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DEVELOPMENT AND TESTING OF AN INFLATABLE CABLE SUPPORT SYSTEM FOR AIRCRAFT ARRESTING EQUIPMENT

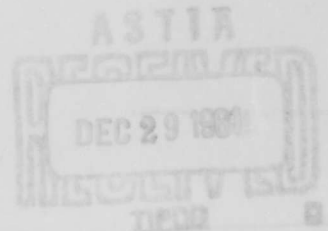
K. M. LANG

RESEARCH, INCORPORATED

AUGUST 1961

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AERONAUTICAL SYSTEMS DIVISION



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**DEVELOPMENT AND TESTING OF AN INFLATABLE CABLE
SUPPORT SYSTEM FOR AIRCRAFT ARRESTING EQUIPMENT**

K. M. LANG

RESEARCH, INCORPORATED

AUGUST 1961

DIRECTORATE OF AEROSPACE GROUND EQUIPMENT ENGINEERING
CONTRACT AF 33(600)-40364
PROJECT 6073

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by Research, Incorporated of Minneapolis, Minnesota. It was written by Mr. K. M. Lang. The program is being conducted under contract AF 33(600)-40364, Project 6073, title, "Aircraft Arresting Barriers", with the Aeronautical Systems Division, Directorate of Aerospace Ground Equipment Engineering under the direction of Lieutenant J. D. Lassiter, USAF, project engineer and Captain J. C. Welsh, USAF, Chief of Arresting and Launching Branch.

At Research, Incorporated, the program is administered by Mr. V. H. Larson as project engineer. Messrs H. L. Peterson and H. R. Meline developed the inflation controls system at Research, Incorporated. Mr. K. M. Lang developed the cable support units and represented Research, Incorporated during the test programs at Edwards Air Force Base.

At Edwards Air Force Base, Mr. P. D. Kennedy represented ASD as liaison engineer. The test group at Edwards Air Force Base was under the direction of Major R. C. Blackwell. The testing periods at Edwards Air Force Base were 1 June to 30 June 1960 and 20 February to 5 April 1961.

ABSTRACT

An inflatable cable support system was designed, developed and tested for the purpose of holding an arresting barrier cable above a runway so that hook equipped aircraft can properly engage the cable in emergency situations during landing or take-off.

The system consists essentially of an air supply controls system, a buried manifold line extending across the runway and a number of inflatable supports installed flush at regular intervals along the manifold line.

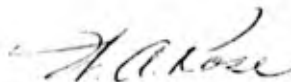
This report describes the development of an inflatable support unit rugged enough to withstand the repeated abuse of aircraft rollovers and the development of an inflation system which permits rapid raising and lowering of the arresting cable.

Tests conducted at Edwards Air Force Base showed that the inflatable cable support concept is entirely feasible for arresting hook equipped aircraft.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER



W. A. ROSE
Chief, Base Equipment Division
Directorate of Aerospace Ground Eqp Engr
Deputy for Engineering

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SECTION I

INTRODUCTION

Various means have been used to hold an arresting cable a given height above the runway. Sections of automobile tires with a cable entrance slot and hole cut in the upper portion of the casing were used in the Korean campaign and have been used since that time. These units are inexpensive and rugged, but are occasionally thrown off the cable (for considerable distances) and must be replaced continually. They do not allow the cable to be lowered unless they are removed.

Solid rubber discs, approximately 6 inches diameter by 3/4 inch thick, are being used but they are thrown off when cut by the cable during a direct rollover or when hit and mangled by the heavy impact of a direct wheel hit. It was also found that the placement of these units is critical with regard to how they affect the position of the cable relative to the hook after main wheel rollover. The Aeronautical Systems Division project engineer at Edwards Air Force Base has reported that certain disc spacings will cause a missed engagement every time. These units do not allow the cable to be lowered.

Spring steel supports that are arched to maintain the cable height have been tried in both the non-retractable and retractable types.

The trough type inflatable air bag units developed and tested during this program allow the cable to be raised very quickly or lowered to the ground when desired for the necessary passage of light planes, snowplows, runway cleaning vehicles or other vehicles. They are not damaged by repeated rollovers or direct hits (except occasionally at high speeds) and they remain in position during the severest rollovers and engagements. These units are flush with the runway when deflated.

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SECTION II

DEVELOPMENT AND TESTING OF INITIAL DESIGNS

Initial cable support (air bag) tests were conducted at Research, Incorporated with a pilot's ejection seat separator bag. This bag is inflated almost instantly with a shotgun type shell to separate the pilot from his seat just after ejection. It was felt that if a simple, lightweight bag could take such treatment it may prove rugged enough to support an arresting cable.

AIR BAG UNITS

Depression Tests

Simple tests were conducted on the sample bag to determine depression of the bag at various pressures due to cable weight. From this information spacing between supports, working pressure and general air bag dimensions were determined. The deflection measurements indicated that the bag pressure required to minimize abrasion due to the cable depression would be about 2 to 10 psig (see graph, figure 1).

Air Bag Spacing

Further experiments showed that a bag pressure of 3 psig and a bag depression of 0.50 inches or less should be the approximate working conditions for the air bag. From the graph it was seen that under these conditions the weight of a 12 foot length of 3/4 inch cable (1.0 pounds per foot) could be supported.

A study of various aircraft main wheel tread distances showed that at present, no aircraft exists with a tread distance in the vicinity of 13.5 feet. It was then decided that this should be the cable support spacing so that two units could not be rolled over at the same time. See figures 2 and 3.

Initial Air Bag Design

Three basic design ideas for complete air bag units were considered (see figures 4, 5 and 6). The sheet rubber hold down cover was devised to keep the bag rigidly in place during rollover, to help deflate the unit and to keep runway debris from collecting under the inflated bags.

Model Air Bag Testing

The basic air bag design selected and the hold down cover idea were tested concurrently using the ejection seat bag (see figures 7, 8 and 9). This model was subjected to abuse tests which included squeezing, jumping on, dropping various weights on, and pulling 150 feet of arresting cable over it to check for abrasion wear. The model unit was not damaged and only slight abrasion wear was noted.

The model was then tested under icing conditions by coating it with a 3 inch layer of solid ice. When inflated quickly, it either cracked the ice and popped through or broke the ice bond and lifted the ice layer off the mounting board without damaging the model in either case. Finally, the unit was secured to the ground and rolled over 10 times by the front and rear wheels of a heavy automobile at speeds up to 60 miles per hour. The model unit was not damaged.

Air Bag Mounting Bases

To provide a simple mounting base for the air bags, a fiberglass frame was designed to allow an air bag unit to be easily slipped in and snapped into place and also removed easily. The mounting bases were also designed for rapid runway installation using the Ramset "stud driving" system. Ten bases were made up with two of the 10 bases made for mounting flush with the runway surface as shown in figure 10. The other eight bases were made for surface mounting on the runway (as shown in figure 21). The front ends of the surface units were tapered down at a 10 degree angle to minimize the impulse to the aircraft during rollover. The sides and back ends were rounded off to protect the aircraft tires during rollover.

Preliminary Construction and Testing of a Full Scale Air Bag Unit

A materials and adhesives search and test program was started for making the first full scale units for tests at Edwards Air Force Base. The materials search resulted in the selection of a Dupont "Fairprene" material of neoprene on nylon fabric construction as the bag material and Eastman 910 pressure sensitive cement as the adhesive. Neoprene was selected for its outstanding comparative properties as shown in Table I. The baseplate material was 1/4 inch thick, rubberized cotton belting and the hold down web material was 1/32 inch thick neoprene sheet stock. A test unit was made up and rollover tested in one of the flush type mounting bases as shown in figures 11 and 12. These preliminary tests showed that baseplate stiffeners and small pylons were required to keep the air bag unit in its mounting base. See figure 13.

Production of Preliminary Air Bag Units

Twenty air bag units were then made up and pressure tested at 7 psig for one hour. The air bag units were not all constructed alike, however. Almost half of the bags had ribs glued inside to form air passages during rollover. The ribs were high density (60 Durometer) neoprene, 1/2 inch square placed 1/2 inch apart and were cemented inside the bottom of the bag for its entire flat length.

Many of the bags were glued to the rubber base plates along the entire length of their bottom by a 1/2 inch wide layer of 910. Other bags were attached to the baseplates with only one large spot of 910 at the forward end just to keep the bag centered during inflation and deflation. All of these bags had two hold-down straps at their forward end made from 3 inch by 15 inch strips of the neoprene-on-nylon bag material and cemented over a large part of their area to the bag and to the baseplate. (See figure 14.) A few of the bags were not attached to the baseplate in any way.

These differences were used to determine to what extent the bags had to be held down to be completely frangible during a direct hook hit without being carried away by the hook.

The air bag units were carefully numbered so that an effective history could be recorded for each.

AIR SUPPLY SYSTEM

While the air bag materials and adhesives were being investigated, an air supply system was assembled to determine the best methods and hardware for rapidly inflating and deflating the cable supports. The air supply system was designed to inflate the cable supports within one or two seconds. It was also made to maintain a given pressure in the air bags and to deflate them quickly after an engagement to clear the runway for retrieving and repositioning the arresting cable. This particular air supply controls system was a prototype unit designed with sufficient flexibility to serve as a test device for varying the inflation parameters for various inflatable cable support test installations. See figures 15 and 16.

Rapid Inflation Cycle

The inflation cycle starts by flipping a small toggle switch to open a large solenoid valve which charges a manifold line with high pressure air.

This charge of air is maintained in the manifold for a short period (less than one second) by a timer while the air meters at high pressure to each air bag unit through pre-sized orifices and the bags quickly fill and become pressurized. A second timer then opens a dump valve to relieve any excess amount of air in the manifold. In a few seconds a third timer closes the dump valve and a make-up air system takes over to maintain the units at required pressure and also make up for any leakages. The make-up system was designed to maintain the units at full pressure with two bags leaking or destroyed. See figures 17 and 18.

Deflation Cycle

To lower the supports quickly, an ejector system was used to evacuate the bags. By flipping a toggle switch, a timer is started to allow the ejector to operate for periods up to 60 seconds.

The air bags can also be deflated by flipping a switch which opens the manifold to atmosphere through the dump valve and allows the units to slowly deflate themselves.

Overpressure Protection

To guard against inadvertently overpressurizing the air bags at any time, a pressure switch and dummy air bag were added to the controls. The dummy bag (in the controls box) has its own variable needle valve orifice and pressure gauge. It can be set to inflate with or slightly ahead of the runway air bags. If at any time, it senses a pressure in excess of the set point pressure of the pressure switch one of the dump valves open and bleeds the excess pressure off. A dummy bag is required instead of a rigid container because the dummy bag like the runway bags is completely evacuated during deflation. Inflation therefore starts with the bag pressures at zero, but this would not be true with a rigid container unless a high vacuum was applied to it.

Orifice Calculations

The size and shape of the orifices are rather critical in properly inflating and deflating the supports. Initial tests with 3 foot diameter toy balloons at each orifice allowed the small volume of air and flow rate to each bag to be accurately measured and also showed that the orifices had to be individually sized so that a total flow variation of not more than 5 per cent results. Otherwise volume differences of up to 30 per cent could take place between the first bag and last bag. The toy balloons demonstrated this characteristic by

inflating to slightly different diameters. The orifices were therefore individually sized for maximum performance.

The exit-air side of the inflation orifices were rounded off to a bell-mouth shape to increase the exit flow coefficient and thereby reduce the deflation time. See figure 19.

Preliminary calculations were made to determine orifice size in order to get a reasonable compromise between fill time and system leakage with one or two support units heavily damaged or otherwise out of commission. For small pressure drops across the orifice, the equation for the air flow can be approximated by

$$W_a = K \rho A V$$

where

W_a	=	air flow, ft ³ /sec
ρ	=	upstream air density, lbs/ft ³
K	=	discharge coefficient, (dimensionless)
A	=	orifice area, ft ²
V	=	air velocity through orifice, ft/sec

The calculations were verified by simple bench tests and the results are shown in figure 20. The curves show that for cable support pressures of 4 and 10 psig, the orifice diameters must be 0.080 and 0.060 inches, respectively, for a maximum orifice leakage flow of one scfm ($\rho = 0.0768$ lbs/ft³) through a ruptured bag. The approximate inflation time using an orifice of 0.070 inches can be obtained by calculating the flow rate under choked flow conditions. For example, assume that an accumulator storing the charging air is at 1000 psia. A manifold supplying the cable supports would then be filled from this accumulator. For a manifold volume equal to the accumulator volume the initial charging pressure at each support location would be approximately 500 psia. The flow rate can then be determined from the choked flow orifice equation:

For perfect gases

$$w = C A_2 p_1 \frac{g}{R T_1} k \left(\frac{2}{k+1} \right)^{\frac{k+1}{k-1}}$$

For air, the ratio of specific heats, $k = 1.4$; the gravitational acceleration, $g = 32.2 \text{ ft/sec}^2$ and the universal gas constant, $R = 53.3^\circ \text{ Rankine}$. Small error will be incurred by assuming a discharge coefficient, C , equal to 0.6. The equation then becomes

$$w = 0.318 p_1 \frac{A_2}{T_1}$$

where w = weight flow, lbs/sec
 p_1 = charging pressure, psfa
 T_1 = manifold air temperature, °R
 A_2 = orifice area, ft²

calculating the flow rate, w

where $p_1 = 500 \times 144 = 72,000 \text{ psfa}$

$$A_2 = \frac{\pi}{4} \frac{(0.070)^2}{12} = 2.67 \times 10^{-5} \text{ ft}^2$$

$T_1 = 500^\circ \text{R}$ (assumed)

$$w = \frac{0.318 \times 7.2 \times 10^4 \times 2.67 \times 10^{-5}}{500} = 0.0273 \text{ lbs/sec}$$

or

$$W_a = \frac{0.0273 \text{ lbs/sec}}{0.0768 \text{ lbs/ft}^3} = 0.357 \text{ scf/sec (at each orifice)}$$

The calculation shows that inflation time for the inflatable cable supports would be well under five seconds providing that their individual filled volume is under one cubic foot.

PRELIMINARY TESTS AT EDWARDS AIR FORCE BASE

To complete the design study phase of this program, a prototype inflatable cable support system was installed and tested at Edwards Air Force Base, California. See figure 21.

Installation

A 2 inch wide slot was cut half way across the runway for the 150 foot manifold pipe. Also, two shallow, 14 inch wide trenches were cut perpendicular to the 2 inch slot to contain the two flush mounting bases. The manifold line and orifice holders were first pressure-leak tested and then grouted in flush with the runway. The flush bases were also grouted in. The surface mounted fiberglass bases were fastened to the runway and then the inflation controls box was connected to the manifold.

Inflation System Tests

Accumulator pressure for these tests was 800 psig with eight orifices ranging from 0.109 to 0.125 inches diameter for eight air bag units spaced 13.5 feet apart across one-half the runway. The inflation pressure was varied between 2 and 10 psig for the units tested, but after several tests, 3 psig appeared to have the most desirable characteristics.

The inflation controls system worked extremely well at all times. It was easy to operate by simply flipping the correct toggle switch on or off. Adjusting the timing controls for proper inflation and deflation was also simple and the air bags were maintained at constant pressure by setting the regulator on the make-up air circuit. (These controls can be seen in figure 16.)

The control timers were set for the following conditions:

Manifold Charging Cycle:	0.25 sec	- Starting at time base zero
Dump Valve Open:	1.50 sec	- After time zero
Dump Valve Closed:	4 - 6 sec	- After time zero
Deflation Cycle:	50 - 55 sec	- Duration with fully pressurized system

The 50 - 55 second deflation time means that the bag units are completely evacuated of all air. Actually the cable is down on the runway after only 12 - 15 seconds deflation, the remaining time being used to evacuate the air which is left in the bags at approximately atmospheric pressure. The ejector, using 100 psi primary air, develops about 4 psi differential pressure which empties the manifold almost immediately. Then the orifices between the manifold and the bags control and also retard the deflation flow of air from the bags.

Remote Operation

The system was operated successfully either locally at the controls box or remotely from the end of a 300 foot extension cable. See figure 22. Remote operation was performed to simulate control tower operation.

Initial Air Bag Tests

With the inflation controls at the settings listed, the eight air bag units were inflated and deflated several times to determine their characteristics. One unit was replaced after it popped out of its frame during a rapid inflation because it had shrunk slightly below tolerance after construction. The only other problem was that of small amounts of unexplained fuzz in the manifold causing the end orifice to clog up. After a few blow down cycles without bags or orifices in the system, the orifices remained clean.

At 3 psig the air bags held a 3/4 inch diameter cable 4-1/2 inches above the runway at the bags and 3-1/2 inches above midway between bags with a cable pretension of 2000 pounds.

Test Methods Involving Aircraft

The air bag units were subjected to tests involving F101, F102 and F84G aircraft. Fourteen valid tests were conducted consisting of rollovers and engagements. Test velocities ranged from 40 to 140 knots. See Table II. The pilot of the test aircraft was instructed as to the desired wheel roll-over position and rollover velocity. The pilot then lined up the aircraft by positioning it relative to a runway joint that ran nearest the air bag being tested. A small red flag was also stationed just beyond the arresting cable to act as a target for the aircraft nose wheel. These methods allowed the test pilot to hit the air bag quite accurately.

To determine the exact location of the wheel during rollover, various "foot-printing" methods were used to show up the tire tread path on the runway. These included painting a black strip on the runway just ahead of the units and allowing runway dust to make a tire print or by sprinkling common baking flour ahead of the black strips. The baking flour method was found more reliable.

To record the test events, high speed 35 mm cameras were focused on the units from an upstream position.

RESULTS OF PRELIMINARY TESTS AT EDWARDS

The preliminary tests demonstrated the initial feasibility of the inflatable cable supports concept.

The air bag units were fully inflated for engagement in less than 10 seconds and deflation was accomplished in less than one minute. At 3 psig these air bags held a 3/4 inch diameter cable 4-1/2 inches above the runway at the bags and 3-1/2 inches above midway between bags with a cable pretension of 2000 pounds. This was considered sufficient for proper engagement.

The inflation control system worked reliably during the tests although unexplained fuzz in the manifold line was a minor problem initially. The system was easy to operate locally and was successfully operated from a remote position 300 feet from the runway. Adjusting the timing controls for the inflation and deflation periods was simple and the make-up air system maintained air bag pressure with one bag out of commission (its inflation orifice open to atmosphere). Pressure could not be maintained with two bags out because the makeup air supply lines were too small to keep up with the flow loss through two orifices.

The various means used to cement the air bag to the baseplates and the use of ribs in some of the air bags did not appear to help (or hinder) their

operation or ability to withstand rollovers. The air bags remained in place during all rollovers and therefore the baseplate stiffeners and pylons were apparently required.

The rollover tests showed, however, that this type of air bag unit construction could not take direct hits or off-center hits very well. See figure 23. Such hits usually blew out the entire air bag and hold down web or severely damaged the cover, requiring replacement. Near misses would sometimes cause the cable to pinch and cut the bag or cover as a result of the cable being slammed to the runway by the wheel rollover. See figures 24 and 25.

Inspection of the blown-out bags showed that in many cases the material remained intact but that the cemented joints had failed in peel. It was also noticed that the materials sometimes ripped right beside the cemented joints which were rather stiff instead of being flexible. Heat and sunlight aging of the black hold down cover material seemed to stiffen it which indicates that it should be made from or coated with a light colored, sunlight-resistant material. By simply spray painting one of the units white, its surface temperature was dropped approximately 15-20°F.

A minor problem was that of sand and debris collecting in the slot behind each mounting base which contains the orifice holder and inflation hose. The simple cover that was provided worked all right for the test program but was considered rather awkward for use in a final installation.

The 13.5 foot spacing between bags was satisfactory for the 3/4 inch arresting cable when pretensioned to 2000 pounds.

PROBLEM AREAS

The preliminary tests showed that certain critical areas still existed which required improvement before the system could be considered fully operational. These included:

1. Redesign of the air bag unit so that it is much more resistant to rupture during rollover.
2. A stronger, more tear-resistant material is required along with an adhesive that remains flexible after setting up.
3. Redesign the mounting base to prevent pinching and cutting of the air bag due to cable slam. The improved mounting base should not require a slot in the runway for the inflation hose.
4. Improve the ability of the make-up air system to operate with two bags out of commission.

SECTION III

DEVELOPMENT AND TESTING OF TROUGH UNIT DESIGN

A "trough" type air bag unit and mounting base was designed and developed as a result of the preliminary tests. Five of the trough type air bags and two mounting bases were fabricated and initially tested at Research, Incorporated then sent to Edwards for full scale tests.

This unit was designed specifically to solve the two main problems of end seam blow-out and cable pinching. The ends of the bag are long and tapered and their construction results in the end seams having an extremely large overlap area which can only be stressed in shear, not peel. See figure 26.

MODEL TROUGH UNIT

A model trough unit was built to check the working principles and characteristics of the design. See figure 27. It was demonstrated to the ASD liaison officer (from Edwards Air Force Base) by rapidly inflating it several times and by filling the trough full with wet sand and several stones. When inflated the model cleared itself completely without damage or abrasion.

TROUGH UNIT AIR BAG CONSTRUCTION

A stronger material was used for making these units. The material selected was another one of the Dupont "Fairprene" materials of neoprene on nylon construction. This material has the same thickness (0.025 inch) but its tensile tear strength is 450 pounds per inch as compared to 300 pounds per inch for the former. The best feature of this material was its improved tear resistance which is at least three times that of the other material. One of the five new units tested was built from special "Fairprene" stock that has a tensile strength of 1000 by 1000 pounds per inch and is about 0.050 inch thick. The heavy material was embossed which made it difficult to fabricate but the unit was made up in order to find out if a material of this strength and thickness is required. For its thickness, it is reportedly the strongest coated fabric available.

A rub strip is cemented to the top of the bag to give additional height to its small cross section and to provide complete protection from cable rub damage during retrieve. The hold down web previously used was eliminated.

A 3/16 inch thick (conveyor belting) wedge plate was cemented inside the air bag to keep the unit firmly wedged in place in the trough. The wedge plate also keeps the air bag from pinching itself off during deflation thereby assuring that the bag will be completely sucked down into the trough. See figures 28 and 29.

Aluminum end fittings on each end of the bag are provided to restrain the bag when hit by a hook. They slip into an opening in the ends of the trough bases and are held in place by a simple pin.

A new adhesive which develops a very high peel strength was used to fabricate the units and tests showed that in many cases the rubber coating of the material delaminated from the nylon before the adhesive would let go. This adhesive called Caram contact cement is specially formulated for bonding neoprene to neoprene. It is a "contact" type adhesive in which both surfaces to be bonded are cleaned, then coated with a thin layer of cement and then allowed to dry for 15 minutes. The surfaces are then carefully lined up. When contact is made and the surfaces pressed or rolled together, a joint is produced having 60 per cent of full strength. Full strength is achieved in 7 days.

TROUGH UNIT MOUNTING BASES

In the trough mounting bases, the combination of a narrow entrance slot and the large cross section trough below the runway, providing a large air circulation path, protects the air bag from being blown out during rollover.

A 1/4 inch thick neoprene pinch pad is cemented on the top surfaces of the slot channel sections to alleviate the pinch problem and then a 1/4 inch thick neoprene slit rubber cover is cemented over it to further reduce pinching and also keep the trough clear of water, sand and general debris. See figure 30.

ORIFICE MODIFICATION

The orifice holes for the trough bags were made smaller in diameter because the new units contain only 1/3 cubic feet of air as compared to 1.3 cubic feet for the previous units. The orifice area was reduced by a factor of 5 for overpressure protection during inflation. The orifice diameter was therefore reduced from 0.118 inches (average) to 0.055 inches and they were again rounded off on the exit side to reduce deflation time. The graph (figure 31) shows that there is a definite orifice size required for a given supply pressure and volume, air bag volume and inflation time.

FINAL TESTS AT EDWARDS AIR FORCE BASE

For the final test phase of the inflatable cable support program, the five trough-type air bags were subjected to rollover and engagement tests by an Air Force F100 and Navy A4D, A3D and F8U aircraft.

Installation

Two trough unit mounting bases were installed in place of the two previous flush mounted fiberglass bases as shown in figure 32. Six of the fiberglass surface mounted bases were reinstalled on the runway to observe how the trough units inflated with a full complement of bags. The smaller orifices were installed for the trough units and the inflation control system was connected to the inflation manifold.

Inflation System Tests

The new units when inflated and deflated rose and retracted smoothly through the slot openings and the slit rubber covers. Accumulator pressure for the tests was initially set for 800 psia.

Inflation was accomplished in about 2 seconds (cable off runway) and the units were fully pressurized to 5-1/2 psig in 7 to 10 seconds with cable height at 2.5 to 3.0 inches maximum.

Deflation required 80 to 90 seconds for the trough units to be fully sucked down through the slit rubber covers and out of sight. During both cycles the trough units lagged behind the surface units because their orifices were apparently too small.

The inflation controls system worked reliably throughout the entire test program and the inflatable units were put through at least 20 complete inflation-deflation cycles.

Initial Air Bag Tests

The time required to remove a damaged trough unit bag and install a new one was checked several times and ranged between 10 and 15 minutes for a one-man operation and about 8 minutes for two men without hurrying. See figure 33.

A 1-1/4 inch diameter arresting cable (2.70 pounds per foot) was used throughout the test program. At bag pressures of 4 psig and 5-1/2 psig the

bottom of the 1-1/4 inch arresting cable was held at various distances above the runway as shown below. The cable heights at 5-1/2 psig are circled.

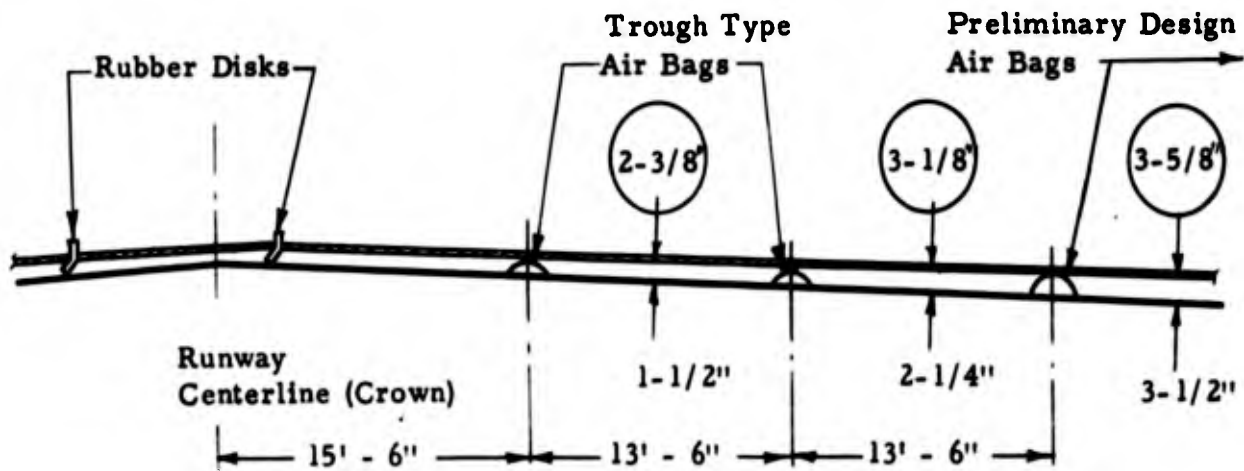


FIGURE 34: CABLE HEIGHTS FOR PRELIMINARY AND TROUGH TYPE AIR BAGS

The ASD liaison officer reported at a later date that when the units were inflated to 10 psig the cable heights were substantially higher, because the units were more able to resist the weight of the cable. The heights at the air bags averaged 1/2 inch higher than the mid-span readings.

Test Methods Involving Aircraft

The same test methods used in the preliminary tests were used again for the final tests, except that the baking flour method of recording tire position during rollovers was discontinued. It was found that the flour and runway dust would sometimes cloud up and obscure the high speed movies.

Instead, the runway ahead of the test area was hosed down to remove all dust and debris, then a thin layer of modeling clay was spread in front of each trough unit and smoothed over after each rollover test. The clay provided a very accurate record of exact tire position and required only one application.

Rollover Tests

The trough units were subjected to eight rollovers by a F-100 aircraft at various speeds and rollover positions as shown in Table III. Air bag pressure was 4 to 6 psig and the cable pretension approximately 800 pounds.

Because the new units present a target only half as wide as the old style units, they were much harder to hit and therefore less "direct hit" data was obtained. Near misses, however, did provide valid data on cable pinching and on the degree of cable-slam damage as a function of wheel position relative to the bag. See figure 35.

It appears that if a wheel centerline passes by 8 to 10 inches off bag centerline, then cable slam from a 1-1/4 inch cable will not damage the units in any way. For smaller diameter, more flexible arresting cables or for large bomber wheels, this may not be the case.

In Run No. 4 where the bag was cut and then blew open, it remains a question as to what caused the puncture type hole in the pinch pad. See figure 36. It appeared that a small 3/8 inch stone had been between the cover and the pinch pad when the cable was slammed down and that the stone or foreign object had been pounded into the pinch pad. No trace of such an object was found, however. The bag was repaired at Research, Incorporated using the original contact cement and a simple patch cut from the original bag material. It was returned to Edwards for continued testing. The bag could have been repaired at the test site.

It should be noted that no damage occurred during rollovers at 100 knots or less and while not listed, no damage occurred during 4 to 5 rollovers at taxiing speeds with a Navy A4D.

Engagement Tests

More than sixty successful engagements were made off the trough units with the arrestments taking place either between the new units or just to one side of them. The ASD liaison officer conducted these tests. The engagements were part of a series of 90 tests being conducted jointly by the Navy and the Air Force at Edwards. The tests were made with Navy A4D and F8U aircraft at speeds of 100, 115, 130, 145 and 160 knots at positions of 0, 20, 35 and 50 feet off center.

Cable Retrieve Tests

When the cable was retrieved after each test by the energy absorber units, it usually went past its pretension centerline and slid up and over the inflated units due to the retrieving technique used. One unit had its rub strip peeled off by the cable during a retrieve. The forward end of the rub strip had come loose during a rollover and stuck up slightly above the slit rubber cover. The returning cable slid between the bag and rub strip and peeled the strip off. No retrieve interference or damage to the new units was incurred in over 20 subsequent retrieves observed. No cutting or abrasion wear was noticed on the 1/4 inch thick rubber cover or pinch pad during these retrieves with the 1-1/4 inch cable.

Camera Record

The washing down of the test area allowed the high speed 35 mm camera to clearly record the rollover events at the air bags. The films showed that the trough unit air bags also throw the arresting cable several inches above its initial supported height after the main wheels pass over them.

Cable Tensioning Effects

When the cable was retrieved and then put under tension, the rub strips on the air bags and the bag itself would tend to roll over to one side slightly as the cable moved longitudinally during tensioning. This occurred at air bag pressures of 4 and 5-1/2 psig. At these pressures the air bags are relatively soft and, consequently, would roll somewhat when subjected to such side forces. See figure 37. At higher pressures of around 8 to 10 psig the ASD liaison officer at Edwards found that the increased pressure (which increases the fabric tension) will adequately resist the roll force. Also, the rub strip has square edges which grip the cable and it is rather high in proportion to the air bag diameter. With an improved rub strip cross sectional design and increased operating pressure, this rolling tendency should be greatly reduced.

Environmental Suitability

The runway washing resulted in both trough unit bases being filled with water. They were in the deflated position when hit directly several times with high pressure streams of water. The water did not effect the operation or construction of the units and much of it was forced out by inflating them. The

slit rubber cover, however, kept the water from evaporating and the remaining water was siphoned out. It appears, however, that if the units are left inflated when it is raining or especially during thawing-freezing conditons, the snug fit of the slit rubber cover will keep water from entering the trough. If water freezes in the troughs while the units are inflated, it would freeze to the shape of the inflated bag and would thereby not interfere with deflation. When the units are down, moderate amounts of ice will not affect inflation. The ice tests with the model unit demonstrated the ice breaking ability of an inflatable bag. During excessive icing conditions the cable supports can be kept clear of ice by deflating and inflating them periodically. It is assumed that the supports will be left inflated for operational readiness during icing conditions.

The trough unit air bags and mounting base covers held up well in direct desert sunlight and 92° F air temperatures, although some of the thick sections of contact cement under the rub strips softened and became weak. Future units would not have any thick layers of cement.

SECTION IV

SUMMARY

The entire installation of the inflatable cable supports system is simple and fast and no special equipment is required. The inflatable units are installed flush with the runway.

The prototype inflation control system is very reliable and easy to operate and it can be readily operated from a remote position. It is easy to adjust for various inflation and deflation times and for various inflation pressures. The make-up air system controls will maintain the supports at full pressure with one unit damaged (its orifice open to atmosphere). Dirt in the lines can be a problem if the system is not sufficiently blown down and cleaned out just after initial installation or if the accumulator union is left open and unprotected while dismantled for inspection or storage.

The orifice diameters should be individually sized for maximum performance in order to inflate the supports evenly and thereby raise the cable in a uniform manner.

The initial rollover tests showed that the preliminary air bag units and mounting bases were not able to withstand direct or near-miss wheel impacts.

The final tests proved that the trough unit air bags and mounting bases are simple, rugged and reliable. Normally, rollovers did not blow them out although damage was caused by occasional cable slam pinching or foreign objects puncture during direct hits at high speeds. The trough unit air bag volume is only 1/3 cubic foot as compared to 1.3 cubic feet for the preliminary units. Therefore, direct hit rollovers were infrequent due to the narrow profile of the units and the 13.5 foot spacing between them. It was decided that for maximum ruggedness and reliability future units should be made from the 1000 by 1000 pound material. Improper cementing procedures can result in a rub strip being peeled off by the combined action of rollover and cable retrieve.

The trough units can be inflated sufficiently in two seconds to lift a 1-1/4 inch diameter arresting cable off the runway. In less than 10 seconds they are fully pressurized to full cable support height of 3 inches above the runway at the unit and approximately 2-1/2 inches midway between units with a cable pretension of about 800 pounds. The deflation cycle lowers the cable to the runway in 12 to 15 seconds and the units are sucked down out of sight in 90 seconds or less.

Both the preliminary and the trough type air bags tend to throw the cable vertically after main wheel rollover and thereby improve the cable's position for engagement. See figure 38 . This effect increases with aircraft velocity and with higher air bag pressure. This effect is also a function of the support spacing, the cable size and the cable pretension.

The units can be left inflated during the cable retrieve operation without being damaged. They are then ready for engagement as soon as the cable is returned and properly pretensioned. If found necessary, however, the supports can be deflated during retrieve and inflated again after cable pretensioning. This may be required if the units are operated at pressures between 3 and 6 psig while supporting a heavy 1 or 1-1/4 inch diameter cable because the units will roll to one side slightly as the cable moves sidewise during pretensioning. The ASD liaison officer at Edwards reported that at pressures of 8 to 10 psig the rolling tendency is greatly reduced because the units are much more rigid.

When the trough units are left deflated or inflated, the snug fit of the slit rubber cover keeps the units essentially free of water, sand and common debris. The trough mounting bases can fill with water if the units are left in the deflated position during heavy or continuous rain, although inflation will remove a substantial part of it.

A trough unit air bag can be replaced in approximately 8 to 10 minutes and if damaged they can usually be easily repaired with simple tools at the installation site.

The 13.5 foot spacing between supports is adequate if all units are inflated. The loss of one support would make engagement in the vicinity of that support improbable although successful engagements could still be made at all other positions on the cable.

The inflation hose slots in the runway were made much smaller for the two trough unit installations, but they still collected sand.

The comments of the test pilots were very favorable during both test programs. They reported that the inflatable supports cause no loss of aircraft control and that they cannot detect hitting a support during rollover.

SECTION V

FINAL DESIGN

The final design of the cable support unit would include the following:

1. The material would be smooth, 0.050 thick, of neoprene on nylon construction having a 1000 by 1000 pound per inch tensile strength.
2. The rub strip would be a neoprene extrusion (60 to 80 durometer) with a cross section as shown in figure 39. The contours of this shape and added joint area under shear loading would greatly reduce the possibility of peeling the rub strip off during retrieve and would also give additional resistance to the rolling action that occurs during cable pretensioning.
3. For faster installation and removal of the units, an inflation hose with a finger tightened connector would be provided in place of the present hose and hose clamp assembly.
4. The slit in the slit rubber cover would be made approximately two inches shorter on each end to improve the "water seal" between the cover and the inflated bag and raise the elevation at which runway water could enter the slit.
5. The inflation hose slot behind each mounting base would be eliminated as shown in figure 40.

The production of trough unit air bags by various dip molding and vulcanizing techniques has been considered but such methods were not used during this program.

The changes in the inflation system are aimed primarily at:

1. Reducing the amount and complexity of both the plumbing and electrical systems in order to simplify the controls and match the requirements that were established during the test programs.

2. Minimizing the amount of compressed air required for the deflation and dump cycles in order to permit economical operation of the system from high pressure storage bottles.

A schematic of the pneumatic components for the final design configuration of the air supply system is shown in figure 41. The system has been designed to give the operator a simple switch control for the cable supports and yet perform several functions automatically to obtain rapid response to the switch commands. The two command switches, "inflate" (raise arresting cable) and "deflate" (lower cable) are located in the control box near the runway installation of the system and also in a remote station (logically, the field control tower).

A full runway complement of cable supports would use approximately 30 inflatable units with an inflated volume of 1/3 cubic foot each. With a support spacing of approximately 8 feet and support pressure at approximately 10 psig, the quantity of air required for inflation is then approximately 20 SCF (standard cubic feet, free air).

The inflation is accomplished using dry air ported into the manifold connecting all of the support units at an initial pressure of 800 psig. Orifices at each support location meters the flow so that the pendant is raised to engagement level in approximately one second. The inflation charge is then closed off and the manifold is relieved (dumped) of the excess air pressure which by this time has dropped to about 50 - 100 psig. The inflation cycle is performed by pilot check valves PCV 1 and PCV 2 shown in the schematic diagram. The arrows on these valves indicate the free flow path, and act as a conventional check valve if no pilot pressure is applied. The application of pilot pressure through SV 2 opens the check regardless of the upstream pressure permitting flow in either direction.

The actual mechanics of the inflation cycle involves simply pressing the "inflate" switch. See figure 42. This operation starts the timer KI and energizes SV2. A locking circuit shown on the schematic maintains the inflate cycle for the set time interval. By energizing SV2 pilot pressure is applied to the pilot check valve PCV1 which opens the manifold to the high pressure inflation charge. At the same time, SV2 exhausts pilot pressure from PCV2, closing the valve thus preventing flow out of the main relief valve shown in the dump circuit. After the inflate time duration has elapsed SV2 is deenergized which closes PCV1 and opens PCV2, dumping excess inflation charge. Leakage in the system is taken care of by the make up air flow through the regulator shown which enters the manifold through a check valve. Support pressure is therefore maintained by the make up circuit and excess pressure is relieved with the relief valve shown since PCV2 is open.

Safety features are provided in addition to the relief valve. An over-pressure sensing switch in a dummy support unit located in the control box overrides other controls and opens the manifold to the atmosphere. In the electrical circuit an interlocking relay, K5, prevents more than one consecutive inflation cycle and also prevents an inflation cycle when power is interrupted or initially turned on. The K5 relay is energized only after a deflation cycle is completed assuring that the support units are completely deflated before an inflation cycle can occur.

Electrical power interruption or complete failure was considered in the system design so that in the event of failure the supports would "fail safe". This is defined as maintaining the inflated condition if already in this mode or if in the retracted position at the time of failure, the supports would be raised by the make up air circuit since SV1 would be opened when deenergized.

To lower the cable supports, the "deflate" switch is pressed. This operation closes SV1, opens SV3 and starts the vacuum pump. The deflation of 30 units would require one to two minutes although the deck pendant is lowered to the runway in 15 to 20 seconds. The additional time is required to remove the ambient pressure air from the support units to completely retract them into the troughs.

These differences from the prototype system are minor and do not change the basic inflation and control methods. The final components have been simplified and sized for an average runway complement of 30 inflatable support units spaced at 8 feet. The improved air supply system would use less storage air by having the small vacuum pump carry out the deflation instead of the air operated ejector. This feature is especially desirable when practical considerations require the use of commercially stored dry air or nitrogen as the inflating gas.

The smaller orifices used with the trough unit bags will allow the system to be operated successfully with two air bags out of commission. It should be noted from figure 20 that with two bags out the leakage flow through two 0.055 orifices at 10 psig is 60 standard cubic feet per hour.

The remote control part of the system will not require any changes. The remote control panel and the control panel in the box will consist of a power on-off switch with indicator light and two push button switches, one to raise the supports, the other to lower them.

SECTION VI

CONCLUSIONS

1. The tests at Edwards Air Force Base showed that the inflatable cable supports concept is a reliable means of raising, lowering and supporting an arresting cable for engaging various hook equipped aircraft.
2. The entire installation of a cable supports system is simple and fast with no special equipment required. The flush installation of the trough units allows aircraft to roll over them at high speeds without any loss of control or other effects. Direct hit rollovers would be infrequent due to the narrow profile of the units.
3. Slight modifications in the design of the trough type air bag will make it an extremely rugged, reliable unit.
4. Minor changes in the inflation system will reduce its complexity, simplify its controls and substantially reduce the amount of air required for the deflation and dump cycles. This will permit economical operation of the system from high pressure storage bottles.
5. The improved electrical system will not permit a double inflation and a fail-safe feature will result in the supports automatically inflating slowly after a power failure so that the cable is raised for engagement regardless of any electrical malfunction of the control circuit.
6. It is suggested that the units be operated at an inflation pressure of 8 to 10 psig and that they be kept inflated during rain or freeze-thaw conditions. The spacing between supports should be reduced to 8 or 8-1/2 feet to maintain the cable at sufficient engagement height in the area where one support is out of commission. This spacing will not allow two supports to be hit at once.

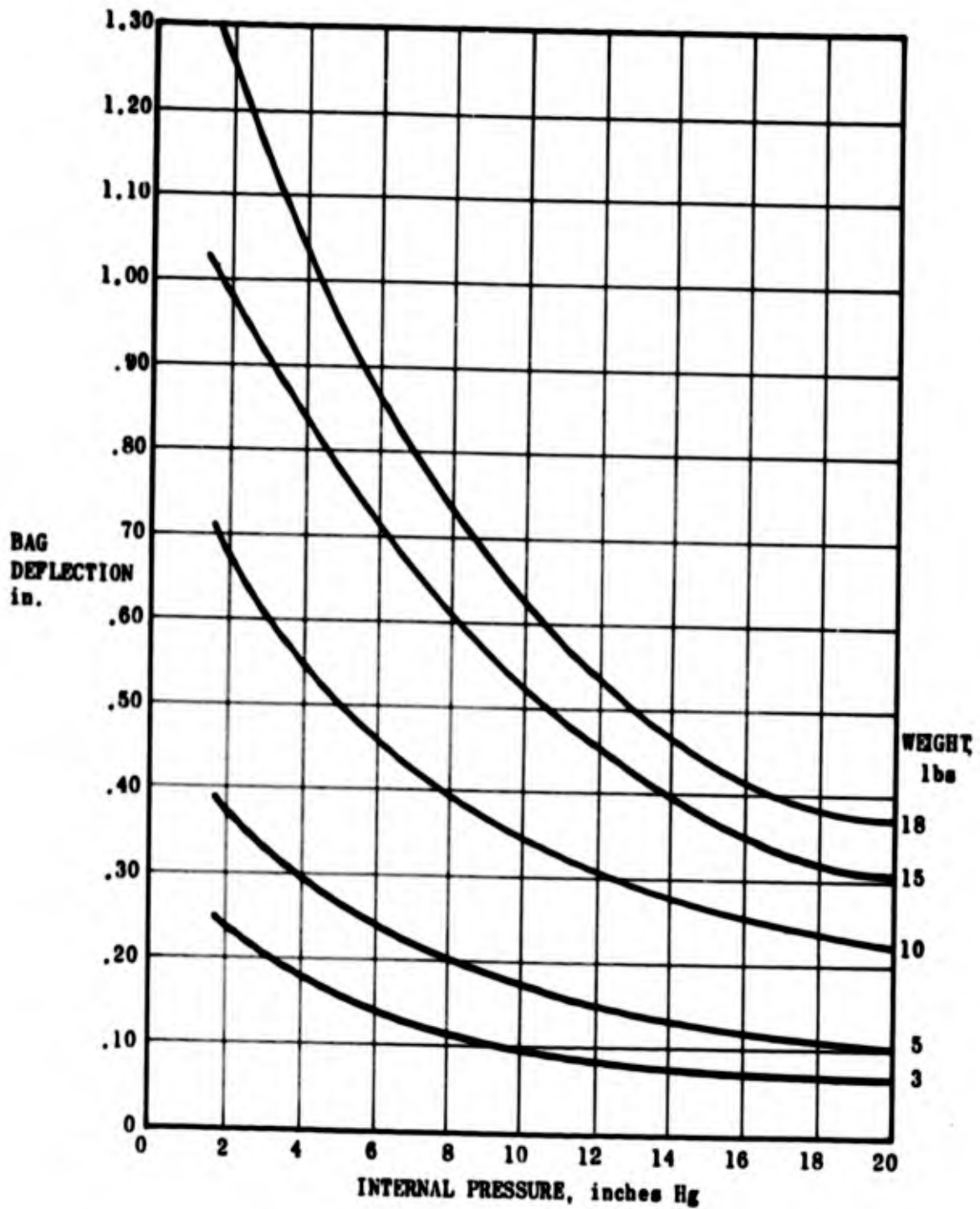


FIGURE 1: AIR BAG DEFLECTION FOR VARIOUS LOADS AND INTERNAL PRESSURES

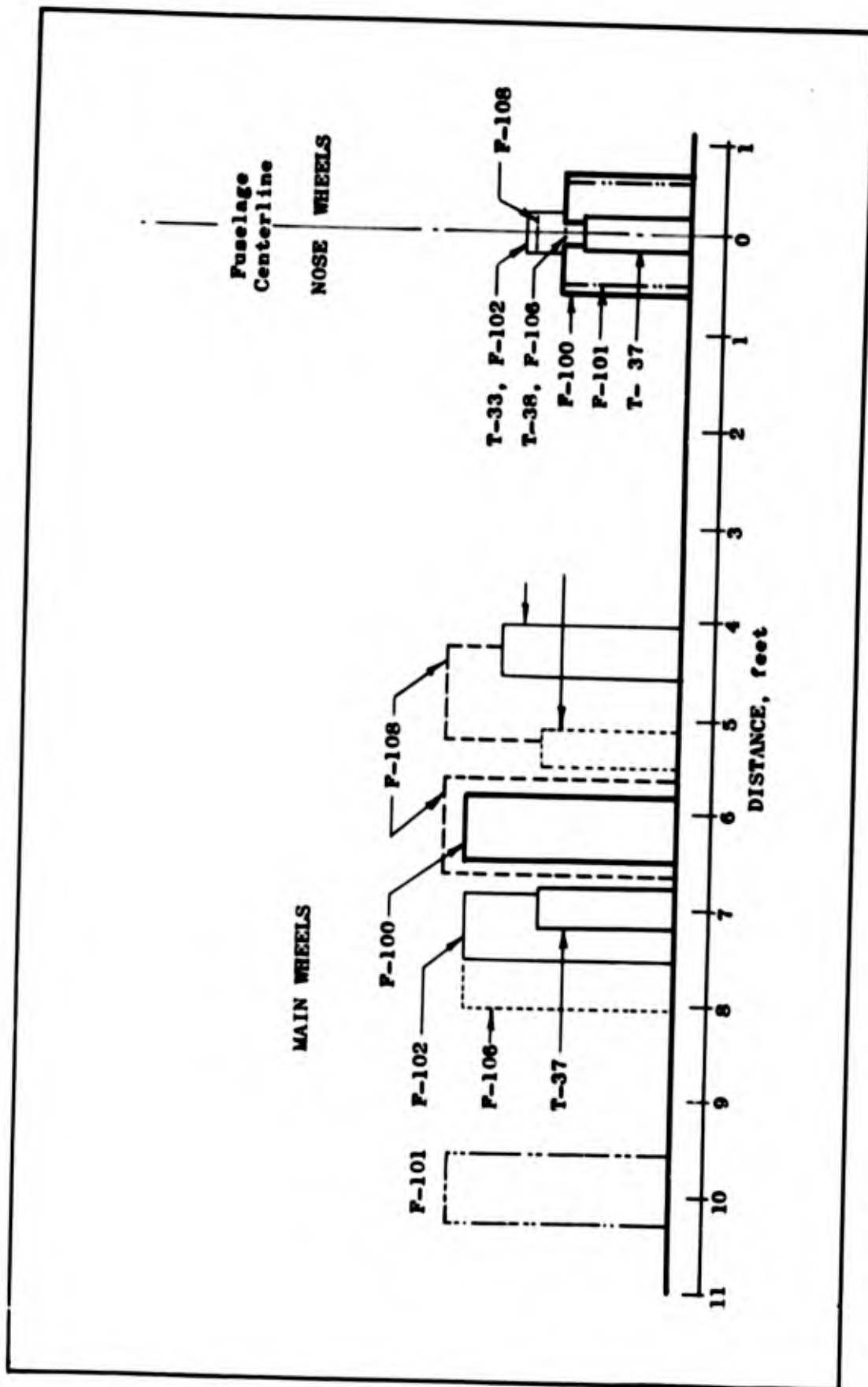


FIGURE 2: WHEEL TREAD PROFILES FOR CURRENT FIGHTERS AND TRAINERS

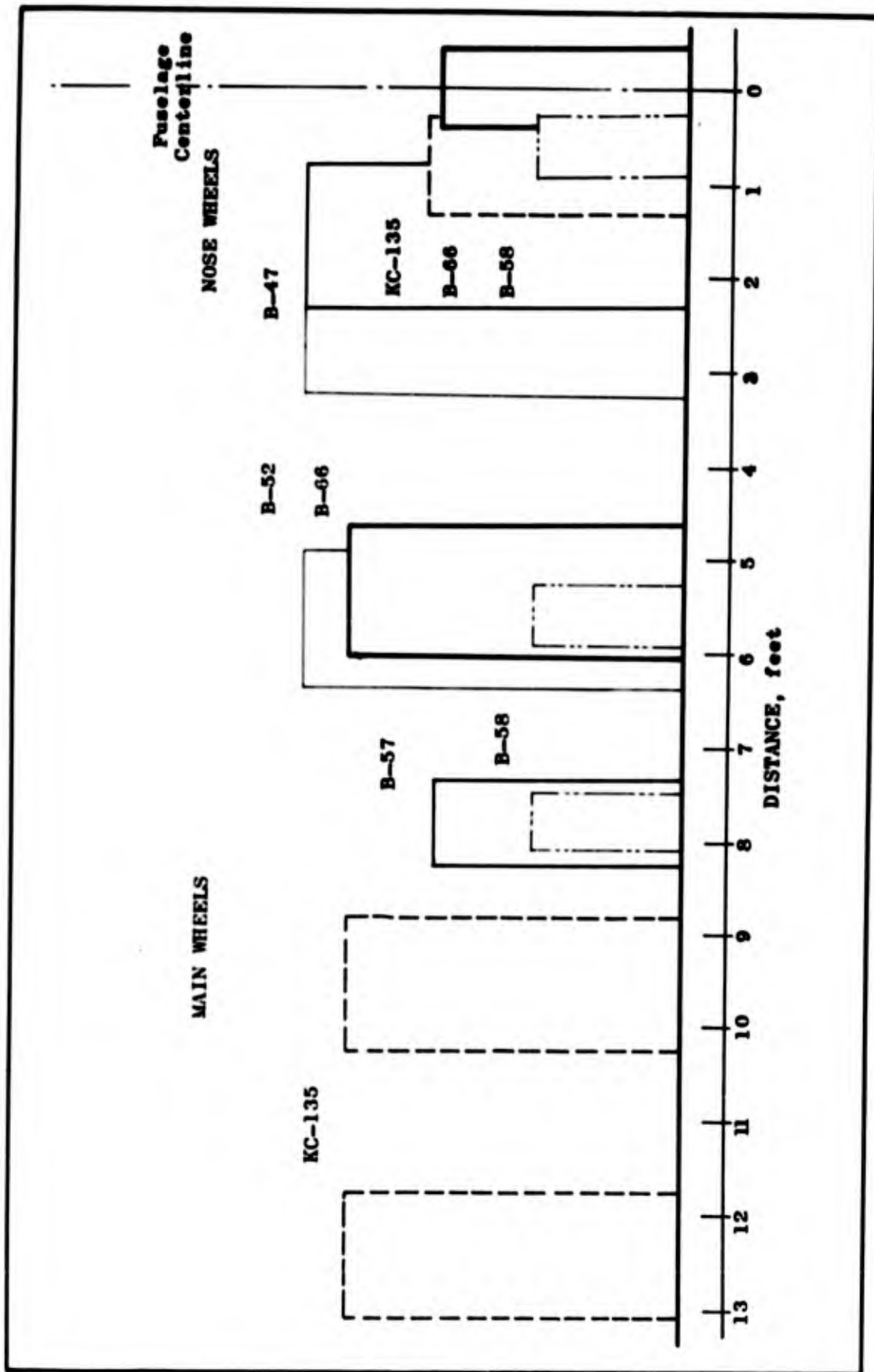


FIGURE 3: WHEEL TREAD PROFILES FOR CURRENT BOMBERS

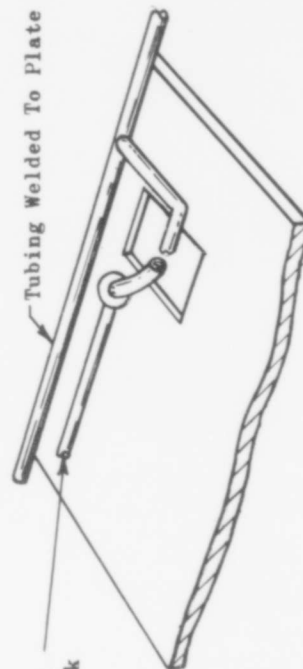
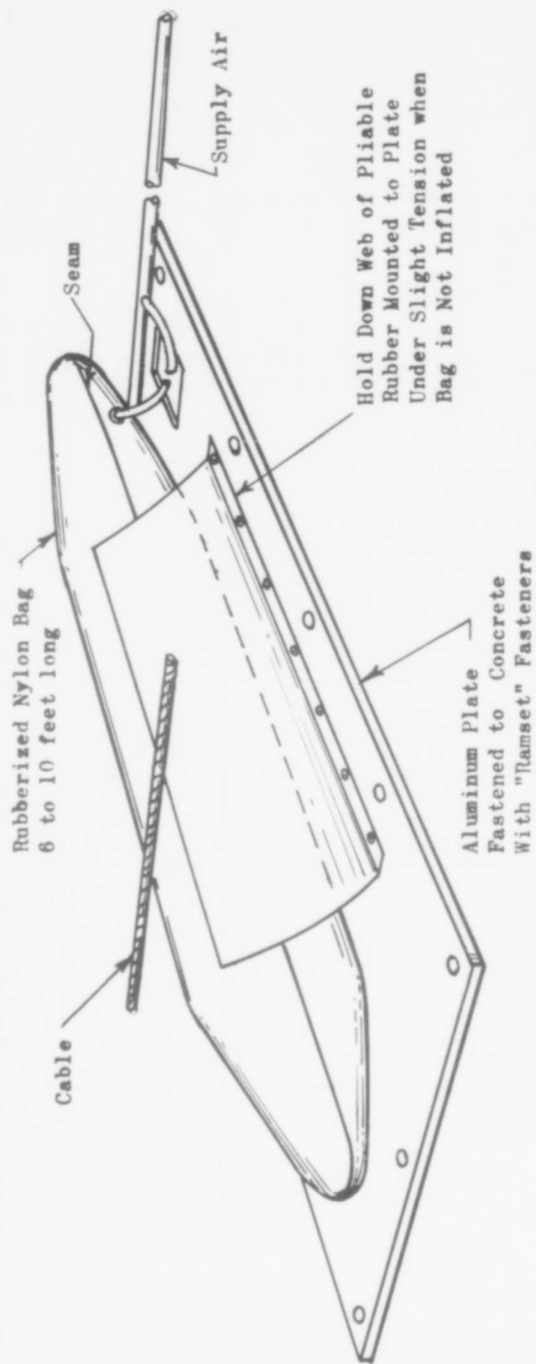


FIGURE 4: INFLATABLE CABLE SUPPORT - DESIGN I

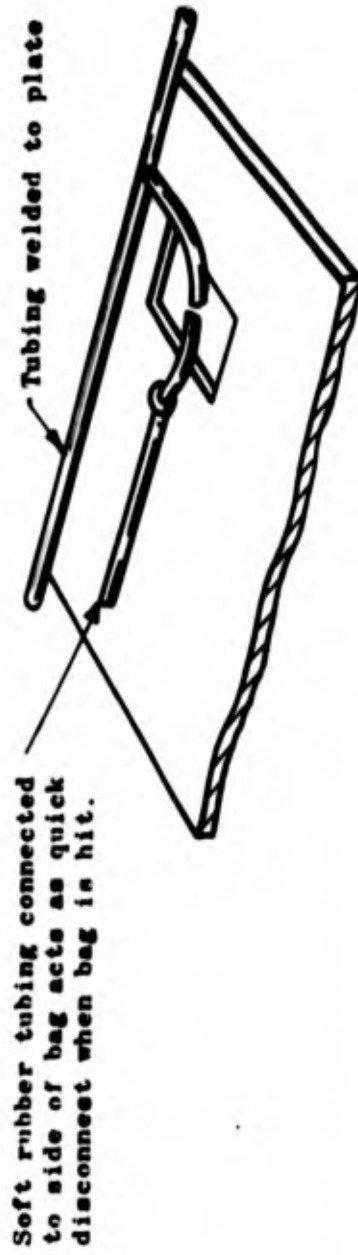
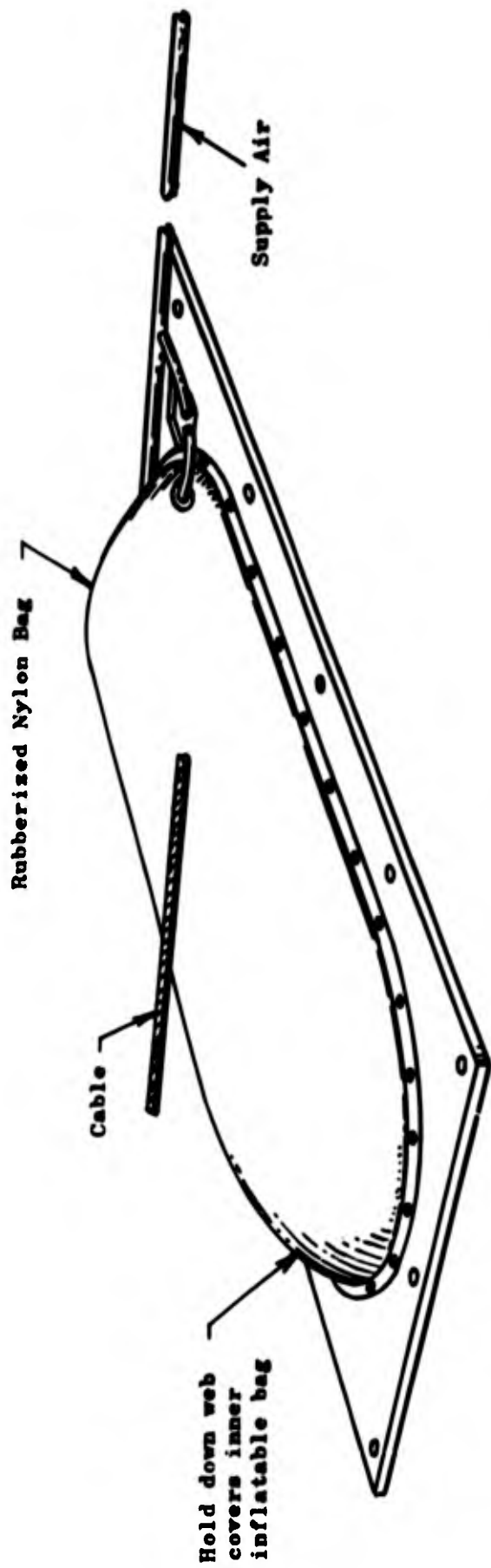


FIGURE 5: INFLATABLE CABLE SUPPORT - DESIGN II

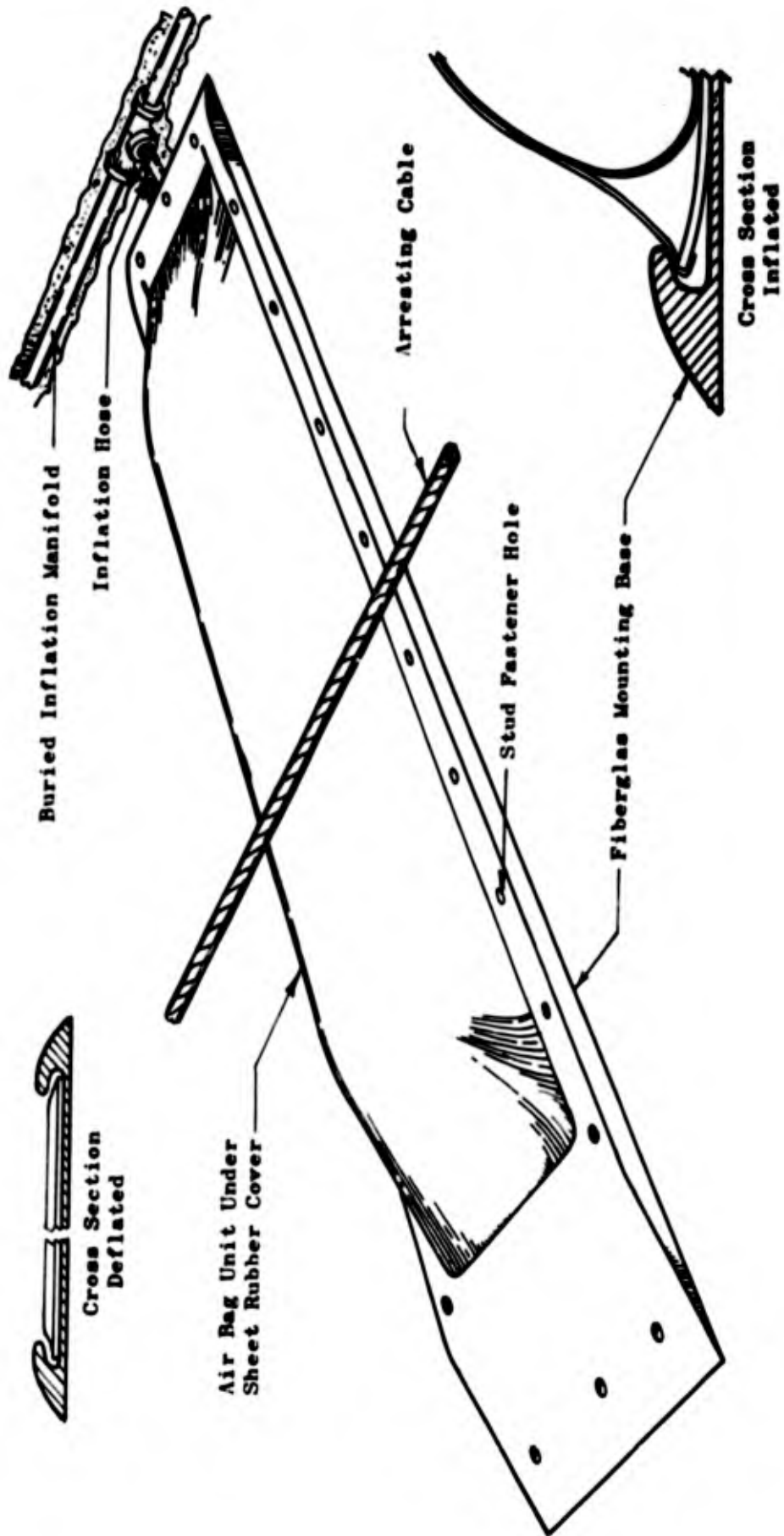


FIGURE 6: INFLATABLE CABLE SUPPORT - DESIGN III



FIGURE 7: TOP SIDE OF TEST MODEL



FIGURE 8: UNDER SIDE OF TEST MODEL



FIGURE 9: TEST MODEL AT 7-1/2 PSIG



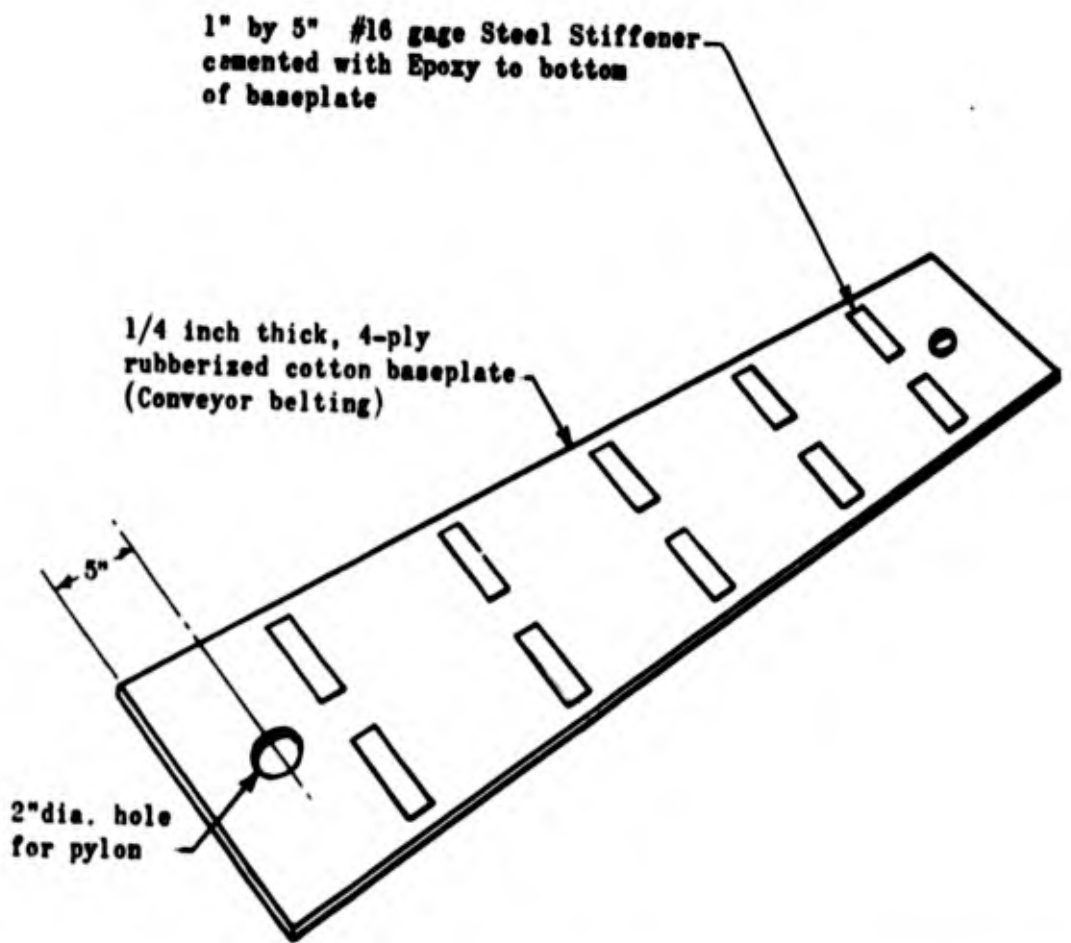
FIGURE 10: FLUSH MOUNTING BASE INSTALLATION



FIGURE 11: AIR BAG UNIT MOUNTED FOR TEST



FIGURE 12: HEAVY CAR HITTING BAG AT 75 MPH



Pylon material - Bakelite.
 Pylon attached to surface of mounting base with Epoxy cement, with flanges toward ends of bases as shown in Fig.

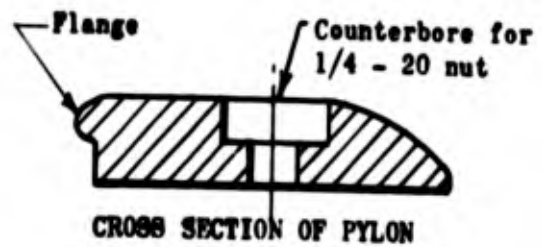


FIGURE 13: MODIFICATIONS FOR RETAINING AIR BAG UNITS IN MOUNTING BASES



FIGURE 14: AIR BAG UNIT ON BASE PLATE SHOWING HOLD-DOWN STRAPS AND SHEET RUBBER COVER

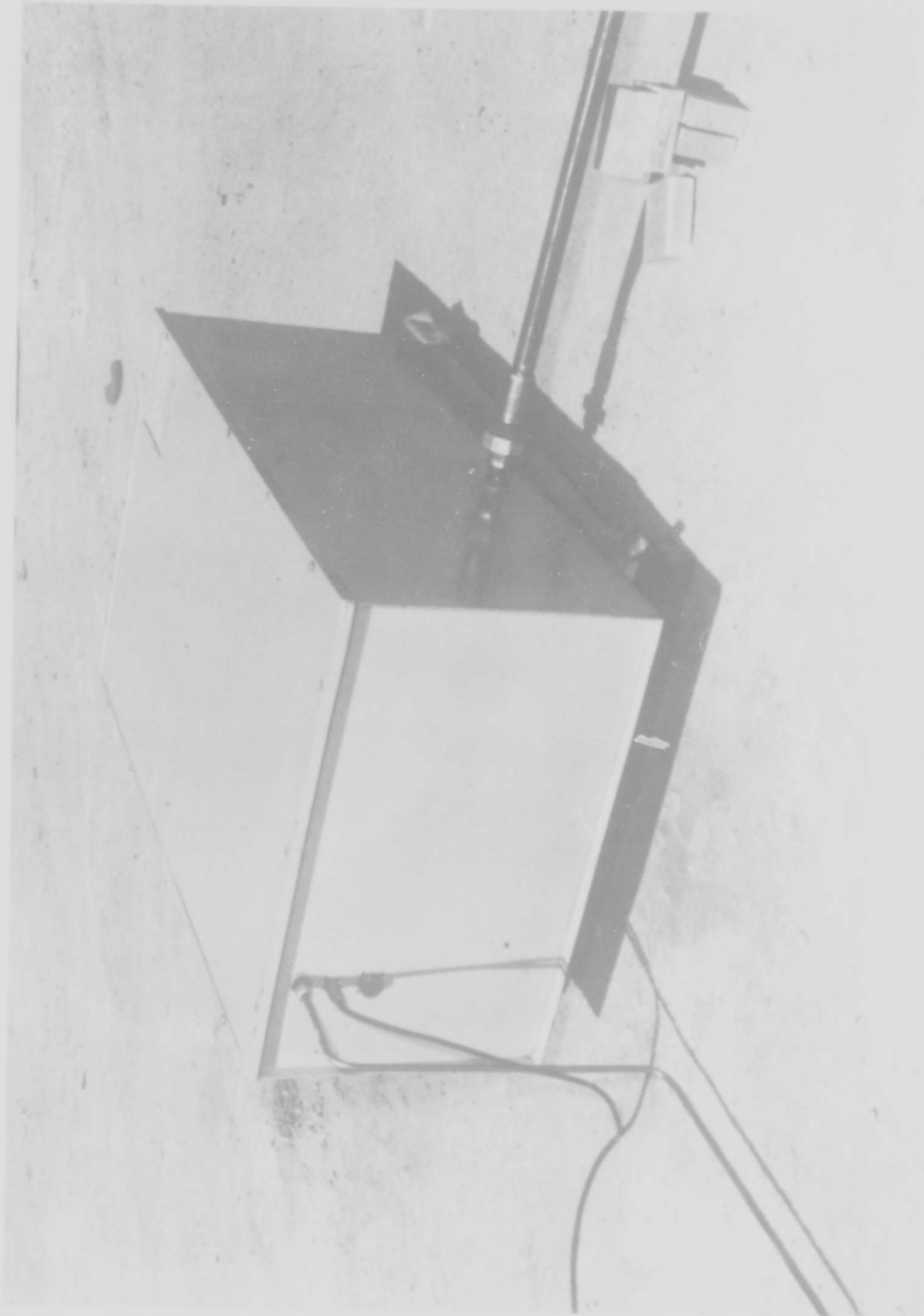


FIGURE 15: INFLATION CONTROLS BOX - EXTERNAL

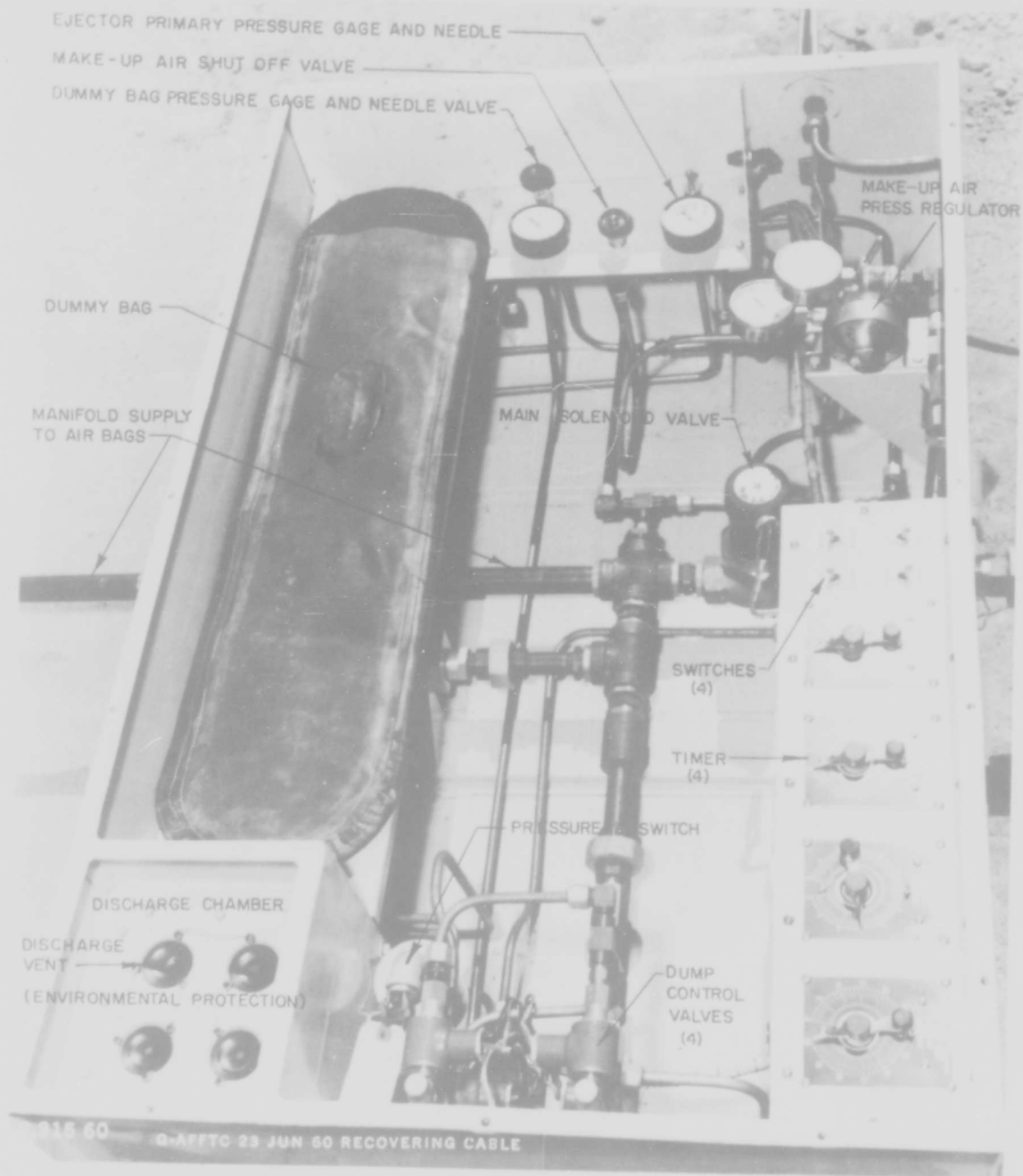


FIGURE 16: INFLATION CONTROLS BOX - INTERNAL

- | | |
|--------------------------------|-------------------------------|
| (1) Deflation Ejector | (6) Pressure Sensitive Switch |
| (2) Pilot Operated Check Valve | (7) Pressure Regulator |
| (3) Pressure Relief Valve | (8) 10 micron Filter |
| (4) Variable Orifice (Valve) | (9) 100 micron Filter |
| (5) Check Valve | (10) Solenoid Valve |

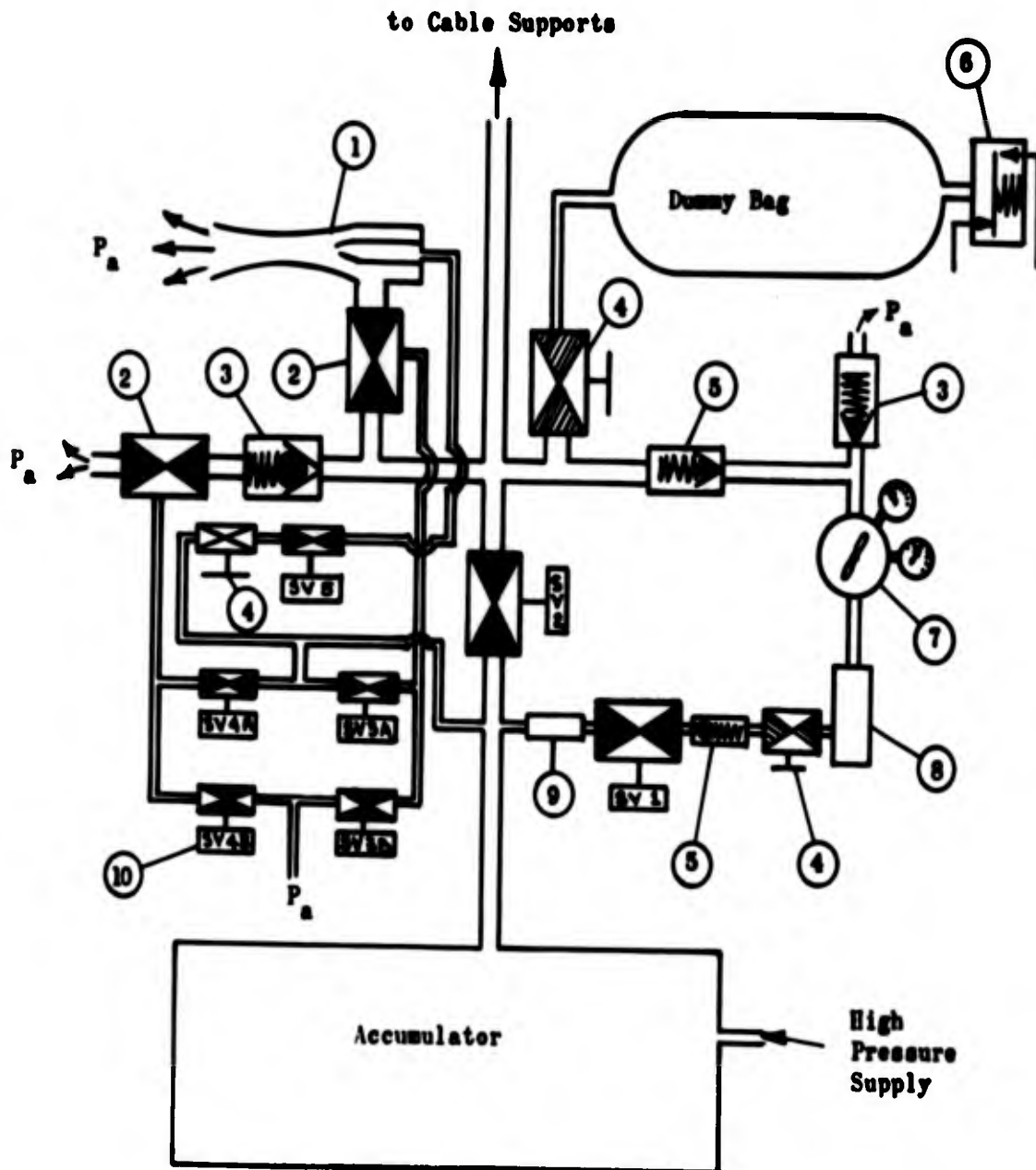


FIGURE 17: AIR SUPPLY CONTROL SYSTEM (SCHEMATIC) PROTOTYPE

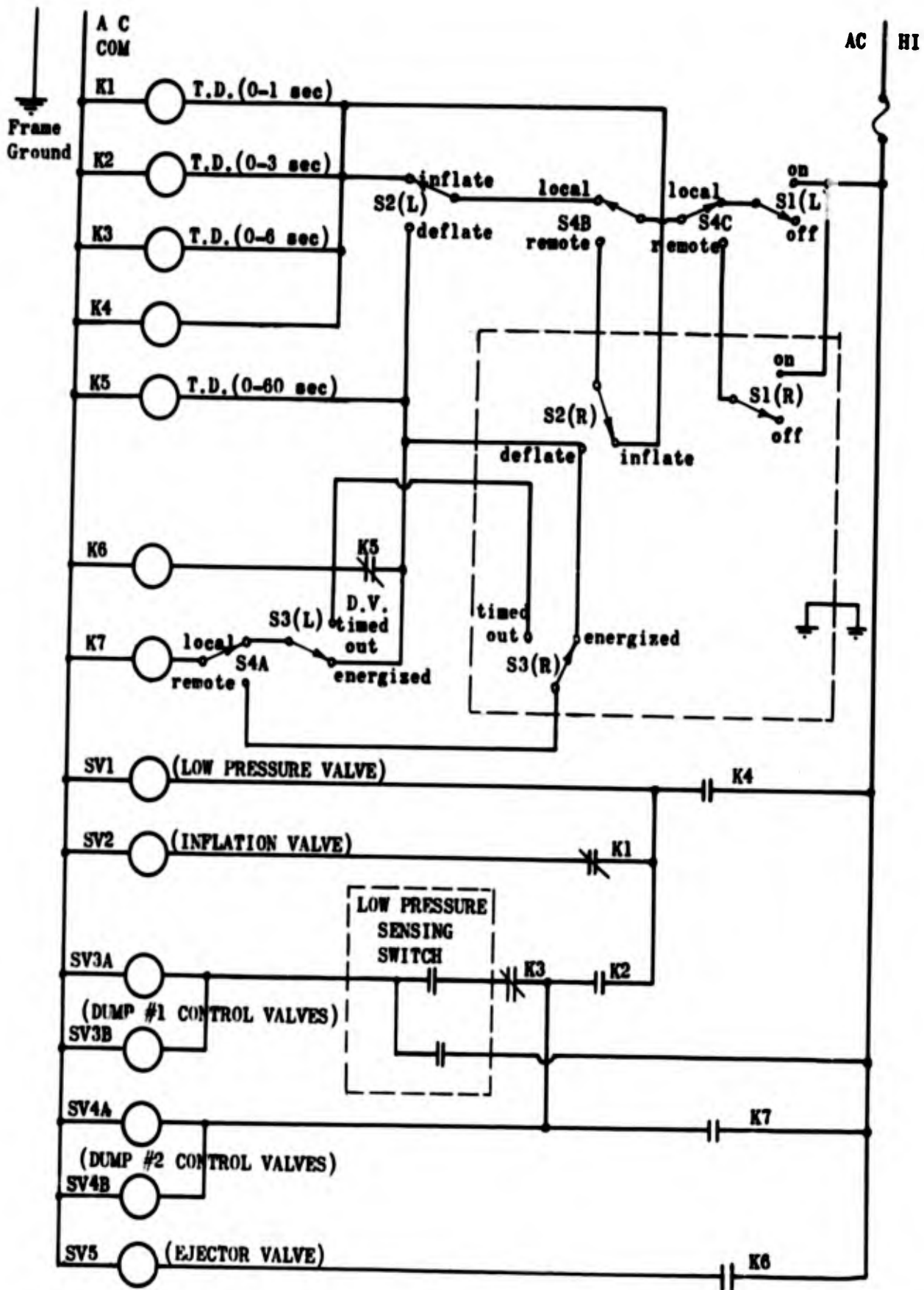


FIGURE 18: AIR SUPPLY ELECTRICAL SYSTEM (SCHEMATIC) PROTOTYPE

ORIFICE DIAMETER, inches	LOCATION Air Bag No.
0.111	1, 2
0.116	3, 4
0.120	5, 6
0.124	7, 8
0.055	Trough Unit Test Bags

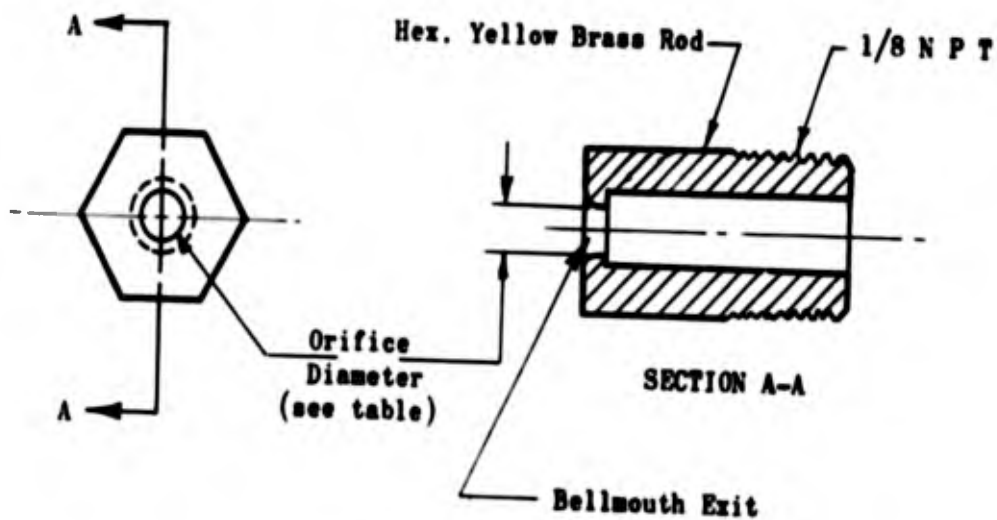
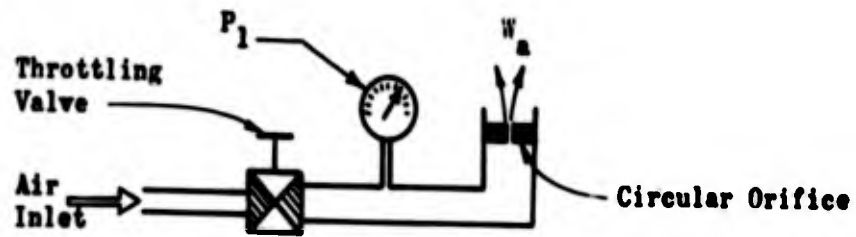


FIGURE 19: ORIFICE DETAILS

$P_{amb} = 15 \text{ psia}$



$\Delta P = P_1 - P_{amb}$

- $\Delta P = 4 \text{ psi}$
- $\Delta P = 6 \text{ psi}$
- △ $\Delta P = 8 \text{ psi}$
- ◇ $\Delta P = 10 \text{ psi}$

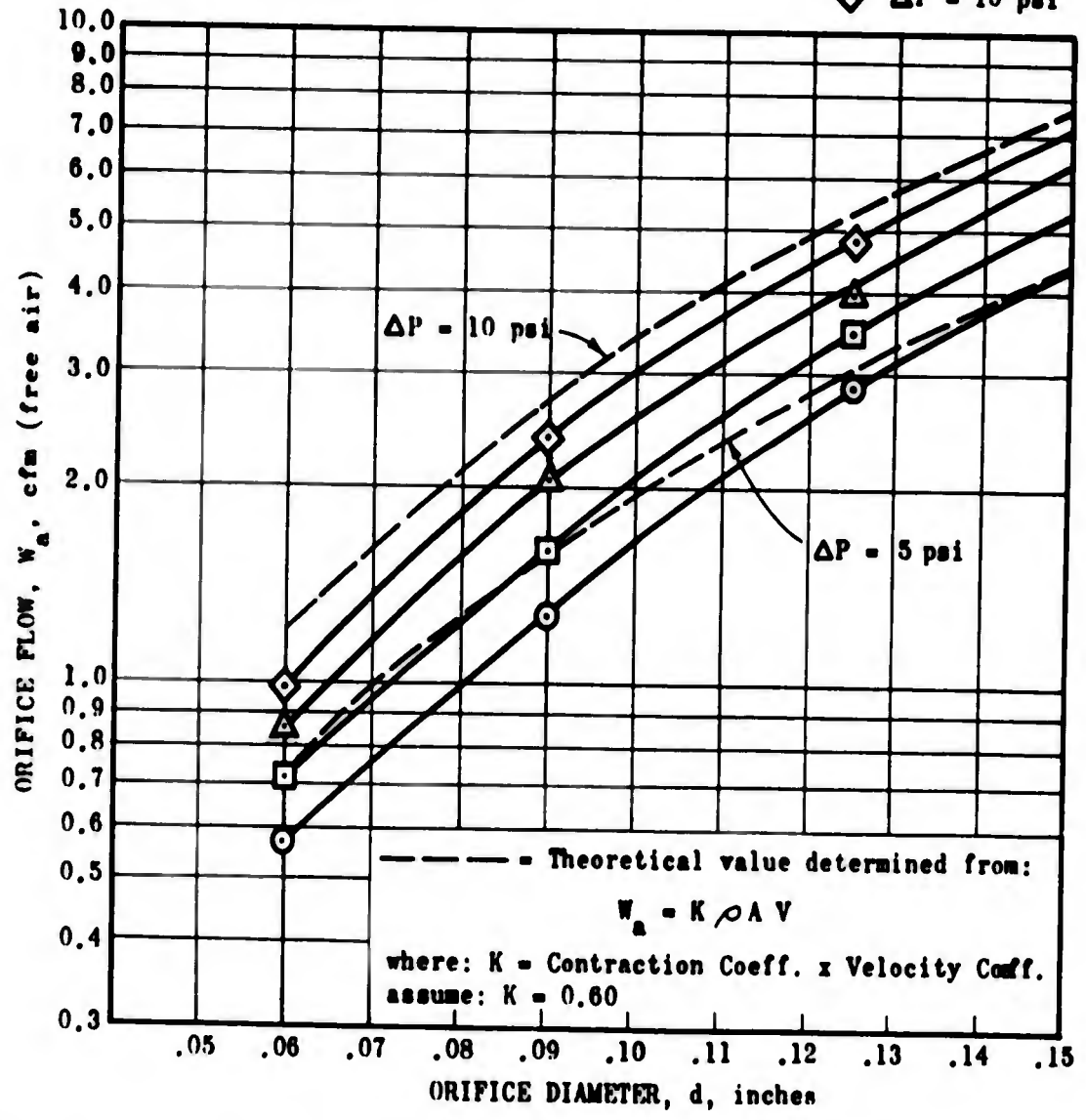


FIGURE 20: ORIFICE LEAKAGE FLOW TESTS



FIGURE 21: INFLATABLE CABLE SUPPORT INSTALLATION

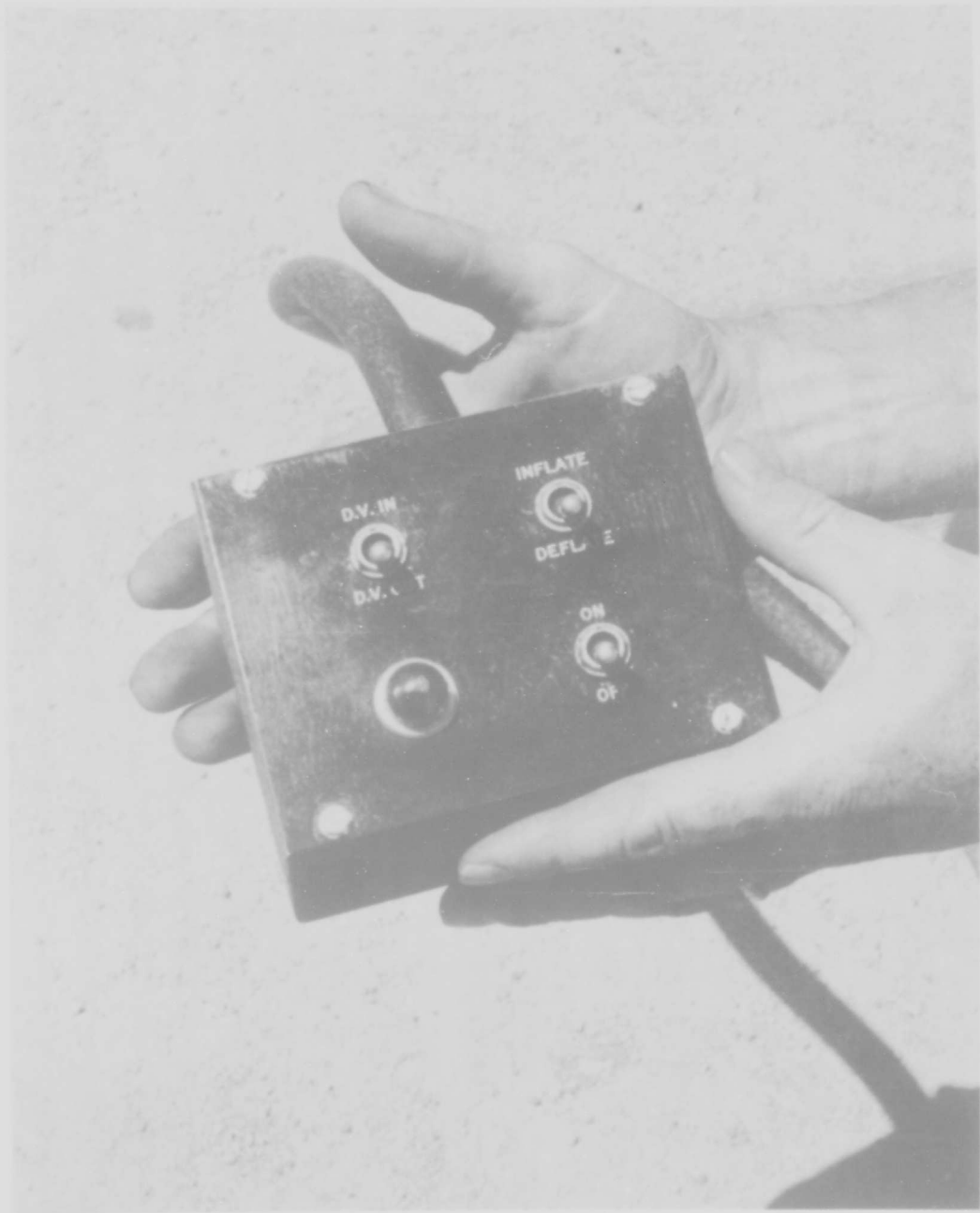


FIGURE 22: CONTROLS BOX FOR REMOTE OPERATION

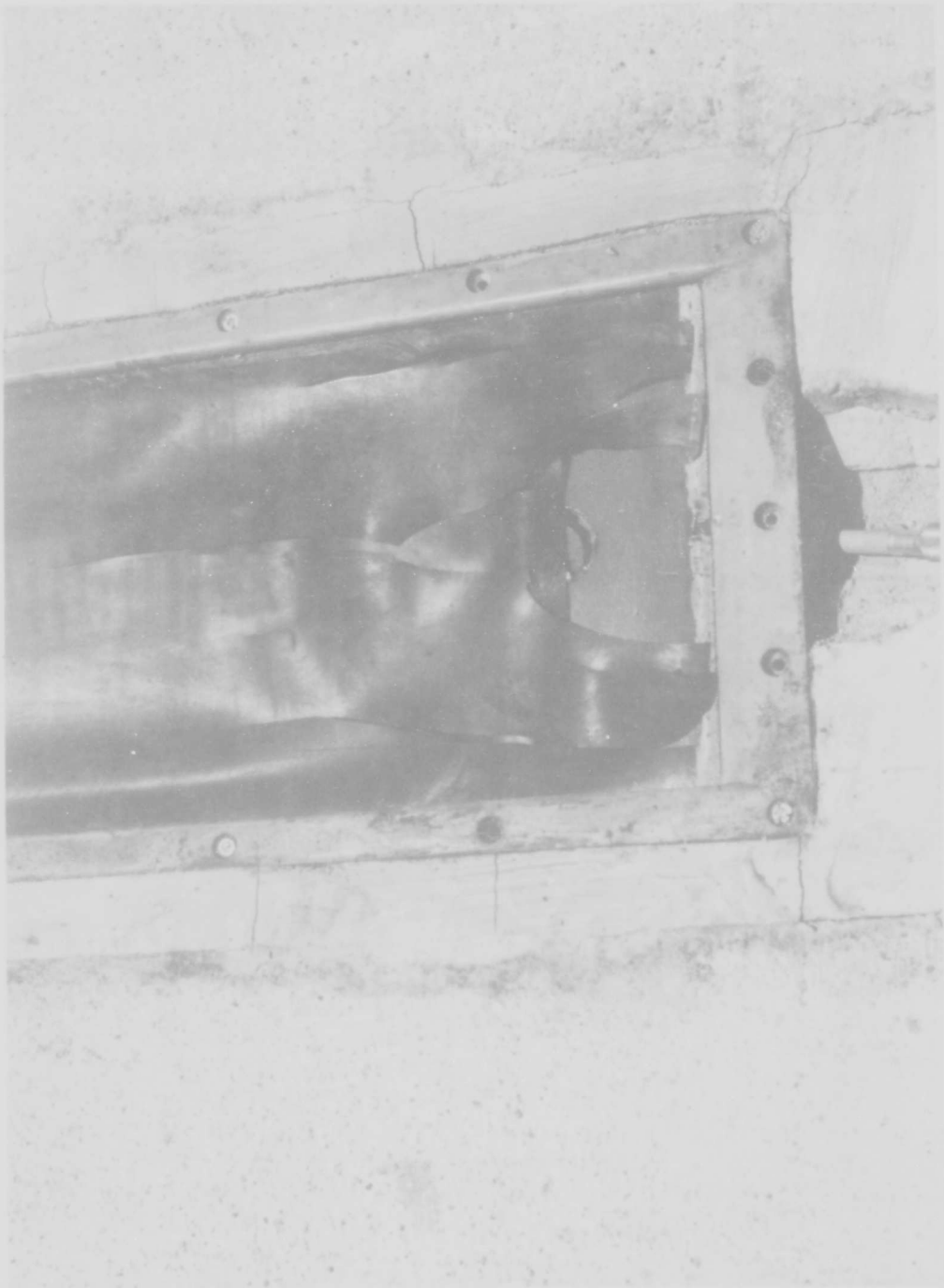


FIGURE 23: TYPICAL BLOW-OUT AT END OF UNIT

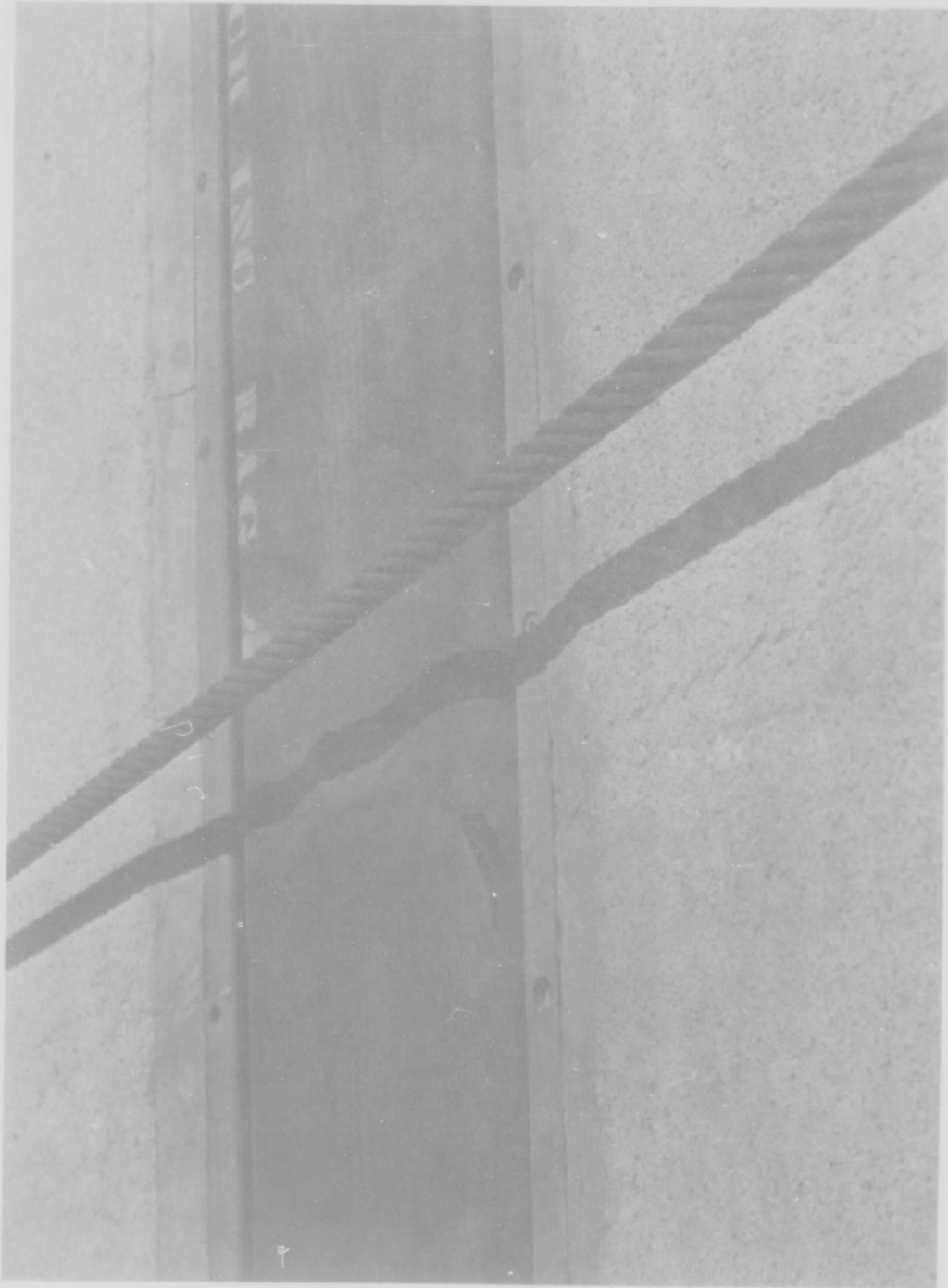


FIGURE 24: PINCH HOLE CAUSED BY CABLE IMPACT

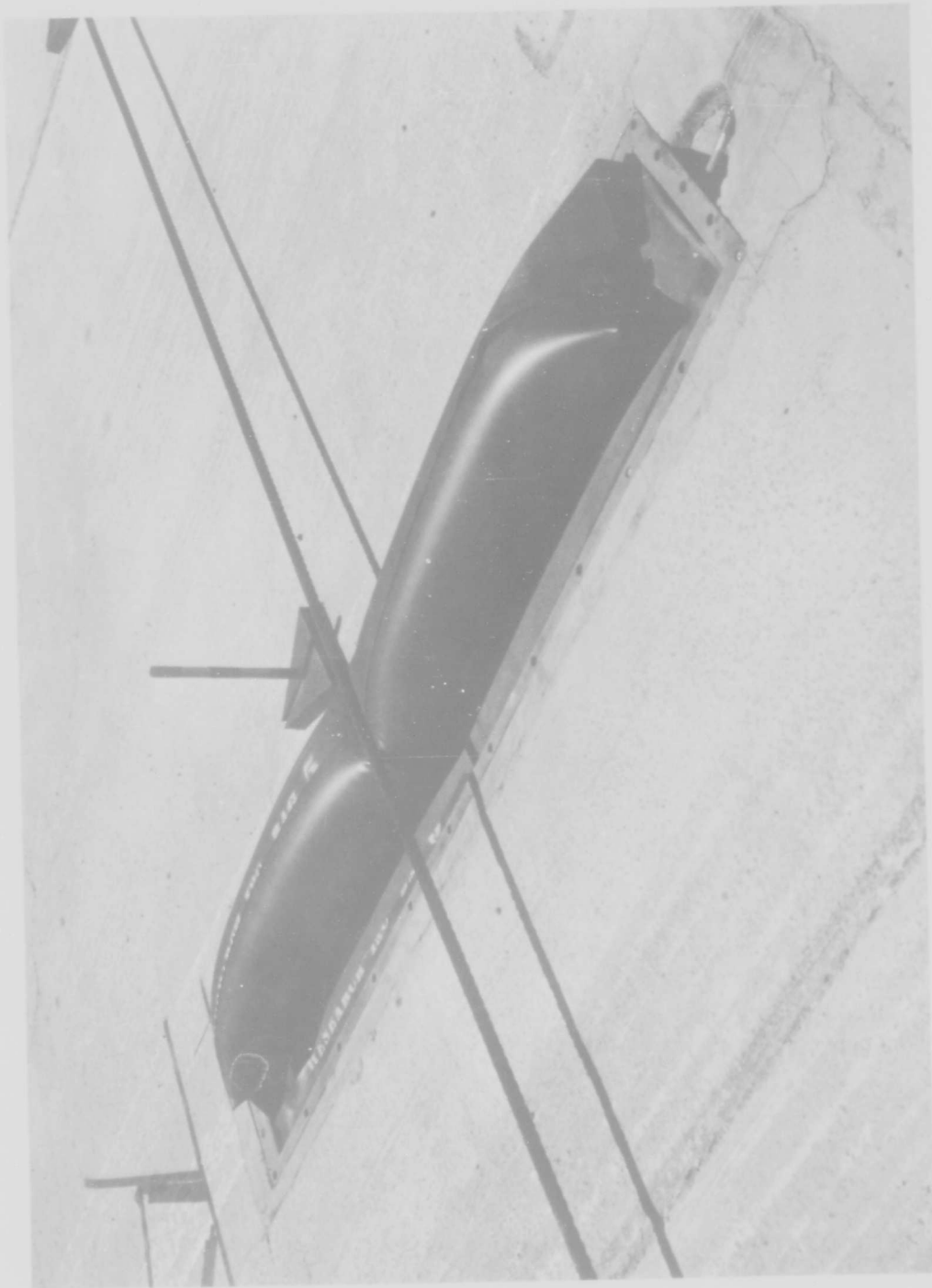


FIGURE 25: BAG COVER SPLIT OPEN



FIGURE 26: INFLATED TROUGH UNIT IN RUNWAY



Air Bag Unit and Frame

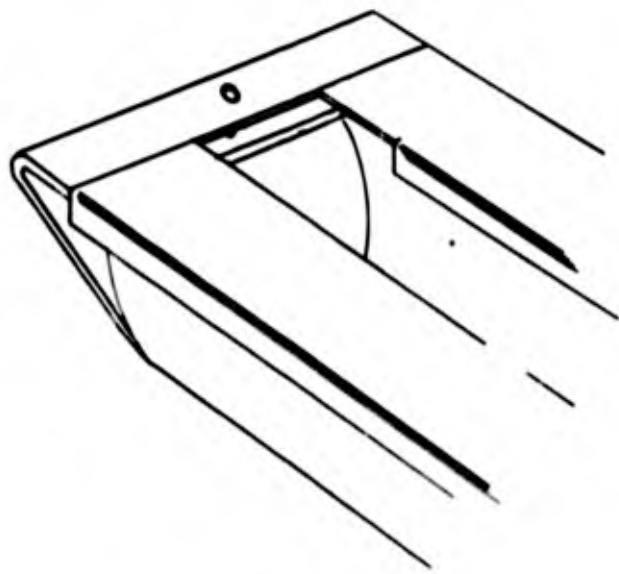


Inflated Unit

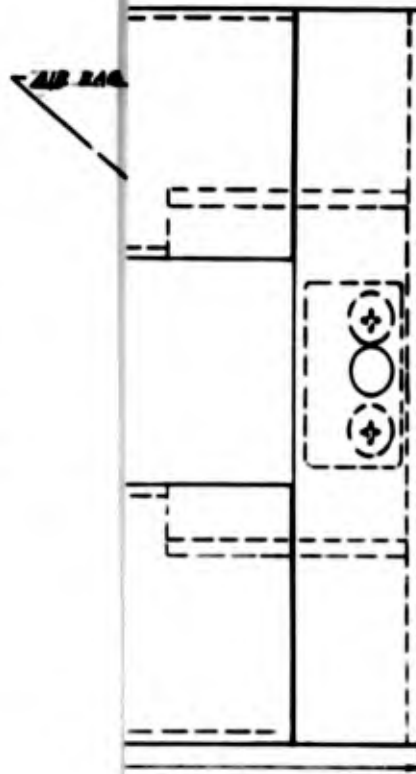


Deflated Unit

FIGURE 27: MODEL TROUGH UNIT



VIEW OF END DETAILS



TRIP ASSEMBLY

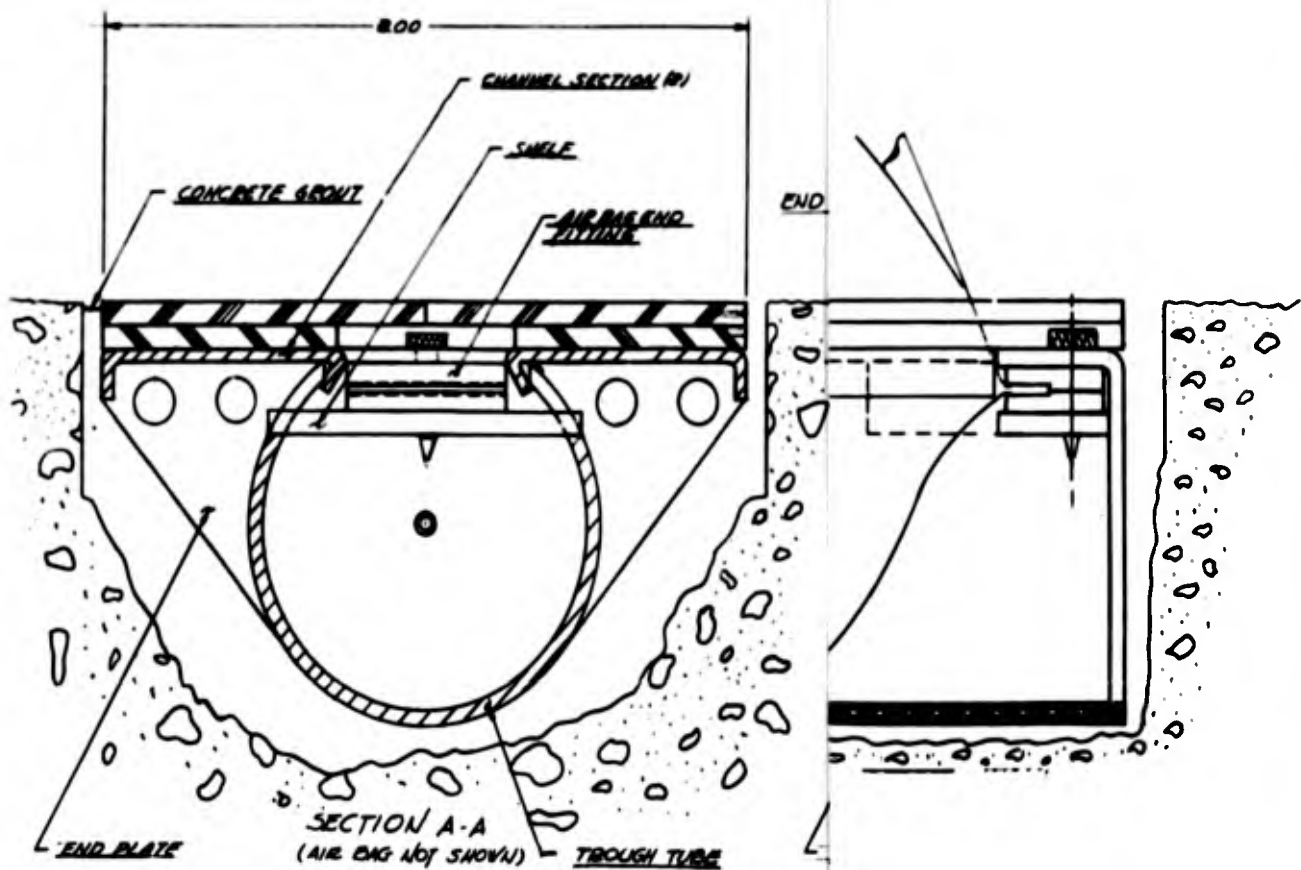
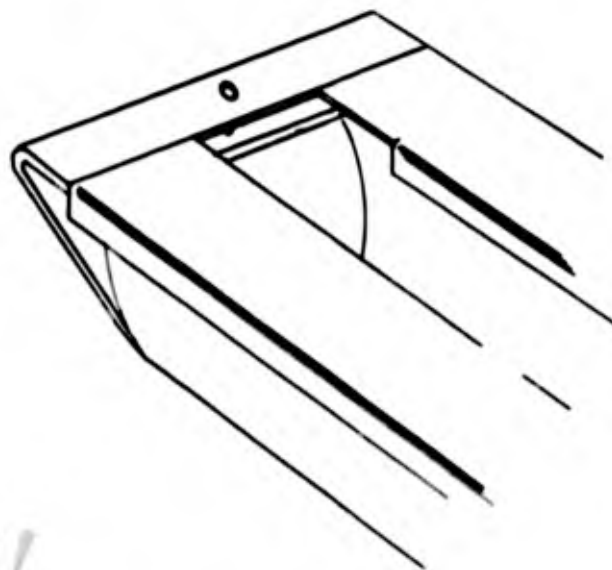


FIGURE 28: TROUGH MOUNTED AIR BAG SYSTEM.

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VIEW OF END DETAILS

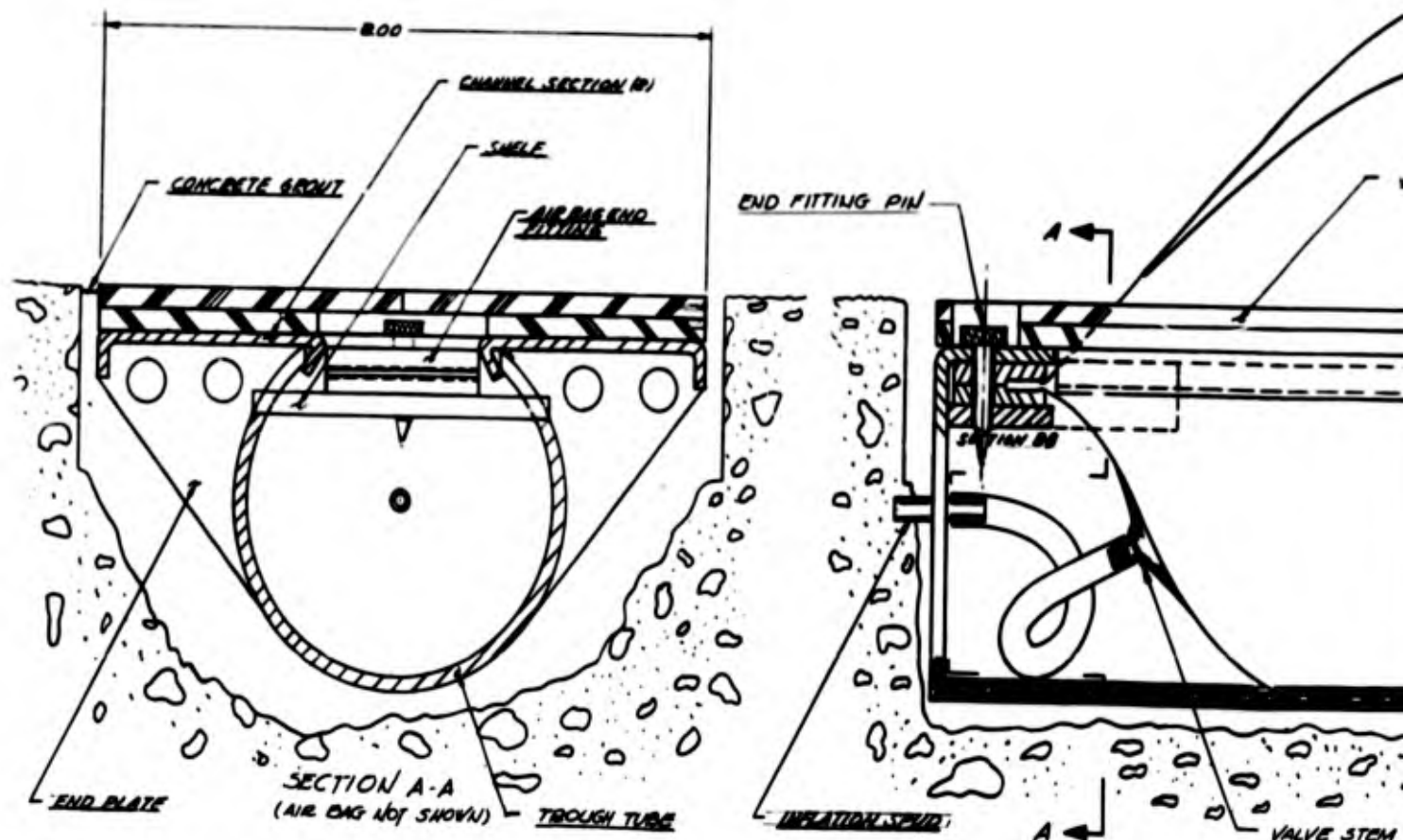
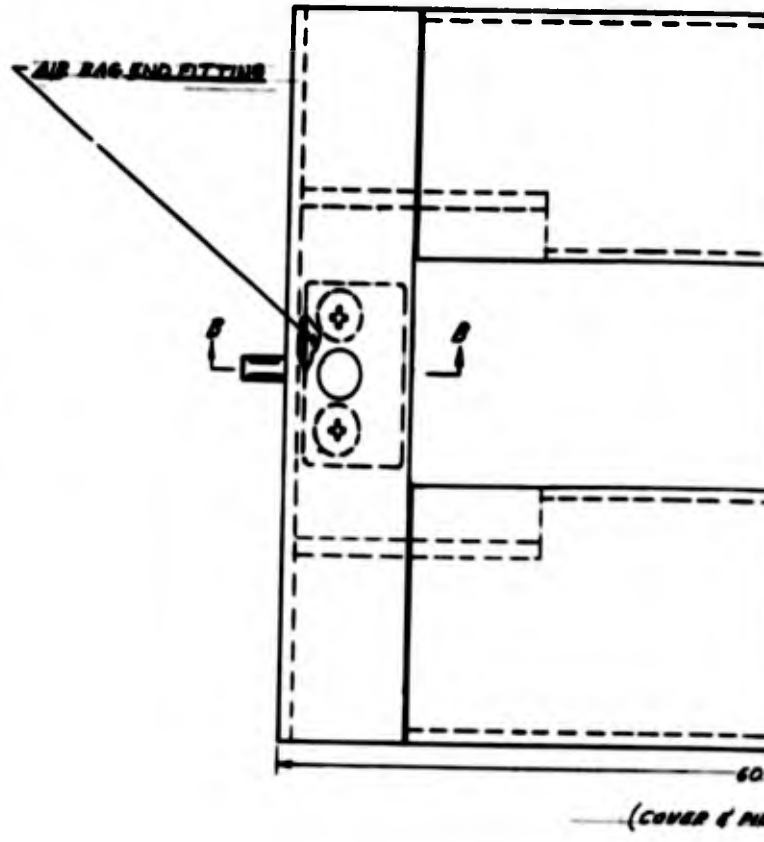
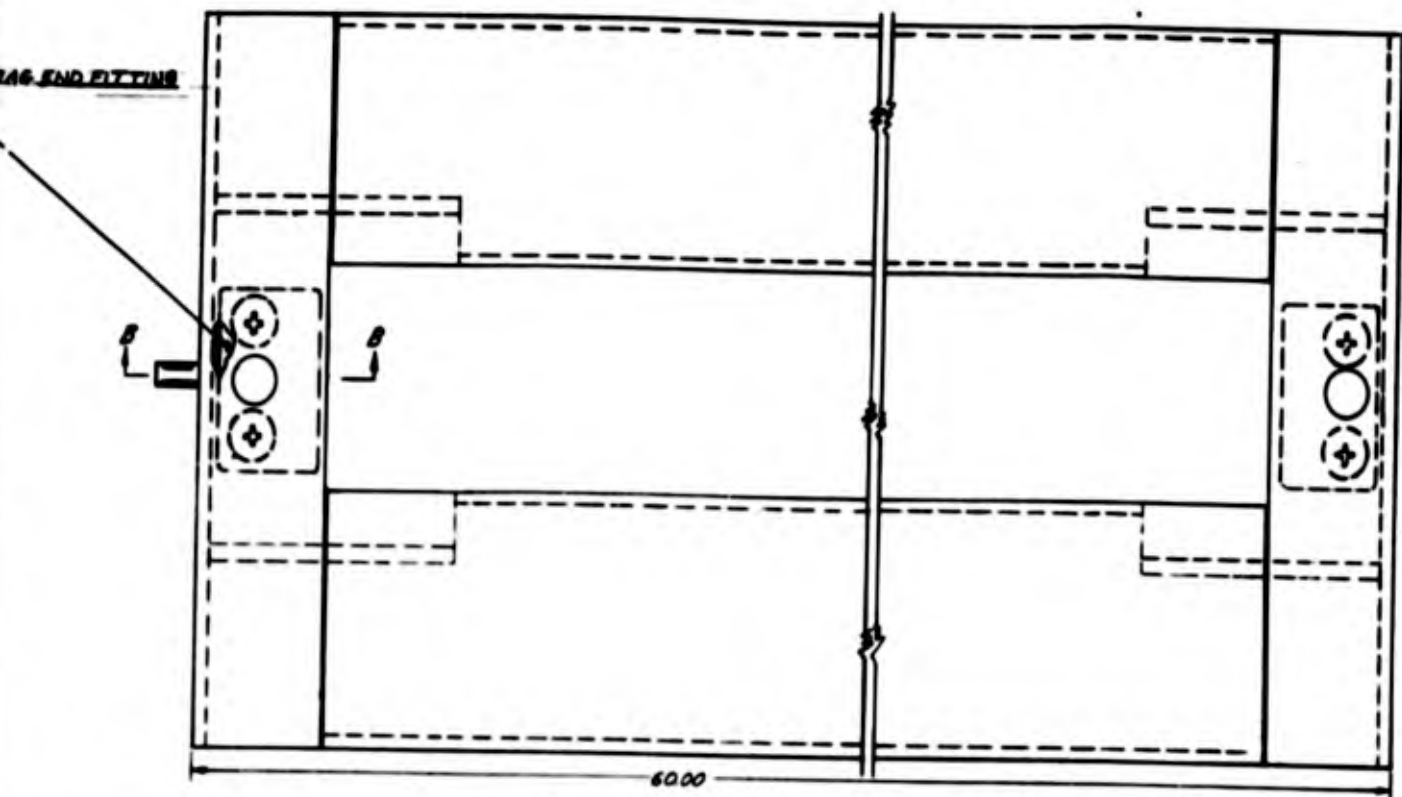
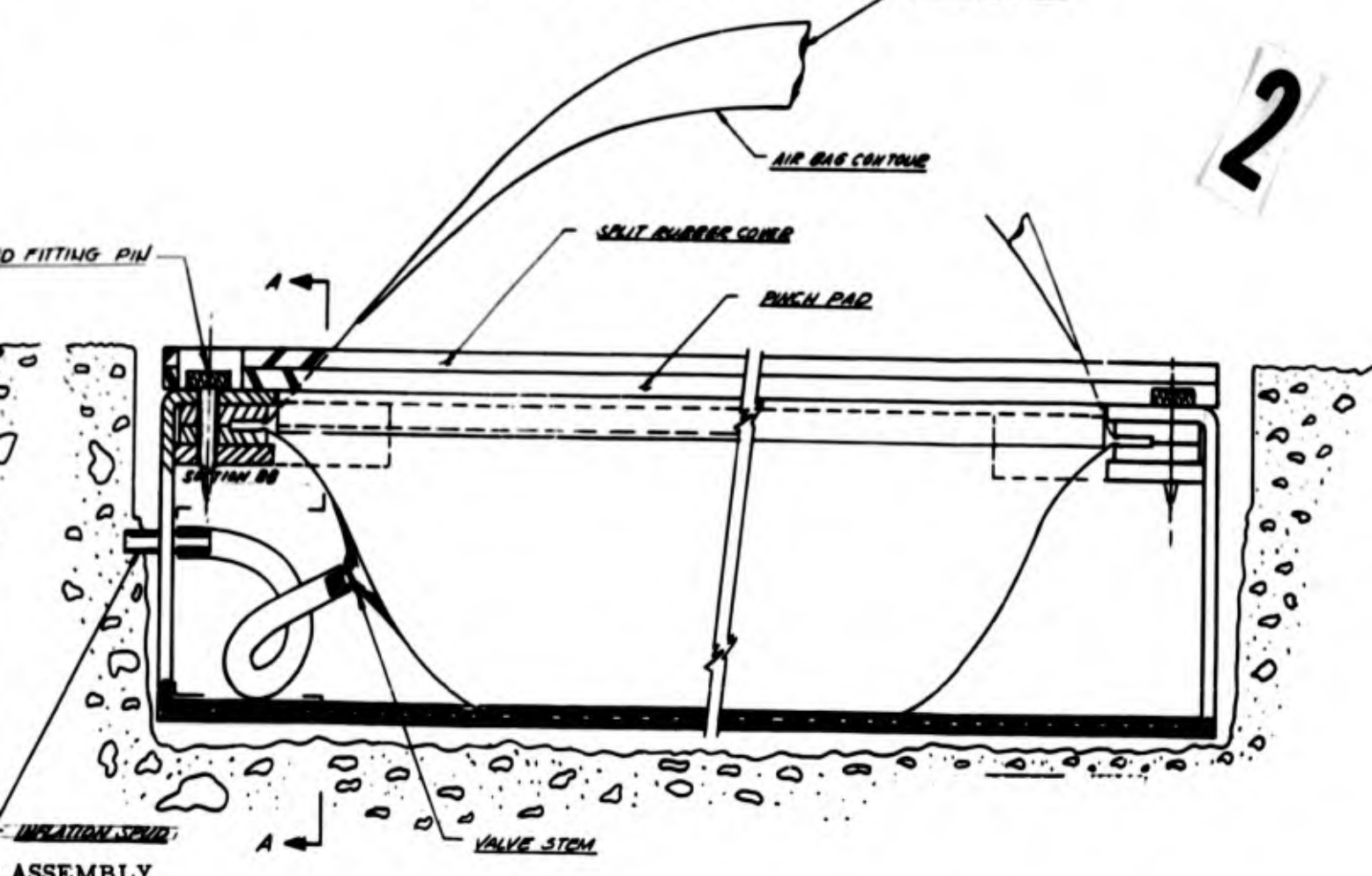


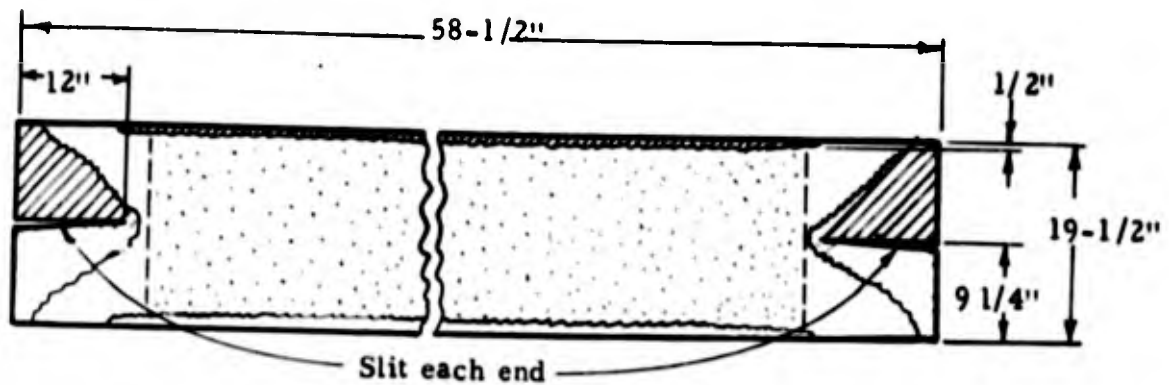
FIGURE 28: TROUGH MOUNTED AIR BAG SYSTEM ASSEMBLY



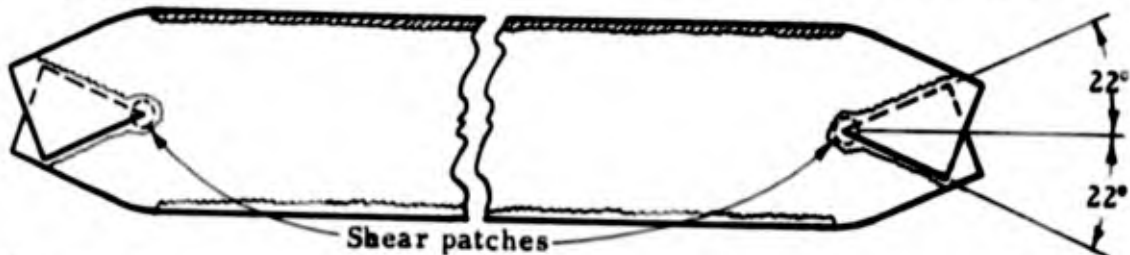
(COVER & PUNCH PADS NOT SHOWN ABOVE)

FOR STRIP ASSY.

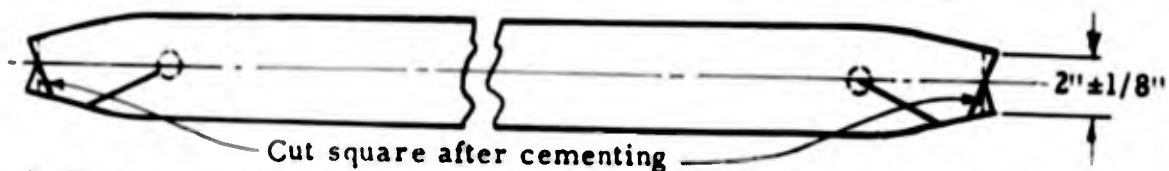




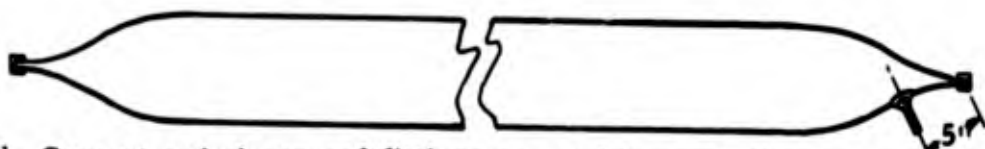
1. Cut Neoprene on Nylon fabric to dimensions shown.
2. Abrade shaded areas underneath and similar area outlined on top.
3. Clean abraded area with Toluol, clean dotted area with Toluol, this side.
4. Coat abraded and dotted areas with cement and cement wedge plate to dotted area.



5. Overlap coinciding flaps and cement to exact angles shown, press together, roll completely and firmly with 1/2" wide roller.
6. Cement two shear patches as shown, centering patch on end of slit.



7. Turn unit over and press long seam together between slit-ends only.
8. Install two remaining shear patches.
9. Finish off by cementing remaining end portions together as in Step 5.
10. Trim off bag ends square with bag centerline.



11. Cement and clamp end fittings on, making sure they are square with bag centerline. Use cement generously. Let dry one hour first.
12. Install valve stem along centerline of bag in position shown.
13. Before cementing stem, locate and punch or cut 1/4" hole for air entry.
14. Use a 1/4" dia. by 10" long rod to locate hole and slide valve down into position.
15. Pressure-leak test bag at 10 psig for 24 hours.

FIGURE 29: TROUGH UNIT AIR BAG CONSTRUCTION DETAILS



FIGURE 30: INFLATED AIR BAG IN TROUGH MOUNTING BASE

Note: Assumed Constant Inflation Pressure = 200 psia
Air Bag Volume = 1/3 cubic ft

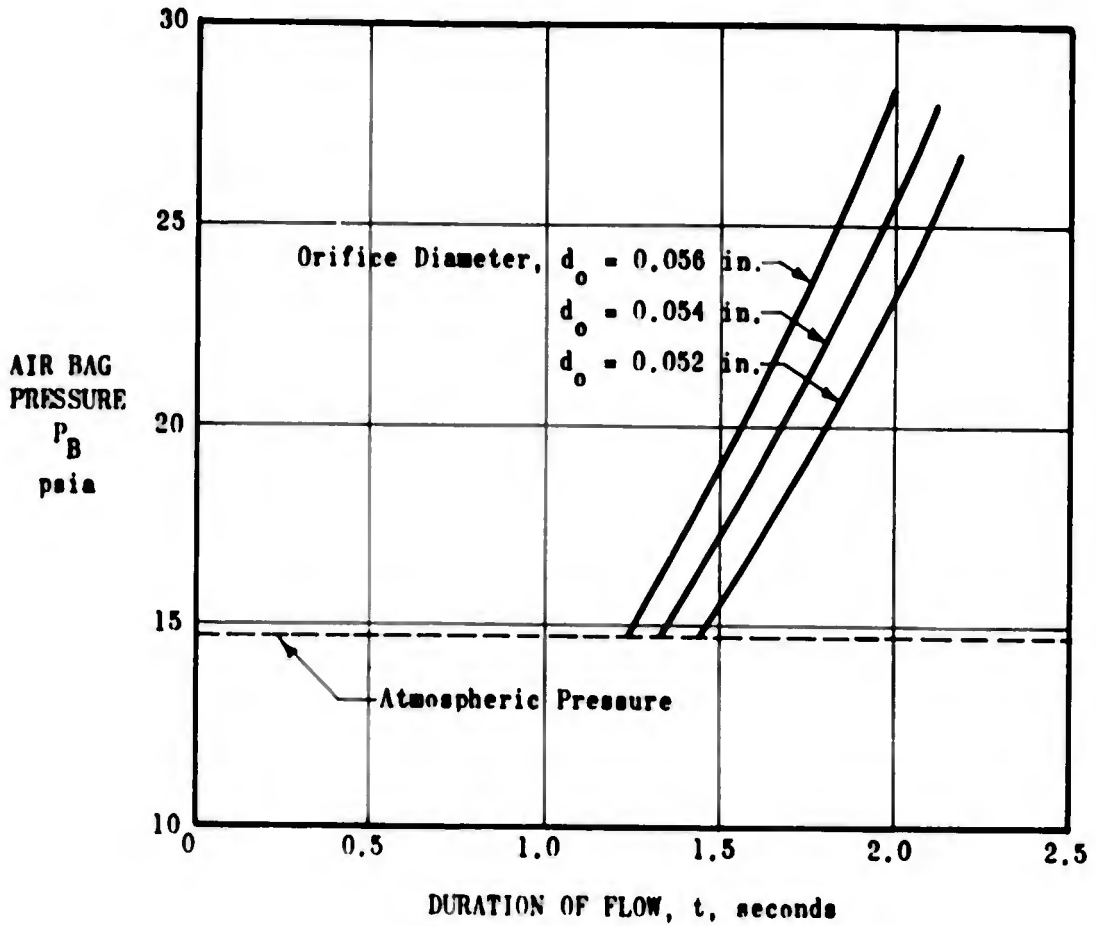


FIGURE 31: VARIATION OF AIR BAG PRESSURE WITH ORIFICE DIAMETER



FIGURE 32: TROUGH UNIT MOUNTING BASE READY FOR GROUTING IN



FIGURE 33: INSTALLING TROUGH UNIT AIR BAG

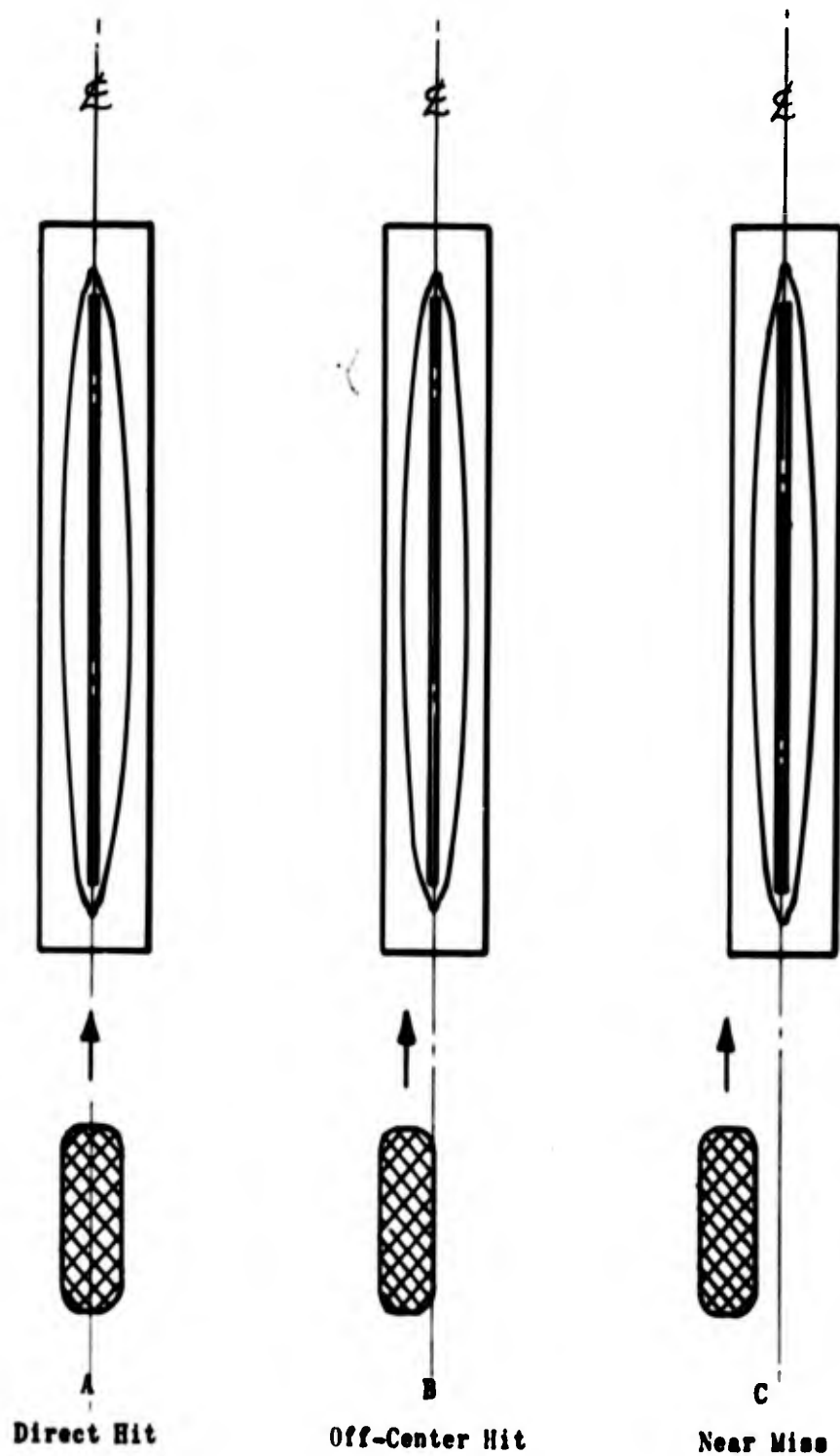


FIGURE 35: DEFINITION OF ROLL-OVER POSITIONS



FIGURE 36: PINCH DAMAGE TO TROUGH UNIT



FIGURE 37: DEPRESSION IN TROUGH UNIT AIR BAG AT 5 PSIG



Nose Wheel Rollover On Cable



Main Wheel Rollover On Cable



FIGURE 38: CABLE POSITION DURING INITIAL ENGAGEMENT

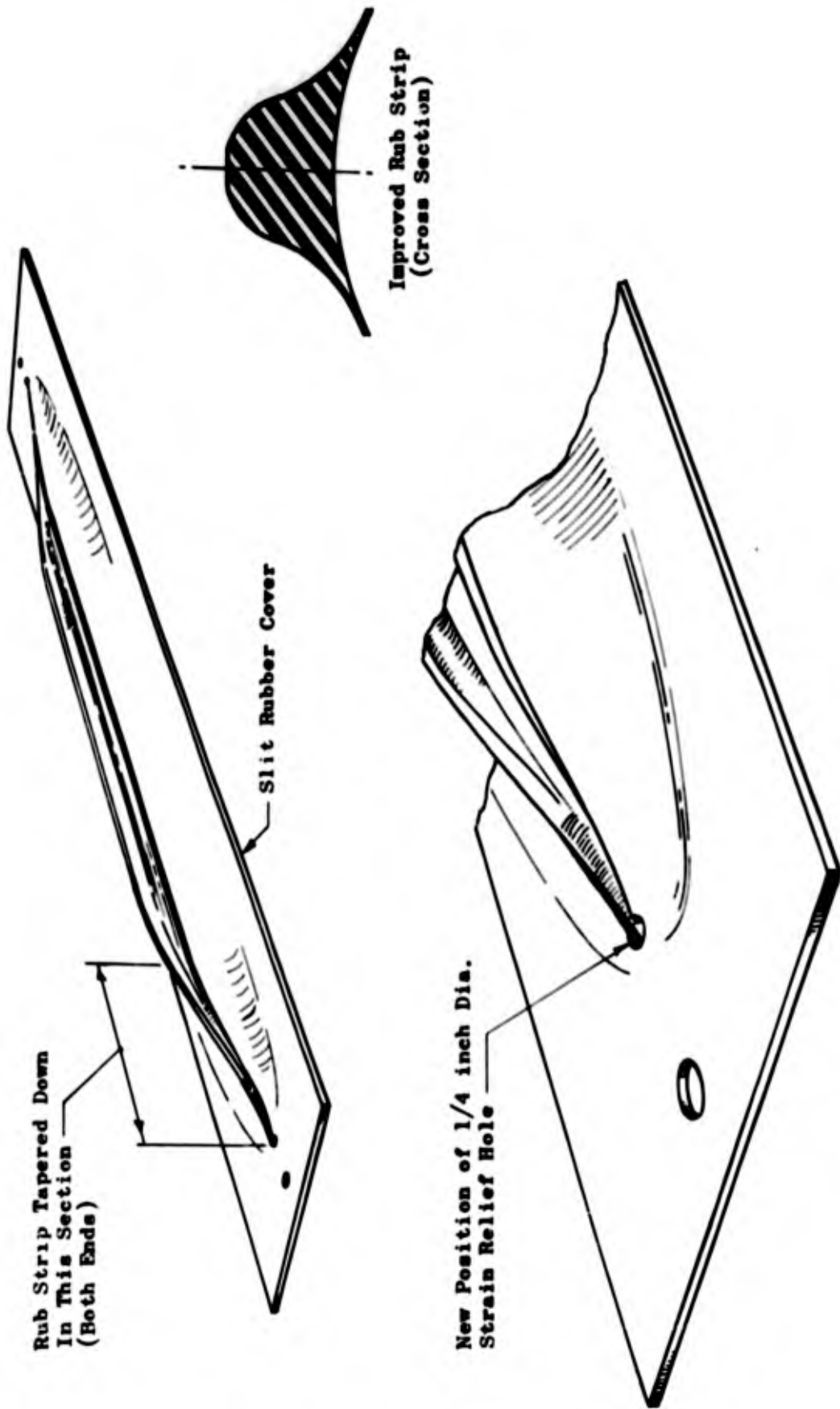


FIGURE 39: FINAL DESIGN MODIFICATIONS FOR TROUGH UNIT AIR BAG

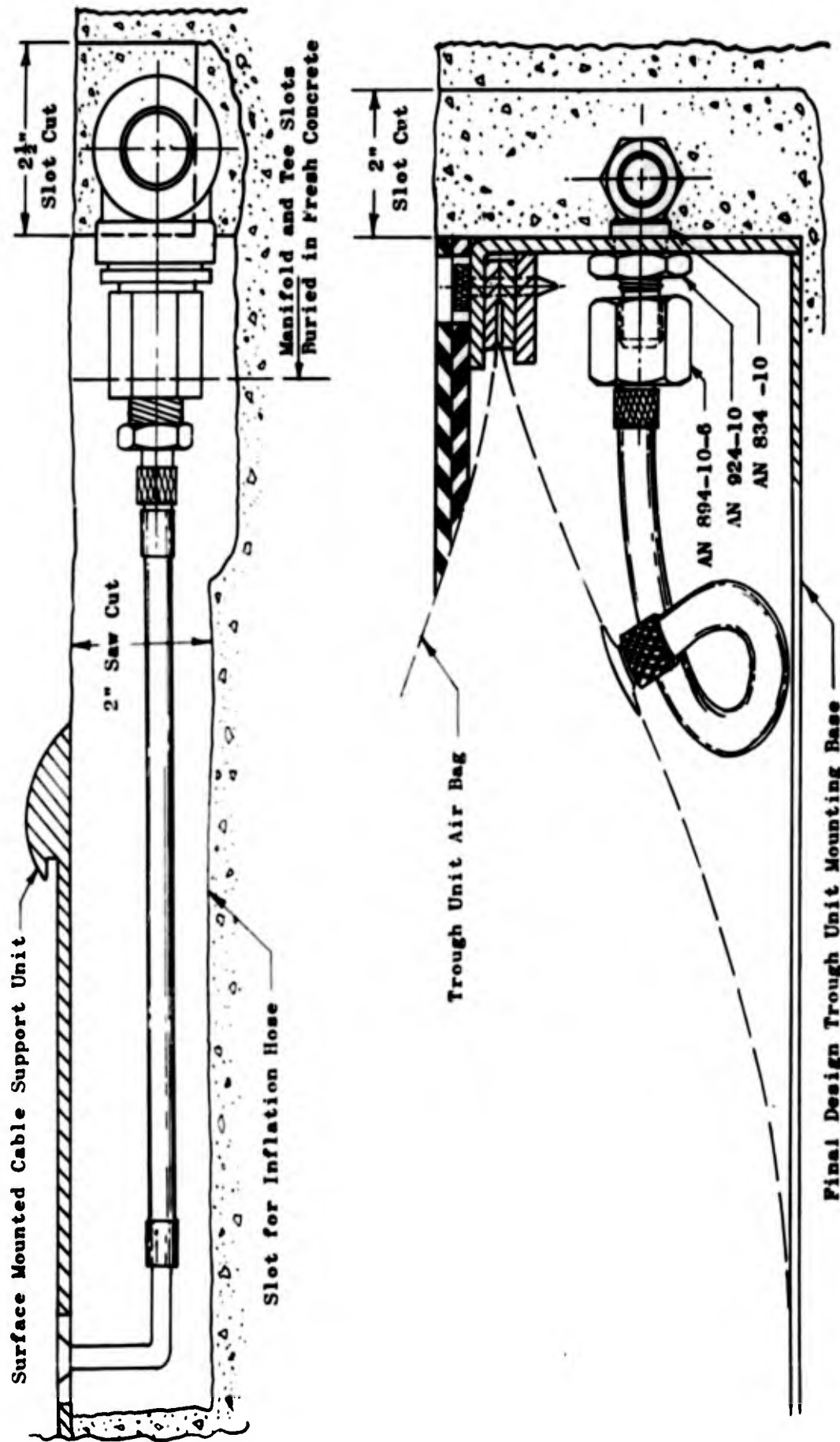


FIGURE 40: IMPROVED INSTALLATION OF MOUNTING BASE

- (1) Pilot Operated Check Valve
- (2) Check Valve
- (3) Vacuum Pump
- (4) Solenoid Valve
- (5) Pressure Regulator
- (6) Relief Valve
- (7) Filter
- (8) Pressure Switch
- (9) Variable Orifice
- (10) Supply Pressure (for repeat cycles)
- (11) Manual Valve

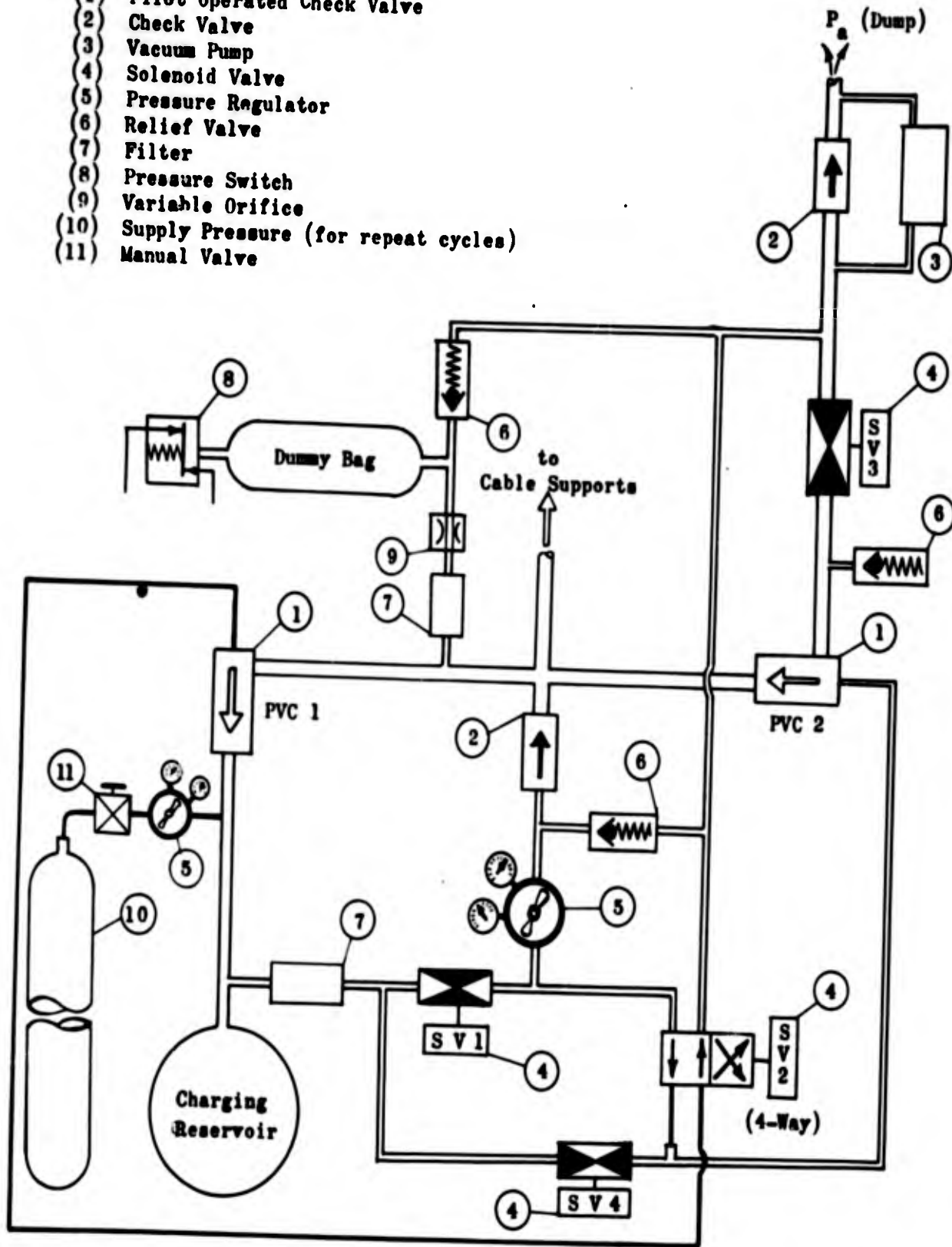


FIGURE 41: AIR SUPPLY CONTROL SYSTEM (SCHEMATIC) - FINAL DESIGN

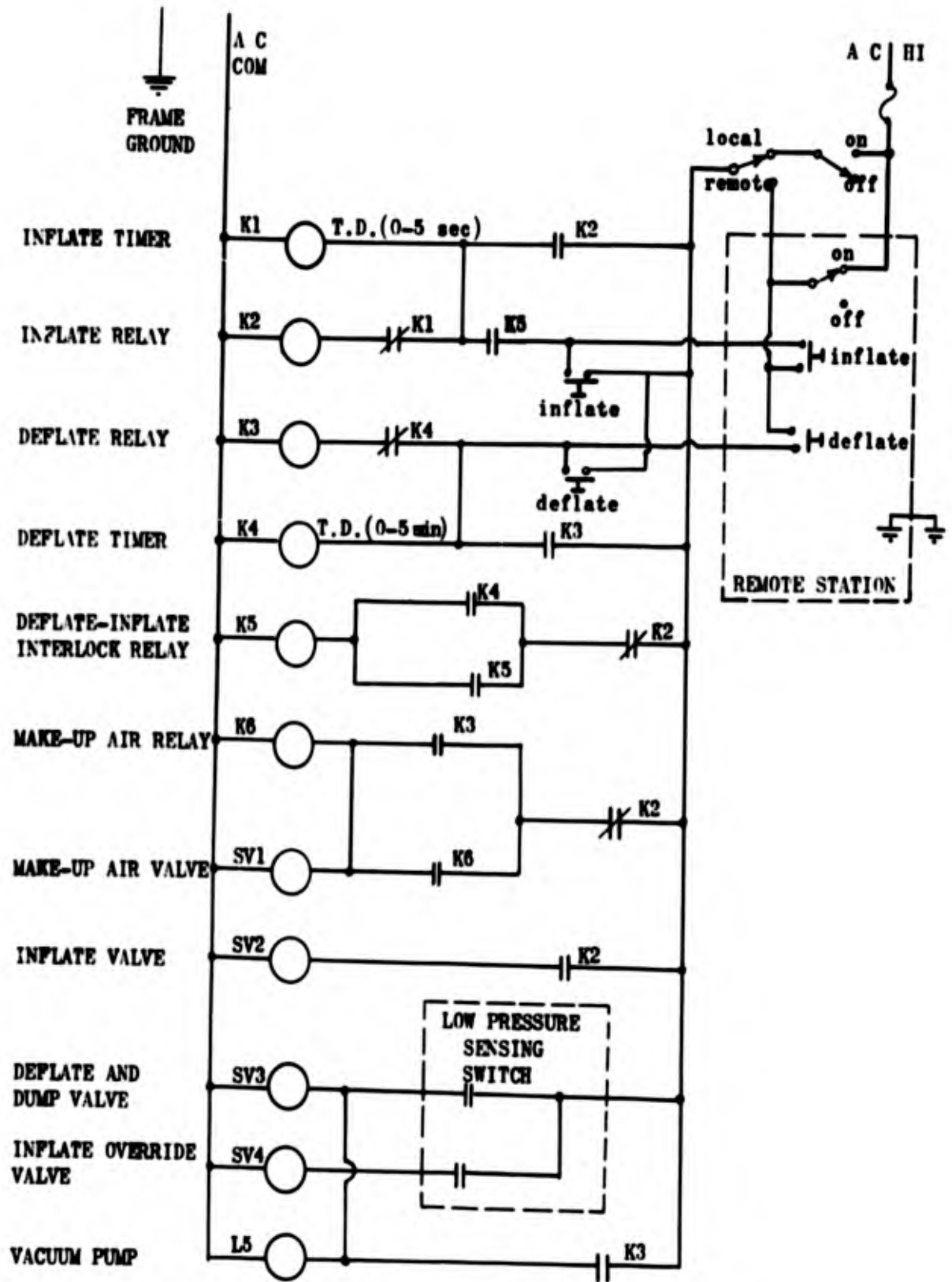


FIGURE 42: AIR SUPPLY ELECTRICAL SYSTEM (SCHEMATIC) FINAL DESIGN

TABLE I
COMPARATIVE PROPERTIES OF RUBBER COMPOUNDS

Temperature Range ° F	Neoprene		Natural Rubber	Hypalon	Buna S	Butyl	Buna N	Urethane
	Minimum	Maximum						
Elongation - % (Comp. Stock)	-60	+250	-60	+350	-60	-50	0	-80
Tensile Strength psi	500-600	3000+	550-650	N.A.	500-600	650-850	450-650	540-750
Adhesion to Fabrics	3000+	3000+	3000+	2500+	1000-	1500+	1000-	4000+
Tear Resistance	Excellent	Good	Excellent	Good	Good	Good	Good	Excellent
Abrasion Resistance	Excellent	Excellent	Excellent	Excellent	Good-Excel	Good	Good	Outstand.
	Excellent	Excellent	Excellent	Good	Good	Poor	Good	(a)
Rebound	Excellent	Excellent	Excellent	Good	Good	Excellent	Good	(b)
	Low	Fair	Fair	Low-Verylow	Fair	Very Low	Fair	Fair
Solvent Resistance to:	Permeability to Gases	Fair	Poor	Fair	Poor	Poor	Good	Fair-Good
	Aromatic Hydrocarbons	Poor	Good	Poor	Good	Good	Poor	Poor
	Ketones, etc.	Poor	Poor	Poor	Poor	Poor	Fair	Poor
	Lacquer Solvents	Good	Good	Good-Excel	Good	Poor	Excellent	Excellent
	Swelling in Oil	Good	Good	Good	Good	Poor	Excellent	Excellent
	Oil and Gasoline	Good	Good	Excellent	Excellent	Good-Excel	Very Good	(c)
	Water Absorption	Excellent	Good	Good	Good	Excellent	Good	Excellent
	Oxidation	Excellent	Fair	Fair	Outstand.	Fair	Excellent	Outstand.
	Ozone	Excellent	Poor	Poor	Outstand.	Poor	Excellent	Good
	Sunlight Aging	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Good
	Heat Aging	Good	Poor	Poor	Good	Poor	Excellent	Good
	Flame	Good	Poor	Poor	Good	Poor	Poor	Fair

(a) Poor at low temperature

(b) Poor at 212° F

(c) Good at room temperature but Poor at 212° F

TABLE II
EDWARDS AFB TEST DATA - PRELIMINARY DESIGN AIR BAGS











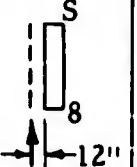

Test No.	A/C	Roll-Over Wheel	Velocity knots	Roll-Over Position	Plain or Ribs	Comments
1	F101	Main	82		P	No roll-over damage. Cable retrieved up and over bag easily without any damage or visible abrasion. <u>No</u> cable on bags.
2	F101	Main	100		P	Direct hit with no damage. <u>No</u> cable on bags.
3	F101	Nose	140		R	Bag burst and blew out at downstream end. Appeared that glue line had let go. Cover blown completely. Unit stayed in frame but downstream pylon let go. <u>No</u> cable on bags.
4	F84G	Main	80		P	Cover blew out on left side only. Bag remained inflated, undamaged. Engagement not attempted.
5	F84G	Main	105		P	No damage. Engagement not attempted.
6	F84G	Main	120		P	Cable pinch cut bag and cover causing side blowout. Engagement not attempted.
7	F84G	Main	90		P	Cable pinch cut hole in cover only. Bag undamaged. Engagement not attempted.
8	F84G	Main	80		P	Braking test on bag. Pilot reported brakes were on. Unit stayed in mounting base. Engagement not attempted. No bag damage.

TABLE II - continued

EDWARDS AFB TEST DATA - PRELIMINARY DESIGN AIR BAG UNITS

Test No.	A/c	Roll-Over Wheel	Velocity knots	Roll-Over * Position	Plain or Ribs	Comments
9	F101	Main	80		P	Purpose: Photograph hook stability and also hit bag. <u>No</u> cable on bags. No bag damage.
10	F101	Main	140		P	Hook qualification. Engagement attempted but missed. Unit burst at downstream corners.
11	F102	Main	40		-	Successful engagement. No bag damage. One bag painted white, reduced its surface temperature approx. 15° - 20° F.
12	F102	Main	60	same as above	-	Good engagement, no bag damage,
13	F102	Main	80	same as above	-	Good engagement. Power failure accident. Re-inflated bags just before test and burst 2 units. Both replaced quickly for test.
14	F102	Main	110		R	Missed engagement due to premature release of cable shear pin. Covers on 3 bag units split open, due to cable transverse rub or heat aging.

* Code:

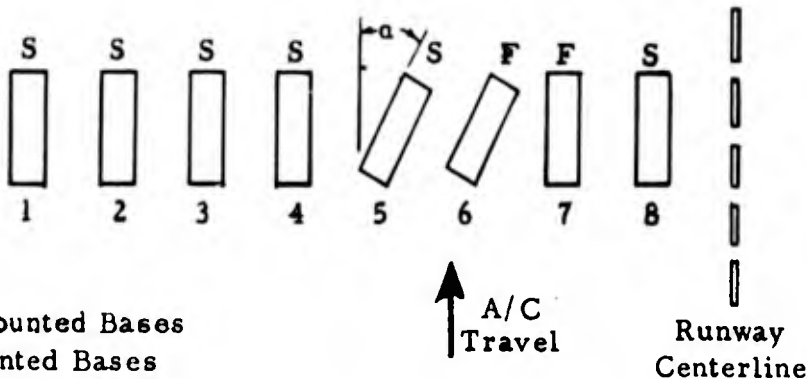


TABLE III

EDWARDS AFB TEST DATA - TROUGH TYPE AIR BAG UNITS

Test No.	Roll-Over Wheel	Velocity knots	Roll-* Over Position	Bag Material lbs/in.	Comments
1	Nose	84	A	450	No damage to bag or rubber cover plates. No pinching.
2	Nose	122	B	1000	No damage noted.
3	Main	80	B	450	No damage noted.
4	Main	100	C	450	No damage noted.
5	Main	120	A	450	Bag cut by cable pinch. 1-inch vertical slit by 5-inch horizontal tear in bag just under cable. Slit cover cut 3/4 inch by cable slam. Unexplained hole forced into pinch pad.
6	Main	120	A	450	No damage. This bag hit when other was missed during Run 8.
7	Main	120	C	1000	Very small leak heard, but bag left in service.
8	Main	120	C	1000	No damage noted.
9 thru 60					The inflatable supports were left in service during these additional Navy tests. They were mounted 15.5 and 29.0 feet off center and functioned very well with no missed engagements or damage to the supports.

* See Figure 37 for explanation of rollover positions.

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