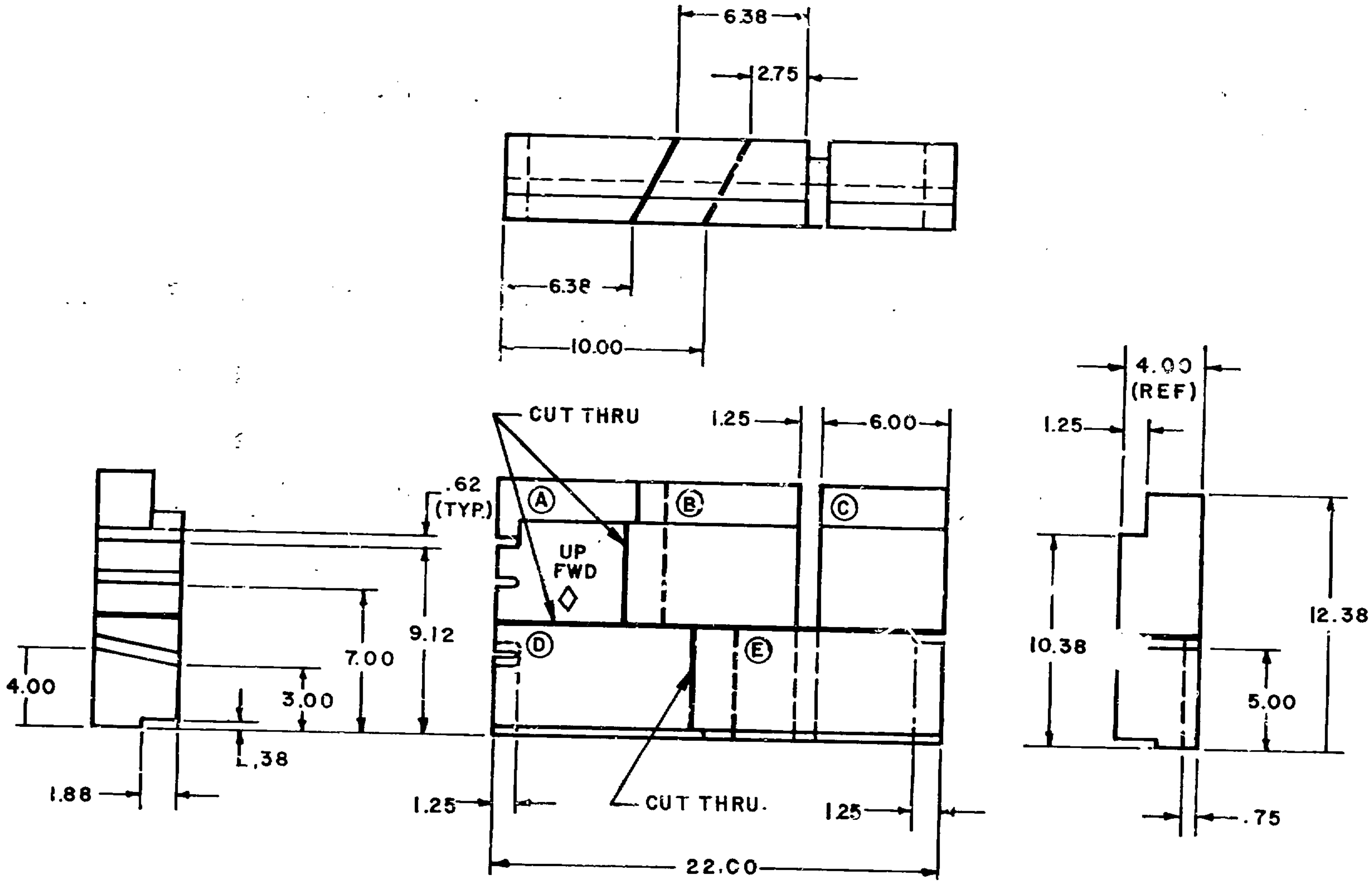


Figure D6-29. Batt 3.09 Detail Compartment 3



(TAG BATT NOS FWD SIDE)

Figure D6-30. Batt 3.10 Detail Compartment 3

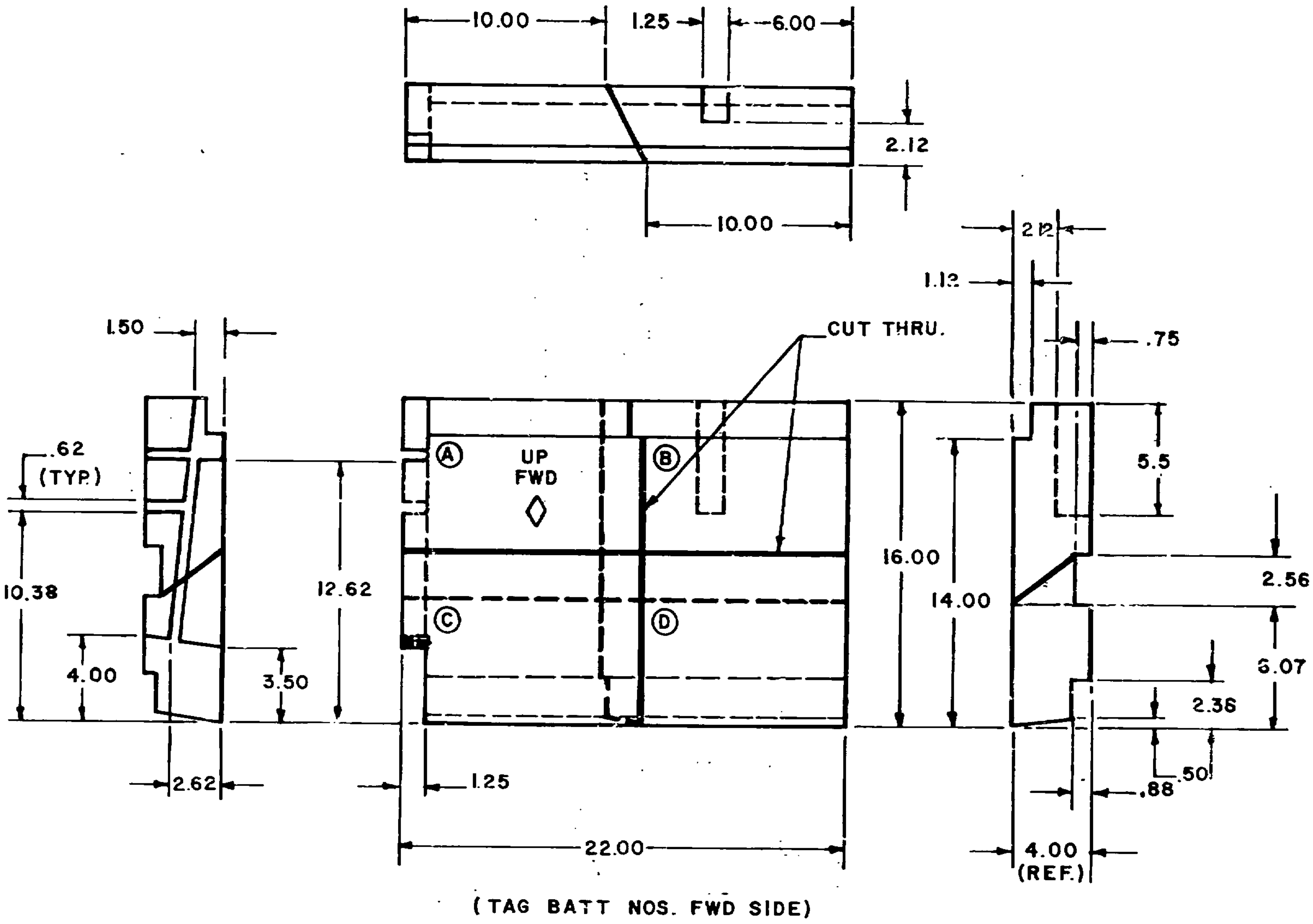


Figure D6-31. Batt 3.11 Detail Compartment 3

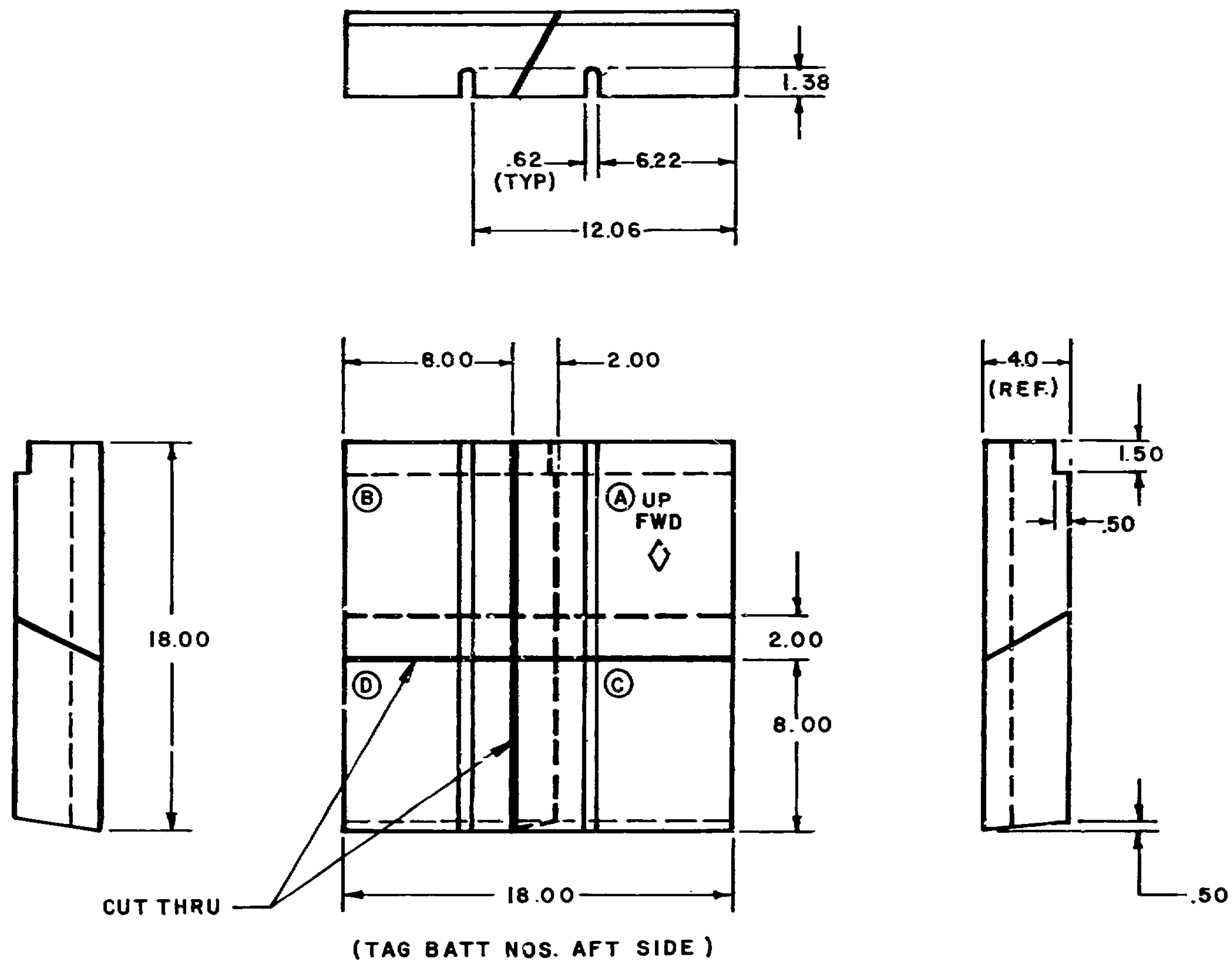
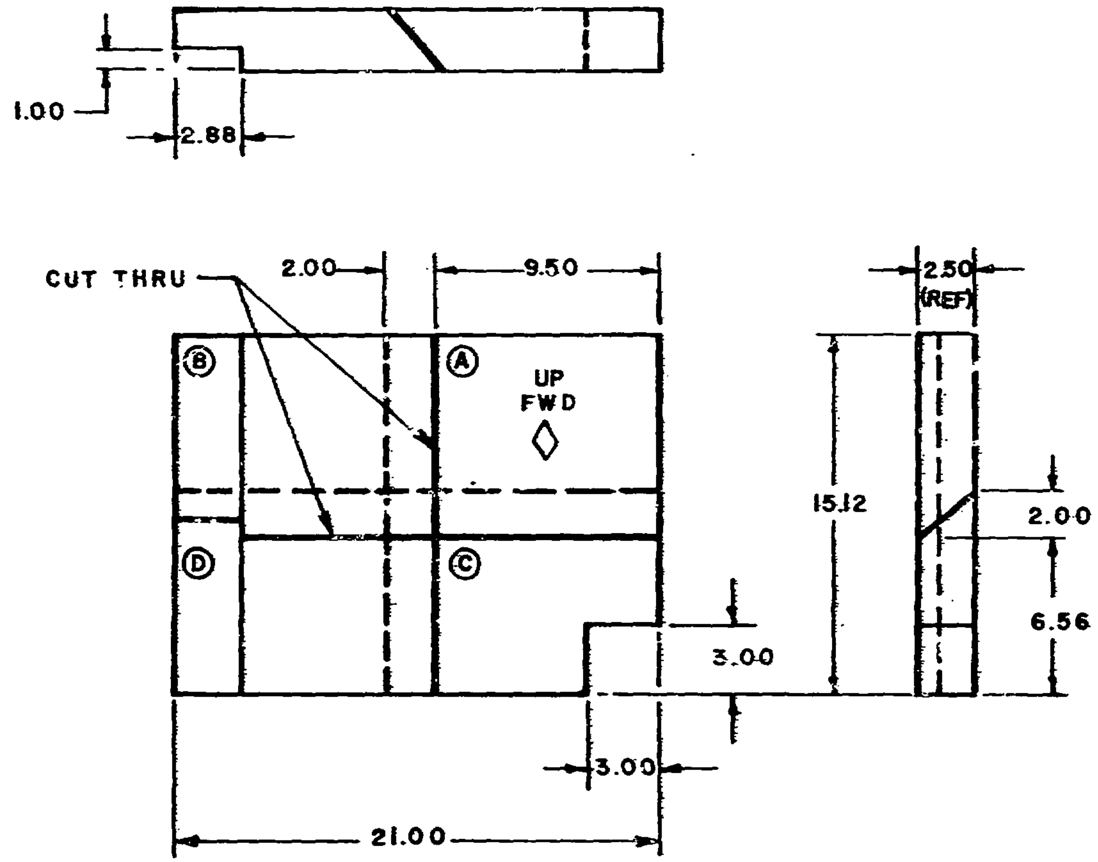


Figure D6-32. Eatt 3.12 Detail Compartment 3



(TAG BATT NOS. AFT SIDE)

Figure D6-33. Batt 3.13 Detail Compartment 3

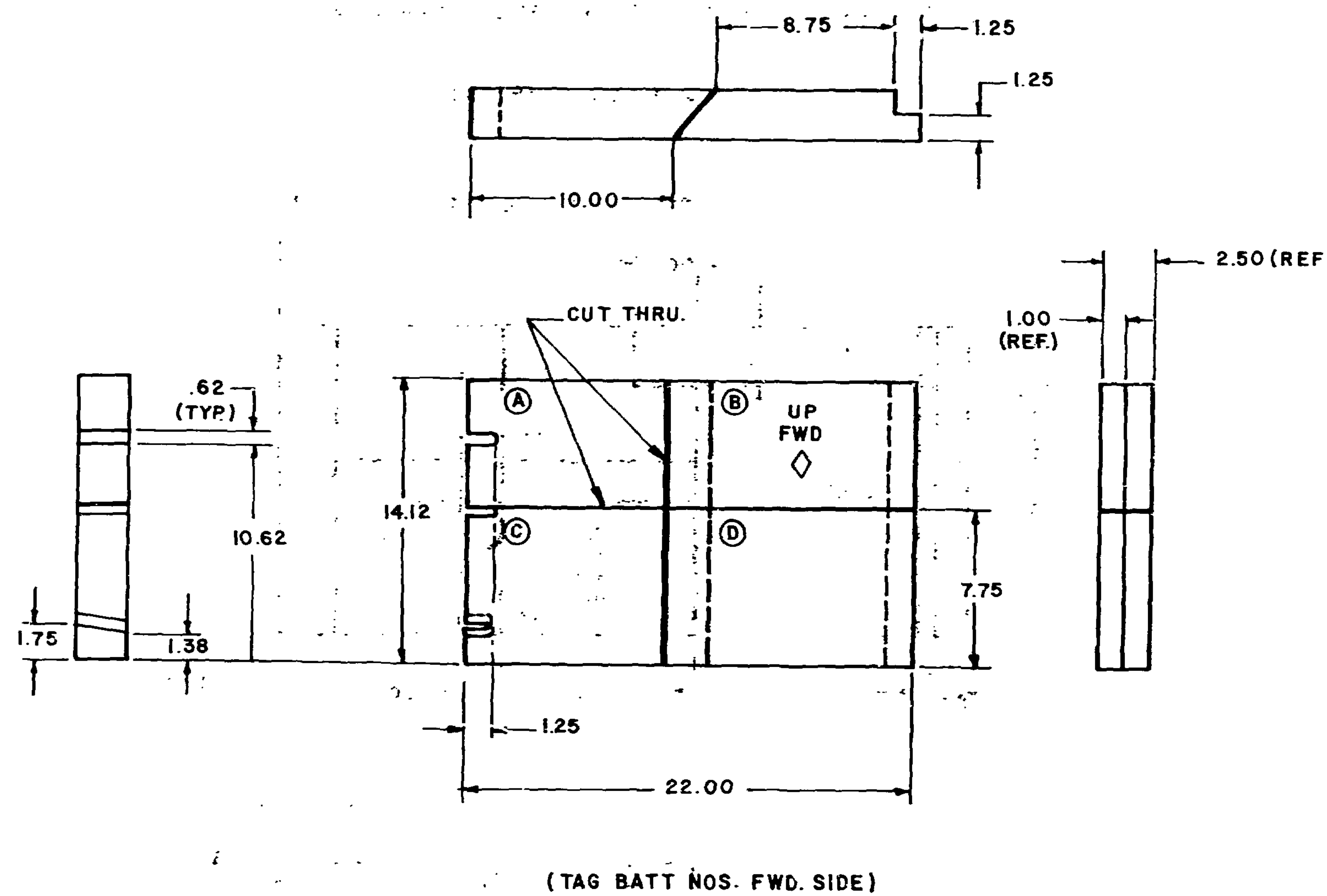
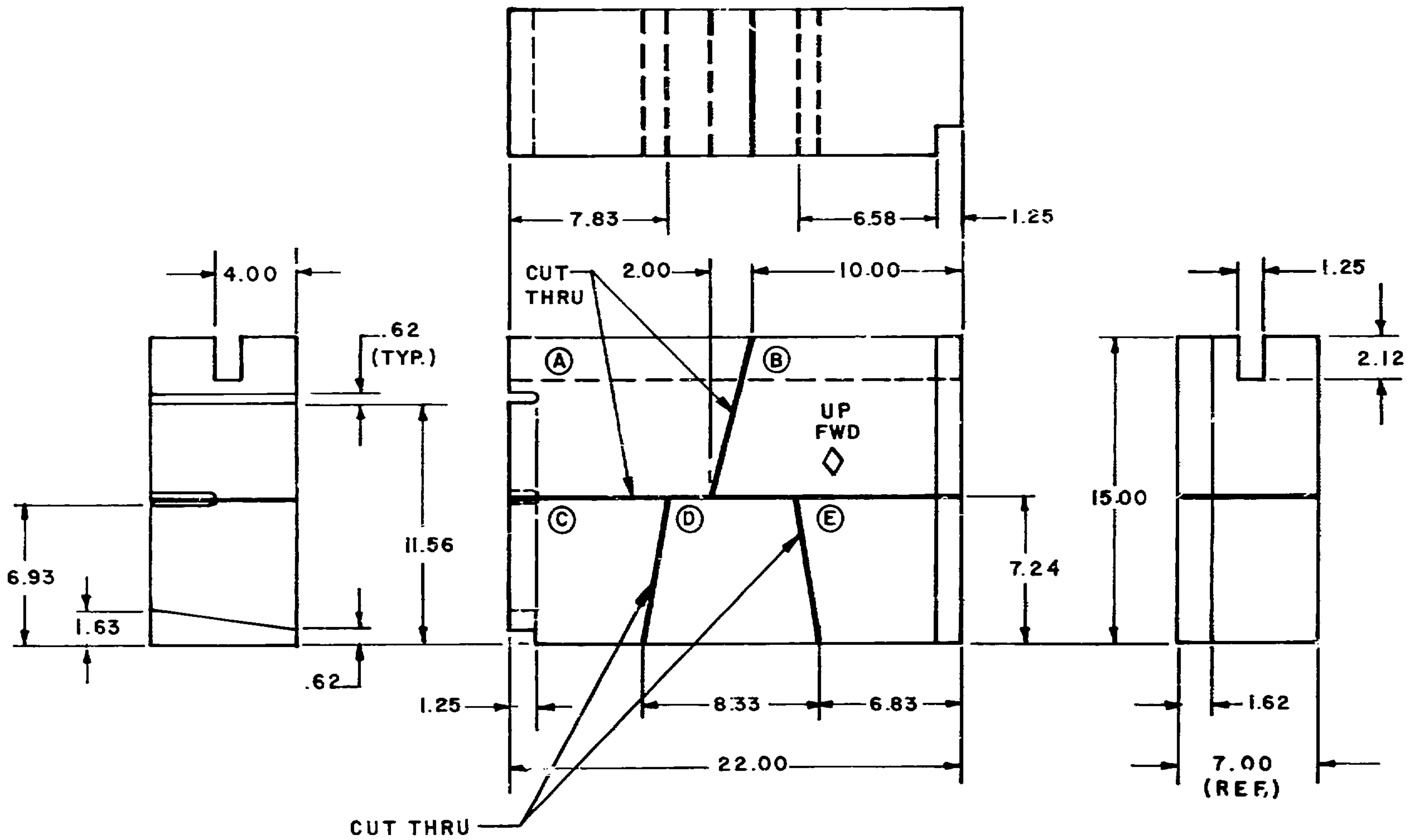


Figure D6-34. Batt 3.14 Detail Compartment 3



(TAG BATT NOS. FWD SIDE)

Figure D6-35. Batt 3.15 Detail Compartment 3

Figure D6-36. Installing Explosafe through Main Access

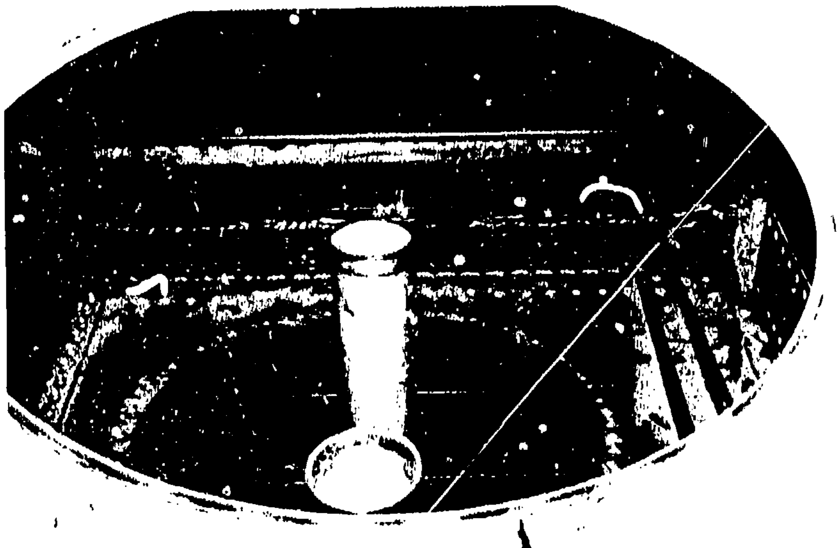


Figure D6-37. Compartment 1 Viewed through Access

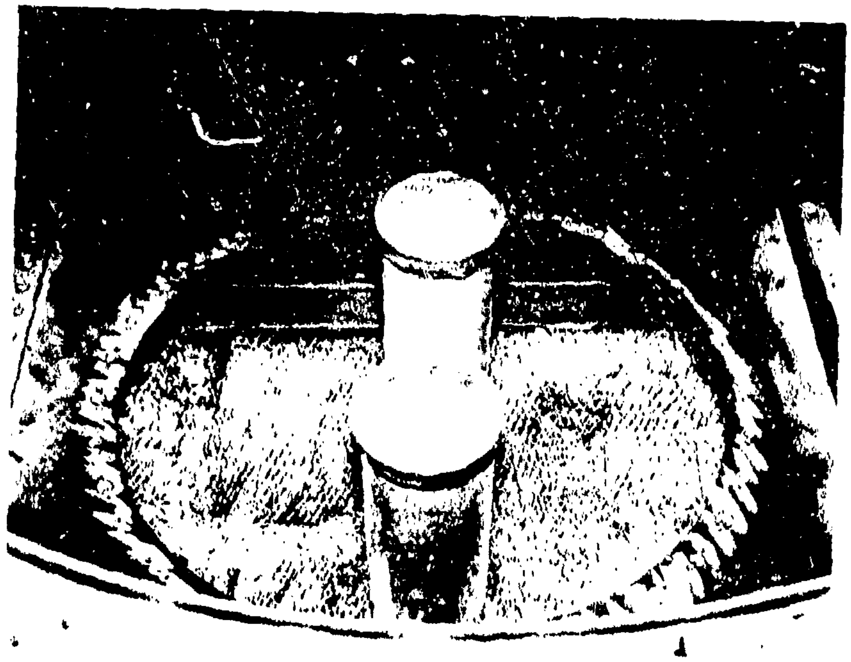


Figure D6-38. Compartment 1 Partially Packed

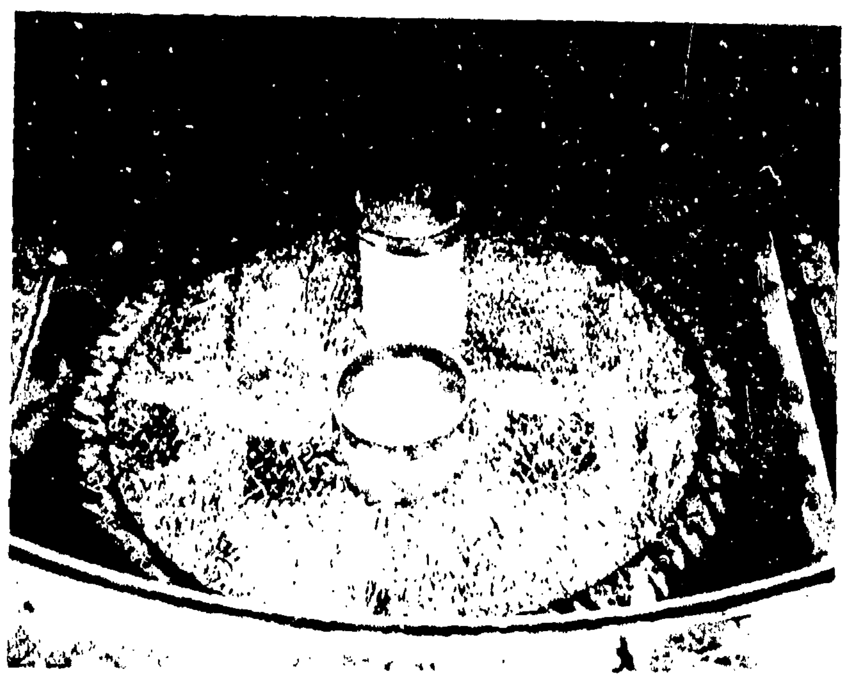


Figure D6-39. Compartment 1 Packed to Fwd of Mid-Spar

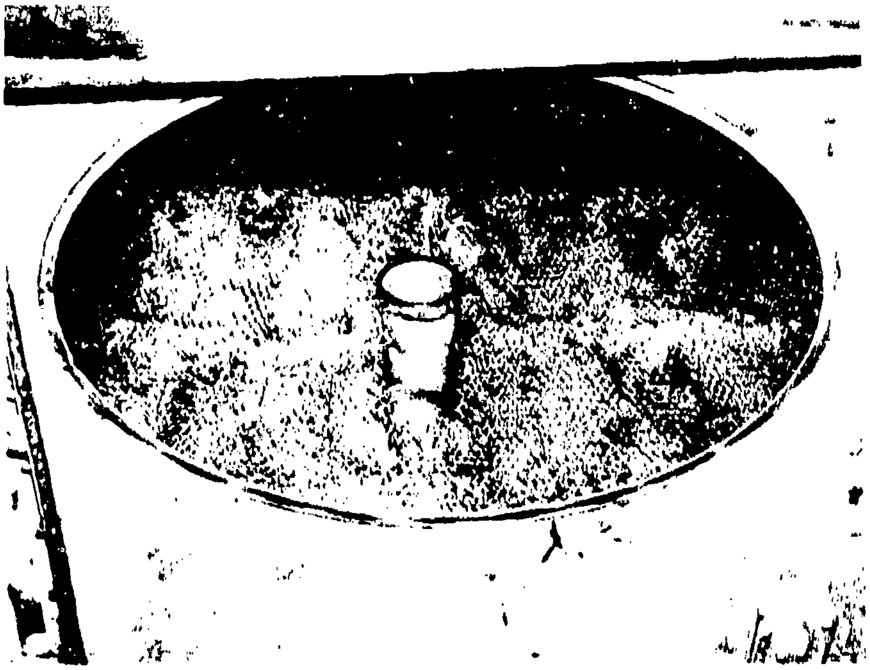


Figure D6-40. Compartment 1: Foil Installed Aft of Mid-Spar

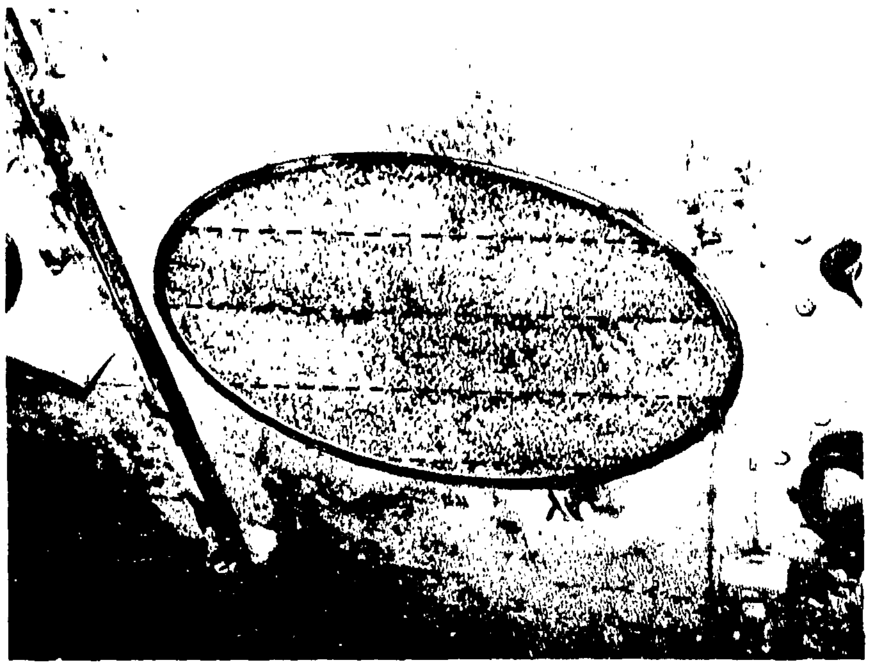


Figure D6-41. Compartment 1 Fully Packed

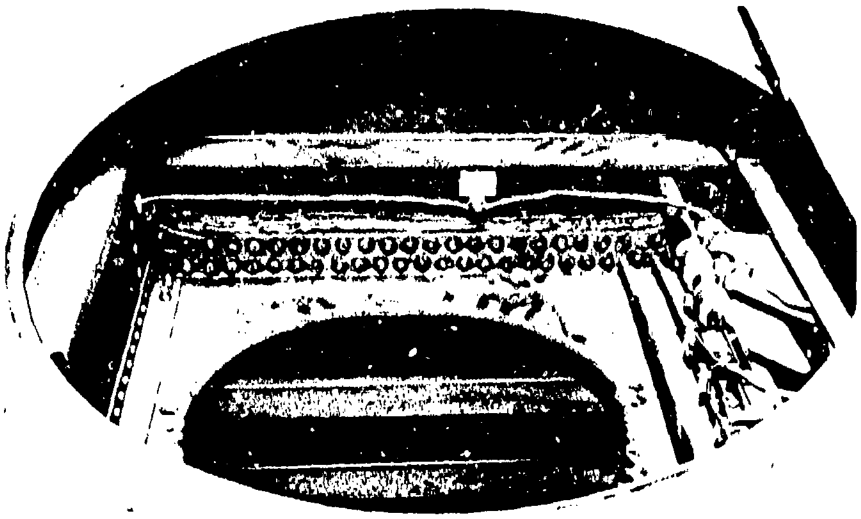


Figure D6-42. Compartment 3 Viewed through Access

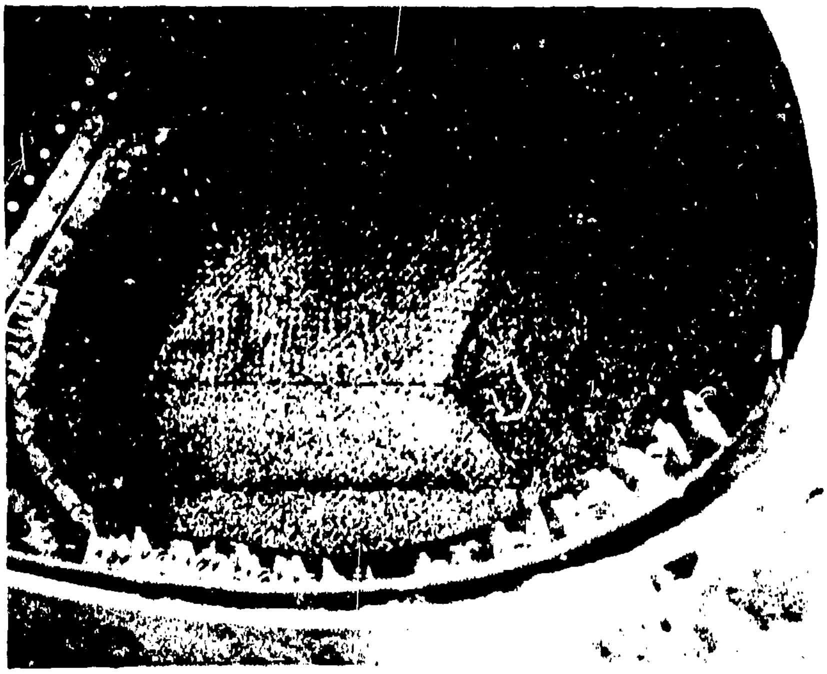


Figure D6-43. Compartment 3 Partially Packed

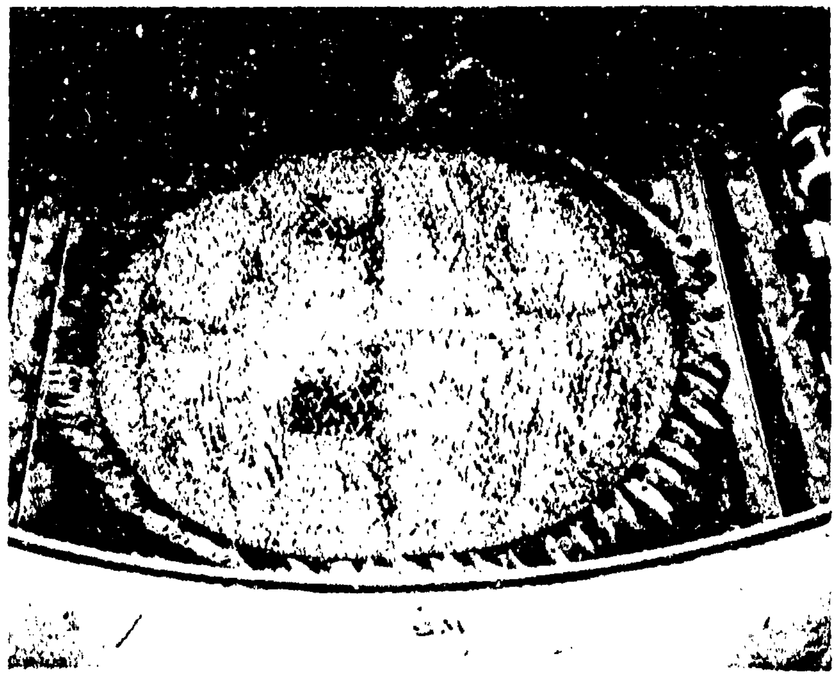


Figure D6-44. Compartment 3 Packed to Fwd of Mid-Spar

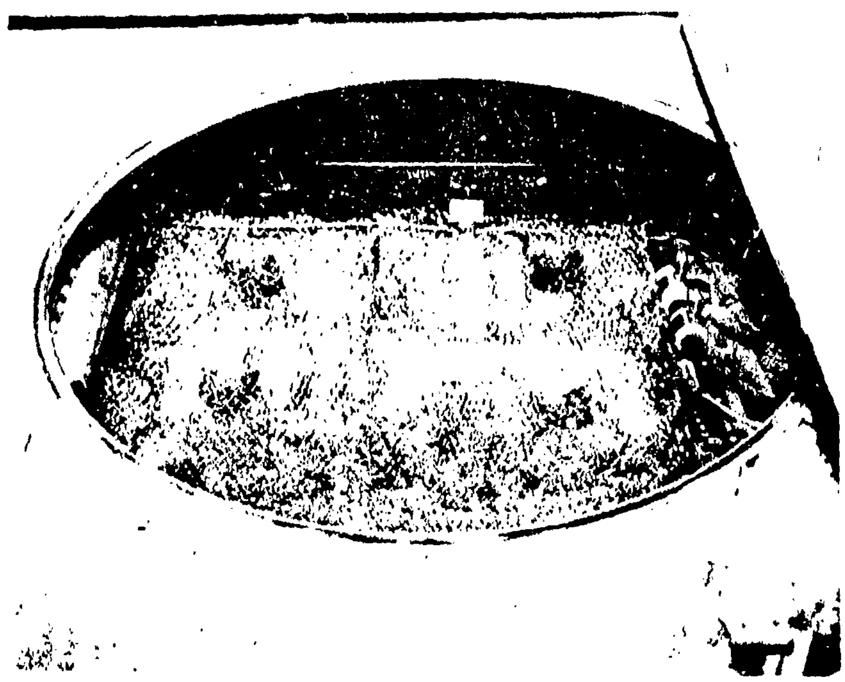


Figure D6-45. Compartment 3: Foil Installed Aft of Mid-Spar

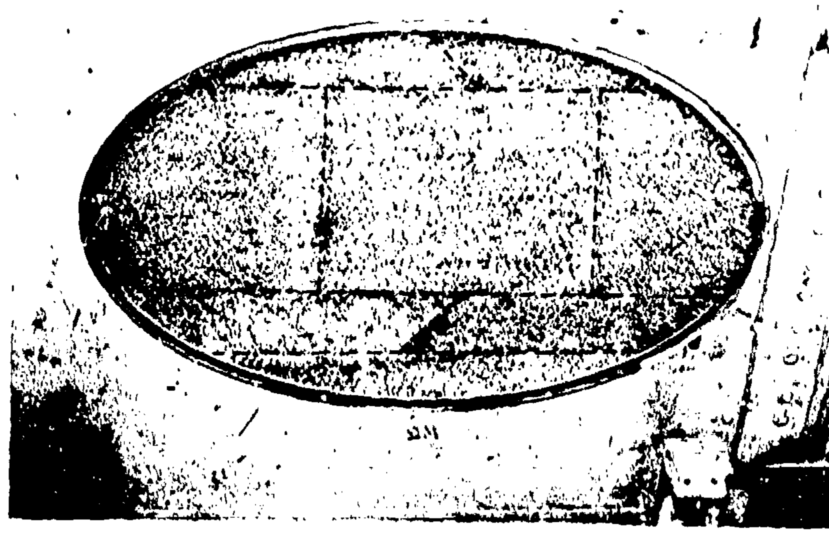


Figure D6-46. Compartment 3 Fully Packed

Figure D6-47. Tank Showing First Five Compartments, Some Partially Packed

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