RECENT APPLICATIONS OF INFLATED STRUCTURES TO AEROSPACE VEHICLES

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Although expandable structures are generally considered for space applications primarily, because of their excellent packageability characteristics and the need for small volumes on the launch pad and large structural items once in space, there are quite a number of applications of expandable structures for aerospace vehicles which do function within the earth's atmosphere. In each of these instances the advantages of packageability, high structural integrity and low weight are paramount and result in a concept which is hard to match with a conventional rigid structure. In space, the prime object is often low weight without too great an emphasis on structural load. However, in most of the aerospace applications that operate on the earth's surface, high strength becomes of paramount importance. Developments in fabrics with high strength/weight ratios and good permeability characteristics are constantly opening new avenues for air inflated structures. The ability to utilize high strength materials in filament form - whether they be synthetic fibers, glass, metal or even the newly considered boron - makes work in this area a stepping stone toward even further improvements with normal development time. Advances in weaving technology, coating of fibers and special scuff resistant and abrasion resistant treatments, as well as finishes for protection from ultraviolet, all tend toward minimizing maintenance and increasing the life and reliability of such structures. This paper will deal with a few of the developments along these lines which have taken place recently and are now in use or being considered for current applications.

Ballutes

One of the most active applications of lightweight, high strength fabric material is the Ballute*, a combination balloon and parachute, which is a form of aerodynamic decelerator which provides stability and deceleration at a wide range of Mach numbers. The actual shape of a Ballute varies considerably depending on the specific application. Figure 1 shows three shapes that have been wind tunnel tested in order to determine their flight characteristics for future applications. These tests have been conducted by both the Air Force and NASA and the most promising ones are then evaluated in flight attached to a missile specifically designed for this purpose. The Air Force program on which this is done is known as ADDPEP (Aerodynamic Decelerator Development Performance Evaluation Program.)

From Figure 2 it can be seen that Ballutes are now available and have been tested over almost all speed ranges currently associated with earth atmosphere flights. These programs are continuing to extend the capability of the Ballute for application to re-entry vehicles and for extraterrestrial flight. As shown by the curve, "q" loadings as high as 3400 lb/sq ft have been achieved and this particular Ballute was about four feet in diameter and used for deceleration of a supersonic sled. It was made of Nomex - a high temperature nylon. Other Ballutes, however, have been made of stainless steel and Rene' 41 filaments and have been tested to temperatures up to 1500°F and speeds to Mach 10 in wind tunnel tests.

At the other end of the scale, Ballutes have been made as ultra low speed descent vehicles for use in the upper atmosphere where dynamic pressures as low as .05 lb/sq ft were used. Figure 3 is a picture of one of these Ballutes

*T.M., Goodyear Aerospace Corporation, Akron, Ohio approximately 14 feet in diameter, which utilizes a payload of about 7 1/2 pounds. This is made of a nylon film approximately .0004 inches thick. As in the case of most Ballutes, this is ram air filled so that it retains its structural integrity throughout its descent.

Perhaps the most popular Ballute is the 4 foot diameter unit shown in Figure 4, used by the Gemini astronaut. This particular unit is ram air filled from side inlets and has been completely tested and man rated for utilization at all escape conditions anticipated for the Gemini vehicle. In the event of an emergency the astronaut would utilize his ejection seat to escape from the capsule; the Ballute would then open and stabilize and orient the astronaut so that he would descend feet first to a sensible atmosphere where his normal recovery chute could be deployed. The main purpose for this Ballute is to prevent the man from going into a spin at altitude where his rate could become injurious or even fatal.

Sea Stilts

Expandable structures are also being considered for application to aerospace vehicles in forms other than for improvements of flight characteristics. A good example of this would be the retractable stabilizing floats now under study by Convair and the Navy for application to aircraft which would land on water and have to remain there in rough seas for extended periods of time. It has been found that an arrangement of vertical floats, "sea stilts", will considerably reduce the movement of the aircraft in wave action. As shown in Figure 5 tests have been conducted on a full sized aircraft using rigid hollow cylinders, proving the feasibility of the principle. At the present time these units are being made in a retractable form which will permit low drag during flight and yet provide the structural integrity for supporting the aircraft while on the water.

In order to permit retraction and extension of the inflatable floats, and maintain rigidity throughout the cycle, a special folding technique is employed. This is shown in Figure 6. The entire float is rolled up on a reel in the base of the unit and unreeled as needed. By providing torque to this reel, and holding a predetermined pressure inside the air tight fabric chamber, the structural properties of the float are retained. The technique is relatively simple, but extremely effective.

Airmat Applications

Airmat continues to provide a capability of expandable structures not possible with conventional bodies of revolution. Here the drop threads which tie together two surfaces of fabric can provide a shape control which is specifically applicable to areas where flat surfaces are required and variable geometry, and packageability are also important. Weaving techniques have progressed from the modified carpet loom, on which the original Inflatoplane* was built, to a pilot type of R & D loom for more versatility and better control of weaving properties to the giant Air Force loom now available for weaving even large size metal structures. Figure 7 shows the size of this facility as compared to a couple of automobiles. It is fully automatic and will weave to a contour as dictated by a scale model. New applications for Airmat are constantly being proposed where standard structural techniques are inadequate. The most current examples of this would be the following:

F-111 Wing Seal

In the General Dynamics concept where the wing changes sweep in order to obtain optimum performance at a wide variety of aircraft speeds, the intersection between the opening of the fuselage and the wing varies considerably for each wing setting. Attempts to seal this with an Airmat structure are considerably simpler than any other technique found so far. It is possible to predetermine the contours desired by weaving the Airmat with finite drop thread lengths that result in a wedge shape body with structural integrity maintained by an internal pressure. See Figure 8. When the wing moves from one position to another, this Airmat seal folds or extends as required to fill the gap. The fabric material is selected to withstand the temperatures and pressures expected and because of the almost infinite fatigue

*T.M.'s, Goodyear Aerospace Corporation, Akron, Ohio characteristics of these structures, they should withstand a considerable number of wing movements. The inflatable components are serviced by bleed air from the jet engines and are equipped with a valving system so that changes in altitude are automatically handled to maintain the proper pressure differential across the structural walls. Each of the seals are preformed at manufacture and are readily attached to the hard structure of the airplane by conventional fastening methods. In Figure 9, can be seen the loom weaving the contoured Airmat for this application. This lightweight approach to filling the wing fuselage intersection should be applicable to any future airplane which considers the use of variable sweep wings. It may also be utilized in STOL type aircraft where increase in wing area could be handled with pneumatic sections instead of with multiple component complex metal segments.

Aircraft Modifications

The development of the new large Airmat weaving facility which is capable of fabricating components with a predetermined contour permits consideration of applications previously not even thought feasible. One such use of Airmat is for converting a land plane into a sea plane. By adding a special inflatable section to the bottom of the fuselage of a high wing airplane, it is possible to provide the necessary flotation and shape to permit the aircraft to operate from water bases. See Figure 10. When retracted, or deflated, the airplane shape returns to its original land configuration, and the fabric material is held tightly against the fuselage by a suction pump. For an aircraft the size of a C-130, this installation might weigh less than 500 pounds. The normal airplane is relatively unchanged, and it takes only about a minute to "lower" the water hull.

This concept might be applied to extra wing area when needed, external fuel supplies, spray tanks, and a wide number of other applications. It is interesting to note that this method of adding volume or structural area to an aircraft is readily performed on already existing vehicles, permiting them to attain increased capabilities without performance penalties. In the retracted form, the space taken by these components is almost imperceptable. Weight penalties are also surprisingly low. Each application, however, must be considered separately and evaluated on its own merits.

Inflatable Aircraft

The original Inflatoplane, which proved the feasibility of developing a complete aircraft structure out of pneumatic components, opened the door for other applications along similar lines. Two of these which might be of interest at the present are the inflatable glider and the inflatable communications drone. The fuel glider would be most applicable to uses at relatively low speeds, such as with helicopters and fixed wing aircraft in the subsonic speed range.

In the case of the fuel glider this can be used either as a delivery unit of fuel, food, water, cargo or possibly even people. Since the cargo compartment is pressurized in order to maintain the shape and integrity of the vehicle, it can be used for low altitude as well as high altitude work with equal ease.

The most immediate application would be with the helicopter as a means for range extension for this vehicle. See Figure 11. By towing an inflated fuel glider with a good L/D ratio and a sizeable payload, the helicopter could substantially increase its own range. At the end of the flight, or when the fuel supply is exhausted in the glider, it could be collapsed and carried back inside the helicopter.

Both the delivery unit and the range extension system have inherent qualities of packageability, resistance to damage and lightweight which are impossible to achieve with conventional construction. By carrying a small auxiliary air supply, which could be either ram air driven, electrically powered by the tow aircraft or by its own integral power supply, it should be possible to replace any air lost by small arms fire without effecting the aerodynamic or structural properties of the vehicle. As a matter of fact, once a source of air pressure is on board the fuel glider, it is possible to utilize this as a means for pumping the fuel, since the tanks are all collapsible and the retension of pressure in the fuselage will automatically force the fuel out if it is released.

As an inflatable drone, it is possible to employ an aircraft of this type as a high altitude relay link for range extension of communication systems. The main advantage for this drone is adaptability to field operations, practical indestructability and ease of transportation. Preliminary analyses show that missions of 24 hours above 40,000 feet altitude are achievable, and that these can be increased as power plant selection improves. These aircraft have excellent payload to gross weight ratios, can operate from small unimproved fields, and are relatively low in initial cost. Maintenance on the aircraft structure itself is almost eliminated, since it is difficult to damage. Figure 12 is one configuration of such a vehicle utilizing the small Allison turboprop engine, and fabric structure that can be readily manufactured on the new loom.

Rotocraft

One of the first applications ever considered for Airmat was the rotor blade, because the centrifugal force maintains the tension and therefore, cone angle, and the internal pressure is merely required for shape retention. However, si most current helicopters are root driven and controlled, requiring more rigidit than easily obtained in the fabric blade, the work progressed slowly. The bene of light weight and packageability still exist, however, and now that compound vehicles, giant flying cranes, and recovery systems are in demand, the Airmat r interest has renewed.

When considering a compound helicopter, where a wing is used to unload the rotor during high speed flight, even before one considers the rotor, it becomes readil evident that an inflatable, retractable wing would be ideal. As shown in Figure 13, this wing could remain folded up into a small pod during hovering, when the rotor must be at its maximum efficiency, and then as the speed increases, it can be unrolled to take over much of the lift function. This capability is available today, and with normal development can become operational.

Another compound helicopter might be one in which the rotor remains stored in a retracted hub during high speed flight and is only deployed from a spinning hu for the landing and take-off position of the flight. Figure 14 illustrates su an aircraft. Here the interference of the wing during hovering would not be too important, because an extremely large radius could be employed to permit operati at a low disc loading. Naturally, during the high speed portion of the flight, which constitutes its major operating time, the aircraft would be performing in its most efficient mode.

Analytical studies of flying crane potential were also made and these showed that tip powered units of large rotor diameter are very promising for fabric blade construction. As shown in Figure 15, the larger the rotor the smaller the engine problem. Reasonably high tip speeds can be maintained at low rpm and hence vibratory problems from cyclic action are minimized. Blade weights look very good, especially with the tip mounted engines which assist in retaining a low coning angle.

Preliminary work has already been started along the lines of developing a blade which is completely collapsible so that it can be rolled up into the hub when not in use. The first unit, about 21 ft in diameter, is shown in Figure 16 mounted on a test truck. In this particular figure the blades are being pre-rotated prior to movement of the truck down the runway, at which time the blades go into autorotation, the rpm of which is set by the truck speed. In these particular tests it was found that these flexible blades work very well in the autorotative mode using only a root setting and a small tip tab to define the blade pitch angle.

As shown in Figure 17, the blades when not in motion are completely flexible and have no rigidity whatsoever. In these first units the inside of the blade was filled with soft plastic foam. In future blades the Airmat material will be employed and it will be possible to pressurize the blades to give a reasonable amount of stiffness when it is desired and by evacuating them to completely remove the stiffness when they must be stored. The vehicle shown in Figure 17 was merely used to check the blades in autorotation to see if they would actually lift the values indicated by the truck tests. This 600 lb vehicle "lifted off" at about 40 mi/hr and was very stable in operation.

Plans are now being made to wind tunnel test an Airmat blade in autorotation and to attempt to vary the pitch of the blades through tip controls.

At the present time this concept is sufficiently far along that it can be considered for recovery applications, utilizing large diameter blades, that can be stored in a small space and deployed slowly through spin up. It should be possible to achieve disc loadings which are low enough to permit zero velocity landings. Transferring the inertia of the blades just before impact to increased pitch of the rotors should completely eliminate the need for impact attenuators. This entire area of recovery is just now being investigated and it should become very fruitful because of the new loom developments which will permit weaving of a complete blade in practically a single operation.

Balloons

In the lighter-than-air field, it appears that the development of the very stable flying Vee-Balloon* has initiated a renewed interest in tethered balloon applications. These vary from the use of very small film constructed expendable units of a few cubic feet for marker applications to giant sized fabric units with long life expectancy in the 100,000 cu ft size for high altitude and heavy load carrying. Two of the most active uses are for communications and logging. See Figure 18.

The balloons used for communications - basically perform the function of elevating an antenna to extend line-of-sight range or to give it length and hence increased efficiency and range. These also have been used in a variety of sizes from 400 cu ft, flown at 500 ft altitude by the Army in Vietnam to 75,000 cu ft flown at 10,000 ft by the Navy. New developments in gas tight fabrics provide for increased endurance, minimizing operational costs and making time on station a reliable factor.

A commercial application of the Vee-Balloon is in the logging industry, here it has been found through studies for the Forest Service that a balloon can be utilized to good advantage to move timber from areas generally considered inaccessible or uneconomical using conventional logging methods. In experiments conducted by Bohemia Lumber Company on a Vee-Balloon, it was determined that by utilizing dynamic lift characteristics it is possible to actually fly the logs from the forest to the landing thus increasing productivity and decreasing chances for breakage. Besides the economical benefits of balloon logging, the Department of Agriculture is very much interested in the conservation effects which result from balloon logging. It is possible to clear areas without the need for extensive roads,

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disruption of the water sheds, soil erosion, etc. It is to be expected that as experience is gained in balloon logging, its utility will greatly increase. The aerospace industry will have to contribute to this field of endeavor by providing flight vehicles with increased performance for the specific properties required in balloon logging. These include high lift, good flight stability, quick turn around, survival in high winds, good bedding down characteristics, etc.

It becomes quite apparent that the advantages provided by new developments in fabrics opens a tremendous number of fields for application to aircraft where strength/weight ratios are so important. Actually the applications are so numerous that the only determining factor that justifies development in any particular area is a current need. From past experience with expandable structures, one can readily predict that wherever it appears feasible, the final application will be both economical and surprisingly effective in operation.

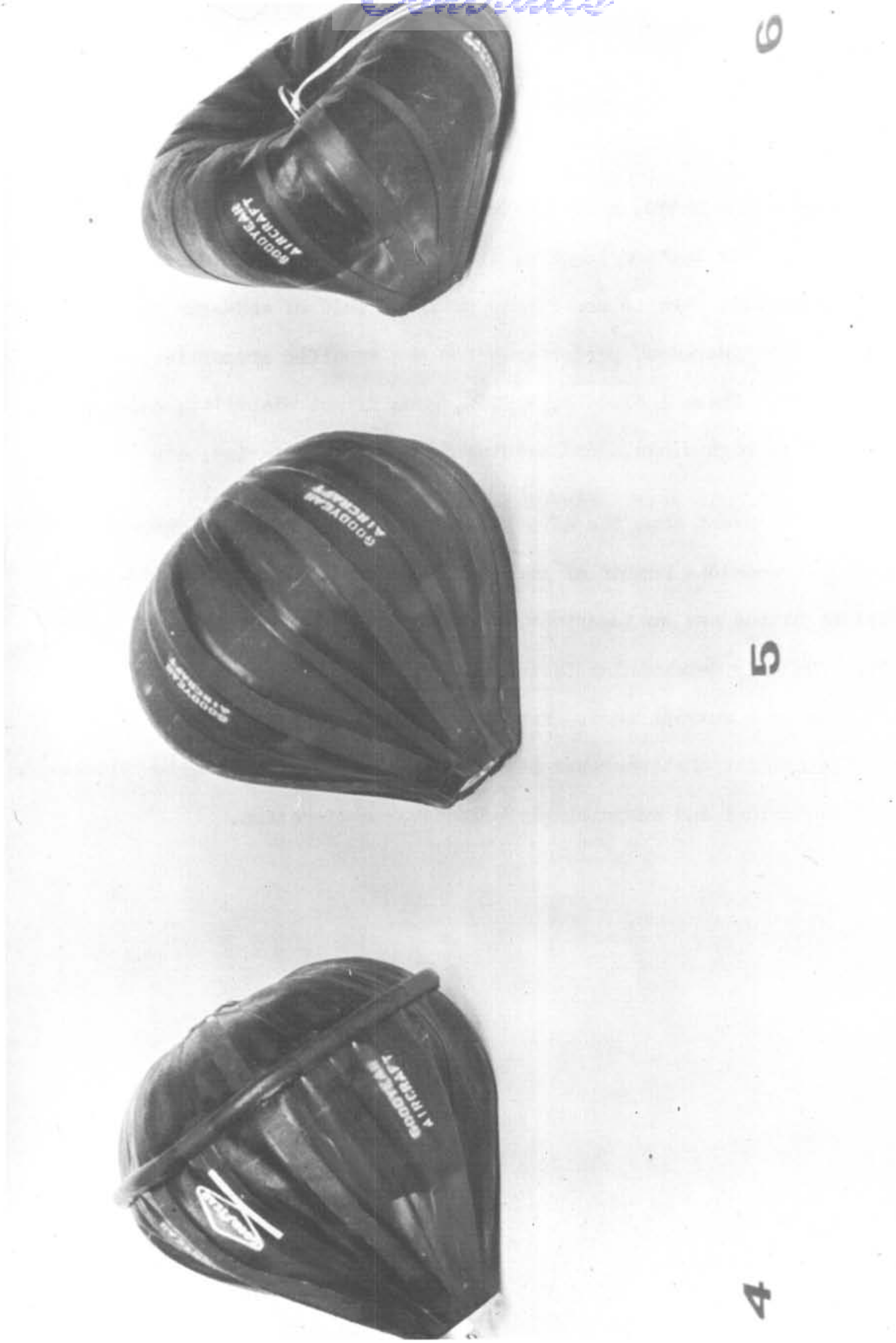

Figure 1. Typical Ballute Shapes for Wind Tunnel Testing

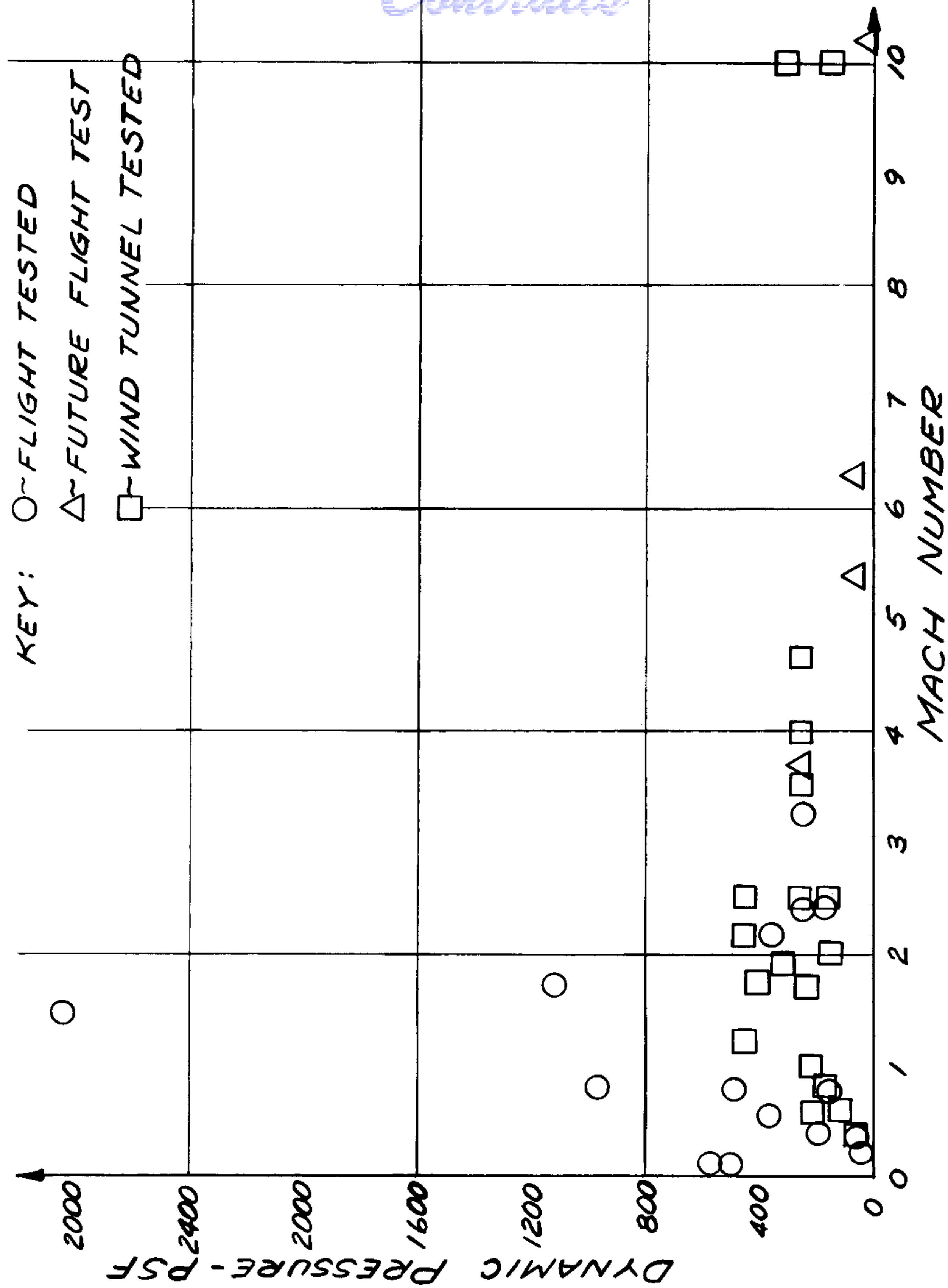

Figure 2. Ram Air Ballute Capabilities

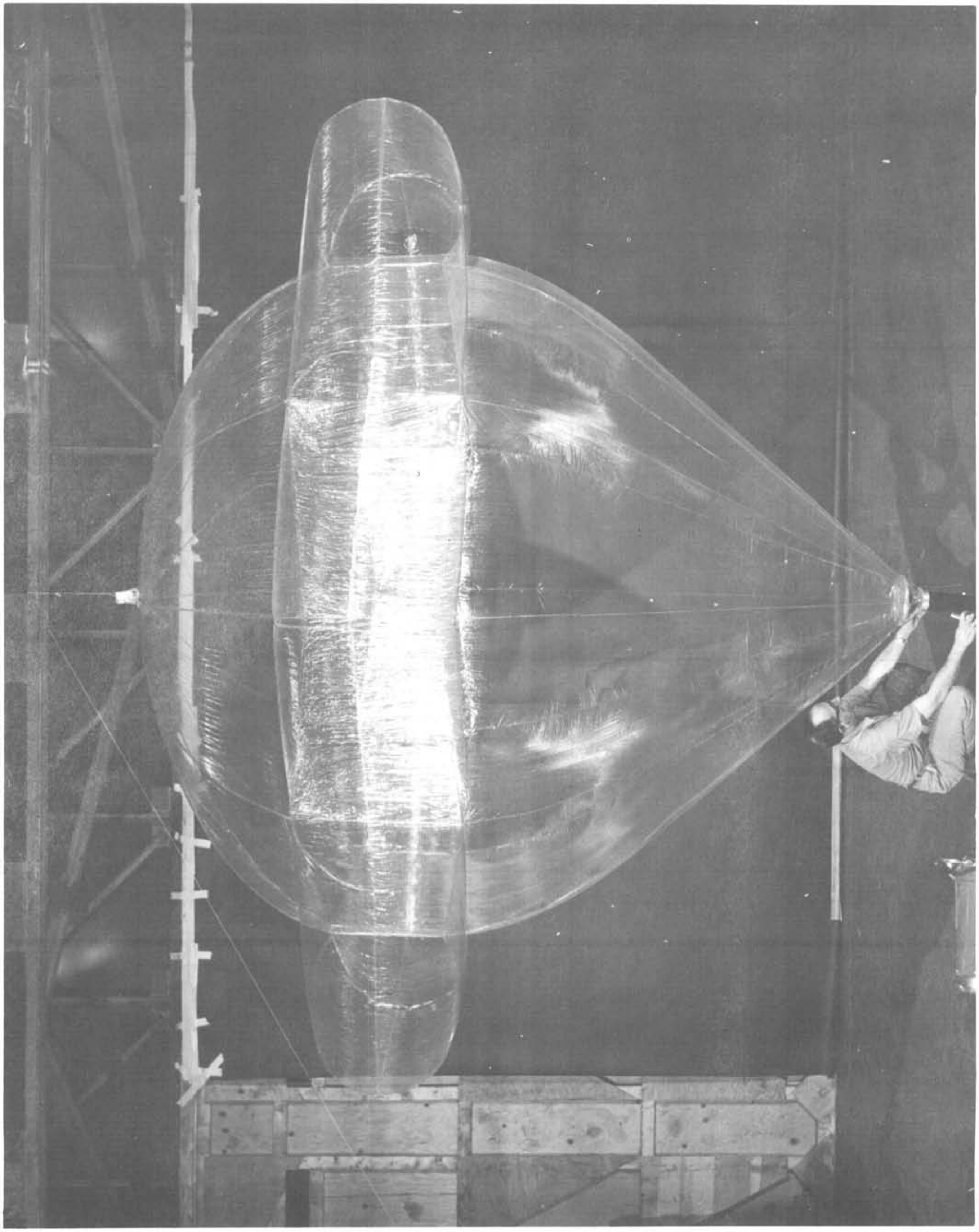

Figure 3. A Low "q" Supersonic Ballute for Upper Atmosphere Use

GEMINI BALLUTE (NASA)
1st LIVE JUMP
CWO CHARLES LAINE (TEST SUBJECT)
6511th TEST GROUP (P) AFFTC
NAF EL CENTRO, CALIFORNIA

Figure 4. Gemini Ballute in Jump Test

Figure 5. Vertical Floats Developed by General Dynamics

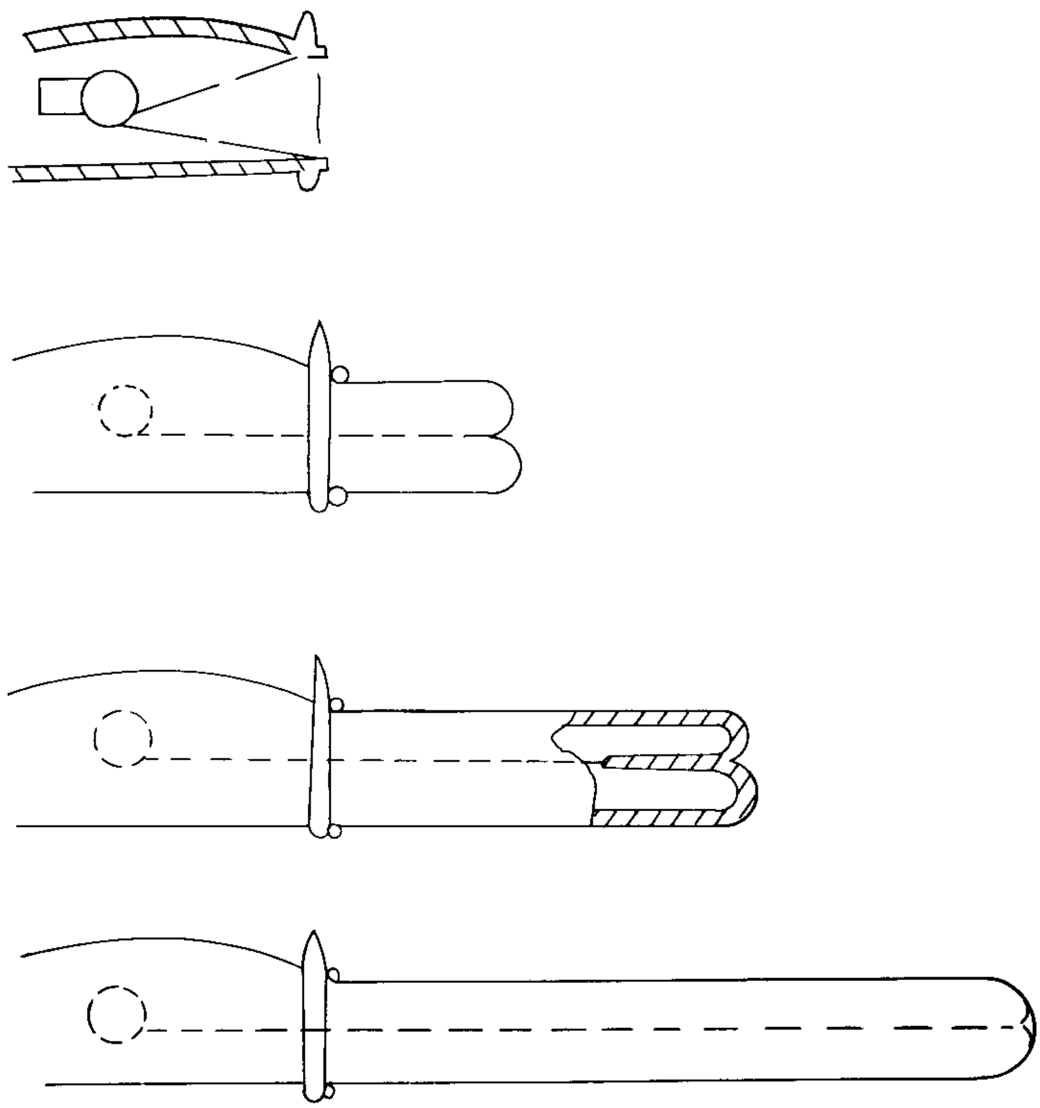

Figure 6. Vertical Float Retraction Concept

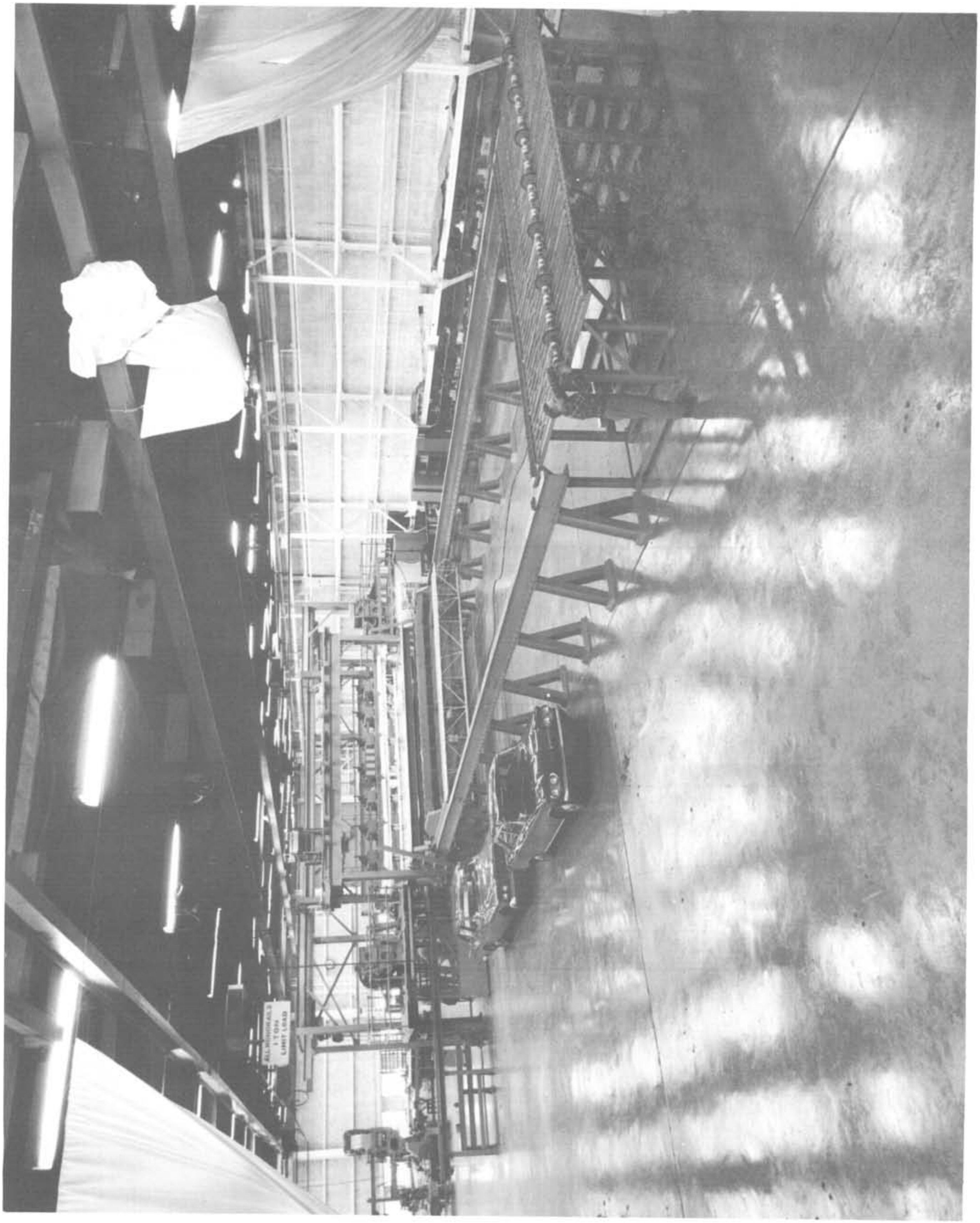

Figure 7. The Giant Air Force Airmat Loom

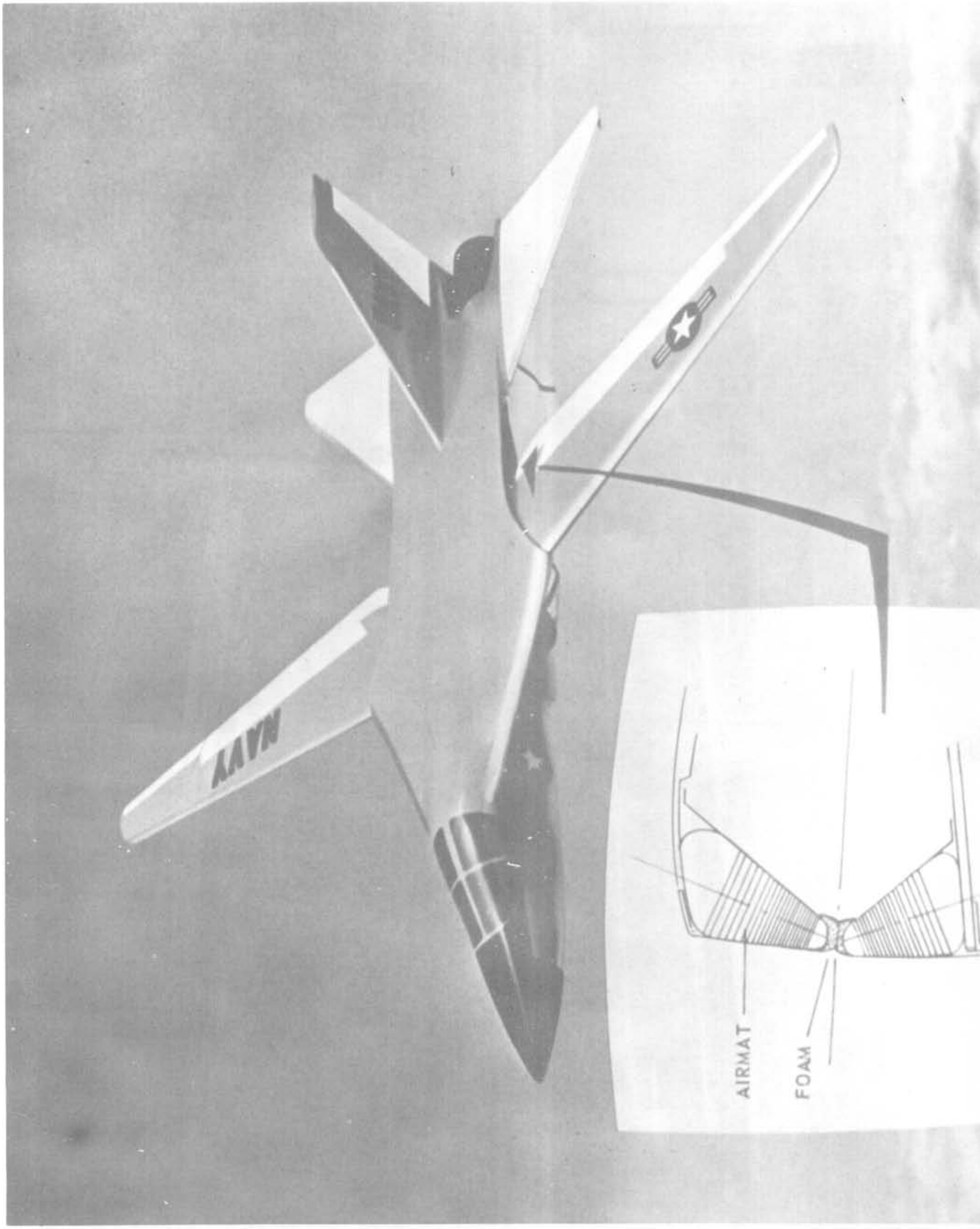

Figure 8. F-111 Wing Fuselage Intersection Seal

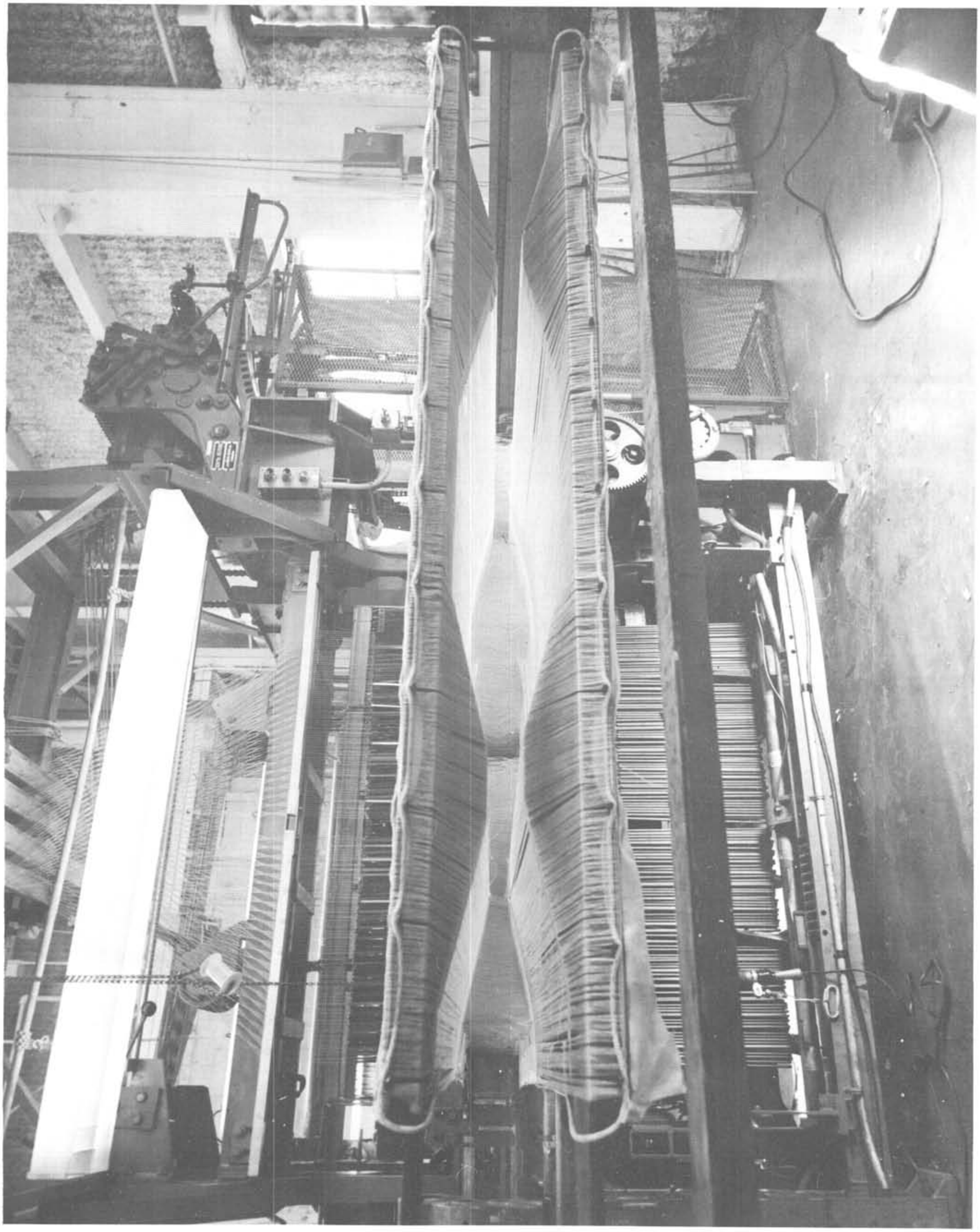

Figure 9. The GAC Airmat Loom Weaving a Single Seal Contour

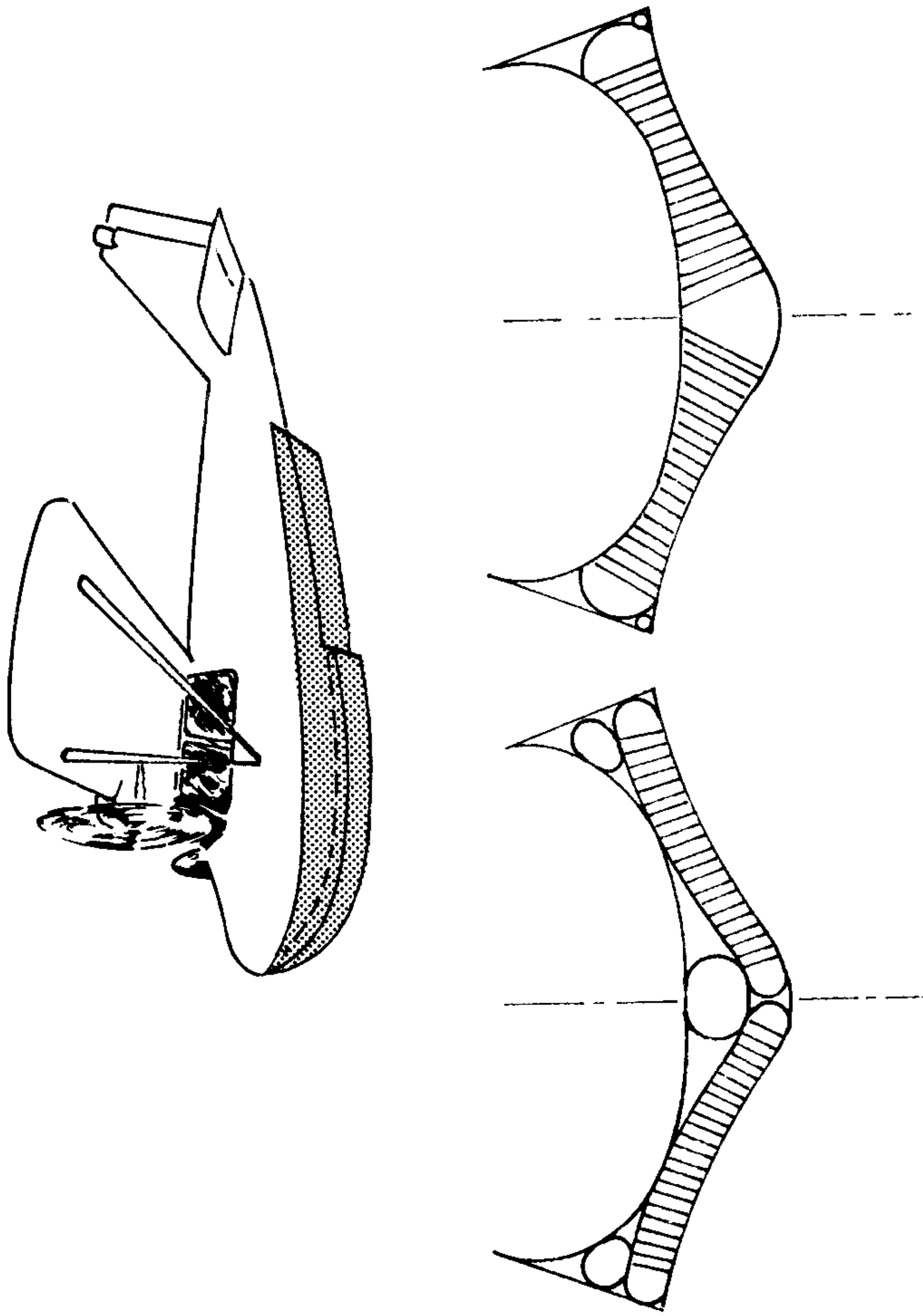

Figure 10. Water Configured Hull for Land Plane

Figure 11. Inflatable Helicopter Towed Glider for Range Extension

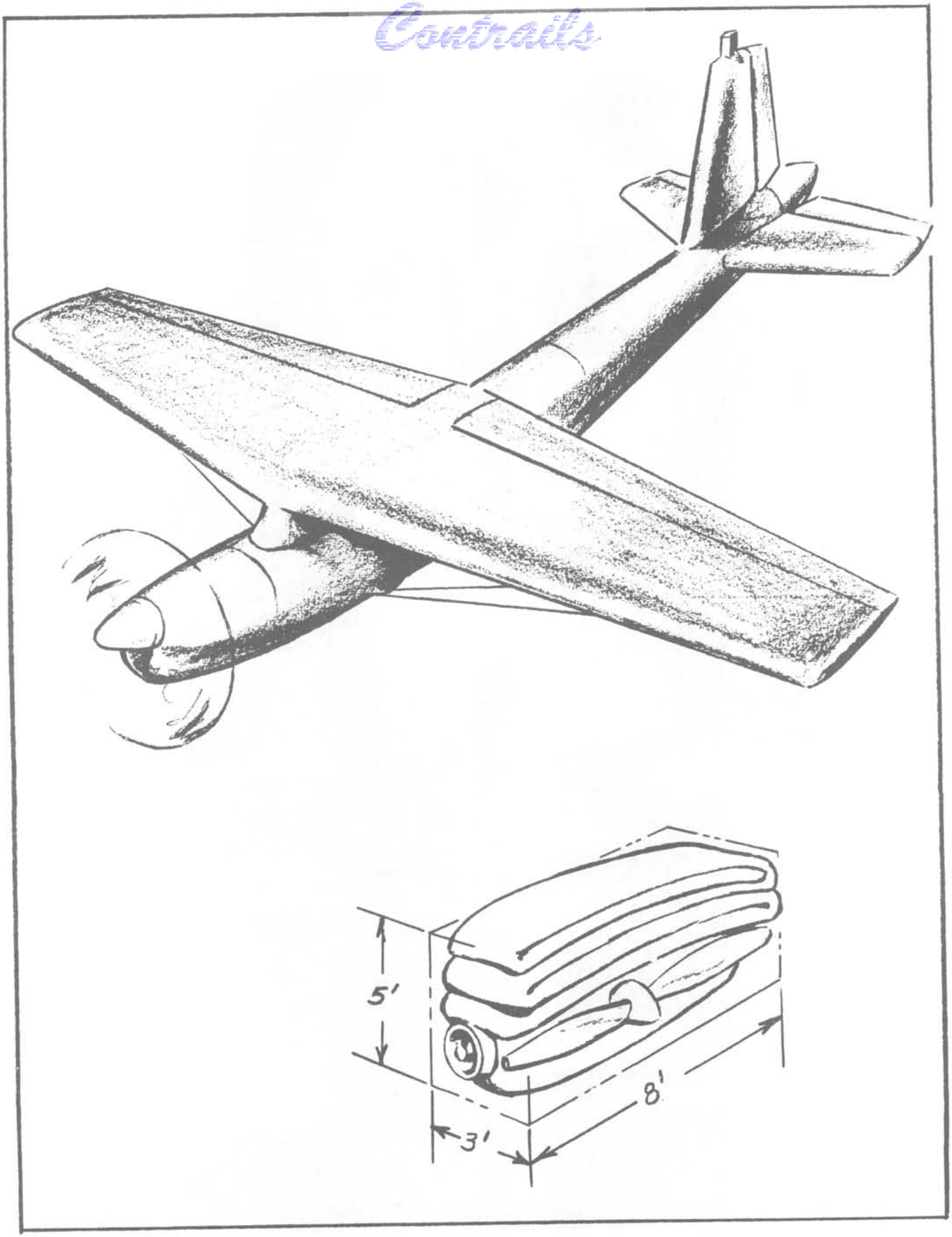

Figure 12. View Showing High Altitude Drone in Flight, Packaged

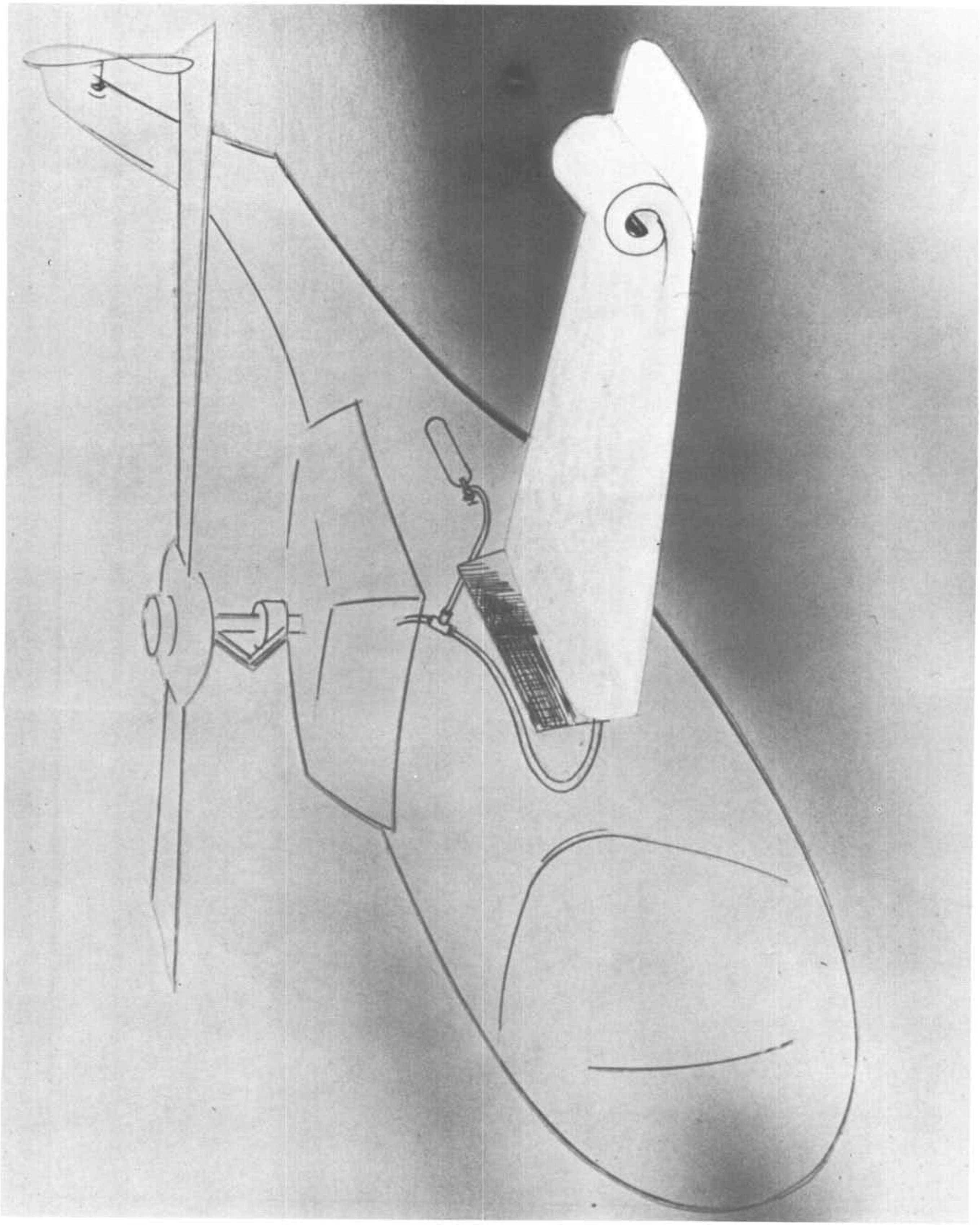

Figure 13. Compound Helicopter Using Inflatable Retractable Wing

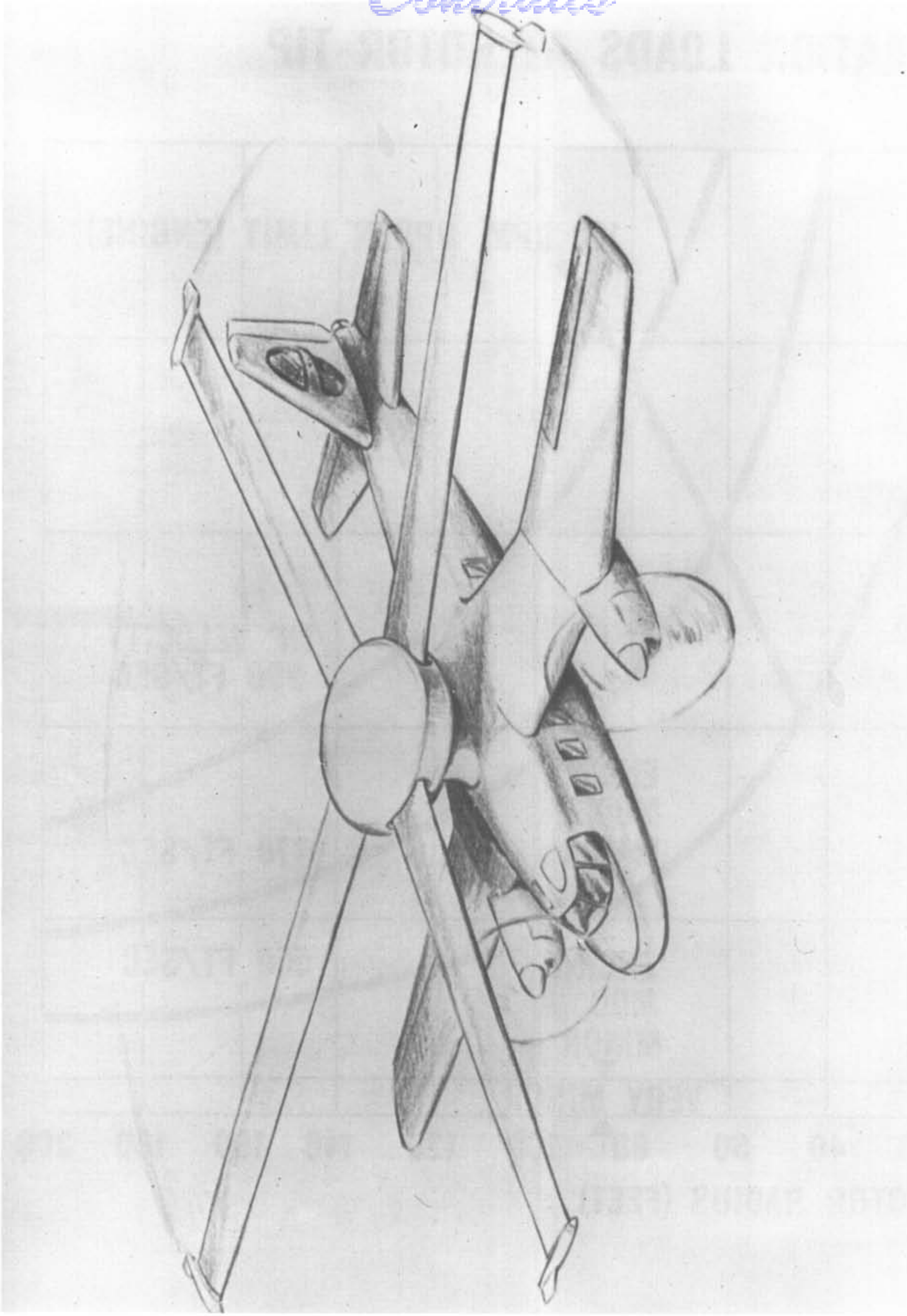

Figure 14. Convertible Aircraft with Retractable Fabric Rotors

ACCELERATION LOADS AT ROTOR TIP

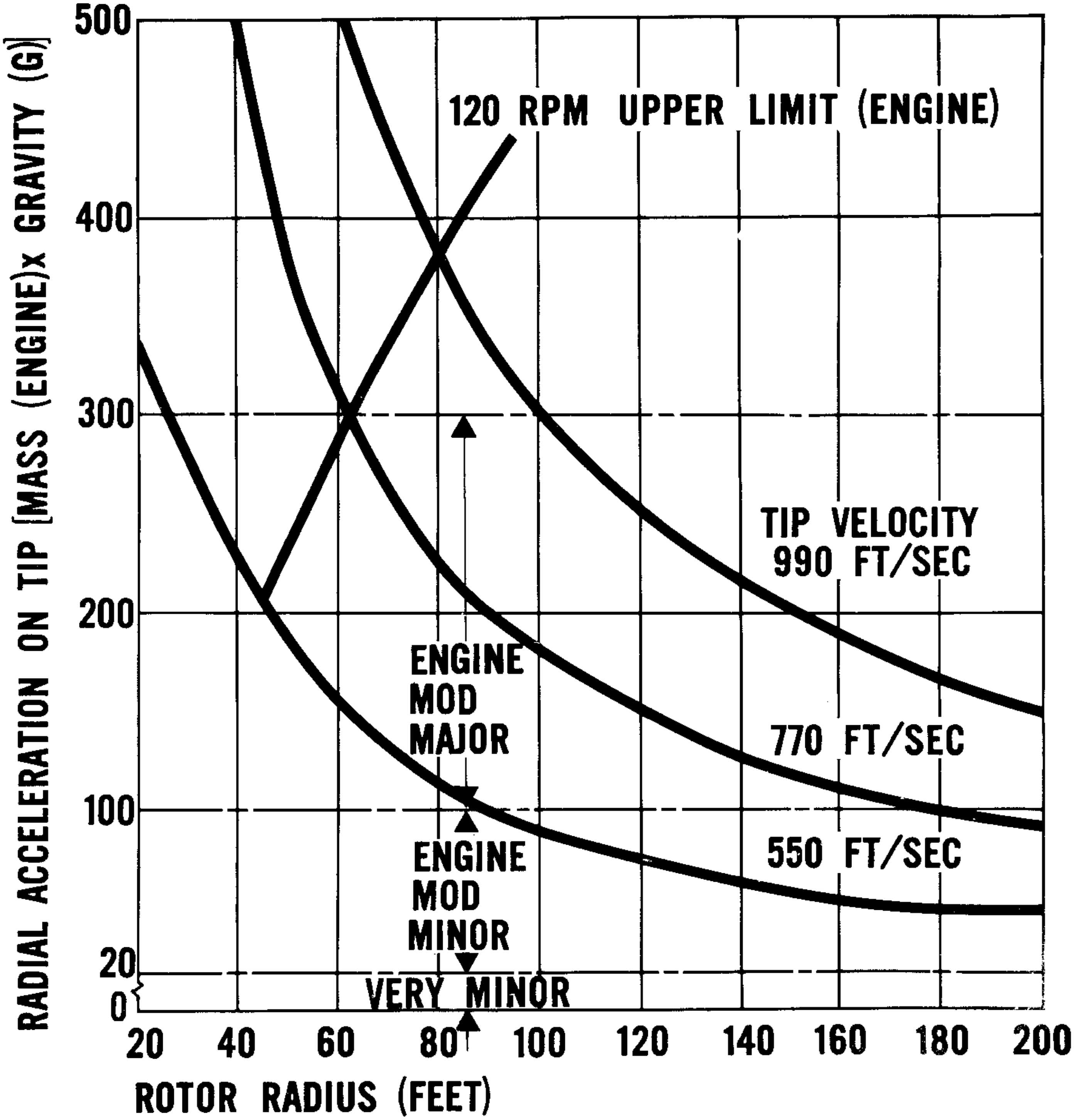

Figure 15. Relative Properties of Tip Powered Rotors

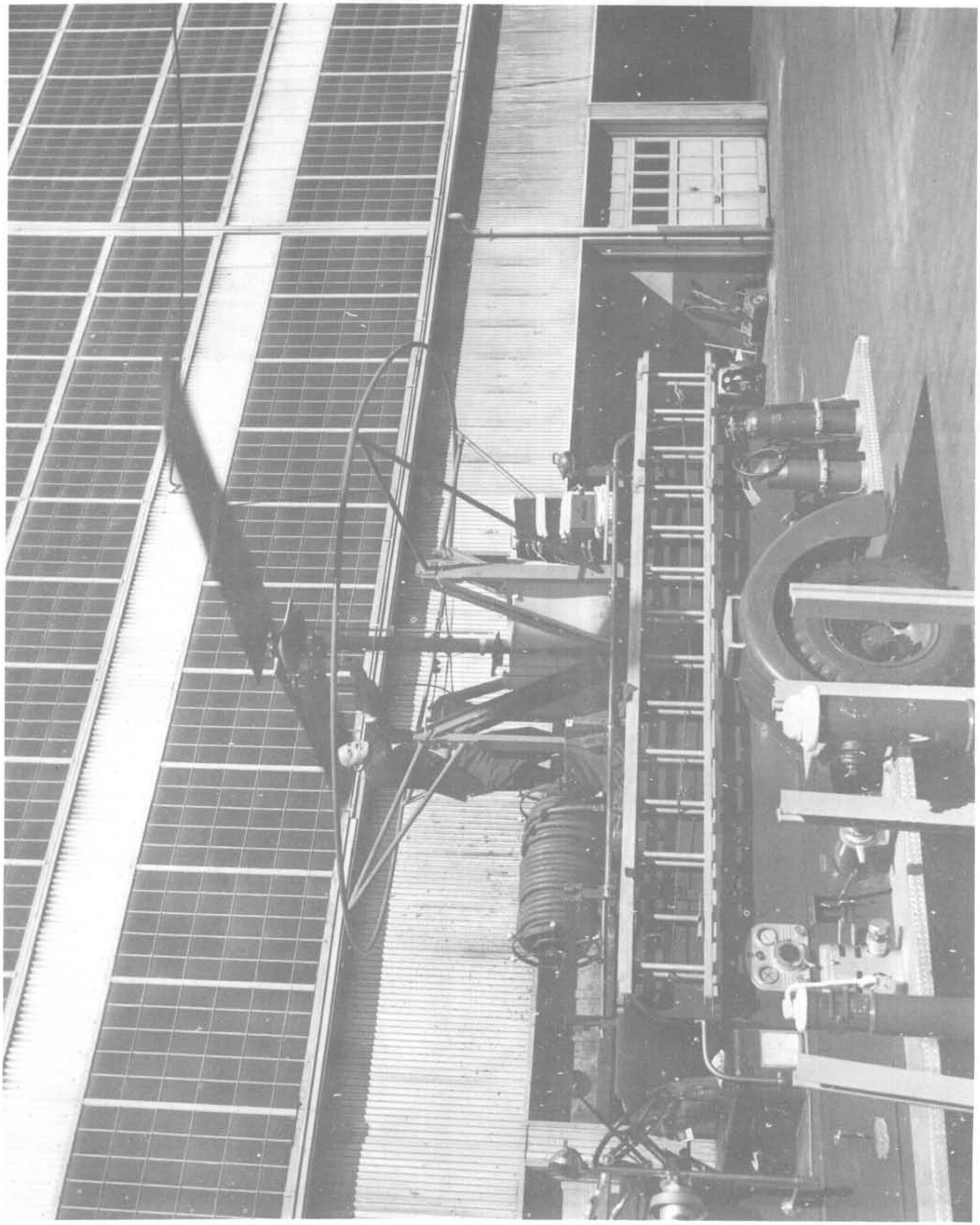

Figure 16. Fabric Rotor Mounted for Autorotation Truck Tests

Figure 17. Six Hundred Pound Test Vehicle for Lift-Off Trials

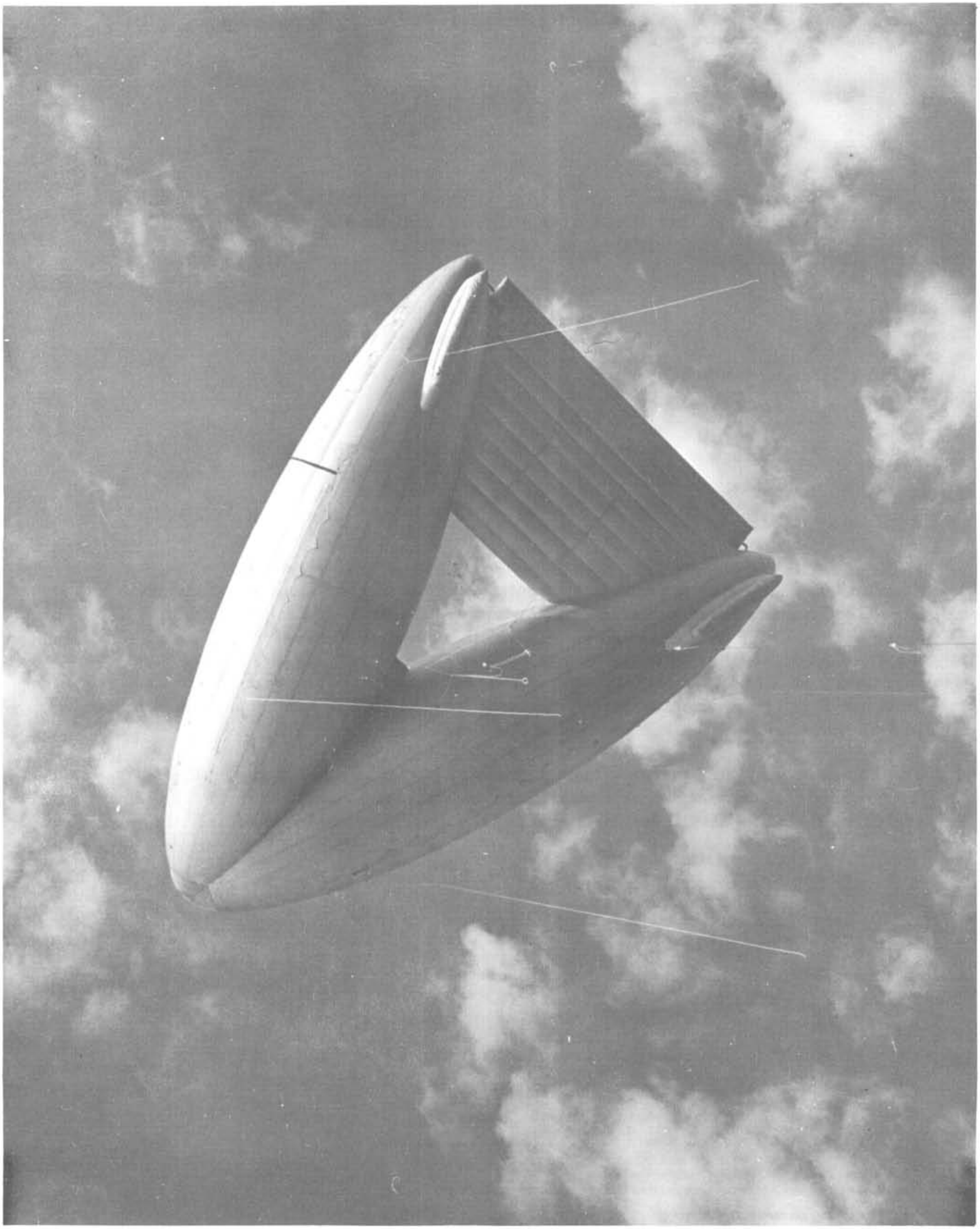

Figure 18. A Typical Stable Vee-Balloon for Tethered Operations