

"DUAL WALL INFLATABLE STRUCTURES FOR SPACE ORIENTED APPLICATIONS"

Herbert Q. Bair, Chief Engineer
Air Inflatable Products Corporation, East Haven, Connecticut

and

William H. Fischer, Technical Director
Air Inflatable Products Corporation, East Haven, Connecticut

(For presentation at the Second Aerospace Expandable
Structures Conference, Minneapolis, Minnesota, May 1965.)

INTRODUCTION

The problem of protecting high frequency radar antennas without degrading transmission or adding weight has led to the development of the wing tab technique. Dual-wall air-supported structures using the wing tab technique were pioneered and developed by Air Inflatable Products Corporation, a subsidiary of the National Union Electric Corporation. In wing tab construction, the attachment flange for the web is an integrally-woven portion of the skin material, thus stress concentrations are virtually eliminated. The ratio of the web width to web spacing has been established for equal loads in all members and may be varied to obtain specific characteristics in special applications.

The wing tab is especially applicable in structures, such as radomes, where the unit must be more stable, lighter weight, more versatile, and have less transmission interference than a single-skin unit. Such a unit is virtually self-erecting and may even be employed to erect the equipment being housed. In addition, individual sections of such a unit may be deflated and lowered, or raised, to permit easy movement of large equipment into or out of the area. Wing tab construction is currently being utilized on Contract No. DA-39-AMC-03744(s) for the Hughes Aircraft Company ComSat Satellite Radomes.

The geometry of wing tab structures may be readily varied and easily contoured in three planes at the same time. Since the materials are light and flexible, the structures are easily packaged and shipped. For example, a radome designed to withstand winds to 110 mph, 38' in diameter by 40' high, with an inside volume of 36,000 cubic feet, weighs less than 1800# and can be packed into less than 120 cubic feet. This radome also provides excellent insulation since it is essentially a rigid dead-air space thirty inches thick.

The ease with which a single radome panel is self-erecting is shown in Figure number 1. This multiple exposure shows the erection of a panel using only air pressure in the wall with no additional assistance.

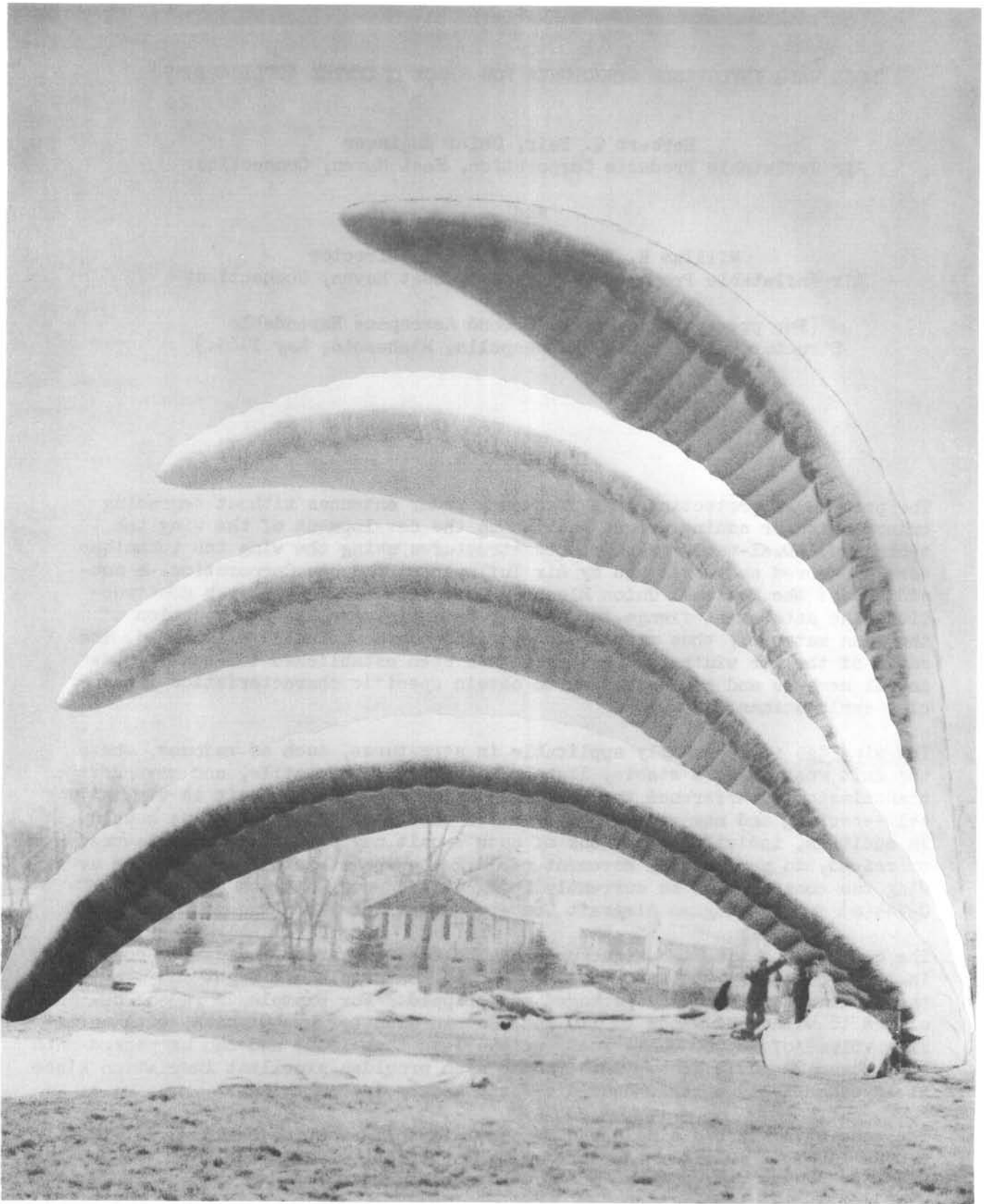


Figure 1

Contrails

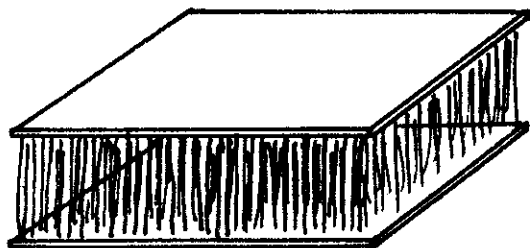
Currently, the materials used in wing tab structures range from the commonly-employed chloroprene-coated nylons and dacron to Kynar-coated fracture-resistant fiberglass, including metallized fibers for RF shielding. The horizontal web construction discussed here also lends itself to rigidization since, after erection, the unit is somewhat compartmentalized and therefore helps distribute any rigidizing material.

Potential uses for this type of structure include: radomes for satellite tracking stations; environmental control areas; housing or operations shelters; moon or planetary shelters; orbital repair or maintenance structures; etc. The unique features and advantages of dual-wall structures have been proven - - - opening new areas of operation to inflatable structures.

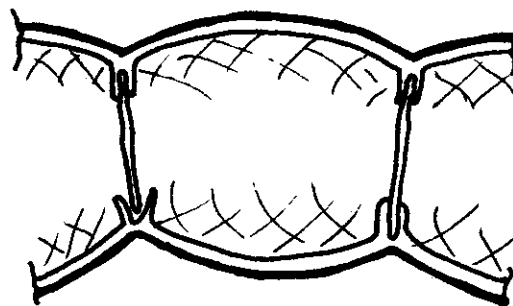
DUAL WALL CONCEPTS

The two main dual wall constructions are pile fabric and "Wing tab" or I-Beam ribs. Pile fabric, called "Airmat" by Goodyear and "Rigidair" by Air Inflatable Products Corporation, is basically a drop stitch fabric with threads tying two parallel faces together. The thread lengths are controlled to maintain a predetermined distance between the two plies of fabric. Wing tab fabric incorporates attachment flanges for the web as integrally-woven portions of the skin material. Two skins of this material, spaced by webs attached to the attachment flanges, form a dual-wall structure which provides adequate protection using a minimum of materials that interfere with the radar transmission. In general, wing tab fabric looks like a large air mattress with I-Beam webs holding the two surfaces parallel, but wing tab construction distributes the stress evenly. There is no possibility of stress concentrations by I-Beams or cross members.

Wing tab construction allows shaping of the structure into compound curves, such as spheres. The webs are contoured to provide the desired contour in their plane; varying the web spacing between the two surfaces provides the contouring in that plane.



RIGIDAIR



WING TAB

Figure 2

Contrails

Since Goodyear is currently doing a great deal of development work on pile fabric, this presentation will be restricted to "Wing tab" construction. Wing tab utilizes an outer and inner skin of air-tight fabric with these skins held in position relative to each other by webs. The webs need not be air-tight since they only space the skins relative to each other and are not an air barrier. The webs can be either horizontal or vertical depending upon the structure configuration and operational requirements.

In radomes, the webs are usually horizontal for self erection, lifting capacity (to help erect the radar), and easy access (large sections of the wall open, permitting movement of large equipment into or out of the area). A dual wall radome (which is sectionalized into a number of easily transportable and handled components) can operate with alternate sections inflated, thus permitting a deflated portion to be raised as a large access opening for the removal or addition of equipment. In an eight section radome, it is possible to raise as many as three adjacent panels at one time for accessibility to the interior with the structure still remaining stable.

On the current contract for radomes, the inside dimensions are 60 feet in diameter by 54 feet high. The sections of these radomes are fastened together by a series of catenary panels along the walls and are under considerable compression when fastened together. This prevents any movement between sections as long as the operating pressure is maintained above six inches of water (up to a 100 knot wind). A static coefficient of friction of 1.3 between the surfaces has been attained and a compression of five inches for each face of the unit is used. This provides for a better than 26 inch flat contact between the panels. Thus the radome is one unit and may be treated as such relative to its resistance to torque and other extraneous loadings. A photograph of this assembly is included as Figure No. 3 for reference.

Previous tests indicate that the base angle of the radome should be at least 52° for stability without raising the pressure over that of the velocity pressure of the wind; this rule has been followed on the radome for the ComSat network, for example. The guy lines are only protection against excessive deflection, as opposed to actual support to fasten the radome to the ground. The radome will withstand 100 knot winds, 20#/ft.² snow load, 3" per hour rainfall and one-inch rime ice load. The guy cables are designed to withstand a 57 knot wind each while carrying the entire wind load against the structure. This provides for a more than adequate safety factor, since no one guy wire should be carrying the wind load independently.

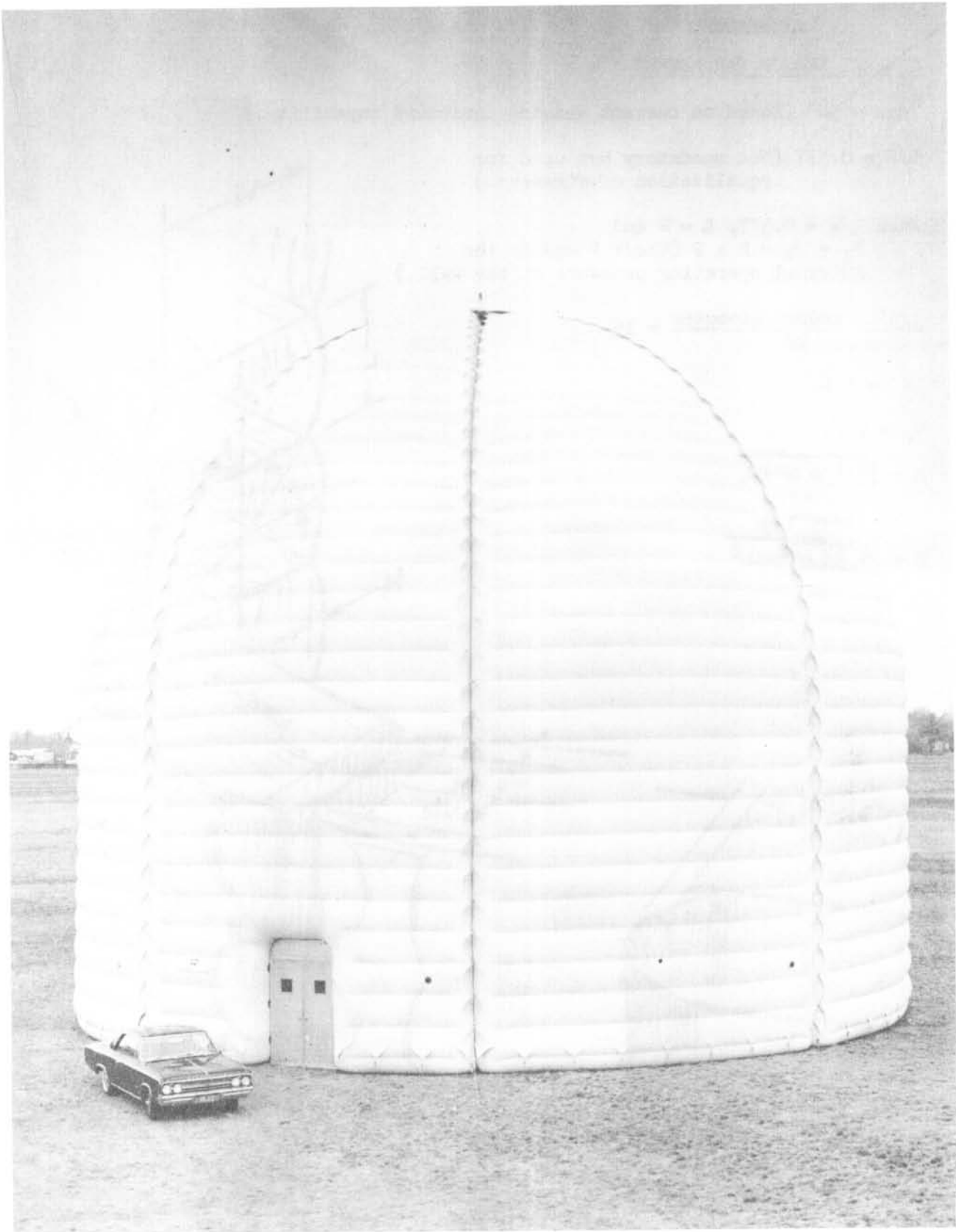


Figure 3

789

Contrails

GENERAL DESIGN PARAMETERS

$A_{\text{max}} = 58''$ (Based on current weaving equipment capability.)

$L/W = 0.577$ (Not mandatory but used for equalization of stresses.)

When $L/W = 0.577$, $L = R$ and
 $F_1 = F_2 = R \times P$ (Where P equals the internal operating pressure of the wall.)

Inside radome diameter = 15
 W

$L/C = 5.4$

$W_C = 2.273 C$

$R = \sqrt{(L^2 + W^2)}/4$

$A = 0.0349 R \phi$

$H = R - \frac{1}{2} \sqrt{4R^2 - L^2}$

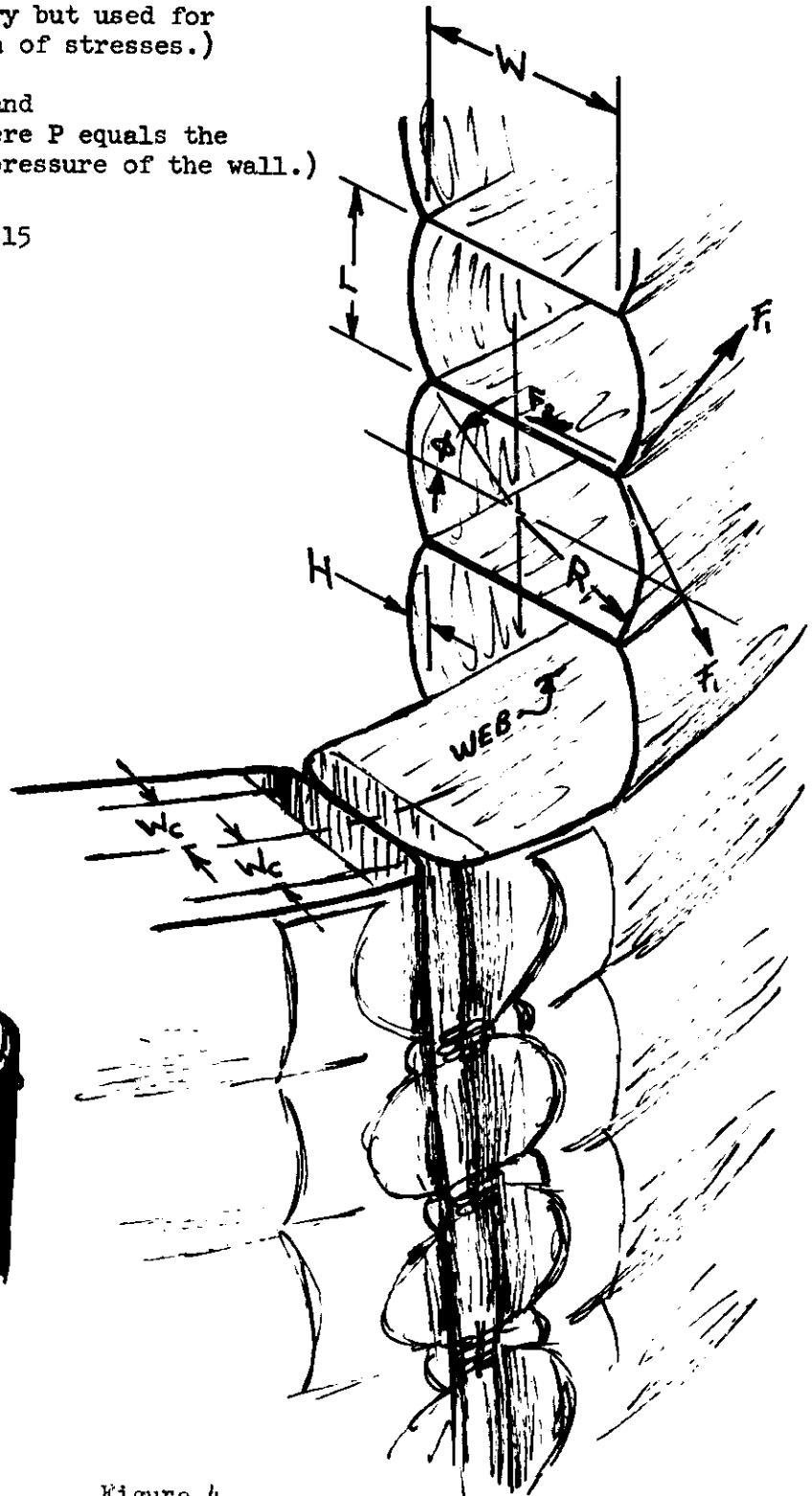
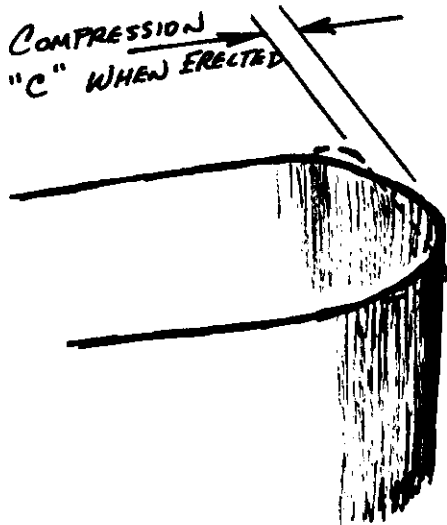


Figure 4

790

Contrails

STRESS ANALYSES

As shown in Figure No. 4, the stresses involved in the wing tab and the outer skin are equal when L equals R. The stress in the fabric is then equivalent to the internal pressure in pounds per square inch times R or L as the case may be. To prevent deformation by wind loads the minimum operating pressure of the radome is as follows: $P = .00037V^2$ where P is pressure in pounds per square inch and V is the wind velocity in knots per hour.

Analysis of the load-lifting or load-carrying capabilities of the dual wall radome was conducted and confirmed by testing the initial unit. The equation evolved seems to omit radome size and wall thickness, but these are proportional and have been taken into account. The final equation is $D = .16\sqrt{W/P}$ where D is the diameter required to support the given load, W equals the load in pounds, and P equals the internal pressure of the unit in PSIG. This is based (see Fig. 5) on the premise that the load is lifted from a distance at least D over two below the point where the load is to be lifted, the maximum allowable deflection of the crown is one foot, and $R/W = 7.5$.

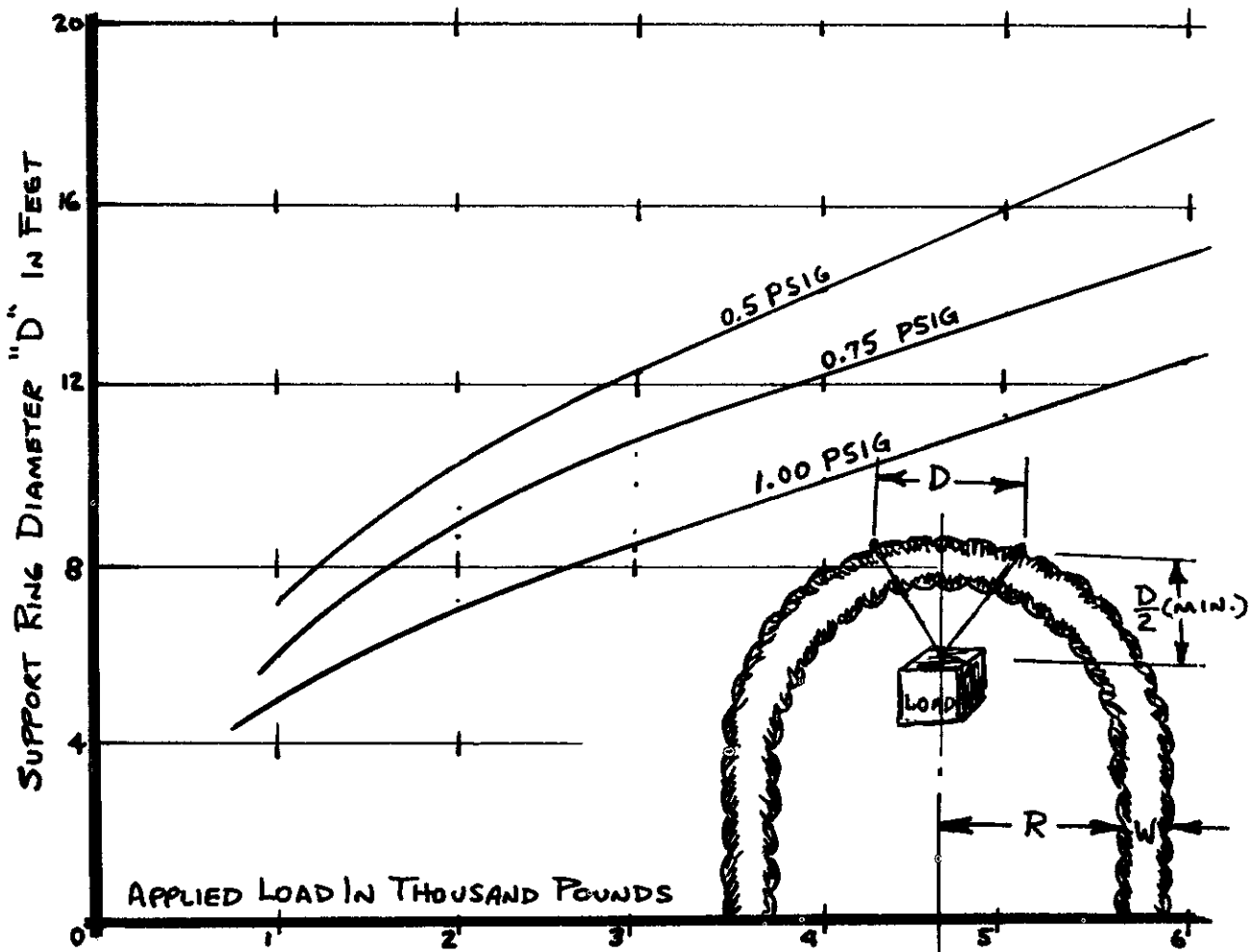


Figure 5

Contrails

The maximum load lifting capability equals the projected horizontal area of the inflatable wall section at the largest diameter times the internal pressure. Of course the load-lifting capability at this point includes the weight of the radome itself. There could conceivably be some localized buckling of tubes in the areas to which the bridle is fastened (assuming it did not contain a continuous rigid ring) but, for the equation given, the shelter would support this load without collapsing or lowering the load. The radome for the Hughes Aircraft Company's ComSat system requires a lifting capability of approximately 2,000 pounds. In this unit there is a seven foot crown ring installed which can readily lift the required load at normal operating pressure.

Other applications have specified load lifting capabilities in the 5,000 to 6,000 pound range. For this, diameter D is extended to provide the required support.

The calculations for the operating pressure of dual wall radomes can be roughly simplified to $0.5 \times$ inside radome diameter \times pressure head caused by wind velocity equals fabric stress in #/inch. For single skin radomes this same type of analysis can be reduced to $3.32 \times$ (wind pressure head plus 0.5) \times radome diameter equals fabric stress in #/inch. These two equations are graphed in Fig. 6. The ratio of fabric stresses for the above equations is in the order of 1 to 7 depending on the wind velocity. Since the wind pressure is exponential with velocity, the ratio of the stresses for the radomes are also exponential relative to the maximum wind speed designed for.

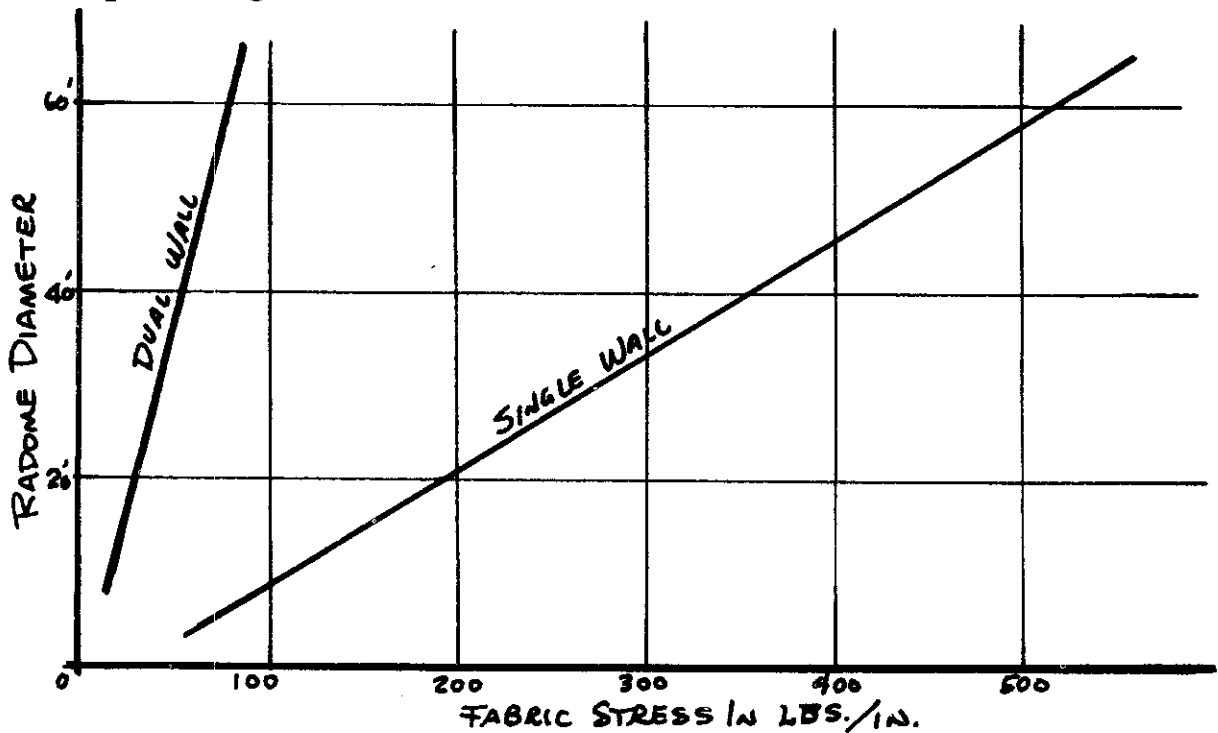


Figure 6

Contrails

Advantages of dual wall over single wall include: the dual wall shelter can be easily reduced to small light-weight packages for easy handling and shipping; they provide for accessibility to the interior without airlocks; sections are readily replaceable and may be added for increased floor space; individual sections may be depressurized for repair and/or modification without putting the unit out of service; lighter weight fabrics can be utilized, thereby reducing total weight of the assembly; the unit is more versatile, since load-lifting bridles can be readily installed to lift virtually any load.

ELECTRICAL PROPERTIES

The electrical properties of dual wall radomes are very similar to single wall radomes in regard to the theoretical equations utilized to evaluate these properties. The equations are linearly related and are directly proportional to the number of plies of material utilized, the variations in the thickness of the material, the thickness of the fabric plies and the dielectric constant of the fabric. The equations are inversely proportional with the wavelength of the radar and the radius of the radar antenna.

Since the equations are virtually identical for single or dual wall assemblies, the only variables are fabric thickness, variations of fabric thickness, number of plies of material seen by the antenna, and the dielectric constant of the material.

A dual wall panel's webs introduce overall variation (thus producing a non-uniform wall for the antenna) therefore it appears that the single wall radome would give less boresight error. If extreme boresight accuracy is necessary, a single wall structure (assuming all other properties are equivalent) should be more accurate. But, boresight errors can be held to ± 0.10 milliradians with dual wall structures.

Pile fabric, from the tests performed on specimens of the fabric, exhibits excellent electrical properties due its uniformity. In essence, the pile is evenly distributed, as opposed to periodically spaced webs, therefore it gives more uniform transmission. Since the equations for boresight shift depend on thickness variations, this could be considerably reduced by using pile fabric but this could possibly cause related problems in regard to weight, packaging, and operating pressures. The above analysis was confirmed by tests on actual fabric specimens.

MATERIALS ANALYSIS

To provide a guaranteed life of at least seven trouble-free years, neoprene-coated dacron is used on the ComSat radome. Since dual wall structures use lighter fabric and need less elastomeric coating than a single skin structure for the same protection, a finer weave fabric and less elastomer may be used. This reduces the dielectric constant by 6.65%. Above a certain structure size, the coated fabric used for dual wall structures is less than half

Contrails

as thick as for an equivalent single-skin unit. This then provides for better RF characteristics. Using the design ratio for the dual wall radomes, (the radome inside diameter divided by the wall-tube thickness equals 15) the dual wall radome theoretically provides identical protection with only 1/15 the fabric strength required of an equivalent single skin radome. Considering the stresses applied during erection and handling operations, this ratio is reduced to approximately 4 to 1. Currently, a dual wall radome which operates at a pressure of 1.48 PSIG requires a fabric strength of 160#/in. tensile which, coated, would not exceed .020" in thickness; a similar single skin radome would require fabric of 768#/in. tensile which would gauge .055". Approximately 20% less material is exposed to the radar antenna, even including the webs.

An advantage of dual wall radomes over single wall radomes is that wing tab dual wall fabrics have a standard carcass and coating on the exterior of the structure surface. This does not increase proportionally to the required strength, therefore a point is reached where the two plies of dual wall material are lighter in gauge thus exhibiting superior electrical properties to its single wall counterpart.

Figure No. 7 gives an indication of radome size to electrical properties by depicting the difference in the curve slopes of size to overall material gauge.

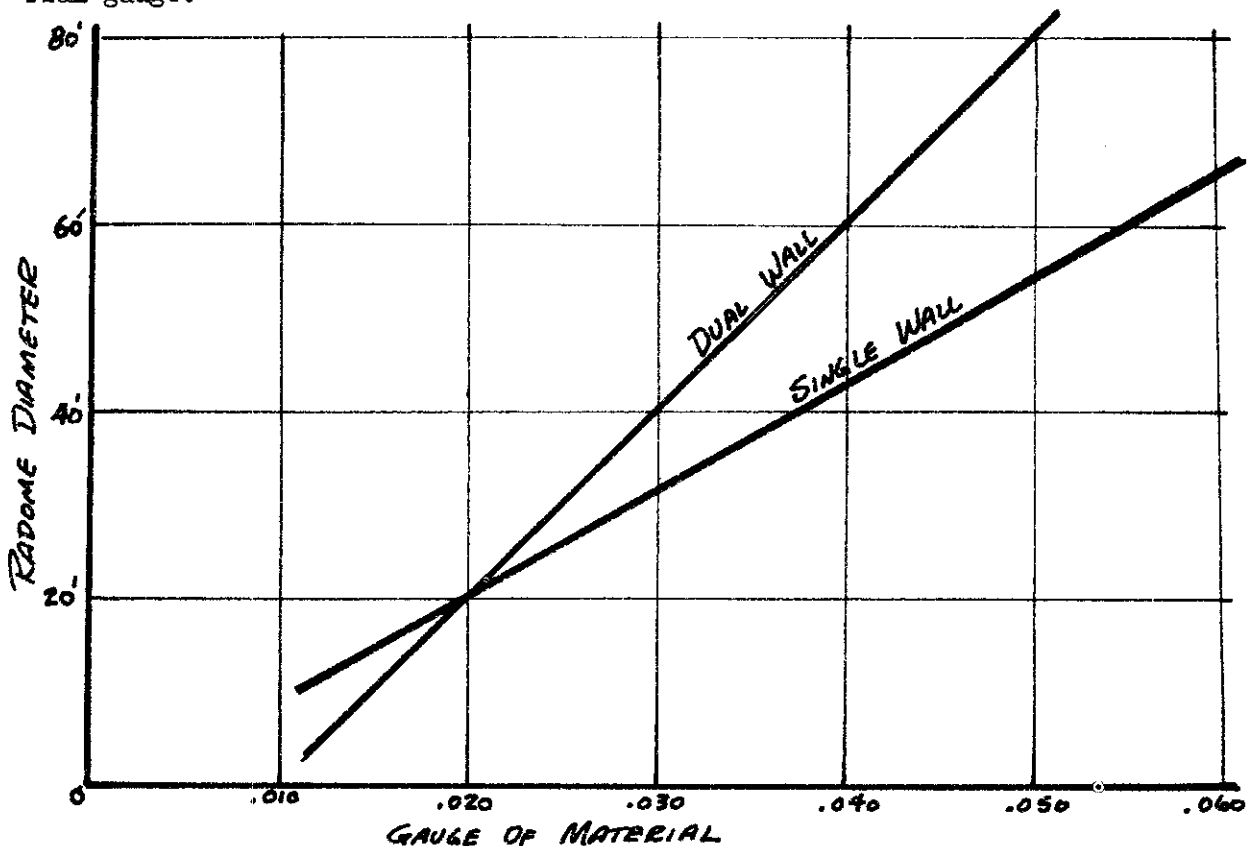


Figure 7

Contrails

Dacron is chosen over Nylon due to its superior sunlight and UV resistance, excellent chemical resistance and higher melting temperatures. Neoprene is still the best all-purpose elastomer combining resistance to ozone, sunlight, oxidation and many petroleum derivatives; further, it has good resilience and tensile strength. A hypalon paint gives the surface color-stability, as well as weather and abrasion resistance.

The webs used for the ComSat radome are not coated with elastomer providing minimum material thickness for maximum transmissibility and minimum electrical interference. Similarly, seams in the webs have been sewn rather than cemented. The webs are bonded onto the integral wing tab as a final operation. Further, to maintain uniformity in the contours and stresses, the webs are segmented to keep fabric fill threads within three degrees of the direction of the concentrated load application.

Experiments are currently being conducted to evaluate the possibility of using fracture-resistant fiberglass in higher temperature applications for longer life and better resistance to environmental hazards, including ultraviolet radiation. The Cordo Division of Ferro Corporation has been coating the glass filaments with vinyl (prior to weaving) for built-in chafing protection for the fibers. Work is also being conducted on laminating kynar film to the coated glass to provide maximum transparency (Ultraviolet light) with lightest weight. This technique is also under development with dacron.

Cordoglas-FR can take abuse and rough treatment since coating adhesion is mechanical rather than by adhesive primers that could break down during long term exposure. This material resists sunlight, weather, acids, mildew, and chemicals. It is also non-stretching and non-shrinking. Due to these characteristics and the use of glass fabric, seam wrinkles and puckers are virtually non-existent.

Tests show no degradation in breaking strength, even after two years outdoor aging. The heat-sealed adhesion and the tear strength degraded less than 5% for the same period. These materials are available in translucent and opaque colors with no sacrifice in UV degradation. The fabric is dimensionally stable with a minimum adhesion loss between the vinyl coating and the woven fiberglass substrate. At higher temperatures, silicone is used. With special compounding it has been used at over 1000 degrees Fahrenheit. The fabric substrate would then be fiberglass or metallic fibers depending on the operational requirements.

HEAT TRANSFER TESTS ON DUAL WALL RADOME OR WING TAB CONSTRUCTION

Wing tab panels have been tested to evaluate their thermal transmittance and to develop their "U" Factor. The tests were conducted on a panel three feet in thickness with the following result: the "U" factor is 0.41 BTU/hour/sq. ft./degree fahrenheit.

Contrails

RF shielding tests conducted by York Research Corporation on specimens in which the fibers were plated with first copper then nickel, indicated a shielding effectiveness ranging from 80 db at .02 Mc to 50 db at 10,000 Mc, including a low point of 26 db at 15 Mc. These tests were conducted on specimens that were first metallized, then coated with neoprene.

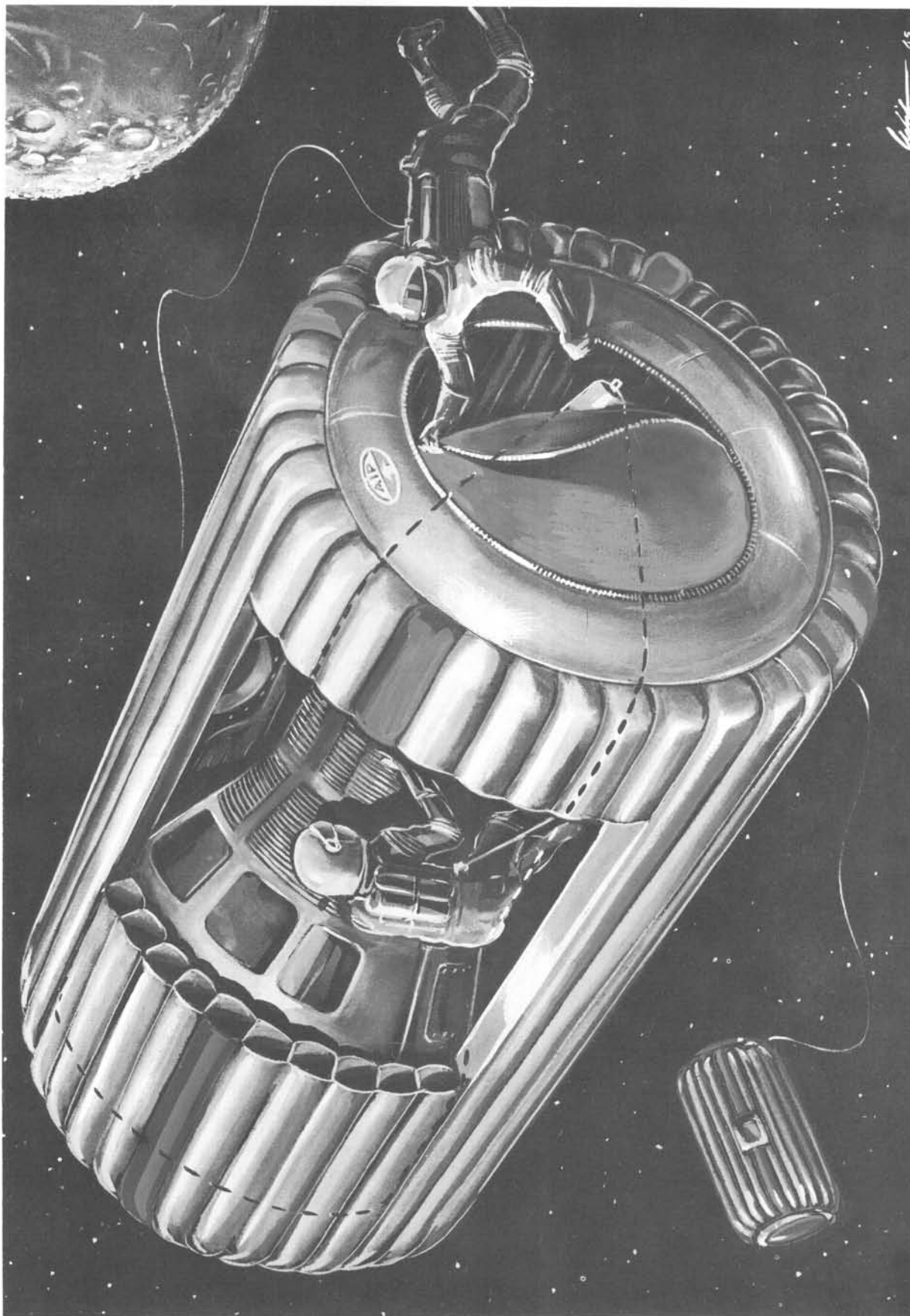
DESIGN CONCEPTS

A few applications of dual wall construction are as shown in the following six sketches with their description included on their respective pages. Dual wall structures (with possible rigidization included) are readily adaptable as emergency "repair garages" for orbiting space capsules or satellites. A pressure-sealing zippered end could be included for rapid entry with minimum effort and time.

Another possible application of the wing tab dual wall structures is as an impact attenuator or support pad. The Impact Cushion Concept is currently being evaluated for sports activities such as a pole vaulters landing mat to replace the chopped or shredded sponge port-a-pit. Such a pad provides a much easier and improved landing, as the jumper cannot snag in a net or otherwise entangle himself.

A light-weight mat could be utilized for such things as landings on the moon, where it would spread out and distribute the load over an extended area (to overcome a possible dust layer or soft surface which would not support the concentrated load) thus providing, not only a support platform, but a work area adjacent to the craft.

Dual wall wing tab could also be utilized in shelters for environment control, portable laboratories, greenhouses, and specialized applications such as RF shielded shelters. Potential uses are limited only by your own imagination.

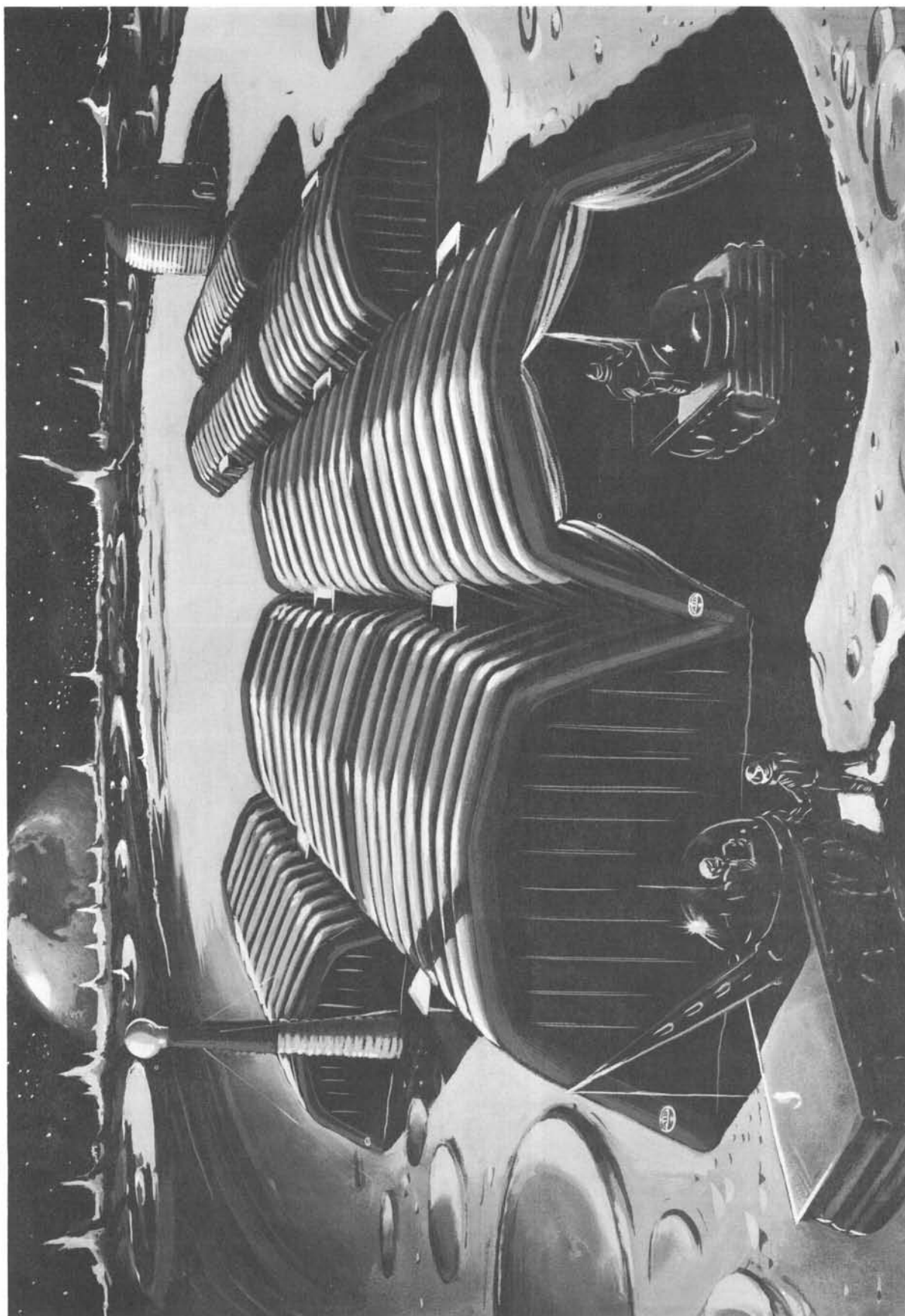


DUAL WALL STRUCTURES ARE ESPECIALLY SUITED TO USE IN OUTER SPACE BECAUSE THEY NEED LITTLE AIR TO INFLATE THEM COMPARED TO THE SINGLE SKIN STRUCTURES. THE DUAL WALL STRUCTURES ARE ALSO SUITED TO RIGIDIZATION IN SPACE SINCE THE BASIC DESIGN PROVIDES EXCELLENT GUIDES FOR DISTRIBUTING RIGIDIZERS.

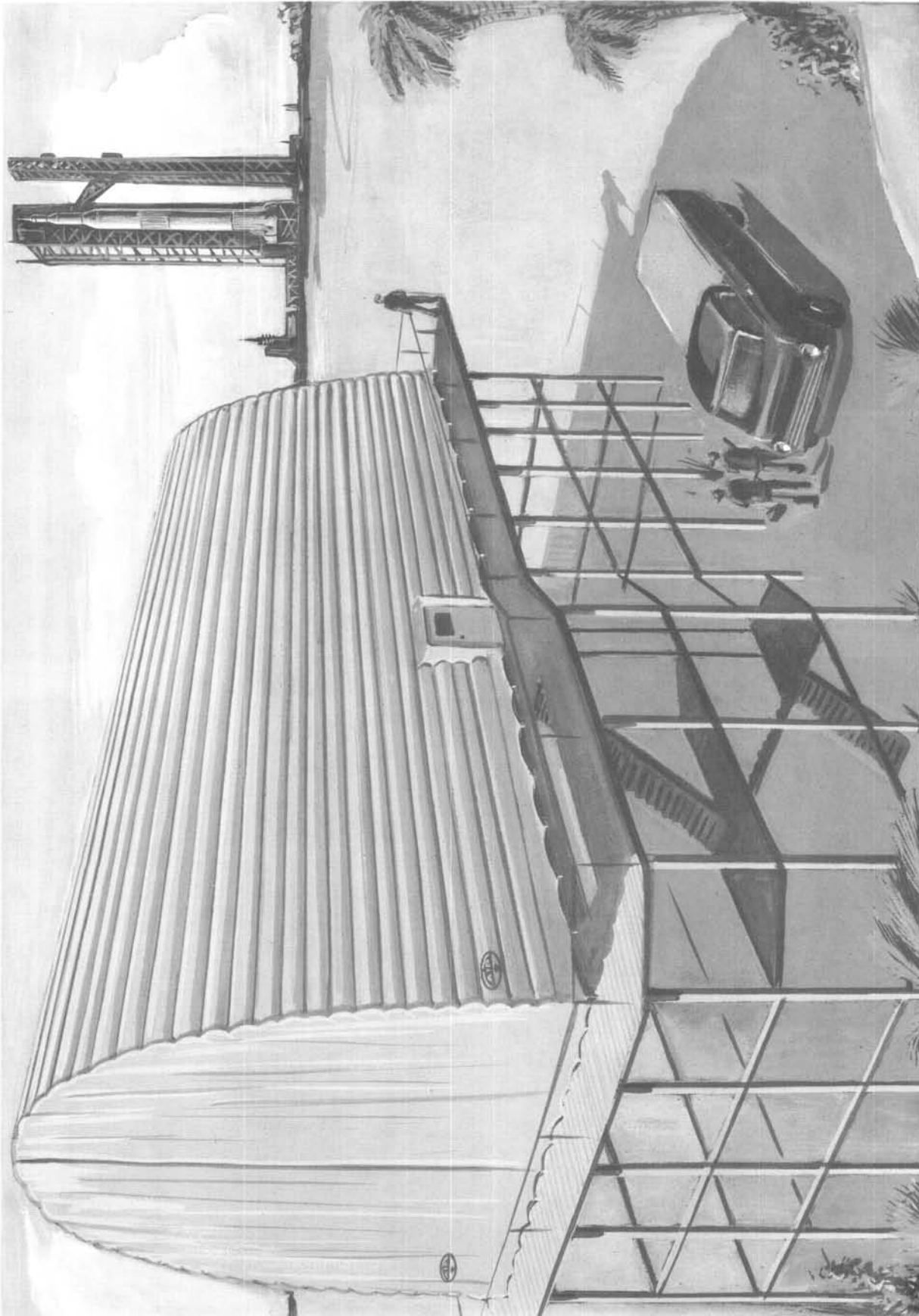
Contrails



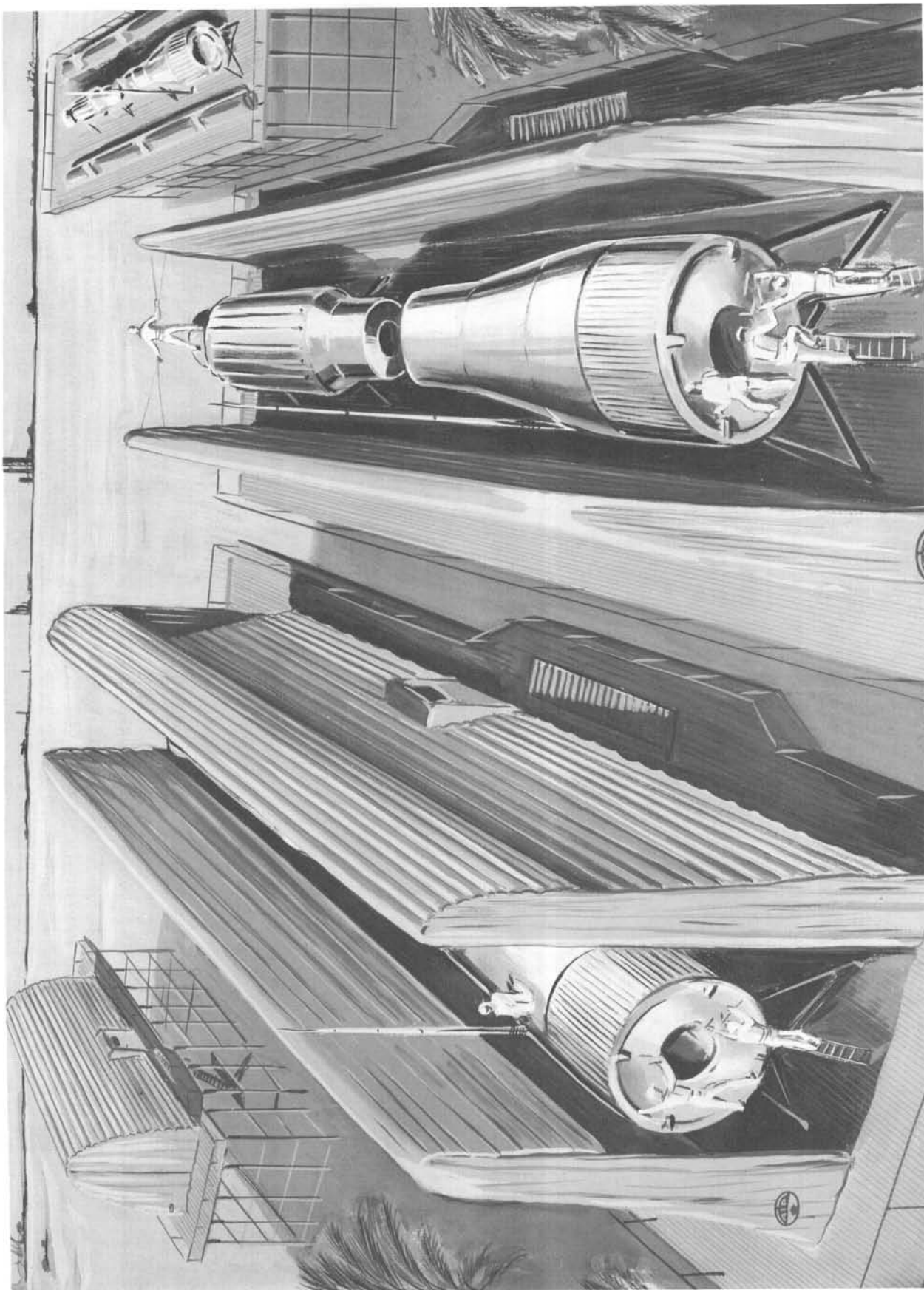
THE SHELTERS CAN BE CONSTRUCTED WITH VERTICAL OR HORIZONTAL WEBS, DEPENDING ON THE CHARACTERISTICS WANTED WITH HORIZONTAL WEBS SHOWN HERE. THE INSULATIVE QUALITIES OF THIS TYPE OF UNIT ARE FAR SUPERIOR TO MOST OTHERS MAKING IT SUITABLE FOR EITHER THE ARCTIC OR THE TROPICS.



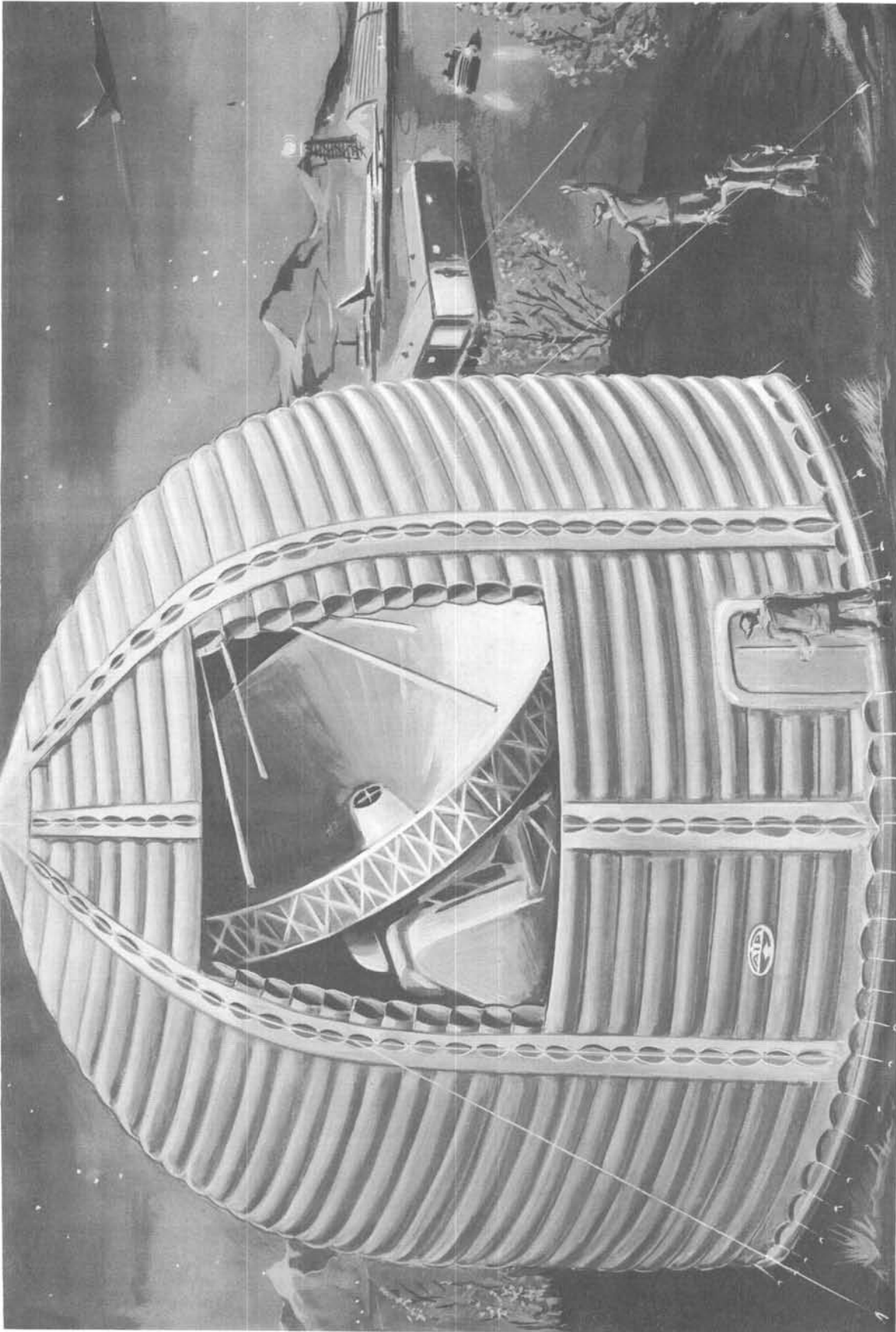
A CLUSTER OF UNIVERSAL SHELTERS POSSIBLY FOR USE IN SPACE OR ON THE MOON. THESE UNITS ARE INTERCHANGEABLE, CAN READILY BE DISCONNECTED AND USED AS INDIVIDUAL SHELTERS OR CAN BE JOINED TO FORM A LARGE COMPLEX. FOR OUTER SPACE WORK AN AIRTIGHT GROUND COVER AND INTERIOR PRESSURE, AS WELL AS THE PRESSURE TO SUPPORT THE STRUCTURE, ARE REQUIRED.



A TEST SHELTER FOR GROUND EXPERIMENTS AND PREFLIGHT TESTS, WHICH ALLOWS THE PROGRAM TO PROCEED DESPITE THE WEATHER. THE SHELTER IS ERECTED OR REMOVED WITHOUT ADDITIONAL EQUIPMENT. SPECIFICATIONS REQUIRE THAT THE UNIT MUST NOT COLLAPSE DURING REMOVAL OF THE SHELTER (REMOVAL IS EFFECTED WITHIN THIRTY MINUTES).



THE TEST SHELTER IN VARIOUS STAGES OF COLLAPSE IS PICTURED HERE. CONTROL OF THE AIR IN THE DUAL WALL ALLOWS DEFLATION BY COMPARTMENTS; THE SECTIONS ARE COLLAPSED OUT OF THE WAY WITHOUT DIFFICULTY.



THE RADOME UNDER CONSTRUCTION FOR THE COMSAT NETWORK IS DESIGNED FOR VERSATILITY, EASY-HANDLING AND RAPID ERECTION. THE COMPONENTS MAY BE ERECTED AROUND THE ASSEMBLED RADOME BUT IT IS EASIER TO ERECT THEM FIRST AND THEN ASSEMBLE THE RADAR INSIDE. THE EIGHT SECTIONS OR PANELS ARE SELF-ERECTING AND CAN BE DEFLATED AND RAISED TO ALLOW PASSAGE OF LARGE EQUIPMENT WITHOUT HINDERING THE OPERATION OF THE RADOME (ASSUMING THIS OPERATION TAKES PLACE WHILE THE WIND DOES NOT EXCEED 30 MPH).

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Aero Propulsion Laboratory in Cooperation with Archer Daniels Midland Company, Minneapolis, Minnesota		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE SECOND AEROSPACE EXPANDABLE STRUCTURES CONFERENCE			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
5. AUTHOR(S) (Last name, first name, initial)			
6. REPORT DATE February 1966		7a. TOTAL NO. OF PAGES 802	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S) AFAPL-TR-65-108	
b. PROJECT NO.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
c.			
d.			
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Air Force Aero Propulsion Laboratory Wright-Patterson Air Force Base, Ohio	
13. ABSTRACT This report contains a presentation of technical contributions summarizing the status of current, significant research in the field of expandable structures. The report is based upon the discussions at the Second Aerospace Expandable Structures Conference held 25-27 May 1965 at the Lafayette Club, Minnetonka Beach, Minnesota. The subject matter has been arranged in six sessions in the order of presentation at the conference, followed by six papers which were not given at the conference.			

DD FORM 1473
1 JAN 64

UNCLASSIFIED

Security Classification

Security Classification

14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	Expandable Materials Structures for Reentry Antennas Solar Collectors Space Stations						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

- 11. SUPPLEMENTARY NOTES:** Use for additional explanatory notes.
- 12. SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.
- 13. ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.