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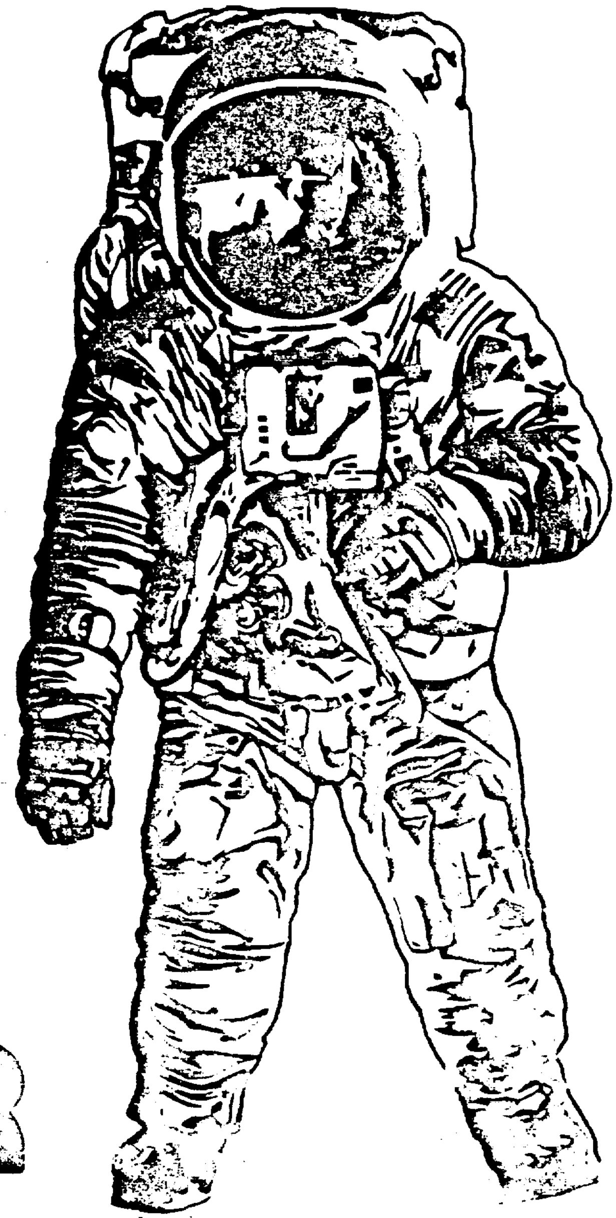
ATTACHMENT I
FOR THE FINAL REPORT

REPORT ON PHASE I

DESIGN DEFINITION OF A LIGHTER-THAN-AIR (LTA) HIGH ALTITUDE POWERED PLATFORM (HAPP)



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REPORT ON PHASE I

DESIGN DEFINITION STUDY OF A LIGHTER THAN AIR (LTA) HIGH ALTITUDE POWERED PLATFORM (HAPP)

NASA Contract No. NAS 6-3131

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HIGH ALTITUDE POWERED PLATFORM

PHASE I REPORT

1.0 INTRODUCTION

This report presents results of Phase I of a two-phase feasibility study for a High Altitude Powered Platform (HAPP) performed under Contract No. NAS6-3131 with the National Aeronautics and Space Administration, Wallops Flight Center, Wallops Island, Va. The objective of Phase I of this study is to develop an integrated and complete set of system characteristics including operational criteria for a lighter-than-air HAPP vehicle powered via microwave link. These characteristics and specifications are to be presented in the form of an engineering vehicle design.

The requirements for the Phase I study included:

(1) Selection of a basic configuration

(2) Development of a parametric analysis for optimization of the selected basic configuration for best performance.

(3) Selection of a design and definition thereof.

(4) System reliability predictions for final selected design.

(5) Development of vehicle operating concepts, including safety and FAA Regulations.

(6) Estimate of costs for prototype system development.

The microwave power transmission system, for purposes of this study, is assumed to be available with characteristics as provided by the sponsor in the contract Statement of Work. This study is concerned only with the physical aspects of the receiving rectenna.

Previous related work in other programs and preparatory work by NASA has provided an excellent background of information and data for this study. References 7 and 8 report developments in kevlar technology oriented towards use on high altitude airships. Reference 9 reports a study which provides the basis on which passive laminar flow control was considered for use on the HAPP vehicle. The "HASPA" program, Reference 14, provided a background of experience for HAPP type operations which was considered in many decisions. NASA, Wallops Island Flight Center, conducted statistical wind studies reported in References 1 and 2 which were specifically oriented toward the HAPP mission and provided the data for wind environment which was crucial to HAPP design. The study reported herein proceeded from this substantial background of pertinent information.

2.0 DESCRIPTION OF PROBLEM

2.1 ENVIRONMENTAL

The conceptual system which this study explores is a geo-stationary lighter-than-air vehicle flying in the stratosphere in a strata of minimum winds and powered by energy received from the ground via electromagnetic microwave transmission.

The intent of the HAPP program is to exploit benefits associated with high altitude flight for the purpose of positioning a communication relay. A primary advantage of operation in the chosen 20 km altitude range includes minimum winds and reduced air density which lowers propulsion power required. This altitude also provides an appropriate vertical position for relaying line of sight transmissions.

To fly on microwave power from the ground, the ship must be within the aiming limits of the microwave beam which is specified as being within 4° of ground station zenith. Outside of this limit, the ship must fly on auxiliary power using on-board fuel. Thus, the timewise distribution of wind velocities during a mission creates a trade-off situation where the weight of a microwave system to accommodate a given wind velocity is balanced against the weight of an auxiliary system to supplement microwave power when the wind exceeds the given velocity.

The typical patterns of wind velocities in the United States at various altitudes for four locations are depicted in Figures 2-1 and 2-2. The details of this wind structure as it might apply to a HAPP Vehicle were studied in considerable detail as reported in References 1 and 2. These

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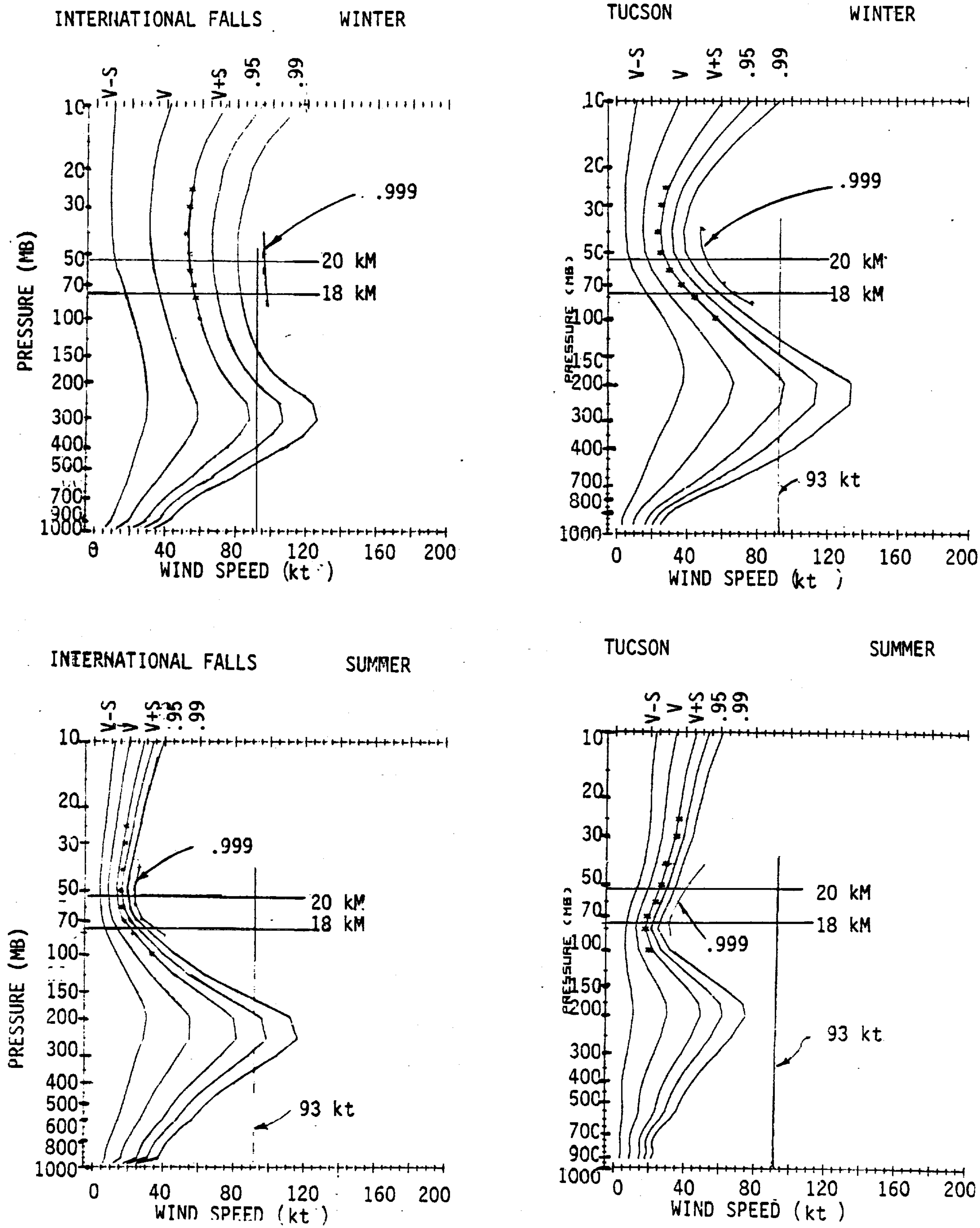

Figure 2-1 WIND PROFILE FOR TUCSON AND INTERNATIONAL FALLS

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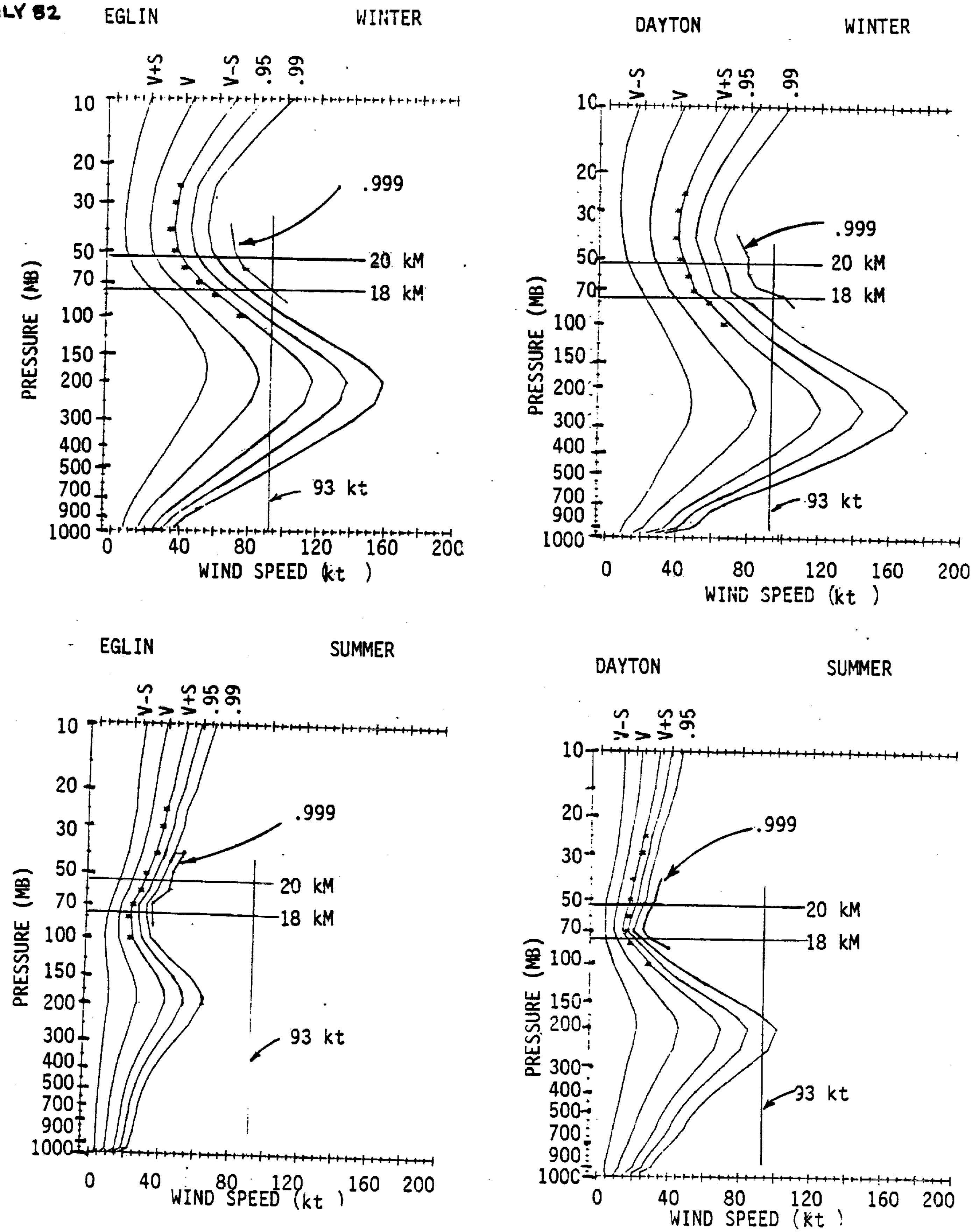


Figure 2-2 WIND PROFILE FOR DAYTON AND EGLIN

references became the basis for the statistical winds used in this study and afforded a variety of options for consideration in determining the most advantageous operating scenarios for the platform.

The effects of reduced air density become apparent in aerodynamic and aerostatic forces. These vary directly with density, and density at 20 km altitude is 1/14 that at sea level. A further effect of the density change with altitude is the change in volume of lifting gas for an airship. For a HAPP vehicle with a 14 to 1 volume change, major consideration must be given to method of accommodating this change, and two alternatives are available. One, launch the ship in a partially inflated condition and let the expanding gas fill out and pressurize the ship at altitude, and two, provide air filled ballonets to pressurize and maintain the ships shape in all phases of flight.

Thermal factors affect airship materials and performance in several ways. Ambient air temperatures are on the order of 217°K (-56°C). The low air density decreases convective heat transfer so that thermal radiation effects tend to predominate in surface heat transfer situations. Thus, thermally passive components may have significant variations from the ambient temperature. Variation of gas temperature from day to night affects the aerostatic lift and airship internal pressures.

Solar ultra-violet radiation is an order of magnitude more intense in the 20 km altitude region than at sea level with a consequent acceleration in the UV degradation of susceptible materials.

Ambient atmospheric pressure at about 1/18th of sea level pressure has a beneficial effect on helium gas loss and air dilution in the ship, in that permeability rates are proportional to the partial pressures of gases across the membrane involved.

2.2 AEROSTATICS

The aerostatic buoyancy of an airship is derived from Archimedes Principle and perfect gas laws, and is developed using equations and symbols from the HAPP Parametric Computer Program (See Appendix A).

The magnitude of the aerostatic buoyancy or lift is given in equation 1.

$$1. \quad L = M_G \left(\frac{P_A T_G R_G}{P_G T_A R_A} - 1 \right)$$

Where M = mass

P = absolute pressure

T = absolute temperature

R = gas constant

and Subscripts A = ambient air and G = lifting gas.

Thus buoyancy is sensitive to environmental and internal factors. Since the difference between aerostatic buoyancy and weight must be compensated by aerodynamic lift, which requires airspeed and power, it is desirable to minimize buoyancy changes. To maintain a constant buoyancy for example, a decrease in supertemperature might be compensated by a corresponding decrease in the differential pressure. This is practical so long as the differential pressure does not fall below the structurally required pressure for rigidity of the ship. The gas constant for air may be regarded as not varying, however, the inflation gas constant will be different for different gases. Also if the same gas, such as helium, loses purity by air contamination the gas constant will change. Ninety-five percent purity is assumed throughout this study.

2.3 POWER SUPPLY

The power to maintain the ship at some required velocity is derived from reception of microwave energy transmission supplemented by a self-contained power system when the microwave power is not adequate, or not available. As long as a given level of microwave energy is available, the operations within this energy level may be varied as desired without any significant effects on the overall results. However, when operations upon the auxiliary power plant become necessary, on board fuel is consumed and constitutes a weight penalty which translates back to increased ship size. This trade-off and associated operational scenarios are addressed in the parametric study, Section 4.0.

2.4 AERODYNAMICS

2.4.1 Laminar Flow Hull Shape

The technology of utilizing section shaping to achieve passive boundary layer control of airfoil sections has been well developed in recent years. The companion technology as applied to bodies of revolution has received some attention, although not as widespread, principally due to the limited range of Reynolds numbers in which it is applicable and to various sensitivities exhibited in maintaining a laminar boundary layer. The Reynolds numbers of a hull flying at relatively slow speed at high altitude imply that with passive boundary layer control shaping, large drag reductions are possible due to extensive laminar flow. The possibility of applying passive laminar boundary layer control to high altitude airship design was favorably reported in Reference 9. Wind tunnel and underwater model tests for a specific shape, the "DOLPHIN" shape, was reported in Reference 10.

The low Reynolds number of the HAPP airship compared to a conventional low altitude blimp, is the primary reason that extensive laminar flow may be realizable with the HAPP. A conventional blimp exhibits laminar flow in the boundary layer only for a short distance and quickly develops a turbulent boundary layer. In the area of the car and toward the unfavorable pressure gradient near the tail section, the boundary layer separates from the hull. This is illustrated in Figure 2-3, Conventional Airship Shape Boundary Layer. With proper hull shaping, the transition from laminar to turbulent flow in the boundary layer can be moved aft on the hull substantially. Immediately after boundary layer transition, while the turbulent boundary layer is still young and thin, the flow is rapidly diffused to above ambient pressure and then subsequently expanded to atmospheric. This serves to maximize the volume/surface area ratio of the body without a severe pressure drag penalty and results in body shapes with rather thin afterbody sting shapes. The flow along a passive boundary layer control hull is illustrated in Figure 2-4, Passive Boundary Layer Control by Hull Shaping.

The boundary layer transition position is a function of angle of attack, surface roughness and waviness, in addition to Reynolds number. The drag will change as angle of attack influences the pressure gradient on the hull (manifested as profile drag) and as the hull develops, left-induced drag is generated. Surface roughness, in the form of steps, protuberances and

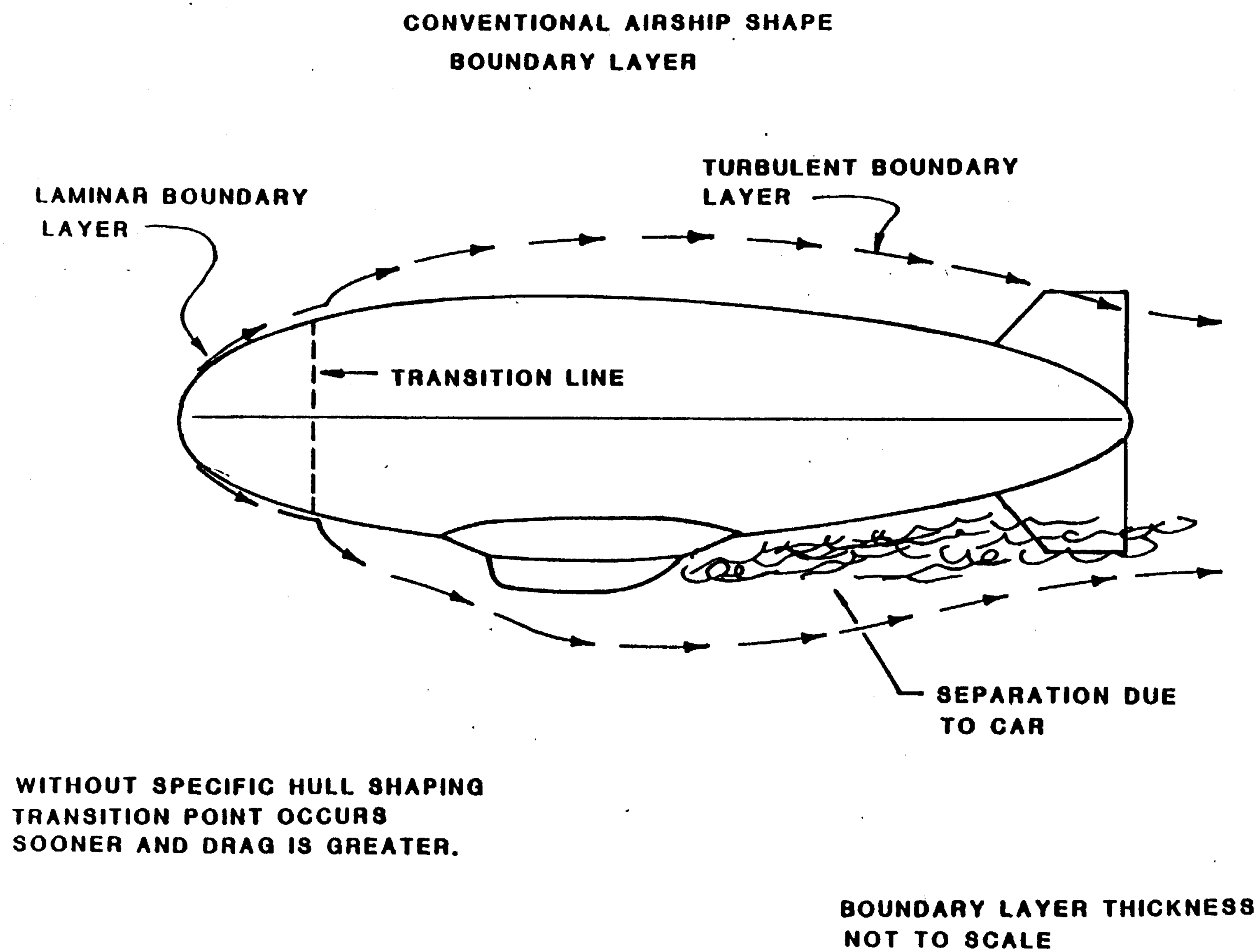
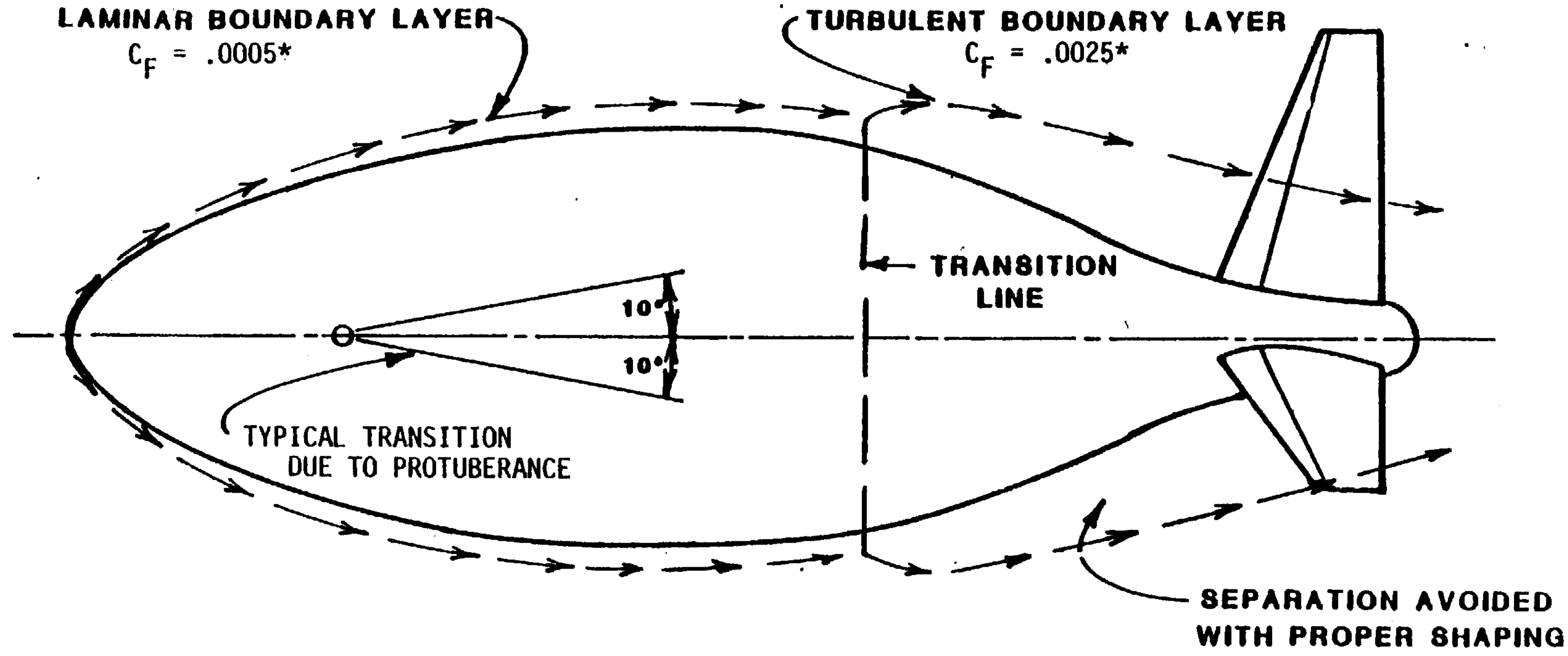


Figure 2-3 CONVENTIONAL AIRSHIP SHAPE BOUNDARY LAYER

PASSIVE BOUNDARY LAYER CONTROL BY HULL SHAPING



BOUNDARY LAYER THICKNESS NOT TO SCALE.

* C_F = SKIN FRICTION COEFFICIENT BASED ON WETTED AREA

POSSIBLE CAUSES OF PREMATURE TRANSITION

- SURFACE ROUGHNESS OR WAVINESS
- HEAT ADDITION (SOLAR RADIATION)
- ACOUSTIC DISTURBANCES
- PROTUBERANCES

Figure 2-4 PASSIVE BOUNDARY LAYER CONTROL BY HULL SHAPING surface waviness can prematurely transition the boundary layer, upsetting the pressure distribution and low drag of the hull. Due to the very low Reynolds number per foot of the HAPP full scale hull, the allowable step seam could likely be as large as 0.031 cm without tripping the boundary layer. Since the hull material is thin, lap joints can be manufactured below this step height. The most likely source of troublesome surface imperfection would be surface waviness, however, modern construction techniques for inflatable hulls should provide tolerable surface waviness. Microwave heating of the rectenna surface may possibly result in localized premature transition of the boundary layer. Preliminary evaluation of new patterning techniques indicate that the HAPP configuration can be manufactured within tolerances necessary to result in a functional passive boundary layer control shape. Future testing on full size preproduction runs of HAPP material would lend additional support to such manufacturing questions.

The candidate shape considered here for low drag will be referred to as the "Dolphin", because of its resemblance of a dolphin animal. In pioneering work by Carmichael (Appendix B), a body shape was developed to exploit the described flow phenomenon, and drag coefficients were calculated by integrating the skin friction drag over the body with suitable laminar and turbulent skin friction coefficients. The resulting "Dolphin" shape was tested both in a wind tunnel and in a deep-sea drop test. Some of the results are presented in Figure 2-5, Experimental Comparisons of the Dolphin and Standard Bodies. The body shape considered for HAPP is a Carmichael test body shape with a shortened tail boom owing to structual considerations. The effect on drag of shortening the tail boom would be related to increased base drag area, on the order of 5%, but the increase may be avoided by proper design for propeller-hull interaction.

2.4.2 Stability And Control

The HAPP vehicle primary mode of flight control is thrust vectoring of the aft propeller. This was chosen over conventional rudders, or propeller cyclic control because of its low weight and effective low-speed control. Conventional rudders on the light-weight inflated fins would have resulted in a large weight penalty, and would not have provided much needed control forces during low speed landing maneuvering. With the aft propeller installation, either a gimballed or cyclic propeller could provide the needed control forces even at low speeds. The gimballed propeller configuration requires clearance from the fins when fully vectored, slightly restricting the fin geometry. The cyclic propeller requires a more complicated control system and is felt to have less reliability than the gimballed installation. The gimballed propeller was selected for HAPP on this basis.

Basic airship hulls are statically unstable in heading. Stabilizing fins are used on the afterbody to provide a margin of static stability. Information in References 11 and 12 were applied in evaluating stability factors. The size and position of the fins have been selected to provide a degree of static margin necessary to reduce airship wallowing in straight line flight. Wallowing is considered detrimental because it could potentially interfere with the laminar flow by altering the hull pressure distribution and moving the boundary layer transition or separation position. The reduction of wallowing is a driver toward large fins.

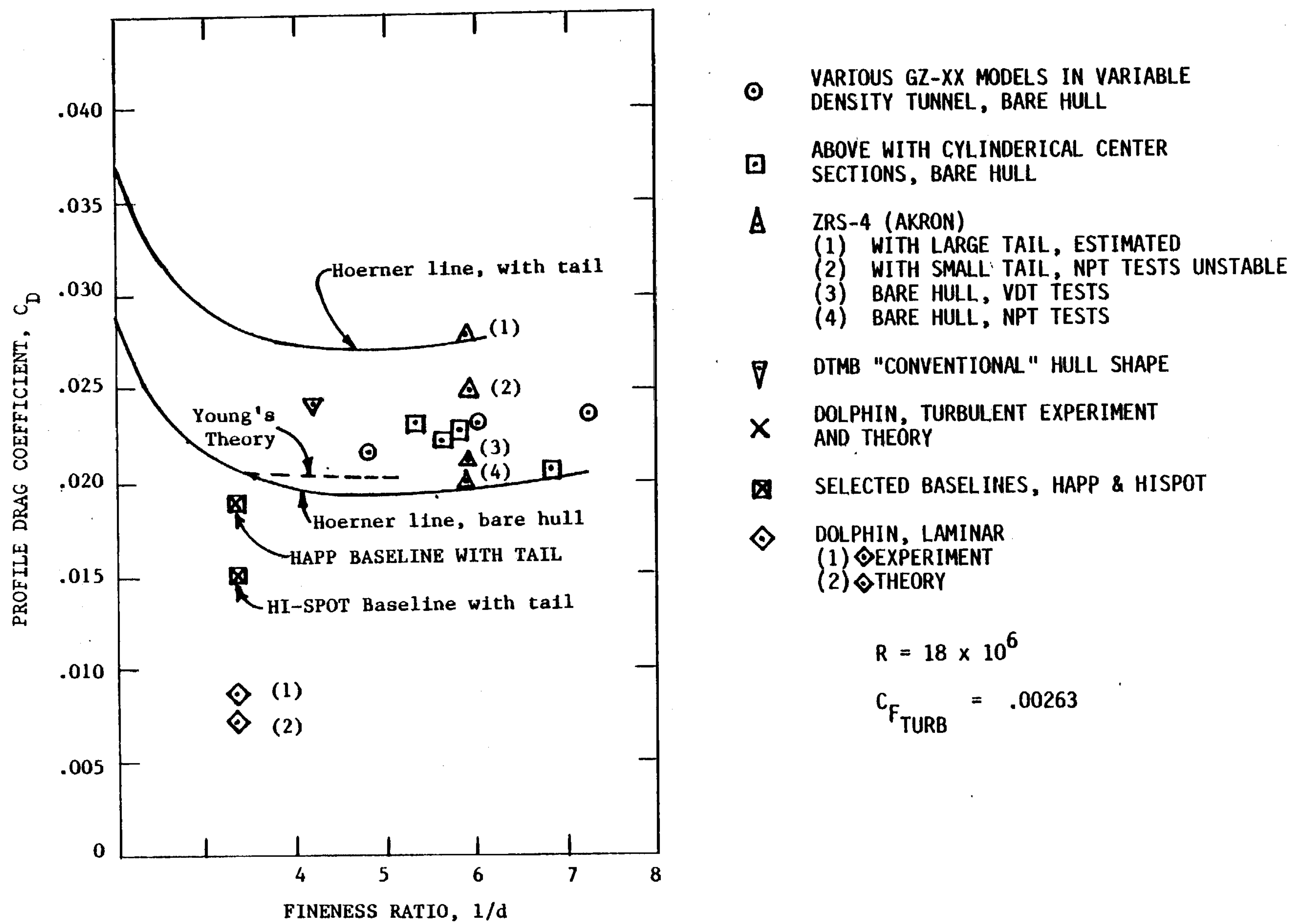


FIGURE 2-5, EXPERIMENTAL COMPARISONS OF DOLPHIN AND STANDARD BODIES

Weight, drag and turning performance, however, are drivers for small fins. Obviously, smaller fins weigh less and have less drag. When turning the airship, the vectored trust is used to cause the airship to fly with an angle of sideslip. This results in a side force which provides the centripetal acceleration to fly in a circle. Because the airship is statically stable in heading, a moment is generated to reduce the sideslip angle. During a steady-state turn, this moment is balanced by the moment generated by the vectored propeller. The larger the fins, the greater the moment and the greater the thrust or thrust angle required from the vectored propeller to balance it. Good turning performance with small vectoring angles is a driver toward smaller fins.

In the HAPP mission, a certain level of turning performance is necessary to maintain flight within the microwave beam cross-section. Because both centripetal acceleration and aerodynamic sideforce are functions of velocity squared and are balanced against each other (canceling the velocity terms) the minimum turning radius is independent of velocity. At high windspeeds, the ship is flown at the wind velocity and only short sections of arcs need be flown to maintain position within the beam. At very low windspeeds in the daytime, the ship is left nearly free floating. In this condition, it is possible to drift ahead of the beam center requiring the ship to fly a full 360 degree circle to return back to the beam center. In very low winds at night, the ship must be flown in a circle to maintain the necessary dynamic lift. As the windspeed increases, the flight path becomes oval.

At an intermediate windspeed, a figure eight path may result in the minimum departure from beam center. Instead of circular flight paths, it may also be possible to slow the ship, lose altitude and drift backwards followed with an increase in speed, a gain in altitude and movement forward. Repeating this cycle over and over keeps the airship within a confined area. Once the windspeed reaches the minimum speed necessary to maintain dynamic lift, circling is no longer necessary. This occurs at approximately 40 knots.

In the full scale vehicle development, careful evaluation of wind tunnel results and demonstrator flights will be necessary to effectively optimize the fin size and position. For the HAPP parametrics, the fin size was based on a circular flight requirement of 500 meter radius (minimum) with ± 22.5° gimbal angle and maintenance of some degree of static stability. The HAPP turning performance is illustrated in Figure 2-6, HAPP Airship Turning Profile. The figure represents a time history plot for the vehicle when linear acceleration is balanced against thrust, drag, centripetal, and side forces.

An inverted "Y" fin tail was chosen as the lightest weight configuration and also results in very good ground clearance. Inflated fins were selected over rigid fins because they showed an advantage in the parametric analysis and they can be deflated to facilitate the transfer of the airship to a marginally sized hangar.

2.4.3 Drag

The low drag Dolphin hull shape has been chosen for HAPP to minimize power required to maintain on station with head winds. The drag coefficient used in the parametric study for the overall vehicle is $C_{D_o} = .018$ (based of $V^{2/3}$). This value is the result of a drag build-up of a basic hull drag,

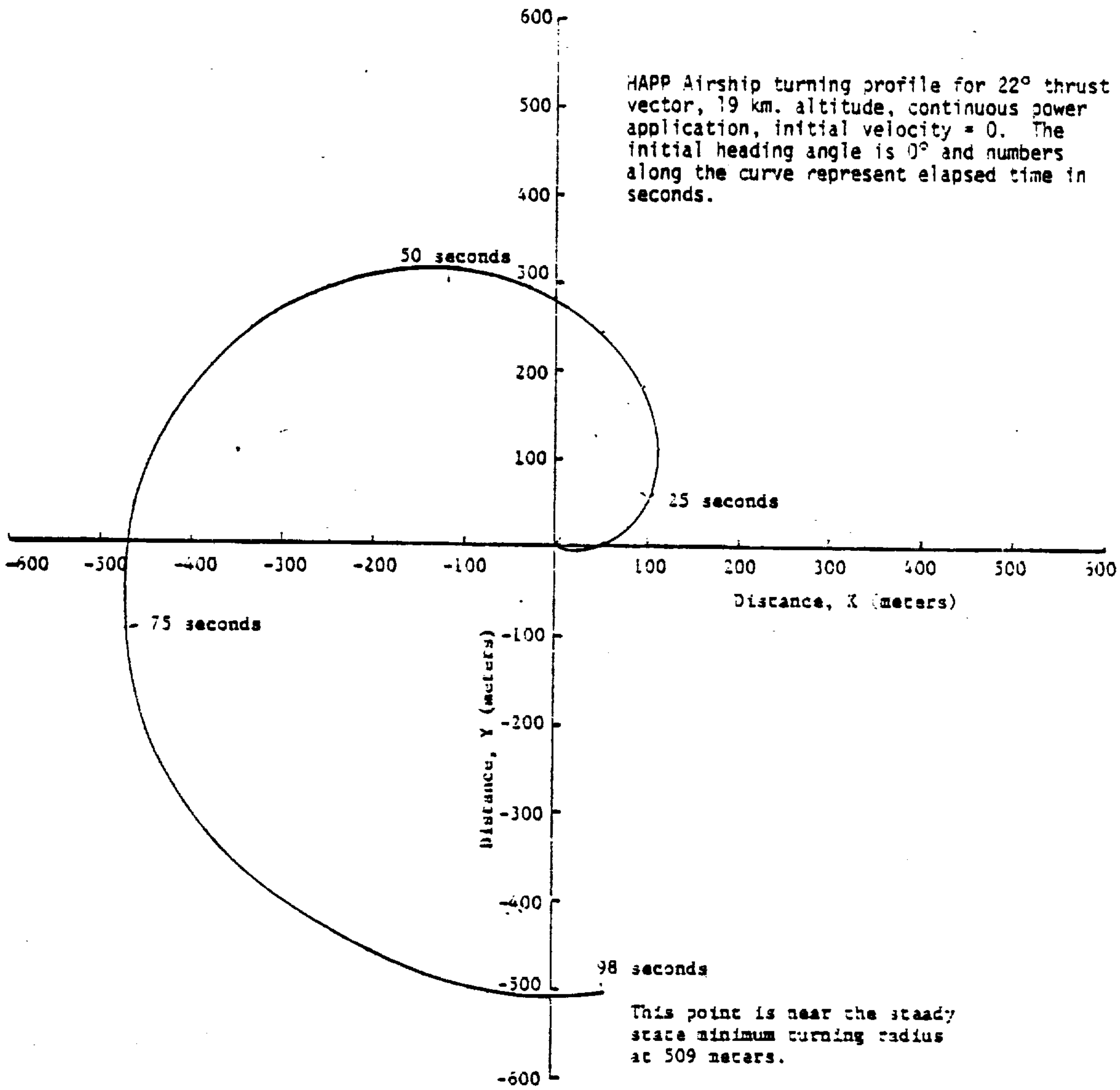


Figure 2-6 HAPP AIRSHIP TURNING PROFILE

fin drag, and windscreen drag. When using dynamic lift, induced drag due to lift is added to the basic vehicle drag.

The bare Dolphin hull drag was determined by examination of the theoretical and experimental data available.

Dolphin Hull Drag @ Rn - 18 x 10^6

TURBULENT	BARE HULL ($V^{2/3}$)
Experimental (wind tunnel)	.0200
Theoretical (Young's calculation)	.0200
LAMINAR (TO 60% OF BODY	
Experimental	.0072
Young's calculation	.0086

From the data, it is felt conservative to select $C_{D_\circ}$ = 0.010 for the Dolphin. At worse case, in the event of a totally turbulent flow condition, $C_{D_\circ}$ = 0.020.

The tail drag coefficient is calculated assuming the tail size selected previously. The soft fin is expected to have a turbulent flow boundary layer due to the waviness of the fin skin. The hard fin is expected to have turbulent flow for the inboard half and laminar flow on the outboard half.

SOFT TAIL	C_D (based on projected area)	C_D (based on $V^{2/3}$)
NACA 0012	.0074	.0051
NACA 0018	.0081	.0056
HARD TAIL		
NACA 0010	.0050	.0034
NACA 0012	.0053	.0036
NACA 0018	.0060	.0041

It was initially felt that the heavier but lower drag hard fins would parametrically trade-off favorably. This was not the case and because of their greater cost and unfavorable impact on weight and balance, hard fins were not selected for the HAPP vehicle. The soft fins selected used the NASA 0018 airfoil and resulted in a larger spar depth and increased bending stiffness. Airfoil data was acquired from Reference 12.

The windscreen is estimated to contribute C_D = .002 based on $V^{2/3}$. This is an estimate based on a nominal windscreen size. The true, full-scale windscreen dimensions and drag are not known.

The Dolphin base drag is now totalled. A worst case, fully turbulent drag coefficient is provided below for the readers background. The laminar flow drag coefficient is felt to be conservative.

ITEM	LAMINAR C_{Do} $(V^{2/3})$	TURBULENT Worst Case C_{Do}
Hull	.0100	.0200
Fins	.0056	.0056
Windscreen	.0020	.0020
Total	0.0176 = .018	0.0276 = .028

2.5 ASCENT, DESCENT

Air compartments called ballonets by which the air volume can be increased and decreased on demand are required in the pressurized structure to accommodate changing volumes of helium with changes of pressure and temperature. The volume requirement for a given mass of lifting gas is given in Equation 2.

$$\text{Equation 2:} \quad V_G = M_G R_G (T_A + S_H)/(P + P_D)$$

Where:
V_G = volume of gas
M_G = mass of gas
R_G = gas constant (for HAPP study, the gas is helium + 5% air contamination)
T_A = ambient absolute temperature
S_H = superheat, the difference gas - ambient temperature
P = ambient absolute pressure
P_D = superpressure, the difference gas - ambient pressure

As altitude is changed from sea level to 20 km, the volume of helium under standard atmosphere conditions changes by a factor of 14. The helium volume change must be compensated by ballonet volume.

A complication with this size ballonet is that at low altitudes the helium occupies a small portion of the envelope and the center of buoyancy moves a great deal as the ship pitches creating an unfavorable pitch situation. This problem must be accommodated in the ship design and operational procedures. It must also be expected that minor unbalances will occur during operation that must be handled in flight by some means such as trim ballonets or weight transfers.

2.6 GUIDANCE

The problems of position keeping and guidance although somewhat complicated are all within state of the art as applied to other aerospace vehicles. The guidance requirement is to position the ship after ascent on station within the confines of the microwave beam energy and to keep it there throughout various wind regimes and to bring it back to station if it should blow off. Generally speaking, in comparison with airplanes and missiles, the accuracy and time response for this ship are not at all severe. The microwave beam is focused into a tight beam with a cross- section at the ship approximating the rectenna area, but the beam can be aimed within an arc of 4° from vertical. At 20 km, this provides a circular operating area for the ship 3 km in diameter.

A positioning information system for operations within the microwave beam has been worked out by Raytheon Corporation. It requires a 1 watt "pilot beam" on the ship pointing down which by means of x-y coordinate interferometry on the ground provides airship-ground antenna relative position information, which is then used to navigate the ship. Microwave beam polarization is sensed at the ship and telemetered to the ground to rotate the ground antenna in synchronization with the ship rotation.

3.0 CONFIGURATION SELECTION

3.1 VEHICLE CONCEPTS

Five different lighter-than-air airship configurations were considered. These represented the total spectrum of concepts that have been proposed in this field. The five configurations are:

(1) Oblate spheroid

(2) Deltoid

(3) Conventional airship, pod drive

(4) Conventional hull, stern drive

(5) Laminar flow hull, stern drive

The four concepts that were seriously considered are shown in Figure 3-1.

Each is discussed below:

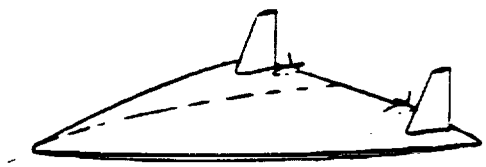
3.1.1 Oblate Spheroid

The expected advantage was a capability of motion in any direction without turning. This is not possible because the aerodynamic center of lift is 1/3 of radius aft of the leading edge and with a fixed center of gravity location, omni-directional flight would not be possible. The shape would have poor volume/surface area efficiency and as a new concept would have a high technology risk. This shape was therefore eliminated as a candidate.

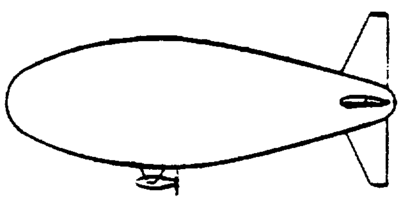
3.1.2 Deltoid Shape

This refers to a hull in which aerostatic lift is efficiently supplemented by aerodynamic lift of the thick delta shaped airfoil body. Analysis of this shape is detailed in Appendix C. This configuration has been eliminated because:

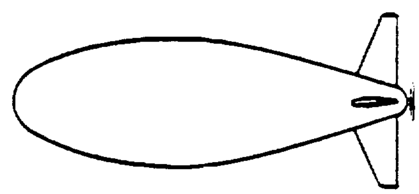
TYPES OF AIRSHIPS CONSIDERED



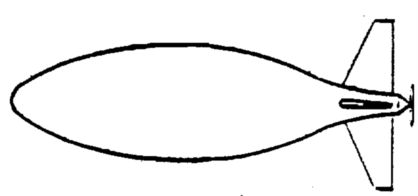
A. DELTOID
ADVANTAGE AT + 80 kt



B. CONVENTIONAL AIRSHIP, POD DRIVE
LIGHT, INEFFICIENT, HIGH DRAG



C. CONVENTIONAL AIRSHIP, STERN DRIVE
LIGHT, EFFICIENT, MODERATE DRAG, TAIL HEAVY



D. PASSIVE LAMINAR FLOW AIRSHIP, STERN DRIVE
LIGHT, EFFICIENT, LOW DRAG, TAIL HEAVY, NEW TECHNOLOGY

FIGURE 3-1, TYPES OF AIRSHIPS CONSIDERED

a. It would provide a power advantage only at speeds above 80 knots, which represents a very small portion of the HAPP flight regime.

b. Poor volume - surface area efficiency compared to an axially symmetric body.

c. A new concept with a high technology risk.

3.1.3 Conventional Airship, Pod Drive

Based on Navy ZPG data, a drag coefficient of .04 would be expected. In addition, propulsion efficiency as affected by propeller disk diameter would be limited by hangar and ground clearance consideration, to an estimated maximum of .85.

3.1.4 Conventional Airship, Stern Drive

The drag coefficient for stern drive would be less than with pod drive by elimination of external pods and supports to approximately $C_D = .028$. Propulsive efficiency would be increased by to perhaps .95 by use of a larger propellor. In addition further minor drag advantages of stern propulsion could accrue by favorable interaction of flow between the aft portion of the hull and the propeller.

3.1.5 Laminar Flow Hull, Stern Drive

As discussed in Section 2.4 under aerodynamics, advanced hull shapes offer the possibility of significantly lower drag. Since the laminar flow hull has to date not been attempted on an airship, there is a technology risk. However, the following factors make the selection of this configuration advisable.

(a) Significant advantages in airship size and power requirements.

(b) At best the drag coefficient of the hull with fins may be .018 or slightly better. At worst a drag coefficient of .028 would still be as good as a conventional hull.

(c) The volume to surface area ratio is very good because of the low fineness ratio of the dolphin shape.

(d) The quiescent atmosphere of the stratosphere is compatible with laminar flow retention.

(e) Manufacturing techniques to meet surface smoothness and waviness requirements for laminar flow are possible.

(f) The airship low speed at low altitudes avoids accrual of surface bumps such as insect impacts.

(g) Stern drive advantages as given in 3.1.4.

Consideration of the above advantages results in selection of this configuration, that is, a laminar flow hull, "dolphin" shape, with stern propulsion.

Factors which are accepted and must be recognized with the use of this concept are:

(1) A risk that aerodynamic flow will not meet expectations, a risk that cannot be obviated until a large model is flown in the stratosphere.

(2) The dolphin shape has a small diameter tail section which requires attention to insure that the structure is adequate to handle the bending moments.

(3) The stern propulsion results in a concentration of weights in the stern area so that airship balance becomes a critical factor in positioning components.

Another decision point in configuration is the choice of "hard" fins or fabric inflated "soft" fins. Hard fins have lower aerodynamic drag but are heavier and more expensive (composite technology). This is a trade-off feature in which the parametric studies for both HI-SPOT and HAPP have favored the "soft" fins for mission performance. Therefore, "soft" fins are selected as part of the configuration.

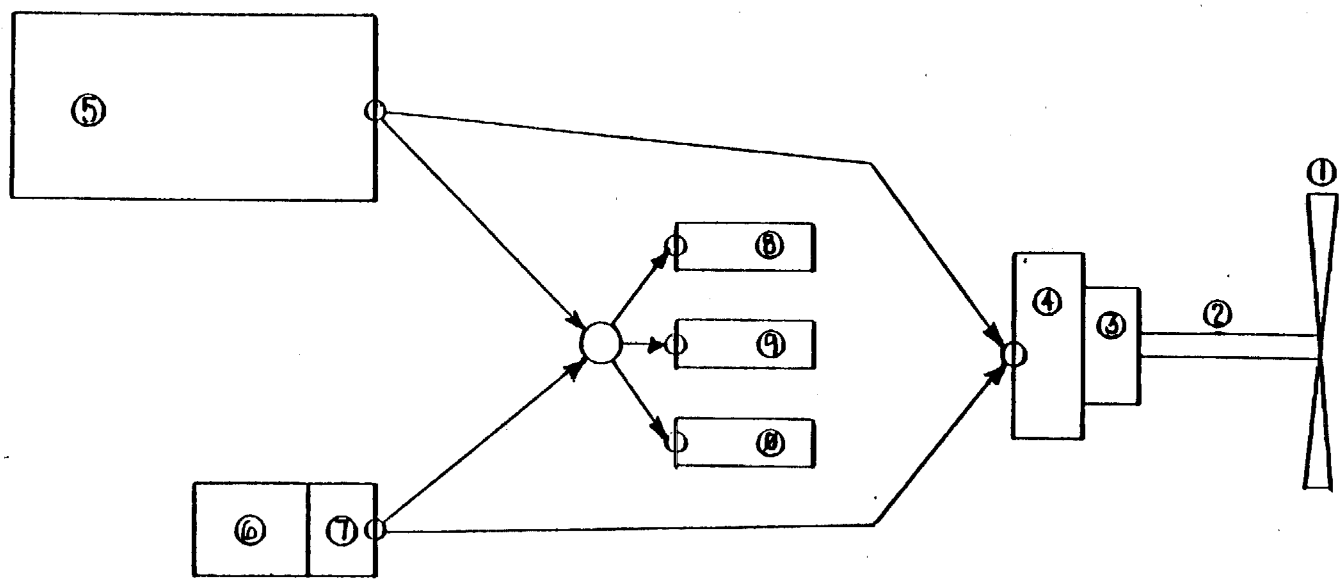
A basic structural decision for the airship is "rigid" vs. "non-rigid". Since the shape selected is a body of revolution, it is compatible with a "non-rigid" pressurized structure. A review of weights of historic rigid airships, and giving allowances for modern materials, indicates that a rigid hull would be several times heavier than a non-rigid. Further, for this unmanned application, there are no significant advantages. Therefore, a non-rigid pressurized structure is selected.

3.2 PROPULSION

The main component in the propulsion system is a synchronous, permanent magnet 3 phase, brushless A.C. motor. Several of these motors will be used in parallel and cascaded through a combining sprag clutch to enable the power system to bring more motors on line as required. This allows the motors to run close to design speed and torque most of the time and allows the unused motors to stand by, thus increasing reliability.

Powerplant configuration selection is described in Appendix D which reports studies done under sub-contract by DSI Inc. A schematic of the energy flow is shown in Figure 3-2.

HAPP POWER FLOW SCHEMATIC



(1) PROPELLER
(2) DRIVE SHAFT
(3) GEAR BOX
(4) DRIVE MOTORS
(5) RECTENNA
(6) AUX. ENG.
(7) GENERATOR
(8) AVIONICS
(9) PAYLOAD
(10) BLOWER

FIGURE 3-2, HAPP POWER FLOW SCHEMATIC

The auxiliary engine drives a generator which provides electric power to the primary electric motor. This arrangement for auxiliary power is selected to provide flexibility in location of the auxiliary engine for airship balance purposes. A deviation from the DSI power plant configuration is that a reciprocating engine is selected for the auxiliary engine rather than a gas turbine. The reason is that engine studies under Project HI- SPOT disclosed that gas turbines cannot readily be started at mission altitudes.

3.3 MATERIALS

3.3.1 Envelope and Fin

Throughout the past several years, ILC has put a considerable amount of effort into the investigation of materials for high altitude airships. Because of the need for a high strength-to-weight ratio fabric, Kevlar has been a desirable candidate. During this period of time, advanced yarn processing and weaving techniques have been developed for Kevlar fabric which have greatly reduced the flex fatigue problems associated with Kevlar in the past.

In 1977, ILC conducted a study for NADC under Contract 77-M3495, which evaluated a Leno weave Kevlar scrim base fabric in conjunction with a film transfer coat. After extensive evaluation of the fabric, it was discovered that when both yarn systems were stressed, the two yarns of the Leno weave in the warp direction were cutting each other as well as the fill yarn system.

In 1979, under another contract with NADC, further development work was performed utilizing custom woven 200 denier, 40 x 40 and 30 x 30 count, plain weave Kevlar fabrics as the base materials in film laminate combinations. Laminates of Mylar/Kevlar, Tedlar/Kevlar and polyurethane film transfer coated Kevlar were constructed and evaluated as reported in Reference 3. Based upon the test results and the excellent inherent weatherability of Tedlar film, the laminate of Tedlar/Kevlar (200 denier, 40 x 30 count, plain weave) was selected to be pursued for further investigation.

Evaluation of white pigmented Tedlar film laminated to the above mentioned Kevlar scrim has been on-going for the past year. Based upon recent thermal studies, however, it has become apparent that a metallized Tedlar film may be more desirable than the white Tedlar. Preliminary investigation has indicated that a clear Tedlar film, with a vapor deposited silver layer, will yield the optimum absorptance, transmittance and reflective characteristics needed for the airship.

ILC recognizes that the incorporation of a metalized surface into the laminate may cause bonding difficulties and is prepared to investigate a variety of adhesives. However, the optimum adhesive for laminates which have been constructed in the past is Hytrel, a polyester elastomer. Various polyurethanes have been evaluated as laminating adhesives, but Hytrel exhibits the best bond strength and flexibility in the finished Tedlar/Kevlar laminate construction.

3.3.2 Taping Materials

Having constructed balloons for many years, ILC is aware of perturbation caused to the envelope material by structural tapes. To remedy this occurrence, ILC investigated a tape construction consisting of low modulus yarns in the warp direction and high modulus/high strength yarns in the fill direction. This type of construction would enable the tape to yield with the hull. The construction selected for evaluation was a Leno weave with 14 groups of 50 denier nylon in the warp direction and 40 yarns of 200 denier Kevlar in the fill direction. Preliminary testing of this material in a taped seam indicates that the stress strain characteristics are nearly identical to those of the base fabric. ILC is planning to utilize Hytrel as the adhesive for attaching the structural tape to the hull and fin material. Hytrel has excellent low temperature performance and heat seals well. Two techniques of utilizing the Hytrel are to coat it directly onto the taping material or to use Hytrel in film form and sandwich it between the hull fabric and taping material. Each of these methods would be sealable by radio frequency techniques and will both be evaluated.

Since recent evaluation has shown that an adequate bond between Tedlar and Hytrel can be obtained when RF sealed, a Hytrel coated Tedlar film will be utilized as the face tape.

Data in References 3 and 4 indicates that an ultimate strength of 260 lb/inch (455 N/cm) in both directions can be attained with a Kevlar fabric weight of 1.8 oz/yd^2 (61 g/m^2) plus film and adhesive weight of 1.7 oz/yd^2 (58 gm/m^2). A total material unit weight of 3.5 oz/yd^2 (119 gm/m^2) was derived from this basis. Increased strength is achieved for parametric study purposes by increasing the Kevlar weight in proportion to strength required and holding the film and adhesive weight constant.

3.3.3 Ballonet Material

At the present time, the most likely ballonet fabric will be a lightweight scrim reinforced film. The candidate scrim is a 40 denier, 80 x 53 count, polyester Leno weave which weighs 0.85 oz/yd^2. This scrim will be film transfer coated with polyurethane to obtain an air holding construction.

The overall construction should be light in weight (under 3.0 oz/yd^2) and easily fabricated by use of RF sealing techniques.

3.4 ASCENT/DESCENT

The need for a very large (nearly 100 percent) ballonet is a unique design problem which has been accommodated as illustrated in Figure 3-3. With this ballonet concept, launch is accomplished with the ship horizontal and the helium contained in a compartment at the top of the ship to avoid sloshing and unbalance of the ship in the launch configuration. The ballonet is a diaphram separating the ship longitudinally into two equal portions. The chamber beneath the diaphram is filled with air at launch and the ballonet presses against the top of the ship with no gas between it and the ship. The ship, while horizontal, commences its ascent to altitude without propulsion by virtue of some excess aerostatic free lift from the helium charge. As the ascent progresses, the helium expands through a port into the chamber above the main diaphram and accumulates in the nose of the ship. This produces a nose up trim which gradually increases until the ship is nose up at about 85 degrees above horizontal. As the helium chamber above the diaphram continues to fill with helium, the center of buoyancy moves toward the tail of the ship thus bringing the center of buoyancy closer to the center of gravity and

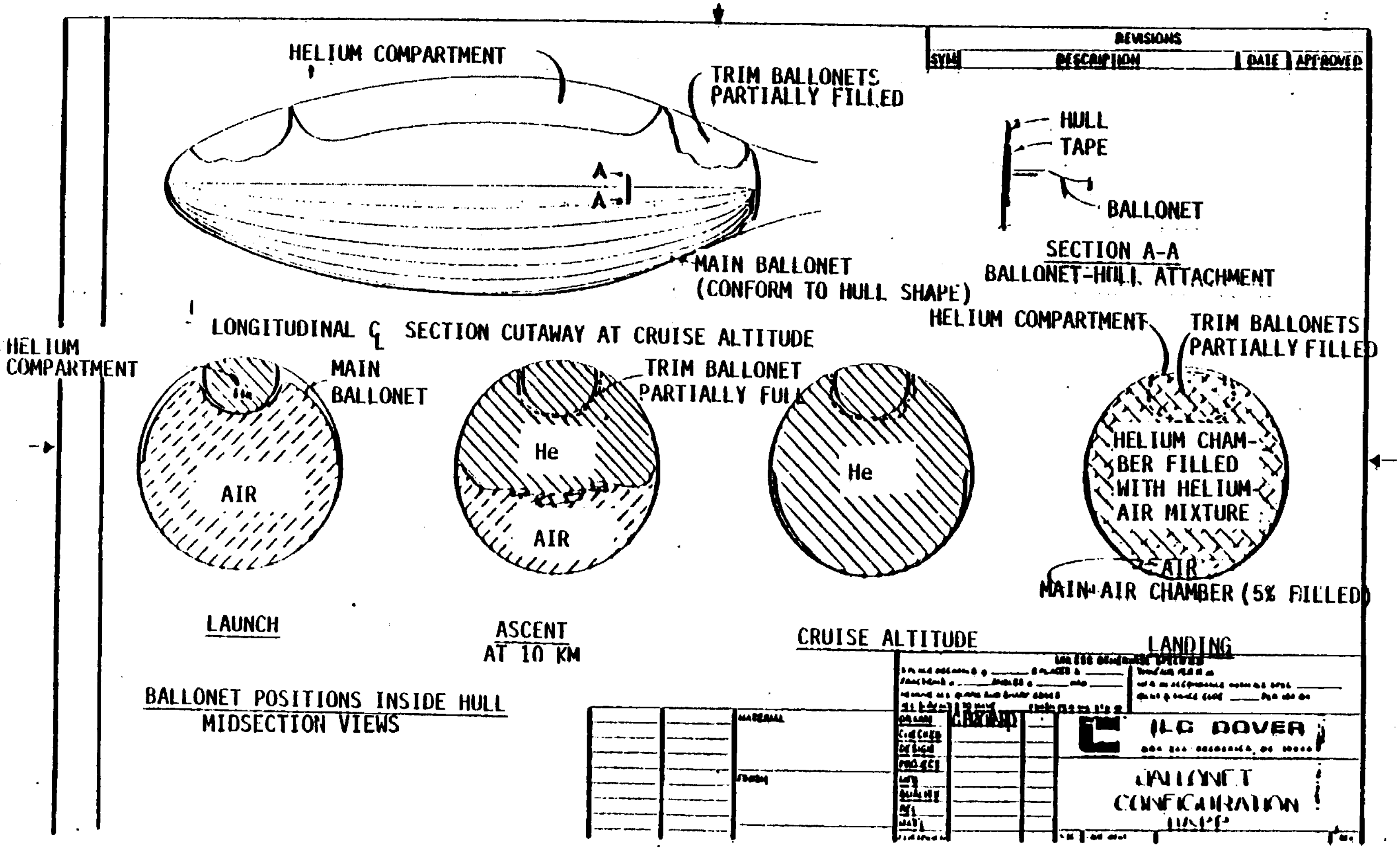


FIGURE 3-3, HAPP BALLONET CONFIGURATION

rotating the ship back toward a horizontal attitude. The rate of ascent is controlled at a reasonable value on the order of 150 meters per minute by valving helium or dropping ballast as necessary. Thus, for this operation, external ballast would be attached to the ship and compensated by additional helium which would be valved off when equilibrium is reached at pressure altitude. During cruise, fine trim control would be achieved by moving air between the fore and aft trim ballonets.

During ascent, the ship would typically encounter high tropospheric winds and would be blown some significant distance away from its desired station position. Upon reaching altitude, the ship would motor with the auxiliary engine to the station and once in the microwave beam the microwave power would take over.

For the descent operation, the ship would first proceed at altitude under auxiliary power to a calculated point where the ship can arrive at the landing spot without need for travel at low altitude. This is done because ship speed at low altitude is slower than at high altitude by a factor inversely proportional to the square root of the air densities (3.7 for 20 km to sea level). Thus, less fuel is required to make the travel distance at altitude.

The airship inflation gas management for descent is quite different from the ascent procedure. In order to fly the ship down in a controllable configuration, the air that must be added to the ship in order to maintain shape and pressure is pumped into the helium compartment. Thus a homogeneous lifting gas mixture is maintained inside the ship and the center of buoyancy remains near the center of gravity. This impure gas is removed and a new pure helium charge is loaded into the helium compartment before launch.

4.0 PARAMETRIC ANALYSIS DEVELOPMENT

Within the general concepts described, a parametric program was developed to analyze quantitatively the relationship of the various factors towards optimization of a final design.

The logic flow for the program is illustrated in Figure 4-1. The program listing is attached in Appendix A. The program is well annotated with remarks so it can be followed with some study. The principle considerations incorporated in the program are discussed below.

Fabric strength is adjusted to an average of three weights distributed over the hull to handle hoop stress as a function of radius, with a minimum hull fabric unit weight of 119 gm/m^2. This is the minimum weight practical from a manufacturing and handling point of view.

Design aerostatic lift is defined as the lift available at maximum superheat and superpressure (daytime). The ship is sized by the program for the lift to match the weight. At night the loss of aerostatic lift is compensated by generating aerodynamic lift, which impacts ship weight by size of the primary and auxiliary propulsion systems. A limitation is placed on the dynamic lift coefficient of 0.3 to avoid regimes where induced drag would be unduly high or flow separation might occur.

The aerostatic lift calculations are based on perfect gas law relationships. The internal pressure of the ship has significant effect on the mass of gas in the ship and thus on the aerostatic lift at altitude and is included in the calculations.

PARAMETRIC ANALYSIS LOGIC FLOW

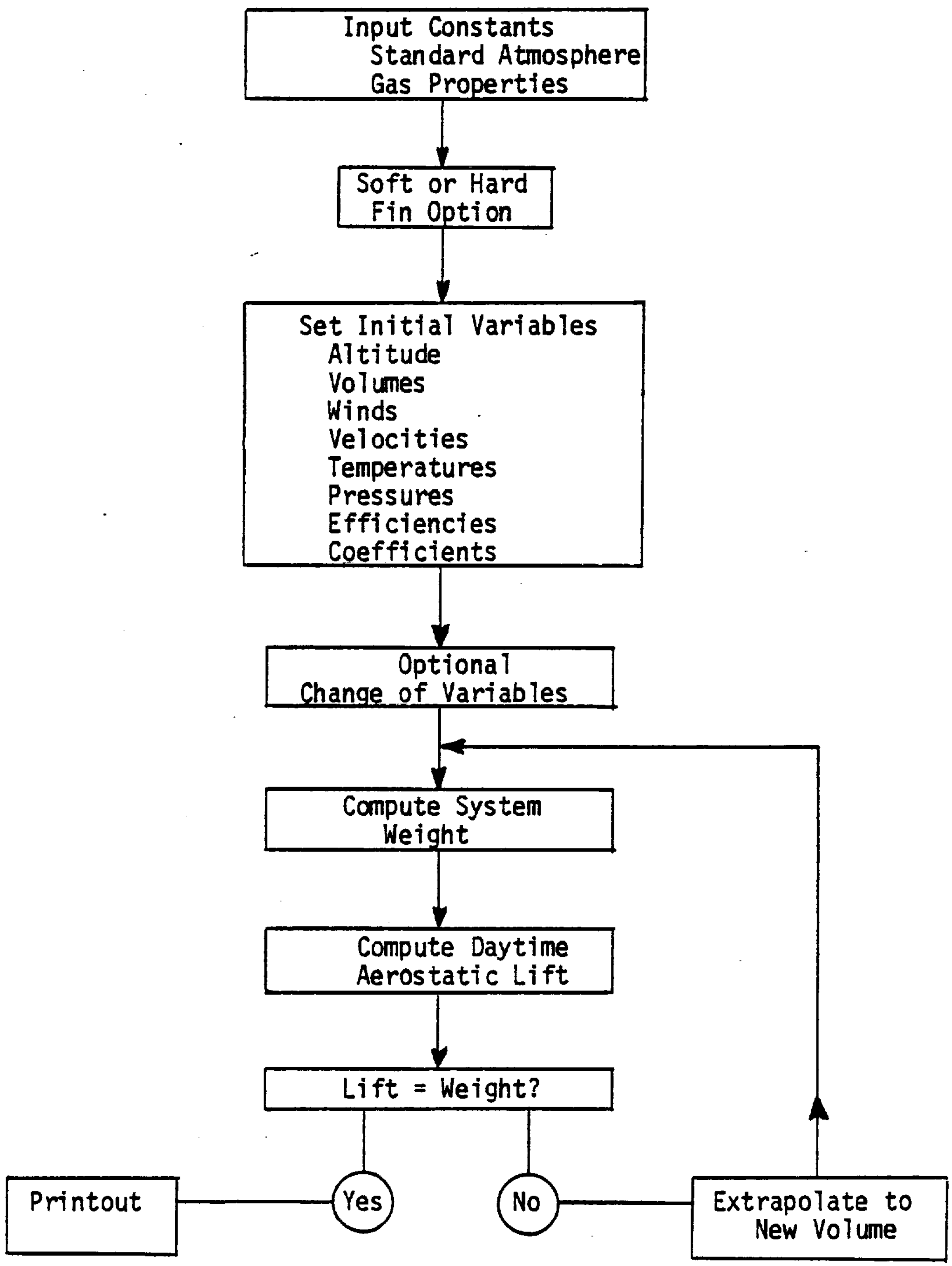


Figure 4-1 PARAMETRIC ANALYSIS LOGIC FLOW

The rectenna area is determined by the power required and includes consideration of the loss of power generation as a function of the cosine squared of the incident microwave power. The rectenna parametrics are based on distributing the rectenna area over the bottom of the ship so that its perimeter is at a constant angle of incidence to the microwave beam. Figures 4-2 and 4-3 are graphical presentations of these rectenna functions.

The program includes power losses (efficiency) for the propeller, gearbox, power transmission wires, rectenna, and auxiliary generator. The auxiliary engine fuel/power coefficient is included.

Hull fabric strength and weight parametrics are based on values for a Tedlar-Kevlar composite fabric tested for the Naval Air Development Center and reported in Reference 4.

Ballonet fabric strength and weight are based on current technological developments in fabrics used by ILC in aerostat construction.

Propeller weight estimates varied widely. For the HI-SPOT program, a weight parameter of 3.6 kg/kw was developed, while DSI in Appendix D, reports 0.4 kg/kw for the HAPP. Some research disclosed Reference 5, a Boeing Vertol empirical study of propellers for airship applications. Data of this reference was utilized to develop the propeller weight parametric as a function of airship volume and propulsion power.

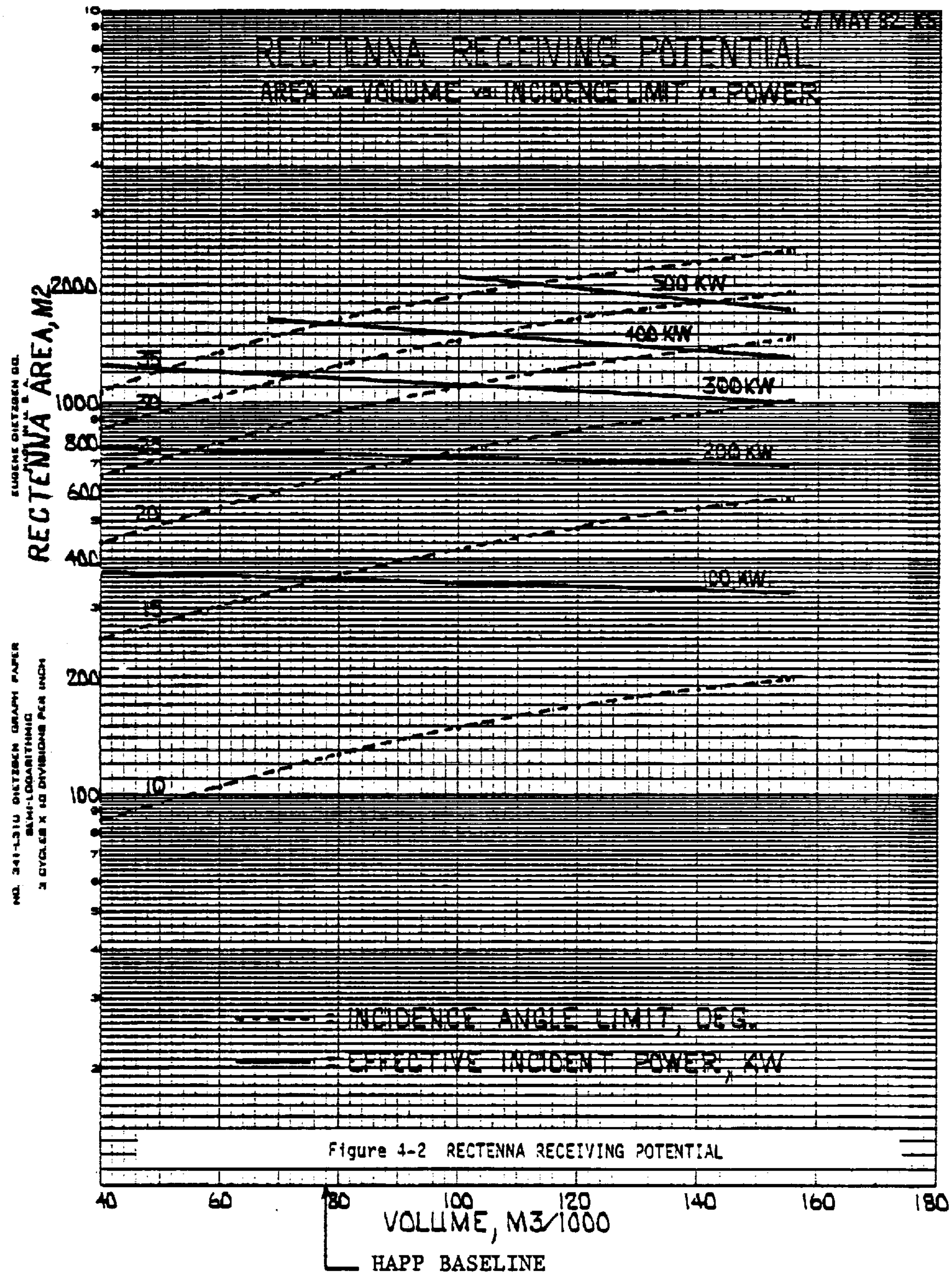


Figure 4-2 RECTENNA RECEIVING POTENTIAL

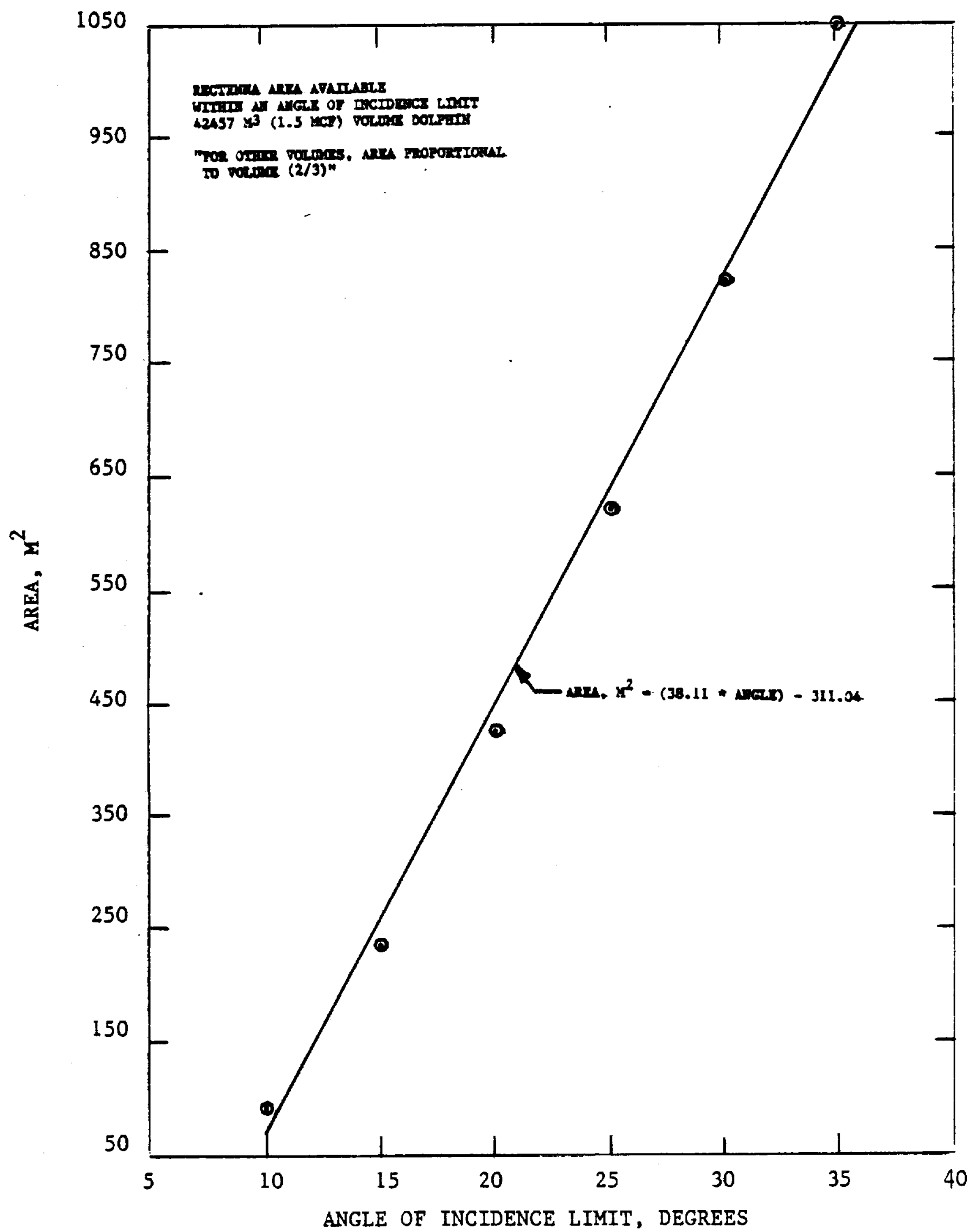


FIGURE 4-3, RECTENNA AREA AVAILABLE

Fuel consumption rate for a turbo-charged reciprocating engine with fossil fuel was adapted from the HI-SPOT program. Fuel tank weight parameter was developed from ILC experience in designing fabric fuel tanks.

The ship must have an auxiliary power system with on-board fuel in any case for flight between "on-station" and the launch/landing site. A trade-off situation arises "on-station" as to the weight of the microwave powered propulsion system for a given speed vs. the weight of an auxiliary system with on-board fuel to supplement microwave power when the wind exceeds the given velocity. Three operational scenarios were selected to study this trade-off. First, the "dedicated" mode in which microwave power alone is adequate for the highest wind expected. Second, the "coupled" mode in which microwave power is provided up to a certain "threshold" speed, and above that speed the ship stays on station by augmenting with auxiliary power. Third, a "divorced" mode in which the ship is allowed to blow off station above "threshold" wind speed and auxiliary power eventually bringing the ship back to station when the wind speed decreases. The program computes for either the "dedicated mode" or the "coupled mode" for power plant operations depending on whether or not input "threshold speed" equals "limit speed". Preliminary study established that the "divorced" mode was inefficient for most situations and it was eliminated from further consideration. The number of hours that the statistical winds blow above a specified "threshold" velocity was derived from References 1 and 2 and is presented as a parametric graph in Figures 4-4 and 4-5.

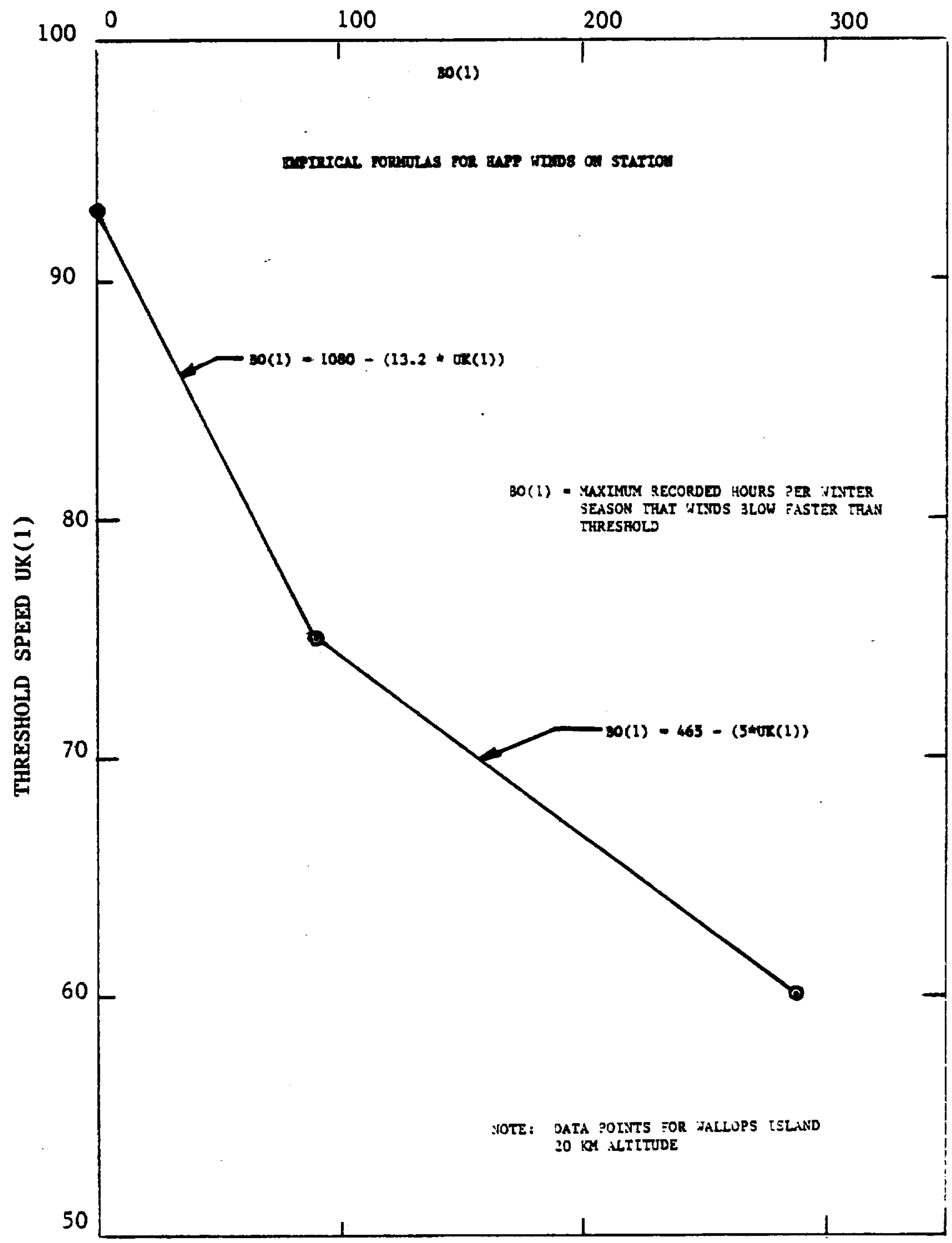


FIGURE 4-4, ON STATION WINDS

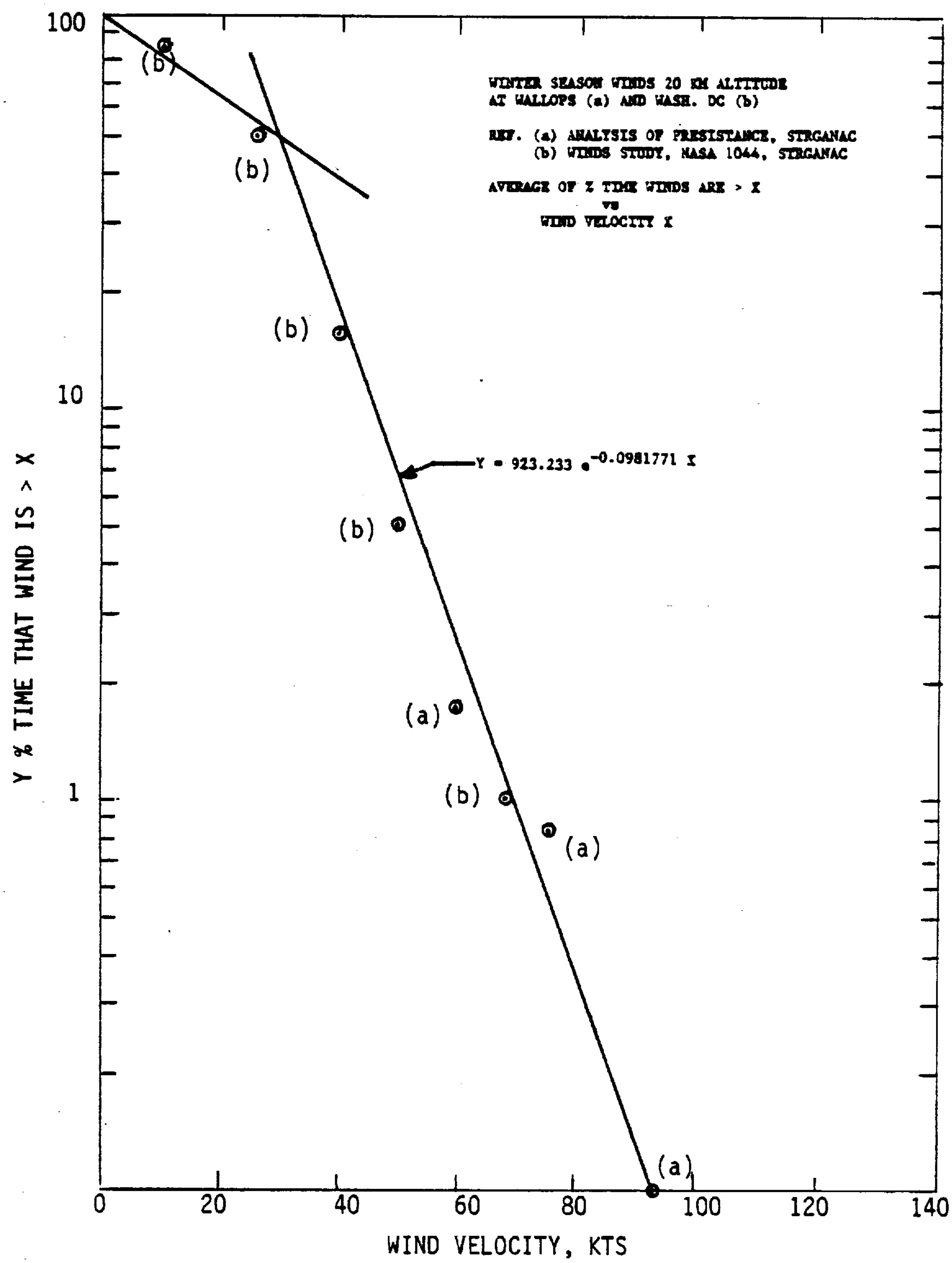


FIGURE 4-5, WINTER SEASON WINDS 20 KM ALTITUDE
(WALLOPS AND WASHINGTON, DC)

Figure 4-5 presents the average of winter season wind occurrences at Wallops Island, Va. and Washington, D.C., while Figure 4-4 presents the maximum number of hours the wind will exceed a given velocity. The curve of Figure 4-4 is based on three points for Wallops Island given Reference 2. In Reference 2 it is found that 93 kts is the maximum wind speed on record at 20km over a 10 year period. Review of data in Reference 1 for 14 locations in the contiguous USA indicates that winds at 20 km within the USA and not within line of sight distance (300 miles) of the northern border will be less than 93 kts at least 99.5% of the time. 93 kts was therefore chosen as a reasonable design point for the maximum winds to be experienced by HAPP.

The equations of Figure 4-4 are used directly in the program to provide the number of hours that the wind blows above a threshold velocity, thus requiring use of the auxiliary power plant on station. Figure 4-5 was used to derive an empirical equation for the "cube average wind" velocity above a given threshold velocity. The "cube average wind" is the equivalent wind for computing the power required over the wind spectrum at velocities above threshold. The equation for "cube average" wind is:

$$UK_{(4)} = (((27460 - (171.37 - UK_{(1)}) \text{ I } 2) \text{ I } .5) - 53.009)$$

Where $UK_{(4)}$ = average power wind of winds above threshold wind $UK_{(1)}$. Wind values knots. When threshold wind equals limit wind, the time above threshold is zero and Figures 4-4 and 4-5 do not apply.

5.0 PARAMETRIC STUDY INPUTS FOR BASELINE COMPARISONS

EFFICIENCIES:

Propeller = .90

This number is developed in Figure 5-1.

With favorable/interactions between the hull and propeller, it may be improved to .93.

Gearbox = .95 from standard practice

Primary Engine = .95 See Appendix A

Rectenna = .80 from Raytheon

Auxiliary Generator = .90 See Appendix A

Transmission Wire .98

With ribbon braid-wire thermal radiation adequately cools a 2% power loss in the wire.

WEIGHTS:

Propeller = f (Volume, Power). See App. A, line 3080 and Ref. 5.

Gearbox, kg/kW = .43 See Appendix D

Primary motor, kg/kW = 1.82 See Appendix D

Auxiliary Engine, kg/kW = 4.75 Developed from HI-SPOT, where the "Block" = 1.25, Turbo Charger 1.0, and heat exchanger = 2.5.

Auxiliary Generator kg/kW = 1.1 See Appendix D

Rectenna, kg/m^2 = 0.40 estimate

Water Recovery System kg/kW = 1.0 estimate

Fuel Tanks and supports kg/kW = .011 estimate for fabric tanks

Payload, kg = 680

Avionics, kg = 117.3

Ballast kg = 448.1 needed in nose for balance

Drive shaft kg/(kW m) = 0.0119 derived

PROPELLER EFFICIENCY

FROM MOMENTUM THEORY:

$$\eta_{ideal} = \frac{2}{1 + \sqrt{1 + \frac{V^{2/3}}{R_P} C_D}}$$

$$= \frac{2}{1 + \sqrt{1 + \frac{V^{2/3}}{R^2} \left(\frac{R}{R_P}\right)^2 C_D}}$$

$$= \frac{2}{1 + \sqrt{1 + 1.61 \left(\frac{R}{R_P}\right)^2 C_D}} \quad \text{FOR DOLPHIN}$$

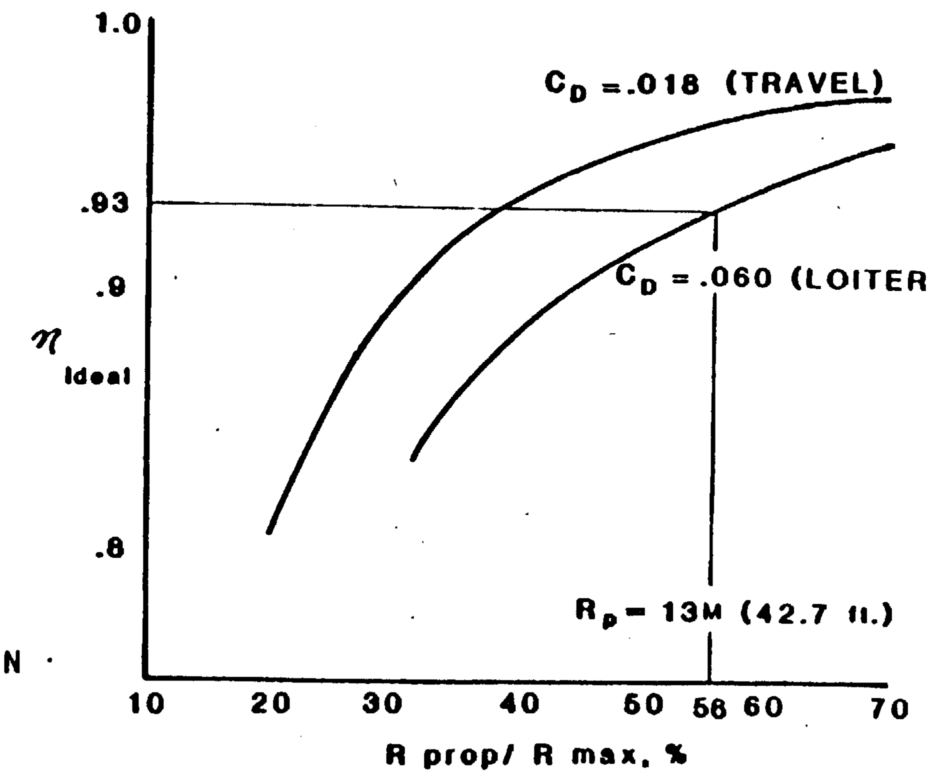


Figure 5-1 PROPELLER EFFICIENCY

Valves = f (volume, rate of ascent, pressure difference).

See Appendix A, line 3640

Blower = f (volume, rate of descent, pressure difference).

See Appendix A, line 3620

Electric Wire = f (length, resistivity, density, voltage, power, % loss). See Appendix B, line 3580

Hull fabric minimum, kg/m^2 = .11867 (See Section 3.0 Fabrics)

Fin surface fabric, kg/m^2 = .11867

Rib fabric, kg/m^2 = .07

Ballonet fabric, kg/m^2 = 0.085

MICROWAVE POWER DENSITY

kW/m^2 = 0.50 from Raytheon.

WIND AND AIRSHIP SPEEDS, Kts

Limit = 93

Threshold = 93

Aux. only = 55

Ascent and Descent Winds - See Figure 5-2

Cubed average of wind above threshold - See Section 4.0

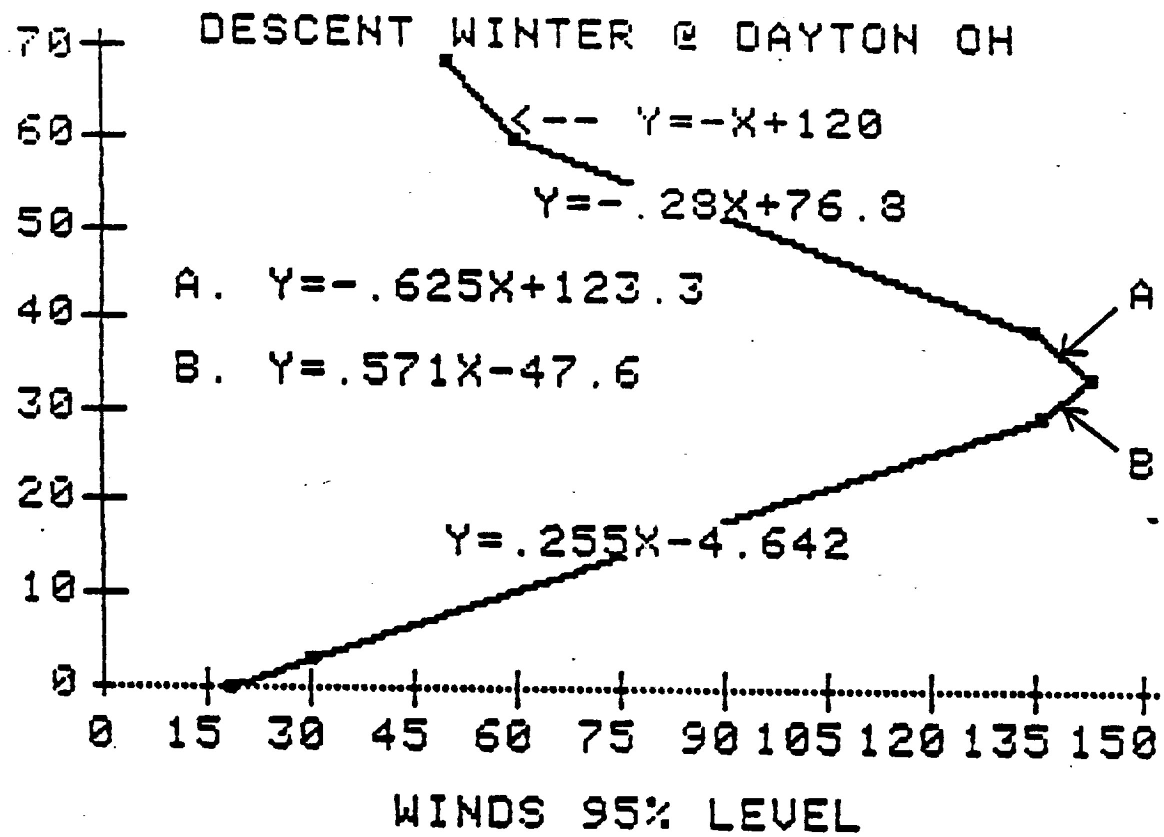
Hours that wind persists higher than threshold - See Section 4.0

SUPERTEMPERATURE

Superheat = + 16.7

Supercool = -17.2 Difference from ambient temperature

SAFETY FACTOR = 5



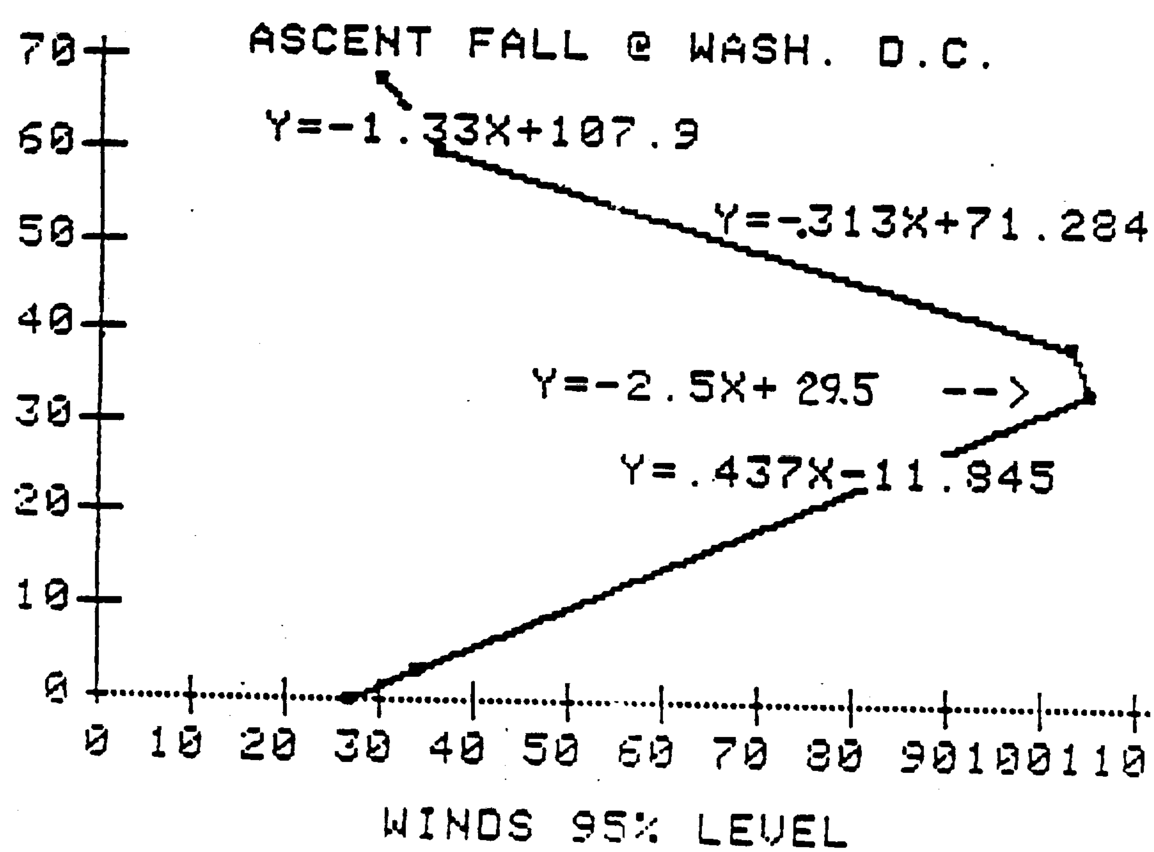


Figure 5-2 WIND PROFILE FOR WASHINGTON, D.C. AND DAYTON

DRAG COEFFICIENTS

Ascent, Descent = .028

At altitude = .018 for soft fins (.016 for hard fins)

Rate of ascent and descent = 150 m/min

Altitude = 20 km

POWERS

Avionics, KW = 1.13   See Appendix D

Payload, KW = 1.0

PRESSURES

Hull pressure, night, cm water = 2.5   for hull rigidity

DAY HULL PRESSURE OPTIONS

Pressure adjusts to fabric strength

Pressure as designated, fabric strength and weight adjusts, but not less than minimum fabric weight. Baseline value: 6.35 cm water.

MISCELLANEOUS

Hull surface area - from Dolphin geometry

Fin area - See Stability discussion, Section 7.6

Aerostatic and Aerodynamic Lift - See Section 2

Helium Purity = .95 (5% air contamination) Experience

Trim ballonet volume = .05 ship's volume Estimate

6.0 SPECIAL STUDIES

The three areas recommended for further study at the Parametric Review of July, 1981 were:

1) Thermal effects: Prediction and control of day/night temperatures were still under question.
2) Gusts: The magnitude of gusts which might be encountered and the structural methods of handling these gusts had not been determined.
3) Ballonet Configuration: A satisfactory arrangement to accommodate all flight requirements is not readily apparent.

6.1 THERMAL EFFECTS

A heat transfer analysis was developed by which thermal equilibrium for flight conditions can be calculated. The program for this analysis is listed in Appendix E. The analytical model is shown in Figure 6-1. Associated equations are shown in Figure 6-2.

Flight performance effects which indicated a need to minimize the day/night temperature swing are shown in Figures 6-3 and 6-4. Figure 6-5 shows a typical temperature distribution over the skin of the ship, day and night, clear and cloudy skies. Cloudy skies cause higher temperatures in the daytime because of solar reflection from cloud tops.

Analyses and experiments were conducted to determine hull skin construction which would minimize day/night thermal changes. The best construction concept is illustrated in Figure 6-6 with absorptivity/emmisivity possibilities as low as 0.1.

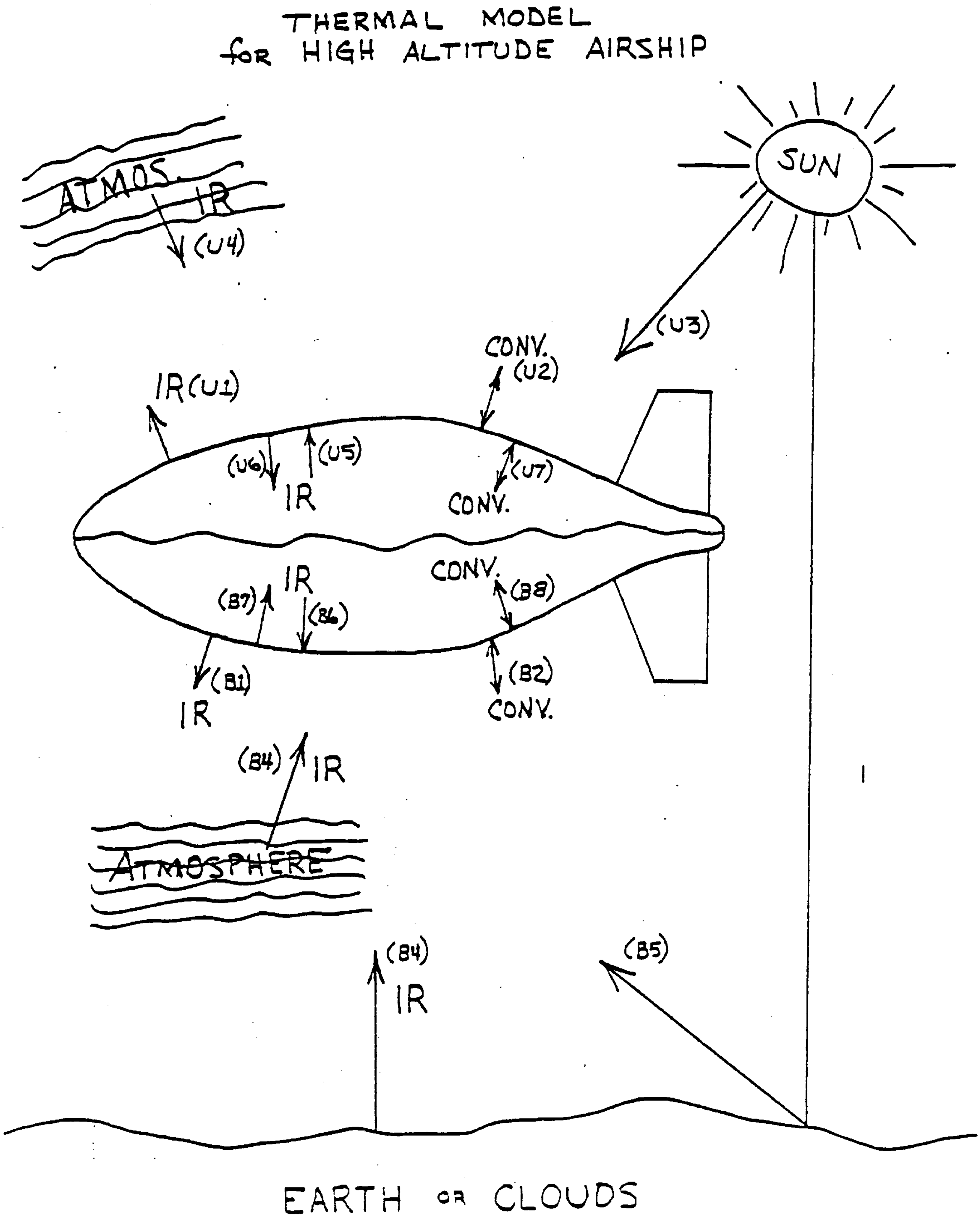


Figure 6-1 THERMAL MODEL FOR HIGH ALTITUDE AIRSHIP

TOP HALF

$$U1 = -SE_1 T_T^4 A/2$$

$$U2 = H_1(T_A - T_T)^{4/3} A/2$$

$$U3 = F_S S_A A/\pi$$

$$U4 = SE_2 T_A^4 E_1 A/2$$

$$U5 = -B_7$$

$$U6 = -SE_3 T_T^4 A/2$$

$$U7 = H_2(T_G - T_T)^{4/3} A/2$$

$$Q_U = U_1 + U_2 + U_3 + U_4 + U_5 + U_6 + U_7$$

FOR SOLVING EQUILIBRIUM CONDITION
SET $T_G = (T_T + T_B)/2$ (AN APPROXIMATION)
AND $Q_U = Q_B$

BOTTOM HALF

$$B1 = -SE_4 T_B^4 A/2$$

$$B2 = H_1(T_A - T_B)^{4/3} A/2$$

$$B3 = SE_5 T_E^4 (1 - E_2) E_4 A/2$$

$$B4 = SE_2 T_A^4 E_4 A/2$$

$$B5 = F_S L S_A A/2$$

$$B6 = -U_6$$

$$B7 = -SE_6 T_B^4 A/2$$

$$B8 = H_2(T_G - T_B)^{4/3} A/2$$

$$Q_B = B_1 + B_2 + B_3 + B_4 + B_5 + B_6 + B_7 + B_8$$

NOTE: REF. 15 FOR L, U_4, B_4

SYMBOLS

EMISSIVITIES

- E_1 TOP FABRIC OUTSIDE
- E_2 ATMOSPHERE
- E_3 TOP FABRIC INSIDE
- E_4 BOTTOM FABRIC OUTSIDE
- E_5 EARTH
- S STEFAN-BOLTZWAN CONSTANT

SOLAR

- F_S FLUX
- S_A FABRIC ABSORBTEVITY
- L ALBEDO

CONVECTION

- H OUTSIDE COEFFICIENT
- H INSIDE COEFFICIENT

AREA

- A TOTAL SURFACE OF SHIP

TEMPERATURE °R

- T_A AMBIENT
- T_G GAS
- T_T TOP FABRIC
- T_B BOTTOM FABRIC
- T_E EARTH

Figure 6-2 THERMAL EQUATIONS

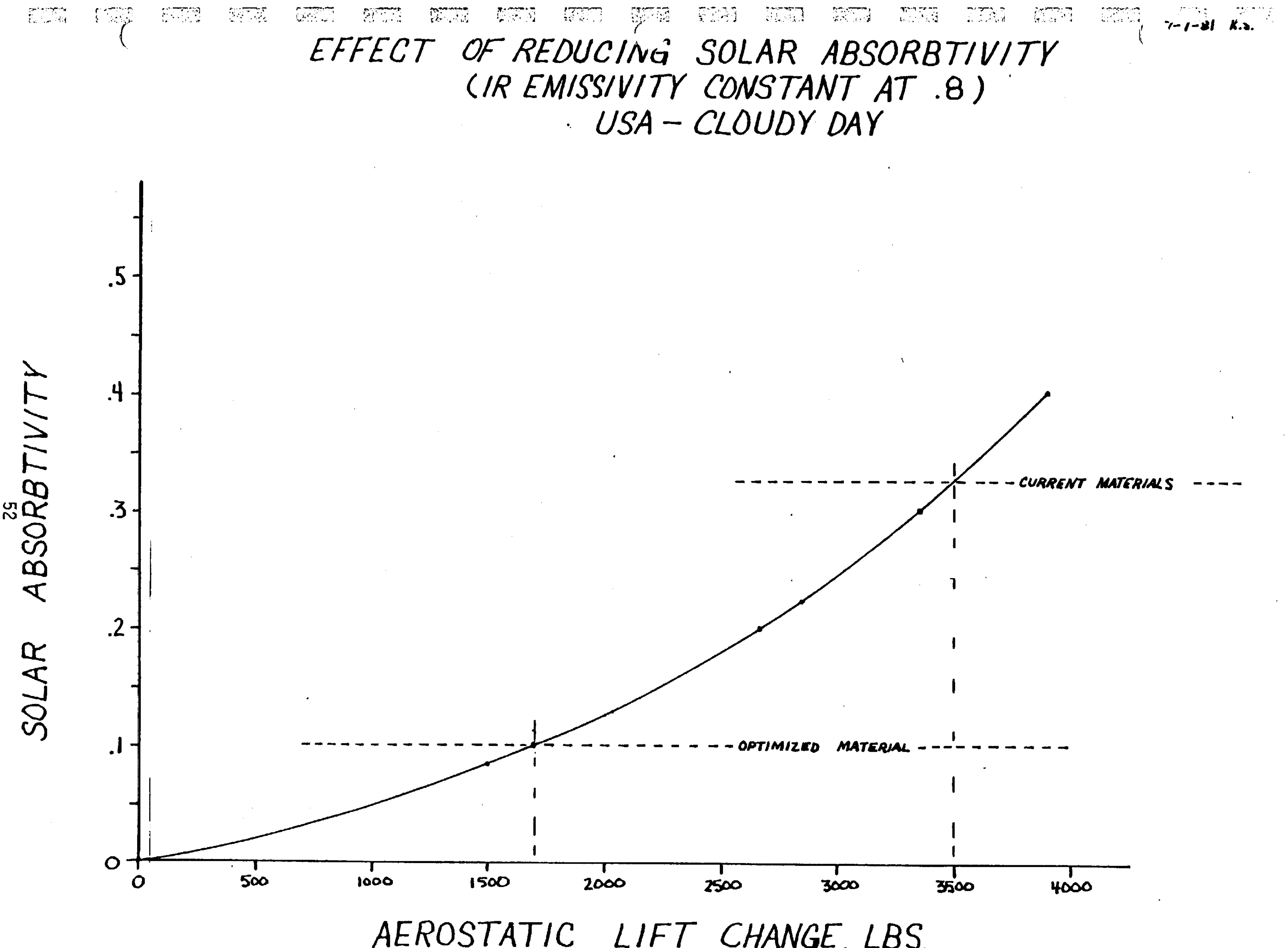


Figure 6-3 EFFECT OF REDUCING SOLAR ABSORPTIVITY

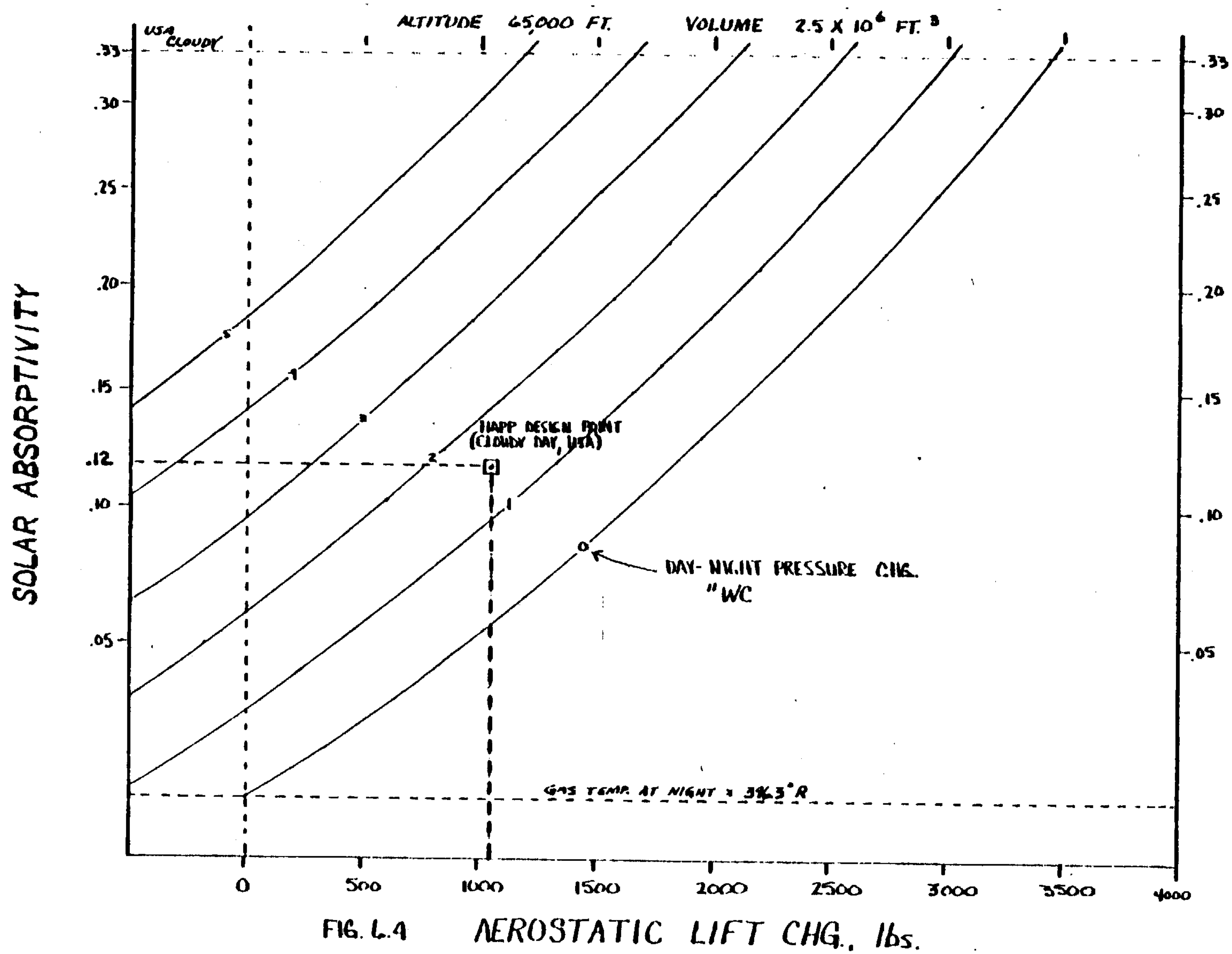


Figure 6-4 SOLAR ABSORPTIVITY vs LIFT CHANGE FOR VARIOUS SUPERPRESSURES

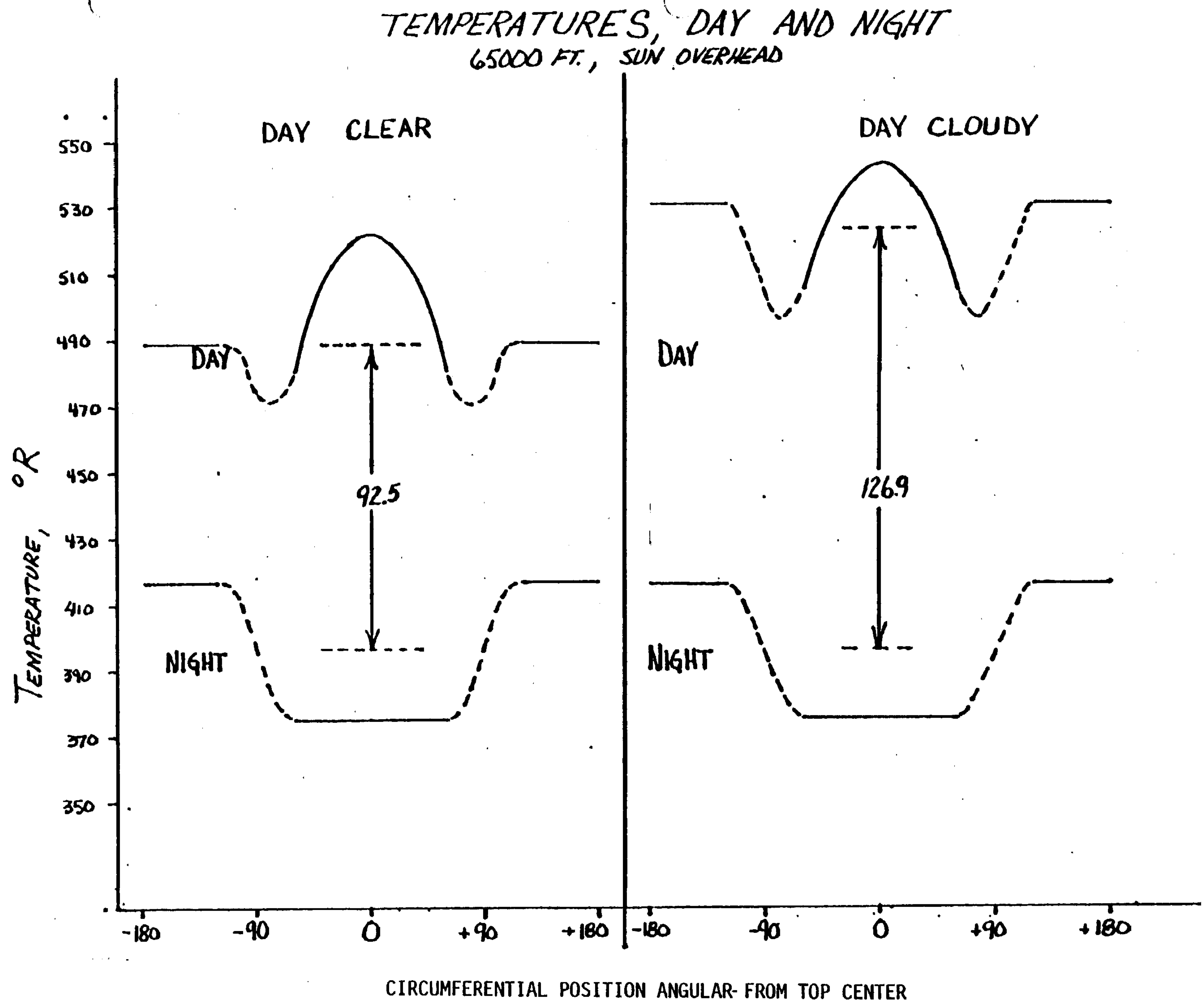


Figure 6-5 DAY/NIGHT TEMPERATURES

ILC DOVER
BOX 266-FREDERICA, DE. 19946

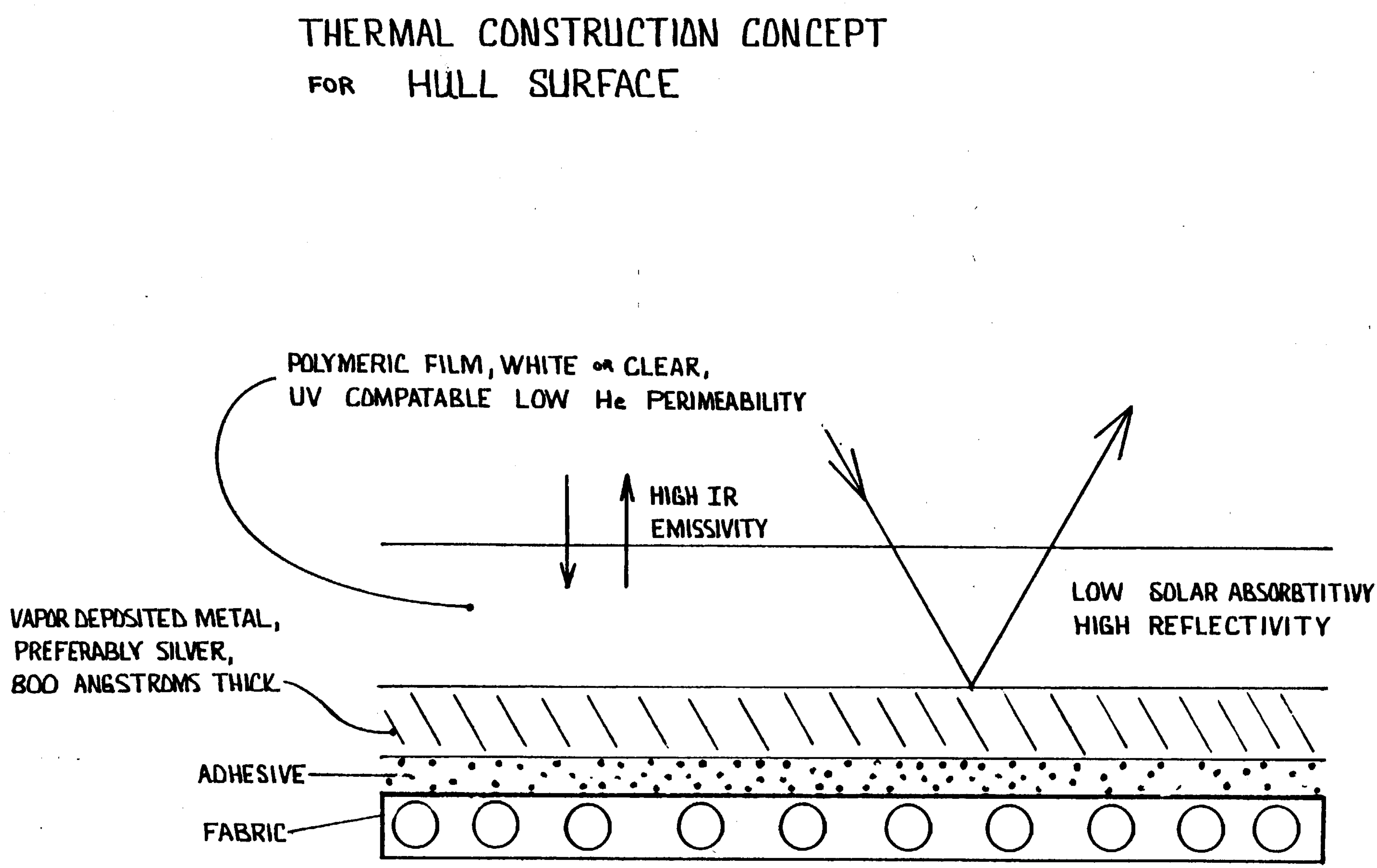


Figure 6-6 THERMAL CONSTRUCTION CONCEPT FOR HULL SURFACE

This possibility is further supported by Figure 6-7 (from Reference 6) for 1 mil Teflon on silver with an a/e of .05/.5 = .1. Samples of metallized Tedlar and Polyurethane films were procured from vendors and were tested for radiation properties by the thermal laboratory at NASA, Langley Research Center. Informal results received to date give an a/e of (.022/.590) = .037 for a clear Tedlar film with a silver backing. If this figure is verified, then temperature change problems for HAPP would become almost negligible.

In order to obtain data for verification of the analytical model and its inputs, a high altitude balloon flight experiment was arranged. A simulated airship was constructed of fabric with a 1 mil white Tedlar film, laminated with Hytrel adhesive to a Kevlar fabric substrate. The laboratory thermal values for the external surface were .796 for I.R. emissivity and .33 for solar absorbtivity. This model airship was cylindrical, 4 feet long and 1 foot diameter, with spherical end caps. It was instrumented with thermistors inside to measure skin temperature around a vertical half of the perimeter every 30°, and three internal gas thermistors were mounted, one, 1 inch from the top, a second in the center and a third, 1 inch from the bottom. The model was flown on two balloon flights, each at about 100,000 ft. altitude, one flight at night and one flight during the day. Figure 6-8 shows the thermal model ready for launch.

A typical set of data from the night flight is shown in Figure 6-9 in comparison with an analytical prediction and shows good correlation of gas temperature results. The top and bottom skin temperatures are

REPRESENTATIVE DIELECTRIC FILMS OVER METAL AND WHITE COATINGS

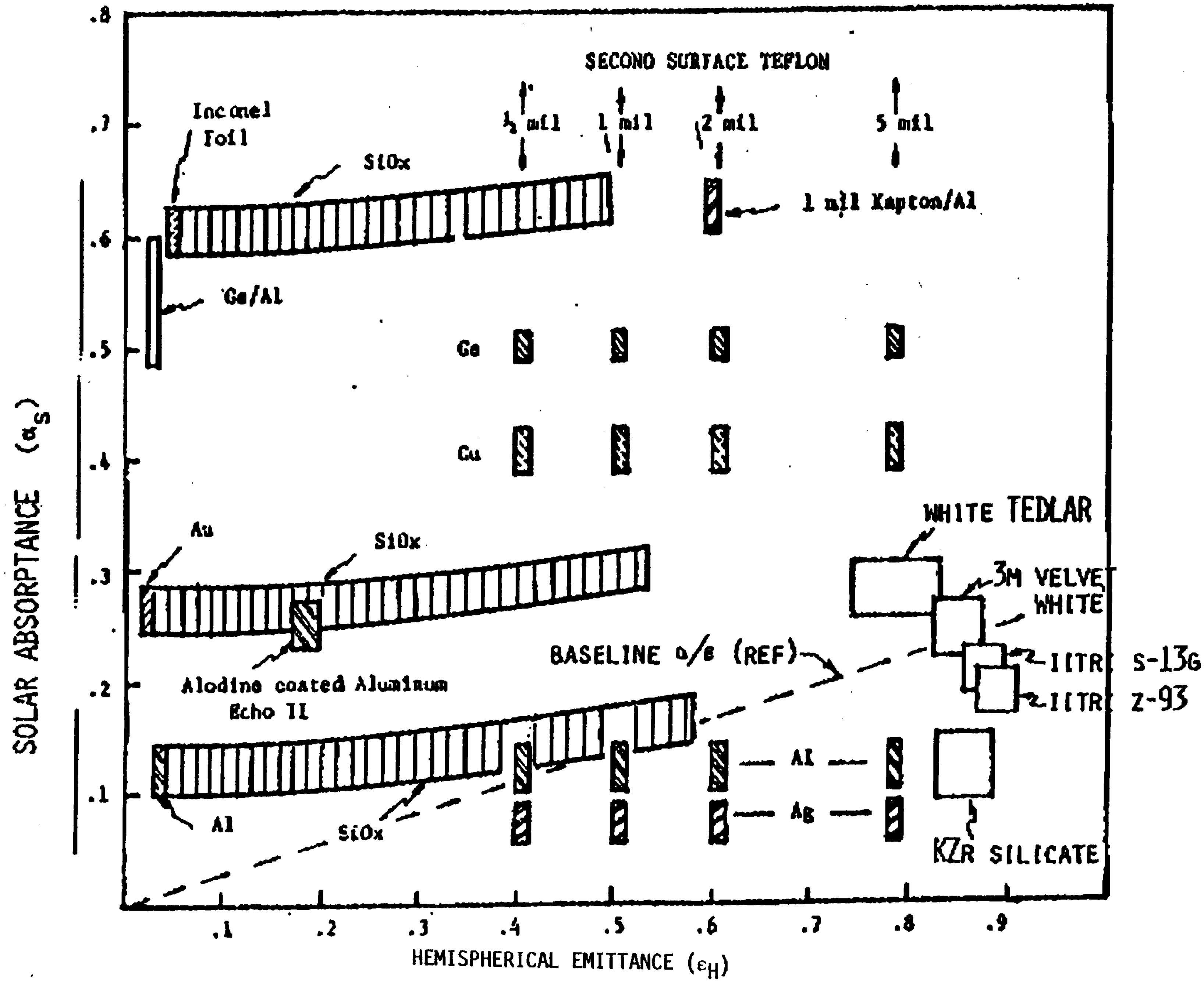


Figure 6-7 REPRESENTATIVE DIELECTRIC FILMS OVER METAL AND WHITE COATINGS

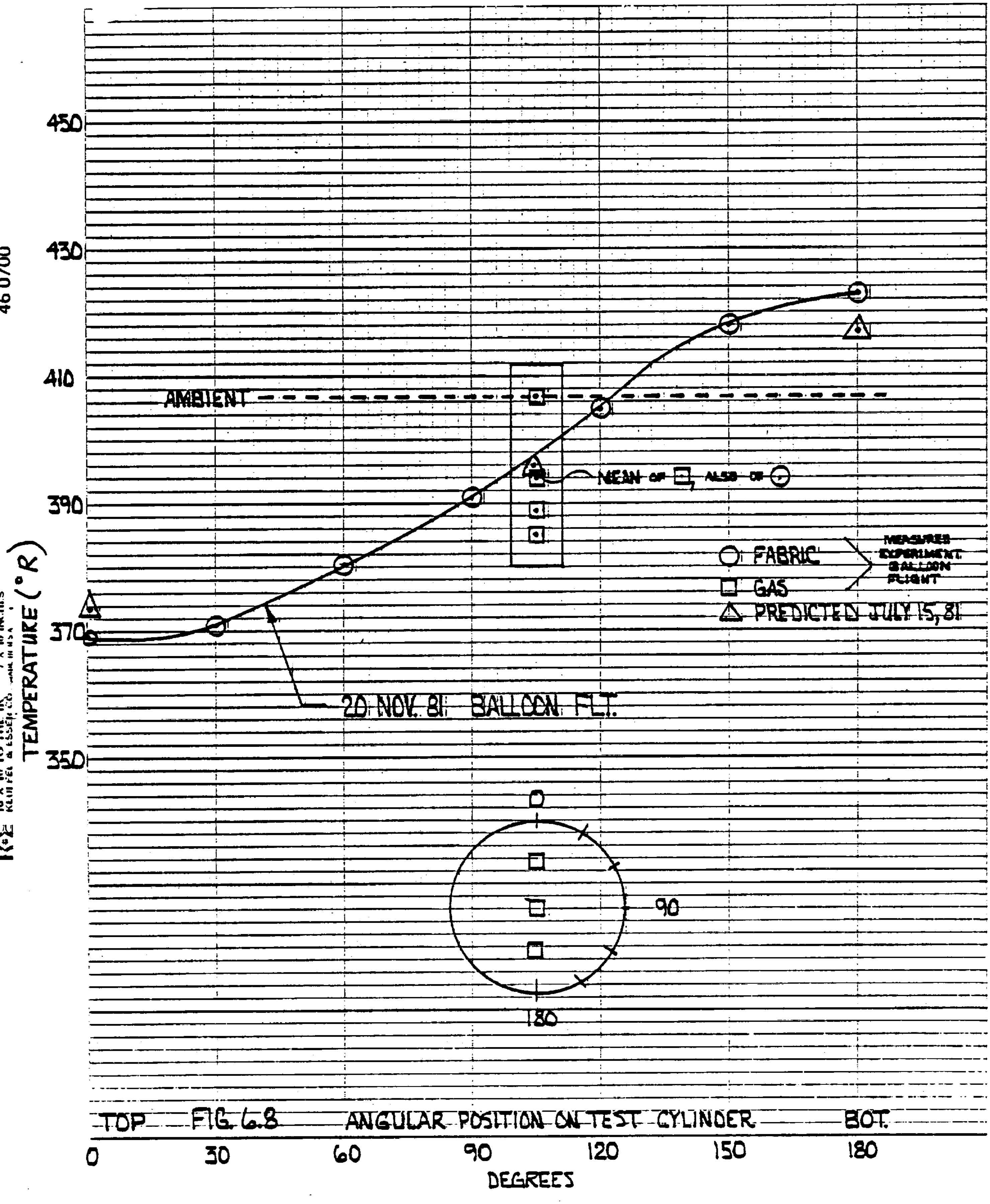


Figure 6-8 NIGHTTIME BALLOON DATA

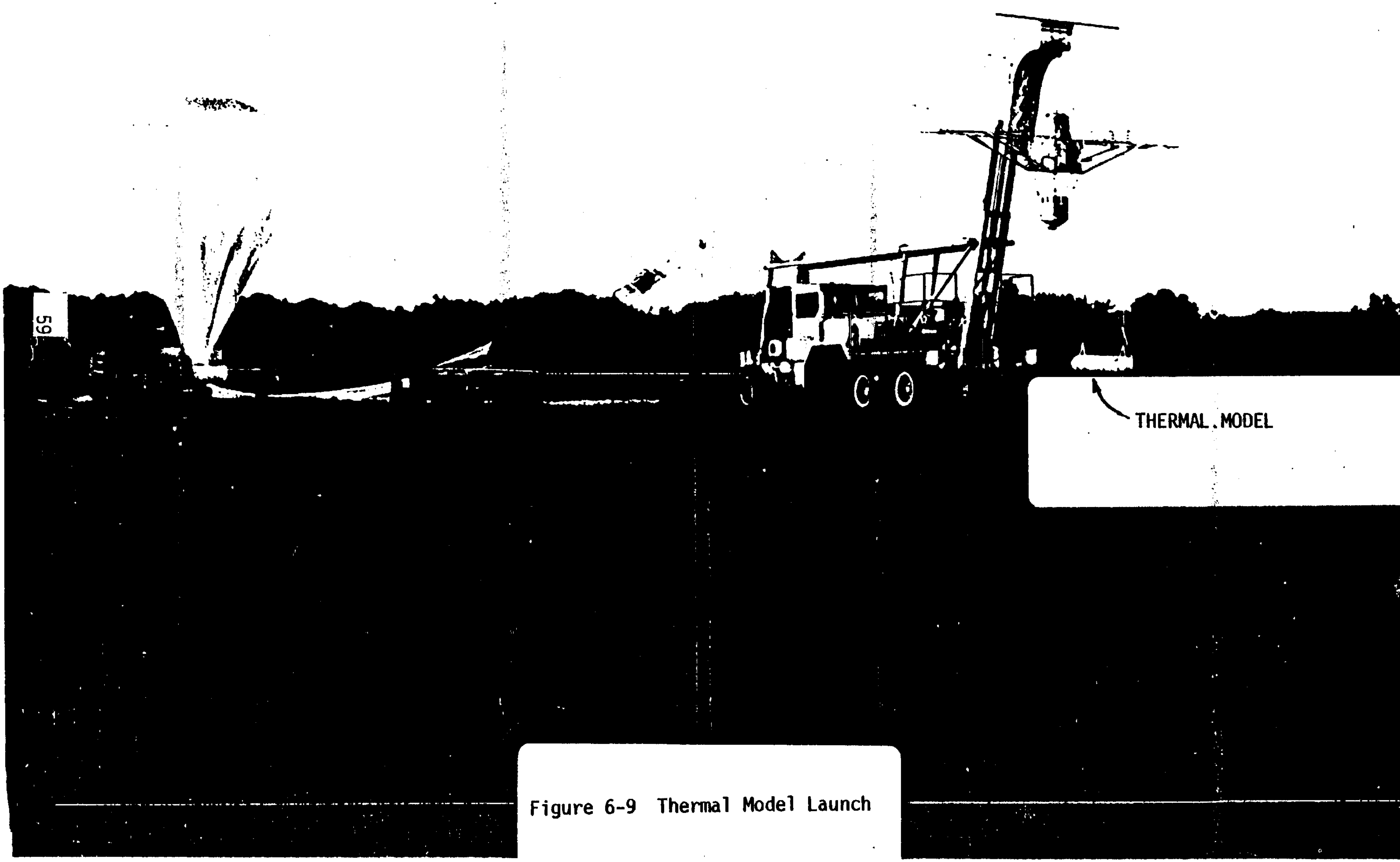


Figure 6-9 Thermal Model Launch

brought into closer agreement if the internal top to bottom heat transfer is reduced in the analytical model.

For the day flight, excellent correlation of analytical and flight model gas temperatures are obtained if outside surface solar absorptivity is set at .37 versus the laboratory value of .33. A set of daytime comparison data is as follows:

	Analytical Model °C	Flight Model °C
Skin Hot Spot	21.7	27.7
Gas	13.5	13.2
Skin Cold Spot	5.3	3

For both day and night, the analytical model gives a smaller difference of top and bottom temperatures than the flight model. However, gas temperature correlation is excellent and the analytical assumption that gas temperature is equal to the average of hottest and coldest skin temperatures is verified.

6.2 GUSTS AND BENDING MOMENTS

The research and evaluation of gusts and bending moments is reported in Appendix F. The conclusions of the work are summarized as follows:

The gust environment for launch or landing is selected as a maximum 17 kt gust superimposed on a steady 10 kt wind, the critical altitude being 300m (Ref. 3 and 4). Thus, launch and landing times must be chosen when winds are within this limitation.

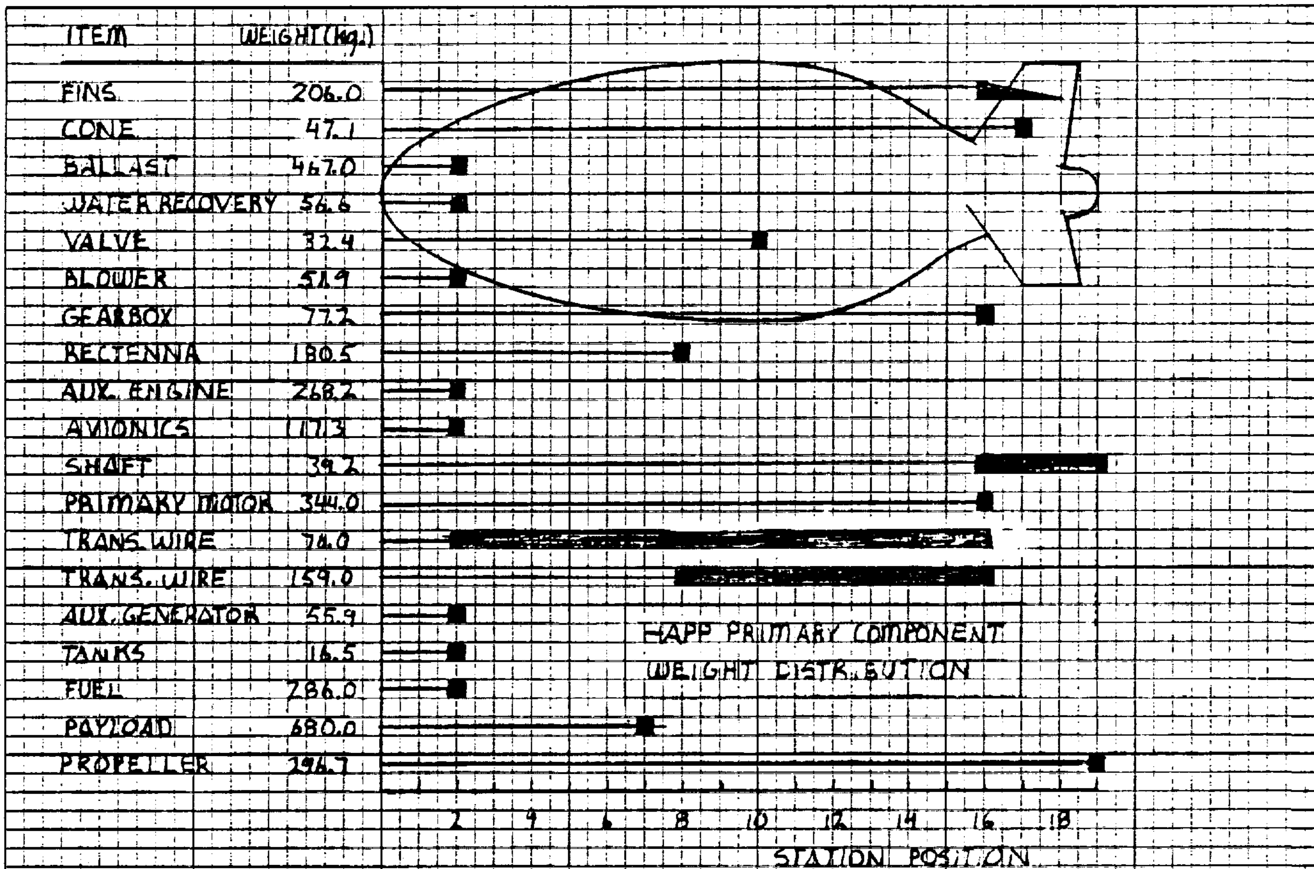
The force and bending moment analyses in Appendix F indicate that in the critical altitude regions, the combination of both static and aerodynamic bending moments maximums can be sustained by the hull with an internal pressure of 3.1 cm water. As will be seen later in the report, the hull will be capable of at least 6cm water pressure. Figures 6-10 and 6-11 present the pertinent data.

The analysis further shows that static bending moments can be sustained with an internal pressure of 1.7 cm water. Control moments at altitude are minimal. A minimum hull pressure of 2.5 cm of water provides satisfactory rigidity for the quiescent stratosphere.

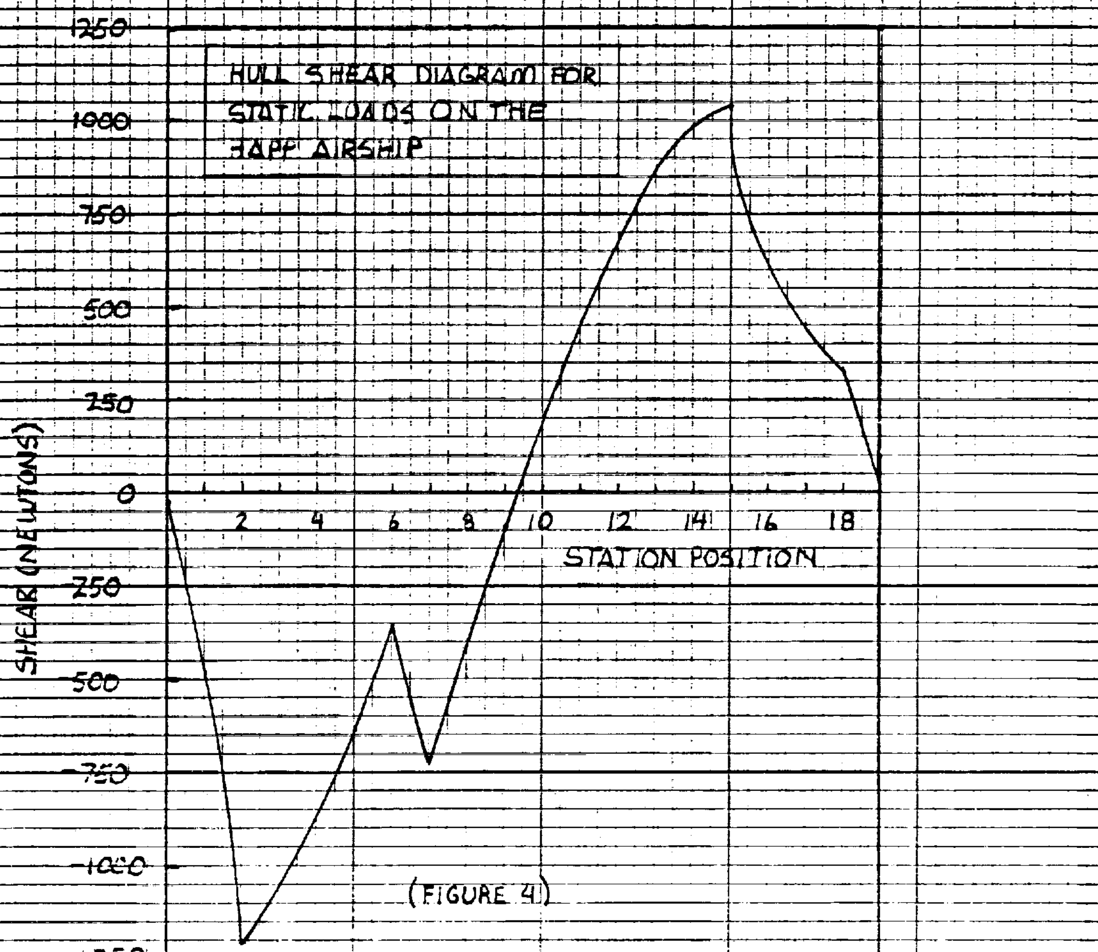
6.3 BALLONET CONFIGURATION

The ballonet configuration was in first concepts either too heavy or inadequate for control of center buoyancy. Project HI-SPOT had similar problems and for that project it was decided to use a large 100 percent ballonet and accept an ascent in a high nose-up position. This solution has been adopted in HAPP. Principle of ballonet operation during ascent is illustrated in Figure 3-2. The configuration consists of a "helium compartment" in the top of the ship which contains the initial charge of helium and prevents sloshing problems during ground handling and launch.

The main ballonet is a half hull shaped diaphragm which separates the ship horizontally into two chambers. The part beneath the diaphragm is the "air chamber" and is filled with air at launch pushing the diaphragm up against the helium compartment and the top skin of the hull. At maximum altitude the helium has expanded out of the "helium compartment" into the "helium chamber" above the diaphragm, pushing the diaphragm down

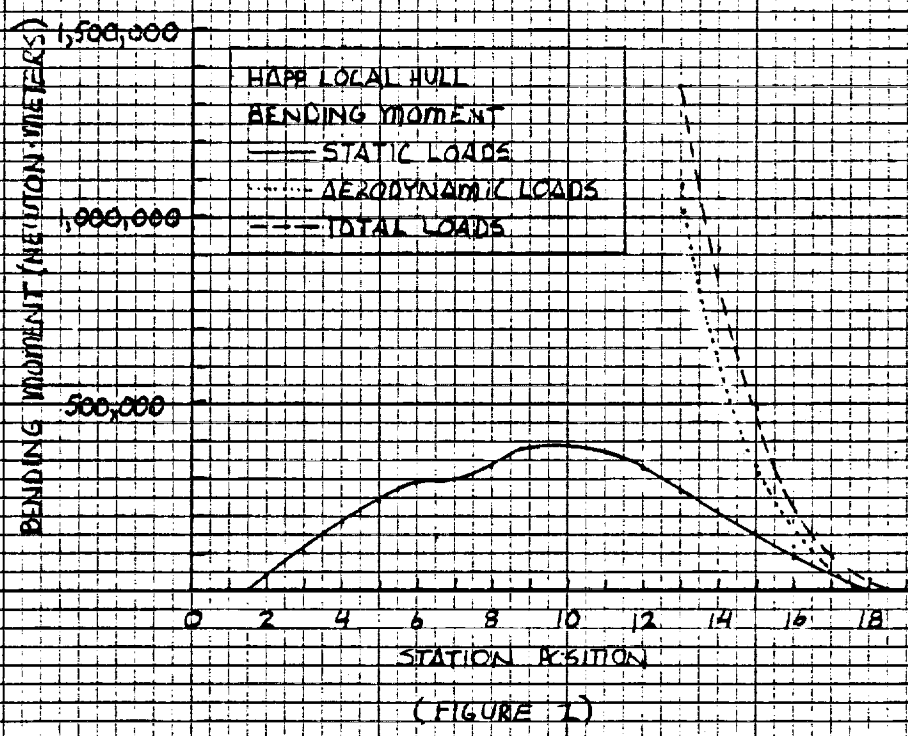


(FIGURE 3)



(FIGURE 4)

Figure 6-10 Static Loads



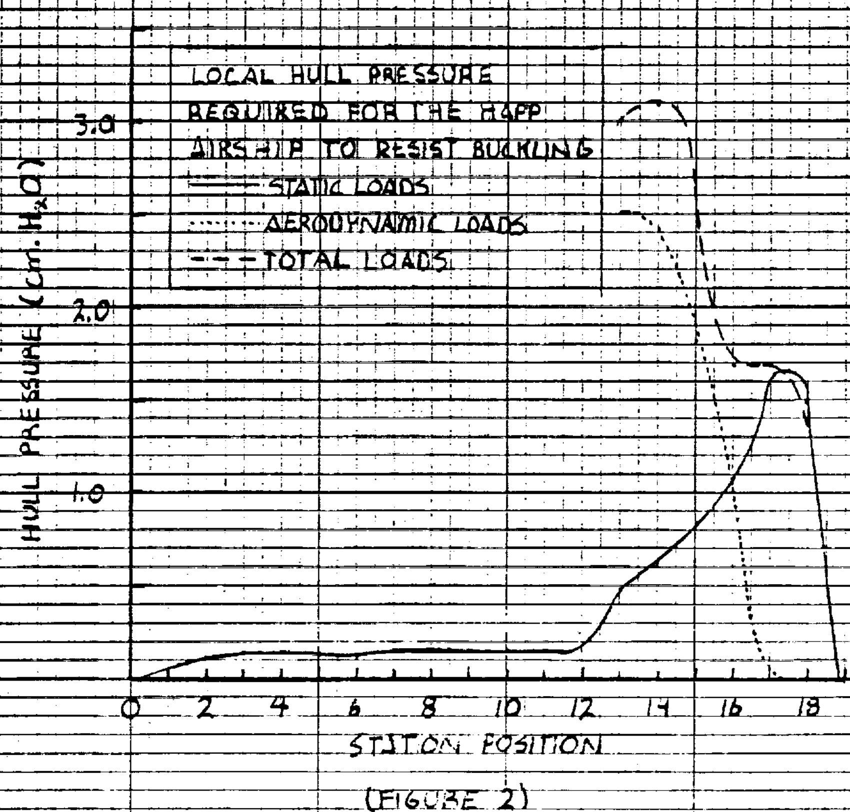


Figure 6-11 Bending Moments and Hull Pressure

flush against the inside bottom of the ship and against the inflated canopies of the payload and utility compartments.

Trim ballonets fore and aft are located in the top of the ship for fine pitch trim during controlled flight.

7.0 PARAMETRIC STUDY RESULTS

The parametric trends are presented in two sections. This section deals with sensitivity of mission performance to various parameters. Appendix E presents thermal parameter effects on gas temperature.

Figure 7-1 is a printout of the airship and mission characteristics for the "Baseline" configuration. The inputs for the baseline are those listed in Section 5.0.

In the parametrics that follow, unless otherwise indicated, only one input parameter at a time is varied with all other remaining at their baseline value. The "Baseline" condition is shown on all graphs by a square symbol.

Figure 7-2 indicates the adverse average affect of adding weight. The volume of the ship is determined by the intersection of the lift and weight curves, which in this case are for the baseline ship with volume 76193 m^3.

Figure 7-3a shows that if the limit speed (speed never to be exceeded) is decreased, the volume and power requirements decrease. The penalty for decreased limit speed is an increased probability of being blown off station.

Figure 7-3b shows the penalty for decreasing the threshold speed (speed powered by the microwave). The additional weight of auxiliary power plant fuel is much greater than microwave system weight savings.

HAPP 1906 20JN82 BASELINE

DOLPHIN SOFT FINS 31AUG82

VOL M↑3	ALT KM	RECT KW IN	AUXE KW	PRLI KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
77911	20	260.46	57.588	192.00	2440.0 47%	1771.0 34%	291.00 5%	680	448.07

SUPER HEAT = 16.7 K
CD = .018
SAFTEY FACTOR = 5
UNIT FAB WT=.11867 KG/M2
---WEIGHTS KGS:---

SUPERCOOL = -17.2 K
PROP CD = .0184356667
DAY PRESS (CM H2O) = 6.302
NITE PRESS= 2.5

ENVELOPE WT

TAPE WT = 102.847913
FIN SYS = 209.056342
CONE WT = 47
VALVE WT = 33.2199201

HULL = 1285.59891
BALONT SYS = 709.484238
BLOWER = 52.7260234

POWER SYSTEM WT

PROPELLER = 301.546801
GEAR BOX = 78.4351439
RECTENNA = 236.781963
AUXE ENG = 273.547453
AVIONICS = 117.3

SHAFT = 40.1574826
PRIME MOTOR = 349.454007
TRANS. WIRE = 242.720659
GENNERATOR = 57.0130482
TANKS = 16.875479
WATER RECOVERY=57.5889376

RECTENNA AREA =591.954906
MICROWAVE BEAM KW/M2= .5
LIFT = 5630.86101 KGS

ANGLE OF INCIDENCE LIMIT=18.5275151

WEIGHT = 5630.90987 KGS

VELOCITIES, KTS

LIMIT=93 THRESHOLD=93
AUX DESIGN=55 CUBE AVE>THRES=92.9983393

****

ASCENT PROFILE

POWER OFF ASCENT AT 150 M/MIN
TIME TO CLIMB TO 20 KM=2.22222222
BLOWOFF DISTANCE =283.860186 KM.
TIME TO AUXBACK TO STATION =2.78677038
FUEL USED ASCENT AND AUXBACK =30.4925577 KG

ON-STATION PROFILE

THRESHOLD SPEED OF 93 KTS EXCEEDED FOR 0 HRS /WINTER AT POWER AVE SPEED OF 93 KTS
FUEL WT = 0 KGS
SHIP SPEED ON PRIMARY POWER(THRESHOLD VEL)=93 KNOTS:LIMITING VEL = 93KTS
FOR 8 HRS @ 75 KTS RESERVE FUEL WT = 87.5351851

DESCENT PROFILE

POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 20 KM=2.22222222 HRS
FUEL FOR DESCENT = 24.3153292 KGS
AUXAWAY AT ALT TIME AND DISTANCE = 4.64311206 HRS AND -472.946983 KM
FUEL FOR AUXAWAY = 50.8044592 KGS
FUEL FOR BLOWER = 10.8028294 KGS
FUEL FOR 8 HR LANDING = 87.5351851 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 173.457803 KG

SUMMARY

TOTAL FUEL WT FOR MISSION = 291.485546

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TL(2)=.106931568

FIGURE 7-1, HAPP BASELINE CHARACTERISTICS

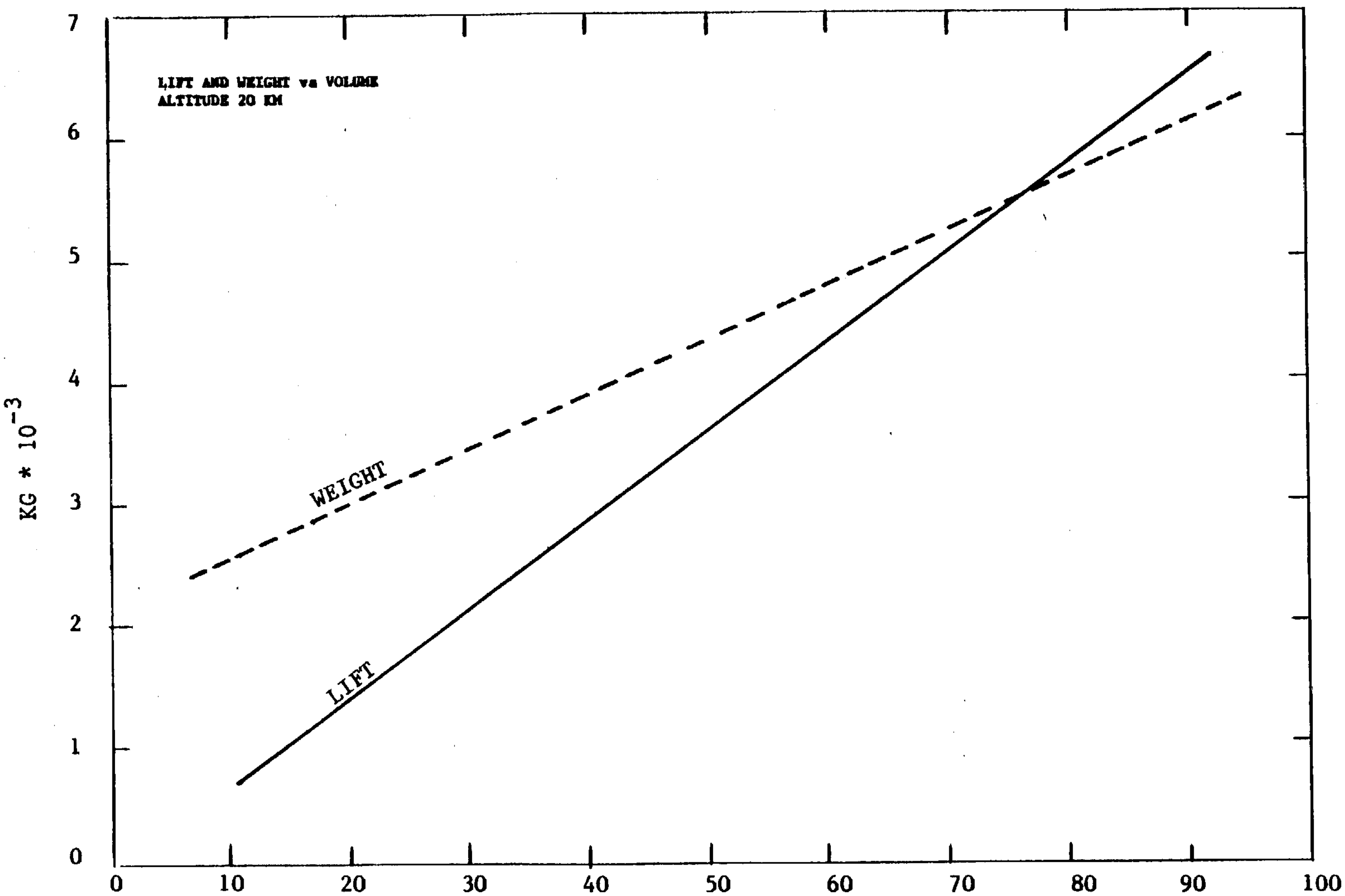


FIGURE 7-2, HAPP LIFT AND WEIGHT VARIATION WITH VOLUME

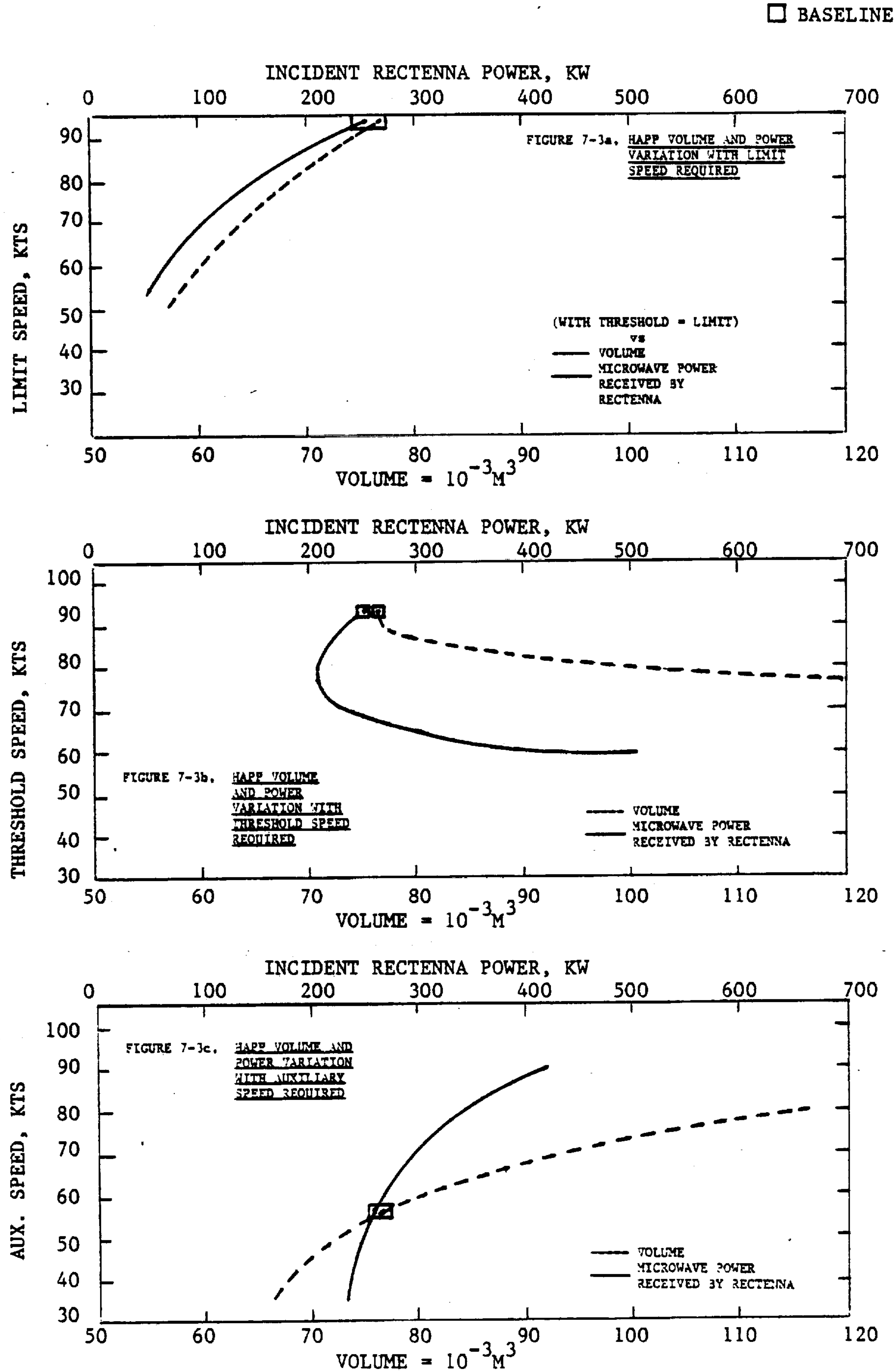


FIGURE 7-3, HAPP VOLUME AND POWER VARIATION

Figure 7-3c shows rapidly increasing penalty for increase in auxiliary capability. Fifty-five knots is chosen as baseline as a reasonable speed to fly against wind aloft. This speed corresponds to 15 knots at sea level which again is a reasonable minimum for landing operations. An auxiliary engine maximum speed of 55 knots limits launch and landing days to these on which winds aloft are sufficiently lower than 55 kts to permit flight to and from station.

Figure 7-4a shows the rather severe penalty for increasing the drag coefficient. At C_D = .028 the volume is over 100,000 m^3. These penalties may be alleviated by designing for a lower altitude as shown later.

Figure 7-4b shows importance of higher propeller efficiency. All power train efficiencies have similar effects.

Figure 7-4c gives effect of changing auxiliary engine fuel consumption rate.

Figure 7-5a shows increasingly adverse effects of superheat/cool, which is the day-night variation of gas temperature from ambient. When the day-night difference increases, aerodynamic lift requirement and consequent induced drag increases requiring greater primary and auxiliary power capability.

Figure 7-5b shows a sharp minimum volume and power at 6.35 cm water pressure. This pressure corresponds to the pressure that can be contained by the minimum acceptable weight fabric (118 gm/m^2). Above this pressure, fabric weight increases at a predominate rate. Below this pressure,

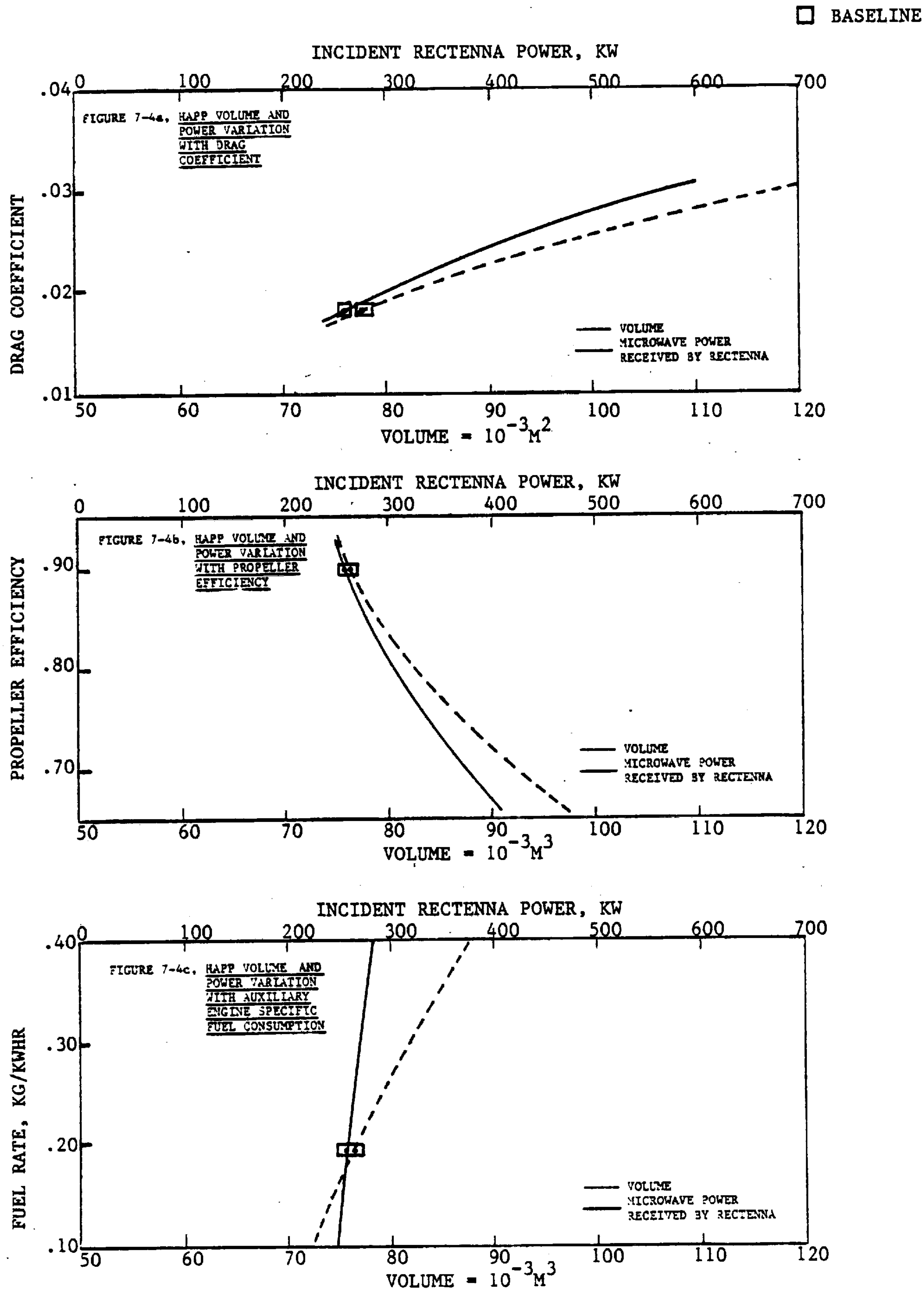


FIGURE 7-4, HAPP VOLUME AND POWER VARIATION

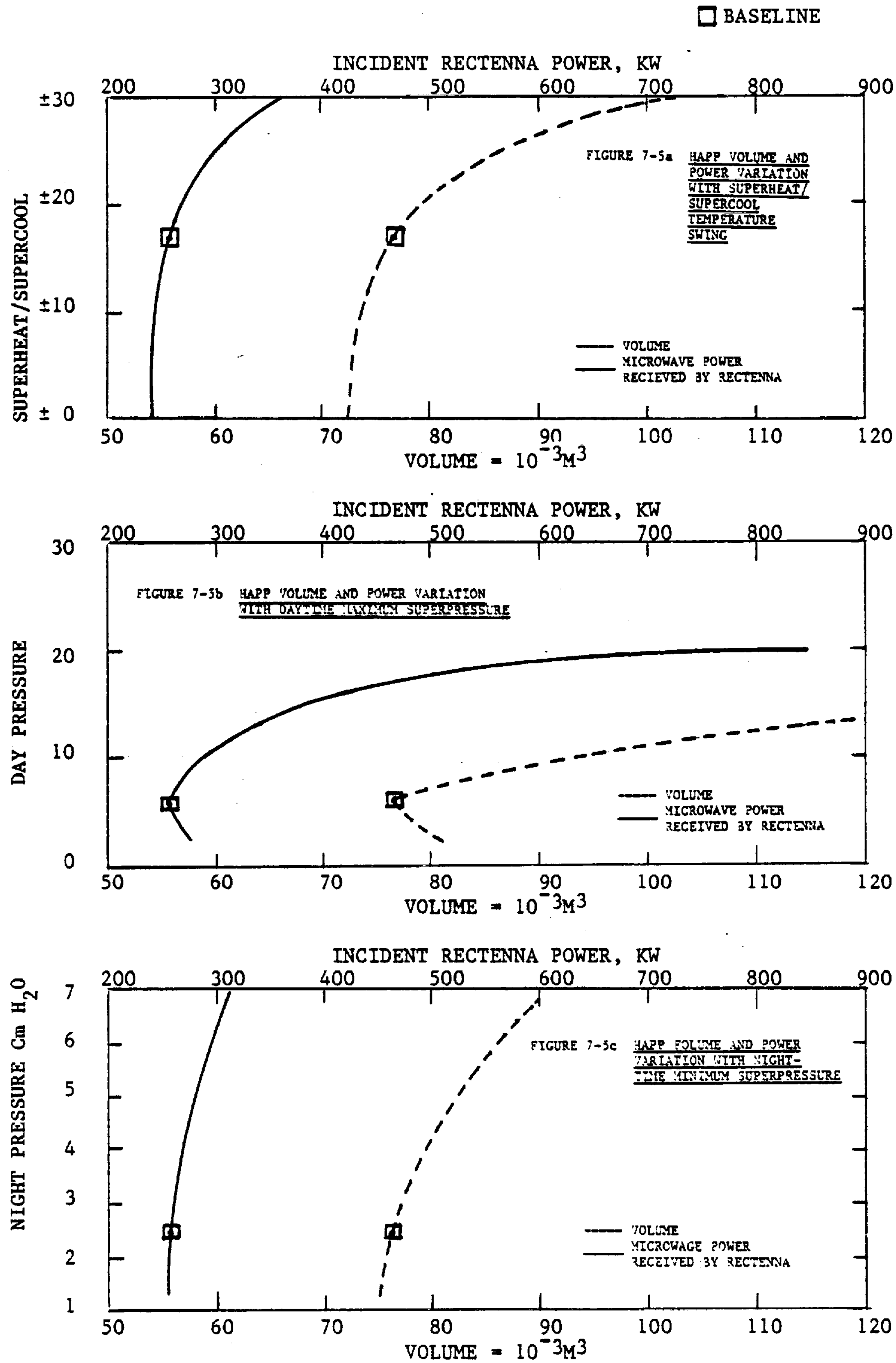


FIGURE 7-5, HAPP VOLUME AND POWER VARIATION

fabric unit weight is constant, so aerodynamic lift and drag increase at a predominate rate.

Figure 7-5c shows night pressure increase detracts from the superpressure available to offset day-night temperature changes resulting in increased aerodynamic lift and drag.

Figure 7-6a gives effect of changing payload weight. This curve applies for any weight change.

Figure 7-6b shows the drastic effect of hull fabric unit weight. In this parametric superpressure was increased as permitted by fabric strength but the weight effect predominated over aerodynamic lift savings.

Figure 7-7a shows a baseline ascent-descent rate of 150 m/min optimum for this configuration.

Figure 7-7b shows that helium purity has very significant effects. This is an area in which improvement should be possible.

Figure 7-7c, microwave power density influences rectenna size and weight. If two cross polarized antennas were used, the increased rectenna size effect can be estimated on this graph by tasking 1/2 the power density x cos 45 which equals .18 w/m^2, corresponding to a ship volume of 97000 m^3.

Figure 7-8 shows Drag coefficient vs Limit Speed with volume constant. It examines the effect of compensating for an increased drag coefficient

☐ BASELINE

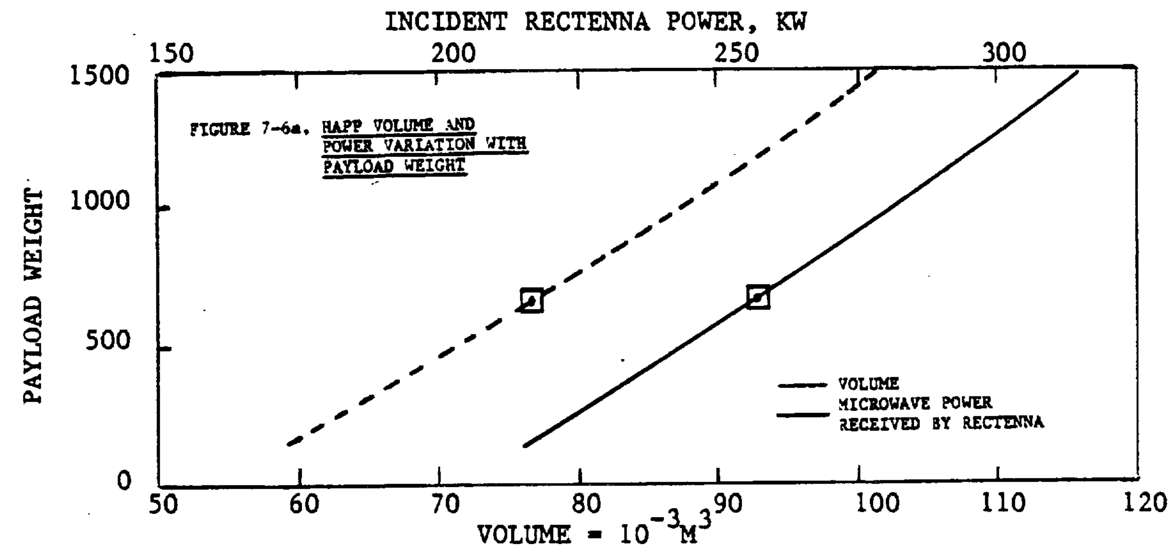


FIGURE 7-6a. HAPP VOLUME AND POWER VARIATION WITH PAYLOAD WEIGHT

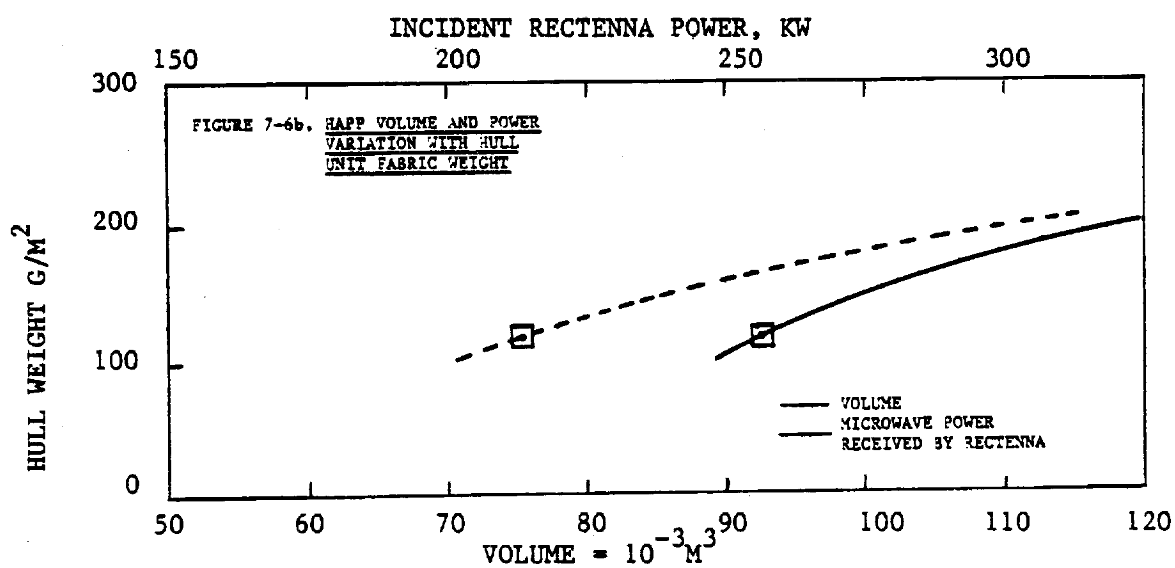


FIGURE 7-6b. HAPP VOLUME AND POWER VARIATION WITH HULL UNIT FABRIC WEIGHT

FIGURE 7-6, HAPP VOLUME AND POWER VARIATION

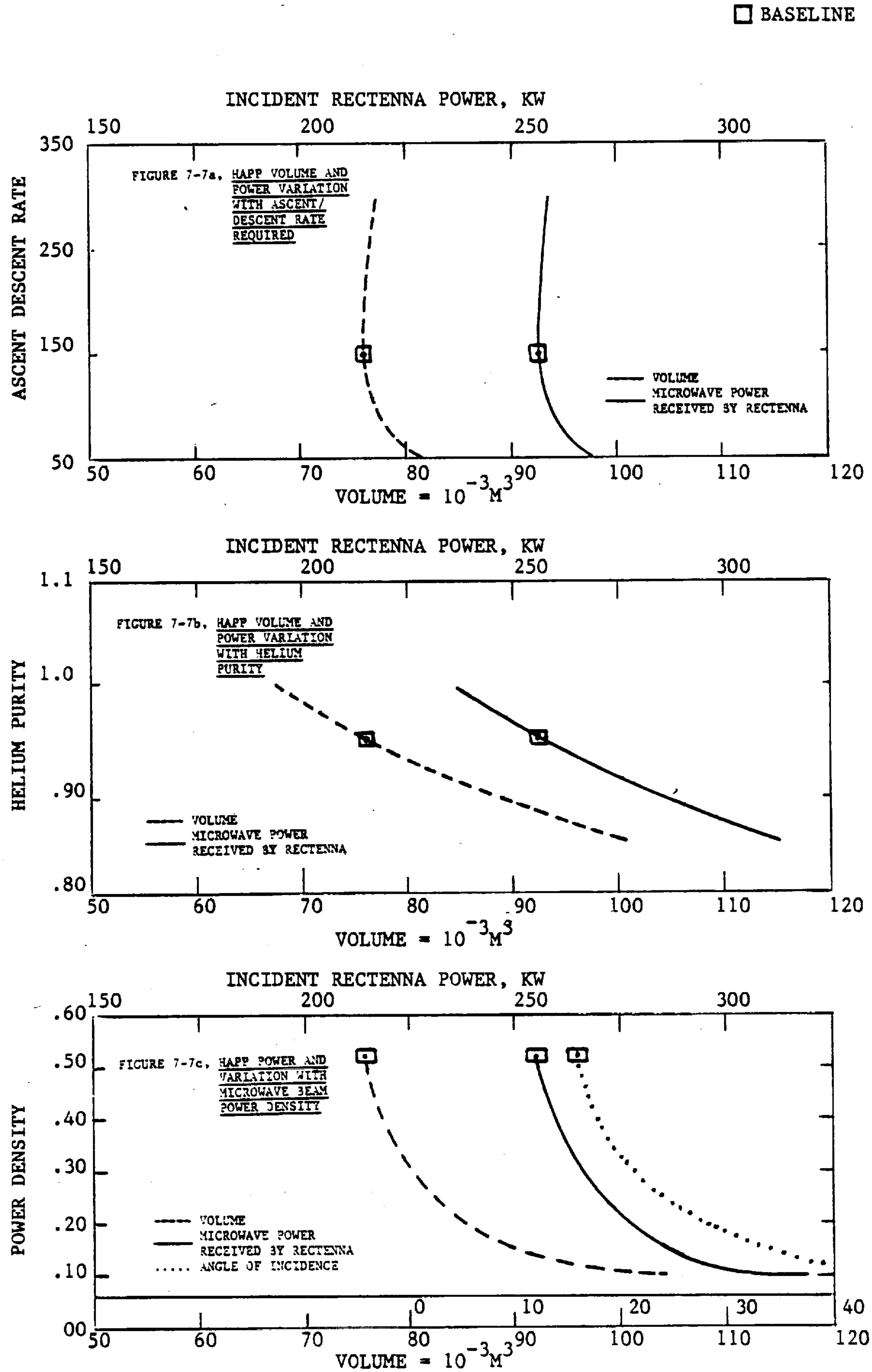


FIGURE 7-7, HAPP VOLUME AND POWER VARIATION

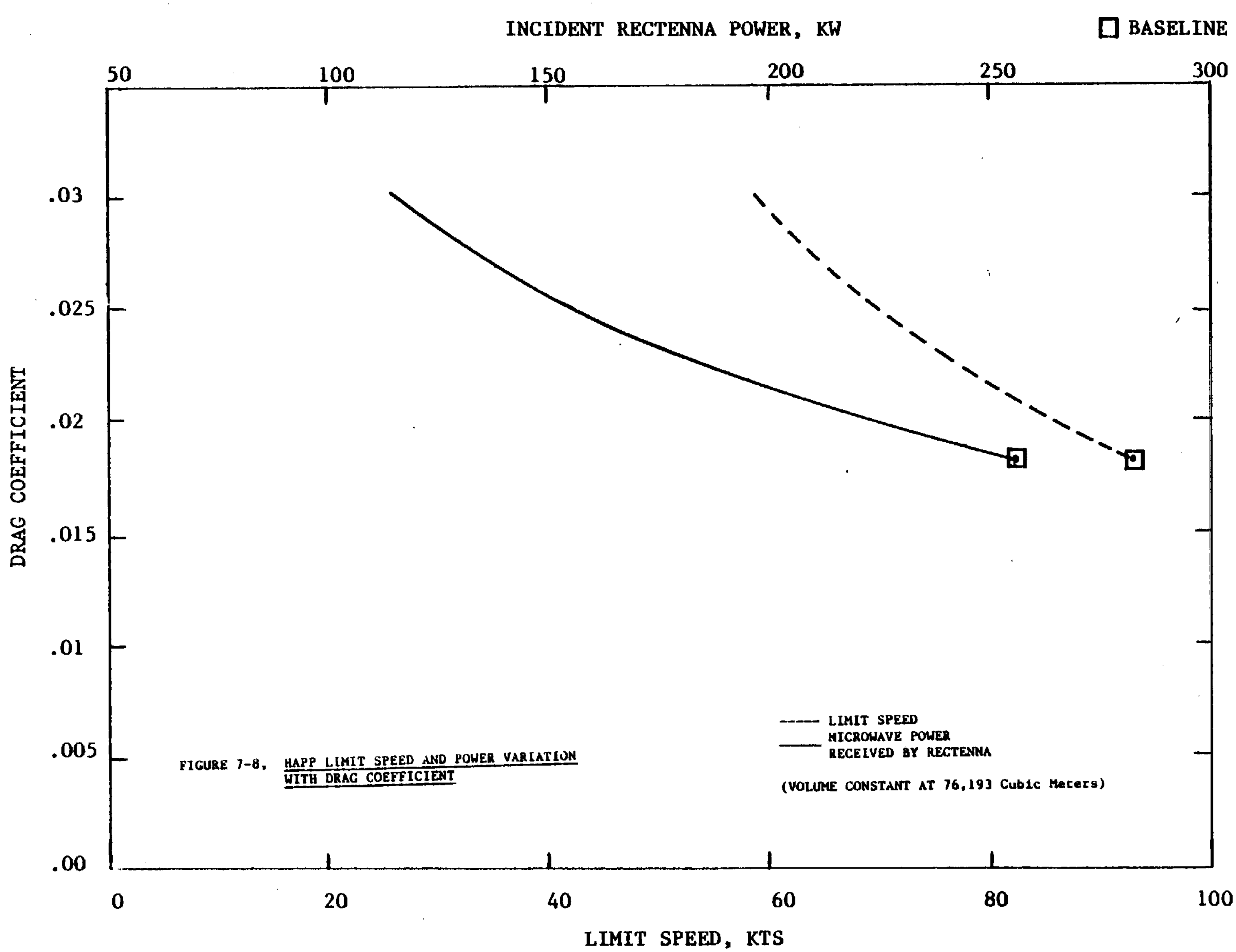


FIGURE 7-8, HAPP LIMIT SPEED AND POWER VARIATION by limiting the top speed. The drop in speed is more rapid than would be expected by a $C_D^{1/3}$ estimate because more auxiliary power is required for flight off station at the higher drag coefficient.

Figure 7-9a shows limit speed effects on volume at drag coefficient .028 at 20 km. For this graph, the "threshold" speed (maximum speed on microwave) is held equal to "limit" speed (the airship maximum design speed) so that on station all power is supplied by microwave beam.

Figure 7-9b shows that by designing for 19 km altitude, the airship volume is significantly decreased as compared to the volume at 20 km. This is a possible means of compensating in case of a high drag coefficient. As the environmental winds figures in Section 2.0 show, at 19 km the winds generally tend to be higher, but still manageable.

Figure 7-9c shows adverse effects on volume at 19 km and C_D .028 if threshold speed is decreased and limit speed held at 93 kts.

Figure 7-10, Parametric for 19 km and C_D .028, showing significant effects of auxiliary speed capability.

Figure 7-11. Correlates the effect of superheat/cool with volume and power if no superpressure is utilized (day pressure = night pressure). Above a superheat of 10° volume and power penalties became significant. Compared with Figure 7-5, top, the small amount of superpressure provided in the baseline noticeably benefits performance.

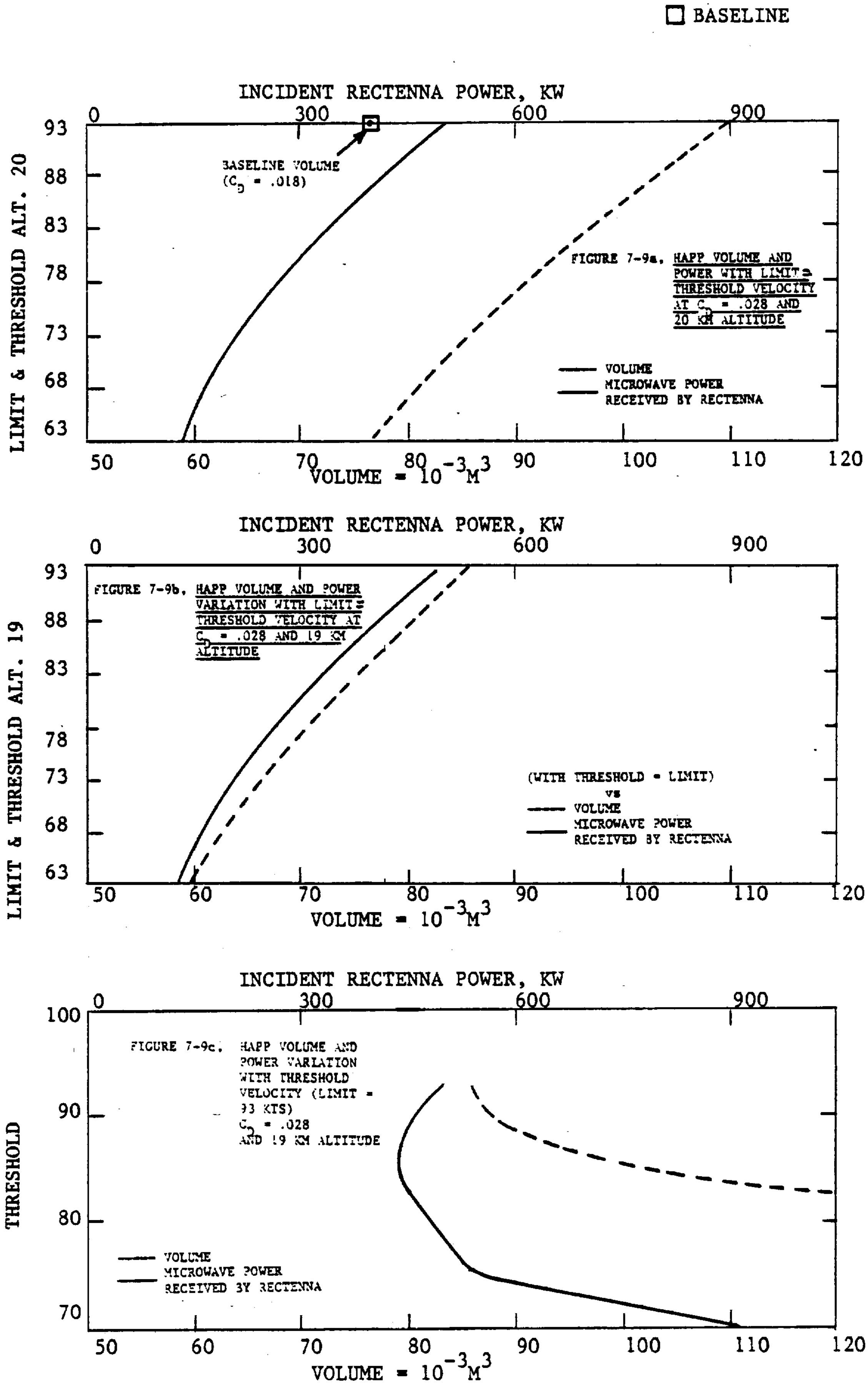


FIGURE 7-9, HAPP VOLUME AND POWER VARIATION

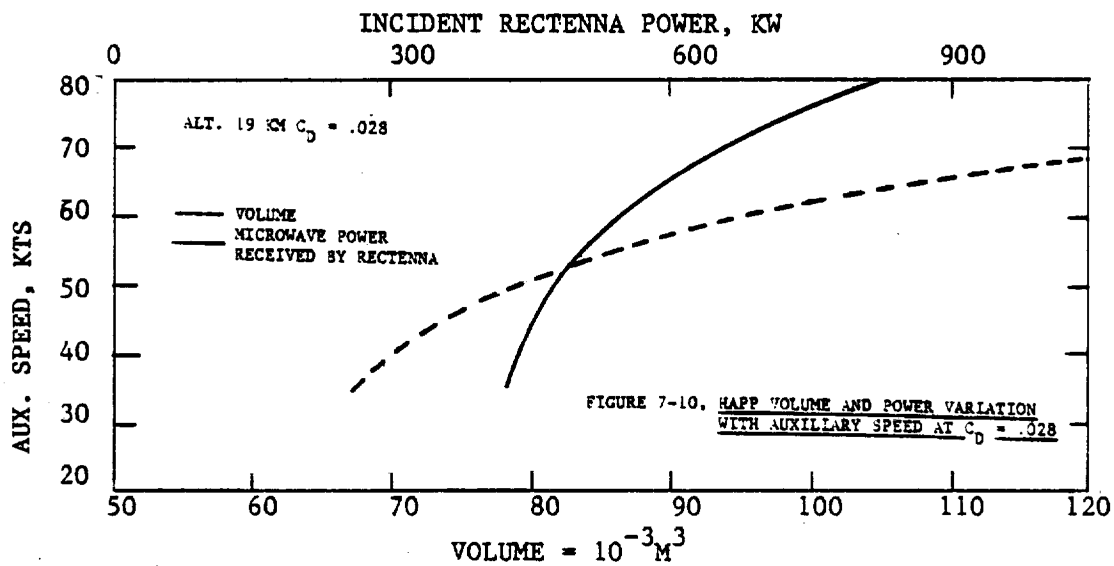


FIGURE 7-10, HAPP VOLUME AND POWER VARIATION

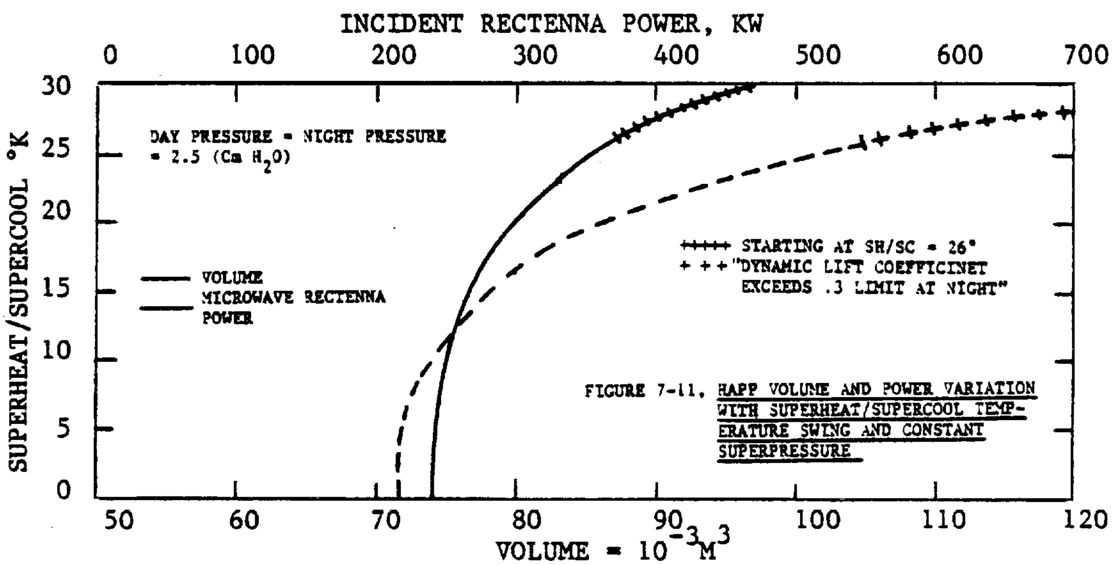


FIGURE 7-11, HAPP VOLUME AND POWER VARIATION

8.0 CONCEPT SELECTION

The HAPP mission profile as it will be accomplished by the selected vehicle is illustrated in the schematic sketch, Figure 8-1. The vehicle is sized to stay on station indefinitely using microwave power transmitted from the ground. The ship will fly on microwave power at speeds up to 93 kts which is the maximum wind speed encountered in the study of Reference 2. Reference 1 indicated a less than 5/1000 probability of higher winds within the USA in the winter season. Thus, at 93 kt capability, 100% coverage of the contiguous USA can be achieved with extremely low probability of being blown off station.

The airship selected has a laminar flow "Dolphin" shaped hull, volume 78000 m^3, with stern propulsion and physical layout as portrayed in Figures 8-2 thru 8-8 and Figure 3-2. This ship is the "baseline configuration" used for the parametric sensitivity curves. The airship and mission features are listed in the baseline computer printout of Figure 8-9 and summarized below.

8.1 DESCRIPTION

Volume	78000	m
Length	123.3	m
Diameter	37.8	m
Gross Weight	5631	kg
Envelope Weight	2440	kg
Power System Wt.	1771	kg
Fuel	291	kg
Payload	680	kg
Ballast	448	kg

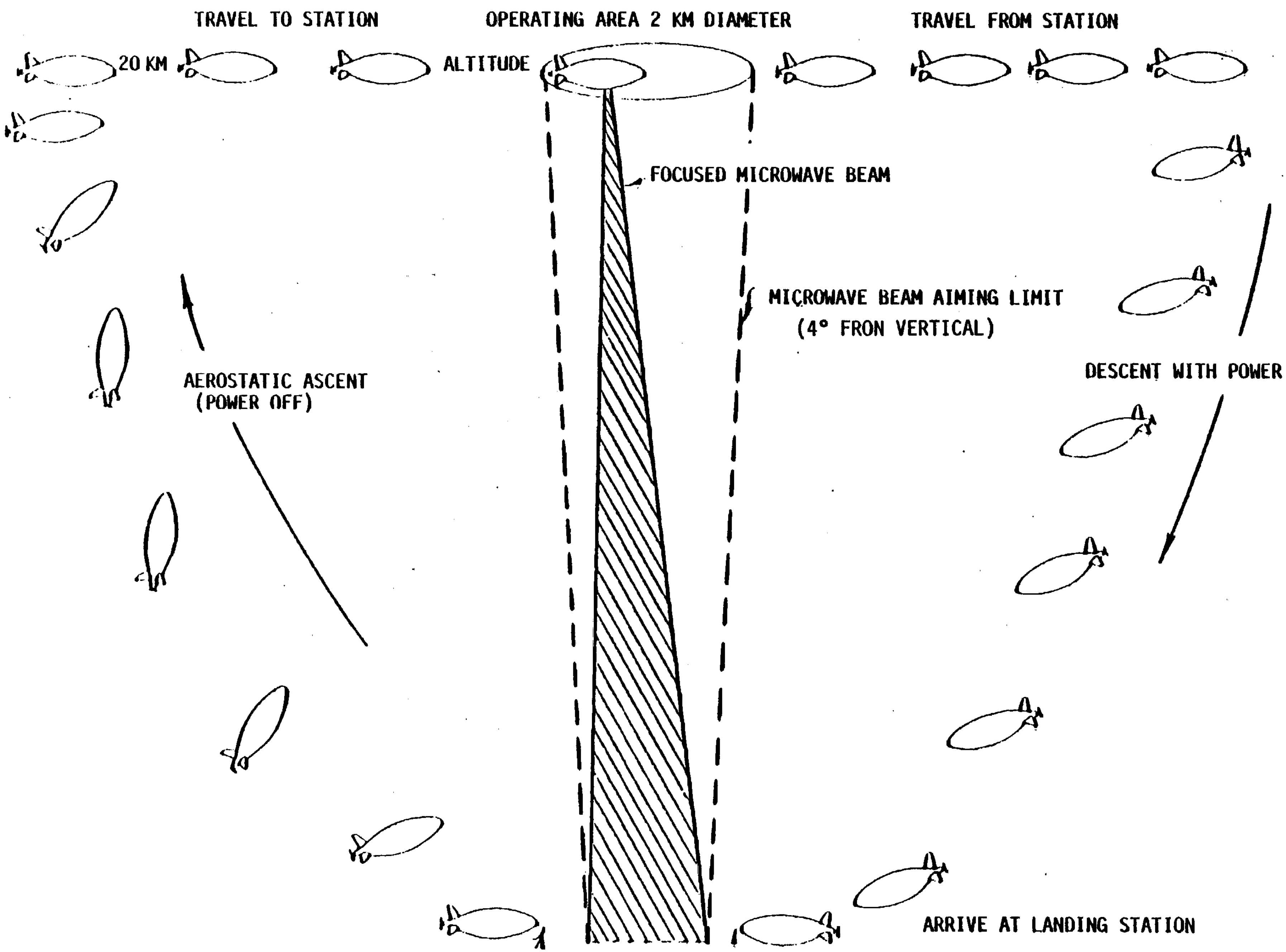
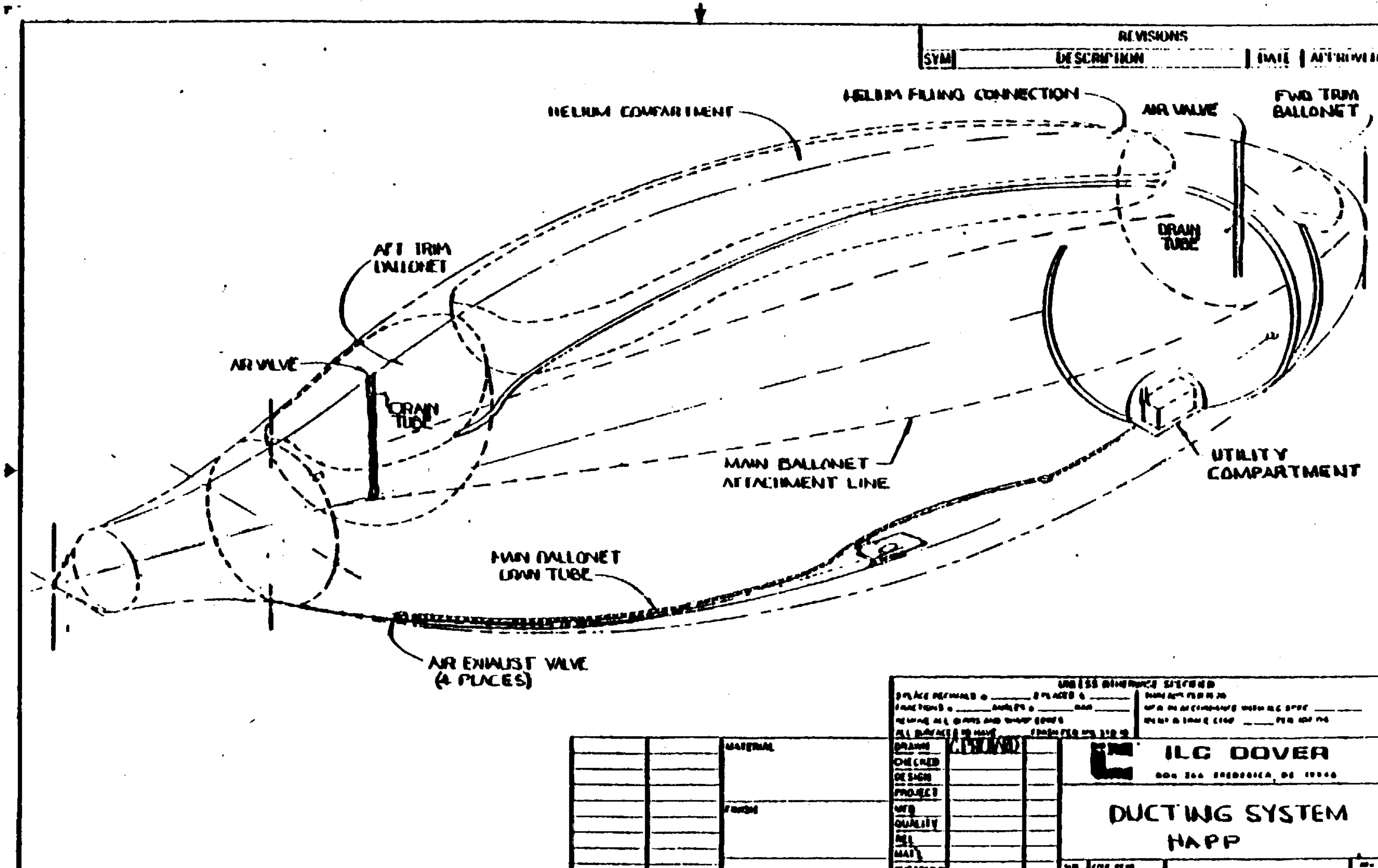


FIGURE 8-1 MISSION PROFILE



1.75 KM CAPACITY 1626 M^3/MIN AT 21 KM ALTITUDE

Figure 8-2 HAPP DUCTING SYSTEM

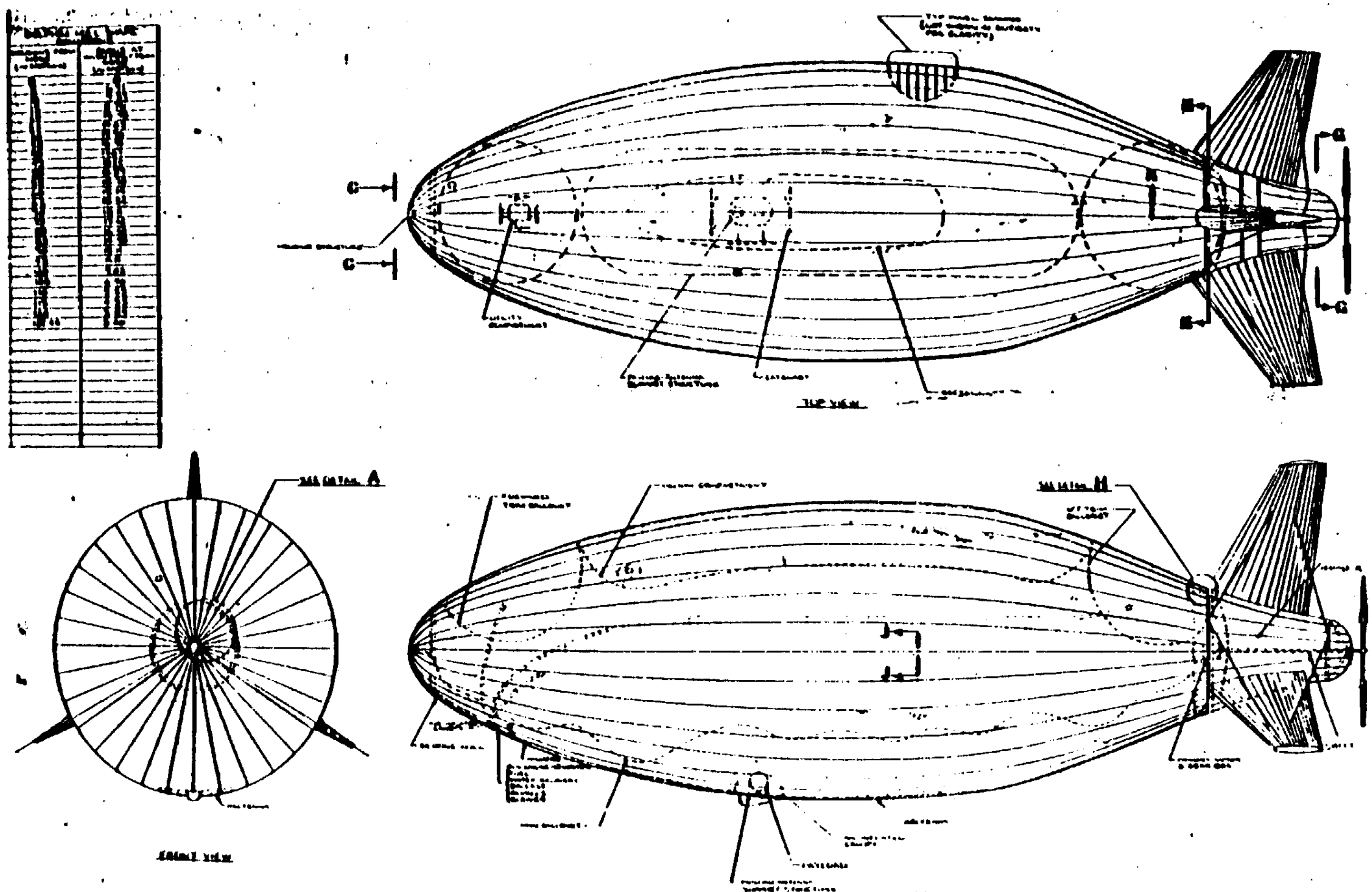


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Figure 8-2A HAPP AIRSHIP DESIGN CONCEPT

1 of 2

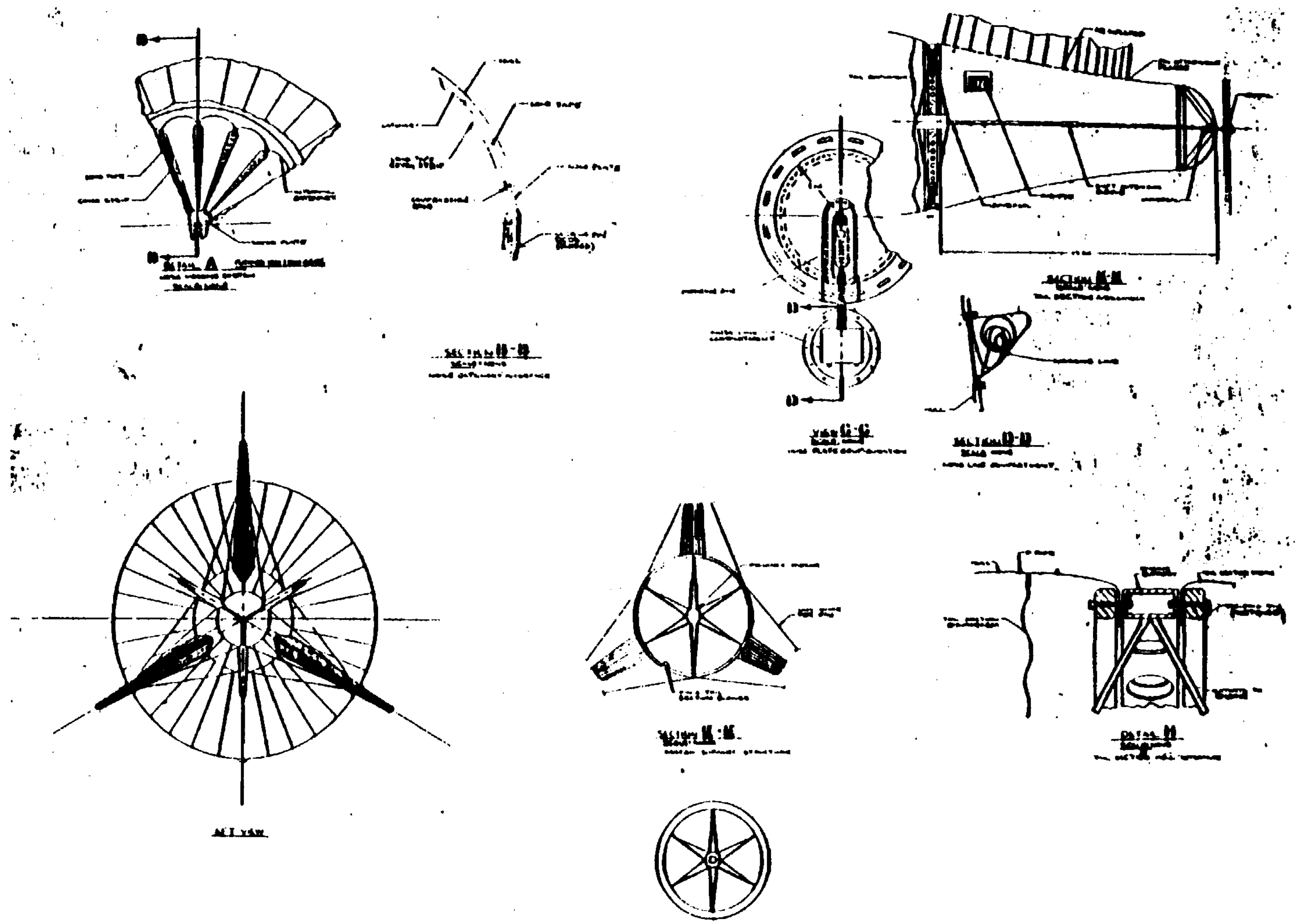


Figure 8-2A HAPP AIRSHIP DESIGN CONCEPT

2 of 2

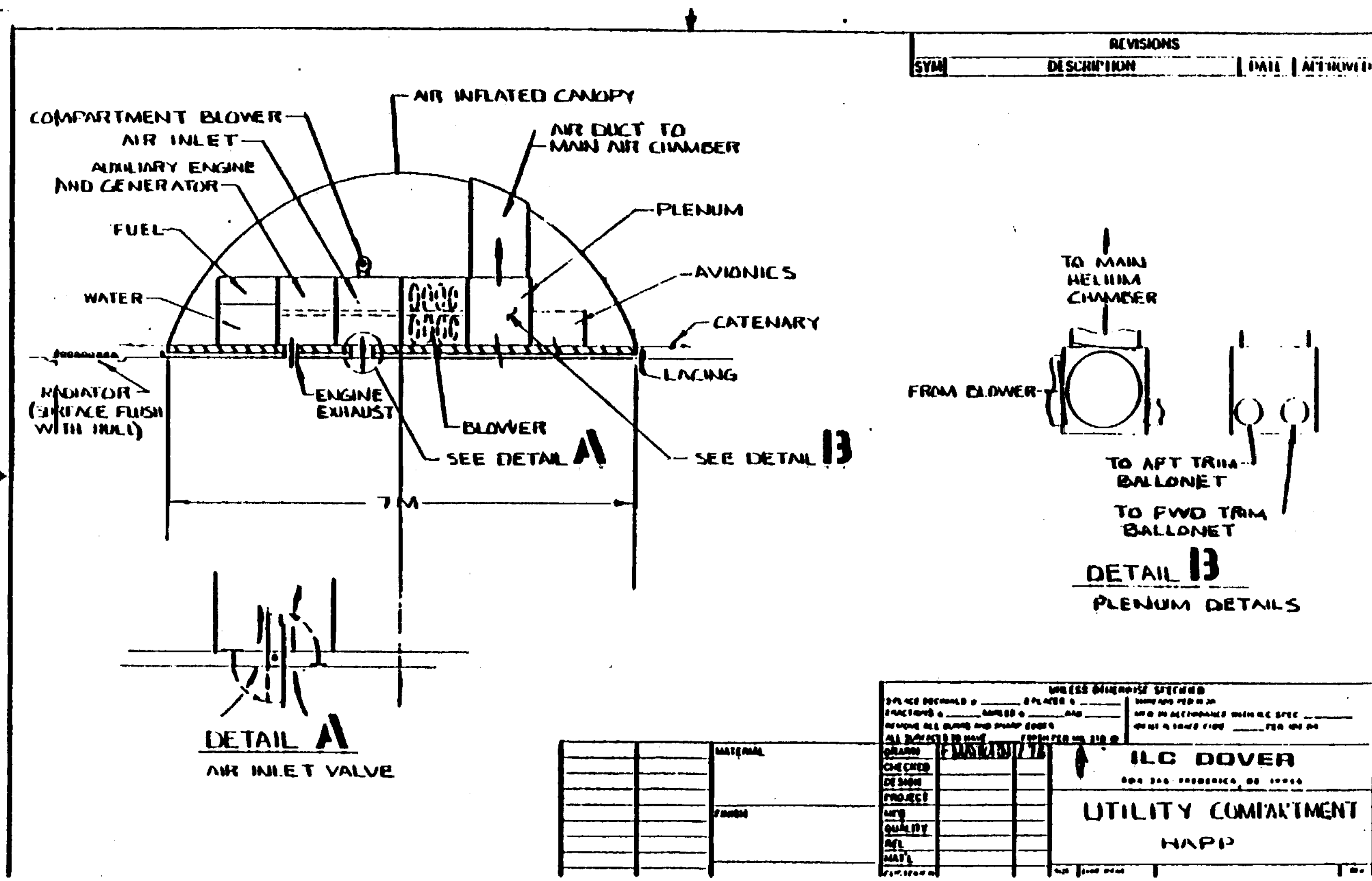


Figure 8-3 HAPP UTILITY COMPARTMENT

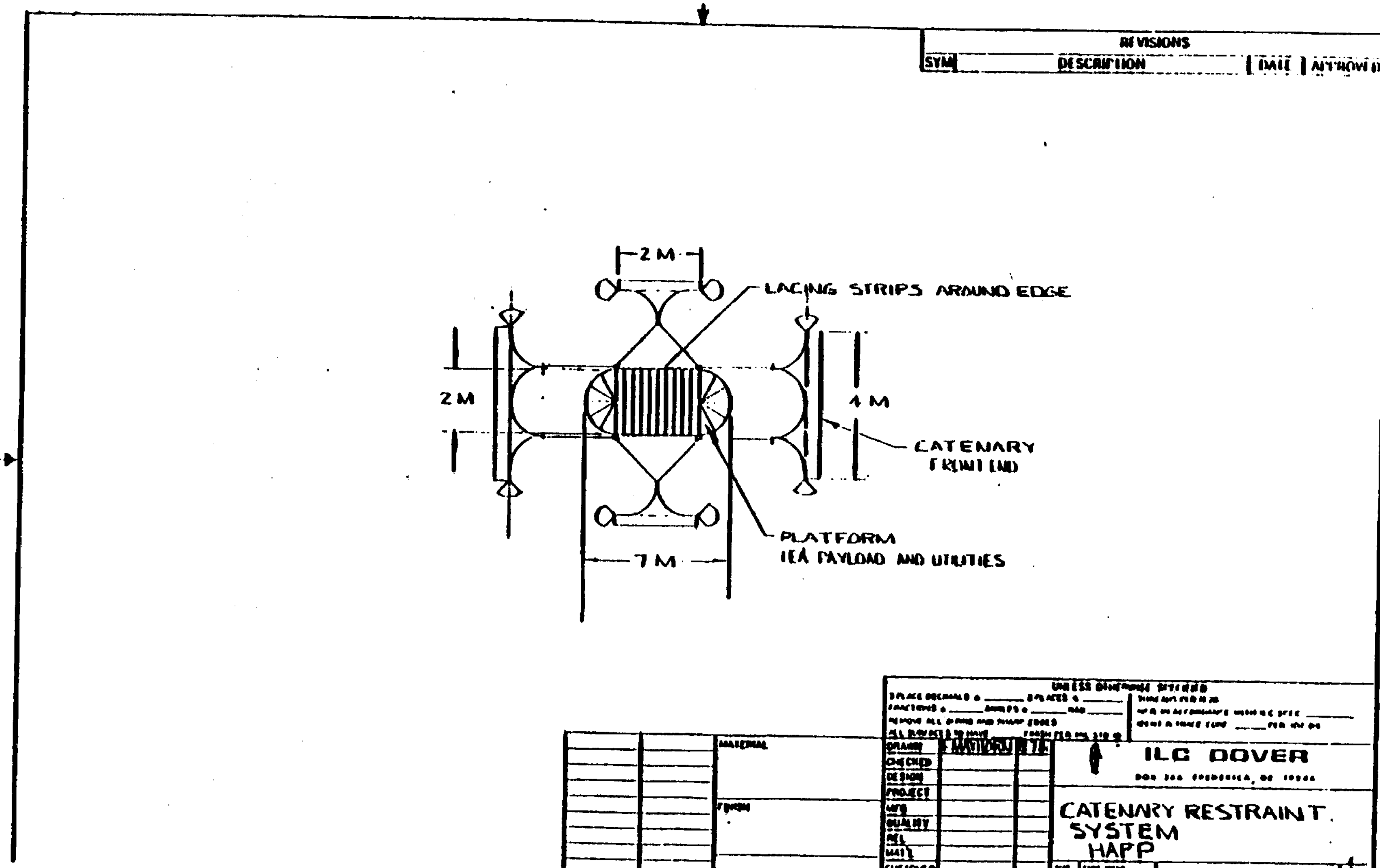


Figure 8-4 HAPP CATENARY RESTRAINT SYSTEM

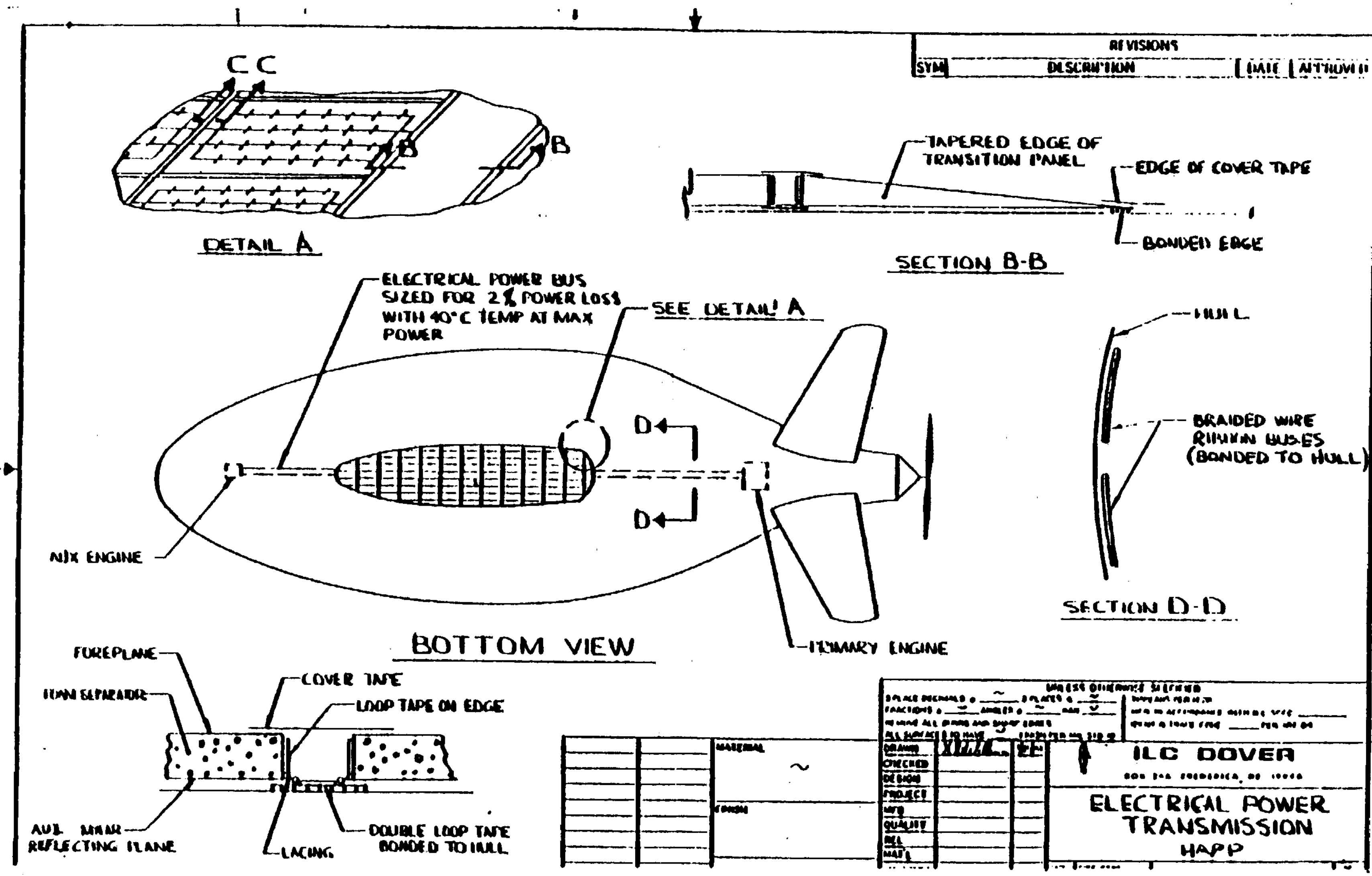
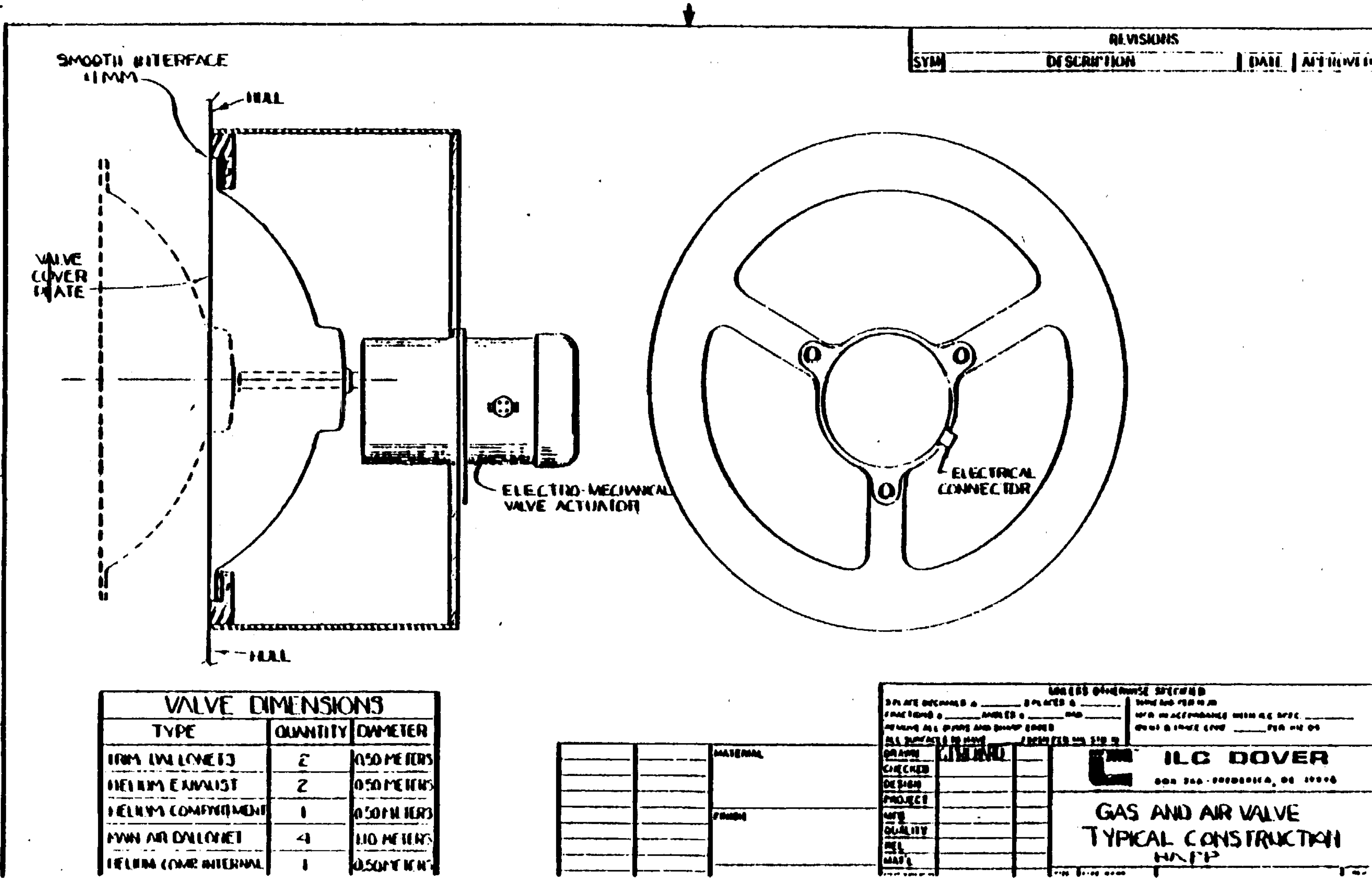


Figure 8-5 HAPP ELECTRICAL POWER TRANSMISSION



VALVE DIMENSIONS		
TYPE	QUANTITY	DIAMETER
TRIM BALLONETS	2	0.50 METERS
HELIUM EXHAUST	2	0.50 METERS
HELIUM COMPARTMENT	1	0.50 METERS
MAIN AIR BALLONET	4	1.10 METERS
HELIUM COMP INTERNAL	1	0.50 METERS

Figure 8-6 HAPP GAS AND AIR VALVE TYPICAL CONSTRUCTION

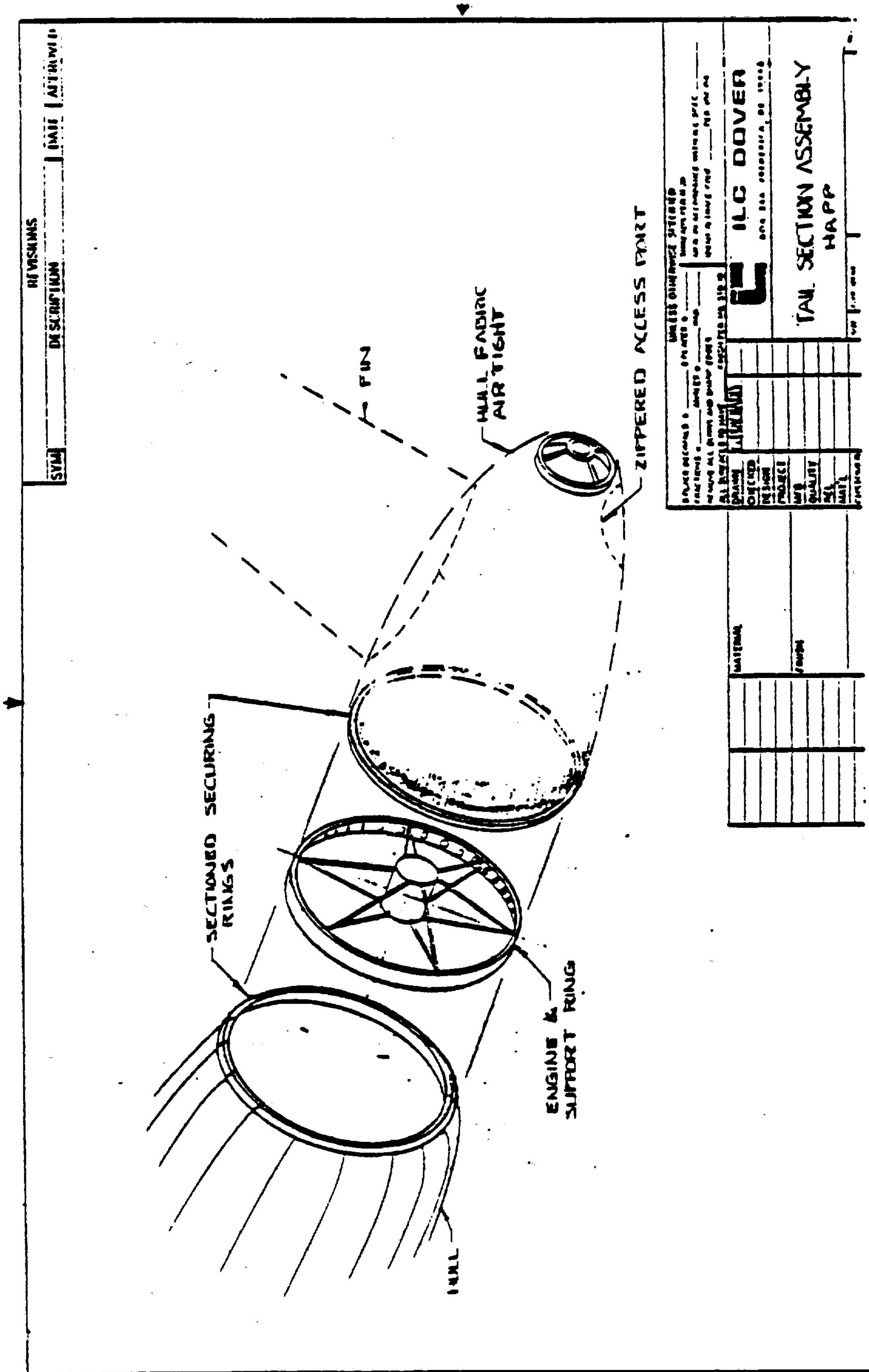


Figure 8-7 HAPP TAIL SECTION ASSEMBLY

HAPP 1906 20JN82 BASELINE
DOLPHIN SOFT FINS 31AUG82

VOL M†3	ALT KM	RECT KW IN	AUXE KW	PRLI KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
77911	20	260.46	57.588	192.00	2440.0 47%	1771.0 34%	291.00 5%	680	448.07

SUPER HEAT = 16.7 K
CD = .018
SAFTEY FACTOR = 5
UNIT FAB WT=.11867 KG/M2
---WEIGHTS KGS:---

SUPERCOOL = -17.2 K
PROP CD = .0184856667
DAY PRESS (CM H2O) = 6.302
NITE PRESS= 2.5

ENVELOPE WT

TAPE WT = 102.847913
FIN SYS = 209.056342
CONE WT = 47
VALVE WT = 33.2199201

HULL = 1285.59891
BALONT SYS = 709.484238
BLOWER = 52.7260234

POWER SYSTEM WT

PROPELLER = 301.546801
GEAR BOX = 78.4351439
RECTENNA = 236.781963
AUXE ENG = 273.547453
AVIONICS = 117.3

SHAFT = 40.1574826
PRIME MOTOR = 349.454007
TRANS. WIRE = 242.720659
GENNERATOR = 57.0130482
TANKS = 16.875479
WATER RECOVERY=57.5889376

RECTENNA AREA =591.954906
MICROWAVE BEAM KW/M2= .5
LIFT = 5630.86101 KGS

ANGLE OF INCIDENCE LIMIT=13.5275151

WEIGHT = 5630.90987 KGS

VELOCITIES, KTS
LIMIT=93 THRESHOLD=93
AUX DESIGN=55 CUBE AVE>THRES=92.9983393

****

ASCENT PROFILE

POWER OFF ASCENT AT 150 M/MIN
TIME TO CLIMB TO 20 KM=2.22222222
BLOWOFF DISTANCE =283.860186 KM.
TIME TO AUXBACK TO STATION =2.78677038
FUEL USED ASCENT AND AUXBACK =30.4925577 KG

ON-STATION PROFILE

THRESHOLD SPEED OF 93 KTS EXCEEDED FOR 0 HRS /WINTER AT POWER AVE SPEED OF 93 KTS
FUEL WT = 0 KGS
SHIP SPEED ON PRIMARY POWER(THRESHOLD VEL)=93 KNOTS:LIMITING VEL = 93KTS
FOR 8 HRS @ 75 KTS RESERVE FUEL WT = 87.5351851

DSCENT PROFILE

POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 20 KM=2.22222222 HRS
FUEL FOR DESCENT = 24.3153292 KGS
AUXAWAY AT ALT TIME AND DISTANCE = 4.64311206 HRS AND -472.946985 KM
FUEL FOR AUXAWAY = 50.8044592 KGS
FUEL FOR BLOWER = 10.8028294 KGS
FUEL FOR 8 HR LANDING = 87.5351851 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 173.457603 KG

SUMMARY

TOTAL FUEL WT FOR MISSION = 291.485546

TL(2)=.106931568

FIGURE 8-8, HAPP BASELINE CHARACTERISTICS

Maximum Speed	93	kt
Max. Speed on on Rectenna Power*	93	kt
Max. Speed on Auxiliary Power*	55	kt
Turning Radius	500	m

* at 20 km. Speeds at lower altitude decrease inversely as the cube root of air density.

Mission Profile

1. Ascend at 150 m/min to 20 km operating altitude. (weather limited)
2. Fly to station on auxiliary power (284 km). (wind limited)
3. Stay on station on microwave power for 3 months (90% reliability).
4. Fly 8 hours at 55 kt on auxiliary engine reserve fuel.
5. Fly to descent start position (473 km). (wind limited)
6. Descend at 150 m/min. (weather limited)
7. Fly 8 hours at sea level, 15 kt. for landing operation. (weather limited)

8.2 SPECIFICATIONS FOR COMPONENTS

Hull Material (skin):

A laminate composed of outer layer, clear Tedlar film, .025 mm thick, weight 34 g/m^2 2nd layer, 800 angstrom thick silver, vapor deposited on the Tedlar. 3rd layer, black Hytrel adhesive, 25 g/m^2, 4th layer Kevlar fabric, 200 denier, 40 count warp and fill, unit weight 60 gm/m^2 Total unit weight of material, 119 g/m^2

Envelope Materials:

Tensile = 455 N/cm

Tongue Tear = 222 N

Helium permeability = 1.0 ($1/m^2$/day)

Solar absorptivity = .12 and infrared emmissivity = .80

The silver layer backed by the black Hytrel provides complete UV protection to the Kevlar.

The Tedlar has poor adhesive bonding characteristics. Structural bonds will be on the inside.

Hull Surface Smoothness Requirement: Aft of nose stagnation area to 60% of hull length,

$$\frac{h}{\sqrt{\lambda}} < 2.147 \times 10^{-3} \quad m^{1/2}$$

h = Wave amplitude

λ = Wavelength

Step height 1.3 mm

Ballonet Material:

Polyester scrim fabric, polyurethane coating

Unit weight 85 g/cm^2

Helium permeability 1.0 ($1/m^2$/day)

Fin Fabric:

Same as hull fabric.

Propeller:

3 Blades; blade chord 1 meter; blade length 11 meters, controllable pitch; cruise RPM about 100. Weight: 297 kg. Gimbal hub, max swivel angle 22 1/2° from ship axis.

Primary Propulsion:

4 electric motors, samarium - cobalt magnet construction, 250 volts, each 52 kw output power. (See Appendix C).

Weight each: 86 kg.

Gear Box:

Planetary gear, clutch to each motor (See Appendix B for detail)

Weight: 77 kg.

Drive Shaft:

Length 19 M, composite tube construction, diameter 25 cm, telescoping secton for length changes. Weight: 39 kg.

Auxiliary Engine:

Supercharged Reciprocating Engine, Fossil fuel, shaft power 56 kw,

Weight: 268 kg.

Fuel Tanks:

Coated fabric (Kevlar Polyurethane) Flexible tanks, Weight: 17 kg.

Capacity: 500 Liters

Water Recovery System:

Condenser, super-insulated 350 Liter tank Weight: 56 kg.

Auxiliary Generator Driven by Auxiliary Engine:

Samarium cobalt magnet construction Output power 51 kw at 250 V.

Weight: 56 kg.

Power Transmission Wire:

Braided copper ribbon, not insulated, maximizing surface area for heat dissipation, mounted on inside surface of hull, 2 conductors. Resistance power less than 2%. Weight: 235 Kg. (Aluminum, if suitable, will be lighter)

Rectenna:

Area: 451 m^2 Sandwich construction - Foreplane 2 1/2 cm Foam spacer, reflecting plane.

Weight: 181 kg.

Avionics:

(See Appendix C for details).

Six fold redundancy with Military rated components, system reliability 99%

Functions:

Air data system generates flight control data and signals.

Sensors: Heading, Dynamic Pressure, Static Pressure, Temperature, Helium Pressure, Ballonet Pressures, Tail Pressure, VOR-DME Position, Loran Position, Inertial System, Pitch Angle, Pitch and Yaw Rates, Propeller Gimbal Angle, Propeller RPM, Data Link to Ground, Command Link to Ground.

Airborne Flight Control System:

Automated response to data system commands, with command override from ground.

8.3 ALTERNATE DESIGNS

Two alternate designs are listed here, (1) for geographic areas or summer conditions where maximum winds are low, and (2) a contingency design for drag coefficient of .028.

Alternate (#1)

As seen in the wind profile data of Section 2, Figures 2-1 and 2-2, many cases can be covered with a limit speed of 75 kts. Features of a ship with 75 kt limit speed would be:

Altitude	20	km
Volume	67056	m^3
Length	123.5	m
Diameter	36.0	m
Gross Weight	4841	kg
Max Speed	75	kts
Max Speed on Rectenna Power	75	kts
Max Speed on Auxiliary Power	55	kts

Details are shown in Figure 8-9.

Alternate (#2)

Should future drag studies show that a drag coefficient of .018 cannot be obtained and .028 is realistic, some sacrifice of operating capability can still result in a reasonably small and useful ship. This design would have an altitude of 19 km and a maximum speed of 75 kts.

Its features would be:

Altitude	19	km
Volume	69684	m^3
Length	125.1	m
Diameter	36.5	m
Gross Weight	5906	kg
Max Speed	75	kt
Max Speed on Rectenna Power	75	kt
Max Speed on Auxiliary Power	55	kt

Details are shown in Figure 8-10.

HAPP 1906 20JN82 ALTERNATE #1

DOLPHIN SOFT FINS 31AUG82

VOL M†3	ALT KM	RECT KW IN	AUXE KW	PRLI KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
67056	20	127.96	50.504	93.327	2210.0	1246.0	256.00	680	448.07
					50%	28%	6%		

```
SUPER HEAT = 16.7 K                       SUPERCOOL = -17.2 K
CD = .018                                 PROP CD = .0189335286
SAFTEY FACTOR = 5                         DAY PRESS (CM H2O) = 6.626
UNIT FAB WT=.11867 KG/M2                  NITE PRESS= 2.5
---WEIGHTS KGS:---
                 ENVELOPE WT
TAPE WT = 93.0582166                      HULL = 1163.22771
FIN SYS = 189.157075                      BALONT SYS = 641.869763
CONE WT = 47                              BLOWER = 47.7072366
VALVE WT = 27.8854244
                 POWER SYSTEM WT
PROPELLER = 219.956956                    SHAFT = 18.5667859
GEAR BOX = 38.1242515                     PRIME MOTOR = 169.855906
RECTENNA = 116.334405                     TRANS. WIRE = 211.132971
AUXE ENG = 239.896472                     GENNERATOR = 49.9994753
AVIONICS = 117.3                          TANKS = 14.8259597
                                          WATER RECOVERY=50.5043205

RECTENNA AREA =290.836012                 ANGLE OF INCIDENCE LIMIT=13.7903152
MICROWAVE BEAM KW/M2= .5
LIFT = 4840.58567 KGS                  WEIGHT = 4840.55789 KGS
          VELOCITIES, KTS
LIMIT=75              THRESHOLD=75
AUX DESIGN=55         CUBE AVE>THRES=81.7976138
 COMMENT ALTERNATE #1  LIMIT 75KT=THRESHOLD
           ALTITUDE 20KM

*************************************************************************************
                            ASCENT PROFILE

POWER OFF ASCENT AT 150 M/MIN
TIME TO CLIMB TO 20 KM=2.22222222
BLOWOFF DISTANCE =283.860186 KM.
TIME TO AUXBACK TO STATION =2.78677038
FUEL USED ASCENT AND AUXBACK =26.7414554 KG

                            ON-STATION PROFILE

THRESHOLD SPEED OF 75 KTS EXCEEDED FOR 0 HRS /WINTER AT POWER AVE SPEED OF 81.7976138 KTS
FUEL WT = 0 KGS
SHIP SPEED ON PRIMARY POWER(THRESHOLD VEL)=75 KNOTS:LIMITING VEL = 75KTS
FOR 8 HRS @ 75 KTS RESERVE FUEL WT = 76.7668711

                            DSCENT PROFILE
POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 20 KM=2.22222222 HRS
FUEL FOR DESCENT = 21.3241309 KGS
AUXAWAY AT ALT TIME AND DISTANCE = 4.65939333 HRS AND -474.605394 KM
FUEL FOR AUXAWAY = 44.7108809 KGS
FUEL FOR BLOWER = 9.77454978 KGS
FUEL FOR 8 HR LANDING = 76.7668711 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 152.576433 KG

                            SUMMARY
TOTAL FUEL WT FOR MISSION = 256.084759
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
TL(2)=.096417797
```

ALTERNATE DESIGN (1)

20 Km MAX SPEED 75 KTS

FIGURE 8-9

HAPP 1906 20JN82 ALTERNATE #2

DOLPHIN SOFT FINS 31AUG82

VOL M13	ALT KM	RECT KW IN	AUXE KW	PRLI KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
69684	19	234.31	90.440	172.53	2278.0 42%	2059.0 37%	441.00 8%	680	448.07

SUPER HEAT = 16.7 K
CD = .028
SAFTEY FACTOR = 5
UNIT FAB WT=.11867 KG/M2
---WEIGHTS KGS:---

SUPERCOOL = -17.2 K
PROP CD = .0291662174
DAY PRESS (CM H2O) = 6.541
NITE PRESS= 2.5

ENVELOPE WT

TAPE WT = 95.4739764
FIN SYS = 194.067529
CONE WT = 47
VALVE WT = 29.1645486

HULL = 1193.42471
BALONT SYS = 670.309337
BLOWER = 48.9457004

POWER SYSTEM WT

PROPELLER = 275.194196
GEAR BOX = 70.4795121
RECTENNA = 213.010809
AUXE ENG = 429.594349
AVIONICS = 117.3

SHAFT = 34.7666972
PRIME MOTOR = 314.009087
TRANS. WIRE = 399.037857
GENNERATOR = 89.5365064
TANKS = 25.5210973
WATER RECOVERY=90.4409156

RECTENNA AREA =532.527022
MICROWAVE BEAM KW/M2= .5
LIFT = 5906.17432 KGS

ANGLE OF INCIDENCE LIMIT=18.2070916
WEIGHT = 5906.16578 KGS

VELOCITIES, KTS
LIMIT=75 THRESHOLD=75
AUX DESIGN=55 CUBE AVE>THRES=81.7976138
COMMENT ALTERNATE #2 ALTITUDE=19KM CD=.028
LIMIT SPD=75KT=THRESHOLD SPD

****

ASCENT PROFILE

POWER OFF ASCENT AT 150 M/MIN
TIME TO CLIMB TO 19 KM=2.11111111
BLOWOFF DISTANCE =277.069834 KM.
TIME TO AUXBACK TO STATION =2.72010675
FUEL USED ASCENT AND AUXBACK =46.7416995 KG

ON-STATION PROFILE

THRESHOLD SPEED OF 75 KTS EXCEEDED FOR 0 HRS /WINTER AT POWER AVE SPEED OF 81.7976138 KTS
FUEL WT = 0 KGS
SHIP SPEED ON PRIMARY POWER(THRESHOLD VEL)=75 KNOTS:LIMITING VEL = 75KTS
FOR 8 HRS @ 75 KTS RESERVE FUEL WT = 137.470192

DSCENT PROFILE

POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 19 KM=2.11111111 HRS
FUEL FOR DESCENT = 36.2768562 KGS
AUXAWAY AT ALT TIME AND DISTANCE = 4.26758026 HRS AND -434.695349 KM
FUEL FOR AUXAWAY = 73.3331346 KGS
FUEL FOR BLOWER = 9.52687911 KGS
FUEL FOR 8 HR LANDING = 137.470192 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 256.607061 KG

SUMMARY

TOTAL FUEL WT FOR MISSION = 440.818953

++

TL(2)=.107766342

ALTERNATE DESIGN (2)

19 km MAX SPEED 75 KT

$C_D = .028$

FIGURE 8-10

9.0 SYSTEM RELIABILITY PREDICTIONS

Reliability details of the HAPP airship system are addressed in Appendix D, a report compiled by DSI. While estimation of the probability of failure of the avionics system relies on past experience and testing, powerplant and airframe probabilities are intuitive estimates.

The uncertainty in propulsion reliability is forced by the untested technology of the system. Endurance testing or field use of another system with similar components can be used to establish a data base for more precise failure predictions. Likewise there is no data base for this type airframe with new technology materials. Avionic systems similar to that required for HAPP are in widespread use in the aerospace industry, leaving little doubt to the credibility of that area of prediction.

Design for reliability must be supported by extensive testing. In these estimates and the accompanying cost estimates, moderate testing has been assumed and does not, for example, approach that required for spacecraft components.

The report shows a reliability estimate for the whole avionics system of 0.8997 over a 3 month operational period. Figure 3 of Appendix D shows that for the most part, triple redundancy is used to achieve that level of success. Table 3 of Appendix D indicates a high failure rate of the airborne data link can be expected. Where four of these units have been used to increase data link reliability to 93%, a group of six would raise the probability of success above 99%. Such a modification would improve the avionics reliability to 0.9708. Figures 9-1, 9-2 and 9-3 summarize the reliability data with the above revisions.

SYSTEM RELIABILITY

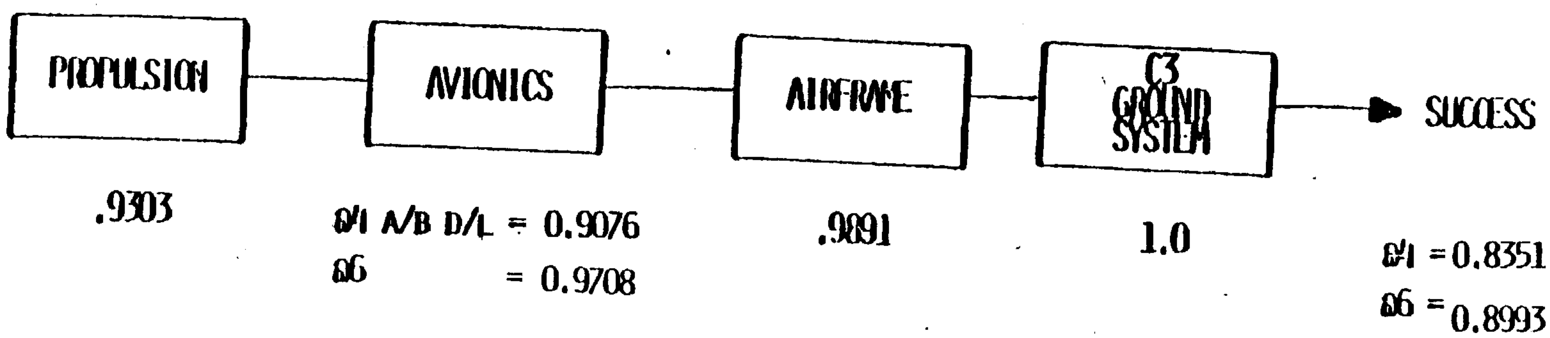


Figure 9-1 SYSTEM RELIABILITY

ILC DOVER
BOX 266 - FREDERICA, DE 19946

AVIONICS RELIABILITY BLOCK DIAGRAM

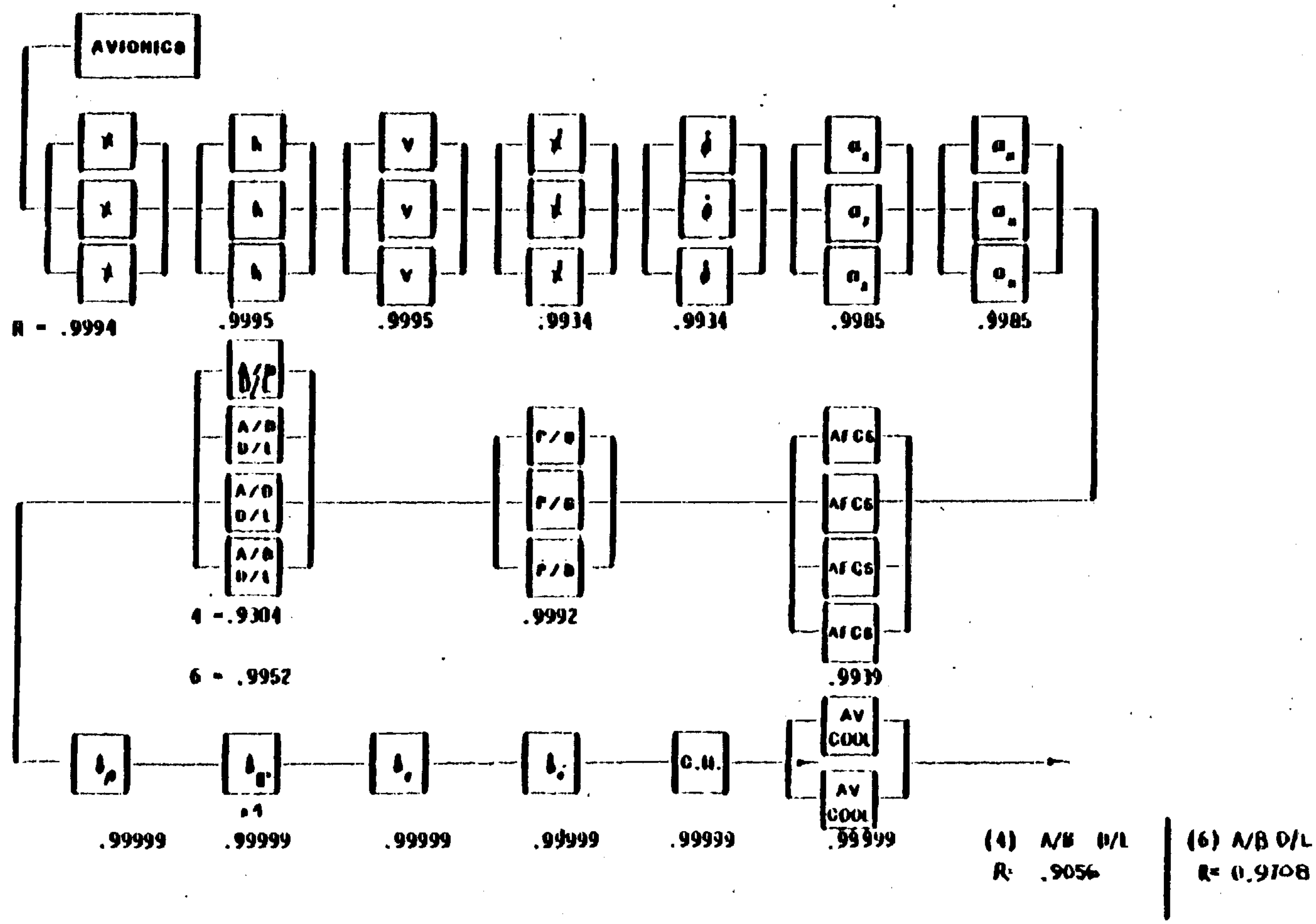


Figure 9-2 AVIONICS RELIABILITY BLOCK DIAGRAM

PRIME PROPULSION RELIABILITY

(50% OF REDUNDANT UNITS REQUIRED FOR SUCCESS - ALL CASES)

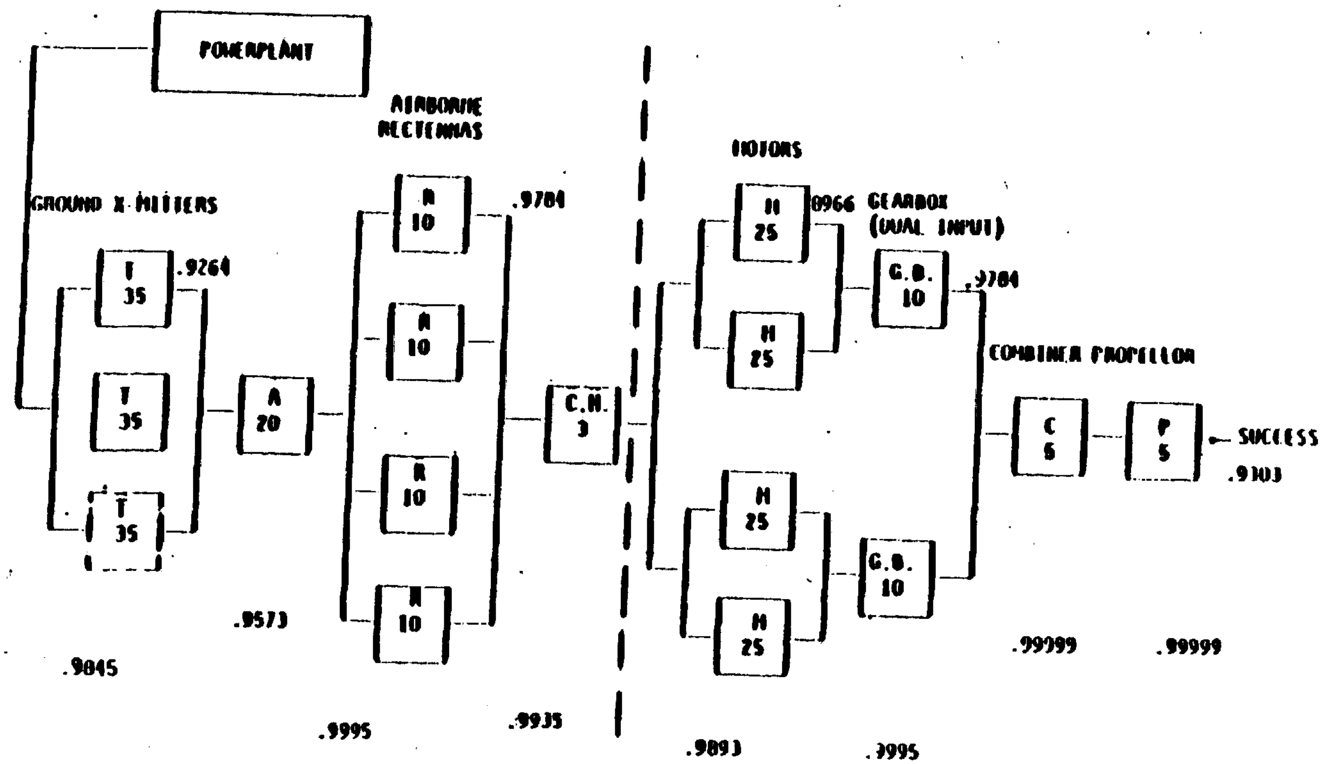


Figure 9-3 PRIME PROPULSION RELIABILITY

The report in Appendix D bases a total system reliability on an airframe failure rate of 10 per 1 million operational hours and a propulsion reliability estimate of 0.9303. Coupled with an avionics reliability of 0.9076, a success rate of 0.8351 can be anticipated. For the avionics system with added redundancy in the airborne data link, a much higher total system success rate of 0.8993 can be expected during three months of operation.

10.0 HAPP OPERATING PROCEDURES

10.1 FLIGHT PREPARATIONS

Inflation sequence for the airship is outlined in Figure 10-1. After the ship is inflated and secured to the mooring dolly, the rectenna is installed after inflation. The mooring cradles will be designed so that the rectenna area is accessible.

Systems checkouts will include the following:

1. Inflated components leak inspection and tests. The leakage tolerances will be very tight and it is expected that after inspection, a week long instrumented pressure holding test will be necessary to assure adequate gas tightness.
2. Rectenna inspection and electrical test.
3. Propulsion system tests including several hours of full power running on primary motors and an auxiliary engine system.
4. Avionics system tests.
5. Mechanical components tests - valves, blowers, air distribution system.

When the in-hangar tests are complete, the system is moved to the launch site, as depicted in Figure 10-2. Fins are inflated, and final preflight checks completed. Telementry and command links with the control station are established. Flight advisories are issued and flight clearance arranged with the appropriate authorities. The auxiliary engine will be started and idled throughout ascent.

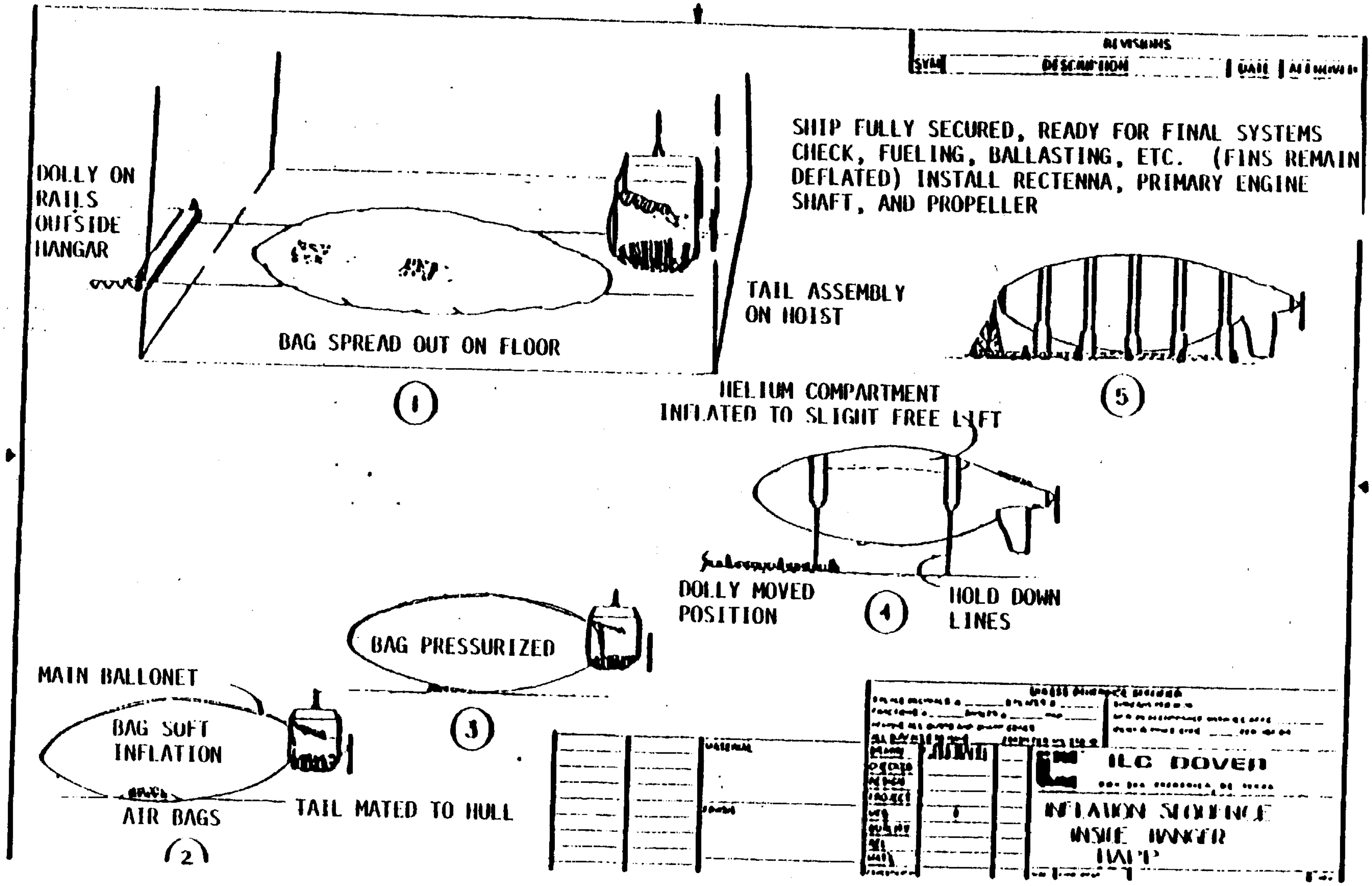


Figure 10-1 HAPP INFLATION SEQUENCE INSIDE HANGAR

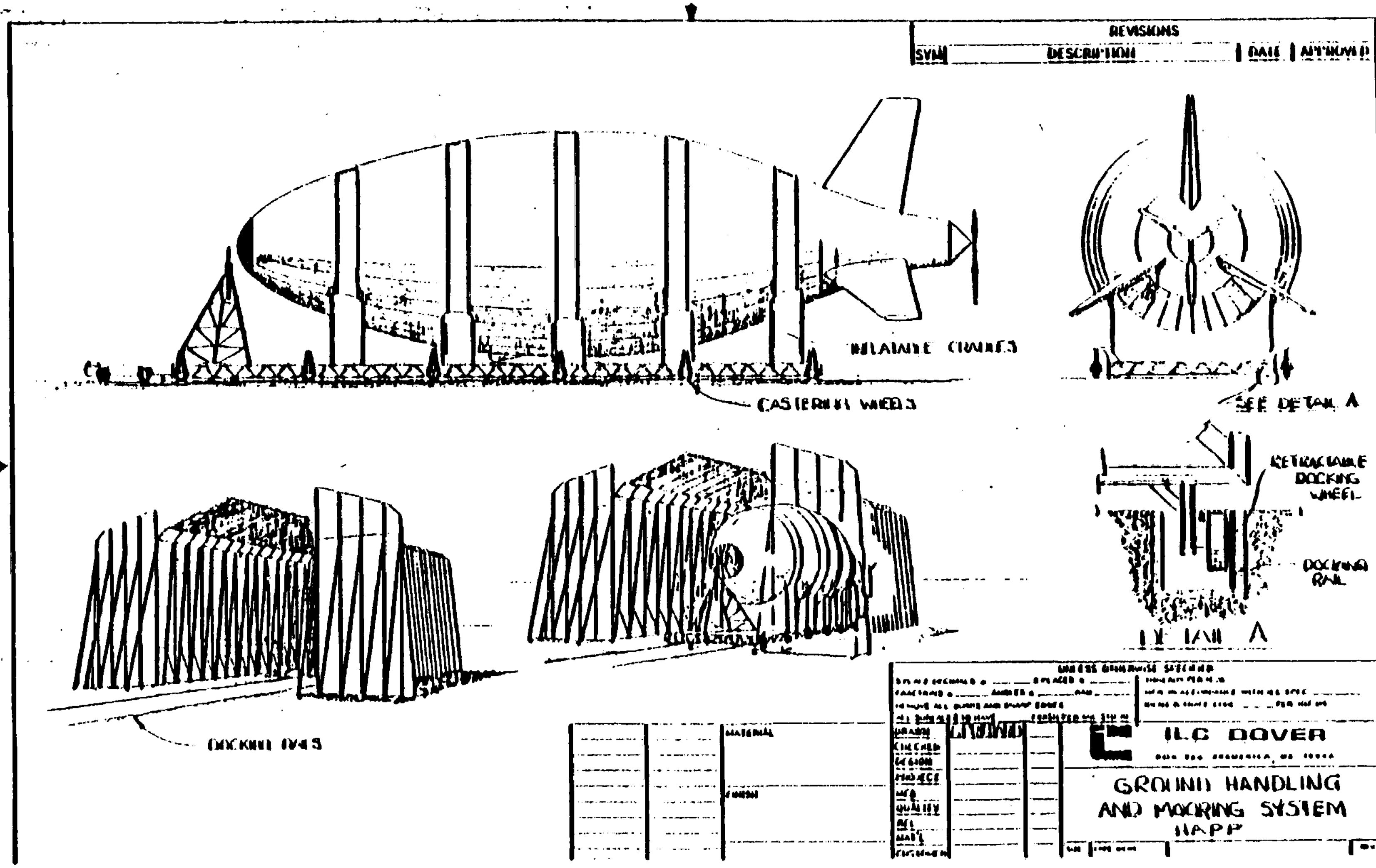


Figure 10-2 HAPP GROUND HANDLING AND MOORING SYSTEM

10.2 LAUNCH

Launch is accomplished as indicated in Figure 10-3.

At launch, the balloon is inflated with air filling the air chamber and helium in the helium containment tube. Helium has been metered to give a theoretical 10% free lift. During ground handling, the outlet valve to the helium tube is locked to prevent inadvertent transfer into the helium chamber. Prior to launch, the helium tube valve to the air chamber is unlocked. The balloon is trimmed to equilibrium condition with 5° nose up attitude prior to launch. External ballast is carried as necessary to balance the free lift. At launch, external ballast is dropped from the CG location to give approximately 1% measured free lift and the hold down straps are released. Ascent velocity is controlled by monitoring internal pressure. The main ballonet valves release air according to a controlled rate based on a schedule of envelope pressures. If the internal pressure of the hull is higher than scheduled, helium flow from the helium tube will be restricted, thus pressurizing the helium tube, but decreasing the aerostatic lift as the ship ascends higher. If the helium tube exceeds its limiting pressure, helium will be vented to the atmosphere. If the hull pressure is too low indicating a low rate of ascent, external ballast will be dropped as needed. Ascent proceeds as sketched in Figure 10-4.

10.3 CEILING APPROACH

As the ship approaches flight altitude, it will rotate towards a horizontal attitude. The altimeter transducer will activate filling of the aft trim ballonet at 2 kilometers, the purpose being to have a controlled amount of air left in the ship for trimming when float altitude is reached. Approaching the pressure ceiling will be indicated by a rise in hull gauge pressure.

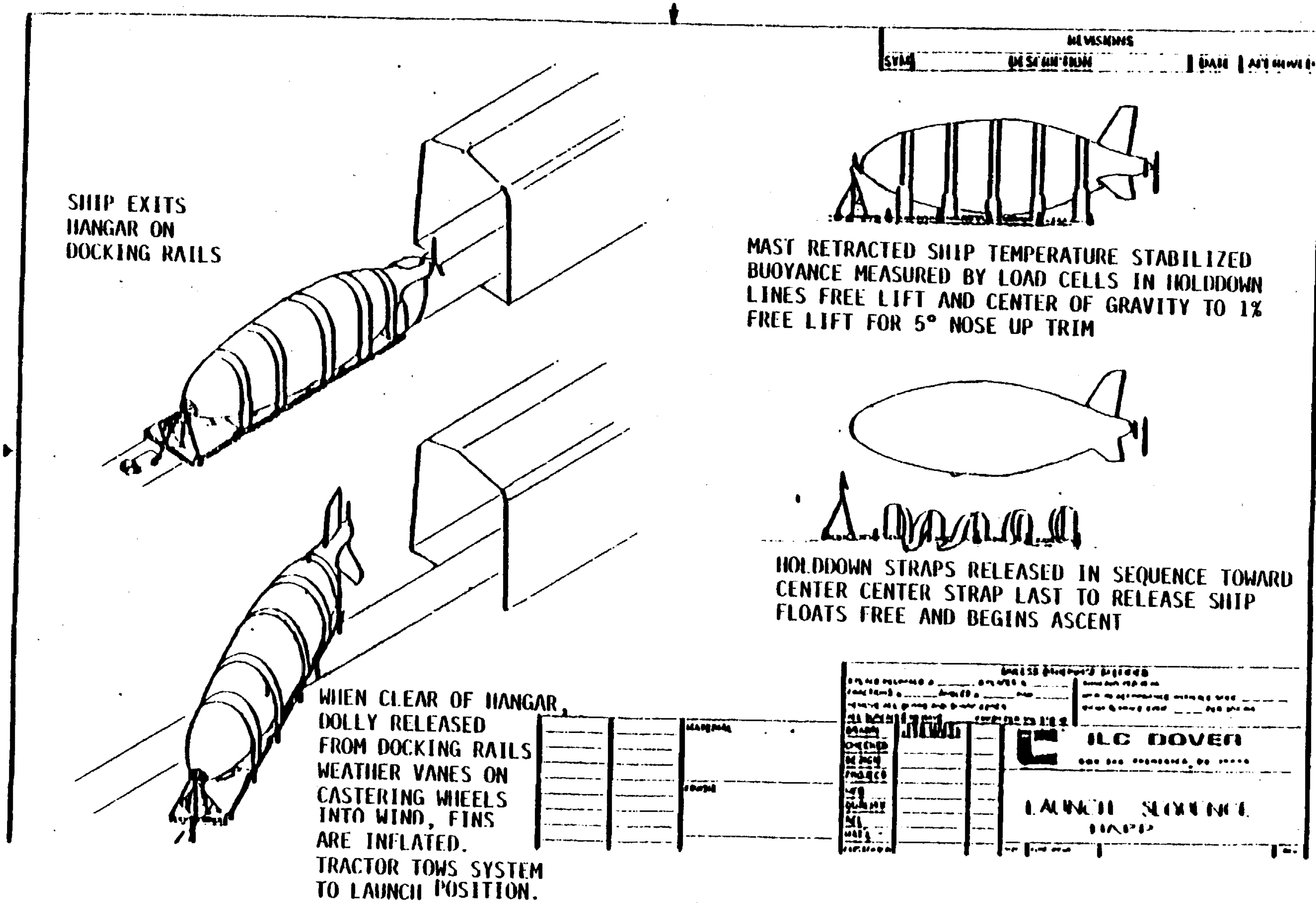


Figure 10-3 HAPP LAUNCH SEQUENCE

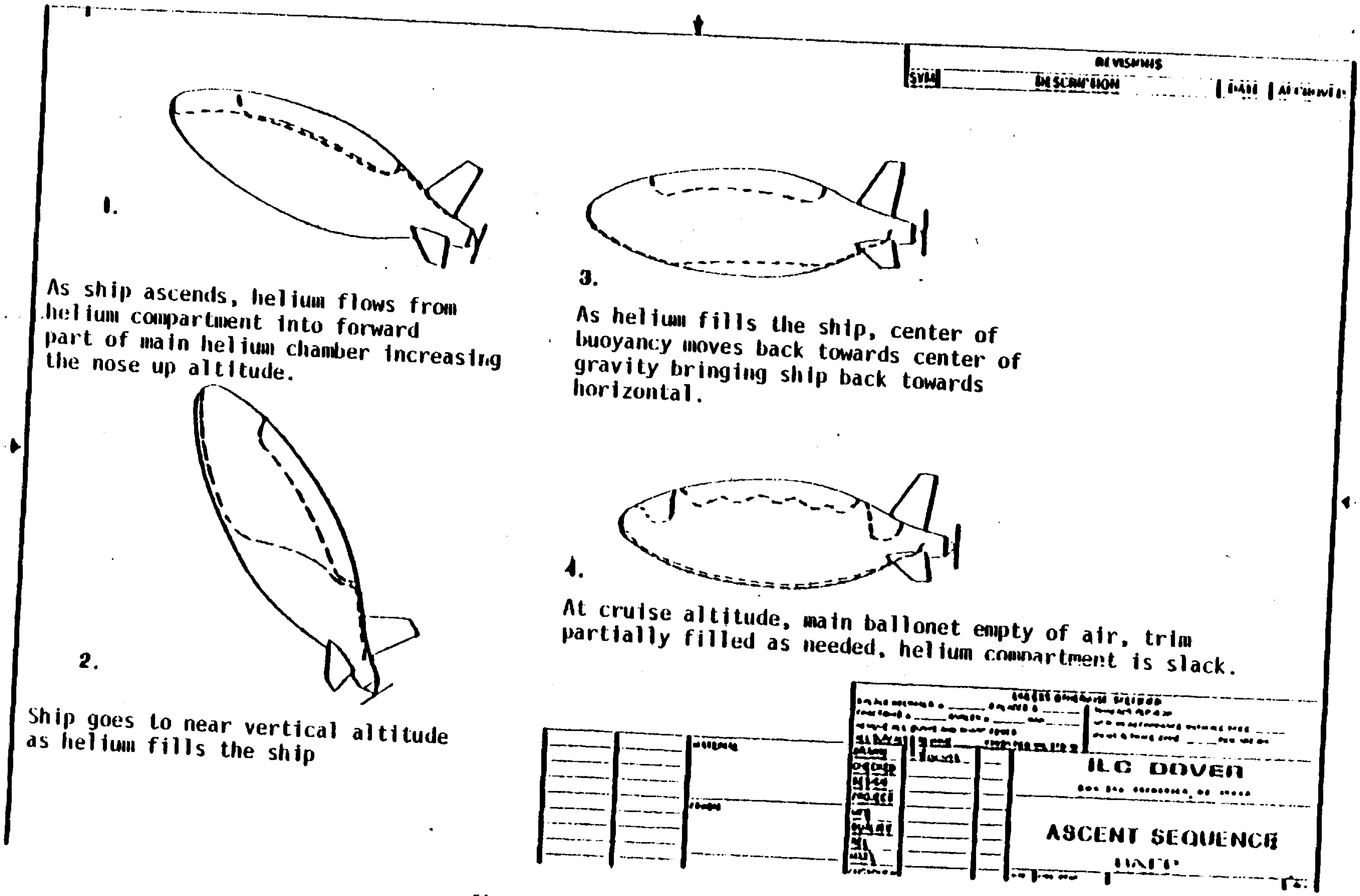


Figure 10-4 HAPP ASCENT SEQUENCE

The pressure in the ship will be allowed to rise to its limiting pressure of 6.35 centimeters water, at which time the main ballonet should be empty and the helium valves will be opened as needed to avoid overpressure. When the ship ascent has ceased, remaining external ballast is jettisoned and propulsion will be activated, which will also activate the trim system and air will be transferred between trim ballonets as needed to achieve a zero angle of attack.

10.4 OPERATION AT ALTITUDE

After flight control has been established, the ship will fly at 55 knots airspeed on it auxiliary engine and navigate to the microwave beam. Once microwave power is available, the auxiliary engine will be shut off and the ship will fly entirely on microwave power for the on-station mission duration.

The HAPP ship will fly at aerostatic equilibrium (zero angle of attack) during the day at its maximum internal pressure (6.35 cm water). At night, as the helium cools, pressure will be allowed to drop to 2.5 cm water, and cooling beyond that point will require aerodynamic lift (about 500 Kg).

Gimballing of the propeller will provide a temporary means of maintaining trim, backed up by transfer of air between trim ballonets which are used to bring the propeller gimbal angle back to zero for best trim efficiency.

An air density sensor (pressure and temperature) will detect changes from the desired altitude and, through a control loop with the propeller gimbal and the trim ballonet transfer pump, adjust the angle of attack to maintain the ship at its proper altitude. During daytime the desired angle of attack is zero and a prolonged deviation from this indicates a departure from aerostatic equilibrium which would be corrected by valving helium or dropping ballast as needed.

Trim forces at night will be influenced by the pitching moment of the aerodynamic lift, and the control loop would operate to balance this out with the trim ballonets.

10.5 CHANGE OF ALTITUDE DURING CRUISE

10.5.1 Ascent

The ship can ascend only when air is available in a ballonet. To ascend, the nose is pitched up by gimballing the propeller and air is vented from the ballonet maintaining pressure greater than minimum. When the new altitude is reached, free lift is adjusted to zero by adjusting super pressure with ballonet pressure controls. If super pressure equilibrium is less than minimum, aerodynamic lift will be needed until heat transfer from ambient air into the ship compensates for the adiabatic gas cooling during ascent.

10.5.2 Descent

To descend, superpressure is increased by pumping air into the main ballonet chamber which gives negative free lift and the ship will sink. If the superpressure margin is not available (as it may not be during daytime when the ship is warm) the ship is pitched down with the propeller and the ship is motored downward maintaining super pressure as it goes. When the desired altitude is reached, superpressure is adjusted to give zero free lift. If this is higher than super pressure limits, negative aerodynamic lift is used until heat transfer from outside cools the ship to a zero lift condition.

10.6 DESCENT FOR LANDING

Upon completion of the on-station mission, the ship will fly at 55 kts airspeed, on auxiliary engine power to the calculated position for commmencement of the descent.

In the final descent mode, a negative free lift is obtained by increasing superpressure of the ship by first pumping air into the main ballonet and trim ballonets. The ship is also pitched down so propulsion will further force downward travel. When the main ballonet is 5% full and the trim ballonet is 50% full, they are thereafter maintained at that level of fullness and excess air requirement is met by blowing air into the helium chamber. This procedure avoids center of buoyancy movement problems and yet provides ballonet air for altitude maneuvering in the landing approach. At 5 kilometers and lower, the super pressure will be maintained at not less than 6 centimeters of water to provide rigidity to resist gusts. When landing approach altitude is reached, the ship levels off and is adjusted to zero angle of attack with trim ballonets. Over the landing field the nose line is dropped. The ship is restrained by the nose line and allowed to weathervane until the mooring mast and dolly are brought into position beneath it. The nose line pulls the nose into the mooring cone while lines from line-throwing guns position straps over the hull and secure it to the cradles and the dolly. Difficulty of the landing maneuver will chiefly be a function of gustiners regardless of wind speed. The practical limits have not been addressed in this study.

NOTE: In so far as possible, the ship control will be programmed to respond to basic commands such as:

1. Change altitude to altitude X.
2. Proceed to latitude X longitude X.
3. Make final descent.

All functions will, however, have remote command override for direct control from the ground in case of malfunction. All sensor outputs will be telemetered to the ground for ground monitoring to detect malfunctions in control.

10.7 EQUIPMENT AND PERSONNEL

It is estimated that a permanent crew of 30 persons will be needed for HAPP operations. Twenty crewmen would be needed for flight preparation, launch, and recovery. Since an abort condition could result in an unscheduled landing on 2 hours notice, 20 men would always be on standby. During normal flight, a crew of three would be needed on watch; one monitor, one emergency control assistant, and one emergency crew coordinator.

10.8 SAFETY AND FAA REGULATIONS

The safety aspects fall in three categories: Crew safety, public on the ground safety, and airspace safety.

Crew safety would be a matter of internal control and no undue problems are anticipated. Normal industrial safety practices should suffice, which would include safety instruction for the crew on special aspects, such as not hanging onto lines as the airship ascends.

Public ground safety is of concern if the ship makes an uncontrolled landing, but the actual hazard is relatively minor. Because of the low density of the ship and its soft construction impact damage to buildings, etc., would generally be minor. The inert characteristics of helium avoids fire and toxic problems in case of its release, and further, since helium rises when released, even a massive release would not pose any suffocation threat to people on the ground.

Airspace hazard could be great, and must be avoided by proper coordination with FAA air traffic control procedures. Federal Aviation Regulation Part 91 would apply, however, the HAPP vehicle because of its unmanned character and unusual operation would need special arrangements made by "waivers" to normal regulatory requirements.

11.0 DEVELOPMENT PLAN

The development plan recommended as a result of the Phase I study will consist of the following steps: 1 - Complete Phase II of this contract (proof of concept model design definition); 2 - Build and flight test a proof-of-concept; 3 - Conduct wind tunnel tests of needed; 4 - Build and flight test a full scale HAPP. Each step is discussed in the following procedures.

11.1 PHASE II (EXISTING CONTRACT)

Phase II calls for a proof-of-concept model design. It was originally thought that this vehicle would be a small (3 - 10K cubic foot) vehicle and fly to some low altitude (3 - 5K ft.). In the course of the study, it became apparent that this type of model would not be very useful as a learning or proof-of-concept tool since it would not demonstrate the extremely large ballonet concept and its impact on ascent/descent/recovery, nor duplicate the full scale HAPP Reynolds Number.

It is generally agreed that the HAPP vehicle proof of concept will not be accomplished until a vehicle is sent to altitude where these critical demonstrations can be achieved. With this in mind, it is necessary to define the steps, after the completion of Phase I that need to be followed in a logical proof of concept program. A multiple stepped program with each vehicle designed to demonstrate increasingly more system factors rather than a single full scale prototype step will provide a sound engineering program approach.

With this philosophy, the proof of concept model is a much larger, much higher fidelity vehicle than originally contemplated. Thus, Phase II of the existing contract will serve to define the size, configuration, and mission of the proof of concept model.

11.2 FIRST DEMONSTRATION VEHICLE

11.2.1 First Flight Test

The HAPP mission will gain its first real step toward demonstration when a vehicle is launched, deployed to altitude and then recovered. The main objectives of this first test vehicle would be to demonstrate the inflation procedures, verify that an inflated ship can "fly" up through the high wind layers, that the ballonet concept is sound, and then return to verify the recovery sequence. This vehicle would use the actual hull materials and configuration anticipated for a full-scale vehicle to permit early real time field verification of the HAPP envelope design and manufacturing techniques.

In order to minimize vehicle size and at the same time keep costs to a minimum, this vehicle would carry only an auxiliary power system, no thin film rectenna or prime power systems would be used. In addition, the station keeping avionics would be greatly simplified and many multiple redundancy features would be eliminated.

Microwave power transmission should be demonstrated on this flight. At some altitude during ascent (dependent upon unit available) microwave power should be transmitted to the balloon and received as evidence by some positive monitor, (power recorder).

It is suggested that this model should have a dummy rectenna to simulate the surface perturbation caused by the rectenna. This could be accomplished by fabricating a foam/mylar sandwich to simulate the rectenna and attach the panels to the balloon in the proposed fashion.

Time on station would be minimum on this first flight; in addition, the flight would be scheduled for favorable ascent/descent winds to minimize fuel consumption. All procedures on this first flight will be true simulations of subsequent flights so all data is directly applicable through size correlations.

11.2.2 Second Flight Test

The first flight of the demonstration vehicle will serve to test the mechanical and aerostatic characteristics of the HAPP concept. A second test flight of this vehicle would be an extremely useful tool for obtaining nearly full scale aerodynamic data which would be extremely costly and subject to great debate over validity if obtained in the wind tunnel. It is proposed that after the first flight successfully demonstrates the vehicle and mission concept, the airship be retrofitted and extensively instrumented to permit a second flight for the purpose of gathering large scale model aerodynamic data.

Accurate lift and drag vs. angle of attack, effects of rectenna surface, effects of rectenna heating, and control and stability feedback parameters are all examples of data which could be accurately obtained from this second flight and be incorporated into the detailed design of the prototype HAPP.

The demonstration vehicle will serve to verify the HAPP concept and will provide the test bed for the accumulation and proofing of aerodynamic data and concepts for large laminar flow bodies.

11.3 WIND TUNNEL MODEL

Depending upon the actual performance of the test vehicle, it may be desirable to use wind tunnel data to optimize the vehicle geometry prior to full scale design of the HAPP prototype. This would include a small amount of computer optimization of the hull shape, fin sizing, etc., followed by wind tunnel verification. If the demonstration vehicle performs well and its performance predictions are in accord with those anticipated, then this program step could be waived.

11.4 PROTOTYPE HAPP

The prototype HAPP, powered by ground based microwave power would be designed, fabricated and flown as the next program step. This vehicle would be the full configuration with regard to size, weight, power components, guidance, etc.

This vehicle would be a "full-up" prototype with design capability for a three month duration. This vehicle is a prototype and would use prototype tooling for manufacture of some of its components. Full production tooling and manufacturing facilities are not justified for a single vehicle in such a phased demonstration program.

11.5 SUMMARY

This four step program will provide a sound engineering approach towards implementing the HAPP concept. The proposed program using four steps with each step demonstrating different and increasingly more complex systems and characteristics is an extension of sound cost effective development philosophies.

An outline summary of the significant advancements to be made with each step is given below:

1. Phase II (Existing Contract)
    a. Define size and mission of "Bare Bones" Demonstration Vehicle
    b. Provide a descriptive list of airship components.
2. Demonstration Vehicle (subscale, Proof-of-Concept Model), Follow-on Contract.
    a. First Flight, Bare
        1. Demonstrate materials
        2. Demonstrate manufacturing techniques
        3. Demonstrate vehicle concept, ballonet concept
        4. Demonstrate operations (launch, ascent, descent, recovery)
    b. Second Flight, Instrumented
        1. Demonstrate propeller design criteria
        2. Verify aerodynamic predictions
        3. Verify control predictions
3. Wind Tunnel Option
    a. Optimize vehicle shape to enhance aerodynamics
    b. Optimize empennage sizing to enhance stability and control
4. Full Scale Prototype Vehicle
    a. Demonstrate full scale operations (launch, ascent, descent, recovery)
    b. Demonstrate prime propulsion system

c. Demonstrate full scale auxiliary power system

d. Demonstrate rectenna, power conversion at altitude

e. Demonstrate coupling of prime/auxiliary power

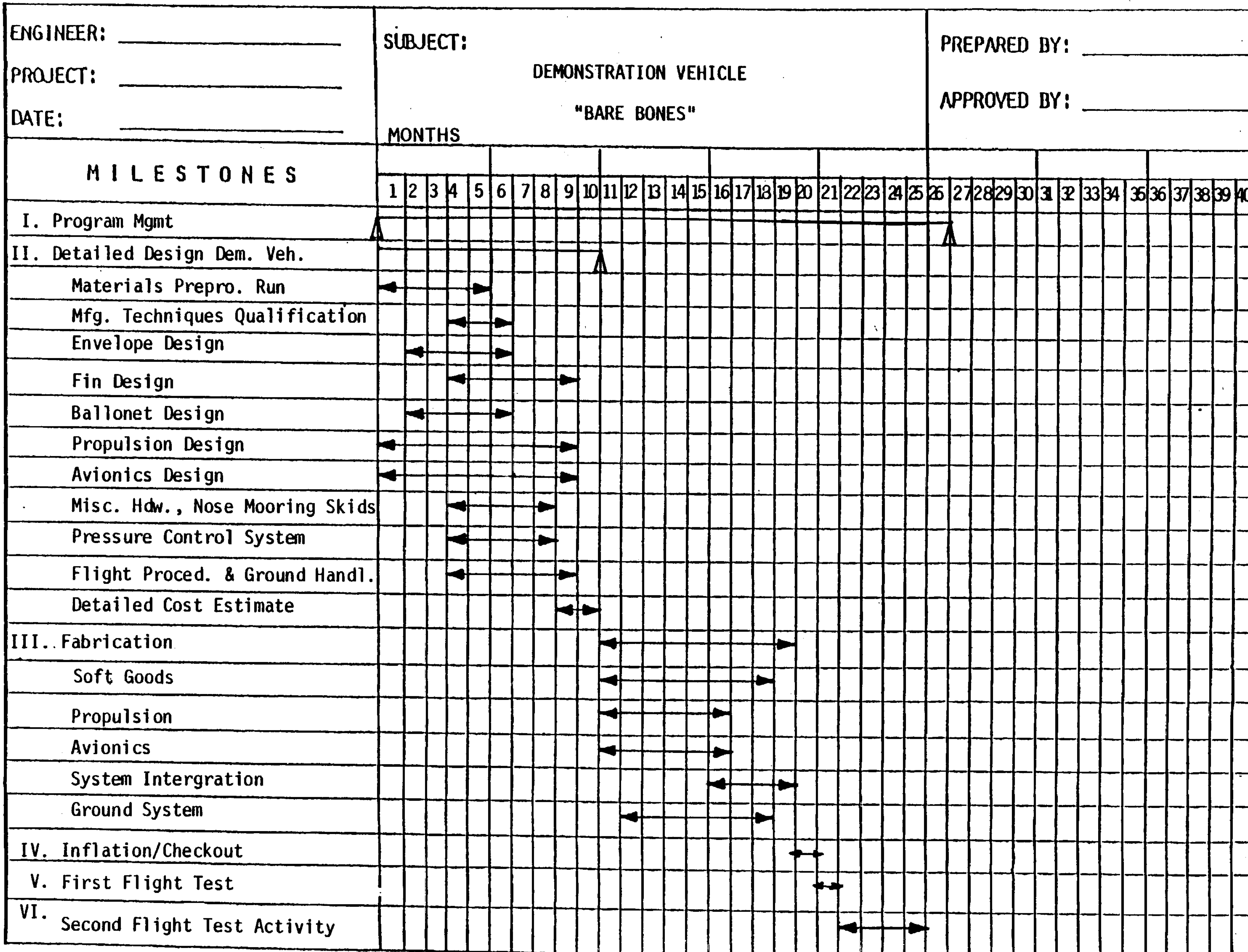
f. Demonstrate navigation and avionics system

g. Demonstrate mission duration

h. Demonstrate all full scale weight and power requirements

j. Demonstrate tracking capability of full scale rectenna ground station

The recommended schedules for items 2 through 4 above appear on the following pages.


ENGINEER:
PROJECT:
DATE:
SUBJECT:
DEMONSTRATION VEHICLE
"BARE BONES"
PREPARED BY:
APPROVED BY:
MONTHS
MILESTONES
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
I. Program Mgmt
II. Detailed Design Dem. Veh.
Materials Prepro. Run
Mfg. Techniques Qualification
Envelope Design
Fin Design
Ballonet Design
Propulsion Design
Avionics Design
Misc. Hdw., Nose Mooring Skids
Pressure Control System
Flight Proced. & Ground Handl.
Detailed Cost Estimate
III. Fabrication
Soft Goods
Propulsion
Avionics
System Intergration
Ground System
IV. Inflation/Checkout
V. First Flight Test
VI. Second Flight Test Activity

ENGINEER: ____________

PROJECT: ____________

DATE: ____________

SUBJECT:

DEMONSTRATION VEHICLE

"BARE BONES"

PREPARED BY: ____________

APPROVED BY: ____________

MILESTONES	MONTHS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Instrumentation Retrofit																																								
Flight Test																																								
VII. Program Review Report/Recomm.																																								

ENGINEER: ______

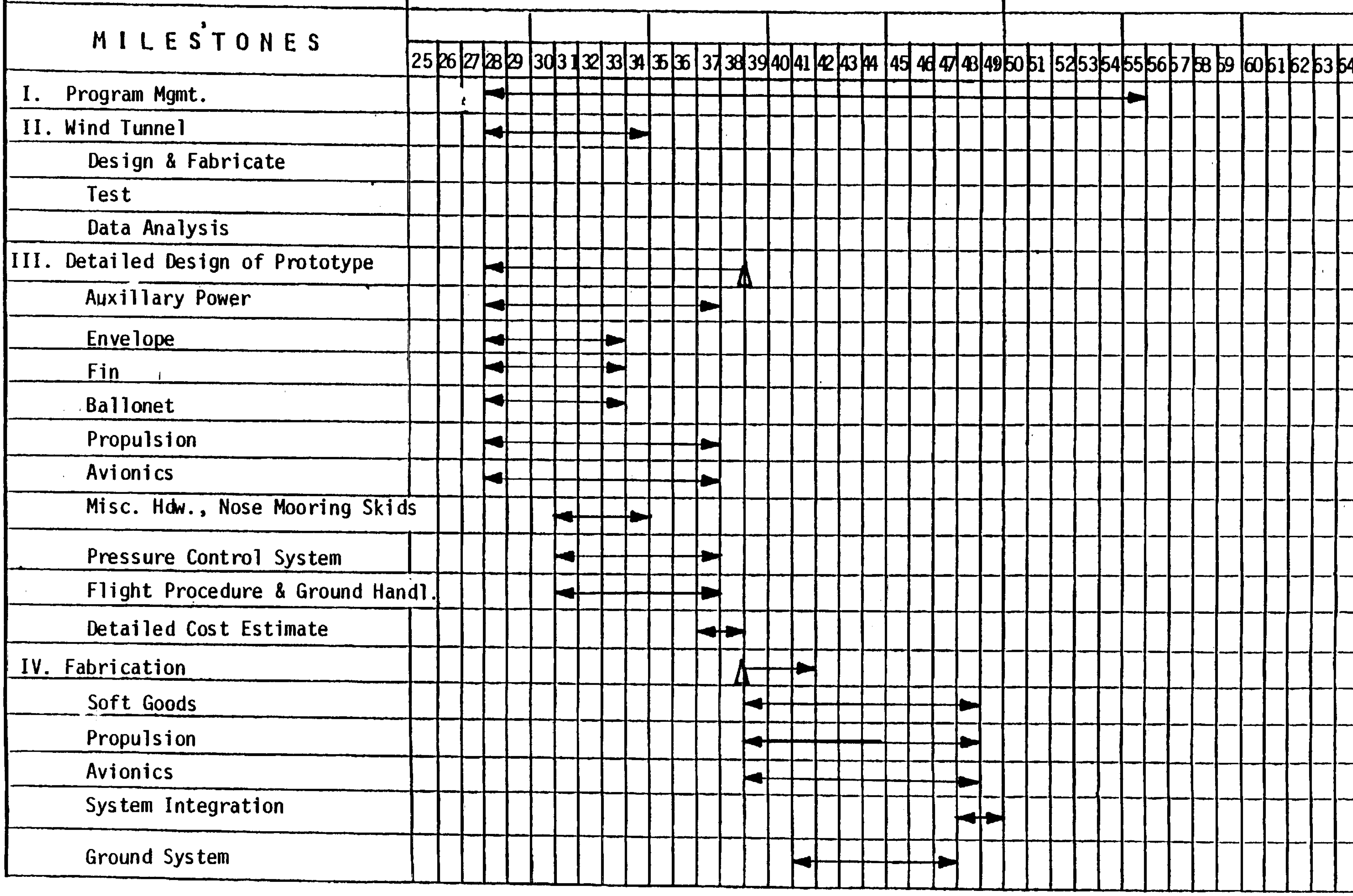
PROJECT: ______

DATE: ______

SUBJECT: PROTOTYPE HAPP

PREPARED BY: ______

APPROVED BY: ______



ENGINEER: ______________

PROJECT: ______________

DATE: ______________

SUBJECT:

PROTOTYPE HAPP

PREPARED BY: ______________

APPROVED BY: ______________

MONTHS

MILESTONES	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
V. Inflation Checkout																																								
VI. Flight Test																																								
VII. Program Review/Reports																																								

12.0 COST ESTIMATE

Demonstration Vehicle

It has been proposed in the Development Plan, that a large demonstration vehicle preceed the full scale HAPP prototype. This vehicle, although it will represent a significant program cost in itself to design, manufacture and conduct flight tests, will still represent a relatively low cost to verify the most critical operational HAPP vehicle performance questions.

Many of the design areas such as materials, patterning, construction techniques, ballonet configuration, launch/recovery techniques, propeller design, blower/valve design, and aerodynamics can all be determined on this vehicle. Phase II of this contract will address this vehicle in more detail in an effort to define its size, component selection and suggest mission scenarios. A cost estimate for this vehicle and its development and flight test program will be provided in the Phase II report.

Prototype Vehicle

After a successful demonstration program, the HAPP development would proceed to the detailed design, fabrication, and flight test of a full scale HAPP prototype. An effort has been made to estimate the cost of such a program. The estimate presented herein is based on the type of serial program outlined in the Development Plan.

The basic guidelines assumed in this estimate are as follows:

a. This HAPP Prototype would follow the successful completion of a large scale demonstration program. (A twenty-six month demonstration program assumed).

b. The use of a GFE hangar facility and vehicle support is assumed.

c. All costs are calculated in 1983 dollars.

d. A twenty-nine month prototype program is assumed.

The major cost areas considered in such a program are discussed below:

12.1 PROGRAM MANAGEMENT $890K

This cost element includes one full time Program Manager, one Chief Engineer, and two full time schedule/costing specialists to run the overall program and coordinate all program activities, meet report requirements, ensure schedules are met, etc. (Twenty nine months of activity).

12.2 OPTIONAL WIND TUNNEL MODEL $125K

This program would include a computer optimization of shape and empennage followed by a wind tunnel verification of the effects of the changes. The basic input data for this activity would come from the data obtained on the second "instrumented" flight test of the demonstrator. A GFE wind tunnel with support personnel is assumed.

12.3 DESIGN $7,380K

The design of the full scale HAPP prototype will, in some areas (such as softgoods design, patterns, procedures) be extrapolations of designs developed on the demonstrator. In other areas new developments totally unrelated to the demonstration will be required (such as electric motor, rectenna, electrical interface, automatic guidance).

The design topics considered in this task are listed below:

1. Materials (potential minor changes from demonstrator)
2. Manufacturing techniques (potential minor changes from demonstrator)

3. Envelope Design (extrapolations, possible change from wind tunnel test)
4. Fin Design (extrapolations, possible change from wind tunnel test)
5. Ballonet Design (extrapolation)
6. Propulsion Motors (new)
7. Avionics (expanded, new guidance system)
8. Manufacturing Procedures (Table of Operations, formal)
9. Miscellaneous Hardware, Nose Mooring, Payload Skids, (scale up, some changes)
10. Pressure Control System (scale up)
11. Propeller/Hub Design (new)
12. Flight Procedures/Ground Handling, Equipment (scale up)
13. Auxiliary Power System (New)

12.4 FABRICATION $6,649K

This topic includes the manufacture and integration of the following equipment/subassemblies:

1. Softgoods
    a. Hull
    b. Empennage
    c. Ballonets
2. Hardware
    a. Air supply, blower, valves, plenums
    b. Gas and air vent valves
    c. Moving hardware
    d. Payload skids
    e. Engines
    f. Gearbox
    g. Propeller

h. Thrust Gimbal

i. Mounting hardware

j. Avionics/guidance

k. Auxiliary power

L. Rectenna interface

3. Ground Mooring System.

12.5 INFLATION/CHECKOUT $88K

A one month inflation checkout is assumed. During this time the HAPP would be inflated, leak checked, fitted with all subsystems, fitted with rectenna, and subjected to systems checkout.

Seven engineers and three technicians are assumed. Handling specialists are not included, it is assumed that these can be locally obtained for unpacking and inflation of the aerostat.

12.6 FLIGHT TEST $696K*

A three month test flight program is assumed. During this period, it is assumed that the contractor would provide a Flight Controller, a Flight Test Engineer and an Electronic Engineer 24 hours per day, 7 days per week.

Ground Handlers would have to be available throughout the test program in the event an unscheduled recovery was required. It is assumed that twenty people would be desired for this. A crew of thirty handlers is suggested with ten on each shift and ten of the remaining twenty on call at all times.

*Nominal environment flight test, certification flights could add $1,500K additional.

It is proposed that rather than a full three month flight at altitude, it may be desirable to fly only two months and use the third month for several launch/recovery sequences to improve and refine ascent/descent/recovery procedures.

12.7 FINAL REPORT 66K

A final report discussing the vehicles predicted performance and its actual performance during the tests. Included would be reports on the softgoods envelope, aerodynamics, rectenna performance, flight control, launch/recovery, refurbishment requirements, and future recommendations.

12.8 TOTAL PROGRAM COST ESTIMATE $15,894K

Plus GFE:

- Rectenna
- Ground Power
- Test Facilities
- Wind Tunnel and Support Personnel
- Helium, Vehicles, Equipment for Flight Tests

13.0 PROGRAM RISK AREAS AND CONCLUSIONS

13.1 RISK AREAS

The risk areas identified for this development are as follows:

a. Aerodynamics: The achievement of significant laminar flow on a large airship hull has not be demonstrated. In the Reynolds number regime of HAPP, it is theoretically achievable. Reduction to practice, however, is a risk area. Failure to achieve laminar flow degrades performance but still would permit useful missions.

b. Materials: Laboratory results indicate Kevlar fabric and low absorptivity/emmisivity thermal constructions are achievable. Reduction to practice in a large vehicle has yet to be demonstrated.

c. Electric Motors: Samarium-cobolt motors and generators offer a "breakthrough" in weight to power ratios which make the HAPP concept acceptable. The technology is continuing to change and improve rapidly, however, practical problems of their application in the design is yet to be determined.

d. Auxiliary Engine: A reciprocating internal combustion, supercharged engine has been selected for restart capability and fuel efficiency. This is an innovative extrapolation of current technology and as such carries risk.

e. Rectenna Operation: Practical factors associated with rectenna installation and operation are surmised to be not severe, but are unknown until some experience is gained.

f. Reliability: Reliability estimates in this report have been estimated assuming failure rates which might be associated with hardware developed for airplane industry. The reliability to be achieved for HAPP will be a tradeoff with the cost of the reliability program.

13.2 CONCLUSIONS

a. With moderate extrapolation of current technological practices an airship to perform the HAPP mission is feasible, and the design features have been defined.

b. There are special mission cases for this vehicle which could result in a smaller or less refined design, however, this study was aimed at a single vehicle capable of operation over the entire continental United States. The selected configuration is such a vehicle.

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APPENDIX A

HAPP BASELINE PARAMETRIC PROGRAM

HAPP BASELINE PROGRAM 1906 20JN82

```
10  REM  FILE NAME "HAPP 1906 20JN82". THIS IS-THE- HAPP BASELINE  SLIGHT MOD FROM 1650 18JN82 TO HANDLE HULL PRES
     S LOWER THAN MIN FAB STR
20  REM  PERSONS FAMILIAR WITH PROGRAM:HAMMET,STEFAN,WEIS,THIELE
30  REM ********************
40  REM *  HAPP PROG METRIC   *
50  REM *  VOLUME DEPENDENT   *
60 BASE$ = "1906 20JN82"
70  REM ********************
80  REM  1.PARTIAL SUPERPRESS PER MIN FAB WT. 2.STATIC EQUIL DAY, DYN LIFT NITE 3.THRESHOLD 93KT. 4.LIMIT 93KT 5.A
     UX 35KT. 6.CD1 INCLUDED FOR EACH AIRSPEED
90  HOME
100  DIM R(24),VE(24),U(24),UA(24),TE(24),P(24),UU(24),UD(24),VX(24),B(13),WC(13)
110 PI = 3.14159:C2 = .514444:C3 = 98.0638: REM  SEE SYMBOLS
120  REM DENSITIES @ 1000 M INCREM
130 R(0) = 1.2250:R(1) = 1.1117:R(2) = 1.0066
140 R(3) = .90925:R(4) = .81935:R(5) = .73643
150 R(6) = .66011:R(7) = .59002:R(8) = .52579
160 R(9) = .46706:R(10) = .41351:R(11) = .36480
170 R(12) = .31194:R(13) = .26660:R(14) = .22786
180 R(15) = .19475:R(16) = .16647:R(17) = .1423
190 R(18) = .12165:R(19) = .10400
200 R(20) = 8.8910E - 2:R(21) = 7.5715E - 2
210 R(22) = 3.8083E - 2:R(23) = 3.6790E - 2:R(24) = 3.5531E - 2
220 TE(16) = 216.65:TE(17) = 216.65:TE(18) = 216.65:TE(19) = 216.65:TE(20) = 216.65:TE(21) = 217.58:TE(22) = 21[illegible].5
     7:TE(23) = 219.57:TE(24) = 220.56
230 P(16) = 10352.8:P(17) = 8849.7:P(18) = 7565.2:P(19) = 6467.5:P(20) = 5529.3:P(21) = 4728.9:P(22) = 4047.5:P(23
     ) = 3466.9:P(24) = 2971.7
240  VTAB 10
250  HTAB 10
260 DA$ = "23JUN82"
270  LIST 260: PRINT : PRINT : PRINT "TO CHANGE CURRENT DATE *RESET*,CHANGE, RUN"
280  FOR I = 1 TO 50:X = 1 ↑ 2: NEXT :X = 0
290  HOME : VTAB 4: HTAB 4: PRINT "IF YOU ARE MAKING CHANGES FROM THE"
300  HTAB 4: PRINT "BASELINE & WOULD LIKE TO HAVE THEM"
310  HTAB 4: PRINT "NOTED YOU HAVE TWO LINES OF 60 CHAR"
320  HTAB 4: PRINT "EACH TO MAKE YOUR COMMENTS": HTAB 4: PRINT "TYPE RTN FOR NO COMMENT"
330  PRINT : PRINT "COMMENT #1": INPUT " ";CO$(1): IF  LEN (CO$(1)) > 60 THEN  PRINT "COMMENT TOO LONG": GOTO 330
340  PRINT : PRINT "COMMENT #2": INPUT " ";CO$(2): IF  LEN (CO$(2)) > 60 THEN  PRINT "COMMENT TOO LONG": GOTO 340
350  HOME : VTAB 5: HTAB 10
360  INVERSE : PRINT "CONFIGURATION OPTION": NORMAL
370  PRINT "          DOLPHIN , SOFT FINS": PRINT
380 FIG$ = "2"
390  INPUT "CHANGE CONFIG. TO HARD FINS? N ";AS$
400  IF AS$ = "Y" THEN FIG$ = "1"
410  REM  **********
420  REM  INIT INPUTS
430  REM  **********
440 E(1) = .90: REM PROP EFFIC
450 E(2) = 1: REM  SHAFT
460 E(3) = .95: REM  GEARBOX EFFIC
470 E(4) = .95: REM  PRIME ENG EFFIC
480 E(5) = .80: REM  RECT EFFIC
490 E(7) = .90: REM  AUX GENERATOR EFFIC
500 E(10) = .98: REM  TRANSWIRE EFFIC
510 WC(3) = .43: REM  GEARBOX WT COEFF
520 WC(4) = 1.82: REM DRIVE MOTOR WT COEFF
530 WC(6) = 4.75: REM  AUX ENG WT COEFF
540 WC(7) = 1.1: REM  AUX GENERATOR WT COEFF
550 K(5) = .500: REM    KW/M2 RECT BEAM
560 WC(5) = .400: REM  KG/M2 WT CO              NST OF RECT, REF BROWN4JN82
570 WC(12) = 1.0: REM  WATER RECOVER EST BYKS
580 UK(1) = 93:UM(1) = UK(1) * C2: REM  UK(1) KTS;UM(1) M/S;THRESHOLD SPEED
590 UK(2) = 55:UM(2) = UK(2) * C2: REM  UK(2) KTS;UM(2) M/S;AUX ONLY SPEED
600 UK(5) = 93:UM(5) = UK(5) * C2: REM  UK(5) KTS;UM(5) M/S;LIMITING SPEED
610 RA = 287.053: REM R-AIR J/KG KELVIN
620 RH = 2077.23: REM  R-HELIUM
630 CP = 1.2:CP(1) = 1: REM  DYNAMIC LIFT COEFF.
640 SH = 16.7: REM  SUPER HEAT KELVIN
650 SC =  - 17.2: REM  SUPER COOL KELVIN
660 V0 = 76193: REM   VOLUME M↑3
670 CA = 85: REM  CLIMB ANGLE DEG
680 DC = .028: REM  CLIMB,DESCENT CD
690 CD = .018: IF FIG$ = "1" THEN CD = .016
```

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700 RD = 150: REM RATE DSCENT M/MIN
710 RC = 150: REM RATE ASCENT M/MIN
720 ALT = 20000:ZT = ALT / 1000: REM  OPERATING ALTITUDE,M
730 PUR = .95: REM  PURITY
740 LH(1) = .19: REM  KG/KWHR FUEL WT
750 LH(2) = .011: REM  KG/KWHR TANK & SUPPORT WT
760 LH = LH(1) + LH(2): REM  KG/KWHR FUEL AND TANK+SUPPORT WT
770 PROP$ = "RECIP ENGINE H2"
780 B(9) = 680: REM PAYLOAD WT KGS
790 B(8) = 117.3: REM AVIONICS WT KGS
800 B(13) = 448.07: REM BALLAST IN NOSE FOR BALANCE
810  HOME : VTAB 12: PRINT "ALTITUDE = "ALT" M"
820  INPUT "DO YOU WANT TO CHANGE ? (Y/N) N ";AS$
830  IF AS$ = "Y" THEN  GOTO 850
840  GOTO 870
850  INPUT "NEW ALTITUDE ";ALT
860 ZT = ALT / 1000
870 P = P(ZT):TE = TE(ZT)
880  HOME : VTAB 12: PRINT "SHAFT LENGTH =SHIP LENGTH LF*(95-.80). IF YOU WANT TO CHANGE, KEY Y AND LIST 2552": INP
     " (Y/N)N";AS$
890  IF AS$ = "Y" THEN  GOTO 900
900  GOTO 910
910 WC(2) = .0119: REM  DRIVE SHAFT WT COEFFFOR RADIUS 0.25M, AL 6061T6
920  HOME : VTAB 12: PRINT "DRIVE SHAFT WT COEFF. = ";WC(2)
930  INPUT "DO YOU WANT TO CHANGE? N ";AS$: IF AS$ = "Y" THEN  GOTO 950
940  GOTO 960
950  INPUT " NEW DRIVE SHAFT WT COEFF = ";WC(2)
960 PC(2) = 2.5:PD(2) = PC(2) * C3: REM  PC CMH2O,PD PASCALS, NITE PRESS DIFF
970 FS = 5: REM  SAFTEY FACTOR
980 MHW = 0.11867: REM  MIN HULLFAB WT(3.5 OZ/YD2)
990 FFW = .11867: REM FIN FABRIC WT KG/M↑2
1000 RFW = .07: REM RIB FABRIC WT KG.M↑2
1010 BFW = .085: REM BALLONET FABRIC WT KG/M↑2
1020 T(4) = .05: REM  PROP SHIP VOL FOR TRIM BALLONET
1030 BV(1) = 0: REM  BALLONET VOL
1040 K(9) = 1: REM  KW PWR P/L
1050 K(8) = 1.13: REM AVIONICS PWR KW
1060 SHIP$ = "DOLPHIP HARD FINS": IF FIG$ = "2" THEN SHIP$ = "DOLPHIN SOFT FINS"
1070  HOME : VTAB 12
1080  PRINT "CLIMB ANGLE = "CA" DEG PWR OFF ASCENT"
1090  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1100  IF AS$ = "Y" THEN 1130
1110  PRINT "P1=ASCENT" TAB( 20)"P2=CRUISE MAX" TAB( 40)"P3=CRUISE PARTIAL"
1120  GOTO 1140
1130  INPUT "NEW CLIMB ANGLE = ";CA
1140  HOME : VTAB 12
1150  PRINT "CLIMB CD = "DC
1160  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1170  IF AS$ = "Y" THEN 1190
1180  GOTO 1200
1190  INPUT "NEW CLIMB CD = ";DC
1200  HOME : VTAB 12
1210  PRINT "PURITY = "PUR
1220  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1230  IF AS$ = "Y" THEN 1250
1240  GOTO 1260
1250  INPUT "PURITY =";PUR
1260  HOME : VTAB 12
1270 RE = (RA * RH) / (PUR * (RA - RH) + RH): REM  EFFECTIVE GAS CONSTANT
1280  PRINT "DRAG COEFF(SHIP)="CD
1290  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1300  IF AS$ = "Y" THEN  GOTO 1320
1310  GOTO 1330
1320  INPUT "NEW COEFF =";CD
1330  HOME : VTAB 12
1340  PRINT "MINIMUM AVE HULL FAB WT="MHW" KG/M2)
1350  INPUT "DO YOU WANT TO CHANGE,(Y/N)N";AS$
1360  IF AS$ = "Y" THEN 1380
1370  GOTO 1390
1380  INPUT "NEW MIN AVE HULL FAB WT=";MHW
1390  PRINT "FIN SKIN FAB WT="FFW" KG/M↑2"
1400  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1410  IF AS$ = "Y" THEN  GOTO 1430
1420  GOTO 1450
1430  INPUT "NEW FIN SKIN WT=";FFW
1440  HOME : VTAB 12
1450  PRINT "RIB FAB WT=";RFW" KG/M↑2"
1460  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1470  IF AS$ = "Y" THEN  GOTO 1490
1480  GOTO 1510
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1490  INPUT "NEW RIB FAB WT=";RFW
1500  HOME : VTAB 12
1510  PRINT "BALNT FAB WT="BFW" KG/M↑2"
1520  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1530  IF AS$ = "Y" THEN  GOTO 1550
1540  GOTO 1560
1550  INPUT "NEW BALNT FAB WT=";BFW
1560  PRINT "BALLONET VOL AT CRUISE ALT = "BV(1)
1570  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1580  IF AS$ = "Y" THEN  GOTO 1600
1590  GOTO 1610
1600  INPUT "BALLONET VOL = "BV(1)
1610  PRINT "PROP OF SHIP VOL FOR TRIM BALLONET = "T(4)
1620  INPUT "DO YOU WANT TO CHANGE? ";AS$
1630  IF AS$ = "Y" THEN 1650
1640  GOTO 1660
1650  INPUT "NEW PROP OF SHIP FOR TRIM BALLONET = ";T(4)
1660  HOME : VTAB 2
1670  HTAB 15: INVERSE : PRINT "WIND OPTIONS": NORMAL
1680  PRINT : PRINT : PRINT "THRESHOLD VELOCITY = "UK(1)" KTS": INPUT "WILL THIS CHANGE (Y/N) N ";AS$
1690  IF AS$ = "Y" THEN  GOTO 1710
1700  GOTO 1720
1710  INPUT "NEW THRESHOLD VELOCITY, KTS";UK(1):UM(1) = UK(1) * C2
1720  PRINT : PRINT
1730  PRINT "AUX DESIGN SPEED = "UK(2)" KTS": INPUT "DO YOU WANT TO CHANGE? ";AS$: IF AS$ = "Y" THEN 1750
1740  GOTO 1760
1750  INPUT "NEW AUX DESIGN SPEED = ";UK(2):UM(2) = UK(2) * C2
1760  PRINT : PRINT
1770  PRINT "LIMITING SPEED = "UK(5)" KTS": INPUT "DO YOU WANT TO CHANGE? ";AS$: IF AS$ = "Y" THEN 1790
1780  GOTO 1800
1790  INPUT "NEW LIMITING SPEED = ";UK(5):UM(5) = UK(5) * C2
1800  HOME : VTAB 12
1810  VTAB 14: PRINT "CALCULATING WIND VALVES"
1820  REM  ASCENT WASH D.C. FALL,KT
1830  FOR I = 0 TO 10:UA(I) = (I + 3.44) / .128: NEXT
1840  FOR I = 11 TO 12:UA(I) = (115 - Y): NEXT
1850  FOR I = 13 TO 18:UA(I) = (21.224 - I) / .08955: NEXT
1860  FOR I = 19 TO 24:UA(I) = (42.01 - I) / .667: NEXT
1870  REM  DSCENT WINTER DAYTON OH,KT
1880  FOR I = 0 TO 10:UD(I) = (I + 1.44) / .08: NEXT
1890  FOR I = 11 TO 12:UD(I) = (45.75 - I) / .25: NEXT
1900  FOR I = 13 TO 18:UD(I) = (22.8 - Y) / .08: NEXT
1910  FOR I = 19 TO 24:UD(I) = (42 - Y) / .4: NEXT
1920  FOR I = 1 TO 24:U(I) = UA(I) * C2:UU(I) = UD(I) * C2: NEXT : REM   CHGS KT TO M/S
1930  HOME : VTAB 12: PRINT "SUPER HEAT & COOL TEMP = "SH" & "SC" K"
1940  INPUT "DO YOU WANT TO CHANGE Y/N N";AS$
1950  IF AS$ = "Y" THEN  GOTO 1970
1960  GOTO 1980
1970  INPUT "NEW HEAT = ";SH: INPUT "NEW COOL = ";SC
1980  HOME : VTAB 12
1990  PRINT "NITE PRESS DIFF = "PC(2)" CM H20": PRINT "SAFTEY FACTOR = "FS
2000  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2010  IF AS$ = "Y" THEN  GOTO 2030
2020  GOTO 2040
2030  INPUT "NEW NITE PRESS DIFF(CM H20)= ";PC(2):PD(2) = PC(2) * C3: INPUT "NEW SAFTEY FACTOR = ";FS
2040 PD(4) = (P + PD(2)) * (TE + SH) / (TE + SC) - P:PC(4) = PD(4) / C3: REM  PASCALS PRESS DIF DAY
2050  PRINT "DAY PRESS DIFF FOR DAYNITE EQUIL, CM H20="PC(4)
2060 PD = 622.570778:PD$ = "FABPRESS": PRINT "DAY PRESS WILL ADJUST TO PRESSURE FOR MIN FAB WT": PRINT : INPUT "DO
     YOU WANT TO CHANGE(Y/N)N";AS$
2070  IF AS$ = "Y" THEN PD$ = "0": GOTO 2090
2080  GOTO 2100
2090  INPUT "NEW DAY PRESS DIFF, CMH20=";PC(3):PD = PC(3) * C3
2100  HOME : VTAB 12
2110  PRINT "P/L WT="B(9)" KGS"
2120  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2130  IF AS$ = "Y" THEN  GOTO 2150
2140  GOTO 2160
2150  INPUT "P/L WT (KGS) = ";B(9)
2160  HOME : VTAB 12
2170  PRINT "AVIONICS WT="B(8)" KGS"
2180  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2190  IF AS$ = "Y" THEN  GOTO 2210
2200  GOTO 2220
2210  INPUT "NEW WT=";B(8)
2220  HOME : VTAB 12
2230  PRINT "P/L PWR="K(9)" KW"
2240  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2250  IF AS$ = "Y" THEN  GOTO 2270
2260  GOTO 2290
2270  INPUT "PWR P/L (KW) = ";KC(9)
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2280  HOME : VTAB 12
2290  PRINT "AVIONICS PWR="K(8)" KW"
2300  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2310  IF AS$ = "Y" THEN  GOTO 2850
2320  GOTO 2340
2330  INPUT "NEW PWR?";KC(8)
2340  HOME : VTAB 12
2350  PRINT "VOLUME = "VO" M↑3"
2360  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2370  IF AS$ = "Y" THEN  GOTO 2390
2380  GOTO 2400
2390  INPUT "NEW VOLUME (M↑3) = ";VO
2400 UO = UK(2)
2410  REM  START HERE FOR RUN WITH NEW VALUES
2420 UO = (UK(5) ↑ 3 - UK(1) ↑ 3) ↑ (1 / 3)
2430  IF UK(2) <  > UO THEN UK(2) = UO
2440  IF UK(2) < UO THEN UK(2) = UO
2450  FOR I = 1 TO 5:UK(I) = UK(I) * C2: NEXT
2460  FOR I = 1 TO 5: PRINT I"  UK("I")="UK(I): NEXT : FOR I = 1 TO 30:X = I ↑ 2: NEXT :X = 0
2470 RE = (RA * RH) / (PUR * (RA - RH) + RH): REM  EFFECTIVE GAS CONSTANT
2480  REM **************
2490  REM SIZING ROUTINE
2500  REM **************
2510 I = 0
2520 QT = 0:TQ = 0:DSCNT$ = " "
2530 RO = R(ZT): REM  DEN AT OPR ALT
2540 V2 = VO ↑ .666666667
2550 VR = 0.44291 * VO ↑ (1 / 3): REM  RADIUS M DERIVED FR 1.5MCF=50.7FT
2560 LF = (VR * 6.863) * .95: REM  LENGTH,TRUNCATED 5% FOR BALANCE
2570 SA = 5.9388 * V2: REM  SFC AREA M2 DERIVED FR 1.5MCF=77820
2580 SL = LF * (.95 - .80): REM  SHAFT LENGTH
2590 L2 = 2 * (LF * (.8 - .4)):L3 = 2 * (LF * (.8 - .1)): REM  WIRE LENGTHS RECTENNA AND AUXGEN TO MOTOR
2600  IF L2$ = "J" THEN 2640
2610  PRINT "WIRE TO MOTOR FROM; RECT IS LF*(.8-.4); AUXGEN LF*(.8-.1)":L2$ = "J"
2620  INPUT "DO YOU WANT TO CHANGE (Y/N)N";AS$
2630  IF AS$ = "Y" THEN  PRINT "CHANGE LENGTHS L2 RECTENA,L3 AUXGEN, 4TH LINE ABOVE": STOP
2640  REM  B(11)=.1204*VO↑(2/3):REM OLD CONE WT
2650 B(11) = 47: REM  B(11)=0.303*XL↑2+25.823*(VO/142000)↑(1/3)*XL+45:REM CONE WT 4JN82 BASIS .015" COMPOSITE CON
     +45KG END RINGS,=600KG FOR 142000M3  SL=19M
2660 EPWR = K(8) + K(9): REM ELEC PWR
2670 ESF = 2.0487: REM  EFF STRESS FACTOR
2680 HFW = MHW * SA: REM  HULL WT MIN FAB
2690  IF PD$ = "FABPRESS" THEN PD = (MHW * SA - (.057642 * SA)) / (1.3404E - 06 * FS * VO * ESF)
2700 PD(4) = (P + PD(2)) * (TE + SH) / (TE + SC) - P:PC(4) = PD(4) / C3: REM  PASCALS PRESS DIF DAY
2710  IF PD$ = "FABPRESS" AND PD(4) < PD THEN PD = PD(4)
2720  IF PD$ <  > "FABPRESS" THEN HFW = 1.3404E - 6 * PD * FS * VO * ESF + (.057642 * SA): REM  HULL WT
2730 UHW = HFW / SA:UFW = UHW: IF UFW < MHW THEN UFW = MHW:HFW = SA * UFW
2740 KTW = HFW * .08: REM TAPE WT KG;4% EACH SIDE
2750 M(1) = (P * VO) / (RA * TE): REM  MASS DISPL AIR
2760 M(2) = ((P + PD) * (VO - BV(1))) / (RE * (TE + SH)): REM  MASS HE
2770 M(3) = ((P + PD) * (BV(1))) / (RA * (TE + SH)): REM  DAY MASS AIR IN BALNT
2780 LD(1) = M(1) - M(2) - M(3): REM  DAY STATIC LIFT
2790 NV = (M(2) * RE * (TE + SC)) / (P + PD(2)): REM  NIGHT VOL HE
2800 M(5) = ((P + PD(2)) * (VO - NV)) / (RA * (TE + SC)): REM  NITE BALNT AIR MASS
2810 LD(2) = M(1) - M(2) - M(5): REM NIGHT STATIC LIFT
2820 BV = VOL - NV: REM  NITE BALLONET VOLUME
2830 LD(3) = LD(1): REM  MAX DAY LIFT FOR DYNAMIC LIFT COEF
2840 LD = (LD(1) - LD(2)): REM  DYNAMIC LIFT DURING NIGHT ONLY
2850  IF LD = 0 THEN LD = .1
2860 TL(1) = (2 * LD * 9.807) / (RO * V2 * UM(1) ↑ 2): REM  DYNAMIC CL AT THRESHOLD SPD
2870 CD(1) = CD + (CP(1) * (TL(1) / CP) ↑ 2) / 2: REM  CD+INDUCED DRAG/2 TO AVE DAY-NITE DRAG
2880 K4(1) = (CD(1) * .5 * R(ZT) * UM(1) ↑ 3 * V2) / (1000): REM PROP KW AT THRESHOLD, PRIME PWR
2890 K4(4) = (K4(1)) / (E(1) * E(3)): REM  THRESHOLD ENG PWR
2900 K4(5) = K4(4) / (E(4) * E(10)) + K(8) + K(9): REM  RECT PWR
2910 K5(5) = K4(5) / E(5)
2920 AR(5) = K5(5) / (K(5) / 0.88): REM  RECT AREA M↑2,.88FACTOR FOR COS↑2 APPROXIMATION
2930 A1 = ((AR(5) / ((VO / 42475) ↑ (2 / 3))) + 311.04) / 38.11: REM  ANGLE OF INCIDENCE LIMIT
2940 B(5) = AR(5) * WC(5): REM  RECT WT
2950 B(4) = K4(4) * WC(4): REM  PRIME ENG WT
2960 TL(2) = (2 * LD * 9.807) / (RO * V2 * UM(2) ↑ 2): REM  DYNAMIC CL
2970 CD(2) = CD + (CP(1) * (TL(2) / CP) ↑ 2) / 2: REM  CD+INDUCED DRAG/2 TO AVE DAY-NITE DRAG
2980 K9(1) = (CD(2) * .5 * R(ZT) * UM(2) ↑ 3 * V2) / (1000): REM PROP KW AT DESIGN, AUX PWR
2990 K9(7) = (K9(1) / (E(1) * E(3) * E(4) * E(10))) + K(8): REM  GENERATOR
3000 K9(6) = K9(7) / E(7): REM  AUX ENG
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3010 B(6) = K9(6) * WC(6): REM  AUX ENG WT
3020 B(12) = K9(6) * WC(12)
3030 TL(5) = (2 * LD * 9.807) / (RO * V2 * UM(5) ↑ 2): REM  DYNAMIC CL AT UM(5)
3040 CD(5) = CD + (CP(1) * (TL(5) / CP) ↑ 2) / 2: REM  CD+INDUCED DRAG/2 TO AVE DAY-NITE DRAG
3050 K1(1) = (CD(5) * .5 * R(ZT) * UM(5) ↑ 3 * V2) / (1000): REM PROP KW AT LIMITING,PWR
3060 K1(2) = K1(1) / E(1):K1(3) = K1(2): REM SHAFT : GEARBOX
3070 K1(4) = K1(3) / E(3): REM  PRIME MOTOR
3080 B(1) = 0.1973 *  SQR (VO) * K1(1) ↑ (1 / 3)
3090 B(3) = (K1(3) * WC(3)): REM  GEAR BOX WT
3100 B(4) = K1(4) * WC(4): REM  PRIME MOTOR WT
3110  REM  FAB UNIT WT DERIVED FROM NADC REPORT WHERE 1.8 OZ/YD↑2 KEVLAR GIVES 260 LB/IN TENSILE + 1.7 OZ COATING A

3120  REM  FAB UNIT WT = (PD (PASCALS) * VR (METERS) * FS * 1.8 * .033907 / (260 * 39.37 * 4.4482)) + (1.7 * .03390
     VR * FS * 1.3404E-6 + .057642
3130 WF = 1.08: REM  SEAM & REENFORC WT FACTOR
3140 KF = VO ↑ (2 / 3) * .5179 * (2 / 3): REM FIN AREA M2
3150 K1 = KF * 2 * FFW * WF: REM  FIN SKIN WT KGS
3160 K1(1) = KF * RFW * WF: REM  K1B WT KGS
3170 K1(2) = KI + K1(1): REM  TOTAL FIN WT KGS
3180  REM  HARD FIN WT FROM GRG HAPP EST. & CONV. TO METRIC. FIN AREA=(V/42475)↑(2/3)*630.44  M↑2 = .5179*V↑(2/3)
     WT=.6787 & CONE .3486, EACH KG/M↑2 OF FIN AREA,TOTAL 1.027 KG/M↑2. 6NOV81 FIN SIZE 2/3 OF HAPP SCHRIEBER&PUGHA
3190  IF FIG$ = "1" THEN K1(2) = .6787 * KF: REM  HARD FIN WT
3200  REM  BALLONET (BLET) SYSTEM:SINGLE BALLONET WITH LAUNCH TUBE AND TRIM BALLONETS. SINGLE BLET DIAPHRAM = 1/2 HU
     LAUNCH TUBE VOL 1.1 SEA LEV GROSS;LENGTH .56 SHIP LEN
3210 WD = SA / 2 * BFW: REM  DIAPHRAM WT
3220 T(1) = LD(1) * 1.1 / (1.0557 * PUR): REM  TUBE VOL
3230 LL = .56 * (LF / .95):R1 =  SQR (T(1) / (PI * LL)): REM  LL=TUBE LEN,R1 IS FIRST EST RADIUS,.95 ADJUSTS FOR TRI
     ME2540
3240 Y = T(1)
3250  GOSUB 3340
3260 X2 = R1:Y2 = TT(1)
3270 R1 = R1 + 1
3280  GOSUB 3340
3290 X1 = R1:Y1 = TT(1)
3300  GOSUB 3350
3310  GOSUB 3340
3320  IF  ABS (TT(1) - T(1)) < .1 THEN 3360
3330 X2 = X1:Y2 = Y1: GOTO 3290
3340 TT(1) = PI * R1 ↑ 2 * (2 * R1 / 3 + LL / 2): RETURN
3350 X = (X2 - X1) * (Y - Y1) / (Y2 - Y1) + X1:R1 = X: RETURN
3360 T(2) = PI * R1 * (R1 + LL) * BFW: REM  TUBE WT KG
3370  REM  PRINTT(1),TT(1),R1
3380 T(3) = ((3 * T(4) * VO) / (4 * PI)) ↑ (2 / 3) * 4 * PI * BFW: REM  TRIM BALL WT
3390 KO = WD + T(2) + T(3): REM BALONT. SYS. WT. KGS
3400  REM  DOLPHIN EFF. STRESS FACTOR: REF KARL S. BOOK 9, PAGE 1
3410 B(2) = SL * K1(2) * WC(2): REM   SHAFT WT
3420 B(7) = K9(7) * WC(7): REM   GENERATOR WT
3430 UK(4) = (((27460 - (171.37 - UK(1)) ↑ 2) ↑ .5) - 53.009):UM(4) = UK(4) * C2: IF UK(1) > 92.9 THEN UM(4) = UK(1)
3440  IF UK(1) < 75 THEN BO(1) = 1080 - 13.2 * UK(1)
3450  IF UK(1) >  = 75 THEN BO(1) = 465 - 5 * UK(1)
3460  IF UK(1) > 93 THEN BO(1) = 0
3470  REM  ABOVE 3 LINES SUBSTITUTED FOR FOLLOWING 3 LINES. EMPIRICAL EQ GIVE EXACT VALUES AT THE THREE DATA POINTS
3480  REM  IFUK(1)=60THENUM(4)=(69.7*C2):BO(1)=288
3490  REM  IFUK(1)=75THENUM(4)=(81.8*C2):BO(1)=21.6
3500  REM  IFUK(1)=94.5THENUM(4)=(94.5*C2):BO(1)=0:BO(2)=0
3510  REM  UM(4)=CUBE AVE M/S,BO(1)=HRS OCCURED
3520 TL(3) = (2 * LD * 9.807) / (RO * V2 * UM(4) ↑ 2): REM DYNAMIC CL AT CUBE AVE SPEED
3530 CD(3) = CD + (CP(1) * (TL(3) / CP) ↑ 2) / 2: REM CD+INDUCED DRAG/2 AVE DAY-NITE DRAG
3540 K3(1) = (CD(3) * .5 * RO * (UM(4) ↑ 3 - UM(1) ↑ 3) * V2) / (1000): REM AUX PROP PWR W/CUBE AVE WIND
3550 K3(6) = K3(1) / (E(1) * E(3) * E(4) * E(7)): REM  AUX ENG PWR CUBE AVE ON STATION
3560 EGV = 250:CYC = 1.673E - 6:WCW = 8.94: REM  VOLTAGE:CU RESIST OHMCM:CU GM/CC
3570 PLT = 0.02: REM  PROPORTION POWER LOST
3580 B2 = 1E4 * CYC * K4(5) * L2 ↑ 2 * WCW / ((1 - E(10)) * EGV ↑ 2): REM  RECT WIRE KG
3590 B3 = B2 * (K3(6) / K4(5)) * (L3 / L2) ↑ 2
3600 B(10) = B2 + B3
3610 EI = B(1) + B(2) + B(3) + B(4) + B(5) + B(6) + B(7) + B(8) + B(10) + B(12): REM  POWERSYSWT
3620 B(0) = 1.46E - 8 * (RD * VO * PD) * .5: REM BLOWER WT KG
3630 VW = (VO * RC / 60 * 4.24E - 3) / ( SQR (PD)): REM VALVE WT
3640 A = KTW + HFW + KI(2) + KO + B(11) + B(0) + VW: REM  HULL WT INCLUDING SKIN,BALLONET,FINS,CONE,BLOWER & VALVE
3650 GDRY = A + EI + B(9): REM GROSS LESS FUEL & TANKS&BALLAST
3660 M = LD(3) - GDRY: REM  FREELIFT LESS FUEL,TANKS,BALLAST
3670  IF AS$ <  > "CV" THEN 3730
3680  PRINT "TAPES = "KTW TAB( 20)"HULL = "HTW
3690  PRINT "FINS = "KI(2) TAB( 20)"BALLONET = "KO
3700  PRINT "CONE = "B(11) TAB( 20)"BLOWER = "B(0)
3710  PRINT "VALVE = "VW
3720  PRINT "THERE ARE " INT (M)" KGS AVAILABLE FOR FUEL & TANKS"
3730  REM  IFMK0THEN5020
3740  REM *************
3750  REM ASCENT PROFILE
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3760 REM **************
3770 ST = 0:ST(1) = 0
3780 CR = CA / PI
3790 SK =  SIN (CR):CC =  COS (CR)
3800  FOR I = 0 TO (ZT)
3810 VX(I) = (K9(6) * 1000 / (.5 * R(I) * DC * V2)) ↑ (1 / 3): REM VEL ON AUX PWR AT ALT I,M/S
3820  NEXT
3830  GOTO 3940: REM  SKIPS POWERED ASCENT
3840  FOR I = 0 TO (ZT): REM  POWERED ASCENT
3850 FW =  SQR (VX(I) ↑ 2 - (RC / 60) ↑ 2): REM   AIRSPEED AT ALT I
3860 DT = (1000 / RC) * 60: REM  SEC 1000M
3870 S1 = FW - U(I): REM  GROUNDSPEED M/S
3880 S = (S1 * DT):ST(1) = S + ST(1): REM  BLOWOFF
3890  NEXT
3900  PRINT
3910 TX = ALT / RC / 60: REM  HOURS CLIMBING
3920 SX = ST(1) * 5.396E - 4
3930 HH = TX * EH: REM  KWHR CLIMB
3940  REM  CONT FR 3470
3950  FOR I = 0 TO ZT: REM  POWER OFF ASCENT
3960 DT = (1000 / RC) * 60: REM SEC 1000M
3970 S = U(I) * DT:ST(1) = ST(1) + S: REM BLOWOFF M
3980  NEXT
3990 TZ = (( ABS (ST(1))) / UM(2)) / 3600: REM   HRS TO AUXBACK
4000 HS = TZ * K9(6): REM KWHR AUXBACK
4010 TX = ALT / RC / 60: REM  TIME TO ALT
4020  IF AS$ < > "CV" THEN 4100
4030  PRINT  SPC( 30)"ASCENT PROFILE": PRINT
4040  PRINT "POWER OFF ASCENT AT "RC" M/MIN"
4050  PRINT "TIME TO CLIMB TO "ZT" KM="TX
4060  PRINT "BLOWOFF DISTANCE ="ST(1) / 1000" KM."
4070  PRINT "TIME TO AUXBACK TO STATION ="TZ
4080  PRINT "FUEL USED ASCENT AND AUXBACK ="HS * LH(1)" KG
4090  PRINT
4100  REM ******************
4110  REM ON STATION PROFILE
4120  REM ******************
4130  REM  ON STATION WINDS AND AUX PWR CALC IN LINES 3110 TO 3190
4140 BO = (BO(1) * K9(6)): REM KWHR AUX ON STATION
4150 RK = K9(6) * 8: REM  RESERVE KWHR
4160  IF AS$ < > "CV" THEN 4220
4170  PRINT  SPC( 30)"ON-STATION PROFILE": PRINT
4180  PRINT "THRESHOLD SPEED OF "UK(1)" KTS EXCEEDED FOR "BO(1)" HRS /WINTER AT POWER AVE SPEED OF "UM(4) / C2" KT
4190  PRINT "FUEL WT = "BO * LH(1)" KGS"
4200  PRINT "SHIP SPEED ON PRIMARY POWER(THRESHOLD VEL)="UK(1)" KNOTS:LIMITING VEL = "UK(5)"KTS"
4210  PRINT "FOR 8 HRS @ 75 KTS RESERVE FUEL WT = "RK * LH(1)
4220  REM **************
4230  REM DSCENT PROFILE
4240  REM **************
4250  IF AS$ = "CV" THEN  GOTO 4450
4260 ST = 0
4270 DT = (1000 / RD) * 60: REM  SEC PER 1000M
4280  FOR I = (ZT) TO 0 STEP  - 1
4290 FW =  SQR (VX(I) ↑ 2 - (RD / 60) ↑ 2): REM  HORIZONTAL AIRSPEED AT ALT I
4300 S1 = FW - U(I): REM  GROUNDSPEED
4310 S = S1 * DT
4320 ST = S + ST: REM  AUXAWAY DISTANCE M
4330  NEXT I
4340 T1 = ( ABS (ST) / UM(2)) / 3600: REM AUXAWAY HRS
4350 HJ = T1 * K9(6): REM AUXAWAY KWHR
4360 TD = ALT / RD / 60: REM  DESCENT HRS
4370 HD = TD * K9(6): REM DESCENT KWHR
4380 HL = K9(6) * 8: REM LANDING KWHR, AUX 8HR
4390 DB = (4.18E - 6 * RD * VO * PD * TD * .001) * (.5 / .59): REM  DSCNT BLOWER KW-HR
4400 HT = HH + HS + HJ + HD + DB + HL + RK + BO: REM  TOTAL MISSION KWHR,ASCENT+AUXBACK+AUXAWAY+DESCENT+BLOWER+LAND
     VE+ON-STATION
4410 FUL = HT * LH(1): REM  MISSION FUEL KG
4420 MTA = HT * LH(2): REM  TANK & STRUCTURE KG
4430 DSF = (HD + DB + HL + HJ) * LH(1): REM  FUEL FOR DESCENT OPS INCL 8HR LANDING
4440  IF AS$ < > "CV" THEN 4590
4450  PRINT
4460  PRINT  SPC( 30)"DSCENT PROFILE"
4470  PRINT "POWERED DESCENT AT "RD" M/MIN"
4480  PRINT "TIME TO DESCEND FROM "ZT" KM="TD" HRS
4490  PRINT "FUEL FOR DESCENT = "HD * LH(1)" KGS"
4500  PRINT "AUXAWAY AT ALT TIME AND DISTANCE = "T1" HRS AND "ST / 1000" KM"
4510  PRINT "FUEL FOR AUXAWAY = "HJ * LH(1)" KGS"
4520  PRINT "FUEL FOR BLOWER = "DB * LH(1)" KGS"
4530  PRINT "FUEL FOR 8 HR LANDING = "HL * LH(1)" KGS"
4540  PRINT "FUEL USED FOR DESCENT OPS INCL 8HR LANDING = "DSF" KG
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4550  PRINT
4560  PRINT  SPC( 30)"SUMMARY"
4570  PRINT "TOTAL FUEL WT FOR MISSION = "FUL
4580  PR# 0: IF AZ = 2 THEN  RETURN
4590  REM
4600 WG = GDRY + FUL + MTA + B(13): REM  GROSS WT KG
4610 DW = LD(3) - WG: REM  FREELIFT AEROSTATIC
4620 PO$ = "2": REM  PR#1; TO ACTIVATE CHANGE THIS LINE TO PR#1 ONLY
4630  PRINT  TAB( 4)"VOLUME,M13, VO="VO
4640  PRINT "GROSS WT,KG, WG=" TAB( 22)WG: PRINT "STATIC LIFT, LD(3)=" TAB( 22)LD(3): PRINT "FREELI[illegible] DW=" TAB(
   . PRINT
4650  IF PO$ = "2" THEN 4690
4660  INPUT "DO YOU WANT DETAILS PRINTED?(Y/N)N";PO$
4670  IF PO$ = "Y" THEN PO$ = "1": GOSUB 4780
4680 PO$ = "2"
4690  PRINT : PR# 0
4700  IF  ABS (DW) > 1 THEN  GOTO 5470
4710  FOR I = 1 TO 5: IF TL(I) >  = .315 THEN  PRINT "STOP:TL("I") IS TOO LARGE,="TL(I)"::SPEED UP OR REDUCE LOAD
4720  NEXT I
4730  GOTO 4760
4740  IF AZ = 1 THEN  RETURN
4750 I = 0
4760  REM  INPUT"DO YOU WANT TO SEE THE ASCENT AND DSCENT PROFILE ? (Y/N) N ";AS$
4770  IF CP = 1 THEN SHIP$ = "CONVENTIONAL SOFT FINS"
4780 FE = FUL:GD = GD + FUL + MTA
4790  PR# 1: PRINT  CHR$ (31)
4800  PRINT  SPC( 29)"HAPP "BASE$" BASELINE"
4810  PRINT SHIP$"      "DA$
4820  PRINT "----------------------------------------------------------------------------"
4830  PRINT "  VOL" SPC( 3)"ALT" SPC( 3)"RECT" SPC( 4)" AUXE" SPC( 3)"PRLI " SPC( 3)"WEVN" SPC( 4)"PSWT" SPC( 4)"
   4)" PLD " SPC( 5)"BLST"
4840  PRINT "  M13" SPC( 3)" KM" SPC( 3)"KW IN" SPC( 3)" KW  " SPC( 3)" KW  " SPC( 3)" KG " SPC( 4)" KG " SPC( 4)
   4)" KG " SPC( 5)" KG "
4850  PRINT "----------------------------------------------------------------------------"
4860 A1 =  INT ((A / GDRY + .0055) * 100):A1$ =  STR$ (A1)
4870 B1 =  INT ((EI / GDRY + .0055) * 100):B1$ =  STR$ (B1)
4880 C1 =  INT (((FE * (LH(1) / LH)) / GDRY + .0055) * 100):C1$ =  STR$ (C1)
4890 A = ( INT (A + .5)) + .0001
4900 B = ( INT ((B * 100) + .5) / 100) + .0001
4910 C = ( INT (FE + .5) + .0001)
4920 E1 = E1 + MTA
4930 E1 = ( INT (E1 + .5)) + .0001
4940 H$ =  STR$ (C)
4950 DP = ( INT (((PD - PD(2)) * 100) + .5) / 100) + .0001
4960 A$ =  STR$ (VOL)
4970 B$ =  STR$ (ZT)
4980 C$ =  STR$ (K5(5))
4990 D$ =  STR$ (K9(6))
5000 E$ =  STR$ (K1(4))
5010 F$ =  STR$ (A)
5020 G$ =  STR$ (EI)
5030 H$ =  STR$ (C)
5040 I$ =  STR$ (B(9))
5050 J$ =  STR$ (B(13))
5060  PRINT  LEFT$ (A$,6) SPC( 3) LEFT$ (B$,3)"  " LEFT$ (C$,6) SPC( 2) LEFT$ (D$,6) SPC( 2) LEFT$ (E$,6) SPC( 2)
   6) SPC( 2) LEFT$ (G$,6) SPC( 2) LEFT$ (H$,6) SPC( 4) LEFT$ (I$,6) SPC( 4) LEFT$ (J$,6)
5070  PRINT  SPC( 39) LEFT$ (A1$,2)"%" SPC( 5) LEFT$ (B1$,2)"%" SPC( 6) LEFT$ (C1$,2)"%"
5080  PRINT
5090  PRINT "SUPER HEAT = "SH" K " TAB( 35)"SUPERCOOL = "SC" K"
5100  PRINT "CD = "CD;" " TAB( 35)"PROP CD = "CD(1)
5110  PRINT "SAFTEY FACTOR = "FS TAB( 35)"DAY PRESS (CM H2O) = "( INT ((PD / C3 * 1000) + .5) / 1000)
5120 UW(2) = UW(2) / C2
5130  PRINT "UNIT FAB WT="UFW" KG/M2" TAB( 35)"NITE PRESS= "( INT ((PD(2) / C3 * 1000) + .5) / 1000)
5140  PRINT "---WEIGHTS KGS:---"
5150  PRINT  TAB( 17)"ENVELOPE WT"
5160  PRINT "TAPE WT = "KTW TAB( 35)"HULL = "HFW
5170  PRINT "FIN SYS = "KI(2) TAB( 35)"BALONT SYS = "KO
5180  PRINT "CONE WT = "B(11) TAB( 35)"BLOWER = "B(0)
5190  PRINT "VALVE WT = "VW
5200  PRINT  TAB( 17)"POWER SYSTEM WT"
5210  PRINT "PROPELLER = "B(1) TAB( 35)"SHAFT = "B(2)
5220  PRINT "GEAR BOX = "B(3) TAB( 35)"PRIME MOTOR = "B(4)
5230  PRINT "RECTENNA = "B(5) TAB( 35)"TRANS. WIRE = "B(10)
5240  PRINT "AUXE ENG = "B(6) TAB( 35)"GENNERATOR = "B(7)
5250  PRINT "AVIONICS = "B(8) TAB( 35)"TANKS = "MTA
5260  PRINT  TAB( 35)"WATER RECOVERY="B(12): PRINT
5270  PRINT "RECTENNA AREA ="AR(5) TAB( 35)"ANGLE OF INCIDENCE LIMIT="A1
5280  PRINT "MICROWAVE BEAM KW/M2= "K(5)
5290  PRINT "LIFT = "LD(3)" KGS","WEIGHT = "WG" KGS"
5300  PRINT  TAB( 10)"VELOCITIES, KTS": PRINT "LIMIT="UK(5) TAB( 20)"THRESHOLD="UK(1): PRINT "AUX DESIGN="UK(2) T
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E AVE>THRES="UK(4)
5310 IF LEN (CO$(1)) < > 0 THEN PRINT " COMMENT ";CO$(1): PRINT SPC( 10);CO$(2): PRINT
5320 PRINT "*************************************************************************************"
5330 PR# 0: IF PO$ = "1" THEN RETURN
5340 INPUT "DO YOU WANT PRINT OF ASCENT,ONSTA,DESCENT DETAILS?(Y/N) N";AS$
5350 IF AS$ = "Y" THEN AS$ = "CV": PR# 1:AZ = 2: GOSUB 4020
5360 PR# 1
5370 REM
5380 PRINT "..................................................................................."
5390 REM PRINTCHR$(12)
5400 PR# 0
5410 PR# 1: PRINT "TL(2)="TL(2): PR# 0
5420 PRINT "END": END
5430 PRINT "***RESTORE OLD VALUES***, SET NEW VALUES, GOTO 2390": STOP
5440 END
5450 REM PRINT"SHIP IS NOT LARGE ENOUGH":PRINT"LIFT = "F,"WEIGHT = "G:END
5460 PRINT "TOO MUCH FUEL USED": PRINT "FUEL WT AVAILABLE AFTER SHIP SIZING = "M: PRINT "FUEL AVAILABLE PRIOR TO
DW: END
5470 REM KARL'S CONVERSION ON VOLUME
5480 IF V(1) = 0 THEN V(1) = VO:F(1) = DW: GOTO 5530
5490 V(2) = VO:F(2) = DW
5500 VO = ( - F(1)) * (V(2) - V(1)) / (F(2) - F(1)) + V(1):VO = INT (VO)
5510 V(1) = V(2):F(1) = F(2)
5520 GOTO 2410
5530 VO = VO - (2000 * SGN (DW))
5540 GOTO 5520
5550 PR# 1: REM ****SYMBOLS PLAN****
5560 HOME : PRINT TAB( 12)"** SYMBOLS PLAN **": PRINT
5570 PRINT TAB( 10)"VELOCITIES"
5580 PRINT "UK=VEL KTS" TAB( 20)"UM=VEL M/S": PRINT
5590 PRINT "(1)=THRESHOLD" TAB( 20)"(2)=AUX ONLY"
5600 PRINT "(3)=MAXIMUM" TAB( 20)"(4)=CUBE AVE MAXS"
5610 PRINT "(10)=DESIGN SPEED" TAB( 20)"(5)=LIMITING "
5620 PRINT "VX(I) - AUX ONLY M/S ASCENT-DESCENT AT ALT I
5630 PRINT : PRINT : PRINT TAB( 10)"COMPONENTS"
5640 PRINT "(0)=BLOWER"
5650 PRINT "(1)=PROPELLER" TAB( 20)"(2)=SHAFT" TAB( 40)"(3)=GEARBOX"
5660 PRINT "(4)=PRIMARY MOTOR" TAB( 20)"(5)=RECTENNA" TAB( 40)"(6)=AUX ENGINE"
5670 PRINT "(7)=GENERATOR" TAB( 20)"(8)=AVIONICS" TAB( 40)"(9)=PAYLOAD"
5680 PRINT "(10)=TRANSWIRE" TAB( 20)"(11)=CONE" TAB( 40)"(12)=WATER RECOVERY SYS
5690 PRINT "(13)=BALLAST"
5700 PRINT : PRINT
5710 PRINT TAB( 10)"POWER,KW; FORMAT K FUNCTION(COMPONENT)"
5720 PRINT "--FUNCTIONS--"
5730 PRINT "K1=LIMITING" TAB( 20)"K2=CRUISE MAX" TAB( 40)"K3=CRUISE PARTIAL"
5740 PRINT "K4=THRESHOLD" TAB( 20)"K5=LIMIT INTO" TAB( 40)"K6=LANDING"
5750 PRINT "K7=RESERVE" TAB( 20)"K8=DESIGN MAX" TAB( 40)"K9=AUX OFF STAT & AUX DESIGN"
5760 PRINT : PRINT TAB( 10)"AUX ENERGY,KWHR: FORMAT H FUNCTION(COMPONENT)
5770 PRINT "--FUNCTIONS--"
5780 PRINT "H1=ASCENT" TAB( 20)"H2=AUXBACK" TAB( 40)"H3=ON STATION"
5790 PRINT "H4=AUXAWAY" TAB( 20)"H5=DESCENT" TAB( 40)"H6=LANDING"
5800 PRINT "H7=RESERVE" TAB( 20)"H8=ASCENT OPS" TAB( 40)"H9=DESCENT OPS"
5810 PRINT "HT=TOTAL MISSION"
5820 PRINT : PRINT TAB( 10)"FUEL,KG: FORMAT F FUNCTION"
5830 PRINT "FUNCTION AS FOR ENERGY ABOVE"
5840 PRINT "FUL=TOTAL MISSION"
5850 PRINT : PRINT TAB( 10)"TANKS,KG"
5860 PRINT TAB( 10)"CONVERSION FACTORS": PRINT "C2=KNOTS TO M/S .514444": PRINT "C3='CM H2O'TO PASCALS 98.0638
5870 PRINT "TKS=TOTAL MISSION"
5880 PRINT : PRINT TAB( 10)"ALTITUDE"
5890 PRINT "ALT=METERS" TAB( 20)"ZT=KILOMETERS"
5900 PRINT : PRINT "WEIGHTS,KG" TAB( 20)"WEIGHT COEFF" TAB( 40)"POWER COEFF" SPC( 10)"MISC"
5910 PRINT TAB( 4)"B(COMP)" TAB( 25)"WC(COMP)" TAB( 40)"KC(COMP)" SPC( 10)"AR(5) RECTENNA AREA"
5920 PRINT TAB( 1)"PLUS" SPC( 53)"A1 ANGLE OF INCIDENCE LIMIT": PRINT TAB( 1)"B2=WIRE RECT TO MOT": PRINT TAB(
E AUX TO MOT:B(10)=B2+B3"
5930 PRINT TAB( 1)"WG=GROSS WT"
5940 PRINT : PRINT TAB( 10)"EFFIC COEFF"
5950 PRINT "E(COMPONENT)
5960 PRINT TAB( 10)"CONVERSION FACTORS": PRINT "C2=KNOTS TO M/S .514444": PRINT "C3='CM H2O'TO PASCALS 98.0638
5970 PR# 0: END
5980 REM SHAFT WT CALC,POWER TO TORQUE TO STRESS TO WT
5990 S(1) = 1.45E8: REM AL6061T6 SHEAR STR N/M2
6000 S(2) = 2700:S(3) = .25: REM AL DENSITYKG/M3, SHAFT RADIUS M
6010 S(4) = (K1(1) * 1000 / E(1)) / (2 * PI * 1.67): REM TORQUE AT 100 RPM
6020 S(5) = S(4) / (S(1) * S(3)): REM XSECT AREA M2
6030 BX = S(5) * S(2) * SL: REM SHAFT WT KG
6040 REM ABOVE REDUCES TO A CONSTANT WC(2)*K1(1)*SL WHERE WC(2)=0.0079 FOR FACTORS AS GIVEN.
6050 B(2) = 0.0079 * K1(1) * SL
6060 REM
6070 REM
```

```
6080  PRINT "B(2)-BX="B(2) - BX
6090  PRINT "B(2),K1(1),SL,S(4),S(5)" TAB( 30)B(2): PRINT K1(1) TAB( 20)SL: PRINT S(4) TAB( 20)S(5)
6100 E(1) = .9:PI = 3.14159
6110  INPUT "K1(1),SL = ";K1(1),SL
6120  GOTO 5980
6130  END
6140  FOR J = 1 TO 9
6150  FOR I = 1 TO 10: GOSUB 6210
6160  PRINT J"     "I"     ";
6170  PRINT X
6180  NEXT
6190 I = 0
6200  NEXT
6210  REM
6220  IF J = 1 THEN X = K1(I)
6230  IF J = 2 THEN X = K2(I)
6240  IF J = 3 THEN X = K3(I)
6250  IF J = 4 THEN X = K4(I)
6260  IF J = 5 THEN X = K5(I)
6270  IF J = 6 THEN X = K6(I)
6280  IF J = 7 THEN X = K7(I)
6290  IF J = 8 THEN X = K8(I)
6300  IF J = 9 THEN X = K9(I)
6310  IF J > 9.1 THEN  END
6320 K1(1) = 1.1111:K5(6) = 6.6666: GOTO 6140
6330  REM
6340  FOR I = 1 TO 10:XK = TL(I):YK = CD(I)
6350 ZK = XK: GOSUB 6400
6360 XK = ZK:ZK = YK: GOSUB 6400
6370 YK = ZK
6380  PRINT I TAB( 5)XK TAB( 15)YK
6390  NEXT
6400 ZK =  INT (ZK * 1E4 + .5) / 1E4: IF I < 10.9 THEN  RETURN
6410  END
```

** SYMBOLS **

VELOCITIES

UK=VEL KTS   UM=VEL M/S

(1)=THRESHOLD   (2)=AUX ONLY
(3)=MAXIMUM   (4)=CUBE AVE MAXS
(10)=DESIGN SPEED   (5)=LIMITING
VX(I) = AUX ONLY M/S ASCENT-DESCENT AT ALT I

COMPONENTS

(0)=BLOWER
(1)=PROPELLER   (2)=SHAFT   (3)=GEARBOX
(4)=PRIMARY MOTOR   (5)=RECTENNA   (6)=AUX ENGINE
(7)=GENERATOR   (8)=AVIONICS   (9)=PAYLOAD
(10)=TRANSWIRE   (11)=CONE   (12)=WATER RECOVERY SYS
(13)=BALLAST

POWER, KW: FORMAT K FUNCTION (COMPONENT)

--FUNCTIONS--
K1=LIMITED   K2=CRUISE MAX   K3=CRUISE PARTIAL
K4=THRESHOLD   K5=LIMIT INTO   K6=LANDING
K7=RESERVE   K8=DESIGN MAX   K9=AUX OFF STAT & AUX DESIGN

AUX ENERGY, KWHR: FORMAT H FUNCTION (COMPONENT)

--FUNCTIONS--
H1=ASCENT   H2=AUXBACK   H3=ON STATION
H4=AUXAWAY   H5=DESCENT   H6=LANDING
H7=RESERVE   H8=ASCENT OPS   H9=DESCENT OPS
HT=TOTAL MISSION

FUEL, KG: FORMAT F FUNCTION

FUNCTION AS FOR ENERGY ABOVE
FUL=TOTAL MISSION

TANKS, KG

CONVERSION FACTORS

C2=KNOTS TO M/S .514444
C3=CM H20' TO PASCALS 98.0638
TKS=TOTAL MISSION

ALTITUDE

ALT=METERS   ZT=KILOMETERS

WEIGHTS,KG	WEIGHT COEFF	POWER COEFF	MISC
B(COMP)	WC(COMP)	KC(COMP)	AR(5) RECTENNA ARE
PLUS			AI ANGLE OF INCIDENT
MIT			

B2=WIRE RECT TO MOT
B3=WIRE AUX TO MOT: B(10)=B2+B3
WG=GROSS WT

EFFIC COEFF

E(COMPONENT)

CONVERSION FACTORS

C2=KNOTS TO M/S .514444
C3=CM H20' TO PASCALS 98.0638

OTHER SYMBOLS NOT COVERED BY THE ARRAY ABOVE ARE AS FOLLOWS:

A		=	HULL WEIGHT INCLUDING SKIN, BALLONET, FINS, CONE, BLOWER & VALVES
A		=	TOTAL HULL WEIGHT
ALT		=	OPERATING ALTITUDE, M
AR	(5)	=	RECTENNA AREA
A1		=	ANGLE OF INCIDENCE LIMIT
B	(0)	=	BLOWER WT KG
B	(10)	=	TOTAL TRANSMISSION WIRE WEIGHT
B	(4)	=	PRIME ENG WT
B	(5)	=	RECT WT
BFW		=	BALLONET FABRIC WEIGHT
BO		=	KWHR AUX ON STATION
BV		=	NIGHT BALLONET VOLUME
BV	(1)	=	BALLONET VOLUME
BX		=	SHAFT WEIGHT KG
B2		=	WIRE WEIGHT, RECTENNA TO MOTOR
B3		=	WIRE WEIGHT, AUX ENGINE TO MOTOR
CA		=	CLIMB ANGLE DEGREES
CD		=	CRUISE DRAG COEFFICIENT
CD	(1)	=	AVERAGE DAY AND NIGHT DRAG
CD	(2)	=	CD + INDUCED DRAG/2 TO AVE DAY-NIGHT DRAG
CD	(3)	=	CD + INDUCED DRAG/2 AVE DAY-NIGHT DRAG
CD	(5)	=	CD + INDUCED DRAG/2 TO AVE DAY-NIGHT DRAG
CP		=	DYNAMIC LIFT COEFFICIENT
CR		=	CLIMB ANGLE, RADIUS
DB		=	DESCENT BLOWER KWHR
DC		=	CLIMB, DESCENT DRAG COEFFICIENT
DSF		=	FUEL FOR DESCENT OPS INCL 8 HR LANDING
DT		=	SEC 1000M

DW		=	FREELIFT AEROSTATIC
EI		=	POWER SYS WT
EI		=	POWER SYSTEM WEIGHT
EPWR		=	ELECTRIC POWER
ESP		=	EFFECTIVE STRESS FACTOR
EVG		=	VOLTAGE: CU RESIST OHMCM
FE		=	FUEL WEIGHT
FFW		=	FIN FABRIC WEIGHT
FS		=	SAFETY FACTOR
FUL		=	MISSION FUEL KG
FW		=	FIN UNIT FABRIC WEIGHT
FW		=	HORIZONTAL AIRSPEED AT ALT I
GDRY		=	GROSS LESS FUEL & TANKS & BALLAST
HD		=	DESCENT KWHR
HFW		=	HULL FABRIC WEIGHT
HH		=	KWHR CLIMB
HJ		=	AUX AWAY KWHR
HL		=	LANDING KWHR, AUX 8 HR
HS		=	KWHR AUX BACK
HT		=	TOTAL MISSION KWHR, ASCENT + AUX BACK + AUX AWAY + DESCENT + BLOWER + LANDING + RESERVE + ON-STATION
KD		=	BALLONET SYSTEM, WEIGHT, KGS
KF		=	FIN AREA M2
KI	(1)	=	RIB WEIGHT KGS
KI	(2)	=	TOTAL FIN WEIGHT KGS
KTW		=	HULL SEAM TAPE WEIGHT
K1		=	FIN SKIN WEIGHT KGS
LD		=	DYNAMIC LIFT DURING NIGHT ONLY

LD	(1)	=	DAY STATIC LIFT
LD	(2)	=	NIGHT STATIC LIFT
LD	(3)	=	MAX DAY LIFT FOR DYNAMIC LIFT COEF
LF		=	LENGTH, TRUNCATED 5% FOR BALANCE
LH		=	KG/KWHR FUEL AND TANK & SUPPORT WEIGHT
LH	(1)	=	KG/KWHR FUEL WEIGHT
LH	(2)	=	KG/KWHR TANK & SUPPORT WEIGHT
LL		=	HELIUM COMPARTMENT LENGTH
L2		=	WIRE LENGTHS RECTENNA AND AUXILIARY ENGINE TO MOTOR
M		=	FREELIFT LESS FUEL, TANKS, BALLAST
M	(1)	=	MASS DISPLACED AIR
M	(2)	=	MASS HELIUM
M	(3)	=	DAY MASS AIR IN BALLONETS
M	(5)	=	NIGHT BALNT AIR MASS
MHW		=	MINIMUM HULL FABRIC WEIGHT
MTA		=	TANK & STRUCTURE KG
NV		=	NIGHT VOLUME HE
P		=	PRESSURE AS SET FOR A GIVEN ALTITUDE
P	(ZT)	=	AMBIENT AIR PRESSURE
PC	(2)	=	NIGHT PRESSURE DIFFERENCE, CM H_2O
PC	(4)	=	DAY PRESSURE DIFFERENCE, CM H_2C
PD		=	DAY PRESSURE DIFFERENCE, PASCALS
PD	(2)	=	NIGHT PRESSURE DIFFERENCE, PASCALS
PD	(3)	=	DAY PRESSURE DIFFERENCE, PASCALS
PD	(4)	=	DAY PRESSURE DIFFERENCE, PASCALS
PLT		=	PROPORTION POWER LOST
PROP$		=	RECIP ENGINE H2
PUR		=	PURITY OF HELIUM

R	(ZT)	=	AMBIENT AIR DENSITY AT ALTITUDE ZT
RA		=	R-AIR J/KG KELVIN
RC		=	RATE ASCENT M/MIN
RD		=	RATE DESCENT M/MIN
RD		=	DENSITY AT OPERATING ALT
RE		=	EFFECTIVE GAS CONSTANT (ADJUSTED FOR PURITY)
RFW		=	RIB FABRIC WEIGHT
RH		=	R-HELIUM
RK		=	RESERVE KWHR
R1		=	HELIUM COMPARTMENT RADIUS
S		=	BLOWOFF
S	(1)	=	ALLOY 6061T6 SHEAR STRENGTH N/M2
S	(2)	=	AL DENSITY KG/M3, SHAFT RADIUS M
S	(4)	=	TORQUE AT 100 RPM
S	(5)	=	X SECT AREA M2
SA		=	SFC AREA M2
SC		=	SUPERCOOL KELVIN
SH		=	SUPERHEAT KELVIN
SHIP$		=	DOLPHIN HARD FINS
SL		=	SHAFT LENGTH
ST		=	AUXILIARY DISTANCE M
ST		=	AUX AWAY DISTANCE
SX		=	BLOWOFF DISTANCE, CLIMB
S1		=	GROUND SPEED M/S
T	(1)	=	HELIUM COMPARTMENT VOLUME
T	(2)	=	HELIUM COMPARTMENT WEIGHT KG
T	(3)	=	TRIM BALLONET WEIGHT
T	(4)	=	PROPORTION SHIP VOL FOR TRIM BALLONET

TD		=	DESCENT HRS
TE	(ZT)	=	AMBIENT AIR TEMPERATURE
TL	(1)	=	DYNAMIC CL AT THRESHOLD SPD
TL	(2)	=	DYNAMIC CL
TL	(3)	=	DYNAMIC CL AT CUVE AVE SPEED
TL	(5)	=	DYNAMIC CL AT UM(5)
TT	(1)	=	HELIUM COMPARTMENT VOLUME
TX		=	HOURS CLIMBING
TX		=	TIME TO ALT
TZ		=	HRS TO AUX BACK
T1		=	AUX AWAY HRS
UHW		=	HULL FABRIC UNIT AREA WEIGHT
UO		=	CUBE ROOT VELOCITY PARAMETER
VO		=	VOLUME M 3
VR		=	RADIUS M DERIVED
VW		=	VALVE WT
VX	(1)	=	VEL ON AUX POWER AT ALT I, M/S
WD		=	DIAPHRAM WEIGHT
WF		=	SEAM & REINFORCING WEIGHT FACTOR
WG		=	GROSS WEIGHT KG
ZT		=	ALTITUDE, KM

APPENDIX B

AERODYMANICS

I. CARMICHAEL'S CONTRIBUTION TO THE HAPP PROPOSAL

THE FLOW REGIME

The problem is defined as:

A one-million-cubic-foot airship of nuetral buoyancy.

Altitude of 70,000 feet. ρ = .000139 slugs/ft.^{3} ν = 21.33 ft.^{2}/sec.

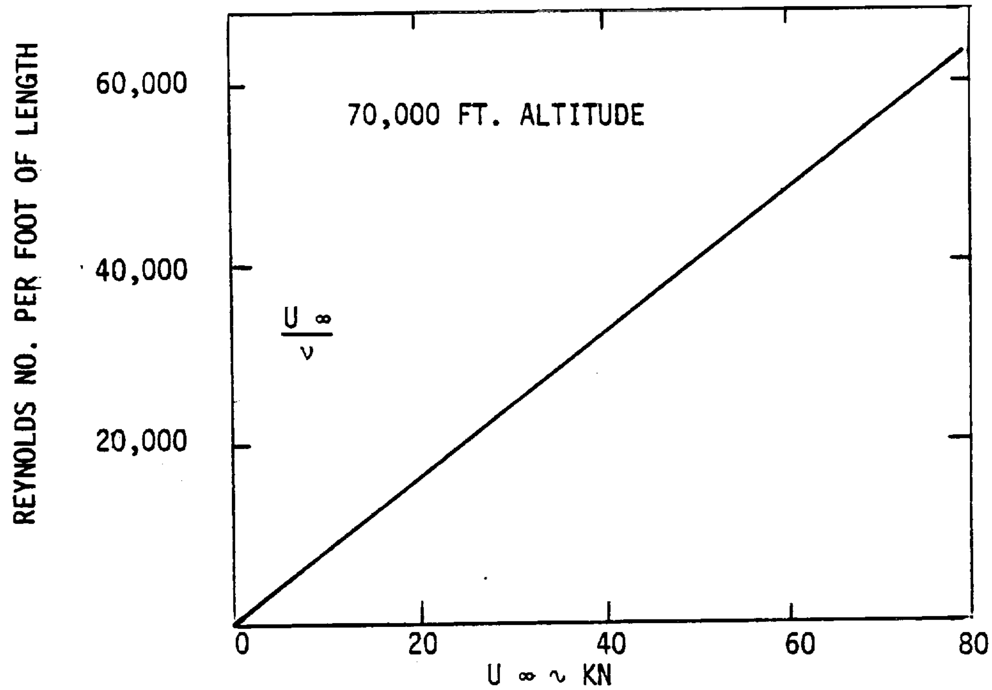
Able to maintain station in wind speeds of up to 70 knots.

The high altitude results in a Reynolds number per foot of length of only 56,000 at 70 knots true speed, thus greatly reducing the practical problems associated with surface finish. Figure 1.

A hull length to diameter ratio of 3.33 results in a basic hull length Reynolds number of 16.4 million at seventy knots, and an arc length Reynolds number to the minimum pressure point at 60% of projected length of 12.5 million (based on a 9.5% increase in arc length over projected length and a 16% increase in local potential velocity over flight speed at min. pressure). Figure 2.

These Reynolds numbers imply that large drag reductions are possible due to extensive laminar flow both on the basis of theory and on the basis of experimental experience.

FIGURE I: UNIT REYNOLDS NUMBER vs TRUE SPEED



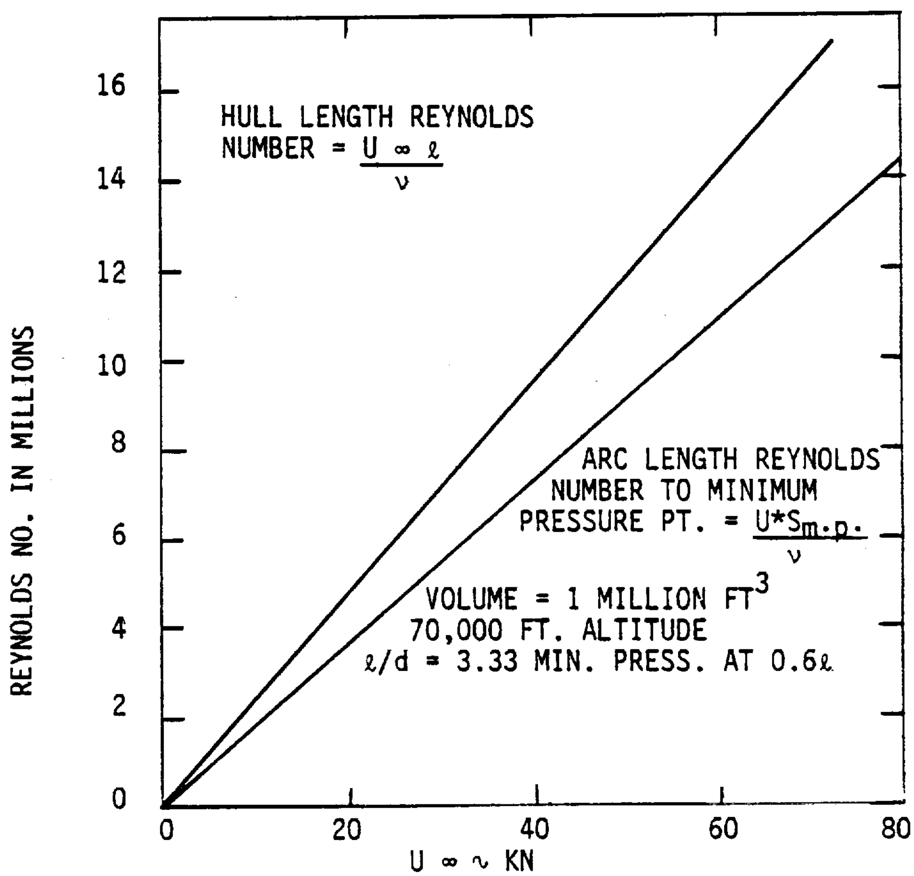


FIGURE 2: HULL STRENGTH & ARC LENGTH RN TO MIN. PRESSURE PT.

The low density at 70,000 feet together with the modest true speed requirements lead to relatively low power requirements. Thrust Horsepower divided by the drag coefficient based on hull volume to the 2/3 power vs. true flight speed in knots is presented in Figure 3.

HULL ALONE DRAG COEFFICIENT - THEORETICAL

A rapid method of computing the drag of streamlined bodies of revolution as a function of length Reynolds number, boundary layer transition location, and length to diameter ratio is found in Reference 1. The solid lines of Figure 4 present calculated values of C_D for a body with length to diameter ratio of 3.33 for fully turbulent flow and for laminar flow to 60% of projected length. At 70 knots the laminar case has only 35% of the drag of the fully turbulent case. The dotted line of Figure 4 reveals that an all-turbulent body of length to diameter ratio of 5, in spite of greater length Reynolds number and lower supervelocities has only 2% less drag than the body with 3.33 length/diameter. Thus there is little risk that use of a low fineness ratio body will carry a penalty should laminar flow not prevail.

HULL ALONE DRAG COEFFICIENT - EXPERIMENTAL

Some experimental points have been placed on Figure 4 at the correct hull length Reynolds numbers to indicate the extent by which theoretical expectations have been achieved in the past.

In the early 1960's, the writer conducted tests in both wind tunnel and in the ocean on the Dolphin body with length to diameter ratio of 3.33 and favorable pressure gradient to 60% of length. In the wind tunnel, Reference 2, in the

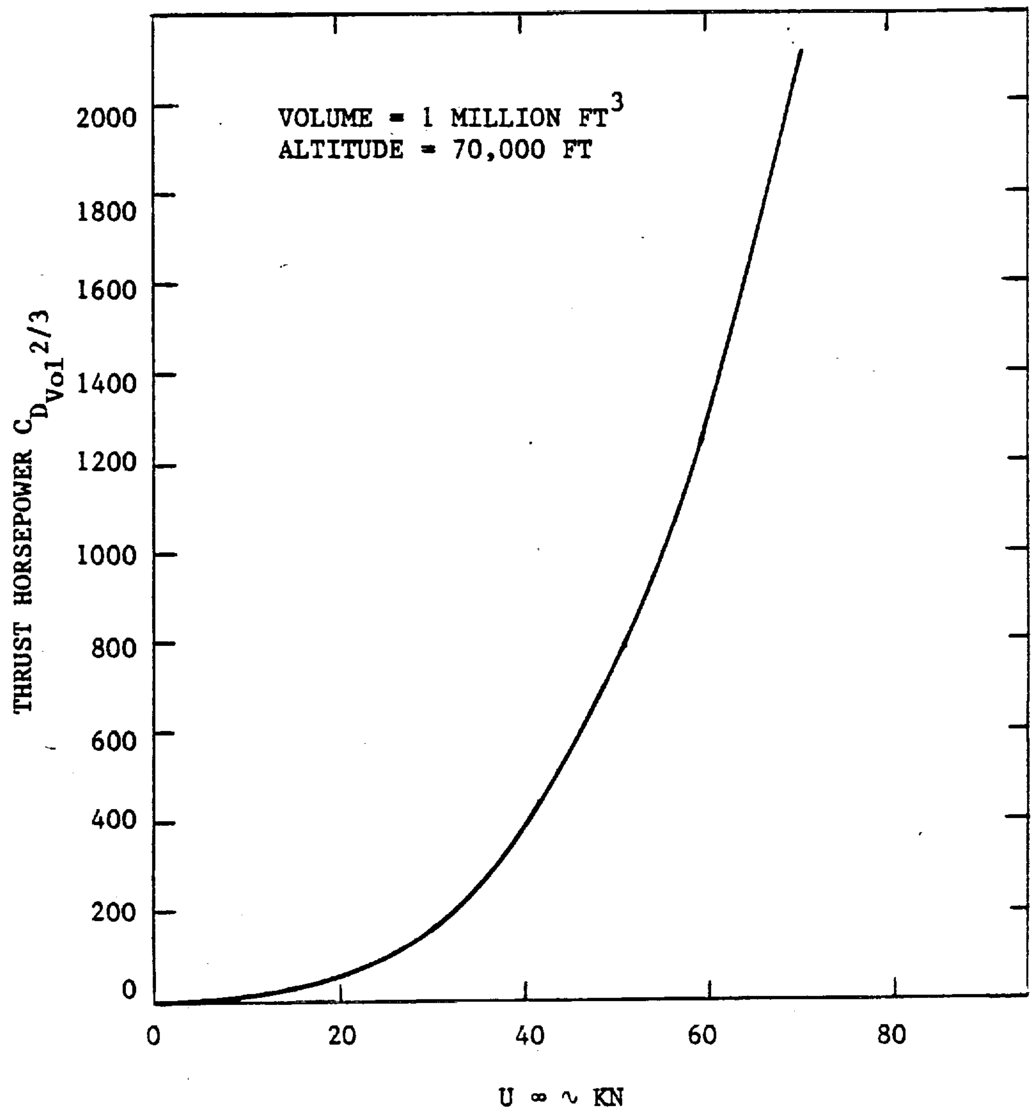


FIGURE 3: HULL ALONE THP/ $C_{D_Y}2/3$

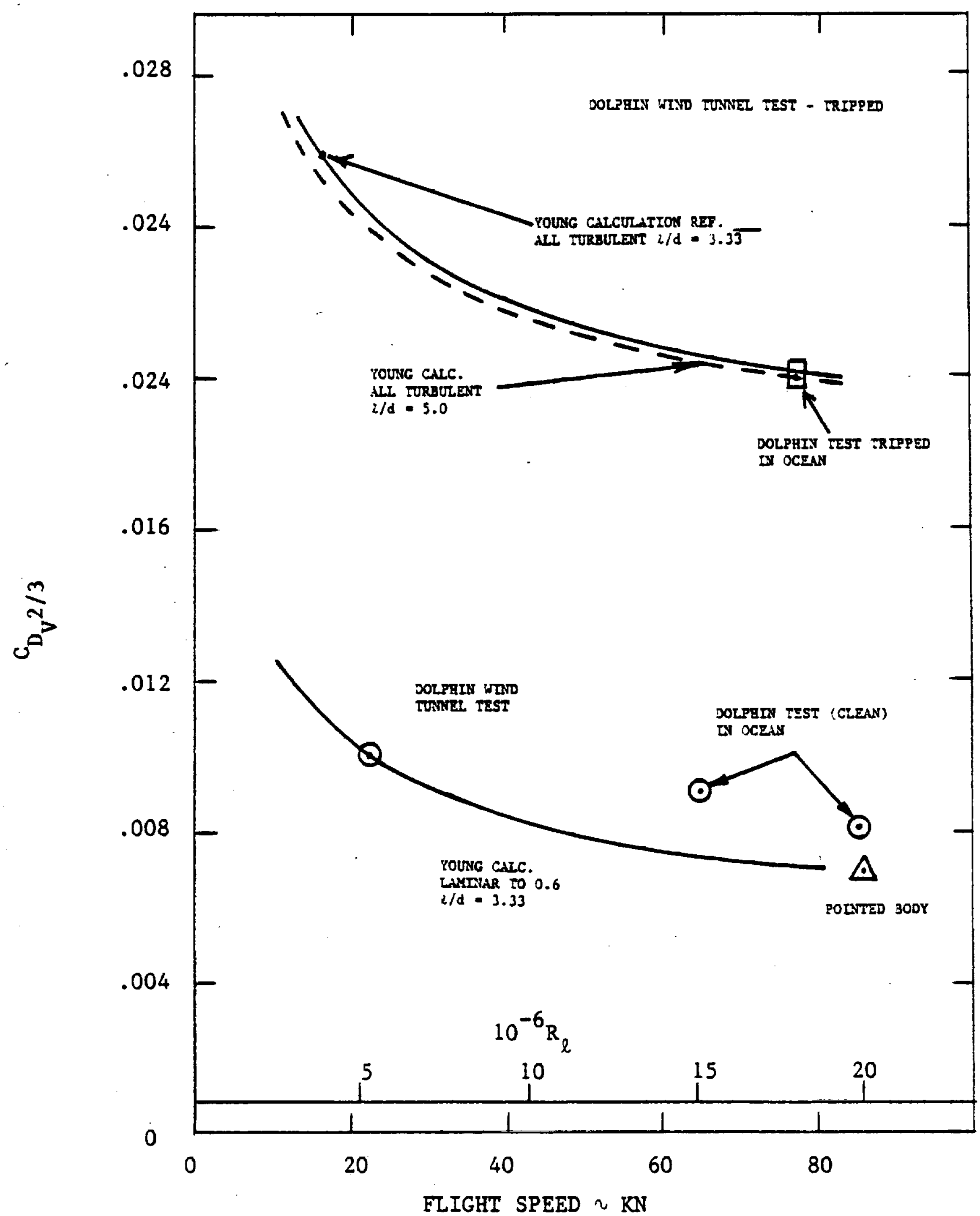


FIGURE 4: THEORETICAL & EXPERIMENTAL HULL DRAG COEFFICIENTS

clean condition at a Reynolds number corresponding to 22 knots in the present application for the clean condition, the experimental point landed right on the theoretical curve at 0.01. With the boundary layer artificially trippled to produce turbulent flow, the experimental point was somewhat above the theoretical at 0.028. This could indicate difficulty in making the afterbody pressure recovery with the thicker turbulent boundary layer at the low Reynolds number.

In the gravity powered ocean tests, References 3 and 4, the clean body points feel slightly above the theory indicating that laminar flow did not extend quite to the minimum pressure point. Even so, by a Reynolds number of 20 million, the value was almost down to 0.008. With boundary layer trippled, the experimental point fell right on the theoretical value at a Reynolds number of 18 million. Additional experimental points from a series of ocean tests are given in Figure 5. The drag appeared to be minimum between RN of 23 and 30 million. The scatter one must expect with extensively laminar bodies in the real world is also apparent. A photo of the Dolphin research body is shown in Figure 6.

Recently, a somewhat larger but slower underwater body as depicted in Figure 8 has demonstrated even lower drag coefficients to even higher Reynolds numbers in a towing basin and as a self-powered free-running body. A deduced data point is shown in Figure 4 from the scanty information available at this time. Its drag is considered half of conventional drag in a reliable manner in the real world, that is to say repeatable. Reference 5.

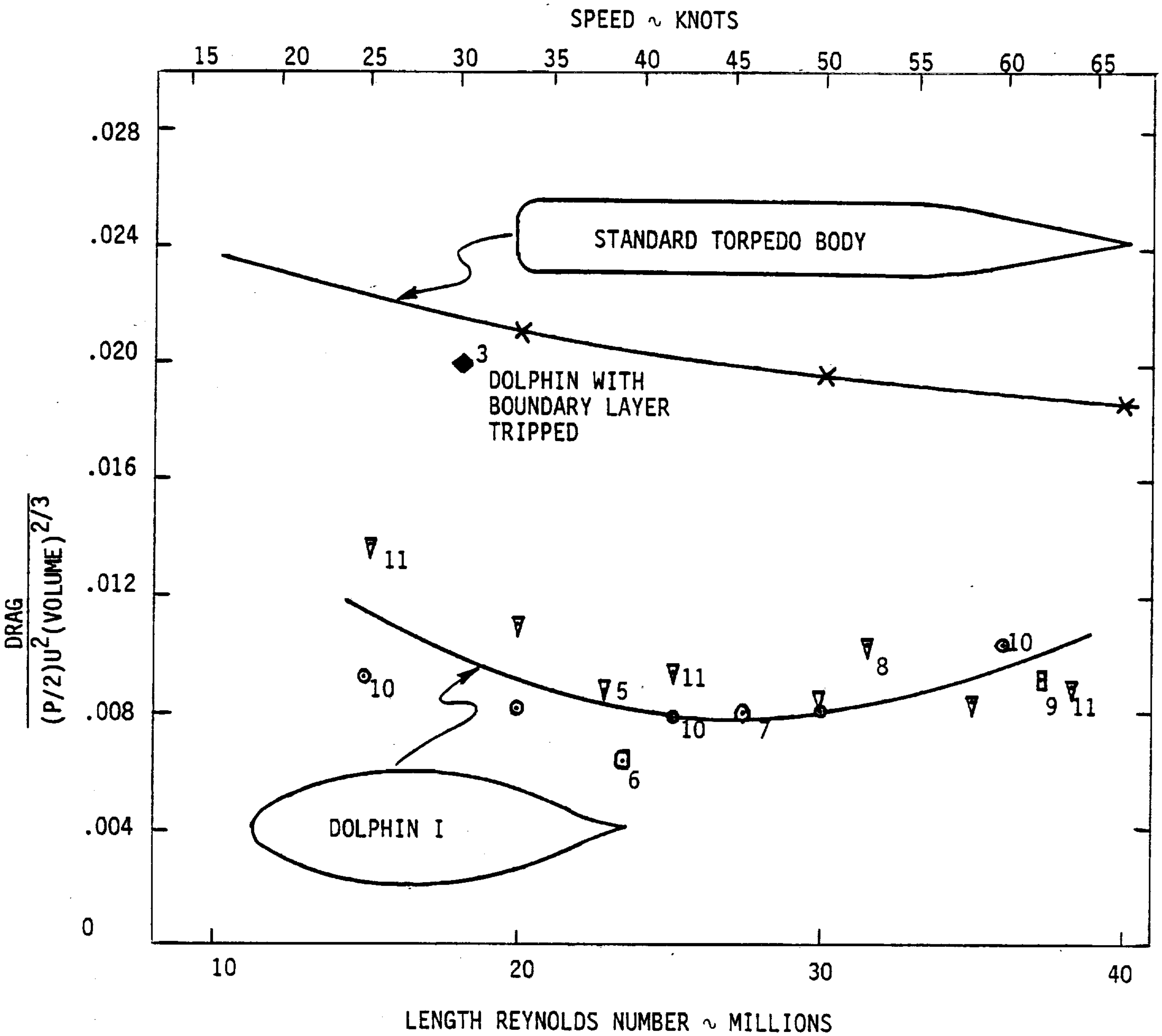


FIGURE 5: EXPERIMENTAL DRAG COMPARISON DOLPHIN vs STANDARD BODY

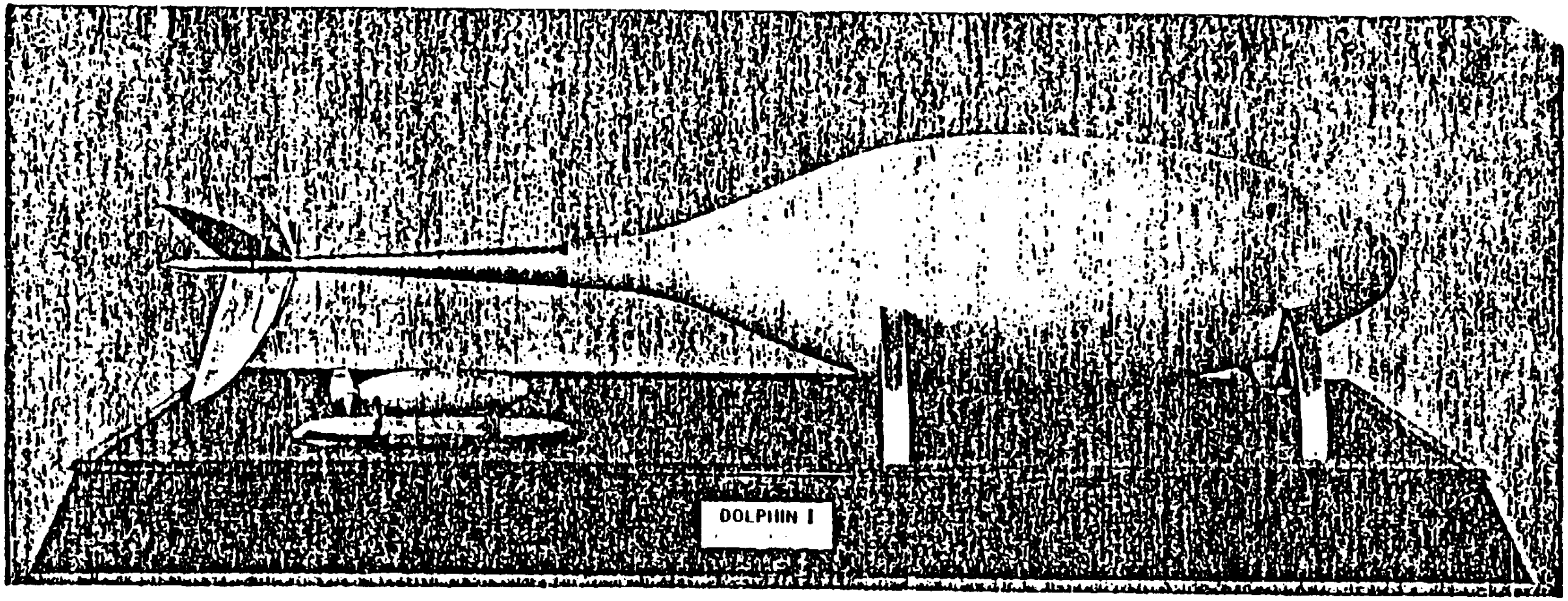


FIGURE 6, GRAVITY POWERED UNDERWATER VEHICLE

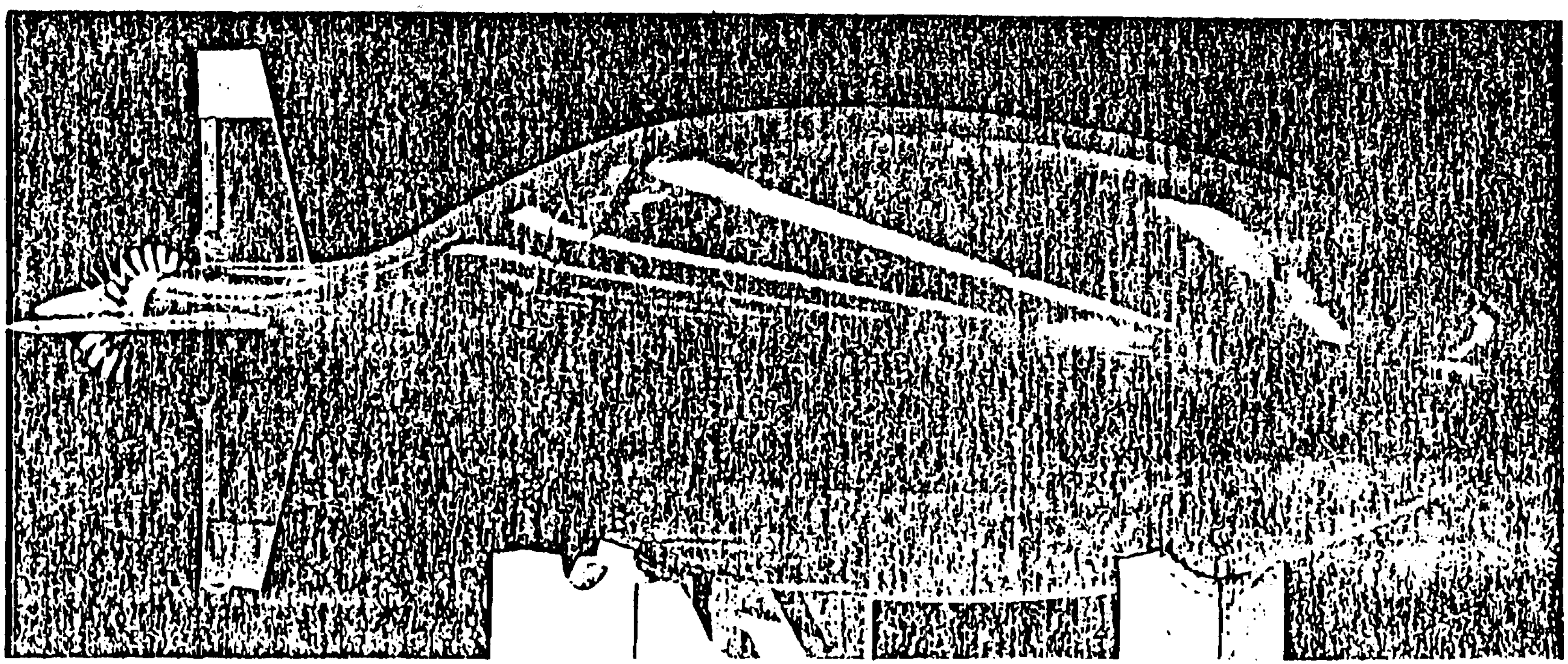
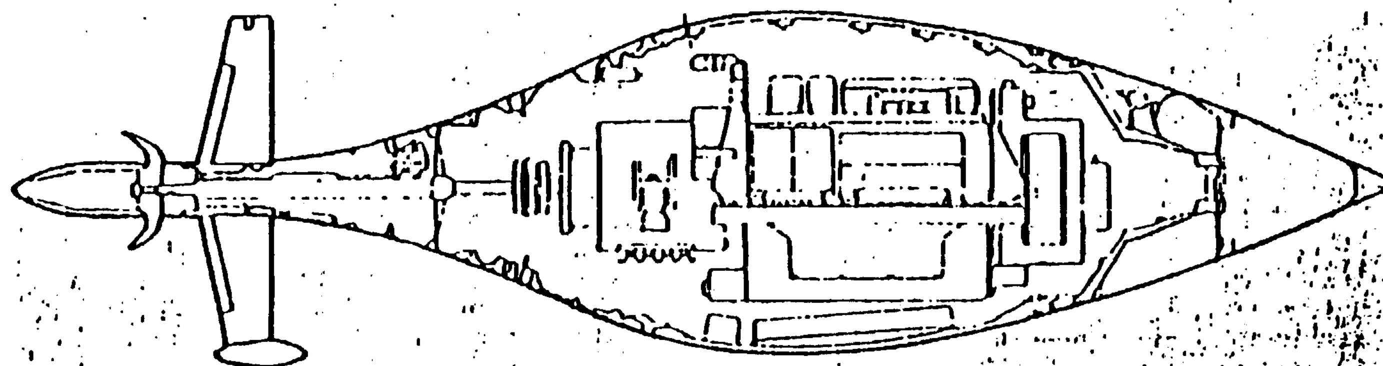


FIGURE 7 ELECTRIC POWERED UNDERWATER VEHICLE

NOSC

FIG. 8 **LAMINAR FLOW TEST VEHICLE**



Vehicle B-1 Characteristics

Length	108 inches
Diameter	27 inches
Volume	14.5 cubic feet
Displacement	928 lbs seawater
Prismatic coefficient	0.44
Velocity, maximum	30-35 knots
Depth, maximum operational	1,000 feet
Propulsion system	25 SHP electric motor/silver-zinc battery
Acoustic sensor candidates	Planar array Partial conformal arrays
Acoustic test electronics	Self noise measurement panels Active transmitter

I-B-44

THOUGHTS ON HULL SHAPE FOR THIS APPLICATION

To minimize hull drag at the upper end of the Reynolds number regime, it is important to retain as strong a favorable pressure gradient as possible all the way to the minimum pressure point. This requires a low length to diameter ratio and can be enhanced by a shape closer to that of the B-1 of Figure 8 than to the older Dolphin. In the case of the Dolphin, the pressure gradient becomes more shallow as one proceeds aft, and in combination with the increasing Reynolds number can result in disturbance amplification and transition to a turbulent boundary layer before the minimum pressure point is reached. A more pointed nose shape and tight curvature just aft of minimum diameter can rectify this to some extent. A combination of low length to diameter ratio, far aft minimum pressure, and shape for maximum laminar boundary layer stability produces a severe adverse pressure gradient on the afterbody. One must avoid separation of the turbulent boundary layer on the afterbody. The probability of separation increases as the Reynolds number becomes lower. In this application, the need to maintain station under wind velcoities of less than 20 knots may become critical from the separation standpoint. Although the power requirements would be low due to the low flight speed, the problem of holding heading into the wind with the fins and control surfaces buried in separated flow should be investigated. The separation problem may be reduced to some extent by use of the Stratford pressure distribution as pioneered for airfoils by Liebeck. Reference 6. If practical, the fins should be placed on a short boom aft of the basic body to increase tail arm and to place them in a favorable pressure gradient which can clean up marginal flow. See the Powered Dolphin, Figure 7 and the Free Running B-1, Figure 8. This feature may be easier said than done on a blimp.

While one could use the Dolphin design directly for this application to capitalize on its data base and minimize engineering effort or even the B-1 design if its data base could be made available (not likely), it will probably be necessary to develope a similar but not Japanese copy as a best compromise with other inputs peculiar to this particular problem. Thoughts on this will follow in the sections on recommended analytics and experiments.

POWER REQUIREMENTS

Combining the Young Theory drag coefficients of Figure 4 with the curve from Figure 3 provides the power-required curves of Figure 9. Note that this data is for hull alone with no appendages and is thrust horsepower rather than shaft horsepower. If stern propulsion is used to accelerate fluid that has been slowed down by friction with the hull, it may be possible to obtain a propulsion efficiency equal to or greater than 100%.

At 70 knots at 70,000 feet, the thrust horsepower requirement of the hull is 15 with laminar flow to 60% projected hull length and 42.7 with fully turbulent flow. The 15 horsepower which provides 70 knots in the laminar case would only provide 48.5 knots in the fully turbulent case.

A self propelled version of the Dolphin underwater research vehicle was tested and is reported in Reference 6. A photo appears as Figure 7. This powered version did not achieve as low a hull drag coefficient as the gravity powered research vehicle. The wave adapted propellers gave an efficiency of 88% as deduced from a run with the boundary layer tripped. The appendage drag was computed to increase the hull drag by 26%. Taking these into account, the deduced hull drag coefficient based on volume to the 2/3 power equals 0.0118.

If we take the volume of 1.45 feet^3, shaft horsepower of 25 and top speed of 35 knots as given in Figure 8 for the B-1, we come up with a coefficient of 0.011. Note that this coefficient includes the appendage drag and the unknown value of the propeller efficiency.

POSSIBLE SOURCES OF LOSS OF EXTENSIVE LAMINAR FLOW SURFACE IMPREFECTIONS DUE TO MANUFACTURE

The divergence of the actual hull contour from the coordinates on which the pressure distribution was calculated is not too critical as long as lengthwise history of surface curvature is smooth. Due to the very low Reynolds number per foot of length at 70,000 feet and 70 knots, the allowable step due seams in the envelope could be as large as 0.051 inch without tripping the boundary layer. Since the hull material is a thin film, lap joints will not exceed 0.001 inch in height. The most likely source of troublesome surface imperfection would be surface waviness. The conservative criteria of Reference 7 which was obtained for waves on a flat plate with zero pressure gradient yields a wave height of 0.015 inches and 0.033 inch for a 6 inch wave length at 10% and 50% of the laminar arc length. In the case of multiple waves, these critical value is proportional to the square root of the wave length. This should not be hard to achieve in the envelope construction. If fixed loads are supported at specific locations within the envelope local waviness could results. One should try to spread out load attachment points as much as possible. Critical wave values also vary as the square root of the wave position expression as fraction of the laminar length.

If nose mooring cannot be avoided, the affected region should be kept as small as possible to keep it in the low velocity region near the forward stagnation point and the hardware should be placed in a cavity. The conventional external car should be eliminated, if possible, as the juncture of the car with the hull will trigger turbulent wedges.

SURFACE IMPERFECTIONS FROM THE FLIGHT ENVIRONMENT

Inspect impingment near the nose has been the most serious problem of laminar aircraft. Once again, the 70,000 foot altitude comes to the rescue in this application. The allowable height of multiple insect remains in about 0.05 inch. The maximum height of insect remains has been found in Reference 8 to not exceed 0.017 inch. Insects do not rupture and contaminate the surface below a flight velocity of 20 knots. One can avoid insect impingement by taking off and climbing above the insect flight regime at dawn before the insects become airborn.

Laminar flow cannot be maintained in rain but will return about 1 minute after leaving the rain area. Due to the very long mission time of this application, it should be possible to take off and climb in fair weather. The mission will be flown at 70,000 feet above the weather.

Frost particles on the surface will be below the critical roughness size. There have been indications that frost particles traveling through the boundary layer shed wakes leading to turbulent spikes of short duration. It has been said that this only occurs in the lower edge of the tropopause. Hopefully the problem will not exist at 70,000. Dr. Paul McCready should be contacted on this point to insure that this will not be a problem.

Ambient turbulence is another source of premature boundary layer transition. Flight tests such as Reference 9 have indicated that the scale of ambient turbulence in the upper atmosphere is sufficiently low and of a scale which does not affect the boundary layer. This factor must be considered in the choice of windtunnel for the development phase of the project.

The uniformity of the envelope and the internal pressure should be studied to avoid the formation of standing or traveling surface waves at high forward speeds. The very low dynamic pressure at 70,000 feet and 70 knots should dictate against this becoming a problem.

Long slender bodies generate sufficient circumferential pressure gradients at angle of ataack to produce large forward transition motion in the plane 90 degrees from the plane of the angle of attack. This does not occur on low length to diameter bodies because the circumferential arc lengths are long enough to keep the transverse pressure gradients low. Experimental data on this point is limited to a hull length Reynolds number of 5 million. See Reference 2. The dymanic stability of the HAPP should be made high enough to avoid excessive wallowing . Angle of attack excursions of at least plus or minus 4 degrees should be acceptable.

Noise and vibration can also cause forward motion of the boundary layer transition point. References 10, 11, and 12 provide most of the known data. Suction stabilized laminar airfoils were subjected to external longitudinal and trnasverse sound waves, internal sound waves and panel vibration. Both distinct frequencies and white noise were employed. Most critical frequencies were found to lie near the upper branch of the TS amplification curves. Under low boundary layer stability conditions 108 db was found to be critical while at high stability the critical level increased to 130 db. While electric propulsion will be essentially noiseless, the beat frequencies of the stern propeller in the wake of the fins could possibly constitute a disturbance. The fact that the propellers may be burried in the hull wake shouldhelp to alleviate this problem. The possibility of panel vibration of the pressure stiffened envelope should be studied.

The possibility of the hull surface temperature being raised above the ambient temperature must be investigated sinc such a differential acting on the viscosity can produce a change in the boundary layer velocity profile in the direction to destabilize the laminar layer. On underwater bodies, the effect of heat on viscocity is resersed and just a few degrees of temperature differential can make a sizeable increase in transition Reynolds number. I have not encountered experimental data in air, but is is believed that Dr. Eli Roshotko of Case is working on this problem. A general theoretical treatment is available in Reference 13.

RECOMMENDED ANALYSIS

A family of hulls with length to diameter ratio and position of minimum pressure as variables should first be defined using the Parsons Goodson method of Reference 14. This method yields shapes with smooth curvature histories and thus smooth pressure distributions. The resulting pressure distributions can be computed using Reference 15. Boundary layer calculations must next be performed by a finite difference method such as Reference 16 and assuming various laminar to turbulent transition points. The most probable transition location in absence of disturbances can be determined by the method of Reference 17. The best body shape will result from considerations of practical asepcts of airship construction, the most favorable pressure distribution from the transition delay standpoint to the minimum pressure point, and avoidance of turbulent b.l. separation on the afterbody where the lowest Reynolds number will be the critical case. The probable surface temperature distribution above ambient due to solar heating should be calculated and fed into the boundary layer calculations. This may be a source of earlier transition on the upper surface of the hull. The afterbody separation problems will be adversely affected by more forward transition locations since the boundary layer thickness at start of pressure recovery will be greater in this case. The boundary layer profile at the stern propeller location will affect the propeller design.

The unstable hull moment slope will be a major input to the dymanic stability calculations to determine the necessary fin geometry. A limited amount of experimental data on low drag hull moment slope is available from past wind tunnel experiments. Fin lift curve slope is complicated by the hull interference but preliminary fin design can be based on previous emperical experience.

EXPERIMENTAL DEVELOPMENT

Wind tunnel tests in a low turbulence tunnel such as the Northrop 7 by 10 foot will be most helpful, even though restricted to the lower Reynolds regime of this application. This will cover the most serious regime from the standpoint of afterbody boundary layer separation and fin effectiveness. Artificial boundary layer tripping can be employed to check out the worst case. In addition to force and moment measurements, surface film can be used for transition point determination and thread tufts can be employed to locate incipient or complete afterbody separation.

To cover the upper Reynolds number regime, it would be necessary to employ the Ames low turbulence 12 foot pressure tunnel. This would provide realistic laminar extent at the high speed end of the flight regime. Thought should be given to artificially heat and model surface to obtain an experimental check on the effect on transition. It is generally difficult to schedule this tunnel.

It may be desirable to proceed from the Northrop tunnel tests to a scale blimp flown at low altitude to match the upper speed Reynolds number at 70,000 feet for the final application. Data collection is more difficult but such a test program would include the real world problems in a conservative manner.

A further thought on wind tunnel testing is to consider use of a powered model to determine overall propulsive efficiency as in the tests in Reference 18.

These were done in the Langley full-scale tunnel which permits coverage of the full Reynolds number regime. The turbulence level has been reported to be too high in this tunnel for laminar work and yet Reference 18 reports a drag coefficient based on volume to the 2/3 power of 0.01 at a hull length RN of 17.5 million which would require extensive laminar flow.

APPENDAGE DRAG

Since power requirement minimization is crucial to this application, and since the vehicle will be unmanned, it should not be necessary to have a control car of the conventional external type. Likewise, the use of stern propulsion will eliminate external engine cars. If battons are required to siffen the nose region, they should be placed internally so as not to trip the laminar boundary layer. The mooring arrangement and any skin laps will not constitute an additional drag source for either the laminar or turbulent case.

The fins and their support wires, if required, will therefore constitute the only appreciable appendage drag. Fin design must be carefully considered since the combination of low Reynolds number, large thickness ratio, and the possibility of unfair surfaces, if they are pressure stabilized in place of internal structure, could lead to a large drag addition which would constitute a high percentage increase for the case with the hull extensively laminar. The contribution of the stern propellers to the vehicle stability will reduce but perhaps not eliminate the fin area requirements. If there were no fins, control would have to be achieved by swiveling the props which might be too complex a development to add to the others.

The relatively modern blimp design of Reference 18 was a stern-propelled, 3-fin design. The projected area of the 3 fins was 30% of the volume to the 2/3 power. In our case, this would lead to 3000 square feet of projected fin area. If our fins were of low aspect ratio like those of Reference 18 with average span exposed equal to 0.56 times the average chord exposed, the chord length RN would be 676,000 and 2,367,000 for 20 knots and 70 knots respectively at 70,000. A 21% thick airfoil, if laminar, could probably have a C_{D0} of 0.006 for the 70 knot condition. With limited laminar flow, the value would be about 0.01. If the airfoil surface is too crude, the value could be much higher and perhaps 21% thickness ratio could not be tollerated.

The percent increase due to the condition of 3000 square feet of fin area to the one million cubic foot hull would be:

A. 23% based on fin C_D = 0.006 and hull $C_{D_{V\ 2/3}}$ = 0.008

B. 38% based on fin C_D = 0.01 and hull $C_{D_{V\ 2/3}}$ = 0.008

C. 9% based on fin C_D = 0.006 and hull $C_{D_{V\ 2/3}}$ = 0.02

D. 15% based on fin C_D = 0.01 and hull $C_{D_{V\ 2/3}}$ = 0.02

The above numbers are based on the fin area to hull volume relationship of Reference 18 being adequate for our case when augmented by stern propulsion. The values do not include the drag of brace wires. Although the drag coefficient of the wires would be between 1.0 and 2.0 due to the low Reynolds number, the projected area of the wires will probably be low enough so that the increase in total drag would be on the order of 2% for the case of the lowest drag fins on the lowest drag hull.

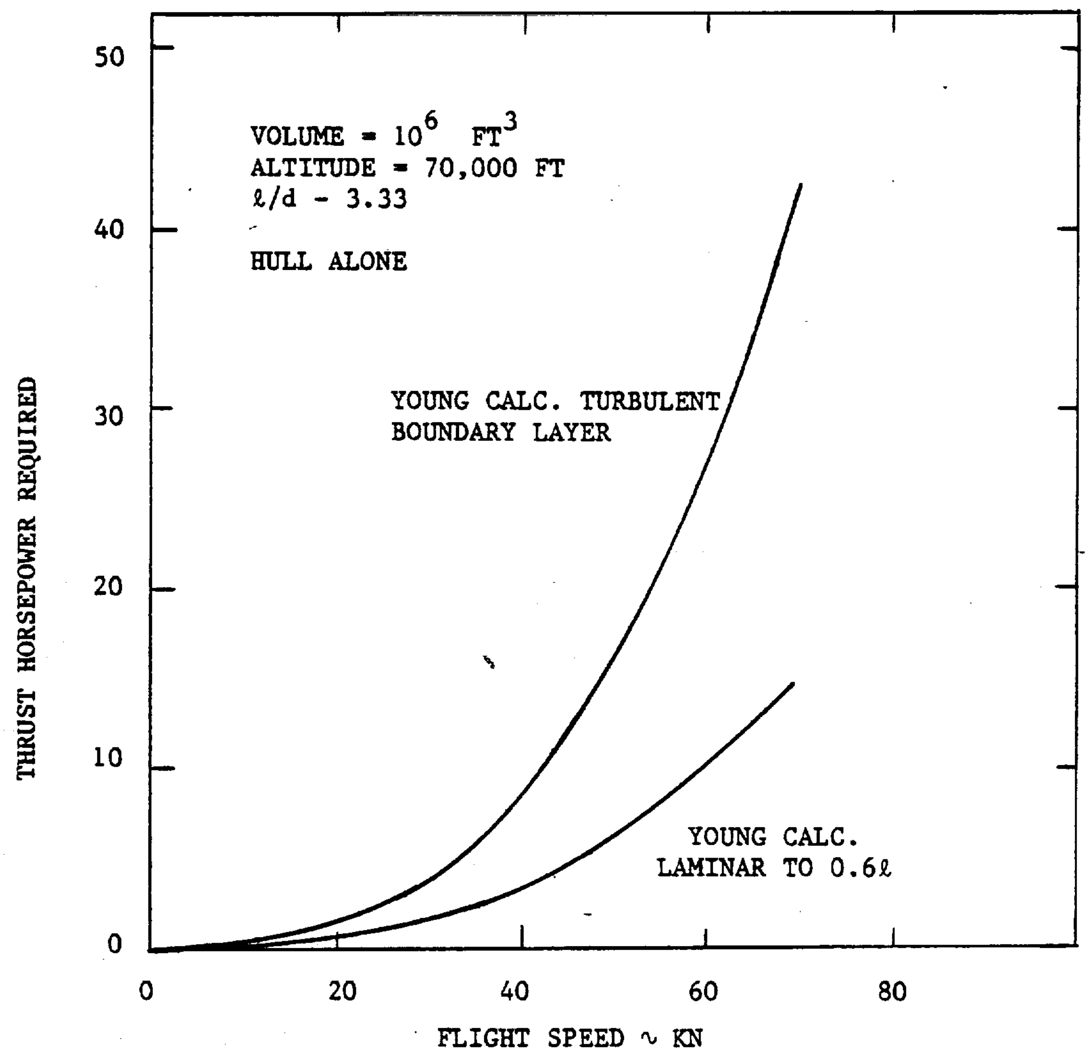


FIGURE 9: HULL THP SAVINGS DUE TO LAMINAR FLOW

II. Potential Flow Computer Simulation

The following is the input and output of the Lockheed aerodymanic flow computer program used to calculate a pressure distribution fo the Dolphin shape. The pressure distribution is representative of a potential flow pressure distribution. There was no boundary layer, no transition and no separation included in the pressure distribution calculations. The pressure distribution should not be considered valid beyond the true full-scale boundary layer transition point.

```
NMNOUT                   $(1)   016541 017247   $(0)   041123 041213    10 SEP 81   10:33:54
                                                $(2)   041214 041231
                                                $(4)   041232 041411
NMNINP                   $(1)   017250 020141   $(0)   041412 041550    10 SEP 81   10:33:26
                                                $(2)   041551 041604
COEF                     $(1)   020142 020605   $(0)   041605 041651    10 SEP 81   10:31:00
                                                $(2)   041652 041672
                                                $(4)   041673 041707
BELMNT (COMMONBLOCK)                                   041710 041725
CRFLOW                   $(1)   020606 020752   $(0)   041726 041751    10 SEP 81   10:31:25
                                                $(2)   041752 042003
SOURCE (COMMONBLOCK)                                   042004 042705
VELPOT (COMMONBLOCK)                                   042706 044511
ARRYS (COMMONBLOCK)                                    044512 174422
BODY (COMMONBLOCK)                                     174423 176226
BLANK$COMMON (COMMONBLOCK)
NEUMN                    $(1)   020753 021626   $(0)   176227 176351    10 SEP 81   10:32:57
                                                $(2)   176352 176371
                                                $(4)   176372 177156

SYS$*RLIB$. LEVEL LMSC54
END MAP.  ERRORS: NONE  TIME: 16.724  STORAGE: 15781/4/032777/0100777
```

INPUT

@XQT	X/R_{max}	R/R_{max}		X/R_{max}	R/R_{max}
1	.000000	-.000000	2	.005385	.061708
3	.021376	.122724	4	.047487	.182377
5	.082925	.240040	6	.126614	.295143
7	.177225	.347190	8	.233221	.395765
9	.292900	.440536	10	.354450	.481254
11	.430265	.525701	12	.506081	.565264
13	.581897	.600940	14	.657713	.633415
15	.733528	.663185	16	.809344	.690623
17	.885160	.716018	18	.960975	.739601
19	1.036791	.761557	20	1.112607	.782039
21	1.188423	.801174	22	1.264238	.819071
23	1.340054	.835819	24	1.415870	.851497
25	1.491686	.866172	26	1.567501	.879901
27	1.643317	.892736	28	1.719133	.904720
29	1.794948	.915890	30	1.870764	.926280
31	1.946580	.935917	32	2.022396	.944827
33	2.098211	.953029	34	2.174027	.960542

	x/R_{max}	R/R_{max}
35	2.249843	.967379
37	2.401474	.979074
39	2.553106	.988175
41	2.704737	.994709
43	2.856369	.998665
45	3.008000	1.000000
47	3.147556	.998946
49	3.287111	.995952
51	3.426667	.990912
53	3.566222	.983338
55	3.705778	.972484
57	3.845333	.957462
59	3.984889	.937375
61	4.124444	.911431
63	4.264000	.879067
65	4.403555	.840077
67	4.543110	.794726
69	4.682666	.743880
71	4.822221	.689123
73	4.962428	.632547
75	5.103285	.575708
77	5.244142	.519330
79	5.384999	.464164
81	5.525856	.411211
83	5.666713	.361608
85	5.807570	.316522
87	5.948427	.277037
89	6.089284	.244041
[illegible]	6.230142	.218122

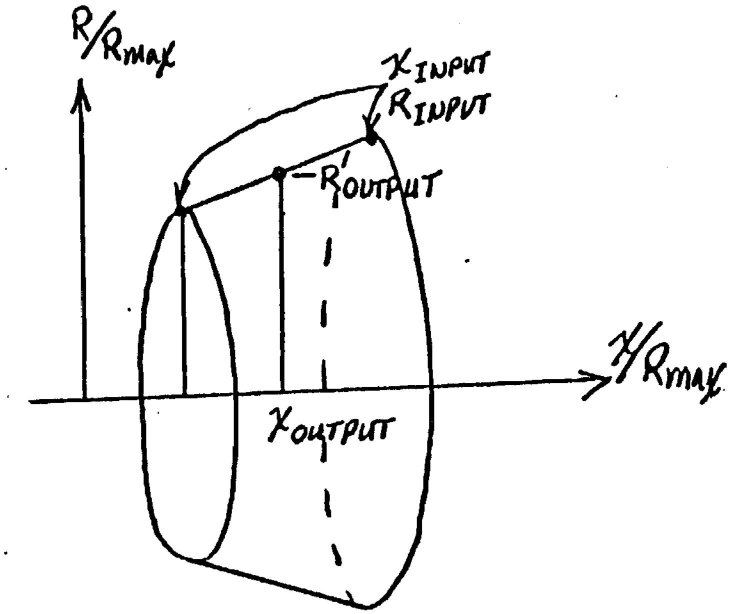
	x/R_{max}	R/R_{max}
36	2.325658	.973554
38	2.477290	.983946
40	2.628921	.991763
42	2.780553	.997011
44	2.932184	.999665
46	3.077778	.999727
48	3.217333	.997687
50	3.356889	.993710
52	3.496444	.987484
54	3.636000	.978375
56	3.775555	.965551
58	3.915111	.948105
60	4.054666	.925177
62	4.194222	.896074
64	4.333777	.860396
66	4.473333	.818158
68	4.612888	.769909
70	4.752444	.716860
72	4.891999	.661000
74	5.032856	.604104
76	5.173713	.547422
78	5.314570	.491538
80	5.455427	.437342
82	5.596285	.385917
84	5.737142	.338430
86	5.877999	.296018
88	6.018856	.259683
90	6.159713	.230175
92	6.300570	.207888

	X/R_{max}	R/R_{max}		X/R_{max}	R/R_{max}
93	6.370999	.199449	94	6.441427	.192742
95	6.511856	.187668	96	6.582284	.184080
97	6.652713	.181788	98	6.723141	.180550
99	6.793570	.180071	100	6.863998	.180000

LOW DRAG BODY SHAPE 1-A

AXISYMMETRIC NEUMANN PROGRAM ZERO ALPHA SOLUTION

X_{OUTPUT}	R_{OUTPUT}	BETA	CP	SIGMAA
.0027	.0309	85.0128	.9932	-.0925767
.0134	.0922	75.3142	.9183	-.0898532
.0344	.1526	66.3602	.7894	-.0848071
.0652	.2112	58.4261	.6396	-.0785394
.1048	.2676	51.5911	.4934	-.0719143
.1519	.3212	45.8014	.3640	-.0655070
.2052	.3715	40.9408	.2559	-.0596238
.2631	.4182	36.8770	.1685	-.0543864
.3237	.4609	33.4866	.1002	-.0497964
.3924	.5035	30.3807	.0401	-.0456745
.4682	.5455	27.5569	-.0117	-.0416017
.5440	.5831	25.2000	-.0506	-.0381742
.6198	.6172	23.1874	-.0813	-.0352168
.6956	.6483	21.4380	-.1060	-.0326249
.7714	.6769	19.8954	-.1262	-.0303254
.8473	.7033	18.5190	-.1428	-.0282644
.9231	.7278	17.2785	-.1567	-.0264011
.9989	.7506	16.1508	-.1685	-.0247038
1.0747	.7718	15.1179	-.1785	-.0231476
1.1505	.7916	14.1653	-.1872	-.0217120
1.2263	.8101	13.2815	-.1947	-.0203804
1.3021	.8274	12.4569	-.2013	-.0191389
1.3780	.8437	11.6835	-.2071	-.0179759
1.4538	.8588	10.9547	-.2123	-.0168815
1.5296	.8730	10.2647	-.2170	-.0158472
1.6054	.8863	9.6086	-.2213	-.0148653



$$C_P = \frac{(P - P_\infty)}{\frac{1}{2}\rho V^2}$$

LOW DRAG BODY SHAPE 1-A

AXISYMMETRIC NEUMANN PROGRAM ZERO ALPHA SOLUTION

X	R	BETA	CP	SIGMAA
1.6812	.8987	8.8820	-.2252	-.0139295
1.7570	.9103	8.3813	-.2289	-.0130339
1.8329	.9211	7.8031	-.2323	-.0121734
1.9087	.9311	7.2443	-.2356	-.0113431
1.9845	.9404	6.7024	-.2387	-.0105390
2.0603	.9489	6.1747	-.2416	-.0097571
2.1361	.9568	5.6591	-.2445	-.0089939
2.2119	.9640	5.1534	-.2473	-.0082458
2.2878	.9705	4.6557	-.2501	-.0075098
2.3636	.9763	4.1642	-.2528	-.0067829
2.4394	.9815	3.6771	-.2555	-.0060623
2.5152	.9861	3.1927	-.2581	-.0053450
2.5910	.9900	2.7093	-.2607	-.0046285
2.6668	.9932	2.2254	-.2633	-.0039101
2.7426	.9959	1.7395	-.2658	-.0031870
2.8185	.9978	1.2499	-.2681	-.0024566
2.8943	.9992	.7551	-.2703	-.0017159
2.9701	.9998	.2535	-.2720	-.0009616
3.0429	.9999	-.2243	-.2726	-.0002566
3.1127	.9993	-.6415	-.2729	.0002851
3.1824	.9983	-1.0331	-.2746	.0007351
3.2522	.9968	-1.4249	-.2783	.0011663
3.3220	.9948	-1.8396	-.2839	.0016403
3.3918	.9923	-2.2967	-.2914	.0022087
3.4616	.9892	-2.8124	-.3002	.0028173
3.5313	.9854	-3.4000	-.3099	.0037976

LOW DRAG BODY SHAPE 1-A

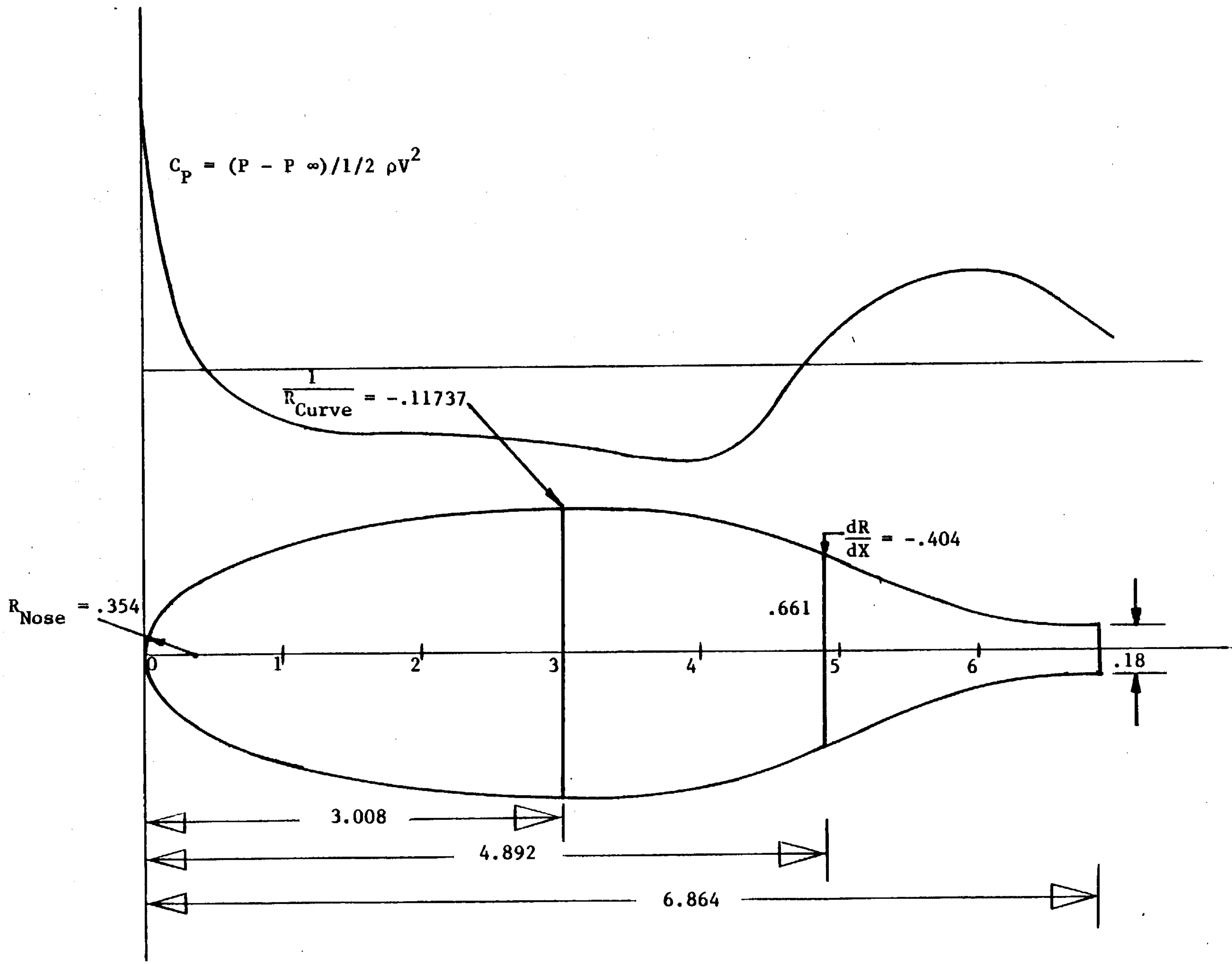
AXISYMMETRIC NEUMANN PROGRAM ZERO ALPHA SOLUTION

X	R	BETA	CP	SIGMAA
3.6011	.9809	-4.0680	-.3199	.0048759
3.6709	.9754	-4.8259	-.3294	.0061690
3.7407	.9690	-5.6738	-.3377	.0076847
3.8104	.9615	-6.6123	-.3441	.0094216
3.8802	.9528	-7.6375	-.3476	.0113695
3.9500	.9427	-8.7423	-.3476	.0135085
4.0198	.9313	-9.9160	-.3434	.0158106
4.0896	.9183	-11.1447	-.3344	.0182387
4.1593	.9038	-12.4117	-.3202	.0207483
4.2291	.8876	-13.6975	-.3006	.0232884
4.2989	.8697	-14.9801	-.2756	.0258028
4.3687	.8502	-16.2358	-.2455	.0282310
4.4384	.8291	-17.4388	-.2108	.0305107
4.5082	.8064	-18.5624	-.1721	.0325777
4.5780	.7823	-19.5783	-.1304	.0343671
4.6478	.7569	-20.4572	-.0867	.0358129
4.7176	.7304	-21.1680	-.0421	.0368466
4.7873	.7030	-21.6779	.0019	.0373931
4.8571	.6751	-21.9509	.0431	.0373584
4.9272	.6468	-21.9987	.0780	.0367529
4.9976	.6183	-21.9916	.1070	.0360269
5.0681	.5899	-21.9588	.1330	.0352884
5.1385	.5616	-21.8820	.1573	.0345094
5.2089	.5334	-21.7453	.1802	.0336614
5.2794	.5054	-21.5351	.2018	.0327211
		[illegible]	.2219	.0316719

LOW DRAG BODY SHAPE 1-A

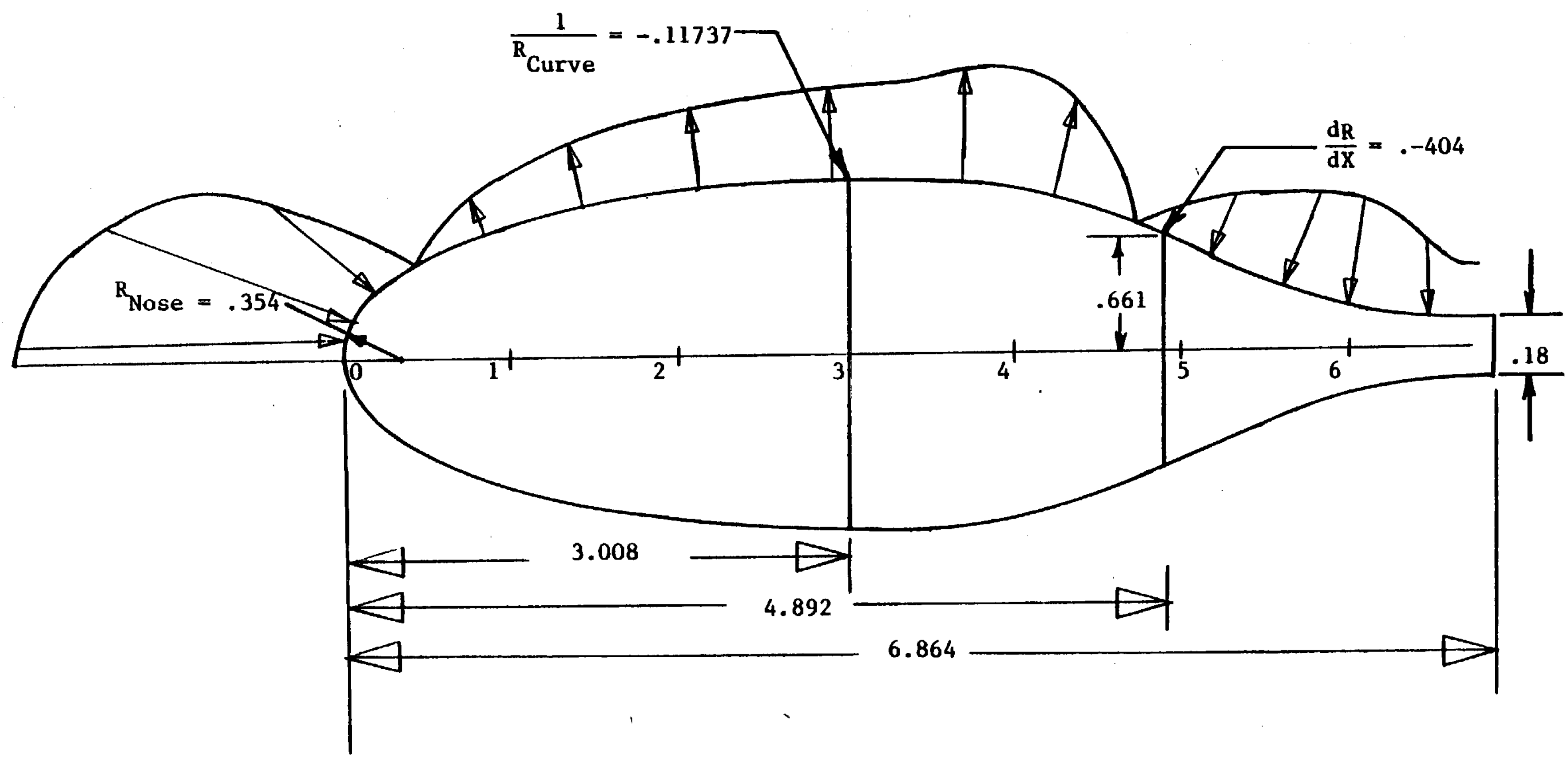
AXISYMMETRIC NEUMANN PROGRAM ZERO ALPHA SOLUTION

X	R	BETA	CP	SIGMAA
5.4202	.4508	-20.8492	.2406	.0305031
5.4906	.4243	-20.3563	.2575	.0292101
5.5611	.3986	-19.7553	.2727	.0277935
5.6315	.3738	-19.0426	.2858	.0262587
5.7019	.3500	-18.2167	.2968	.0246154
5.7724	.3275	-17.2787	.3055	.0228763
5.8428	.3063	-16.2322	.3119	.0210572
5.9132	.2865	-15.0835	.3157	.0191749
5.9836	.2684	-13.8423	.3170	.0172475
6.0541	.2519	-12.5215	.3158	.0152930
6.1245	.2371	-11.1379	.3119	.0133295
6.1949	.2241	-9.7119	.3055	.0113749
6.2654	.2130	-8.2676	.2966	.0094477
6.3358	.2037	-6.8330	.2852	.0075684
6.4062	.1961	-5.4394	.2714	.0057607
6.4766	.1902	-4.1213	.2553	.0040538
6.5471	.1859	-2.9162	.2369	.0024851
6.6175	.1829	-1.8640	.2163	.0011019
6.6879	.1812	-1.0069	.1935	-.0000344
6.7584	.1803	-.3893	.1687	-.0008455
6.8288	.1800	-.0580	.1425	-.0012320



BODY SHAPE 1-A

$C_P = (P - P_\infty)/1/2\ \rho V^2$



BODY SHAPE 1-A

III. Allowable Waviness Criteria

III. ALLOWABLE WAVINESS

The allowable waviness to prevent undesired boundary layer transition on a passive BLC body of revolution is estimated below. What this waviness criteria means in terms of airship hull contruction is also quantified.

From Carmichael's contribution to HAPP (Reference 1), a waviness criteria is proposed. The criteria, based on spanwise corrugation effects of flat plat with zero pressure gradient (Ref. Fage), yields a wave length of 0.015 inch and 0.033 inch for a 6.0 inch wave length at 10% and 50% of the laminar arc length.* Carmichael suggests that in the case of multiple waves these criteria values should be reduced by a factor of two. These points are shown in Figure 1, Allowable Waviness.

A second criteria is proposed by Warner (Reference 2). The criterion is based on a data correlation by Carmichael. The criterion, adapted from data on laminar flow wings with mild boundary layer suction, follows.

$$\frac{h}{\lambda} = \left[\frac{59000\ 1}{\lambda (R_1)^{2/3}}\right]^{1/2}$$

h = allowable wave amplitude

λ = wave length

l = arc - length from the nose of the vehicle to the laminar separation location

* 70,000 feet and 70 knots

The criterion, referred to as the Carmichael Criterion, is also shown in Figure 1. The relationship between wave amplitude and wave length in the Carmichael criterion was used to expand the two Fage data points. This too is presented in Figure 1.

Carmichael mentions that the Fage data points, calculated with zero pressure gradient could be as much as 7.3 times as low as the Carmichael data points, calculated with a favorable pressure gradient. The Fage data points are also representative of a single transverse wave and Carmichael states that the waviness requirement could halve as a result of multiple waves. Also, the Fage data indicates that the waviness requirement (assuming zero pressure gradient) is more strict at the nose of the hull. The decrease in allowable wave heights are due to the decreased boundary layer thickness at the forward area of the Fage zero pressure gradient plate. Since the hull pressure gradient is not zero, and becomes increasingly favorable as one moves forward of the minimum pressure point, this effect should compensate for the thinner boundary layer. The favorable hull pressure gradient should also compensate for the effect of multiple waves. Surface heating will also effect the waviness requirement by altering boundary layer characteristics. For lack of data, this waviness criteria does not include the effects of heating.

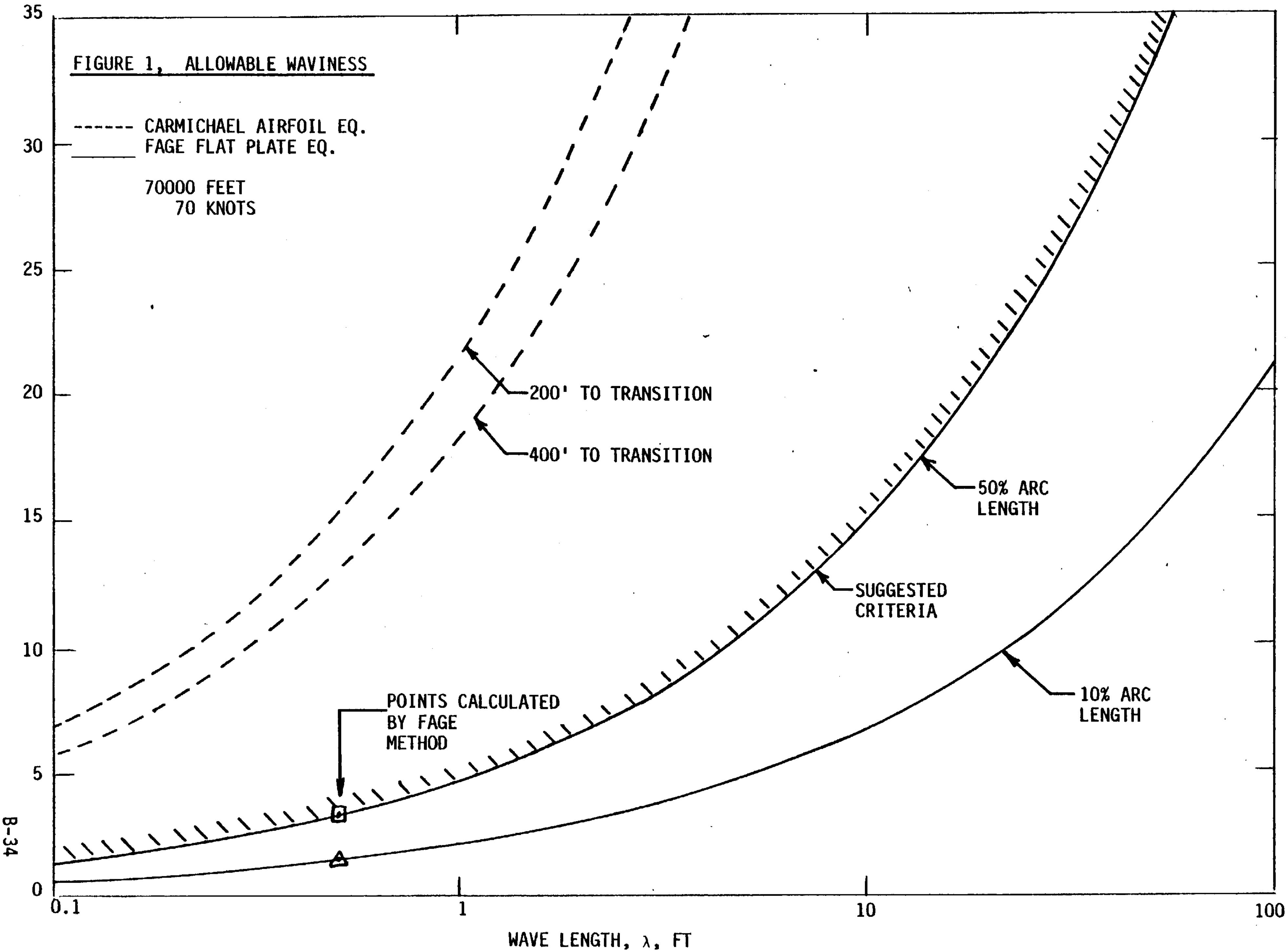


FIGURE 1, ALLOWABLE WAVINESS
CARMICHAEL AIRFOIL EQ.
FAGE FLAT PLATE EQ.
70000 FEET
70 KNOTS
200' TO TRANSITION
400' TO TRANSITION
50% ARC LENGTH
SUGGESTED CRITERIA
10% ARC LENGTH
POINTS CALCULATED BY FAGE METHOD
35
30
25
20
15
10
5
0
0.1
1
10
100
WAVE LENGTH, λ, FT

In view of these various considerations, the waviness requirement shall be;

$$\frac{h}{\sqrt{\lambda}} = .0467$$

h = Wave Amplitude IN

λ = Wave Length Ft

$$= \frac{.033"}{\sqrt{0.5'}} = .0467 \frac{IN}{\sqrt{FT}}$$

Hull construction must be tailored to meet the waviness requirements. Panel seams and dimensional accuracy requirements to meet the waviness requirements are estimated below.

Panel Width Tolerance

Assume: 100 Foot Diameter

70 Inch Fabric Width

4 Feet Wave Length

With λ = 4 foot, h = .093"

So radius must not vary more than .093" in four feet.

$$\text{\# of Gores} = \frac{\text{Circumference}}{\text{Panel Width}} = \frac{\pi\ 100}{70/12} \cong 54 \text{ Gores}$$

$$\text{Total Circumferential Error} = 2\pi R_{error} = 2\pi(.093") = 0.58"$$

$$\text{Tolerance in Single Panel} = \frac{\text{Circumferential Error}}{\text{\# of Gases}} = \frac{0.58}{54} = .0107 \cong 0.01$$

ALL PANELS MUST BE CUT AND SEALED ± 0.01" in 4 feet

± 0.005" in 1 foot

± 0.032" in 50 feet

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APPENDIX C

DELTOID SUMMARY

DELTOID SUMMARY

PRIMARY ADVANTAGE: AERODYNAMIC LIFT CAN BE USED TO AUGMENT BOUYANT LIFT.

A. IN RANGE OF SIZES OF INTEREST, DELTOID WOULD ONLY PROVIDE POWER ADVANTAGE AT HIGH VELOCITIES (ABOVE 80 KNOTS)

B. IN THE HAPP MISSION PROFILE, WINDS WILL ALWAYS BE LESS THAN 80 KNOTS.

C. POOR VOLUME EFFICIENCY, INCREASED STRUCTURAL WEIGHT OVER SURFACE OF REVOLUTION.

D. NEW CONCEPT, VERY HIGH TECHNOLOGY RISK.

CONCLUSION: SINCE THE ORIGINAL APPARANT ADVANTAGE IS NOT REAL, THIS CONCEPT HAS BEEN ELIMINATED FROM FURTHER EVALUATION.

"DELTOID FEASIBILITY ANALYSIS by William Putman

For a deltoid of elliptical cross section * and with an NACA 00XX airfoil section, steamwise, it can be shown in the "NACA Four-Digit Thickness Distribution Summary" at the end of this appendix that $V = 0.452\ K(\frac{t}{c})_{root}\ C^3$ where

K = tan (leading edge 1/2 apex angle)

$(t/c)_{root}$ = thickness ratio of root airfoil section

m $(t/c)_{root} \equiv$ 0.XX for NACA 00XX

and C = root chord, giving finally

$$B_\Delta = 1.58 \times 10^{-3}\ K\ (t/c)_{root}^{\ 3}$$

* The ellipsoidal cross section is the preferred shape from a volumetric and structural efficiency standpoint and is a patented development of the Aeveau Corporation, Princeton, N.J.

For the aerodymanic lift, L_Δ, we can write $L_\Delta = q\ S_\Delta\ C_L$,

where $S_\Delta \equiv$ platform area = $K\ C^2$ and q is the dymanic pressure, $q = .058 \times .001180\ V^2$

$= 6.89 \times 10^{-5}\ V^2$, psf

We now have the deltoid hybrid gross lift exprssed as

$$GW_\Delta = 1.58 \times 10^{-3}\ K\ (t/c)_{max}\ C^3 \qquad + K\ C_L\ (\tfrac{1}{2}\rho V^2)^2\ .$$

Turning now to the drag aerodymanics, for the conventional airship, we can use Hoerner (1) to express:

$$C_{D_{frontal}} = C_f \, [3\ (1/d) + 4.5\ (d/1)^{\frac{1}{2}} + 21\ (d/1)^2$$

$$= 0.042 \text{ for } C_f = .003 \text{ @ } R_e = 10^7 \, .$$

Assuming, for present purposes, no aerodymanic lift in the case of the conventional airhsip, the above expression is complete for airship drag.

In the case of the deltoid hybrid, both profile and induced drat terms will exist. For the accessories required herein, the developments of Putman, will suffice and drag coefficient components can be expressed as:

$$C_{D_o} = 2\ C_F \left[1 + 1.2\ (t/c)_{root} + 60\ (t/c)^4_{root} \right]$$

$$C_{D_o} = \frac{C_L{}^2}{\pi\ \mathcal{R}\, e} = \frac{C_L{}^2}{4\pi K\ e}\ , \text{ based on planform area}$$

Where $\mathcal{R}$ = 4 K and e is a Frost - Rutherford leading - edge singularity factor dependent on leading edge radius Reynolds number. For the vehicle size, velocities and altitudes of intent, Ke can be assumed = 0.08.

We now have complete parametric expressions for the lift, drag, and hence, lift-to-drag ratios of both conventional ellipsoidal airship and the deltoid hybrid. By means of these expressions and an assumed veloctiy profile we can make a quantitive comparison of the two types of vehicles in performing the HAPP mission.

Combining the previously developed expressions for C_{D_Δ} and C_{L_Δ}, we can express the dimensional drag as:

$$D_\Delta + 2\,q\,C_F\,K\,c^2\,[1 + 1.2\,(t/c)_{root} + 60\,(t/c)^4_{root}]$$

$$\frac{[8050 - 1.58 \times 10^{-3}\,K(t/c)\ root\ C^3]^2}{6.9328 \times 10^{-4}\,V^2\,K^2\,C^2}, \text{ lb.}$$

Evaluating the drag expression at a standard density altitude of 70,000 feet;

$$D_{\Delta_{70K}} = 4.14 \times 10^{-7}\,[1 + 1.2\,(t/c)_{root} + 60\,(t/c)^4_{root}]\,K\,C^2\,V^2 + \left[\frac{3.061412}{KcV} - \frac{.06008\,(t/c)_{root}\,C^2}{V}\right]^2, \text{ lb.}$$

and correspondingly for hte conventional airship of 3.1 fineness ratio and 7138 lb gross lift;

$$D_{A/S_{70K}} = 2.75\,c\,10^{-2}\,V^2, \text{ lb.}$$

The expressions for steady level flight power required follow as

$$HP_\Delta = 7.53 \times 10^{-10}\,[1 + 1.2\,(t/c)_r + 60\,(t/c)^4_r\,]\,KC^2\,V^3 \left[\frac{13.05 \times 10^3}{KcV} - \frac{2.57 \times 10^{-4}\,(t/c)_{root}\,C^2}{V}\right]^2 V, \text{ Horsepower,}$$

$$HP\ A/S = 4.99 \times 10^{-5}\,V^3, \text{ Horsepower.}$$

In order to affect a remainingful comparison of the deltoid hybrid and the conventional airship in performance of the HAPP mission, it will be necessary to prescribe an operating velocity time history representative of the year-on-station HAPP mission. Utilizing this profile and the power required expressions, we can then obtain a mission energy requirement as well as peak power requirements. These two indices must be then used to judge the relative merit of the configurations.

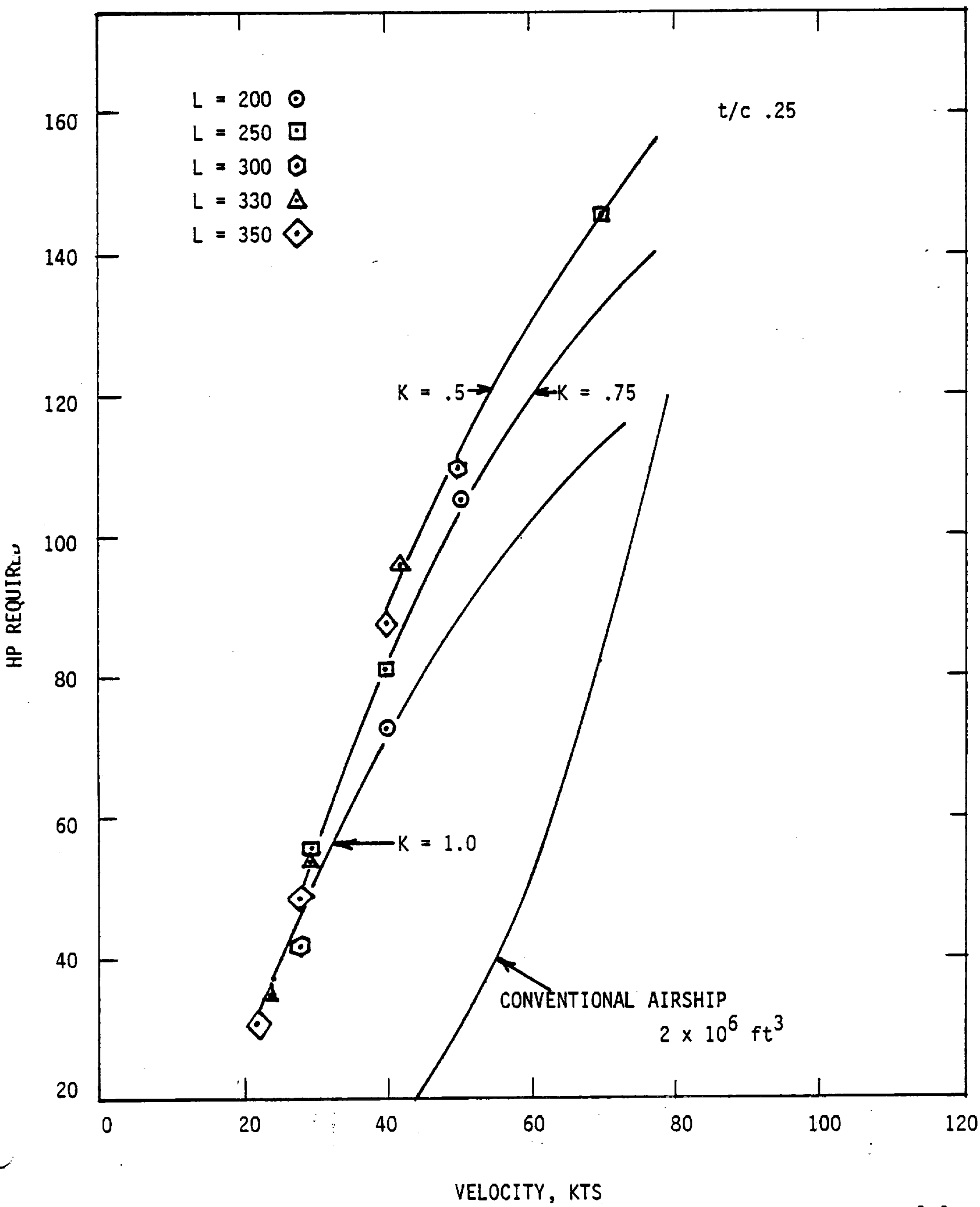
The following parametric field is suggested to be adequately representative for the deltoid configuration in the HAPP mission.

$(t/c)_{root}$ = 0.20, 0.25 and 0.30

K = 0.25, 0.50 and 1.00

C = 150 , 200, 250, and 300 feet

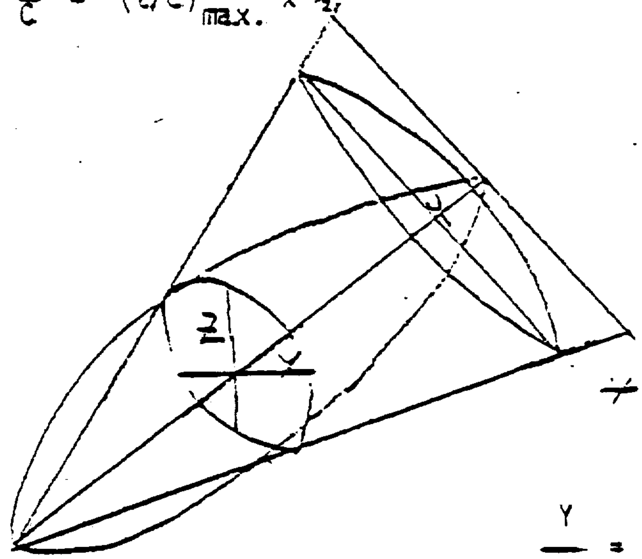
DELTOID FEASIBILITY



NACA Four-Digit thickness Dist.

$$\pm\ z = \frac{t}{.2}(.297\overset{A}{\ }\sqrt{x} - \overset{B}{.126}\,x - \overset{C}{352}\,x^2 + \overset{D}{.284}\,x^3 - \overset{E}{.101}\,x^4)$$

$$= \pm \frac{z}{C} = (t/c)_{max.} \times k_t$$



$$\forall \int_0^{o} \pi z\, ydx$$

$$\frac{Y}{C} = K X$$

$$\frac{z}{C} = \frac{t}{.2c}(A\sqrt{x} - Bx - C x^2 + D x^3 - E x^4)$$

$$\frac{\forall}{C^3} = \frac{t}{C}\Big|_{max} \frac{K\pi}{.2}\int_0 (A x^{3/2} - Bx^2 - Cx^3 + Dx^4 - Ex^5)\ dx$$

$$= \frac{t}{c}\Big|_{max} \times 5\ K\ \pi\left[2/5\ A\ x^{5/2} - \frac{B}{3}x^3 - \frac{C}{4}x^4 + \frac{D}{5}x^5\ \frac{E}{6}x^6\right]\ dx$$

$$= \left(\frac{t}{c}\right)_{max} 5\ K\ \pi\left[.4 \times .297 - \frac{.126}{3} - \frac{.352}{4} - \frac{.284}{5} - \frac{.101}{6}\right]$$

$$= \left(\frac{t}{c}\right) \pi K \quad \left[.0288\right]$$

$$= .452\ K\ (t/c)_{max}$$

For 60^{o} leading edge sweep, K = 30 = 0.58

$$\mathcal{V} = .261\ (t/c)_{max}\ l^{3}, \quad \text{for } t/c = .24, \quad \mathcal{V} = .0625\ l^{3}$$

APPENDIX D

DSI REPORT

DESIGN DATA FOR

HAPP VEHICLE

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April 1, 1982

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INTRODUCTION

This report describes various aspects of the work performed for ILC by Developmental Sciences, Inc. (DSI), on the HAPP program under Contract No. NAS 6-3131.

While much of the work under this contract has already been submitted in the form of report viewgraphs, progress reports, verbal presentaions during visits, etc., this document serves to refine and condense in one place the efforts devoted to avionics, propulsion, and system reliability in response to ILC letter request dated February 9, 1982.

1.0 AVIONICS

1.1 Architecture

Figure (1) shows a proposed architecture for the avionics system. This scheme was configured to maximize reliability. Devices such as vertical gyros (for attitude measurement) have been rejected because of the relatively poor reliability of this type of device.

The sensor suite is listed below:

Heading Sensor	Used to measure magnetic heading for the purpose of aligning the ground power transmitting antenna. This would be a three-axis device, augmented with attitude data supplied from the strapdown system. Magnetic heading would also probably be required for certain kinds of mission payloads.
Air Data	Pressure transducers are employed to measure baro altitude (h) and airspeed (V). This information is used for outer loop altitude control (h), and in gain scheduling (V).
Inertial Instruments	Yaw rate ($\dot{\psi}$) and pitch rate ($\dot{\theta}$) are measured by means of inertial quality rate gyros. Vertical and axial acceleration (a_z and a_x) are sensed by means of inertial quality accelerometers. Together the latter three instruments furnish the information required for strapdown computation of pitch attitude. All of the four sensors are also employed for inner loop damping of yaw and pitch rates.

The ground based data link furnishes information on position error (via a tracking antenna) to the airborne flight control computer.

As shown in Figure (1), all sensors are triplex. The reasons for this choice become evident from the analysis of Section (1.4).

The output functions of the system are comprised of the downlink, the control surface actuators (δ_e, and δ_r)* the propellor pitch servo (δ_β), and the four electric motor control actuators (δ_p). Each actuator is configured as shown in Figure (2), with two motors driving through a common differential. Individual feedback potentiometers are used on each motor.

Triply redundant power supplies are used to convert from the rectanna raw power to conditioned power required by the avionics. Two of the power supplies are on standby in this scheme.

A dual redundant liquid cooling system is included to collect dissipated heat from the avionics (and payload). The system would be designed to "cold-soak" the avionics, especially the computers in order to enhance reliability. It would consist of two small (~ 3 feet^2 face area) glycol-water radiators with cooling lines connected to cold plates built into the various avionics boxes.

The airborne flight control computers are quad-redundant. Computer capacity is roughly estimated at 2 K of PROM and 2 K of RAM. The processing rates vary as a function of the particular computations being performed. Strapdown computations would be done at about 50 bits/second, while other flight control functions would be computed at 25 bits/second and less. The computer would be based on a microprocessor in the class of the Z-8000 or the MC 68,000.

To maximize computer reliability, it is desirable to maintain the cold-plate at a temperature of about 0°F.

1.2 Weights and Power

Table (1) shows a weight breakdown of the avionics system, based upon

---

* δ_e = elevator deflection, δ_r = rudder deflection.

DEVICE	NUMBER	WEIGHT (LBS)
Magnetic Heading Sensor	3	7.5
Altitude Sensor	3	1.8
Airspeed Sensor	3	1.8
Yaw Rate Sensor	3	2.4
Pitch Rate Sensor	3	2.4
Vertical Accelerometer	3	1.8
Airborne Flight Control Computer	4	36.0
Power Supply	3	21.0
Airborne Data Link	4	48.0
Actuators	8	40.0
Cable Harness	1	50.0
Installation	-	20.0
Avionics Cooling (Liquid)	2	26.0
TOTAL		258.7 LBS

AVIONICS WEIGHT BREAKDOWN

TABLE (1)

AIRBORNE AVIONICS ARCHITECTURE

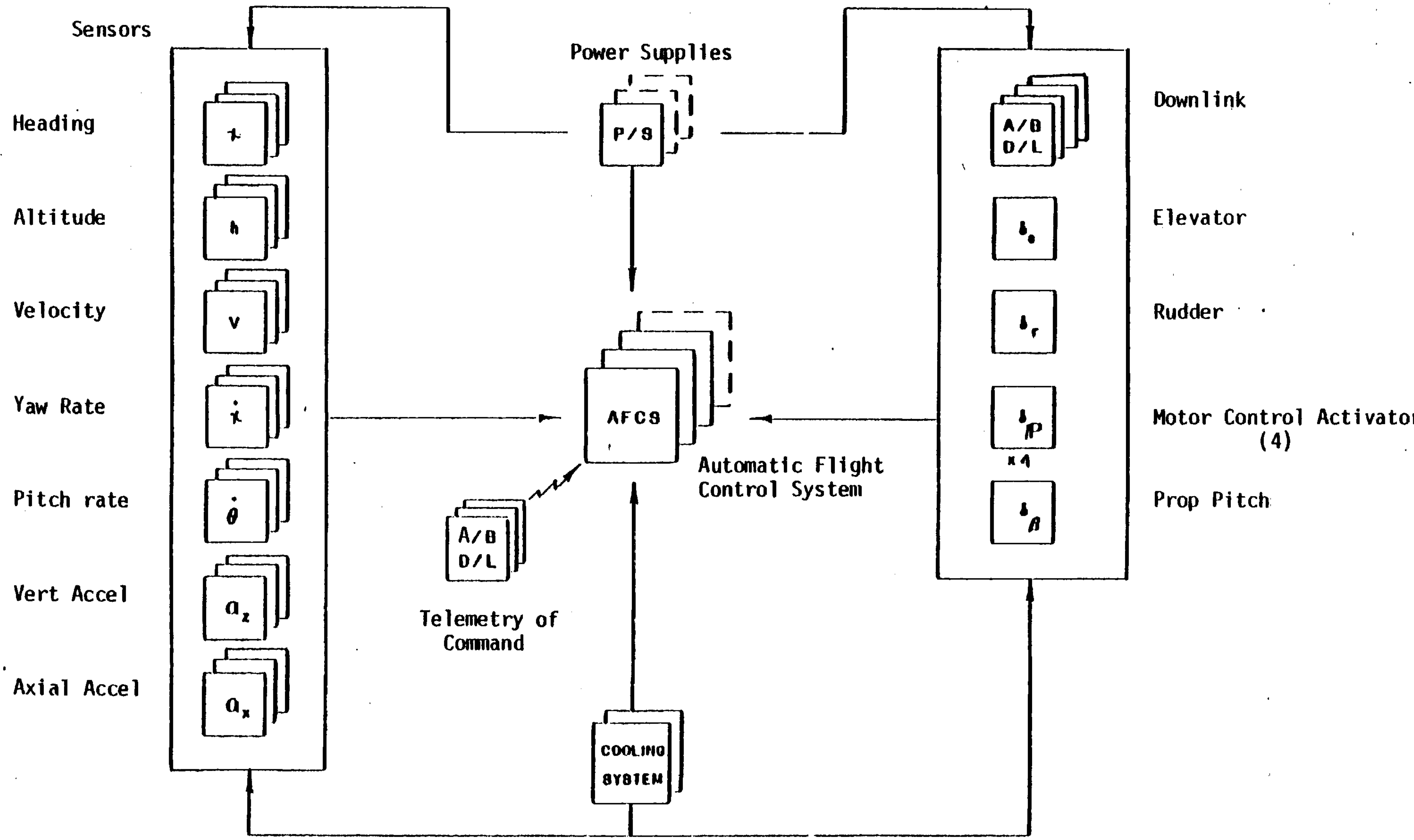


FIGURE (1)

DUAL SERVO ACTUATOR FUNCTIONAL BLOCK DIAGRAM

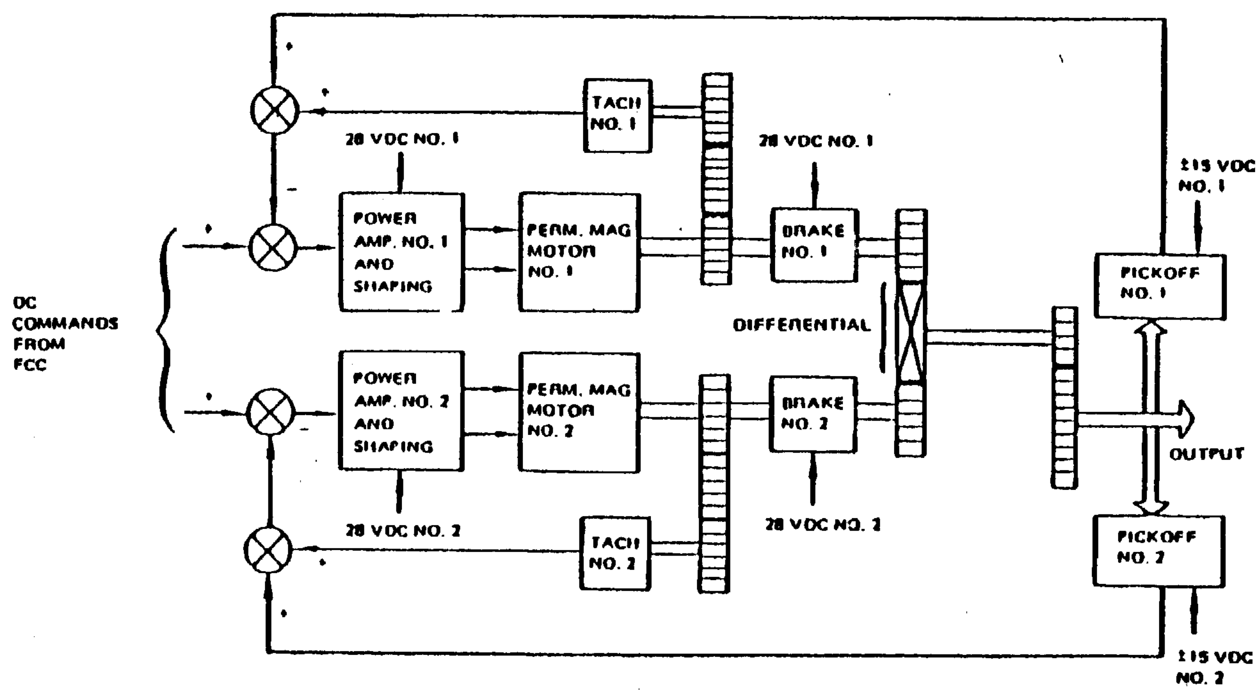


FIGURE (2)

data assembled on other DSI programs. Table (2) presents the power consumed by the flight control system.

1.3 Redundancy Management

The following elements of redundancy management would be included:

- o In-line monitoring (reasonableness)
- o Sensor/Actuator/Computer self-test
- o Cross channel voting

All system elements would be cross-strapped where practical. In this way, very high coverage on fault detection and isolation can be achieved. For purposes of simplicity in predicting faults for this preliminary exercise, 100% coverage will be assumed.

1.4 Reliability Estimate

Figure (3) shows the reliability block diagram for the avionics system. Dashed line boxes indicates units on standby. Table (3) gives failure rate data for each of the components shown in the block diagram. Using classical reliability prediction methods, the following values are obtained for this system (assuming one of each required for success).

TIME PERIOD	RELIABILITY
3 months	.9076*
12 months	.2727

It should be noted that actual values would be somewhat lower since fault isolation coverage is not accounted for, as discussed earlier.

* This number has been changes from the original value of 0.8997 published in this report. A mathematical error was discovered by ILC.

DEVICE	NUMBER	POWER CONSUMED (Σ Channels)
Mag. Heading Sensor	3	1.5 watts
Air Data System Static and dynamic pressure trandudcers (P_s and Q_c)	1 (triplex)	5 watts
Strapdown Ins.	1 (dual)	125 watts
Airborne Flight Control System	4	200 watts
Airborne Data Link	4	150 watts
Control Surface Actuators		250 watts
Power Supply*	1 (at any time)	400 watts
	Total	1,132 watts

*For 5 KW payload + avionics.

AVIONICS POWER REQUIREMENT

TABLE (2)

DEVICE	FAILURE RATE (Per Million Hours)	SOURCE
Magnetic Heading Sensor	40	Develco
Altitude Sensor	37.5	Rosemont
Airspeed Sensor	37.5	Rosemont
Yaw Rate Sensor	95.0	Draper Labs
Pitch Rate Sensor	95.0	Draper Labs
Vertical and Axial Acceleration	55	Draper Labs
Airborne Flight Control Computer	150	LSI Based on MIL HDBK 217 c
Power Supply	45	Electropacific Summary Report, Ref. DSI P.O. 13836
Airborne Data Link	330	Vega Precision Labs
Actuators (Dual Motors, Common X-mission)	5	LSI
Cable Harness	3	LSI
Cooling System	10	DSI

AVIONICS FAILURE RATE VALUES

TABLE (3)

AVIONICS RELIABILITY BLOCK DIAGRAM

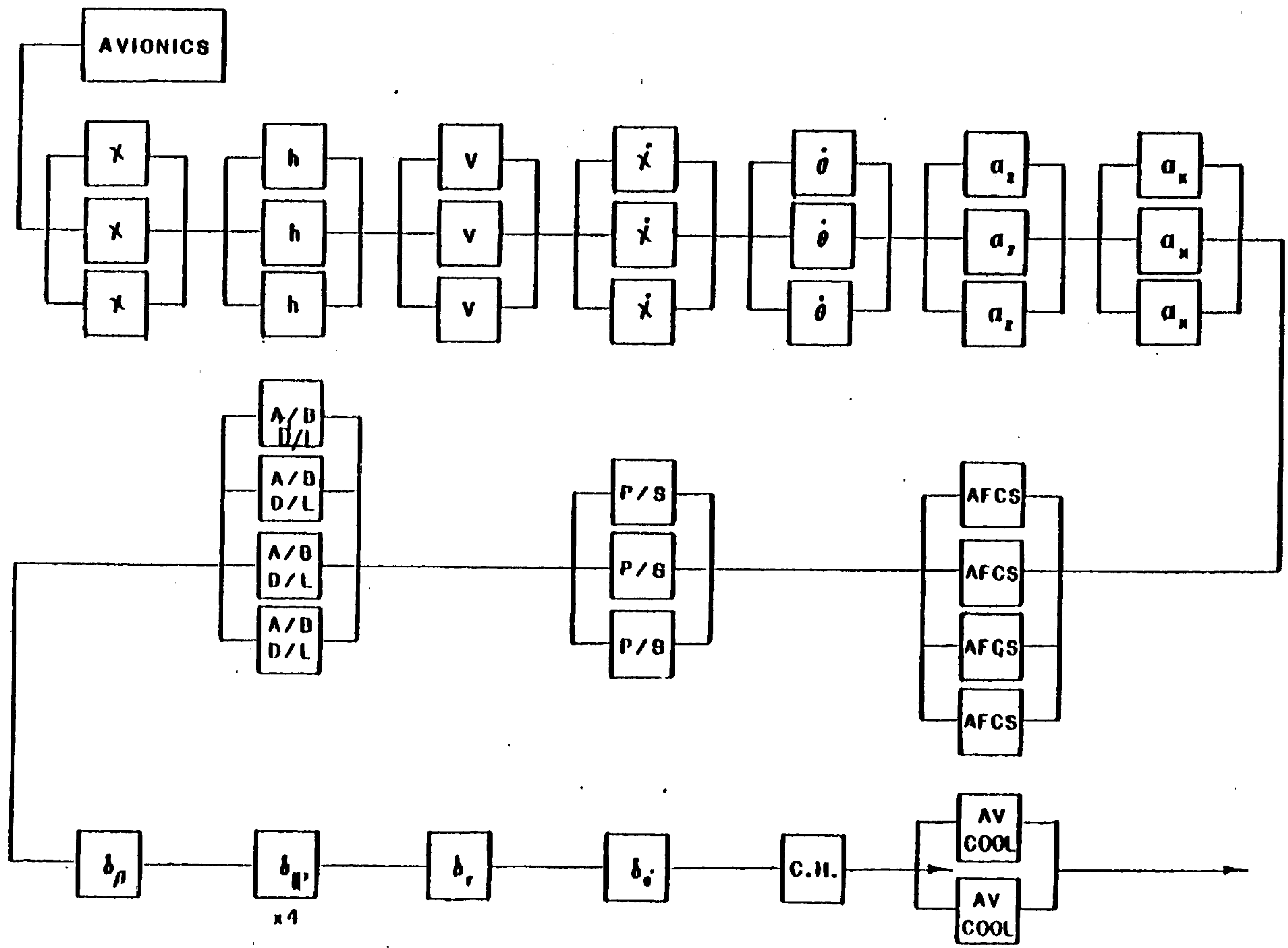


FIGURE (3)

2.0 POWERPLANT

2.1 Configuration

The block diagram of the airborne powerplant (prime and auxiliary) is shown in Figure (4). This diagram characterizes the airborne end-to-end function of the propulsion system. The receiving antennas on the airborne platform (R) convert the RF energy into electrical power at about 250 volts. The cable harness (CH) transmits this power to a series of four Samariam Cobalt brushless motors, each in the 25 to 50 shaft HP size range. Shaft power is transmitted through a pair of dual input gearboxes, then into a sprague clutch combiner and finally to a single variable pitch propellor. Auxiliary power is brought on line as shown in the block diagram. This power is furnished to the electric motors by a turbo-generator unit.

This particular arrangement was chosen over other configuration studies because it appeared to maximize reliability per unit cost and weight.

2.2 Electric Motors

The Samarium Cobalt brushless d.c. motor was selected over other candidate (Table(4)) systems for three basic reasons:

- o High power to weight ratio
- o High efficiency
- o Ability to generate output power over a wide range of torque and shaft speeds.

The last reason is important because of the necessity to generate power efficiently over a wide range of altitudes and propellor advance ratios, especially during ascent/descent to and from station-keeping altitudes.

Present state-of-the-art motors of this kind and in this power class have weight to power ratios of about 2.5:1 lb/H.P., including controllers End-to-end efficiencies are over 90%.

Each motor will require liquid cooling. A common radiator for each pair of motors would be provided to reject dissipated heat to the atmosphere.

TYPE	CHARACTERISTICS
Samarium Cobalt Permanent Magnet a.c. Motor (Brushless)	Very High Efficiency ($.85 < \eta < .9$) Very High Power/Weight (2.5 lb/H.P.) Wide Control Range Control Technology New Reliability TBD (Switching with each Rev.)
Samarium Cobalt Permanent Magnet d.c. Motor (Brush)	High Efficiency ($.8 < \eta < .85$) Very High Power/Weight (2.5 lb/H.P.) Difficult to cool Narrow Control range Electronically Noisy Life Limited by Brushes
Wound-Field ac/dc Motor (Brush)	Modest Efficiency ($.7 < \eta < .75$) Heavier (4 lb/H.P.) Wide Control Range Difficult to Cool High Torque Life Limited by Brushes
Induction	Widely Controllable (speed Freq.) Heavy (10 lb/H.P.)

CHARACTERISTICS OF VARIOUS TYPES OF ELECTRIC MOTORS

TABLE (4)

POWERPLANT BLOCK DIAGRAM (AIRBORNE)

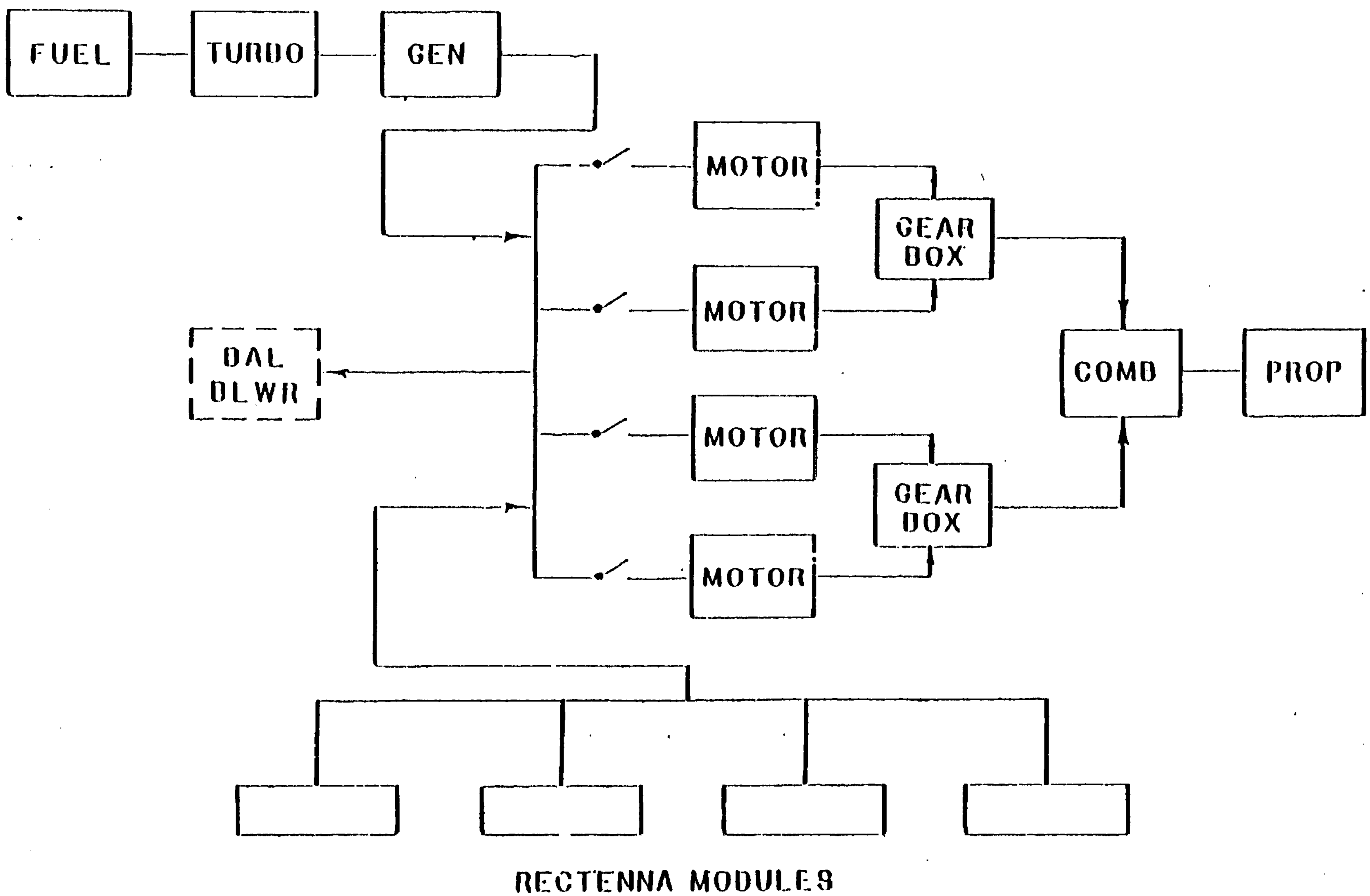


FIGURE (4)

Unfortunately, at this time, little failure rate data on this type of motor is available for reliability estimates. Table (5) summarizes the characteristics of this type of motor.

2.3 Gear Box

The propellor analysis (Section 2.6) indicates the need for two-speed output to accommodate the range of altitudes and advance ratios required.

For reliability reasons, the reductions will be accomplished in the following two steps:

1) Two speed dual input gearbox for each pair of motors.

2) A single fixed ratio (2:1) sprag clutch combiner.

Figure (5) shows a schematic of the dual input planetary gearbox. Its operation can be summarized as follows. The input from each motor is provided by quill shafts designed to isolate the gear train, particularly the input reduction set, from any torque fluctuation of the motors. Each input drive incorporates an engine disengaging feature which operates (without sensors, control circuitry, or actuators) when the drive torque of one motor passes through zero to a negative value. This is accomplished with a helical scroll system which reacts to torques solidly to the gearbox case in one direction, but which rotates and moves gears axially out of engagement when torque is reversed.

The gear train, comprised of four gear sets, provides for continuous correct phasing of both motors which run at identical rpm. The gear sets include an input planetary set for each motor, a spur gear transfer set and an output planetary set which incorporates the speed changing mechanism. The gearbox overall reduction is 11.11 to 1 in low ratio and 7.33 to 1 in high ratio. Speed change is accomplished by means of a multi-plate clutch and a sprag clutch with the output planetary set. The speed changing system sustains power through all gear changes and has no possibility of neutral. In the event of a clutch failure, the unit will drive at the higher ratio.

Type	Synchronous, 8 poles, permanent magnet, 3-phase, brushless A.C.
Power	30 H.P. @ 4500 R.P.M.
Weight	65 lbs
Efficiency	95% @ 4500 R.P.M.
Voltage	250 V d.c. @ 100 A
NRE Required	250 K (12 Mtrs)
Motor Cost (Prod.)	20 K/Unit

ELECTRIC MOTOR SPECIFICATION

TABLE (5)

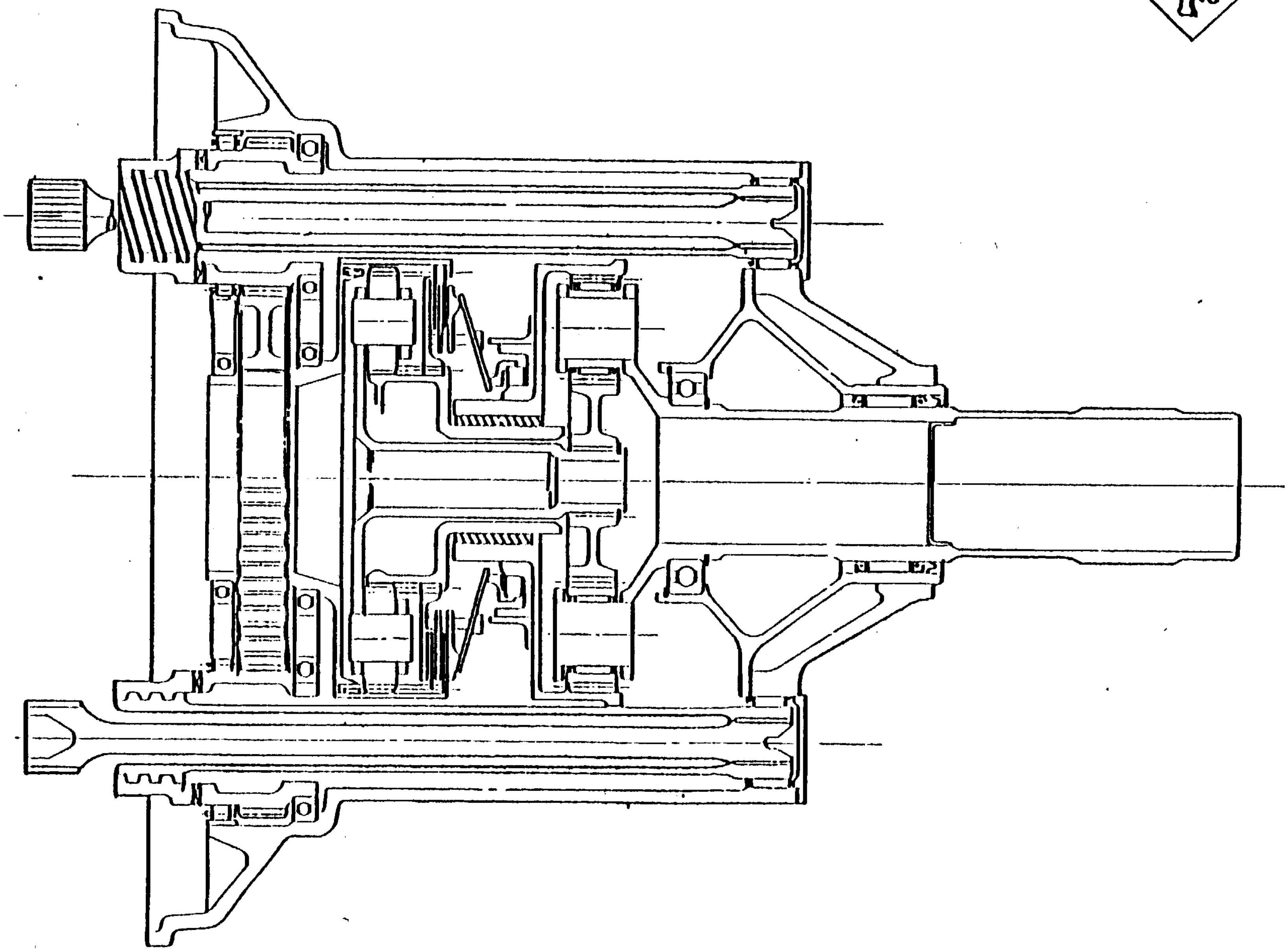


FIGURE (5)

The combiner is a simple 4:1 ratio sprag clutch transmission, whose disengagement function is similar to that described above. This unit combines torque inputs from each motor pair into a single output shaft at propeller speed. The end to end efficiency of the gear reduction system is estimated to be 0.95.

A single propeller was chosen to operate symmetrically in the wake of the body, and hence, give maximum efficiency. Two, counter-rotating propellers were considered to enhance redundancy, but this scheme was finally dropped because it was felt that failure of one would in fact cause failure of the other.

Table (6) gives the weight summary of the prime propulsion system for 100 SHP total.

2.4 Auxiliary Propulsion

A turboshaft driven electrical generator is used to supply electrical power to the electric motors in the case where no power is available from the rectenna system (auxiliary divorced scheme). One can also consider a configuration where the auxiliary power is used along with the prime power system to increase the total power to the propeller shaft (auxiliary-coupled arrangement). The latter case would, of course, require the electric motors, transmission, and propeller to have greater capacity.

The turbine engine used for this application would probably be a modification of an existing unit, adjusted to operate at the higher altitudes. Preliminary studies conducted for DSI by various engine companies (e.g., Garrett, Solar, and G.E.*) on other programs suggest that a power to weight of nominally 4.0 lbs/H.P. at 65,000 ft for the basic engine, delivering shaft power at around 40,000 --> 50,000 rpm. In this size range and at the maximum altitude under consideration, one could expect an SFC in the range of .40 to .52 KG/KWHR.

It should be noted that the re-configuration of an existing engine for this application would be a relatively costly undertaking.

---

* e.g., the G.E. CT-7.

	LBS
4 MOTORS/CONTROLLERS (25 H.P.)	260
2 COOLING RADIATORS	40
2 GEARBOXES	50
1 COMBINER	20
PROPELLER	65
WIRE HARNESS	100
RECTENNA	--
MISCELLANEOUS	50
TOTAL	585

PRIME PROPULSION WEIGHT BREAKDOWN

TABLE (6)

An electrical generator of the Samarium-Cobalt type operating at these rpm's in this size range would weigh about 1.5 lb/H.P. (including conditioning). Adding an additional 20% for cable harness, installation, and miscellaneous items, the installed auxiliary powerplant weight to power ratio would be about 6.6 lb/H.P. For 100 available H.P., the installed weight of the auxiliary would be about 660 lbs.

2.5 Propeller

The propeller is a two-blade, fifty-foot diameter, variable pitch design. Power absorption of the propellor is held constant during climb to altitude by adjusting propellor blade pitch and by selecting the appropriate gear ratio in the two-speed gearbox.

2.6 Propeller Aerodynamic Design and Performance

The propeller aerodynamic design was generated with the aid of a DSI computer program that is based on an algorithm published by Dr. E. Eugene Larrabee of the Massachusetts Institute of Technology. This program optimizes the radial distribution of local chord times lift coefficient, producing a propeller that exhibits minimum induced losses at the selected design conditions (forward speed, rpm, power, etc.). The resulting radial distribution of blade loading is analogous to the (optimum) elliptical loading on an airplane's wing.

Propeller performance in operating conditions different from those at the design point is predicted using a second computer program that is based on another Larrabee algorithm. This program accommodates changes in flight speed, rpm, blade pitch angle, and local air density, and computes thrust delivered, power absorbed, and efficiency. The Prandtl-Betz-Goldstein tip-loss correction factor is incorporated in the algorithm, ensuring good correlation between computer-predicted and experimentally-observed performance characteristics.

Because the climb to altitude encompasses such a wide range of operating conditions, multiple propeller speeds are required. (Not even the provision for variable blade pitch angle is sufficient to efficiently accommodate the range of flight speeds and air densities encountered during climb.) Proper selection of the design operating point from within the range of operating conditions can minimize the number of speeds required. Designing the propeller for full-power (150 bhp) operation at 60,000 ft results in excellent efficiency throughout the climb to 70,000 ft, using only a single gearbox ratio change. The blade geometry generated by this design/evaluation iteration is shown in Figure (6).

Propeller operation during full-power climb to altitude is shown in Table (7) and Figure (7). The propeller is run at low speed (90 rpm) and "flat" pitch at sea level. As altitude increases, the blade pitch is progressively "coarsened", until the vehicle reaches 42,000 ft. At this point, the gearbox is shifted into its high-speed range (135 rpm), and the blade pitch angle is simultaneously reduced. The climb from 42,000 ft to 70,000 ft involves a second coarsening of the blade pitch. Note that the optimum efficiency is not obtained at the station altitude of 70,000 ft. This is a consequence of not only the selection of 60,000 ft as the design altitude (discussed previously), but also Reynolds number effects. Note, however, that the deviation between on-station and maximum efficiencies is only 2 1/2 percent, and furthermore, that the best efficiency occurs at shear-layer altitudes, where maximum efficiency is most beneficial in minimizing "drift".

Partial-power operation at any altitude can be achieved by running the propeller at "flatter" pitch angles than those seen in Figure (7). While this may entail reductions in operating efficiency, this is a less critical consideration at reduced power levels.

2.7 Prime Propulsion Reliability

Figure (8) shows a reliability block diagram for the powerplant. The failure rates (in failures per million hours) for each component are given in the blocks.

The blocks to the left of the dashed line are associated with the RF transmission elements. It is believed that very little knowledge of failure rates exist for this element. The assumed values are merely estimated.

h k ft	V_{max} f/s	ρ sl/f^3	ν f^2	λ	$\beta_\circ$
0	52.5	.002377	.0001564	ℓ	-10.5
5	55.2	.002049	.0001776	ℓ	-9.2
10	58.1	.001757	.0002013	ℓ	-7.9
15	61.3	.001498	.0002203	ℓ	-6.5
20	64.8	.001270	.0002633	ℓ	-4.9
25	68.6	.001069	.0003017	ℓ	-3.2
30	72.8	.0008933	.0003488	ℓ	-1.3
35	77.5	.0007407	.0004057	ℓ	+0.8
40	83.6	.0005894	.0005056	ℓ	+3.5
45	90.6	.0004642	.0006423	ℓ h	+6.5 +6.9
50	98.0	.0003657	.0008159	h	+4.7
55	106.2	.0002880	.001036	h	-2.2
60	115.0	.0002269	.001316	h	+0.4
65	124.5	.0001788	.001671	h	+2.8
70	135.0	.0001401	.002143	h	+6.

PROPELLOR SETTINGS
AS FUNCTION OF ALTITUDE

TABLE (7)

BLADE GEOMETRY

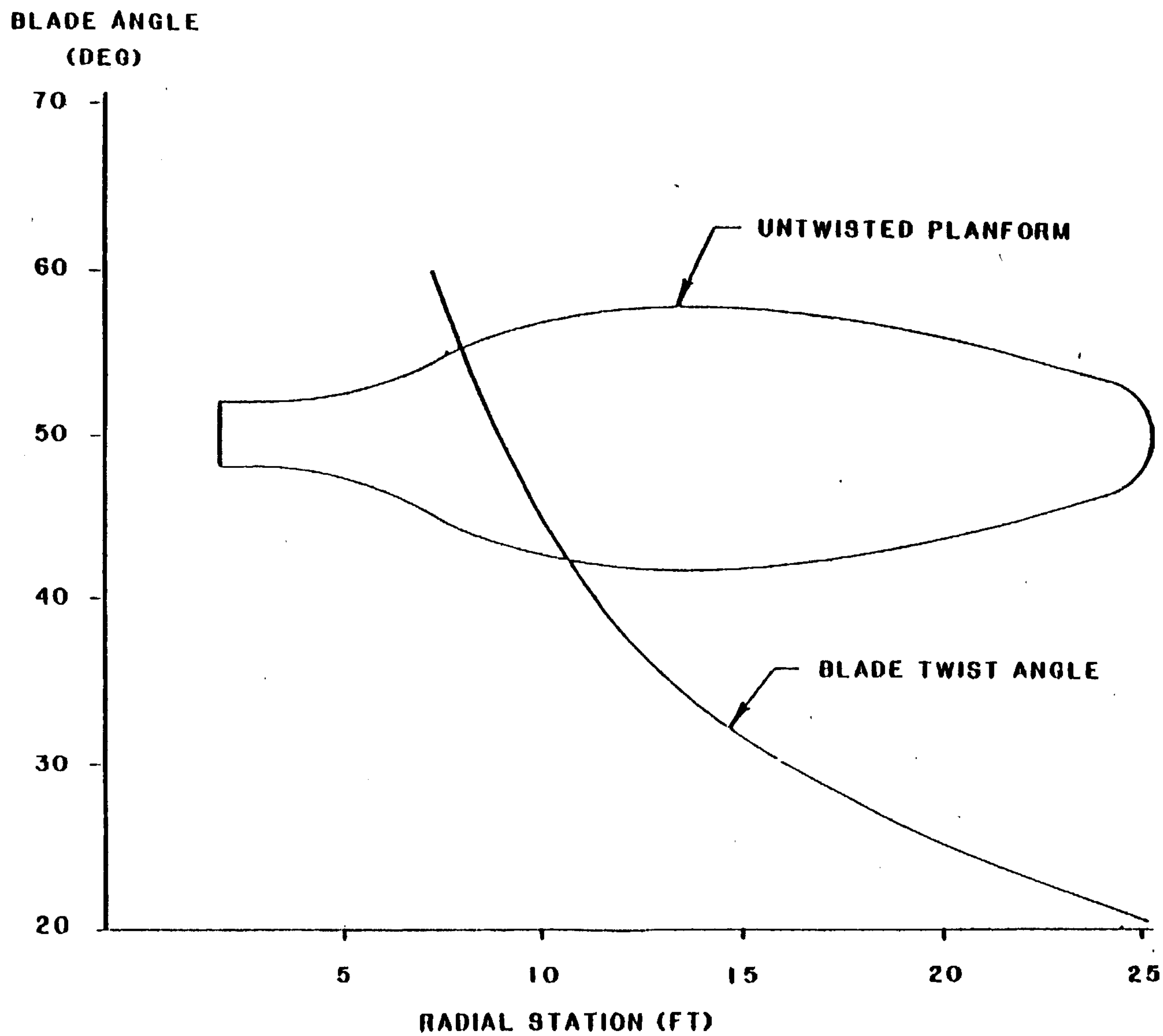


FIGURE (6)

PROPELLOR OPERATION

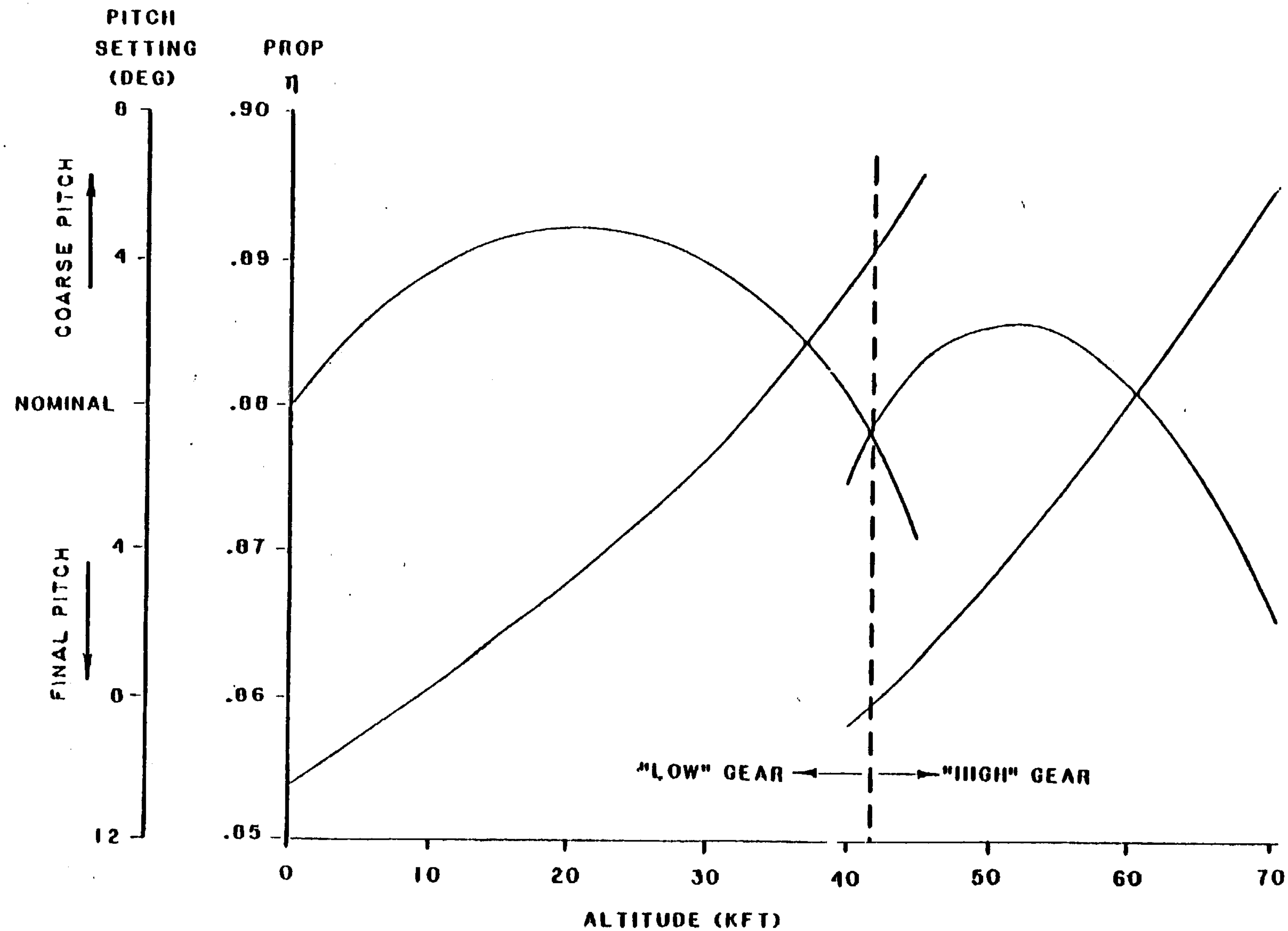


FIGURE (7)

PRIME PROPULSION RELIABILITY

(50% OF REDUNDANT UNITS REQUIRED FOR SUCCESS - ALL CASES)

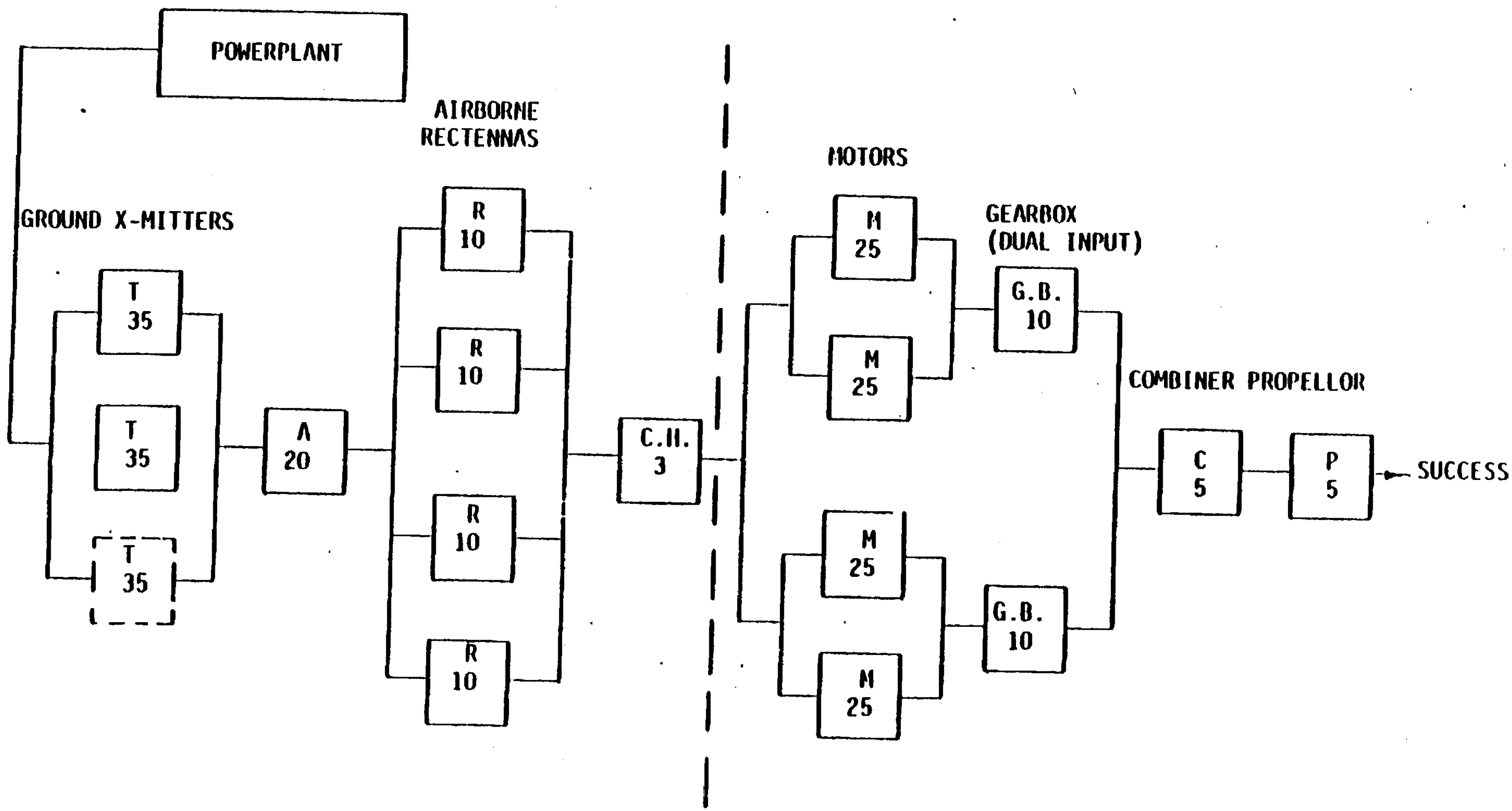


FIGURE (8)

The blocks to the right are related to the power drive system. The failure rate numbers quoted are based on analyses performed on other programs by DSI.

The prime propulsion reliability for three month and one year periods are summarized below.

PERIOD	RELIABILITY
3 Mo.	.9303
12 Mo.	.7282

3.0 SYSTEM RELIABILITY

Figure (9) shows a block diagram of the system elements. Airframe failure rates are taken to be 10 failures per million hours. The C^3 ground system was assumed in this analysis to be completely reliable.

The system reliability summary is given below:

PERIOD	RELIABILITY
3 Mo.	.8351*
12 Mo.	.1821

It should be noted that these values do not include payload.

* This value is based on a corrected avionics reliability shown on Page 7 of this Appendix. The original figure published in the report was 0.8191.

SYSTEM RELIABILITY

Developmental Sciences Inc

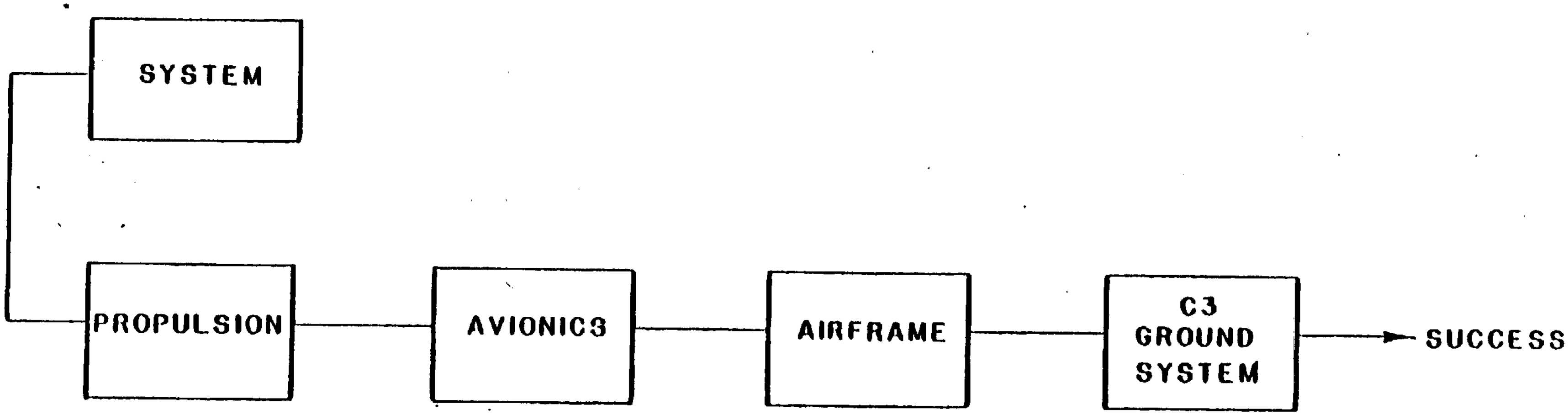


FIGURE (9)

APPENDIX E

THERMAL DATA AND TRENDS

APPENDIX E

THERMAL DATA AND TRENDS

This appendix contains the HAPP Thermal Equilibrium Program, Attachment EA, for computing gas and skin temperatures during flight, and a set of graphs depicting sensitivity of the temperatures to variations of the thermal factors.

Figures E2 through E15 present the sensitivity information. Each curve represents variation of one parameter on an arbitrary baseline representing a possible HAPP flight situation. The baseline values are listed in Figure E1. It is to be noted on all the graphs that TTC and TBC are top skin and bottom skin temperatures, and that gas temperature, which is not shown, lies halfway between them.

Figures E2 through E5 present solar parameters which have an effect only during the day. Other factors are all presented for nighttime only, (solar flux zero) but would also have an effect during daytime. Figures E6 through E15 are nighttime values, all associated with infrared energy (except the convection graphs).

All factors except convection have a significant effect. Convection is graphed only for low values expected at the altitudes and airspeeds where day-night temperature swings are most critical. The source for the convection coefficient value is given in Figure E16.

The influence of each of these thermal factors is to some degree additive to the influence of other factors. We are most concerned with the factors that cause in-flight changes of superheat or supercool, which is primarily solar flux. Changes of ambient temperature per se are not serious, except that the hottest temperature experienced by the airship gas fixes the mass of helium in the ship and thus its aerostatic lift. Therefore, this "hottest" temperature is an important design consideration.

APPENDIX E - ATTACHMENT EA

THERMAL EQUILIBRIUM PROGRAM FOR HAPP

26 April 82

```
30 O$ = "THEREQD 10JL82 = THEREQD 26AP82 WITH SA=SB=1.9 TO GIVE 33.2C DAY-NITE DIFF MATCHING
      APP BASELINE DIFF. +AND-VALS FROM AMBIENT NOT THE SAME"
35  HOME : PRINT "FOR NO PRINTOUT SET PR=10"
37 P$ = "PROGRAM THEREQD OF 26APR82": PR# 1: PRINT P$: PR# 0
50  REM :THEREQD IS SAME AS ORIGINAL THEREQ WITH PROGRAM IMPROVEMENTS. IT DIFFERS FROM THERE
       FOR IR INWARD FLUXES. THIS PROGRAM RETAINS B3,B4,U4 WITH EARTH AND ATMOS TEMPS INPUT
51  REM  THEREQC HAS INWARD IR FLUXES AS DIRECT INPUTS; THEREQD OF 26APR82 GIVES SAME RESULT
      AS THEREQC WITH THE SET INPUTS

100 PI = 3.1416:S = 1.714E - 9:PT = 0:PN = 0: PR# 0
150 Z = 65000:KT = 0: PRINT Z,KT
155  INPUT "CHANGE ALTITUDE OR AIRSPEED (Y/N)";A$
156  IF A$ = "Y" THEN  GOTO 158
157  GOTO 250
158  INPUT "NEW ALTITUDE Z, AIRSPEED KT,=";Z,KT
250 VO = 3.1416: PRINT VO
297  INPUT "CHANGE VOLUME, Y/N";B$
298  IF B$ = "Y" THEN  GOTO 300
299  GOTO 350
300  INPUT "VOLUME=VO=";VO
350 A = 5.868 * VO ↑ (2 / 3)
400 LQ = .1: PRINT LQ
447  INPUT "CHANGE ITERATION LIMIT LQ ? , Y/N  ";C$
448  IF C$ = "Y" THEN  GOTO 450
449  GOTO 500
450  INPUT "ITERATION LIMIT FOR QU=LQ=";LQ
500 E1 = .796:E4 = .796: PRINT E1,E4
547  INPUT "CHANGE IR OUTSIDE EMISSIVITY?, Y/N  ";D$
548  IF D$ = "Y" THEN  GOTO 550
549  GOTO 600
550  INPUT "IR EMISSIVITYS, OUTSIDE, TOP=E1=,BOT=E4=";E1,E4
600 E3 = .773:E6 = .773: PRINT E3,E6
647  INPUT "CHANGE IR INSIDE EMISSIVITY ? , Y/N";E$
648  IF E$ = "Y" THEN  GOTO 650
649  GOTO 671
650  INPUT "IR EMISSIVITYS, INSIDE,TOP=E3=,BOT=E6= =";E3,E6
671 E2 = .6765:E5 = .6865: PRINT E2,E5
672  INPUT "CHANGE ATMOSPHERE OR EARTH EMISSIVITY ?, Y/N";J$
674  IF J$ = "Y" THEN  GOTO 678
676  GOTO 700
678  INPUT "ATMOS E2=, EARTH E5=";E2,E5
700 FS = 000: PRINT FS
705  INPUT "CHANGE SOLAR FLUX FS, Y/N?";F$
710  IF F$ = "Y" THEN  GOTO 720
715  GOTO 725
720  INPUT "SOLAR FLUX, FS= ";FS
725 SA = .19:SB = .19: PRINT SA,SB
730  INPUT "CHANGE SOLAR ABS TOP SA? OR BOT SB? Y/N?";S$
735  IF S$ = "Y" THEN 745
740  GOTO 760
745  INPUT "SOLAR ABSORBTIVITY,TOP SA=?, BOT SB=? ";SA,SB
760 L = .11: PRINT "L="L
762  PRINT "ENVIRONMENT FOR ALBEDO 'L':"
763  PRINT "USA CLEAR DAY, L=.11"
764  PRINT "USA CLOUDY DAY, L=.52"
765  PRINT "ARCTIC CLEAR DAY, L=.36"
766  PRINT "ARCTIC CLOUDY DAY, L=.79"
767  INPUT "CHANGE ? ALBEDO, Y/N?";FB$
768  IF FB$ = "Y" THEN  GOTO 770
769  GOTO 800
770  INPUT "ALBEDO, L=";L
800 H1 = .02:H2 = .08: PRINT H1,H2
847  INPUT "CHANGE ? CONVECTION COEFFICIENTS?? ,Y/N  ";G$
848  IF G$ = "Y" THEN  GOTO 850
849  GOTO 900
850  INPUT "CONVECTION COEFFICIENTS, OUTSIDE=H1=, INSIDE=H2= -";H1,H2
900 TA = 406.2:TE = 501: PRINT TA,TE
947  INPUT "CHANGE ? AMBIENT OR EARTH TEMP?? , Y/N  ";H$
948  IF H$ = "Y" THEN  GOTO 950
949  GOTO 1075
```

```
950  INPUT " TEMP DEG R, AMBIENT=              TA=, EARTH=TE= =";TA,TE
1075 TG = 390:DT = 10
1080  PRINT "INITIAL GAS TEMP TG, AND GASTO SKIN DIFF DT, SET AT 400 AND 10"
1090 NN = 0:MM = 0: PR# 1: PRINT P$: PR# 0
1100 TT = TG + DT:TB = TG - DT
1150  REM : CALCULATES TOP NET HEAT, QU
1200 U1 =  - 1 * S * E1 * TT ↑ 4 * A / 2
1250 U2 = H1 *  ABS (TA - TT) ↑ (4 / 3) * (A / 2) * (TA - TT) /  ABS (TA - TT)
1300 U3 = FS * SA * A / PI
1350 IR(1) = S * E2 * TA ↑ 4:U4 = IR(1) * E1 * A / 2
1400 B7 =  - S * E6 * TB ↑ 4 * A / 2
1450 U5 =  - B7
1500 U6 =  - S * E3 * TT ↑ 4 * A / 2
1550 U7 = H2 *  ABS (TG - TT) ↑ (4 / 3) * (A / 2) * (TG - TT) /  ABS (TG - TT)
1600 QU = U1 + U2 + U3 + U4 + U5 + U6 + U7
1640  IF PT = 1 THEN  PR# 1
1650  PRINT : PRINT
1651  PRINT "U1="U1: PRINT "U2="U2: PRINT "U3 = "U3: PRINT "U4 =              "U4
1700  PRINT "B7="B7: PRINT "U5="U5: PRINT "U6="U6: PRINT "U7="U7
1750  PRINT "QU="QU
1751  PRINT
1755  PR# 0
1800  IF  ABS (QU) > LQ THEN  GOTO 2750
1850  REM : CALCULATES BOT NET HEAT
1900 B1 =  - 1 * S * E4 * TB ↑ 4 * A / 2
1950 B2 = H1 *  ABS (TA - TB) ↑ (4 / 3) * (A / 2) * (TA - TB) /  ABS (TA - TB)
2040 IR(5) = S * E5 * TE ↑ 4 * (1 - E2):B3 = IR(5) * E4 * (A / 2)
2050 IR(6) = S * E2 * TA ↑ 4:B4 = IR(6) * E4 * A / 2
2060 IR(2) = IR(5) + IR(6)
2100 B5 = FS * L * SB * A / 2
2150 B6 =  - U6
2200 B7 =  - S * E6 * TB ↑ 4 * A / 2
2250 B8 = H2 *  ABS (TG - TB) ↑ (4 / 3) * (A / 2) * (TG - TB) /  ABS (TG - TB)
2300 QB = B1 + B2 + B3 + B4 + B5 + B6 + B7 + B8
2340  IF PT = 1 THEN  PR# 1
2350  PRINT "B1="B1: PRINT "B2="B2: PRINT "B3="B3: PRINT "B4="B4
2400  PRINT "B5="B5: PRINT "B6="B6: PRINT "B7="B7: PRINT "B8="B8
2450  PRINT "QB="QB
2451  PRINT
2455  PR# 0
2500  IF  ABS (QB) > (2 * LQ) THEN  GOTO 2900
2502  PRINT "SET PR=10 FOR NO PRINT"
2505  PR# 1
2506  IF PR = 10 THEN  PR# 0
2507  PRINT
2510  GOSUB 5000
2512  PRINT "E1,E4,E3,E6 = ";E1;"  ";E4;"  ";E3;"  ";E6
2514  PRINT "E2,E5 = ";E2;"  ";E5
2516  PRINT "FS, SA, SB ="FS;"  ";SA;"  ";SB
2517  PRINT "L= "L
2518  PRINT "H1,H2 = ";H1;"  ";H2
2520 TX = TA: GOSUB 10000
2522 TA(1) = TX(1)
2524 TX = TE: GOSUB 10000
2526 TE(1) = TX(1)
2528  PRINT "TA,TE ="TA;"  "TE;"    TAC,TEC ="TA(1);"  "TE(1)
2530  PRINT "VOL="VO,"TA="TA,"ALT ="Z,"AIRSPEED="KT
2600  PRINT "U1,U2,U3,U4= ";U1;"  ";U2;"  ";U3;"  "U4
2602  PRINT "U5,U6,U7= ";U5;"  ";U6;"  ";U7
2604  PRINT "B1,B2,B3,B4="B1;"  "B2;"  "B3;"  "B4
2606  PRINT "B5,B6,B7,B8= ";B5;"  ";B6;"  ";B7;"  ";B8
2610  PRINT "IR(1)="IR(1);"   IR(2)="IR(2)
2650  PRINT "TT="TT,"TB="TB,"TG="TG: PRINT
2652 TX = TT: GOSUB 10000
2654 TT(1) = TX(1)
2656 TX = TB: GOSUB 10000
2657 TB(1) = TX(1)
2658 TX = TG: GOSUB 10000
2660 TG(1) = TX(1)
2662  PRINT "TTC="TT(1);"   TBC="TB(1);"   TGC="TG(1): PRINT
2690  PRINT : PRINT : PRINT
2691  PR# 0: PRINT "SET PR=10 FOR NO PRINT, PR=11 TO PRINT"
2692  PRINT "FOR RERUN,SET NEW VALUES,THEN GOTO 1090"
2700  END
2750  PR# 0
2751  IF PN = 1 THEN  PR# 1
2753  PRINT "QU="QU,"DT="DT
2758  IF NN = 0 THEN  GOTO 5500
2760 X2 = X1:Y2 = Y1:X1 = DT:Y1 = QU
2765 DT = Y1 * (X1 - X2) / (Y2 - Y1) + X1
```

```
2805  PRINT "NEW DT="DT
2810  PR# 0
2850  GOTO 1100
2900  PR# 0
2901  IF FN = 1 THEN  PR# 1
2910  PRINT "QB="QB,"TG="TG
2915  IF MM = 0 THEN  GOTO 5600
2920 X4 = X3:Y4 = Y3:X3 = TG:Y3 = QB
2925 TG = Y3 * (X3 - X4) / (Y4 - Y3) + X3
2955  PRINT "NEW TG="TG,"DT="DT
2960  PR# 0
3000  GOTO 1100
5000  REM ; SUB FROM 2510
5010  IF FS < 1 THEN  PRINT "NIGHT"
5011  IF FS < 1 THEN  GOTO 5070
5020  IF FS =  > 1 THEN  PRINT "DAY"
5030  IF L = .11 THEN  PRINT "USA, CLEAR"
5040  IF L = .52 THEN  PRINT "USA, CLOUDY"
5050  IF L = .36 THEN  PRINT "ARCTIC, CLEAR"
5060  IF L = .79 THEN  PRINT "ARCTIC, CLOUDY"
5070  RETURN
5500 X1 = DT:Y1 = QU:DT = DT + 1:NN = 1
5510  GOTO 2805
5600 X3 = TG:Y3 = QB:TG = TG + 1:MM = 1
5610  GOTO 2955
10000  REM  SUB CONVERTS DEGF TO DEGC
10010 TX(1) = (TX / 1.8) - 273.15
10012 TX(1) =  INT (TX(1) * 10 + 0.5) / 10
10020  RETURN
```

**** THEREQD TYPICAL OUTPUTS****

English Units
BTU/(HR-Ft^2-°R)

```
]RUPROGRAM THEREQD OF 26APR82
PROGRAM THEREQD OF 26APR82

NIGHT
E1,E4,E3,E6 = .796  .796  .773  .773
E2,E5 = .6765  .6865
FS, SA, SB =0  .19  .19
L= .11
H1,H2 = .02  .08
TA,TE =406.2  501    TAC,TEC =-47.5  5.2
VOL=3.1416       TA=406.2
ALT =65000       AIRSPEED=0
U1,U2,U3,U4= -203.247797  4.2309134  0  158.141334
U5,U6,U7= 230.514509  -197.375059  7.73433416
B1,B2,B3,B4=-237.373284  -.227523166  120.1389  158.141334
B5,B6,B7,B8= 0  197.375059  -230.514509  -7.73433416
IR(1)=31.5673624   IR(2)=55.5488737
TT=392.240091    TB=407.758929
TG=399.99951

TTC=-55.2   TBC=-46.6   TGC=-50.9


PROGRAM THEREQD OF 26APR82

DAY
USA, CLEAR
E1,E4,E3,E6 = .796  .796  .773  .773
E2,E5 = .6765  .6865
FS, SA, SB =429  .19  .19
L= .11
H1,H2 = .02  .08
TA,TE =406.2  501    TAC,TEC =-47.5  5.2
VOL=3.1416       TA=406.2
ALT =65000       AIRSPEED=0
U1,U2,U3,U4= -406.183792  -29.6745976  326.575827  158.141334
U5,U6,U7= 351.820345  -394.447326  -6.19866103
B1,B2,B3,B4=-362.28848  -21.3616739  120.1389  158.141334
B5,B6,B7,B8= 56.4283841  394.447326  -351.820345  6.19866103
IR(1)=31.5673624   IR(2)=55.5488737
TT=466.365234   TB=453.220088
TG=459.792661

TTC=-14.1   TBC=-21.4   TGC=-17.7
```

BASELINE VALUES FOR THERMAL
PARAMETRICS OF APPENDIX E

```
***PROGRAM THEREQD OF 26APR82

DAY
USA, CLEAR
E1,E4,E3,E6 = .796  .796  .773  .773
E2,E5 = .6765  .6865
FS, SA, SB =429  .19  .19
L= .11
H1,H2 = .02  .08
TA,TE =406.2  501     TAC,TEC =-47.5  5.2
VOL=2690000        TA=406.2
ALT =65000         AIRSPEED=0
U1,U2,U3,U4= -3662482.13  -267555.897  2944771.7  1425978.55
U5,U6,U7= 3171915.21  -3556656.64  -55970.7865
B1,B2,B3,B4=-3266293.02  -192525.228  1083306.24  1425978.55
B5,B6,B7,B8= 508821.213  3556656.64  -3171915.21  55970.7865
IR(1)=31.5673624   IR(2)=55.5488737
TT=466.361295   TB=453.202615
TG=459.781955

TTC=-14.1   TBC=-21.4   TGC=-17.7


PROGRAM THEREQD OF 26APR82

NIGHT
E1,E4,E3,E6 = .796  .796  .773  .773
E2,E5 = .6765  .6865
FS, SA, SB =0  .19  .19
L= .11
H1,H2 = .02  .08
TA,TE =406.2  501     TAC,TEC =-47.5  5.2
VOL=2690000        TA=406.2
ALT =65000         AIRSPEED=0
U1,U2,U3,U4= -1832174.91  38254.7488  0  1425978.55
U5,U6,U7= 2077562.16  -1779235.18  69614.6405
B1,B2,B3,B4=-2139378.36  -1964.82544  1083306.24  1425978.55
B5,B6,B7,B8= 0  1779235.18  -2077562.16  -69614.6405
IR(1)=31.5673624   IR(2)=55.5488737
TT=392.211528   TB=407.709208
TG=399.960368

TTC=-55.3   TBC=-46.6   TGC=-50.9
```

FIG. E1

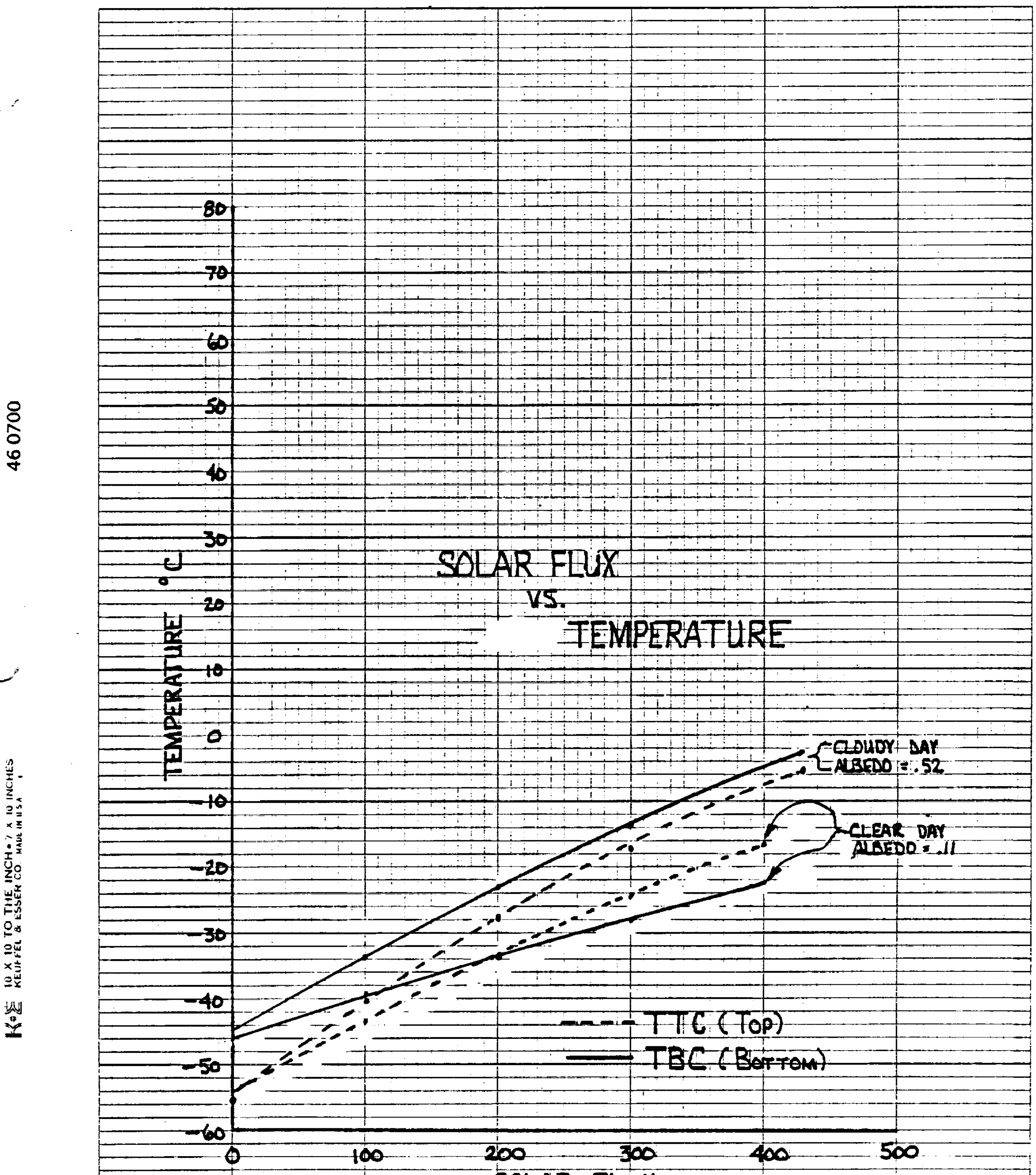
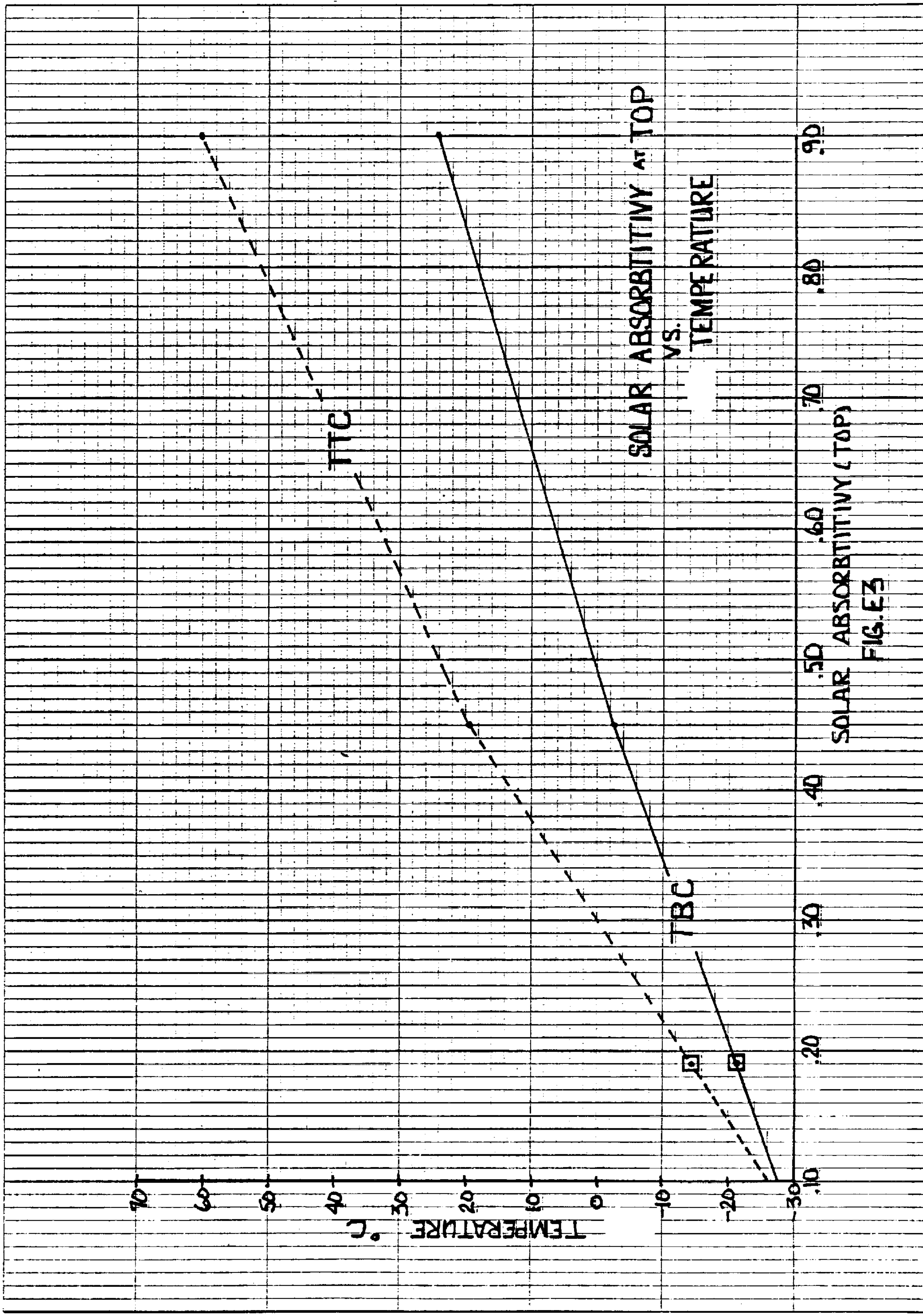

SOLAR FLUX
VS.
TEMPERATURE
TEMPERATURE °C
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
100
200
300
400
500
SOLAR FLUX
CLOUDY DAY
ALBEDO = .52
CLEAR DAY
ALBEDO = .11
TTC (Top)
TBC (Bottom)
46 0700
10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG. E2


SOLAR ABSORBTITIVY AT TOP
VS.
TEMPERATURE
TTC
TBC
TEMPERATURE °C
70
60
50
40
30
20
10
0
-10
-20
-30
.10
.20
.30
.40
.50
.60
.70
.80
.90
SOLAR ABSORBTITIVY (TOP)
FIG. E3

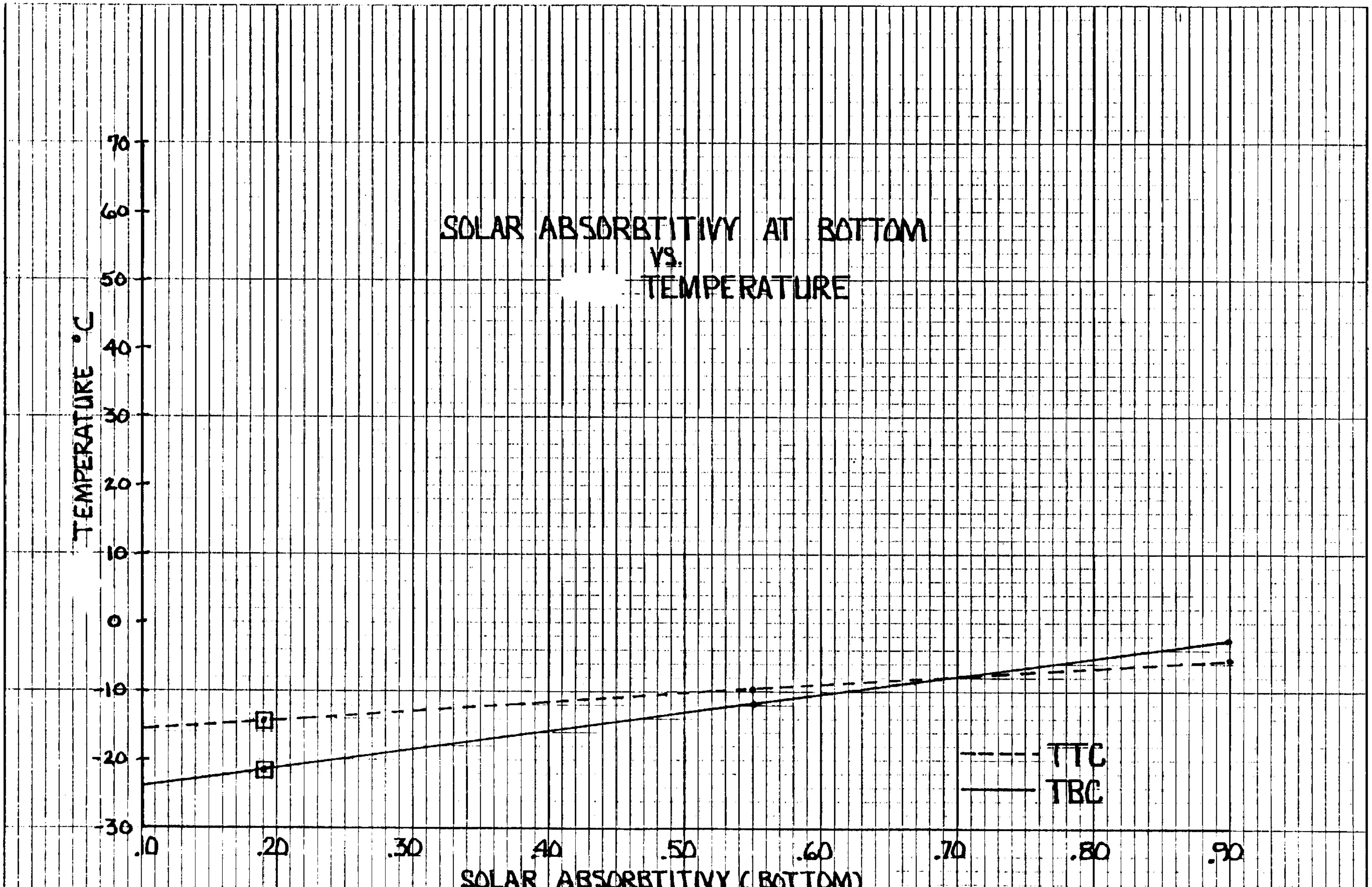
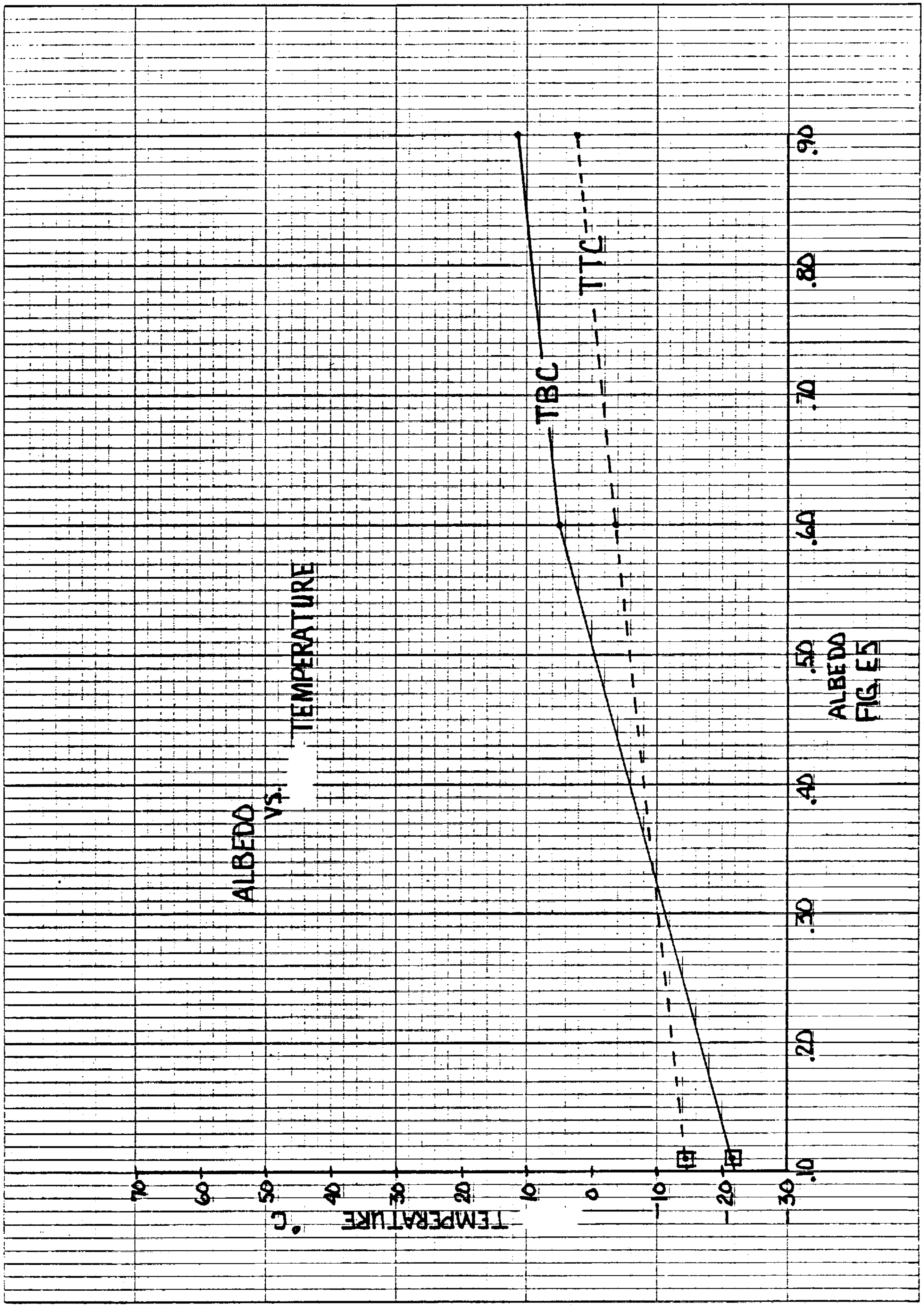

SOLAR ABSORBTITIVY AT BOTTOM
VS.
TEMPERATURE
TEMPERATURE °C
70
60
50
40
30
20
10
0
-10
-20
-30
.10
.20
.30
.40
.50
.60
.70
.80
.90
TTC
TBC
SOLAR ABSORBTITIVY (BOTTOM)

FIG. E4


ALBEDO VS. TEMPERATURE
TBC
TTC
TEMPERATURE °C
70
60
50
40
30
20
10
0
-10
-20
-30
ALBEDO
.10
.20
.30
.40
.50
.60
.70
.80
.90
FIG. E5

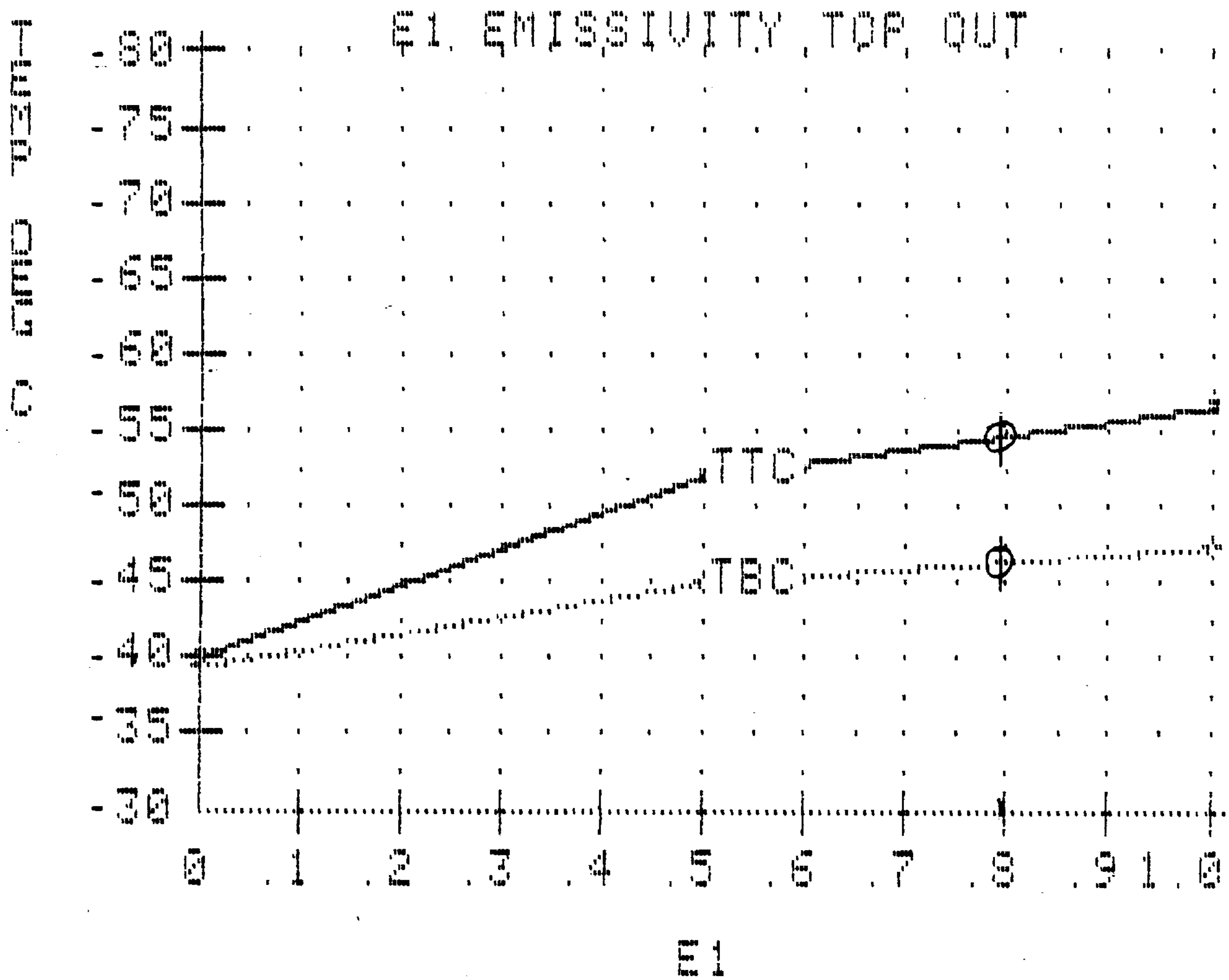

E1 EMISSIVITY TOP OUT
TEMP DEG C
80
75
70
65
60
55
50
45
40
35
30
TTC
TBC
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
E1

FIG. E6

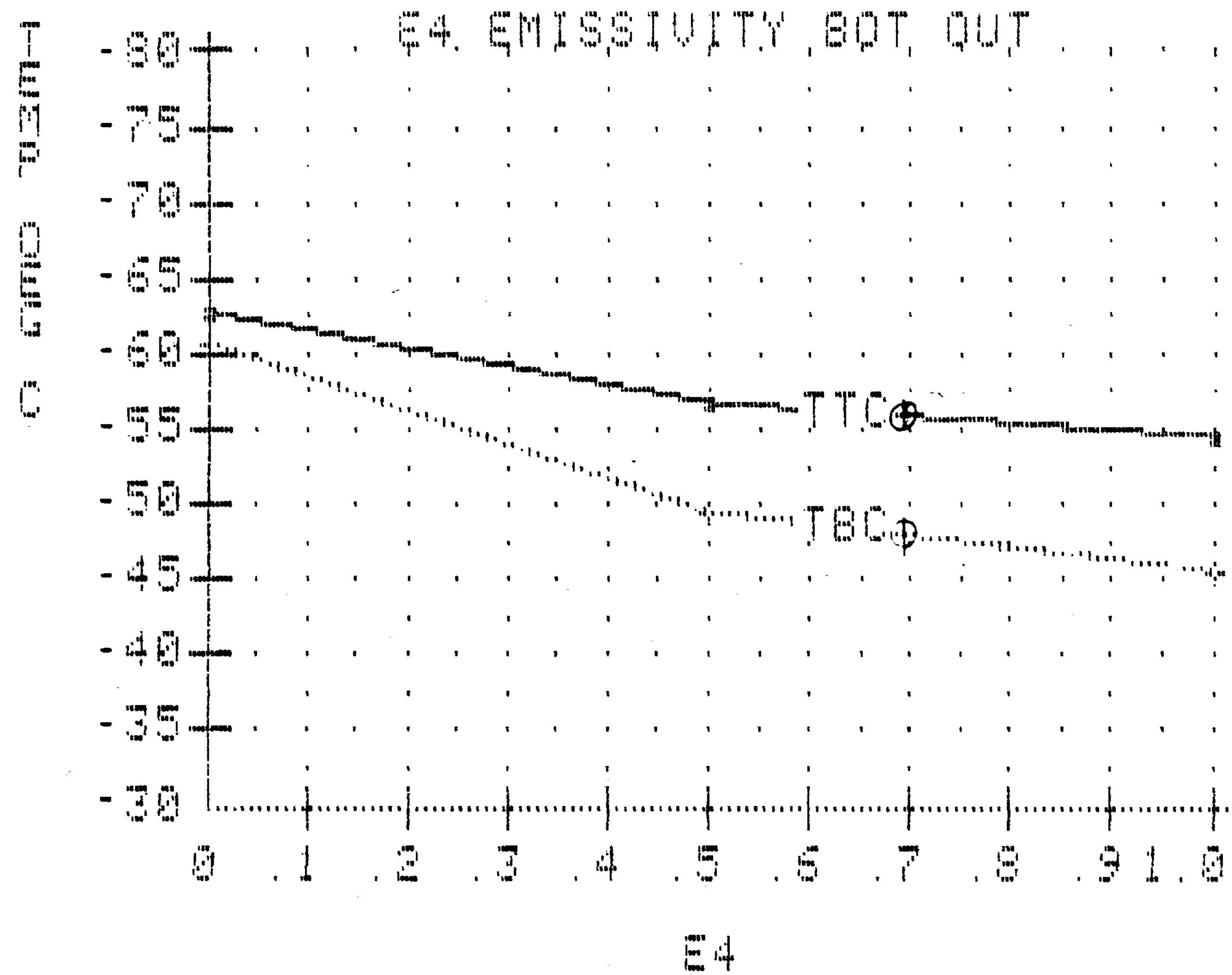

E4 EMISSIVITY BOT OUT
TEMP DEG C
80
75
70
65
60
55
50
45
40
35
30
TTC
TBC
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
E4

FIG. E7

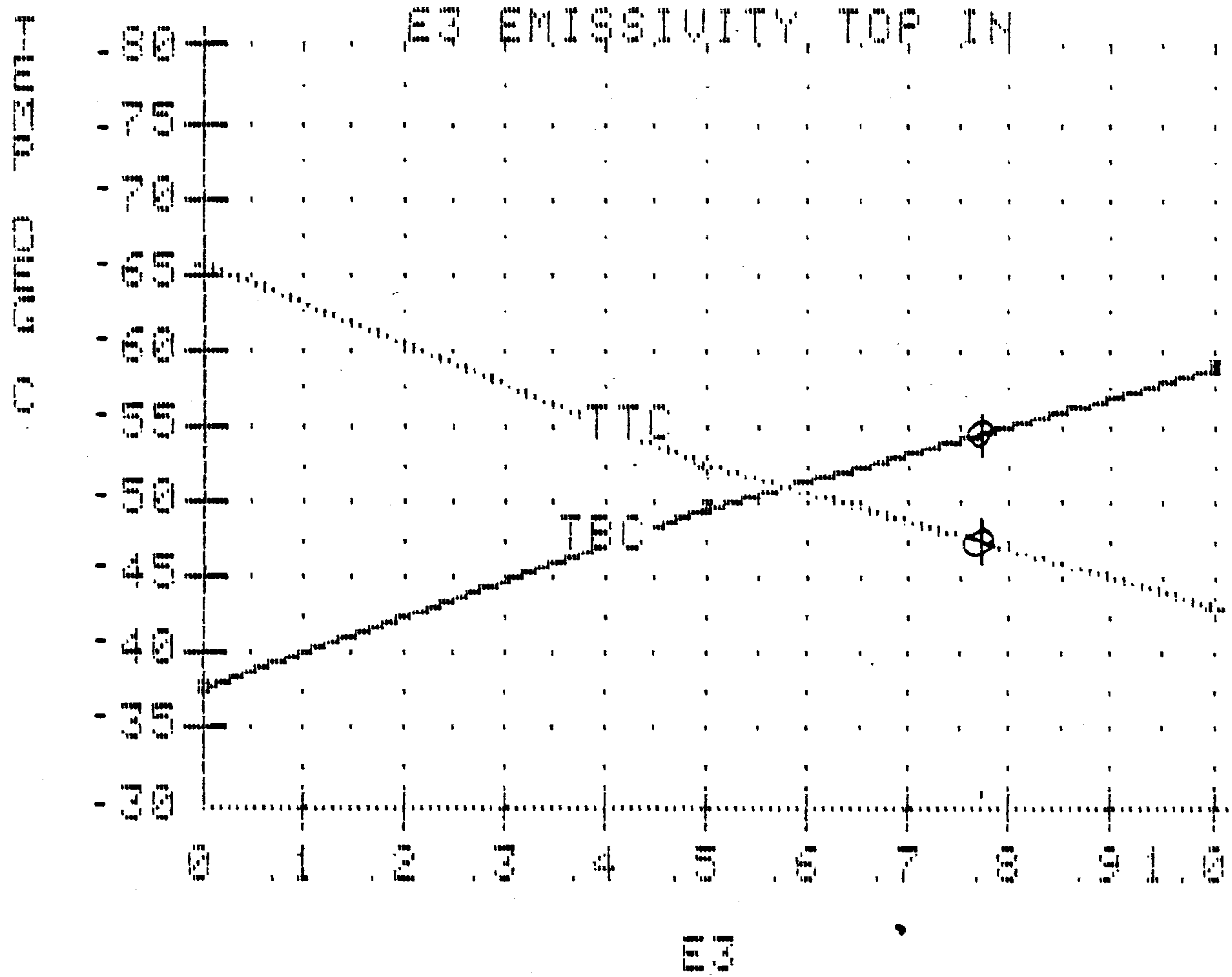

E3 EMISSIVITY, TOP IN
TEMP DEG C
80
75
70
65
60
55
50
45
40
35
30
TTC
TBC
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
E3

FIG. E8

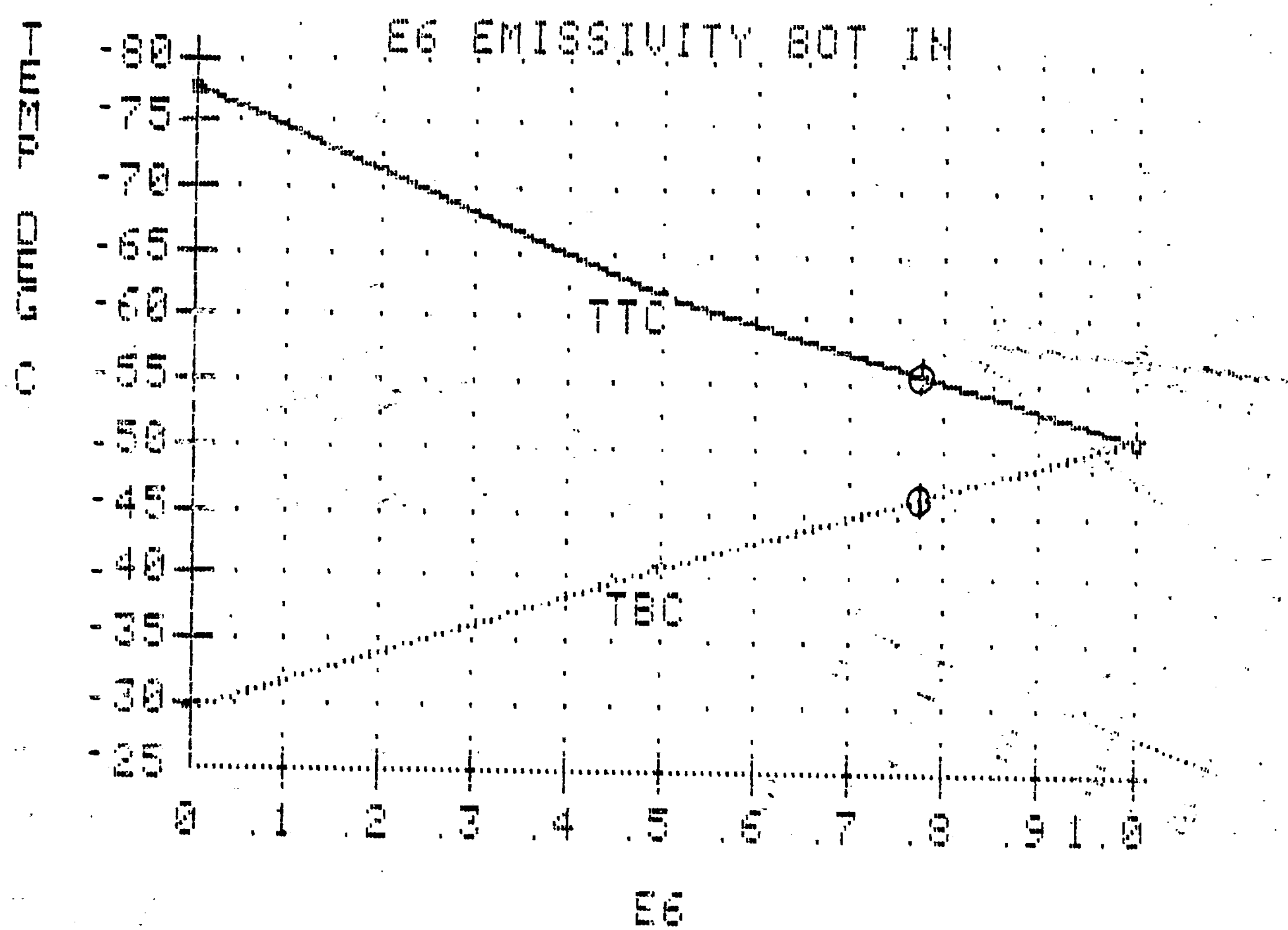

E6 EMISSIVITY BOT IN
TEMP DEG C
80
75
70
65
60
55
50
45
40
35
30
25
TTC
TBC
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
E6

FIG. E9

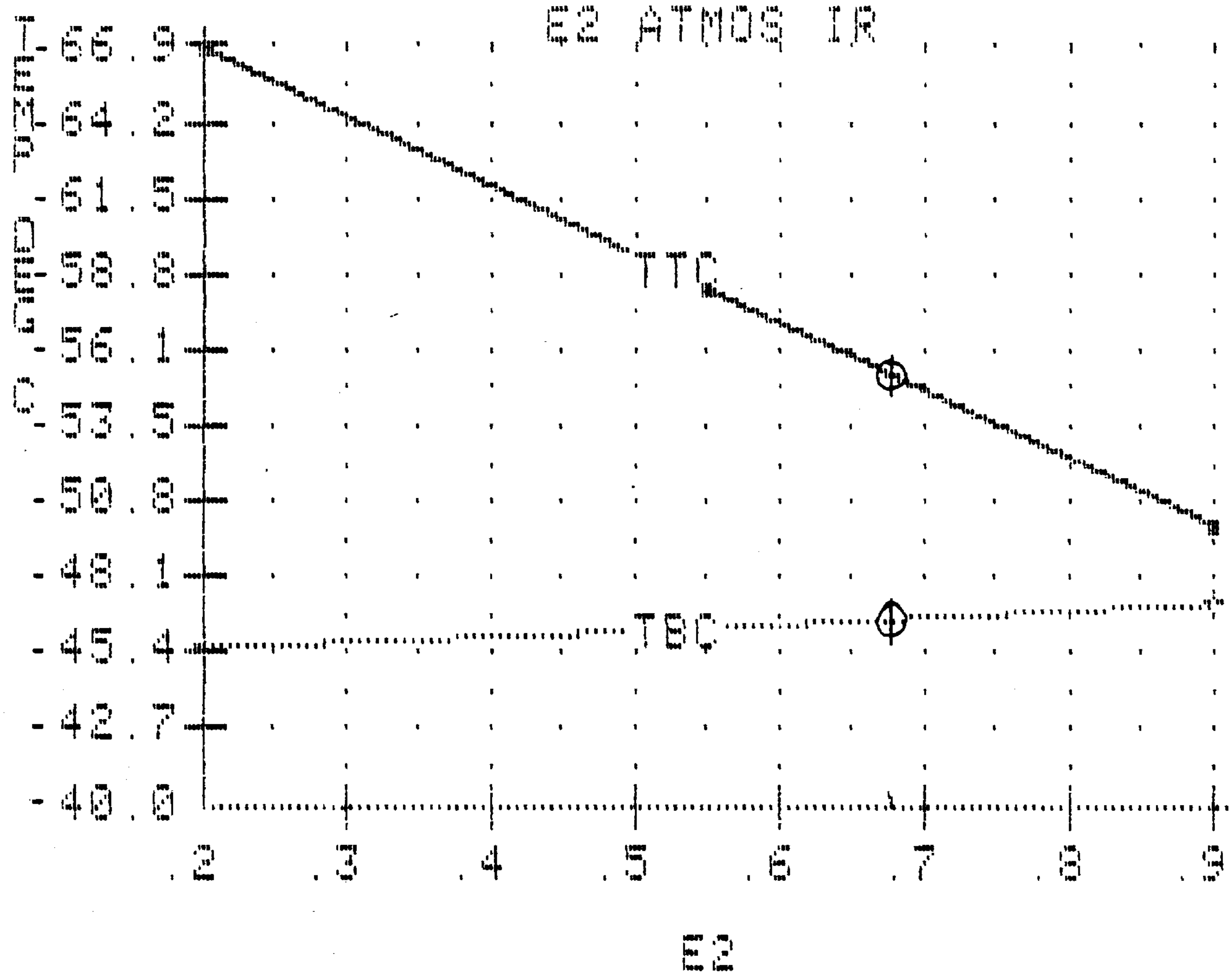

E2 ATMOS IR
T_DEG_C
66.9
64.2
61.5
58.8
56.1
53.5
50.8
48.1
45.4
42.7
40.0
TTC
TBC
.2
.3
.4
.5
.6
.7
.8
.9
E2

FIG. E10

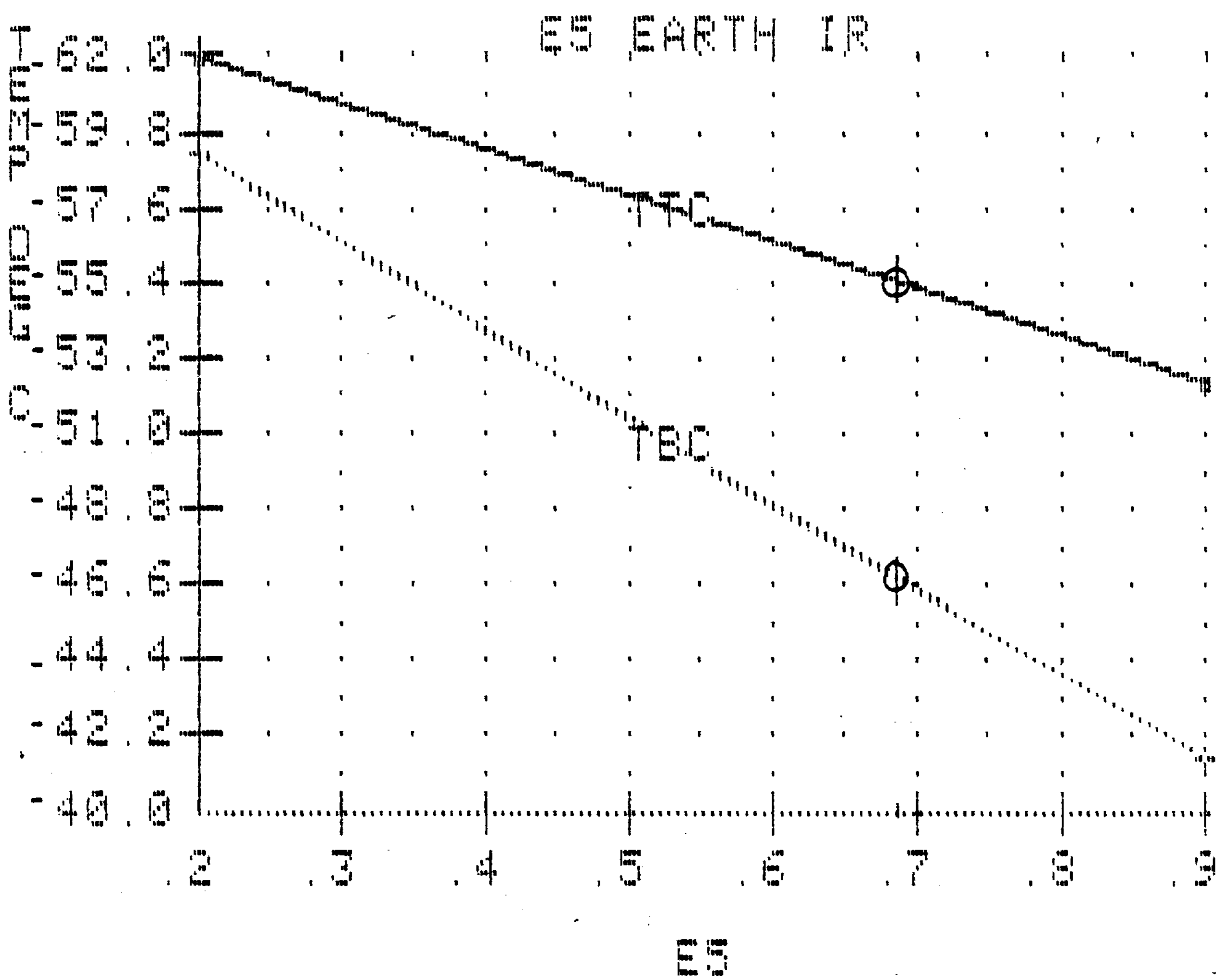

E5 EARTH IR
TEMP GEO C
62.0
59.8
57.6
55.4
53.2
51.0
48.8
46.6
44.4
42.2
40.0
TTC
TBC
.2
.3
.4
.5
.6
.7
.8
.9
E5

FIG. E11

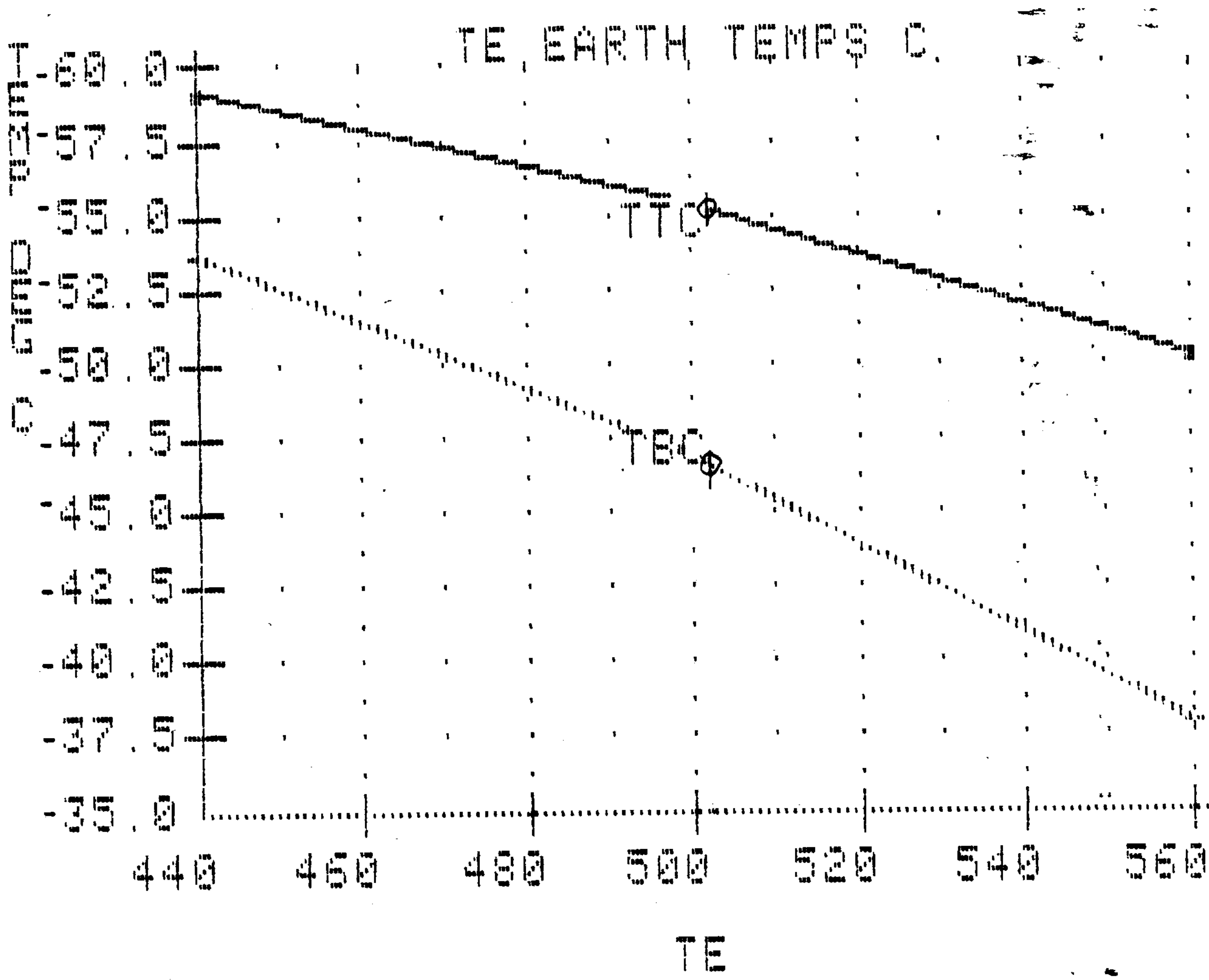

TE EARTH TEMPS C.
TEMP DEG C
-60.0
-57.5
-55.0
-52.5
-50.0
-47.5
-45.0
-42.5
-40.0
-37.5
-35.0
TTC
TBC
440
460
480
500
520
540
560
TE

FIG. E12

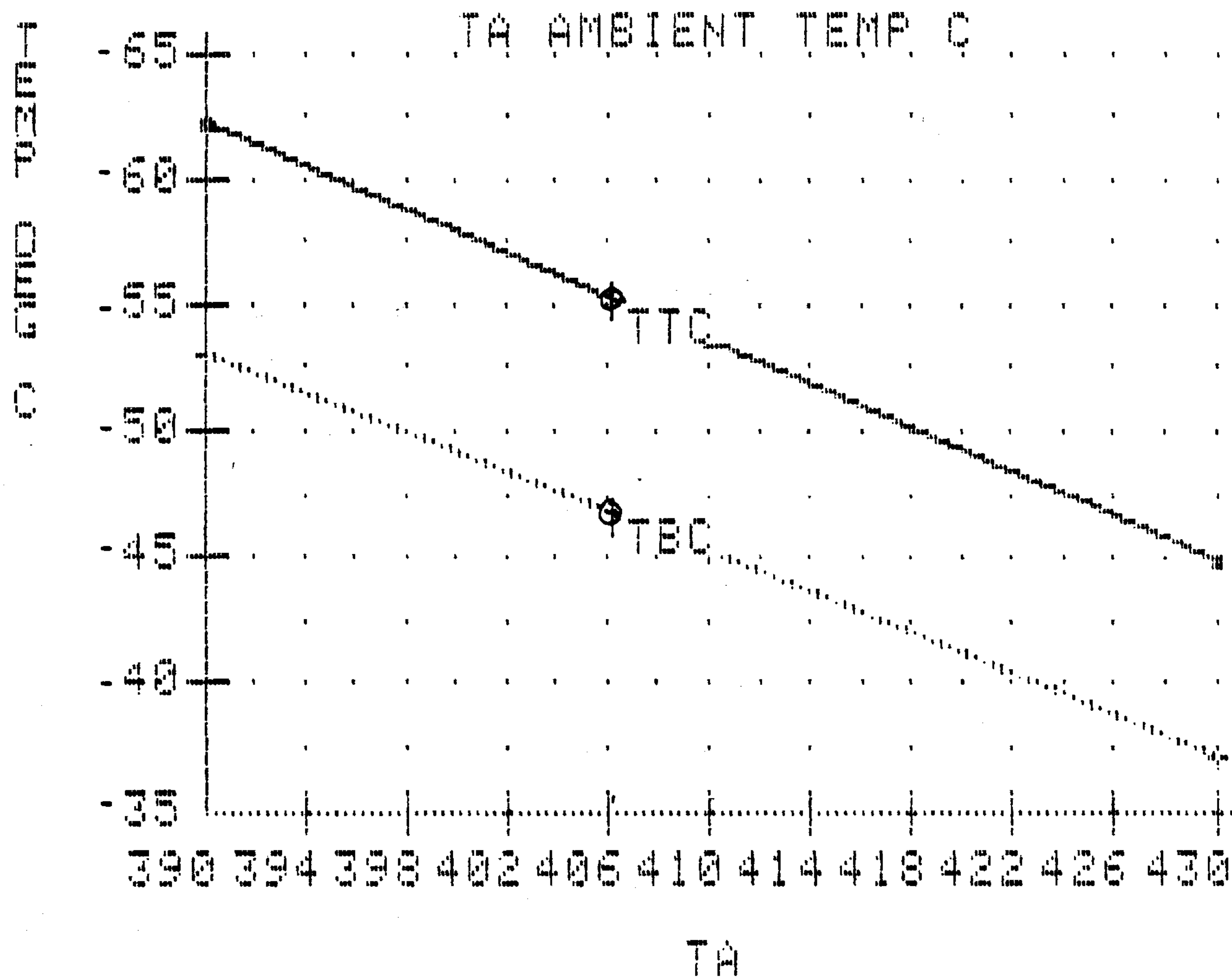

TA AMBIENT TEMP C
C GMD TEMP
-65
-60
-55
-50
-45
-40
-35
TTC
TBC
390 394 398 402 406 410 414 418 422 426 430
TA

FIG. E13

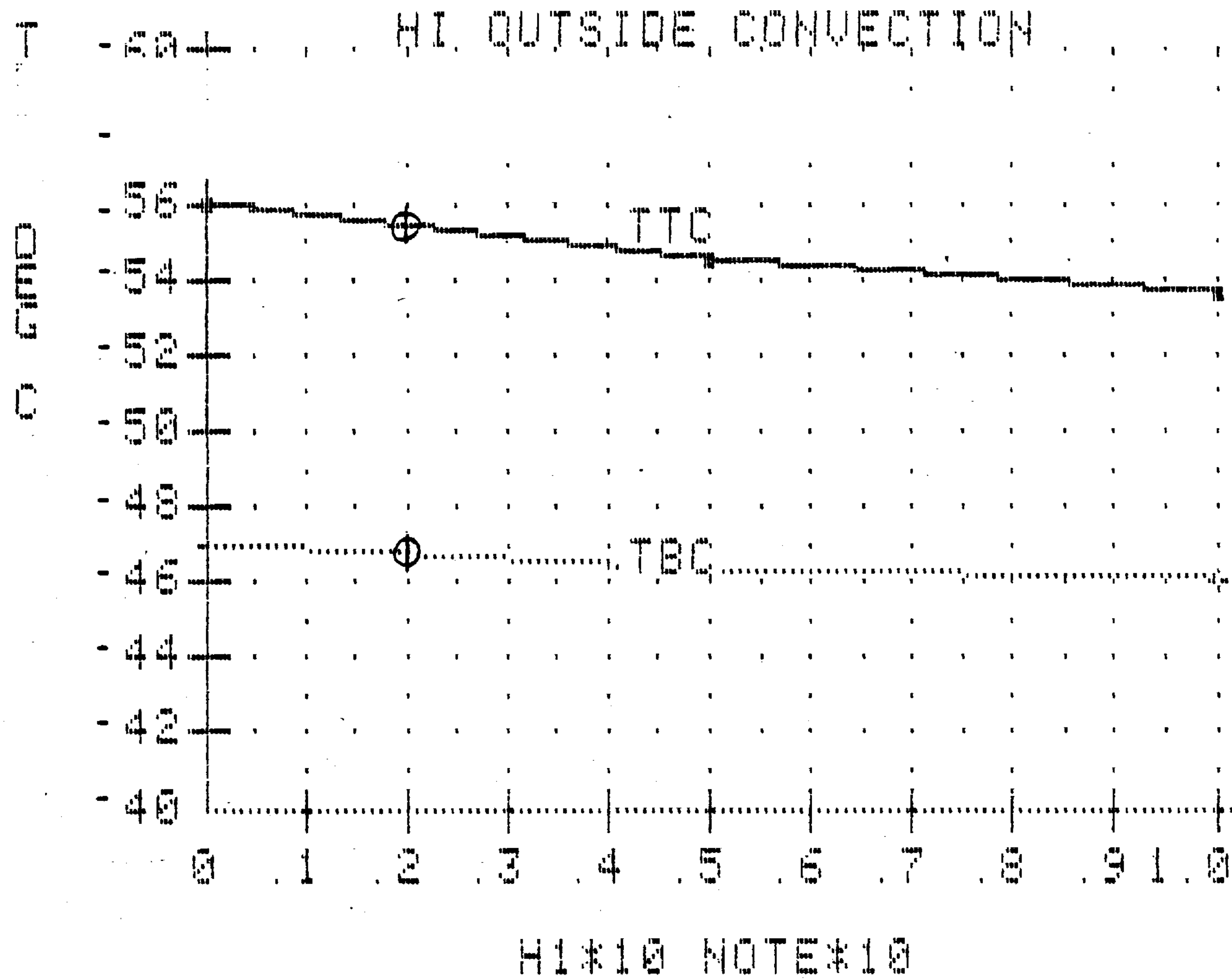

HI OUTSIDE CONVECTION
T DEG C
60
56
54
52
50
48
46
44
42
40
TTC
TBC
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
H1*10 NOTE*10

FIG. E 14

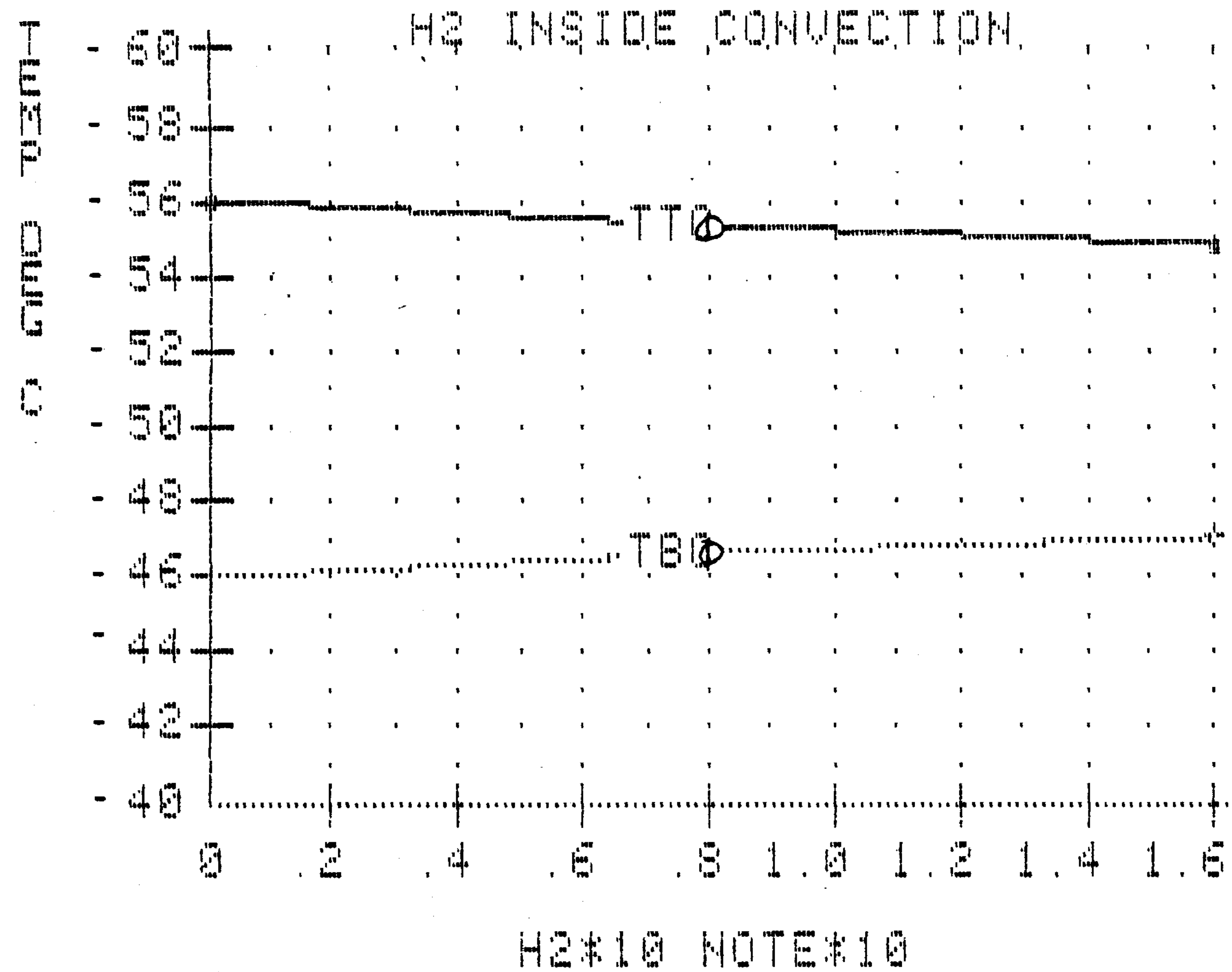
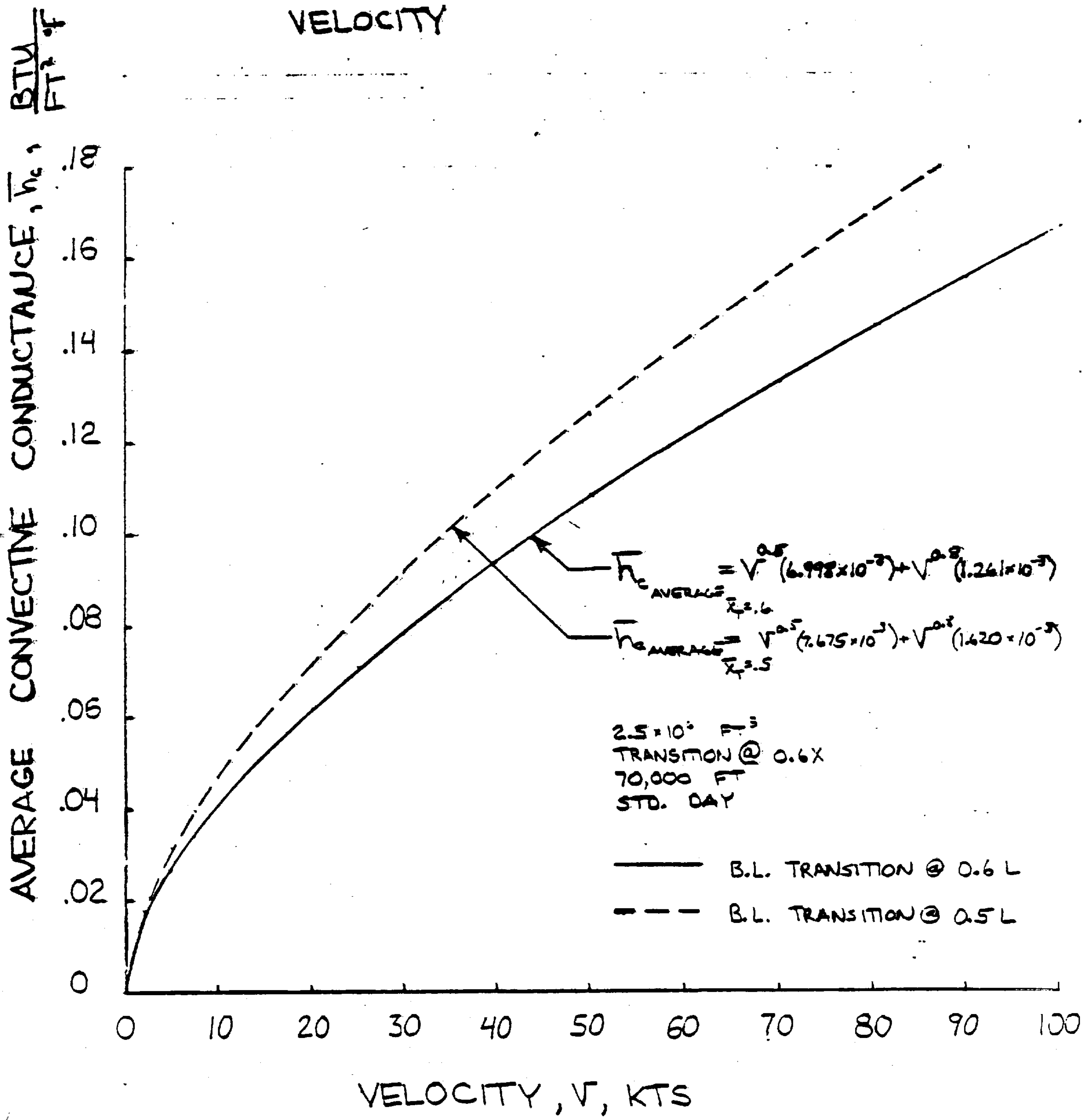

H2 INSIDE CONVECTION
TEMP C DEG
60
58
56
54
52
50
48
46
44
42
40
TT0
TB0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
H2*10 NOTE*10

FIG. E15

DOLPIN HULL AVERAGE CONVECTIVE CONDUCTANCE VARIATION WITH VELOCITY



Reference - "Principles of Heat Transfer" Krieth

FIG. E16

APPENDIX F

HULL BENDING MOMENT ANALYSIS

APPENDIX F

HULL BENDING MOMENT ANALYSIS

A primary concern with any non-rigid airship is the ability of the hull to resist buckling under bending moments. The HAPP airship requires a hull pressure of 1.64 cm. of water to maintain the ships profile under static loads, and up to 3.10 cm. of water during portions of the flight envelope where aerodynamic loads become significant.

Two routines were developed to determine the magnitude of the bending moment along the length of the ship. The first divided the airship into 20 lengthwise stations where static loads were located to calculate the static bending moments. Another method used more refined increments to calculate the aerodynamic loads due to gusts in the area of the tail. The small diameter of the tail region identifies it as the area which will need the greatest hull pressure to resist buckling. In the critical region, aerostatic and aerodynamic bending moments were summed to find the hull pressure required.

Aerostatic bending moments were found by modeling the ship as a cantilever beam held rigid at the tail. Station diameters were used to calculate lift over that region, summed against hull and ballonet fabric weights and any other operational components located there. The net force is multiplied by a moment arm equal to the length to the next station, resulting in a bending moment at the adjacent station. The moment at the third station in the sequence is equal to the sum of the forces over the first two stations, multiplied by the length between the second and third stations, and added to the moment of the preceeding station. The routine follows to the end of the ship.

Prior to finding aerodynamic loads due to gusts, a gust criteria must be determined. According to the NASA technical memorandum 78118, Terrestrial Environment (Climatic) Criteria Guidlines for Use in Aerospace Vehicle Development, 1977 Revision, above 300 m. altitude, there is a 1% risk of encountering a discrete gust with an amplitude greater than 17 kts. A thousand feet, standard atmosphere, 17 kt. discrete gust 10 kt. forward velocity will be identified as the critical case. Lower altitudes see a significantly reduced gust magnitude, and greater altitudes a reduced air density for the same 17 kt. gust.

An outline of the equations and method used to calculate aerodynamic bending moments is included at the end of this text. It was transcribed from a set of notes supplied by Bill Putman, aerodynamic consultant to ILC.

To find the aerodynamic bending moments, each section of the ship is aerodynamically approximated as a frustrum of a cone, the diameter and angle of which is determined from the profile of the hull. A discrete gust of the "1-cosine" shape is fixed along the length of the hull, corresponding to a local angle of attack for the section of the ship being analyzed. An equation referenced to Upson is used to calculate the force on the section, and from that, the bending moment applied to the ship. The force results in a moment about the centerline of the hull, and a force acting tangent to it.

The force contribution of the tail is input to the hull as a triangular distribution with the peak at the leading edge of the root. Moments, and total forces multiplied times moment arms, are summed to find the aerodynamic bending moments due to gusts at every increment of the analysis.

The final step in the aerodynamic bending moment analysis to find a combination of gust wavelength, and phase shift relative to the length of the ship, that requires the highest hull pressure. The need for this search is based on the concept of the ship passing through the gust while in flight, giving a range of phase shifts from 0^o to 360^o. In this analysis a number of wavelengths were run through the routine. Then, with the critical wavelength fixed, a peak in the phase shift curve was found by iteration.

Aerostatic and aerodynamic bending moments are summed, then compared with corresponding local diameters to calculate hull pressures required to resist buckling from the loads. Pressure is found by viewing each segment of the ship as a thin shell tube whose full circumference must remain in tension to avoid buckling. In this case, pressure is equal to twice the moment, divided by PI and the local radius to the third power.

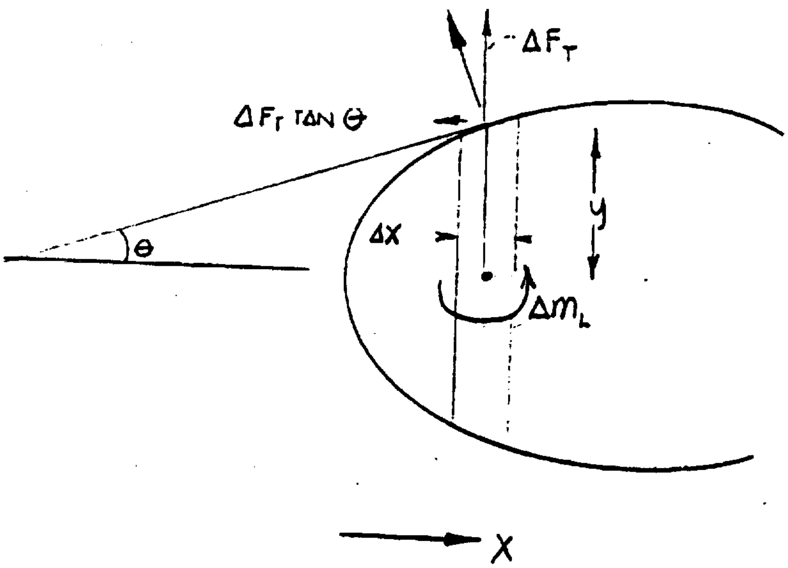
Figures 1, 2, and 3, show the calculation build-up from component locations and weights in the first, to a shear distribution in the second. The third graph shows the bending moment diagram derived from the static shear diagram added to the moments from the aerodynamic bending moment calculations.

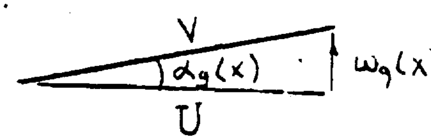
Results of the analysis are shown in Figure 4 where hull pressure required is plotted as it varies with position along the length of the ship. The graph shows a peak of 1.64 cm. of water when the ship is under the influence of static loads only. Just over 3 cm. of water is required to resist buckling when the ship encounters the critical gust criteria. In this instance, aerodynamic and aerostatic curves are summed to represent the worst case where the gust compounds the loads on the ship.

APPENDIX F

AERODYNAMIC LOADING DUE TO GUSTS

by William Putman, 1982



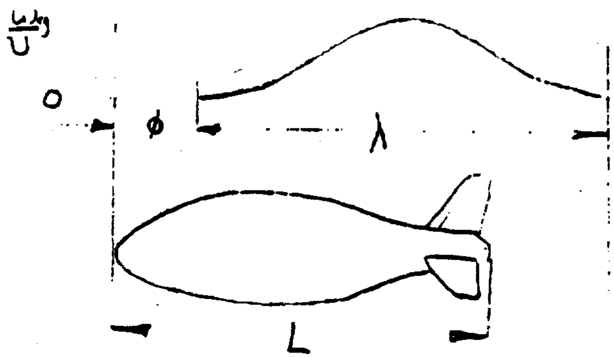


$$\frac{\Delta F_T}{\Delta x} = \left(\tfrac{1}{2}\rho v^2\right) \frac{AB}{2} \pi y \sin 2\theta \sin 2\alpha_g, \quad \frac{LB}{Ft}$$

$$\Delta M_L = -(y \Delta F_T \;\; \text{TAN}\; \Theta) \; \frac{\text{Ft. lbs}}{\text{Ft.}}$$

For the finess ratios from $3 \rightarrow \infty$, the virtual mass terms A and B are such that $\frac{AB}{2} = (1 \pm 0.01) \approx 1$. This observation, due to Upson, implies that as long as the body is relatively smooth, one can use the potential flow results in the local flow situation and the AB/2 term can be set = 1.

If we represent the gust field by a distribution:



$$\text{Then, } \alpha_g = \frac{1}{2}\frac{w_g}{U}\left[1-\cos\left(\frac{x}{\lambda}(360°)+\phi°\right)\right]$$

The bending moment distribution will be given by the integral of the shear distribution and the local applied moment, M_L, and the shear distribution given by the integral of $\Delta F_T(x)$. The computation is:

$$\text{Shear } Q(x) = \sum_{o}^{\ell} \frac{\Delta F_T(x)}{\Delta x} \Delta x$$

Where Y, θ and α_g are all functions of (x).

Similarly, the bending moment distribution will be:

$$M(x) = \sum_{o}^{\ell} [Q(x) + M_L(x)] \Delta x$$

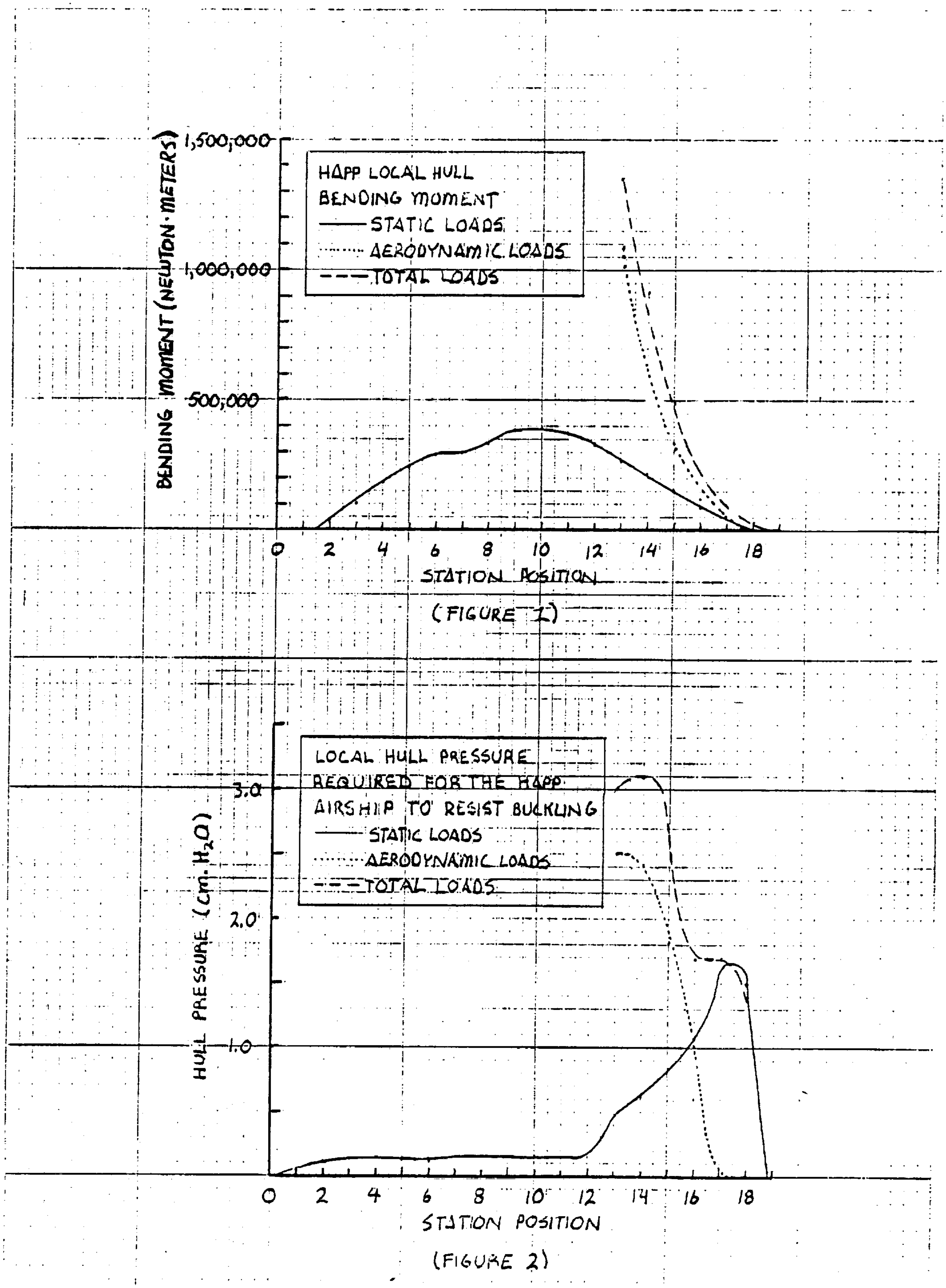
With the same functional dependence.

The resulting shear and moment diagrams will, in general, not close; ie. they will not go to zero at the tail end. The unclosed values represent untrimmed force and moment acting at and about the center of volume. After subtracting the tail force and moment contribution, any residual force and moment represent acceleration terms that will force closure of the shear and moment diagrams.

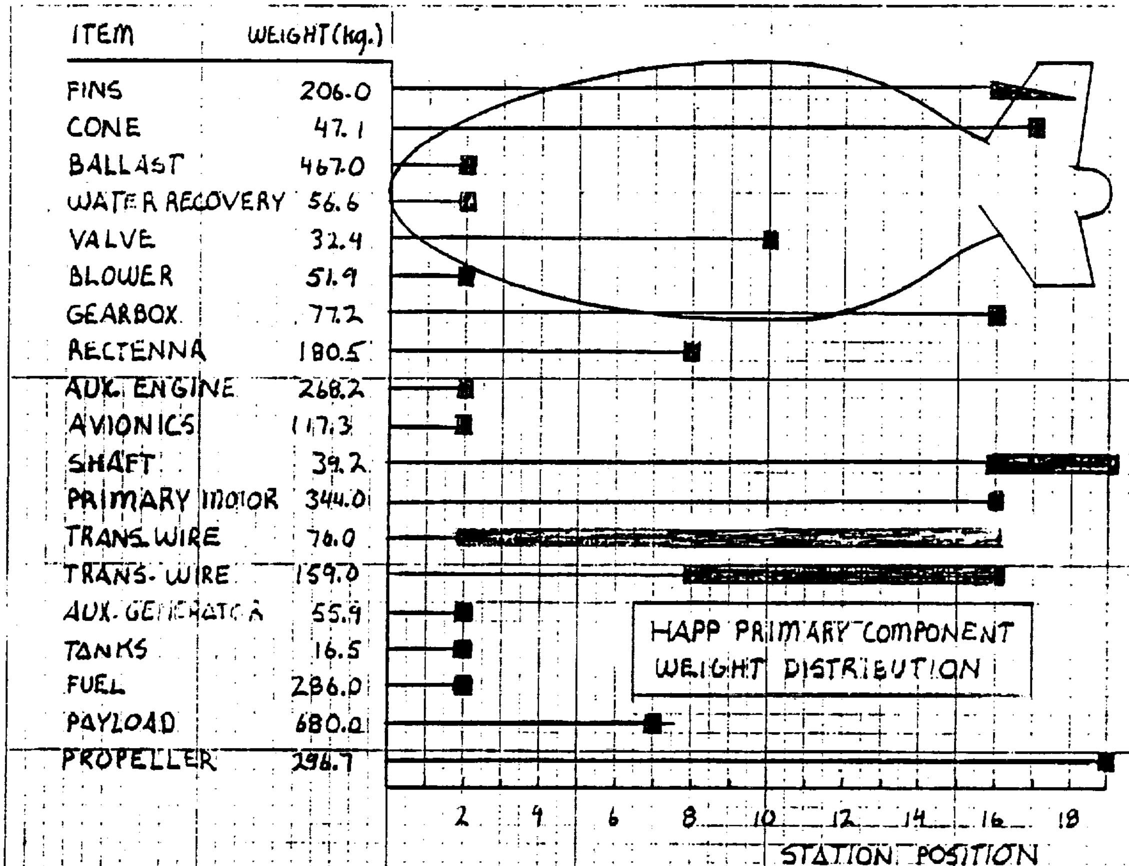
$$\frac{M_{Tail_{cg}}}{g \rho \ell^3} = -1.143 \times 10^{-3} \, ATAN \left(\frac{w_g}{U}\right)$$

$$\frac{L_{Tail}}{g \rho \ell^2} = +2.54 \times 10^{-3} \, ATAN \left(\frac{w_g}{U}\right)$$

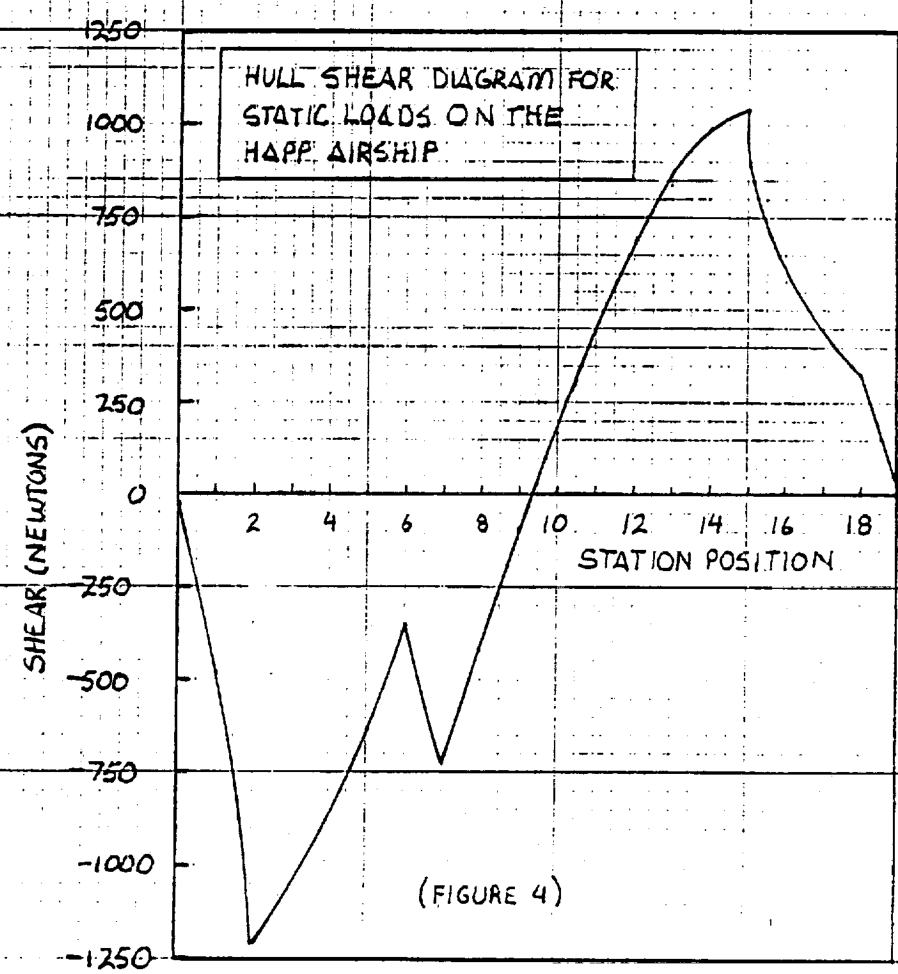
Note that the ATAN (W_g/u) has the units of degrees.



Bending Moments and Hull Pressure



(FIGURE 3)



(FIGURE 4)