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ATTACHMENT II
FOR THE FINAL REPORT

REPORT ON PHASE II

DESIGN DEFINITION OF THE PROOF-OF-CONCEPT MODEL FOR THE LTA HIGH ALTITUDE POWERED PLATFORM (HAPP)

NASA CONTRACT NO NAS 6-3131

<u>PREPARED FOR:</u>

NASA
GODDARD SPACE FLIGHT CENTER
WALLOPS SPACE FLIGHT CENTER
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PREPARED FOR:

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REPORT ON PHASE II

1.0 INTRODUCTION

This report presents results of Phase II of a 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, Goddard Space Flight Center, Wallops Island, VA.

The objective of Phase II, paraphrased from the Statement of Work, was to develop the design definition for a proof-of-concept model of the HAPP airship as conceived in Phase I. This scaled proof-of-concept model is representative of the final HAPP design of Phase I except that it is powered by a self contained power system and not by a microwave link. The proof-of-concept model, hereafter called the "Demonstrator" is designed to verify the HAPP vehicle concept as well as its operational feasibility, but will not totally address the final design mission requirements.

The design objectives for the Demonstrator are more specifically outlined in correspondence* as follows. The scale model will serve to demonstrate the major program objectives and uncertainties by demonstrating system erection, launch, ascent to some reasonable altitude (probably on the order of 50K ft), descent, and recovery. The efforts during this phase included scaling studies to determine the

*ILC Dover letter to Harvey Needleman, NASA Wallops Flight Center dated August 7, 1982.

optimum model size, and operating scenario to most accurately demonstrate full-scale vehicle objectives. Aerostat configurations, ballonet control, materials, power system specification, control systems, guidance system, launch and recovery procedures were addressed in this effort.

The model goal is maximum simulation of full scale components and characteristics.

2.0 OPERATIONAL REQUIREMENT

The operations for the demonstrator vehicle have been conceived as consisting of two flight programs. The first flight program will primarily be proof of the structural and physical handling characteristics of the ship. The flight or flights in this program will explore and develop the practical techniques for ground handling and launching as well as the ship recovery. The flight itself must go to an altitude high enough to demonstrate the practicality of the ballonet concept and the ability to physically trim and control the airship during cruise and descent for landing. In the descent phase it will be especially important to demonstrate that the mixing of air with the helium is sufficiently uniform to retain trim control. The scale model size for an adequate demonstration of these characteristics must be such that it can ascend to an altitude where density difference requires that the ballonet volume be a major portion of the ship, so that the practical aspects of the main ballonet diaphragm operating in conjunction with the helium compartment and the trim ballonets is demonstrated. The ship must also be of sufficient physical dimensions that ground handling equipment, forces, and wind effects will be representative of the problems associated with handling a large smooth-skinned airship.

The second part of the flight program will be aimed at the collection of aerodynamic and performance data for the airship. To this end, after the first flight program is completed, the ship will be instrumented for the collection of the aerodynamic and performance data.

The flight program will then provide data for verifying the analytical basis and design parameters for the ship and providing information for changes where needed. To this end the most essential parameter to be simulated in the demonstrator is the Reynolds number of the full scale HAPP vehicle in its operational environment. Further the structural features as they affect the aerodynamics and performance must be so that the operational results either verify the actual physical design, or alternately verify the analytical procedure to provide confidence in applying the procedure to the full-scale vehicle.

The demonstrator flight capabilities to meet the above requirements was established as follows:

1. Launch and recover in surface winds up to 10 knots.
2. Winds aloft profile not to exceed the Washington DC summer 84% profile (Figure 2-1).
3. Ascend at 150 meters per minute.
4. After remote-power ascent, the ship will motor back to station at 55 knots (Threshold power) air speed. It will stay on station for eight hours of daytime and nighttime maneuvering at 55 knots.
5. The ship will then motor away from station to proper position for commencing descent.
6. Descent will be powered and controlled at threshold power to arrive at the landing site.
7. Descent would be interrupted at the appropriate altitude for forty minutes of flight at maximum Reynolds number.

WASHINGTON, DC WIND SUMMER 1 + σ PROFILE

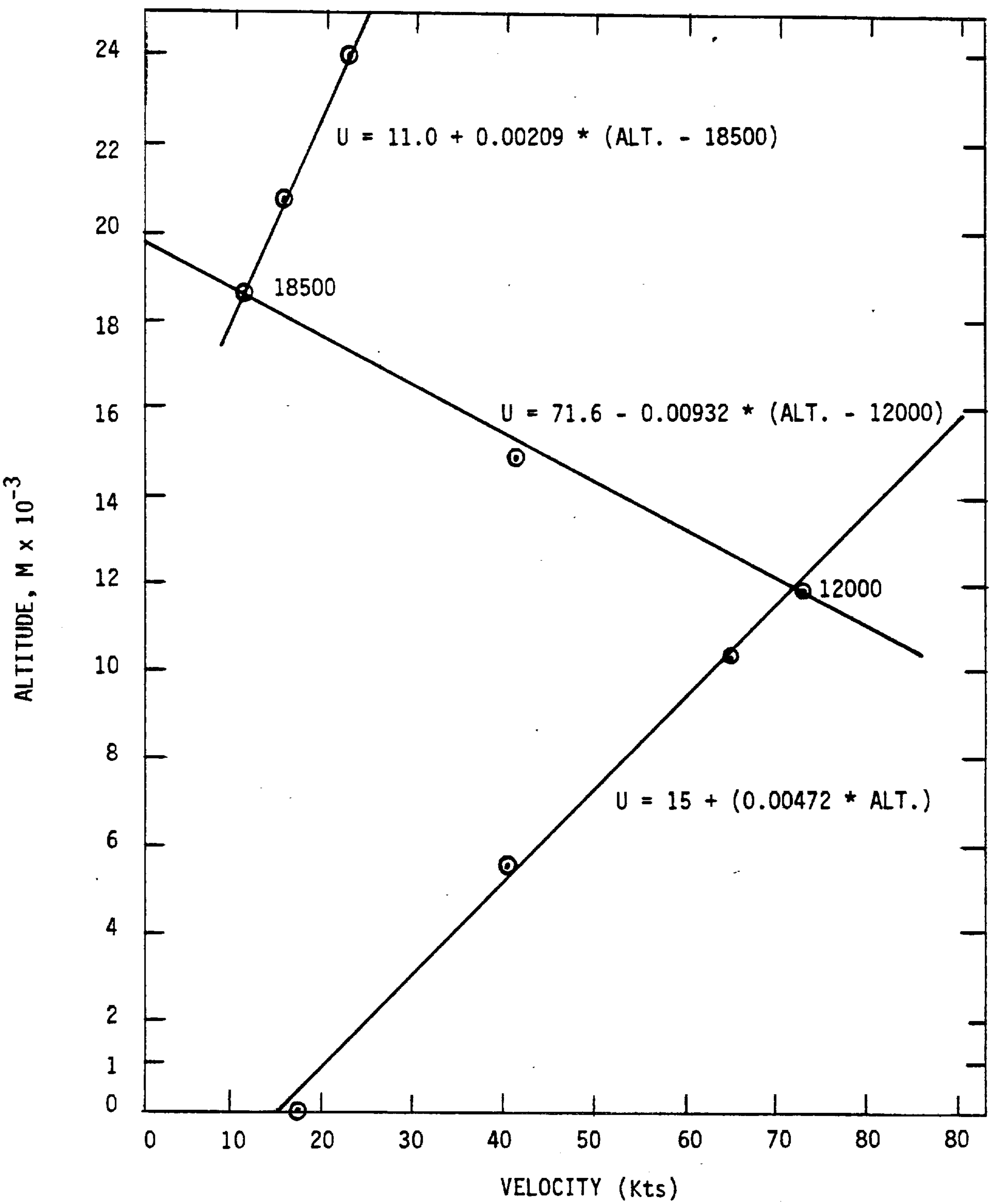

FIGURE 2-1

8. Eight hours of fuel at threshold power for landing would be provided.

9. Four hours reserve fuel at maximum power would be provided.

The maximum Reynolds number to be duplicated is 36.9 million. This is the Reynolds number for the full scale HAPP vehicle, length 123.3 M at 20 km and 93 Kts.

3.0 SYSTEM SELECTION

3.1 SCALING STUDY

The HAPP parametric computer program as reported in Phase I was adapted for the HAPP demonstrator scaling studies. Changes were made to comply with the flight profile outlined in section 2, above, and to include Reynold's number evaluations. A copy of the program is included in Appendix A. A list of input data is given in Table 3-1 and a sample data printout from the program is given in Table 3-2.

With the use of this program, the chart of Figure 3-1 was developed to facilitate the decision with regard to demonstrator size and operating altitude. A basic assumption for this study was the engine power of 56 kilowatts as discussed in Section 4.1.2 Propulsion Systems. With reference to Figure 3-1, a calculation of demonstrator size and performance parameters with the 56 kilowatt power plant was made for each altitude from 13 to 21 kilometers altitude. The airship volume for each altitude along with the airship airspeed at maximum power and the 84 percentile wind velocity is shown for each altitude. The downward pointing arrow from the balloon at each altitude terminates at the altitude to which the airship must descend in order to duplicate the maximum Reynold's number of 36.9 million which the full scale HAPP may achieve. At the termination of each of these arrows the airship velocity at full power is listed, which also corresponds to the 36.9M maximum Reynold's number for the full scale HAPP. Under it is listed the sea level air speed that is achievable with this power for purposes of landing maneuvers.

TABLE 3-1

INPUTS TO HAPP DEMO 26 OCT 82 COMPUTER PROGRAM

SYMBOL	ITEM	INPUT
P(), TE(), R() E(1) E(2)	AMBIENT PRESSURE TEMPERATURE DENSITY EFFICIENCY, PROPELLER, E(1) EFFICIENCY, GEARBOX, E(3)	U.S. STANDARD ATMOSPHERE 1962 0.90 0.95
WC(1) WC(2) WC(3) WC(4) WC(7)	WEIGHT COEFFICIENT, PROPELLER WEIGHT COEFFICIENT, SHAFT WEIGHT COEFFICIENT, GEARBOX PRIMARY ENGINE (RECIP) GENERATOR	2.1 Kg/Kw 0.0119 Kg/Kw M) 0.43 Kg/Kw 4.2 Kg/Kw 1.1 Kg/Kw
UK(1) U(ZT) RA RH	AIRSPEED, THRESHOLD WINDS ALOFT R-AIR R-HELIUM	55 Kt WASH. D.C. SUMMER 84% PROFILE 287.053 J(KG °R) 2077.23 J(KG °R)
CP CP(1)	DYNAMIC LIFT FACTOR DYNAMIC LIFT FACTOR	1.2 1.0
SH SC	SUPERHEAT SUPERCOOL	16.7 °K -17.2 °K
VO DC CD	AIRSHIP VOLUME DESCENT DRAG COEFFICIENT CRUISE DRAG COEFFICIENT, SOFT FINS HARD FINS	10550 M^3 0.028 0.018 0.016
RD RC ALT PUR	RATE OF DESCENT RATE OF CLIMB CRUISE ALTITUDE HELIUM PURITY	150 m/min 150 m/min 15000 M 0.95
LH(1) LH(2)	FUEL UNIT WEIGHT FUEL TANK AND SUPPORT UNIT WEIGHT	0.19 Kg/KwHr 0.022 Kg/KwHr
K(9) K(8) K1(4)	PAYLOAD POWER REQUIREMENT AVIONICS POWER REQUIREMENT PRIMARY ENGINE POWER OUT	1.0 Kw 1.13 Kw 56 Kw
B(9) B(9) B(13)	PAYLOAD WEIGHT AVIONICS WEIGHT BALLAST WEIGHT	100 Kg 117.3 Kg ENGINE WEIGHT
FS	SAFETY FACTOR, TEXTILE STRUCTURES	5

TABLE 3-1 (cont)

INPUTS TO HAPP DEMO 26 OCT 82 COMPUTER PROGRAM

SYMBOL	ITEM	INPUT
MHW	HULL FABRIC MINIMUM UNIT WEIGHT	0.11867 Kg/M^2
FFW	FIN FABRIC UNIT WEIGHT	0.11867 Kg/M^2
RFW	RIB FABRIC UNIT WEIGHT	0.07 Kg/M^2
BFW	BALLONET FABRIC UNIT WEIGHT	0.085 Kg/M^2
T(4)	TRIM BALLONETS VOLUME AS PORPORTION OF AIRSHIP VOLUME	0.05
BV(1)	BALLONET VOLUME AT MAXIMUM SUPER-HEAT	0
SL	SHAFT LENGTH	10 M

TABLE 3-2

```
                                   HHPPDEMO 26OCT82 BASELINE
DOLPHIN SOFT FINS      23AUG82
```

VOL M13	ALT KM	THRSH. KW	LIMIT KW	PROP KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
10550	15	23.290	56	45.963	692.00 48%	498.00 35%	149.00 9%	100	235.2

```
SUPER HEAT = 16.7 K                 SUPERCOOL = -17.2 K
CD = .018                           PROP CD = .0187681845
SAFTEY FACTOR = 5                   DAY PRESS (CM H2O) = 12.273
UNIT FAB WT=.11867 KG/M2            NITE PRESS= 2.5
---WEIGHTS KGS:---
               ENVELOPE WT
TAPE WT = 27.1205152                HULL = 339.00644
FIN SYS = 55.1271831                BALONT SYS = 206.590892
CONE WT = 47                        BLOWER = 13.9036066
VALVE WT = 3.22350151
               POWER SYSTEM WT
PROPELLER = 96.5223                 SHAFT = 6.3308
GEAR BOX = 22.876                   PRIME MOTOR = 235.2
RECTENNA = 0                        TRANS. WIRE = 0
AUXE ENG = 0                        GENNERATOR = 2.343
AVIONICS = 117.3                    TANKS = 17.3103388
                                    WATER RECOVERY=0

RECTENNA AREA =0                    ANGLE OF INCIDENCE LIMIT=0
MICROWAVE BEAM KW/M2= 0
LIFT = 1674.48424 KGS             WEIGHT = 1674.55296 KGS
        VELOCITIES, KTS
LIMIT=73.3835826   THRESHOLD=55
AUX DESIGN=0       CUBE AVE>THRES=0
VOLUME=10550 M3.    DIAMETER =19.43 M    LENGTH WITH 5% CUT=63.33 M
DEMONSTRATOR VOLUME= 10550 CUBIC METERS ----> = 372569 CUBIC FEET


                  * * * * * * * * * * * * * * *
CALC LIMIT SPEED AT OTHER ALT, SAME PWR
VD=10550  ALT,KM=15    ENG KW=56    PROP KW=45.963
ALT, KM=12    U, KTS=62.7      RN/E6=52.5
ALT, KM=13    U, KTS=66.1      RN/E6=44.8
ALT, KM=14    U, KTS=69.6      RN/E6=38.3
ALT, KM=15    U, KTS=73.4      RN/E6=32.8 <---DESIGN
ALT, KM=16    U, KTS=77.3      RN/E6=28
ALT, KM=17    U, KTS=81.5      RN/E6=23.9
                  * * * * * ASCENT PROFILE * * * * *
POWER OFF ASCENT AT 150 M/MIN; WINDS WASHDC SUMMER 84%
TIME TO CLIMB TO 15 KM=1.66666667
BLOWOFF DISTANCE =145.492994 KM.
TIME TO AUXBACK TO STATION =6.91549296HRS, AT THRESHOLD SPD
FUEL USED ASCENT AND AUXBACK =30.602088 KG
                  * * * * * ON-STATION PROFILE * * * * *
STATION WIND =43.64 KTS
SHIP SPEED ON THRESHOLD POWER=55 KNOTS:LIMITING VEL = 73.3835826KTS
FOR 4HRS RESERVE + 4HRS MANEUVERING @ LIMIT 73.4 KTS STATION FUEL WT = 85.12
         * * * * * DSCENT PROFILE,  AUXAWAY AND DSCENT AT THRESHOLD * * * * *
POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 15 KM=1.66666667 HRS
FUEL FOR DESCENT = 7.37524863 KGS
AUXAWAY AT ALT TIME AND DISTANCE = 1.48332981 HRS AND -31.2073336 KM
FUEL FOR AUXAWAY = 6.5639557 KGS
FUEL FOR BLOWER = 2.13649184 KGS
FUEL FOR LANDING 4HR AT THRESHOLD PWR(SL 29.8KT)=17.7005967 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 33.7762929 KG
                  * * * * * SUMMARY * * * * *
TOTAL FUEL WT FOR MISSION = 149.498381
```

With the use of this program the chart of Figure 3-1 was developed to facilitate the decision with regard to demonstrator size and operating altitude. A basic assumption for this study was the engine power of 56 kilowatts as discussed in section 4.1.2 Propulsion Systems. With reference to Figure 3-1, a calculation of demonstrator size and performance parameters with the 56 kilowatt power plant was made for each altitude from 13 to 21 kilometers altitude. The airship volume for each altitude along with the airship airspeed at max power and the 84 percentile wind velocity is shown for each altitude. The downward pointing arrow from the balloon at each altitude terminates at the altitude to which the airship must descend in order to duplicate the maximum Reynold's number of 36.9 million which the full scale HAPP may achieve. At the termination of each of these arrows the airship velocity at full power is listed which also corresponds to the 36.9M maximum Reynold's number for the full scale HAPP. Under it is listed the sea level air speed that is achievable with this power for purposes of landing maneuvers.

Ballonet air volume at sea level is a function of the altitude to which the ship will ascend. It is 78% of the total ship volume for a design altitude of 13km and increased to 93% for flight at 20 km where the full-scale HAPP will fly. It is considered that any flight design altitude from 13 to 20 Km sets a major portion of the airship into ballonet volume and would adequately demonstrate the ballonet concept.

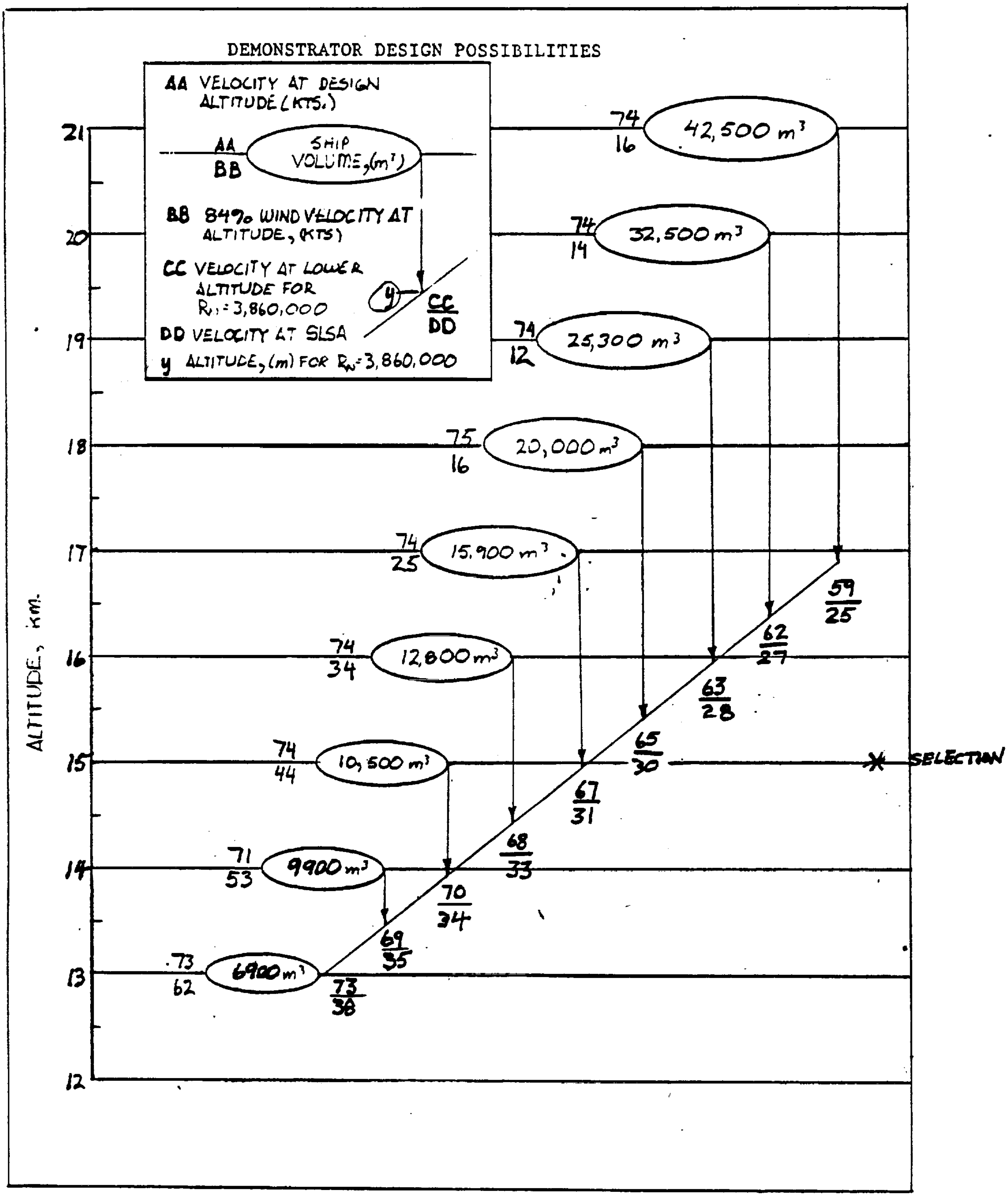
DEMONSTRATOR DESIGN POSSIBILITIES
AA VELOCITY AT DESIGN ALTITUDE (KTS.)
SHIP VOLUME, (m³)
BB 84% WIND VELOCITY AT ALTITUDE, (KTS)
CC VELOCITY AT LOWER ALTITUDE FOR Rₙ = 3,860,000
DD VELOCITY AT SLSA
y ALTITUDE, (m) FOR Rₙ = 3,860,000
ALTITUDE, km.
42,500 m³
32,500 m³
25,300 m³
20,000 m³
15,900 m³
12,800 m³
10,500 m³
9900 m³
6900 m³
SELECTION

FIGURE 3-1

Ballonet air volume at sea level is a function of the altitude to which the ship will ascend. It is 78% of the total ship volume for a design altitude of 13 km and increased to 93% for flight at 20 km where the full-scale HAPP will fly. It is considered that any flight design altitude from 13 to 20 km sets a major portion of the airship into ballonet volume and would adequately demonstrate the ballonet concept.

The probability of atmospheric turbulence and/or high winds is an important consideration for selection of the demonstrator flight altitude. The wind must be low enough at cruise altitude to permit execution of a maneuvering test program without being blown far off station, and the atmosphere must be non-turbulent to avoid disturbance to laminar flow tests. For these reasons 15 km appears as a minimum demonstrator design altitude. The higher altitudes require increased volumes and vehicle manufacturing costs. In consideration of these factors, an altitude of 15 kilometers, which is safely above the tropopause, has been selected for the demonstrator design altitude. This results in a ship of 10,500 cubic meters which with 56 kilowatts of power will fly at 74 knots at 15 km altitude where the 84 percentile wind is 44 knots. To duplicate the 36.8 million Reynold's number, the ship would descend to 14 kilometers where it could fly at 70 knots. On descent to sea level, it could maneuver at 34 knots for its landing operations. Table 3-2 presents the detailed computer printout for this configuration.

3.2 WEIGHT AND BALANCE STUDY

As in the Phase I airship concept, the stern propulsion does penalize the system with undesirable weight in the tail area requiring careful disposition of other weights as far forward as possible, and also the addition of ballast forward to give a balanced situation. In the demonstrator, the fuel is placed at the center of buoyancy in order to avoid the complication of a water recovery system (as required for the full scale HAPP). The disposition of weights in the demonstrator is presented in Table 3-3. In order to achieve the balanced condition, two rather drastic steps were taken. One is foreshortening of the tail from the idealized dolphin shape by 5% and secondly, placing the engine 10m forward of the propeller.

Similar measures were also taken on the full-scale HAPP so the demonstrator will in this respect simulate the full-scale vehicle and possible problems that may attend these measures.

TABLE 3-3

HAPP DEMONSTRATOR WEIGHT & BALANCE

REF: DISK "HAPP DEMOWTB 22 OCT 82" AND DRAWING SK 82-1537

CENTER OF BUOYANCY AT 30.53 m FROM NOSE ON CENTERLINE

CENTER OF GRAVITY LOCATION

LONGITUDINAL, 30.56 m FROM NOSE
VERTICAL, BELOW CENTERLINE
AT LAUNCH 2.08 m
CRUISE 3.38 m
LANDING 2.36 m

WEIGHT DISTRIBUTION

NO.	ITEM	LONGITUDINAL		VERTICAL	
		WEIGHT, KG	STATION, M	WEIGHT, KG	BELOW CL
0	BLOWER	13.9	52.5	13.9	0
1	PROPELLER	96.52	62.3	96.5	0
2	SHAFT	6.33	58.14	6.3	0
3	GEARBOX	22.88	53.1	22.9	0
4	PRI MOTOR	235.2	52.5	235.2	0
5	RECTENNA	0	0	0	-
6	AUX ENGINE	0	0	0	-
7	GENERATOR	2.34	52.5	2.34	0
8	AVIONICS	117.3	6	117.3	-7
9	PAYLOAD	100	6	100	-7
10	WIRE	0	0	0	-
11	CONE RINGS	47	52	47	0
12	H2O RECOVERY	0	0	0	-
13	BALLAST	235.2	6	235.2	-7
14	FINS	55.1	55.9		
15	FUEL	149	30.5	149	-11.5
16	TANKS&STR	17.2	30.5	17.3	-11.5
17	HULL&BALS	572.7	29.62		
18	VALVES	3.2	30.53	3.2	0
19	0	0	0	0	
20	CENTER OF BUOYANCY	1673.9	30.53	1673.9	0
21	HE CEMPT.			58.3	+8.5
22	2 TRIM BALLONETS			26.8	+4.5
23	MAIN BAL-LONET DISC			121	+8 to -10
24	HULL&TAPES			365.5	0
25	TOP FIN			18.3	+7.5
26	2 LOWER FINS			36.7	-3.5

4.0 SYSTEM DESCRIPTION

The demonstrator is a one-half linear scale model (.52 to be exact) of the full-scale HAPP. The shape is proportioned down in a linear fashion and in-so-far as possible, the components simulate the full-scale vehicle. The airship assembly is illustrated in ILC drawing SK82-1537 (Enclosure 2-1).

4.1 SUB-SYSTEMS

For discussion purposes, the ship is divided into the following sub-systems: hull structure, propulsion system, gas pressure system, electrical system, flight control system, guidance and information system, and payload.

4.1.1 Hull Structure

Hull structure consists of the basic envelope of fabric and seams, the fins, the main ballonet, the trim ballonets, the helium compartment and the tail compartment. The structure and materials of all of these hull components duplicates (except for size) that of the full-scale ship. The envelope skin material is specifically the lightest weight hull fabric that is specified for the full-scale ship in the Phase I report Section 8.2.

4.1.2 Propulsion System

The Propulsion System consists of the engine, drive shaft, propeller hub and the propeller. The main propulsion engine for the demonstrator is intended to be of the same type and construction as the auxiliary engine for the full-scale vehicle. This engine is conceptually a four-cylinder aluminum block reciprocating engine with a turbo-charger and liquid cooling. A report on a brief investigation into engine possibilities is presented in Appendix B. As a result of this study, the engine power selected is 56 kilowatts (75 horsepower) which would be available by modification of an existing engine block. An existing engine would be selected to minimize development expense. A two-step turbo-charger with intercoolers would also be required and a radiator for disposition of engine heat at the 15 kilometer altitude would be required. The sizing parameters selected which appear to comply with current technology is 0.88 kilograms per kilowatt for the turbo-charger, 1.11 kilograms per kilowatt for the engine block assembly, and 2.21 kilograms per kilowatt for the cooling system, including liquid, radiator, and intercooling. This gives 4.20 Kg/kw for the engine system.

As discussed under weight and balance, it is necessary to carry the engine in a forward position for balance purposes and a 10 meter long shaft is needed to carry the engine torque to the propeller assembly. The shaft weight is carried parametrically in the program as a thin walled aluminum tube.

The propeller would be a 3-bladed kevlar composite propeller developed with technology similar to that used in existing composite propellers and wind turbines as reported in descriptive material by T.M. Development Company in Appendix C. The propeller diameter would be 10.4 meters with 3-bladed construction and weigh 96.5 kilograms with its hub. The propeller hub would provide for full-pitch control of the propeller blades including reverse pitch for landing purposes. The propeller is to provide a vectored thrust for propulsion and steering of the vehicle, therefore, the propeller hub will be of a gimbled construction to permit vectoring the propeller up to 22½° from the longitudinal centerline in any direction. The propeller hub mechanically would be similar to the mounting mechanism on front-wheel-drive automobiles, except gimballing would be required in two planes. A conceptual sketch of such a mechanism is shown in Figure 4-1.

4.1.3 Gas Pressure System

The gas pressure system is the means whereby the hull of the ship is pressurized to maintain its shape. The entire hull plus the fins is carried at a positive gauge pressure. The schematic of the system is shown in Figure 4-2. (SK82-1538) The various compartments within the hull of the ship which must be pressurized are the air chamber which is the space in the hull beneath the main ballonet diaphragm, the helium compartment which is the semi-cylindrical tube attached to the top center of the hull to contain the initial charge of helium, the trim ballonets, one located forward and one aft, which are inflated according to the pitch trim requirement of the ship, the tail section consisting of the fins and the aft ten meters of the hull, and finally the utility compartment canopy. As shown in the schematic, the air is supplied from the main blower through a plenum chamber to the air chamber, the helium chamber, the trim ballonets, and the tail section. The utility canopy is fitted with its own

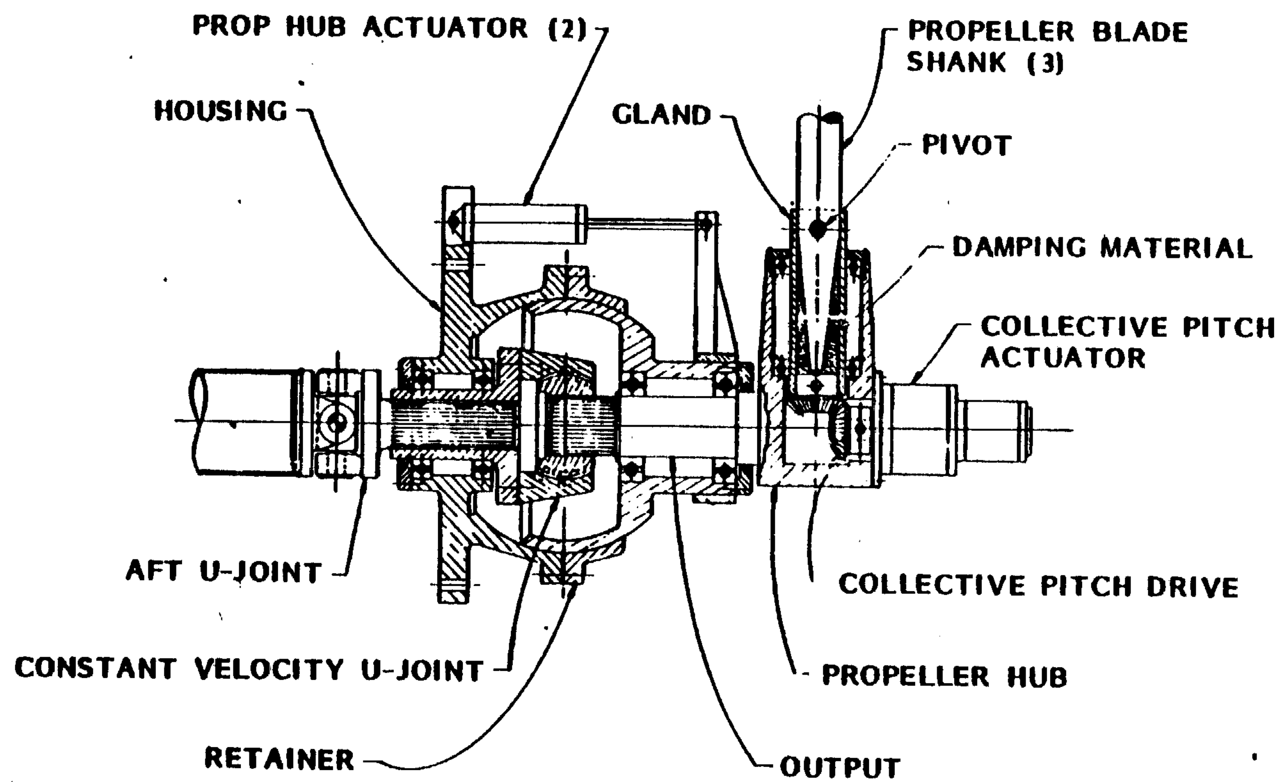
PROP HUB ACTUATOR (2)
HOUSING
GLAND
PROPELLER BLADE SHANK (3)
PIVOT
DAMPING MATERIAL
COLLECTIVE PITCH ACTUATOR
AFT U-JOINT
COLLECTIVE PITCH DRIVE
CONSTANT VELOCITY U-JOINT
PROPELLER HUB
RETAINER
OUTPUT

FIGURE 4-1

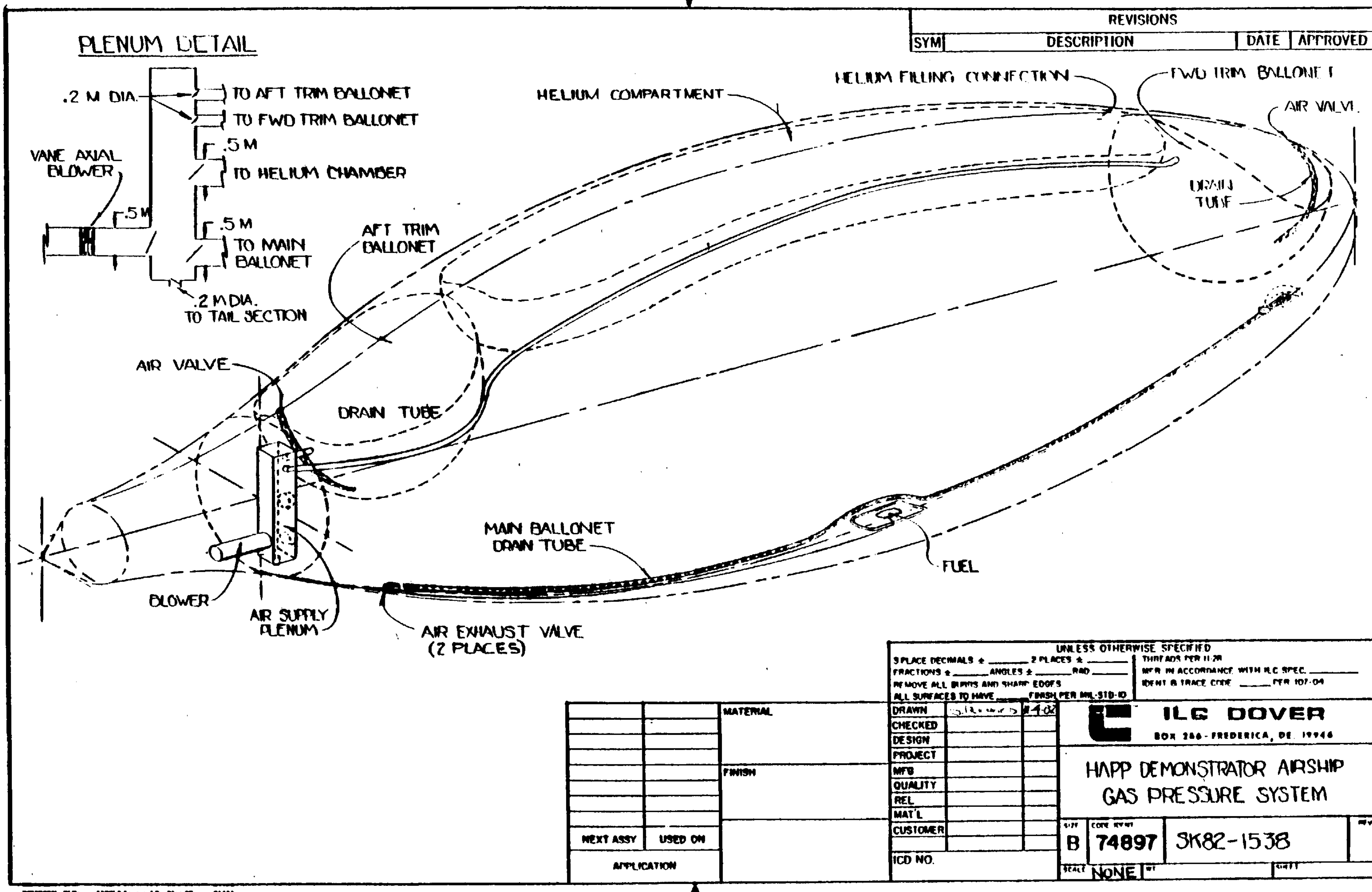

FIGURE 4-2, HAPP DEMONSTRATOR AIRSHIP GAS PRESSURE SYSTEM blower which takes air from the main air chamber into the utility area to maintain it at a pressure slightly above the air chamber pressure. During periods of high demand, the tail section with fins is supplied with air from the main blower through the plenum chamber. During a steady-state flight condition, a small blower provides the air required to compensate for minor leaks and thus avoid the use of the main blower. All the compartments are fitted with vent valves by which excess air or helium may be vented to the atmosphere. Drain tubes are provided in the main ballonet air chamber and in the trim ballonets to provide for complete scavenging of air from these compartments when they are in collapsed condition. When the ship is in the launch condition, air in the main air chamber under the main diaphragm would fill the ship to about 84% full of air, and the tail section would be full of air. The remainder of the ship volume would be occupied by helium in the helium compartment. During ascent, the air chamber vent valves would be activated by pressure sensors to maintain the hull at a programmed pressure above ambient for structure purposes. In the troposheric region, where atmospheric turbulence may be encountered, hull pressure would be maintained at about 12 centimeters of water. When the ship has reached cruise altitude, programmed operation of the blower and chamber vent valves will allow pressure to vary from 2.5 cm. of water at night to 12.3 cm. of water in the day time. The trim ballonets would be inflated with air differentially as needed to maintain the desired pitch trim. When the trim ballonets are filled or deflated according to trim needs, the main air chamber air controls would be activated as needed to maintain the programmed pressure within the hull.

The tail section consisting of the aft portion of the hull and the fins are all interconnected and inflated with air. This air pressure is maintained at a pressure slightly higher than the helium pressure so that the tail section diaphragm will be slightly stressed to a convex forward shape.

Gas pressure control system will consist of pressure sensors, delivering signals to a micro processor which then issues command to the blower, plenum valves, and vent valves. Pressure sensors would be located on top of the ship, one forward, one mid-ship inside the helium compartment, one mid-ship outside the helium compartment, and one aft. Another set of sensors would be positioned along the bottom of the ship, one forward, one mid-ship, one aft. One pressure sensor would be located in the tail section. A redundant sensor would be provided at all locations.

4.1.4 Electrical System

Electrical power will be required for the flight control system, the guidance and information system, thermal control on some components, the payload, and external lighting. The overall power requirement is estimated at 2.13 kilowatts for which a generator weighing 2.3 kilograms will be required. A battery with 1 kilowatts capacity will provide for 8 hours of airship operation in case of generator failure and 24 hours of avionics operation in case of engine failure.

4.1.5 Flight Control System

The Demonstrator Flight Control System would consist of a manned ground control station with telemetry and command links to sensors and controls on the airship. The ship would be controlled from the ground by a trained operator acting as "pilot". The pilot's task would be a facilitated by information and command processing units on the ground and on the ship.

4.1.5.1 Functions

The following flight functions will be required:

For all flight operations:

Keep hull pressure above minimum.

Maintain pitch trim with ballonets to minimize propeller gimbal angle.

Ascent

Control ascent rate

Travel to Station

Maintain designated altitude

Navigate to station

Station Keeping

Maintain designated altitude

Maintain position

Maneuver for flight tests

Travel from Station

Maintain designated altitude

Navigate to descent position

Descent

Control descent rate

Navigate to landing field

Landing

Make landing approach

4.1.5.2 Logic Requirement

Figure 4-3 outlines the logic for the "maintain altitude" function. Similar logic developments will apply for the following functions:

Maintain Altitude (as given in Figure 1)

Ascent Rate

Trim Control

Navigation

Descent Rate

Landing Approach

Abort

Logic functions would be performed by a "pilot" in a ground control station assisted by microprocessors in the ship and on the ground. The microprocessor would provide an "auto pilot" function for simple maneuvers. Airship data would be provided to the pilot in real time via telemetry and displayed on a console. Position information on a

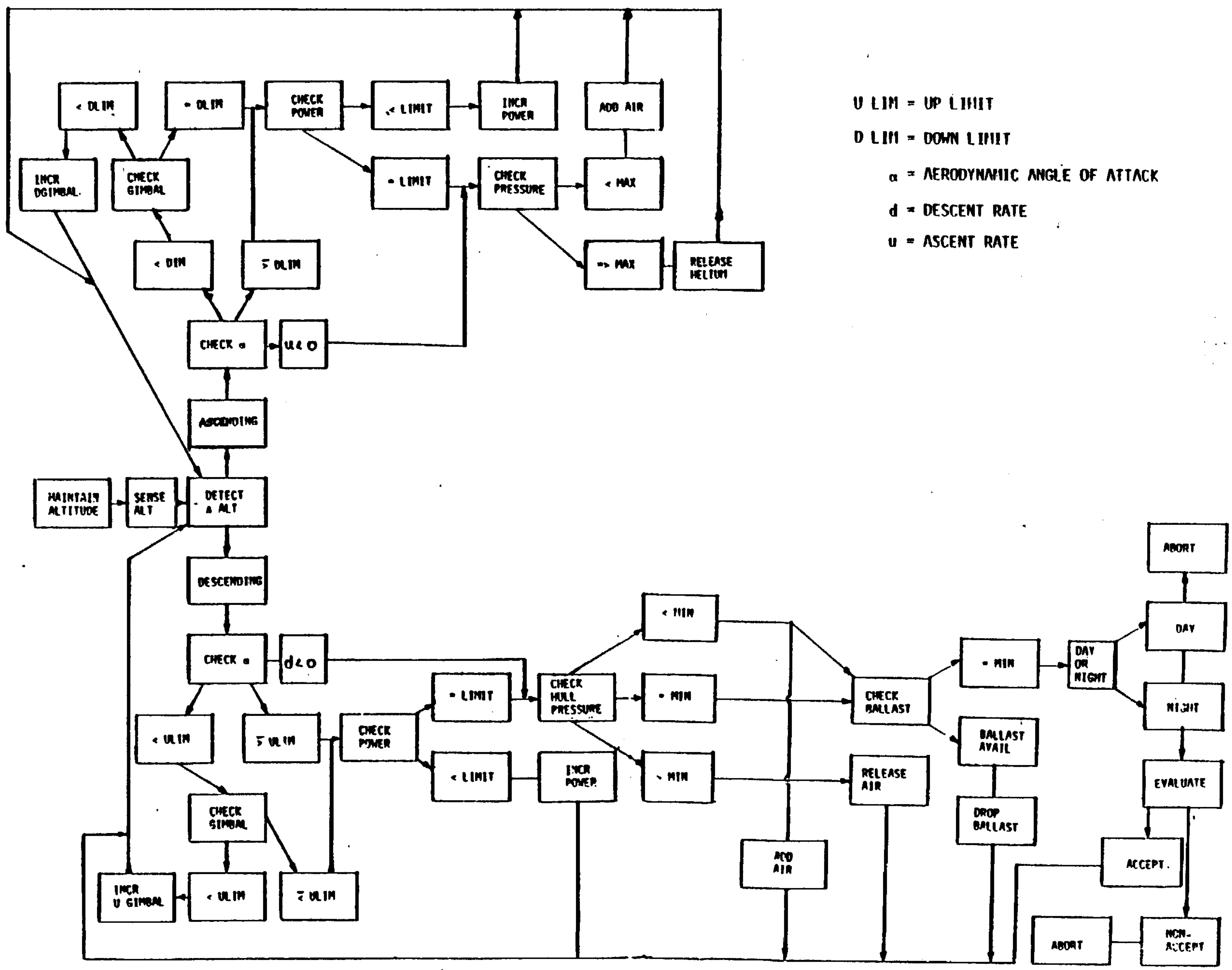
U LIM = UP LIMIT
D LIM = DOWN LIMIT
α = AERODYNAMIC ANGLE OF ATTACK
d = DESCENT RATE
u = ASCENT RATE
MAINTAIN ALTITUDE
SENSE ALT
DETECT Δ ALT
ASCENDING
DESCENDING
CHECK α
u ≤ 0
d ≤ 0
< DLIM
= DLIM
INCR DGIMBAL
CHECK GIMBAL
< DIM
≥ DLIM
CHECK POWER
≤ LIMIT
= LIMIT
INCR POWER
CHECK PRESSURE
ADD AIR
< MAX
=> MAX
RELEASE HELIUM
< ULIM
≥ ULIM
CHECK GIMBAL
INCR U GIMBAL
< ULIM
≥ ULIM
CHECK POWER
= LIMIT
< LIMIT
CHECK HULL PRESSURE
INCR POWER
< MIN
= MIN
> MIN
ADD AIR
CHECK BALLAST
RELEASE AIR
= MIN
BALLAST AVAIL
DROP BALLAST
DAY OR NIGHT
ABORT
DAY
NIGHT
EVALUATE
ACCEPT.
NON-ACCEPT
ABORT

FIGURE 4-3

CRT plot would be from ground based tracking radar supplemented by on-board GPS data.

Sensors which will be required for the Demonstrator are as follows:

4.1.5.3 Sensors

ITEM SENSED	SENSOR
Ambient pressure, absolute	Transducer
Magnetic heading	Stabilized compass
Pitch angle	Damped Pendulum
Angle of Attack	Ion-drift meter (TSI)
Airspeed	Ion-drift meter (TSI)
Gimbal vertical angle	Angle
Gimbal horizontal angle	Angle
Propeller RPM	Tachometer
Latitude, Longitude	Ground Radar, on-board Loran
Differential Pressures	
Helium Compartment to Helium Chamber	Transducer
Main Air Chamber to Helium Chamber	Transducer
Forward Trim Ballonet to Helium Chamber	Transducer
Rear Trim Ballonet to Helium Chamber	Transducer
Helium Chamber to Ambient	Transducer
Temperature, gas and surfaces (10)	Thermistor
Engine RPM and Health Information	Tachometer, Vibration, Temperatures

Fuel quantity and flow rate	Liquid Quantity, Flow Rate
External Ballast Remaining	On-off Circuit
Internal Ballast Remaining	Liquid Quantity

4.1.5.4 Pilot Display

Sensor information would be telemetered to the ground, processed, and displayed to give the pilot information as follows:

Altitude and Altitude change rate

Pitch angle

Angle of Attack

Gimbal vertical angle

Propeller RPM

Engine RPM

Airspeed

Geographic position plot

Track plot

Heading and Heading rate of change

Ground Speed

Gimbal horizontal angle

Helium Compartment Gage Pressure

Main Air Chamber percent full

Forward Trim Ballonet percent full

Rear Trim Ballonet percent full

Envelope Gage Pressure

Gas Temperature

Fuel Quantity and Fuel Flow

Engine vibration and temperatures

Clutch disengaged, speed 1, speed 2

Propeller Forward or Reverse Pitch

4.1.5.5 Controls

The pilot would have radio command controls as follows:

Gimbal vertical angle, proportional

Gimbal horizontal angle, proportional

Engine speed, proportional

Engine - propeller gear ration, 3 position (2 speeds and disengage)

Propeller pitch, 2 position (forward and reverse)

Helium compartment transfer valve, proportional

Helium compartment vent valve

Forward Trim ballonet inlet valve and vent valve

Rear trim ballonet inlet valve and vent valve

Main air chamber inlet valve and vent valve

Main helium chamber vent valve and air inlet valve

Air blower on-off

External ballast drop, timed

Internal ballast drop, timed

Airship hull minimum pressure would be safeguarded by automatic circuitry to energize the blower and deliver air to the main air chamber if the main helium chamber pressure falls below a preset minimum.

Air ship over pressure is prevented by automatic opening first of air chamber vent valves and next by opening of helium chamber vent valves if preset pressure limits are exceeded.

Tail and fins pressures are automatically maintained by a dedicated small blower. A general description of the system electronics hardware conceived by Motorola Corp. is attached as Appendix D.

4.1.6 Payload

The only payload which has been specified is a small scale microwave link with the ground to simulate in miniature the transmission of power by microwave to the airship. One hundred kilograms of weight has been allocated for a payload.

4.2 GROUND COMPONENTS

The ground components will parallel the full-scale system components in practically all respects. The launching facility will require a hangar with rigging, electronic, and machine shops and a control point such as a control tower, and open field space at least one thousand feet in diameter to accommodate the launch and recovery.

The ship would be mounted on a large dolly for the ground handling activities. Docking rails into the hangar would be desirable to simulate the full-scale vehicle handling. Procedures will be as outlined in the Phase I report.

5.0 FABRICATION PROCEDURES

The fabrication procedures will parallel those employed for the full-scale vehicle and will provide valuable experience for the future full-scale ship. The components of the ship would be manufactured separately at various manufacturers plants and integrated into a final assembly at an appropriate facility such as the Navy airship hangar at Lakehurst.

5.1 COMPONENTS MANUFACTURING

5.1.1 Hull System

The manufacturing procedure for the hull would be the same as for the full-scale system as reported in the Phase I report with the exception that the system could be fabricated in its entirety at a manufacturer's plant because of its smaller size as compared to the full-scale vehicle.

The textile materials of the hull must be custom woven and laminated and will be long lead time items. Several critical properties such as strength, flex life, permeability, laminate adhesion, thermal radiation properties, etc. must be closely controlled.

The hull surface with its requirement for smoothness to retain laminar flow will require unusually close tolerance patterns, cutting and joining of panels. Seams will be butt joints with the bi-modules structural tape inside and then film facing tape outside. Sealing method will be thermal, either by RF or by heat.

The subassemblies would be moved to a hangar for final assembly. Hardware components such as valves and nose mooring would be installed and the ship air inflated for inspection and watering with the tail assembly. With the ship pressurized, final installations of propulsion system, blowers, support structures, avionics and payload would be accomplished.

The textile parts of the hull would be manufactured as three major subassemblies, top, bottom and tail. Each of the subassemblies would include all the textile components such as ballonets, catenaries, reinforcements, etc. Top and bottom would be mated at the manufacturers' plant.

5.1.2 Propulsion System

The propulsion system consisting of the fuel supply, engine, gear box, drive shaft, propeller hub, and propeller would be manufactured at sub-contractors plants and subjected to environmental and operational reliability tests. Since the propulsion system would have many new features as compared to current aircraft hardware, extensive testing of the components and the system would be desirable. As a minimum the engine gear box and propeller hub should be environmentally tested for a thousand hours of operation, and the propeller should be subjected to a thousand hours of spin testing simulating flight conditions.

5.1.3 Control System

The control system will consist largely of proven components so that although system testing will certainly be in order, extensive reliability testing will probably not be needed. The control system, including the information and guidance systems would be manufactured at an electronic manufacturers plant with established manufacturing and quality control procedures.

5.1.4 Ground Handling

Equipment manufacture would require a specialized design and manufacturing team. The ground handling system requirements will be specified by the airship system designer and then assigned to a civil engineering firm for translation into a ground handling system. Standard construction practices would suffice for all portions except the airship mounting dolly, which because of lightweight requirement would best be constructed following aeronautical engineering practices.

5.2 SYSTEM INTEGRATION

The system integration is similar to that illustrated schematically in Phase I Report, Figure 10-1. The airship hull would be taken to the assembly facility such as the Lakehurst hangar. The airship hull would be spread out on the hangar floor and partially inflated with air at which time the nose mooring hardware, the valves, drain tubes, utility compartment components, would be installed in the ship. The ship could then be fully inflated and pressurized with air. Meanwhile the empennage would be assembled consisting of the tail section and the fins. With the engine and propeller shaft all installed, this assembly would be inflated with a temporary air barrier added at the forward end. The fins would be attached but not inflated at this stage of assembly. The inflated tail section would be supported in an external rigid support jig and would be raised into position and mated with the pressurized main airship hull. After the mating has been accomplished, the temporary tail gas barrier would be removed and the pressurized hull system would structurally support the inflated tail section. If space permits in the hangar, the tail fins would be inflated and pressure tested at this point. The airborn guidance and information system would be installed and detailed system check-out in conjunction with the ground control station accomplished. With the airship mounted on it's dolly and secured to the docking rails, all ground handling system vehicles and hardware would be checked for compatibility and function.

5.2.1 System Inspection and Test

Following component installation and test, the entire system would be tested following the check-list developed during the design phase.

6.0 FLIGHT PROCEDURES

Except as noted below, all flight procedures parallel those for the full scale HAPP as presented in the Phase I report Section 10.0

6.1 DEVIATIONS FROM FULL SCALE OPERATIONS/PROCEDURES

Rectenna power will not be available for propulsion.

Limit pressure for the demonstrator hull is 12.3 cm H_2O.

Flight control will be more dependent on pilot manual control, automation will be at a lower level.

7.0 SAFETY AND FLIGHT REGULATIONS

The safety and flight regulation aspects for the system have been addressed in the Phase I report Section 10.8. These factors are entirely paralleled by the demonstrator and the only significant difference which can be foreseen at this time is that FAA clearances at a 15 kilometer altitude may be more restrictive than at the higher HAPP altitude of 20 kilometers. However, since the period of operation for the demonstrator is only a few hours, no serious problem in arranging the clearance is foreseen.

8.0 COST ESTIMATE

The cost estimate is based on 1983 dollars and on the schedule shown in Figure 8-1. Detailed costs are given in Table 8-1, and are summarized below.

	Cost (K Dollars)
Program Management	375
Design	1839
Fabrication	2473
Inflation/Checkout	60
Flight Tests	220
Final Report	27
TOTAL	4994

These costs might be reduced if some components were GFE. Some of the more obvious candidates which might come from other government programs are:

Battery or Fuel Cell

Avionics

Sensors

Telemetry - command

TABLE 8-1

DEMONSTRATOR COST ESTIMATE

THOUSANDS OF DOLLARS

			Cost
1.0	Prog. Mgmt.		375
2.0	Design		
	2.1	Material	73
	2.2	Mfg. Tech.	57
	2.3	T/O's	71
	2.4	Hull	33
	2.5	Fin	33
	2.6	Ballonet	32
	2.7	Propulsion	427
	2.8	Avionics	197
	2.9	Misc. Hdwe; Nose	134
	2.10	Pressure Control	132
	2.11	Propeller/Hub/Gimbal	428
	2.12	Flight Procedure	82
	2.13	Ground Handling Equip., Mooring	63
	2.14	System	77
		2.0 TOTALS	1839
3.0	Fabrication		
	3.1	Softgoods, Valves, Plenum, Nose	1129
	3.2	Ground System (Mooring)	514
	3.3	Propulsion	126
	3.4	Avionics	376
	3.5	Misc. Hdwe.	25
	3.6	Pressure Control	75
	3.7	Propeller Hub	125
	3.8	System	103
		3.0 TOTALS	2473
4.0	Inflation/Checkout		60

TABLE 8-1

DEMONSTRATOR COST ESTIMATE

THOUSANDS OF DOLLARS

(cont'd)

	Cost
5.0 Flight Tests	
5.1 1st Total	61
5.2 2nd Total	
5.2.1 1st Flight	113
5.2.2 2nd Flight	46
5.0 TOTALS	220
6.0 Reports Final	27
PROGRAM TOTALS	4994

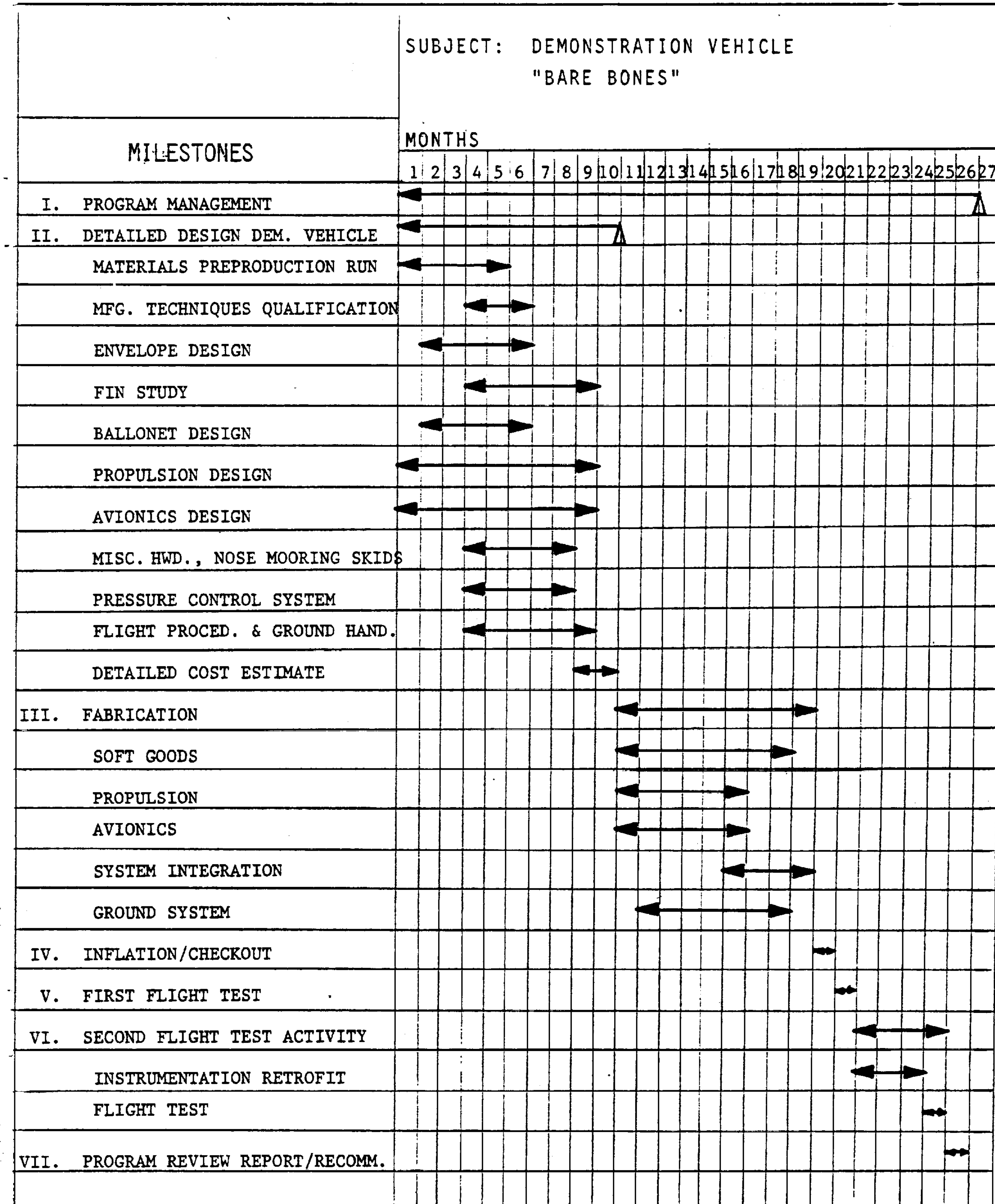
SUBJECT: DEMONSTRATION VEHICLE "BARE BONES"
MILESTONES
MONTHS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
I. PROGRAM MANAGEMENT
II. DETAILED DESIGN DEM. VEHICLE
MATERIALS PREPRODUCTION RUN
MFG. TECHNIQUES QUALIFICATION
ENVELOPE DESIGN
FIN STUDY
BALLONET DESIGN
PROPULSION DESIGN
AVIONICS DESIGN
MISC. HWD., NOSE MOORING SKIDS
PRESSURE CONTROL SYSTEM
FLIGHT PROCED. & GROUND HAND.
DETAILED COST ESTIMATE
III. FABRICATION
SOFT GOODS
PROPULSION
AVIONICS
SYSTEM INTEGRATION
GROUND SYSTEM
IV. INFLATION/CHECKOUT
V. FIRST FLIGHT TEST
VI. SECOND FLIGHT TEST ACTIVITY
INSTRUMENTATION RETROFIT
FLIGHT TEST
VII. PROGRAM REVIEW REPORT/RECOMM.

FIGURE 8-1

9.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusion of this report is that a HAPP demonstration vehicle with a volume of 10,500 cubic meters operating with a design altitude of 15 kilometers does fulfill the objectives for a "proof of concept" model. Technical simulation is achieved for the physical and aerodynamic configurations of the full-scale ship. The operations of this one-half full-scale model provides a valuable operational simulation and confidence for the full-scale model. The same conclusion is true for the manufacturing of the model which will demonstrate and de-bug the techniques for the new manufacturing technology of Kevlar fabric and of close tolerance surface smoothness.

The estimated cost for the Demonstrator program including design, manufacture, and flight tests is $4,994,000. over a time span of 26 months.

9.1 RECOMMENDATIONS

It is recommended that a proof of concept model as defined in this report is an important step in the development of the full-scale HAPP vehicle and the program should be pursued.

APPENDICIES FOR HAPP

PHASE II REPORT

APPENDIX	SUBJECT
A	COMPUTER PROGRAM FOR PARAMETRIC STUDY
B	PROPULSION ENGINE SURVEY AND THUNDER ENGINE PROPOSAL
C	TM DEVELOPMENT CO. LIGHTWEIGHT PROPELLERS
D	MOTOROLA COMMAND AND TELEMENTRY CONCEPT

APPENDIX A

"HAPP PROOF-OF-CONCEPT MODEL PARAMETRIC PROGRAM"

```
]LIST

5   REM  HAPPDEMO26OC82 HAS SHAFT LENGTH 10M, ALT 15000M,HELIUM COMP 1
     6% OF TRUNCATAED HULL LENGTH WHICH IS CUT OFF 5% OF ORIGINAL DOL
     PHIN LENGTH. SEE LINES2910 TO 2940
10   REM  PERSONS FAMILIAR WITH PROGRAM:HAMMET,STEFAN,WEIS,THIELE
20   REM *********************
30   REM *  HAPP PROG METRIC  *
40   REM *  VOLUME DEPENDENT  *
50  BASE$ = "HAPPDEMO 26OCT82"
60   REM *********************
70   REM  1.DEMONSTRATOR, ASCENT PWR OFF, AUX BACK AND AWAY AND DESCEN
     T AT THRESHOLD POWER: 2.PARTIAL SUPEARPRESS PER MIN FAB WT: 3.WI
     NDS WASHDC SUMMER 84%: 4.ON STATION FUEL 8 HRS AT LIMIT: 4. LIMI
     T SPEED SET BY 56KW RECIP ENGINE:
80   HOME
90   DIM MV(24),R(24),VE(24),U(24),UA(24),TE(24),P(24),UU(24),UD(24),V
     X(24),B(13),WC(13)
100 PI = 3.14159:C2 = .514444:C3 = 98.0638: REM  SEE SYMBOLS
110  REM DENSITIES @ 1000 M INCREM
120 R(0) = 1.2250:R(1) = 1.1117:R(2) = 1.0066
130 R(3) = .90925:R(4) = .81935:R(5) = .73643
140 R(6) = .66011:R(7) = .59002:R(8) = .52579
150 R(9) = .46706:R(10) = .41351:R(11) = .36480
160 R(12) = .31194:R(13) = .26660:R(14) = .22786
170 R(15) = .19475:R(16) = .16647:R(17) = .1423
180 R(18) = .12165:R(19) = .10400
190 R(20) = 8.8910E - 2:R(21) = 7.5715E - 2
200 R(22) = 3.8083E - 2:R(23) = 3.6790E - 2:R(24) = 3.5531E - 2
210  FOR I = 12 TO 20:TE(I) = 216.65: NEXT :TE(21) = 217.58:TE(22) =
     218.57:TE(23) = 219.57:TE(24) = 220.56
220 P(12) = 19399.4:P(13) = 16579.6:P(14) = 14170.4:P(15) = 12111.8: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
230  VTAB 10
240  HTAB 10
250 DA$ = "28OCT82"
260  LIST 250: PRINT : PRINT : PRINT "TO CHANGE CURRENT DATE *RESET*,
     CHANGE, RUN"
270  FOR I = 1 TO 50:X = I ↑ 2: NEXT :X = 0
280  GOTO 350
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  GOTO 420
400  INPUT "CHANGE CONFIG. TO HARD FINS? N ";AS$
410  IF AS$ = "Y" THEN FIG$ = "1"
420  REM  **********
430  REM  INIT INPUTS
440  REM  **********
450 E(1) = .90: REM PROP EFFIC
460 E(2) = 1: REM  SHAFT
470 E(3) = .95: REM  GEARBOX EFFIC
480 WC(1) = 2.1: REM  PROPELLER KG/KW EST BY KS WITH TM DEV CO 23AU82
     INCL 3BLADES FULL PITCH CONTROL W GIMBAL HUB
490 WC(3) = .43: REM  GEARBOX WT COEFF
500 WC(4) = 4.2: REM DRIVE MOTOR WT COEFF
510 WC(7) = 1.1: REM  AUX GENERATOR WT COEFF
520 UK(1) = 55:UM(1) = UK(1) * C2: REM  UK(1) KTS;UM(1) M/S;THRESHOLD
     SPEED
530 RA = 287.053: REM R-AIR J/KG KELVIN
540 RH = 2077.23: REM  R-HELIUM
550 CP = 1.2:CP(1) = 1: REM  DYNAMIC LIFT COEFF.
```

```
560 SH = 16.7: REM  SUPER HEAT KELVIN
570 SC =  - 17.2: REM  SUPER COOL KELVIN
580 VO = 10550:V2 = VO ↑ (2 / 3)
590 CA = 85: REM  CLIMB ANGLE DEG
600 DC = .028: REM  CLIMB,DESCENT CD
610 CD = .018: IF FIG$ = "1" THEN CD = .016
620 RD = 150: REM RATE DSCENT M/MIN
630 RC = 150: REM RATE ASCENT M/MIN
640  IF SK$ = "SKIP" THEN 660
650 ALT = 15000
660 ZT = ALT / 1000
670 PUR = .95: REM  PURITY
680 LH(1) = .19: REM  KG/KWHR FUEL WT
690 LH(2) = .022: REM  KG/KWHR TANK.011 & SUPPORT WT .011
700 LH = LH(1) + LH(2): REM  KG/KWHR FUEL AND TANK+SUPPORT WT
710 PROP$ = "RECIP ENGINE H2"
720 K(9) = 1: REM  KW PWR P/L
730 K(8) = 1.13: REM AVIONICS PWR KW
740 K1(4) = 56:B(4) = K1(4) * WC(4): REM  PRI ENGINE
750 K1(3) = K1(4) * E(3) - (K(9) + K(8)):K1(1) = K1(3) * E(1)
760 B(9) = 100: REM PAYLOAD WT KGS
770 B(8) = 117.3: REM AVIONICS WT KGS
780 B(13) = B(4): REM BALLAST IN NOSE FOR BALANCE
790  HOME : VTAB 12: PRINT "ALTITUDE = "ALT" M"
800  GOTO 860
810  INPUT "DO YOU WANT TO CHANGE ? (Y/N) N ";AS$
820  IF AS$ = "Y" THEN  GOTO 840
830  GOTO 860
840  INPUT "NEW ALTITUDE ";ALT
850 ZT = ALT / 1000
860 P = P(ZT):TE = TE(ZT)
870  HOME : VTAB 12: PRINT "SHAFT LENGTH =SHIP LENGTH LF*(95-.80). IF
      YOU WANT TO CHANGE, KEY Y AND LIST 2552": GOTO 900: INPUT " (Y/
     N)N";AS$
880  IF AS$ = "Y" THEN  GOTO 890
890  GOTO 900
900 WC(2) = .0119: REM  DRIVE SHAFT WT COEFFFOR RADIUS 0.25M, AL 6061
     T6
910  HOME : VTAB 12: PRINT "DRIVE SHAFT WT COEFF. = ";WC(2)
920  GOTO 960
930  INPUT "DO YOU WANT TO CHANGE? N ";AS$: IF AS$ = "Y" THEN  GOTO 9
     50
940  GOTO 960
950  INPUT " NEW DRIVE SHAFT WT COEFF = ";WC(2)
960 PC(2) = 2.5:PD(2) = PC(2) * C3: REM  PC CMH20,PD PASCALS, NITE PR
     ESS 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 SHIP$ = "DOLPHIP HARD FINS": IF FIG$ = "2" THEN SHIP$ = "DOLPHIN
      SOFT FINS"
1050  HOME : VTAB 12
1060  PRINT "CLIMB ANGLE = "CA" DEG PWR OFF ASCENT"
1070  GOTO 1130
1080  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1090  IF AS$ = "Y" THEN 1120
1100  PRINT "P1=ASCENT" TAB( 20)"P2=CRUISE MAX" TAB( 40)"P3=CRUISE PA
     RTIAL"
1110  GOTO 1130
1120  INPUT "NEW CLINB ANGLE = ";CA
1130  HOME : VTAB 12
1140  PRINT "CLIMB CD = "DC
1150  GOTO 1200
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  GOTO 1270
1230  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
1240  IF AS$ = "Y" THEN 1260
1250  GOTO 1270
1260  INPUT "PURITY =";PUR
1270  HOME : VTAB 12
1280 RE = (RA * RH) / (PUR * (RA - RH) + RH): REM  EFFECTIVE GAS CONS
```

```
TANT
1290  PRINT "DRAG COEFF(SHIP)="CD
1300  GOTO 1350
1310  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";A$$
1320  IF A$$ = "Y" THEN  GOTO 1340
1330  GOTO 1350
1340  INPUT "NEW COEFF =";CD
1350  HOME : VTAB 12
1360  GOTO 1420
1370  PRINT "MINIMUM AVE HULL FAB WT="MHW" KG/M2)
1380  INPUT "DO YOU WANT TO CHANGE,(Y/N)N";A$$
1390  IF A$$ = "Y" THEN 1410
1400  GOTO 1420
1410  INPUT "NEW MIN AVE HULL FAB WT=";MHW
1420  PRINT "FIN SKIN FAB WT="FFW" KG/M↑2"
1430  GOTO 1490
1440  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";A$$
1450  IF A$$ = "Y" THEN  GOTO 1470
1460  GOTO 1490
1470  INPUT "NEW FIN SKIN WT=";FFW
1480  HOME : VTAB 12
1490  PRINT "RIB FAB WT=";RFW" KG/M↑2"
1500  GOTO 1780
1510  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";A$$
1520  IF A$$ = "Y" THEN  GOTO 1540
1530  GOTO 1560
1540  INPUT "NEW RIB FAB WT=";RFW
1550  HOME : VTAB 12
1560  PRINT "BALNT FAB WT="BFW" KG/M↑2"
1570  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";A$$
1580  IF A$$ = "Y" THEN  GOTO 1600
1590  GOTO 1610
1600  INPUT "NEW BALNT FAB WT=";BFW
1610  PRINT "BALLONET VOL AT CRUISE ALT = "BV(1)
1620  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";A$$
1630  IF A$$ = "Y" THEN  GOTO 1650
1640  GOTO 1660
1650  INPUT "BALLONET VOL = "BV(1)
1660  PRINT "PROP OF SHIP VOL FOR TRIM BALLONET = "T(4)
1670  INPUT "DO YOU WANT TO CHANGE? ";A$$
1680  IF A$$ = "Y" THEN 1700
1690  GOTO 1710
1700  INPUT "NEW PROP OF SHIP FOR TRIM BALLONET = ";T(4)
1710  HOME : VTAB 2
1720  HTAB 15: INVERSE : PRINT "WIND OPTIONS": NORMAL
1730  PRINT : PRINT : PRINT "THRESHOLD VELOCITY = "UK(1)" KTS": INPUT
     "WILL THIS CHANGE (Y/N) N ";A$$
1740  IF A$$ = "Y" THEN  GOTO 1760
1750  GOTO 1770
1760  INPUT "NEW THRESHOLD VELOCITY, KTS";UK(1):UM(1) = UK(1) * C2
1770  PRINT : PRINT
1780  HOME : VTAB 12
1790  VTAB 14: PRINT "CALCULATING WIND VALVES"
1800  REM  ASCENT & DESCENT WINDS, WASH DC SUMMER, M/S
1810  FOR I = 0 TO 24:ZLT = I * 1000: REM  U(I) IS IN M/S
1820  IF ZLT > 0 AND ZLT <  = 12000 THEN U(I) = (15 + 0.00472 * (ZLT -
     0)) * C2
1830  IF ZLT > 12000 AND ZLT <  = 18500 THEN U(I) = (71.6 - 0.00932 *
     (ZLT - 12000)) * C2
1840  IF ZLT > 18500 THEN U(I) = (11.0 + 0.00209 * (ZLT - 18500)) * C
     2
1850  NEXT
1860  FOR I = 0 TO 24:UU(I) = U(I): NEXT : REM  SETS DESCENT WINDS =
     ASCENT, M/S
1870  HOME : VTAB 12: PRINT "SUPER HEAT & COOL TEMP = "SH" & "SC" K"
1880  GOTO 1990
1890  INPUT "DO YOU WANT TO CHANGE Y/N N";A$$
1900  IF A$$ = "Y" THEN  GOTO 1920
1910  GOTO 1930
1920  INPUT "NEW HEAT = ";SH: INPUT "NEW COOL = ";SC
1930  HOME : VTAB 12
1940  PRINT "NITE PRESS DIFF = "PC(2)" CM H20": PRINT "SAFTEY FACTOR
     = "FS
1950  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";A$$
1960  IF A$$ = "Y" THEN  GOTO 1980
1970  GOTO 1990
1980  INPUT "NEW NITE PRESS DIFF(CM H2O)= ";PC(2):PD(2) = PC(2) * C3:
     INPUT "NEW SAFTEY FACTOR = ";FS
1990 PD(4) = (P + PD(2)) * (TE + SH) / (TE + SC) - P:PC(4) = PD(4) /
     C3: REM  PASCALS PRESS DIF DAY
```

```
2000  PRINT "DAY PRESS DIFF FOR DAYNITE EQUIL, CM H2O="PD(4)
2010 PD = 622.570778:PD$ = "FABPRESS": PRINT "DAY PRESS WILL ADJUST T
     O PRESSURE FOR MIN FAB WT": PRINT : GOTO 2050: INPUT "DO YOU WAN
     T TO CHANGE(Y/N)N";AS$
2020  IF AS$ = "Y" THEN PD$ = "O": GOTO 2040
2030  GOTO 2050
2040  INPUT "NEW DAY PRESS DIFF, CMH20=";PC(3):PD = PC(3) * C3
2050  HOME : VTAB 12
2060  GOTO 2340
2070  PRINT "P/L WT="B(9)" KGS"
2080  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2090  IF AS$ = "Y" THEN  GOTO 2110
2100  GOTO 2120
2110  INPUT "P/L WT (KGS) = ";B(9)
2120  HOME : VTAB 12
2130  PRINT "AVIONICS WT="B(8)" KGS"
2140  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2150  IF AS$ = "Y" THEN  GOTO 2170
2160  GOTO 2180
2170  INPUT "NEW WT=";B(8)
2180  HOME : VTAB 12
2190  PRINT "P/L PWR="K(9)" KW"
2200  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2210  IF AS$ = "Y" THEN  GOTO 2230
2220  GOTO 2240
2230  INPUT "PWR P/L (KW) = ";KC(9)
2240  HOME : VTAB 12
2250  PRINT "AVIONICS PWR="K(8)" KW"
2260  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2270  IF AS$ = "Y" THEN  GOTO 2690 .
2280  GOTO 2300
2290  INPUT "NEW PWR?";KC(8)
2300  HOME : VTAB 12
2310  PRINT "VOLUME = "VO" M↑3"
2320  INPUT "DO YOU WANT TO CHANGE (Y/N) N ";AS$
2330  IF AS$ = "Y" THEN  GOTO 2520
2340 UM(5) = (K1(1) * 1000 / (CD * .5 * R(ZT) * V2)) ↑ (1 / 3):UK(5) =
     UM(5) / C2
2350  REM  REITERATION STARTS HERE
2360  FOR I = 1 TO 5:UM(I) = UK(I) * C2: NEXT
2370  FOR I = 1 TO 5: PRINT I"  UK("I")="UK(I): NEXT : FOR I = 1 TO 3
     0:X = I ↑ 2: NEXT :X = 0
2380  REM *************
2390  REM SIZING ROUTINE
2400  REM *************
2410 I = 0
2420 QT = 0:TQ = 0:DSCNT$ = " "
2430 RO = R(ZT): REM  DEN AT OPR ALT
2440 V2 = VO ↑ (2 / 3)
2450 VR = 0.44291 * VO ↑ (1 / 3): REM  RADIUS M DERIVED FR 1.5MCF=50.
     7FT
2460 LF = (VR * 6.863) * .95: REM  LENGTH,TRUNCATED 5% FOR BALANCE
2470  PRINT "VO="VO
2480 SA = 5.9388 * V2: REM  SFC AREA M2 DERIVED FR 1.5MCF=77820FT2
2490 SL = 10: REM  SHAFT LENGTH
2500 B(11) = 47: REM  SUPPORT RINGS FOR ENGINE AND PROPELLER, NO HARD
     CONE
2510 ESF = 2.0487: REM  EFF STRESS FACTOR
2520 HFW = MHW * SA: REM  HULL WT MIN FAB
2530  IF PD$ = "FABPRESS" THEN PD = (MHW * SA - (.057642 * SA)) / (1.
     3404E - 06 * FS * VO * ESF)
2540 PD(4) = (P + PD(2)) * (TE + SH) / (TE + SC) - P:PC(4) = PD(4) /
     C3: REM  PASCALS PRESS DIF DAY
2550  IF PD$ = "FABPRESS" AND PD(4) < PD THEN PD = PD(4)
2560  IF PD$ <  > "FABPRESS" THEN HFW = 1.3404E - 6 * PD * FS * VO *
     ESF + (.057642 * SA): REM  HULL WT
2570 UHW = HFW / SA:UFW = UHW: IF UFW < MHW THEN UFW = MHW:HFW = SA *
     UFW
2580 KTW = HFW * .08: REM TAPE WT KG;4% EACH SIDE
2590 M(1) = (P * VO) / (RA * TE): REM  MASS DISPL AIR
2600 M(2) = ((P + PD) * (VO - BV(1))) / (RE * (TE + SH)): REM  MASS H
     E
2610 M(3) = ((P + PD) * (BV(1))) / (RA * (TE + SH)): REM  DAY MASS AI
     R IN BALNT
2620 LD(1) = M(1) - M(2) - M(3): REM  DAY STATIC LIFT
2630 NV = (M(2) * RE * (TE + SC)) / (P + PD(2)): REM  NIGHT VOL HE
2640 M(5) = ((P + PD(2)) * (VO - NV)) / (RA * (TE + SC)): REM  NITE B
     ALNT AIR MASS
2650 LD(2) = M(1) - M(2) - M(5): REM NIGHT STATIC LIFT
2660 BV = VOL - NV: REM  NITE BALLONET VOLUME
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2670 LD(3) = LD(1): REM  MAX DAY LIFT FOR DYNAMIC LIFT COEF
2680 LD = (LD(1) - LD(2)): REM  DYNAMIC LIFT DURING NIGHT ONLY
2690  IF LD = 0 THEN LD = .1
2700 TL(1) = (2 * LD * 9.807) / (RO * V2 * UM(1) ↑ 2): REM  DYNAMIC C
     L AT THRESHOLD SPD
2710 CD(1) = CD + (CP(1) * (TL(1) / CP) ↑ 2) / 2: REM  CD+INDUCED DRA
     G/2 TO AVE DAY-NITE DRAG
2720 K4(1) = (CD(1) * .5 * R(ZT) * UM(1) ↑ 3 * V2) / (1000): REM PROP
      KW AT THRESHOLD, PRIME PWR
2730 K4(4) = (K4(1)) / (E(1) * E(3)): REM  THRESHOLD ENG PWR
2740 B(4) = K1(4) * WC(4): REM  PRIME ENG WT
2750 B(12) = K1(4) * WC(12): REM  WATER REC
2760 TL(5) = (2 * LD * 9.807) / (RO * V2 * UM(5) ↑ 2): REM  DYNAMIC C
     L AT UM(5)
2770 CD(5) = CD + (CP(1) * (TL(5) / CP) ↑ 2) / 2: REM  CD+INDUCED DRA
     G/2 TO AVE DAY-NITE DRAG
2780 UM(5) = (K1(1) * 1000 / (CD(5) * .5 * R(ZT) * V2)) ↑ (1 / 3):UM(
     5) = UM(5) / C2
2790 K1(3) = K1(4) * E(3):K1(2) = K1(3): REM GEARBOX,SHAFT
2800 B(1) = K1(1) * WC(1): REM  PROPELLER
2810 B(3) = (K1(3) * WC(3)): REM  GEAR BOX WT
2820  REM  FAB UNIT WT DERIVED FROM NADC REPORT WHERE 1.8 OZ/YD↑2 KEV
     LAR GIVES 260 LB/IN TENSILE + 1.7 OZ COATING AS FOLLOWS:
2830  REM  FAB UNIT WT = (PD (PASCALS) * VR (METERS) * FS * 1.8 * .03
     3907 / (260 * 39.37 * 4.4482)) + (1.7 * .033907) = PD * VR * FS
     * 1.3404E-6 + .057642
2840 WF = 1.08: REM  SEAM & REENFORC WT FACTOR
2850 KF = VO ↑ (2 / 3) * .5179 * (2 / 3): REM FIN AREA M2
2860 KI = KF * 2 * FFW * WF: REM  FIN SKIN WT KGS
2870 KI(1) = KF * RFW * WF: REM  RIB WT KGS
2880 KI(2) = KI + KI(1): REM  TOTAL FIN WT KGS
2890  REM  HARD FIN WT FROM ORG HAPP EST. & CONV. TO METRIC. FIN AREA
     =(V/42475)↑(2/3)*630.44  M↑2 = .5179*V↑(2/3). FIN UNIT 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&PUTMAN
2900  IF FIG$ = "1" THEN KI(2) = .6787 * KF: REM  HARD FIN WT
2910  REM  BALLONET (BLET) SYSTEM:SINGLE BALLONET WITH LAUNCH TUBE AN
     D TRIM BALLONETS. SINGLE BLET DIAPHRAM = 1/2 HULL AREA. LAUNCH T
     UBE VOL 1.1 SEA LEV GROSS;LENGTH .54 SHIP LEN
2920 WD = SA / 2 * BFW: REM  DIAPHRAM WT
2930 T(1) = LD(1) * 1.1 / (1.0557 * PUR): REM  TUBE VOL
2940 LL = .56 * (LF / .95):R1 =  SQR (T(1) / (PI * LL)): REM  LL=TUBE
      LEN,R1 IS FIRST EST RADIUS,.95 ADJUSTS FOR TRUNCATE LINE2540
2950 Y = T(1)
2960  GOSUB 3050
2970 X2 = R1:Y2 = TT(1)
2980 R1 = R1 + 1
2990  GOSUB 3050
3000 X1 = R1:Y1 = TT(1)
3010  GOSUB 3060
3020  GOSUB 3050
3030  IF  ABS (TT(1) - T(1)) < .1 THEN 3070
3040 X2 = X1:Y2 = Y1: GOTO 3000
3050 TT(1) = PI * R1 ↑ 2 * (2 * R1 / 3 + LL / 2): RETURN
3060 X = (X2 - X1) * (Y - Y1) / (Y2 - Y1) + X1:R1 = X: RETURN
3070 T(2) = PI * R1 * (R1 + LL) * BFW: REM  TUBE WT KG
3080  REM  PRINTT(1),TT(1),R1
3090 T(3) = ((3 * T(4) * VO) / (4 * PI)) ↑ (2 / 3) * 4 * PI * BFW: REM
      TRIM BALL WT
3100 KO = WD + T(2) + T(3): REM BALONT. SYS. WT. KGS
3110  REM  DOLPHIN EFF. STRESS FACTOR: REF KARL S. BOOK 9, PAGE 1
3120 B(2) = SL * K1(2) * WC(2) + Q: REM SHAFT+FLANGES
3130 B(7) = (K(8) + K(9)) * WC(7): REM  GEN WT
3140 EJ = B(1) + B(2) + B(3) + B(4) + B(5) + B(6) + B(7) + B(8) + B(1
     0) + B(12): REM  POWERSYSWT
3150 B(0) = 1.46E - 8 * (RD * VO * PD) * .5: REM BLOWER WT KG
3160 VW = (VO * RC / 60 * 4.24E - 3) / ( SQR (PD)): REM VALVE WT
3170 A = KTW + HFW + KI(2) + KO + B(11) + B(0) + VW: REM  HULL WT INC
     LUDING SKIN,BALLONET,FINS,CONE,BLOWER & VALVE
3180 GDRY = A + EJ + B(9): REM GROSS LESS FUEL & TANKS&BALLAST
3190 M = LD(3) - GDRY: REM  FREELIFT LESS FUEL,TANKS,BALLAST
3200  IF A$ <  > "CV" THEN 3260
3210  PRINT "TAPES = "KTW TAB( 20)"HULL = "HTW
3220  PRINT "FINS = "KI(2) TAB( 20)"BALLONET = "KO
3230  PRINT "CONE = "B(11) TAB( 20)"BLOWER = "B(0)
3240  PRINT "VALVE = "VW
3250  PRINT "THERE ARE "  INT (M)" KGS AVAILABLE FOR FUEL & TANKS"
3260  REM  IFM<0THEN5020
3270  REM *************
3280  REM ASCENT PROFILE
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3290  REM *************
3300 ST = 0:ST(1) = 0
3310 CR = CA / PI
3320 SR =  SIN (CR):CC =  COS (CR)
3330  FOR I = 0 TO (ZT)
3340 VX(I) = (K4(1) * 1000 / (.5 * R(I) * DC * V2)) ↑ (1 / 3): REM VE
     L ON THRESH PWR ALT I,M/S
3350  NEXT
3360  GOTO 3470: REM  SKIPS POWERED ASCENT
3370  FOR I = 0 TO (ZT): REM  POWERED ASCENT
3380 FW =  SQR (VX(I) ↑ 2 - (RC / 60) ↑ 2): REM   AIRSPEED AT ALT I
3390 DT = (1000 / RC) * 60: REM  SEC 1000M
3400 S1 = FW - U(I): REM  GROUNDSPEED M/S
3410 S = (S1 * DT):ST(1) = S + ST(1): REM  BLOWOFF
3420  NEXT
3430  PRINT
3440 TX = ALT / RC / 60: REM  HOURS CLIMBING
3450 SX = ST(1) * 5.396E - 4
3460 HH = TX * EH: REM  KWHR CLIMB
3470  REM   CONT FR 3360(GOTO 3470)
3480  FOR I = 0 TO ZT: REM  POWER OFF ASCENT
3490 DT = (1000 / RC) * 60: REM SEC 1000M
3500 S = U(I) * DT:ST(1) = ST(1) + S: REM BLOWOFF M
3510  NEXT
3518 UJ(1) = UM(1):KK(1) = K4(4): IF UJ(1) = UM(5) THEN KK(1) = K1(4)
     : REM  FOR AUXBACK TZ AND HS, UM(1)THRESHOLD, UM(5)LIMIT
3520 TZ =  ABS (ST(1)) / ((UJ(1) - U(ZT)) * 3600): REM  HRS TO AUXBAC
     K
3530 HS = TZ * KK(1): REM KWHR AUXBACK
3540 TX = ALT / RC / 60: REM  TIME TO ALT
3550  IF AS$ <  > "CV" THEN 3620
3560  PRINT  TAB( 20)"* * * * * ASCENT PROFILE * * * * *"
3570  PRINT "POWER OFF ASCENT AT "RC" M/MIN; WINDS WASHDC SUMMER 84%"

3580  PRINT "TIME TO CLIMB TO "ZT" KM="TX
3590  PRINT "BLOWOFF DISTANCE ="ST(1) / 1000" KM."
3600  PRINT "TIME TO AUXBACK TO STATION ="TZ"HRS, AT THRESHOLD SPD"
3610  PRINT "FUEL USED ASCENT AND AUXBACK ="HS * LH(1)" KG
3620  REM *****************
3630  REM ON STATION PROFILE
3640  REM *****************
3650  REM  ON STATION WINDS AND AUX PWR CALC IN LINES 3110 TO 3190
3660 BO = 0: REM KWHR      ON STATION
3670 RK = K1(4) * 8: REM  KWHR, 4HR RESERVE, 4HR MANEUVER, AT LIMIT P
     WR
3680  IF AS$ <  > "CV" THEN 3730
3690  PRINT  TAB( 20)"* * * * * ON-STATION PROFILE * * * * *"
3700  PRINT "STATION WIND ="U(ZT) / C2" KTS"
3710  PRINT "SHIP SPEED ON THRESHOLD POWER="UK(1)" KNOTS:LIMITING VEL
     = "UK(5)"KTS"
3720  PRINT "FOR 4HRS RESERVE + 4HRS MANEUVERING @ LIMIT " INT (UK(5)
     * 10 + .5) / 10" KTS STATION FUEL WT = "RK * LH(1): PR# 0
3730  REM *************
3740  REM DSCENT PROFILE
3750  REM *************
3760  IF AS$ = "CV" THEN  GOTO 3970
3770 ST = 0
3780 DT = (1000 / RD) * 60: REM  SEC PER 1000M
3790  FOR I = (ZT) TO 0 STEP  - 1
3800 FW =  SQR (VX(I) ↑ 2 - (RD / 60) ↑ 2): REM  HORIZONTAL AIRSPEED
     AT ALT I
3810 S1 = FW - UU(I): REM  GROUNDSPEED
3820 S = S1 * DT
3830 ST = S + ST: REM  AUXAWAY DISTANCE M
3840  NEXT I
3848 UJ(3) = UM(1):KK(3) = K4(4): IF UJ(3) = UM(5) THEN KK(3) = K1(4)
     : FOR USE INT 1 =  AND HJ =
3850 T1 =  ABS (ST) / ((UJ(3) - U(ZT)) * 3600): REM  AUXAWAY HRS
3852  IF UM(5) < U(ZT) THEN  PRINT "AIRSPEED LESS THAN WIND SPEED AT
     CRUISE ALTITUDE; GOTO 5710 FOR NEW RUN": STOP
3860 HJ = T1 * KK(3): REM AUXAWAY KWHR
3870 TD = ALT / RD / 60: REM  DESCENT HRS
3878 UJ(4) = UM(1):KK(4) = K4(4): IF UJ(4) = UM(5) THEN KK(4) = K1(4)
     : REM  FOR USE IN HD=
3880 HD = TD * K4(4): REM DESCENT KWHR
3890 HL = K4(4) * 4: REM  KWHR 4HR LANDING
3900 DB = (4.18E - 6 * RD * VO * PD * TD * .001) * (.5 / .59): REM  D
     SCNT BLOWER KW-HR
3910 HT = HH + HS + HJ + HD + DB + HL + RK + BO: REM  TOTAL MISSION K
     WHR,ASCENT+AUXBACK+AUXAWAY+DESCENT+BLOWER+LANDING+RESERVE+ONSTAT
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    ION
3920 FUL = HT * LH(1): REM  MISSION FUEL KG
3930 MTA = HT * LH(2): REM  TANK & STRUCTURE KG
3940 EI = EJ + MTA
3950 DSF = (HD + DB + HL + HJ) * LH(1): REM  FUEL FOR DESCENT OPS INC
     L 8HR LANDING
3960  IF AS$ <  > "CV" THEN 4100
3970  PR# 1
3980  PRINT  TAB( 10)"* * * * * DSCENT PROFILE,  AUXAWAY AND DSCENT A
     T THRESHOLD * * * * *"
3990  PRINT "POWERED DESCENT AT "RD" M/MIN"
4000  PRINT "TIME TO DESCEND FROM "ZT" KM="TD" HRS
4010  PRINT "FUEL FOR DESCENT = "HD * LH(1)" KGS"
4020  PRINT "AUXAWAY AT ALT TIME AND DISTANCE = "T1" HRS AND "ST / 10
     00" KM"
4030  PRINT "FUEL FOR AUXAWAY = "HJ * LH(1)" KGS"
4040  PRINT "FUEL FOR BLOWER = "DB * LH(1)" KGS"
4050  PRINT "FUEL FOR LANDING 4HR AT THRESHOLD PWR(SL 29.8KT)="HL * L
     H(1)" KGS"
4060  PRINT "FUEL USED FOR DESCENT OPS INCL 8HR LANDING = "DSF" KG
4070  PRINT  TAB( 20)"* * * * * SUMMARY * * * * *"
4080  PRINT "TOTAL FUEL WT FOR MISSION = "FUL
4090  PR# 0: IF A% = 2 THEN  RETURN
4100  REM
4110 WG = GDRY + FUL + MTA + B(13): REM  GROSS WT KG
4120 DW = LD(3) - WG: REM  FREELIFT AEROSTATIC
4130 PQ$ = "2": REM  PR#1; TO ACTIVATE CHANGE THIS LINE TO PR#1 ONLY

4140  PRINT  TAB( 4)"VOLUME,M↑3, VO="VO
4150  PRINT "GROSS WT,KG, WG=" TAB( 22)WG: PRINT "STATIC LIFT, LD(3)=
     " TAB( 22)LD(3): PRINT "FREELIFT, DW=" TAB( 22)DW: PRINT : PRINT

4160  IF PQ$ = "2" THEN 4200
4170  INPUT "DO YOU WANT DETAILS PRINTED?(Y/N)N";PQ$
4180  IF PQ$ = "Y" THEN PQ$ = "1": GOSUB 4290
4190 PQ$ = "2"
4200  PRINT : PR# 0
4210  IF  ABS (DW) > 1 THEN  GOTO 4930
4220  FOR I = 1 TO 5: IF TL(I) >  = .315 THEN  PRINT "STOP:TL("I") IS
      TOO LARGE,="TL(I)"::SPEED UP OR REDUCE LOAD": STOP
4230  NEXT I
4240  GOTO 4270
4250  IF A% = 1 THEN  RETURN
4260 I = 0
4270  REM  INPUT"DO YOU WANT TO SEE THE ASCENT AND DSCENT PROFILE ? (
     Y/N) N ";AS$
4280  IF CP = 1 THEN SHIP$ = "CONVENTIONAL SOFT FINS"
4290 FE = FUL:GD = GD + FUL + MTA
4300  PR# 1: PRINT  CHR$ (30)
4310  PRINT  SPC( 29)BASE$" BASELINE"
4320  PRINT SHIP$"     "DA$
4330  PRINT "-----------------------------------------------------------
      -----------------------"
4340  PRINT "  VOL" SPC( 3)"ALT" SPC( 3)"THRSH" SPC( 4)"LIMIT" SPC( 3
     )"PROP" SPC( 3)"WEVN" SPC( 4)"PSWT" SPC( 4)"FUEL" SPC( 4)" PLD "
      SPC( 5)"BLST"
4350  PRINT "  M↑3" SPC( 3)" KM" SPC( 4)"KW" SPC( 6)" KW " SPC( 4)" K
     W " SPC( 3)" KG " SPC( 4)" KG " SPC( 4)" KG " SPC( 4)" KG " SPC(
     6)" KG "
4360  PRINT "-----------------------------------------------------------
      -----------------------"
4370 A1 =  INT ((A / GDRY + .0055) * 100):A1$ =  STR$ (A1)
4380 B1 =  INT ((EI / GDRY + .005) * 100):B1$ =  STR$ (B1)
4390 C1 =  INT (((FE * (LH(1) / LH)) / GDRY + .0055  * 100):C1$ =  STR$
     (C1)
4400 A = ( INT (A + .5)) + .0001
4410 B = ( INT ((B * 100) + .5) / 100) + .0001
4420 C = ( INT (FE + .5) + .0001)
4430 EI = ( INT (EI + .5)) + .0001
4440 H$ =  STR$ (C)
4450 DP = ( INT (((PD - PD(2)) * 100) + .5) / 100) + .0001
4460 A$ =  STR$ (VOL)
4470 B$ =  STR$ (ZT)
4480 C$ =  STR$ (K4(4))
4490 D$ =  STR$ (K1(4))
4500 E$ =  STR$ (K1(1))
4510 F$ =  STR$ (A)
4520 G$ =  STR$ (EI)
4530 H$ =  STR$ (C)
4540 I$ =  STR$ (B(9))
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4550 J$ =  STR$ (B(13))
4560  PRINT  SPC( 1) LEFT$ (A$,6) SPC( 3) LEFT$ (B$,6) SPC( 3) LEFT$
     (C$,6) SPC( 5) LEFT$ (D$,6) SPC( 3) LEFT$ (E$,6) SPC( 2) LEFT$ (
     F$,6) SPC( 2) LEFT$ (G$,6) SPC( 2) LEFT$ (H$,6) SPC( 4) LEFT$ (I
     $,6) SPC( 5) LEFT$ (J$,6)
4570  PRINT  SPC( 39) LEFT$ (A1$,2)"%" SPC( 5) LEFT$ (B1$,2)"%" SPC(
     6) LEFT$ (C1$,2)"%"
4580  PRINT
4590  PRINT "SUPER HEAT = "SH" K " TAB( 35)"SUPERCOOL = "SC" K"
4600  PRINT "CD = "CD;" " TAB( 35)"PROP CD = "CD(1)
4610  PRINT "SAFTEY FACTOR = "FS TAB( 35)"DAY PRESS (CM H2O) = "( INT
     ((PD / C3 * 1000) + .5) / 1000)
4620 UK(2) = UM(2) / C2
4630  PRINT "UNIT FAB WT="UFW" KG/M2" TAB( 35)"NITE PRESS= "( INT ((P
     D(2) / C3 * 1000) + .5) / 1000)
4640  PRINT "---WEIGHTS KGS:---"
4650  PRINT  TAB( 17)"ENVELOPE WT"
4660  PRINT "TAPE WT = "KTW TAB( 35)"HULL = "HFW
4670  PRINT "FIN SYS = "KI(2) TAB( 35)"BALONT SYS = "KD
4680  PRINT "CONE WT = "B(11) TAB( 35)"BLOWER = "B(0)
4690  PRINT "VALVE WT = "VW
4700  PRINT  TAB( 17)"POWER SYSTEM WT"
4710  PRINT "PROPELLER = "B(1) TAB( 35)"SHAFT = "B(2)
4720  PRINT "GEAR BOX = "B(3) TAB( 35)"PRIME MOTOR = "B(4)
4730  PRINT "RECTENNA = "B(5) TAB( 35)"TRANS. WIRE = "B(10)
4740  PRINT "AUXE ENG = "B(6) TAB( 35)"GENNERATOR = "B(7)
4750  PRINT "AVIONICS = "B(8) TAB( 35)"TANKS = "MTA
4760  PRINT  TAB( 35)"WATER RECOVERY="B(12): PRINT
4770  PRINT "RECTENNA AREA ="AR(5) TAB( 35)"ANGLE OF INCIDENCE LIMIT=
     "AI
4780  PRINT "MICROWAVE BEAM KW/M2= "K(5)
4790  PRINT "LIFT = "LD(3)" KGS","WEIGHT = "WG" KGS"
4800  PRINT  TAB( 10)"VELOCITIES, KTS": PRINT "LIMIT="UK(5) TAB( 20)"
     THRESHOLD="UK(1): PRINT "AUX DESIGN="UK(2) TAB( 20)"CUBE AVE>THR
     ES="UK(4)
4810  PRINT "VOLUME="VO" M3.     DIAMETER =" INT (VR * 2 * 100 + .5) /
     100" M     LENGTH WITH 5% CUT=" INT (LF * 100 + .5) / 100" M"
4820  IF  LEN (CO$(1)) <  > 0 THEN  PRINT " COMMENT "$CO$(1): PRINT  SPC(
     10)$CO$(2)
4830  PR# 0: IF PQ$ = "1" THEN  RETURN
4840  PR# 1
4850  REM
4860  REM  PRINTCHR$(12)
4870  PR# 0
4880  PR# 1: PRINT "DEMONSTRATOR VOLUME= "VO" CUBIC METERS ----> = " INT
     (VO / (.3048 ↑ 3))" CUBIC FEET


4890  GOTO 5600
4900  END
4910  REM  PRINT"SHIP IS NOT LARGE ENOUGH":PRINT"LIFT = "F,"WEIGHT =
     "G:END
4920  PRINT "TOO MUCH FUEL USED": PRINT "FUEL WT AVAILABLE AFTER SHIP
     SIZING = "M: PRINT "FUEL AVAILABLE PRIOR TO TRAVEL = "DW: END
4930  REM   KARL'S CONVERGENCE ON VOLUME
4940  IF V(1) = 0 THEN V(1) = VO:F(1) = DW: GOTO 4990
4950 V(2) = VO:F(2) = DW
4960 VO = ( - F(1)) * (V(2) - V(1)) / (F(2) - F(1)) + V(1):VO =  INT
     (VO)
4970 V(1) = V(2):F(1) = F(2)
4980  GOTO 2350
4990 VO = VO - (2000 *  SGN (DW))
5000  GOTO 4980
5010  PR# 1: REM  ****SYMBOLS PLAN****
5020  HOME : PRINT  TAB( 12)"** SYMBOLS PLAN **": PRINT
5030  PRINT  TAB( 10)"VELOCITIES"
5040  PRINT "UK=VEL KTS" TAB( 20)"UM=VEL M/S": PRINT
5050  PRINT "(1)=THRESHOLD" TAB( 20)"(2)=AUX ONLY"
5060  PRINT "(3)=MAXIMUM" TAB( 20)"(4)=CUBE AVE MAXS"
5070  PRINT "(10)=DESIGN SPEED" TAB( 20)"(5)=LIMITING "
5080  PRINT "VX(I) = AUX ONLY M/S ASCENT-DESCENT AT ALT I
5090  PRINT : PRINT : PRINT  TAB( 10)"COMPONENTS"
5100  PRINT "(0)=BLOWER"
5110  PRINT "(1)=PROPELLER" TAB( 20)"(2)=SHAFT" TAB( 40)"(3)=GEARBOX"

5120  PRINT "(4)=PRIMARY MOTOR" TAB( 20)"(5)=RECTENNA" TAB( 40)"(6)=A
     UX ENGINE"
5130  PRINT "(7)=GENERATOR" TAB( 20)"(8)=AVIONICS" TAB( 40)"(9)=PAYLO
     AD"
5140  PRINT "(10)=TRANSWIRE" TAB( 20)"(11)=CONE" TAB( 40)"(12)=WATER
```

```
     RECOVERY SYS
5150  PRINT "(13)=BALLAST"
5160  PRINT : PRINT
5170  PRINT  TAB( 10)"POWER,KW; FORMAT K FUNCTION(COMPONENT)"
5180  PRINT "--FUNCTIONS--"
5190  PRINT "K1=LIMITING" TAB( 20)"K2=CRUISE MAX" TAB( 40)"K3=CRUISE
     PARTIAL"
5200  PRINT "K4=THRESHOLD" TAB( 20)"K5=LIMIT INTO" TAB( 40)"K6=LANDIN
     G"
5210  PRINT "K7=RESERVE" TAB( 20)"K8=DESIGN MAX" TAB( 40)"K9=AUX OFF
     STAT & AUX DESIGN"
5220  PRINT : PRINT  TAB( 10)"AUX ENERGY,KWHR:  FORMAT H FUNCTION(COM
     PONENT)
5230  PRINT "--FUNCTIONS--"
5240  PRINT "H1=ASCENT" TAB( 20)"H2=AUXBACK" TAB( 40)"H3=ON STATION"
5250  PRINT "H4=AUXAWAY" TAB( 20)"H5=DESCENT" TAB( 40)"H6=LANDING"
5260  PRINT "H7=RESERVE" TAB( 20)"H8=ASCENT OPS" TAB( 40)"H9=DESCENT
     OPS"
5270  PRINT "HT=TOTAL MISSION"
5280  PRINT : PRINT  TAB( 10)"FUEL,KG: FORMAT F FUNCTION"
5290  PRINT "FUNCTION AS FOR ENERGY ABOVE"
5300  PRINT "FUL=TOTAL MISSION"
5310  PRINT : PRINT  TAB( 10)"TANKS,KG"
5320  PRINT  TAB( 10)"CONVERSION FACTORS": PRINT "C2=KNOTS TO M/S .51
     4444": PRINT "C3='CM H2O'TO PASCALS 98.0638
5330  PRINT "TKS=TOTAL MISSION"
5340  PRINT : PRINT  TAB( 10)"ALTITUDE"
5350  PRINT "ALT=METERS" TAB( 20)"ZT=KILOMETERS"
5360  PRINT : PRINT "WEIGHTS,KG" TAB( 20)"WEIGHT COEFF" TAB( 40)"POWE
     R COEFF" SPC( 10)"MISC"
5370  PRINT  TAB( 4)"B(COMP)" TAB( 25)"WC(COMP)" TAB( 40)"KC(COMP)" SPC(
     10)"AR(5) RECTENNA AREA"
5380  PRINT  TAB( 1)"PLUS" SPC( 53)"AI ANGLE OF INCIDENCE LIMIT": PRINT
      TAB( 1)"B2=WIRE RECT TO MOT": PRINT  TAB( 1)"B3=WIRE AUX TO MOT
     :B(10)=B2+B3"
5390  PRINT  TAB( 1)"WG=GROSS WT"
5400  PRINT : PRINT  TAB( 10)"EFFIC COEFF"
5410  PRINT "E(COMPONENT)
5420  PRINT  TAB( 10)"CONVERSION FACTORS": PRINT "C2=KNOTS TO M/S .51
     4444": PRINT "C3='CM H2O'TO PASCALS 98.0638
5430  PR# 0: END
5440  REM
5450  REM  SHAFT WT CALC,POWER TO TORQUE TO STRESS TO WT; FOR RECORD
     PURPOSES, NOT PART OF MAIN PROGRAM
5460 E(1) = .9:PI = 3.14159
5470  INPUT "K1(1),SL      = ";K1(1),SL
5480 S(1) = 1.45E8: REM   AL6061T6 SHEAR STR N/M2
5490 S(2) = 2700:S(3) = .25: REM  AL DENSITYKG/M3, SHAFT RADIUS M
5500 S(4) = (K1(1) * 1000 / E(1)) / (2 * PI * 1.67): REM   TORQUE AT
     100 RPM
5510 S(5) = S(4) / (S(1) * S(3)): REM  XSECT AREA M2
5520 BX = S(5) * S(2) * SL: REM  SHAFT WT KG
5530  REM  ABOVE REDUCES TO A CONSTANT WC(2)*K1(1)*SL WHERE WC(2)=0.0
     079 FOR FACTORS AS GIVEN.
5540 B(2) = 0.0079 * K1(1) * SL
5550  PRINT "B(2)-BX="B(2) - BX: REM  COMPARES SIMPLIFIED B(2) WITH E
     XACT BX
5560  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)
5570  GOTO 5450
5580  END
5590  END
5600  PR# 1: PRINT  TAB( 20)"* * * * * * * * * * * * * * *"
5610  PRINT "CALC LIMIT SPEED AT OTHER ALT, SAME PWR"
5620  FOR I = 12 TO 24: READ KV(I): NEXT
5630  PRINT "VO="VO"  ALT,KM="ZT"    ENG KW="K1(4)"    PROP KW="K1(1)
5640  FOR I = 12 TO 24:U = UK(5) * ((R(ZT) / R(I)) ↑ (1 / 3)):RN = UM
     (5) * LF / KV(I): PRINT "ALT, KM="I"   U, KTS=" INT (U * 10 + .5
     ) / 10; TAB( 30)"RN/E6=" INT ((RN / 1E6) * 10 + .5) / 10;: IF I =
     ZT THEN  PRINT " <---DESIGN";:J = I
5650  PRINT
5660  IF U < UK(1) THEN  PRINT "LIMIT < THRESHOLD OF "UK(1)" KTS"
5670  IF I = J + 2 THEN 5690
5680  NEXT
5690 A$ = "CV": PR# 1:A% = 2: GOSUB 3550
5700  PR# 1: PRINT  CHR$ (12): PR# 0
5702  STOP
5710  CLEAR
5720  INPUT "VARIABLES CLEARED, GOES TO 10, INPUT NEW ALT=";ALT
5730 SK$ = "SKIP": GOTO 10
```

```
5740  DATA  4.5574E-5,5.3325E-5,6.2391E-5,7.2995E-5,8.5397E-5
5750  DATA  9.9902E-5,1.1686E-4,1.3670E-4,1.5989E-4,1.8343E-4,2.2201E
     -4,2.6135E-4,3.0743E-4
5760  PR# 1: PRINT  CHR$ (29): PRINT "FUEL USED": PRINT "FUEL USED": PRINT
     : PRINT
5770  PRINT  CHR$ (31): PRINT "FUEL USED, CHR$(31)": PRINT "FUEL USED
     ": PRINT : PRINT : END
```

```
JRUN
                                   HAPPDEMO 26OCT82 BASELINE
DOLPHIN SOFT FINS      28OCT82
```

VOL M↑3	ALT KM	THRSH KW	LIMIT KW	PROP KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
10550	15	23.290	56	45.963	692.00 48%	498.00 35%	149.00 9%	100	235.2

```
SUPER HEAT = 16.7 K                          SUPERCOOL = -17.2 K
CD = .018                                    PROP CD = .0187681845
SAFTEY FACTOR = 5                            DAY PRESS (CM H2O) = 12.273
UNIT FAB WT=.11867 KG/M2                     NITE PRESS= 2.5
---WEIGHTS KGS:---
                    ENVELOPE WT
TAPE WT = 27.1205152                         HULL = 339.00644
FIN SYS = 55.1271831                         BALONT SYS = 206.590892
CONE WT = 47                                 BLOWER = 13.9036066
VALVE WT = 3.22350151
                    POWER SYSTEM WT
PROPELLER = 96.5223                          SHAFT = 6.3308
GEAR BOX = 22.876                            PRIME MOTOR = 235.2
RECTENNA = 0                                 TRANS. WIRE = 0
AUXE ENG = 0                                 GENNERATOR = 2.343
AVIONICS = 117.3                             TANKS = 17.3103388
                                             WATER RECOVERY=0

RECTENNA AREA =0                             ANGLE OF INCIDENCE LIMIT=0
MICROWAVE BEAM KW/M2= 0
LIFT = 1674.48424 KGS                      WEIGHT = 1674.55296 KGS
        VELOCITIES, KTS
LIMIT=73.3835826    THRESHOLD=55
AUX DESIGN=0        CUBE AVE>THRES=0
VOLUME=10550 M3.     DIAMETER =19.43 M     LENGTH WITH 5% CUT=63.33 M
DEMONSTRATOR VOLUME= 10550 CUBIC METERS ----> = 372569 CUBIC FEET


                    * * * * * * * * * * * * * * *
CALC LIMIT SPEED AT OTHER ALT, SAME PWR
VO=10550  ALT,KM=15   ENG KW=56   PROP KW=45.963
ALT, KM=12   U, KTS=62.7      RN/E6=52.5
ALT, KM=13   U, KTS=66.1      RN/E6=44.8
ALT, KM=14   U, KTS=69.6      RN/E6=38.3
ALT, KM=15   U, KTS=73.4      RN/E6=32.8 <---DESIGN
ALT, KM=16   U, KTS=77.3      RN/E6=28
ALT, KM=17   U, KTS=81.5      RN/E6=23.9
                    * * * * * ASCENT PROFILE * * * * *
POWER OFF ASCENT AT 150 M/MIN; WINDS WASHDC SUMMER 84%
TIME TO CLIMB TO 15 KM=1.66666667
BLOWOFF DISTANCE =145.492994 KM.
TIME TO AUXBACK TO STATION =6.91549296HRS, AT THRESHOLD SPD
FUEL USED ASCENT AND AUXBACK =30.602088 KG
                    * * * * * ON-STATION PROFILE * * * * *
STATION WIND =43.64 KTS
SHIP SPEED ON THRESHOLD POWER=55 KNOTS:LIMITING VEL = 73.3835826KTS
FOR 4HRS RESERVE + 4HRS MANEUVERING @ LIMIT 73.4 KTS STATION FUEL WT = 85.12
            * * * * * DSCENT PROFILE,  AUXAWAY AND DSCENT AT THRESHOLD * * * * *
POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 15 KM=1.66666667 HRS
FUEL FOR DESCENT = 7.37524863 KGS
AUXAWAY AT ALT TIME AND DISTANCE = 1.48332981 HRS AND -31.2073336 KM
FUEL FOR AUXAWAY = 6.5639557 KGS
FUEL FOR BLOWER = 2.13649184 KGS
FUEL FOR LANDING 4HR AT THRESHOLD PWR(SL 29.8KT)=17.7005967 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 33.7762929 KG
                    * * * * * SUMMARY * * * * *
TOTAL FUEL WT FOR MISSION = 149.498381
```

```
                                      mAPPDEMO 26OCT82 BASELINE
DOLPHIN SOFT FINS       28OCT82
```

VOL M↑3	ALT KM	THRSH KW	LIMIT KW	PROP KW	WEVN KG	PSWT KG	FUEL KG	PLD KG	BLST KG
10550	15	23.290	56	45.963	692.00 48%	498.00 35%	149.00 9%	100	235.2

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SUPER HEAT = 16.7 K                    SUPERCOOL = -17.2 K
CD = .018                              PROP CD = .0187681845
SAFTEY FACTOR = 5                      DAY PRESS (CM H2O) = 12.273
UNIT FAB WT=.11867 KG/M2               NITE PRESS= 2.5
---WEIGHTS KGS:---
              ENVELOPE WT
TAPE WT = 27.1205152                   HULL = 339.00644
FIN SYS = 55.1271831                   BALONT SYS = 206.590892
CONE WT = 47                           BLOWER = 13.9036066
VALVE WT = 3.22350151
              POWER SYSTEM WT
PROPELLER = 96.5223                    SHAFT = 6.3308
GEAR BOX = 22.876                      PRIME MOTOR = 235.2
RECTENNA = 0                           TRANS. WIRE = 0
AUXE ENG = 0                           GENNERATOR = 2.343
AVIONICS = 117.3                       TANKS = 17.3103388
                                       WATER RECOVERY=0

RECTENNA AREA =0                       ANGLE OF INCIDENCE LIMIT=0
MICROWAVE BEAM KW/M2= 0
LIFT = 1674.48424 KGS               WEIGHT = 1674.55296 KGS
        VELOCITIES, KTS
LIMIT=73.3835826   THRESHOLD=55
AUX DESIGN=0       CUBE AVE>THRES=0
VOLUME=10550 M3.    DIAMETER =19.43 M    LENGTH WITH 5% CUT=63.33 M
DEMONSTRATOR VOLUME= 10550 CUBIC METERS ----> = 372569 CUBIC FEET


                 * * * * * * * * * * * * * * *
CALC LIMIT SPEED AT OTHER ALT, SAME PWR
VO=10550   ALT,KM=15    ENG KW=56    PROP KW=45.963
ALT, KM=12   U, KTS=62.7      RN/E6=52.5
ALT, KM=13   U, KTS=66.1      RN/E6=44.8
ALT, KM=14   U, KTS=69.6      RN/E6=38.3
ALT, KM=15   U, KTS=73.4      RN/E6=32.8 <---DESIGN
ALT, KM=16   U, KTS=77.3      RN/E6=28
ALT, KM=17   U, KTS=81.5      RN/E6=23.9
                 * * * * * ASCENT PROFILE * * * * *
POWER OFF ASCENT AT 150 M/MIN; WINDS WASHDC SUMMER 84%
TIME TO CLIMB TO 15 KM=1.66666667
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TIME TO AUXBACK TO STATION =6.91549296HRS, AT THRESHOLD SPD
FUEL USED ASCENT AND AUXBACK =30.602088 KG
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STATION WIND =43.64 KTS
SHIP SPEED ON THRESHOLD POWER=55 KNOTS:LIMITING VEL = 73.3835826KTS
FOR 4HRS RESERVE + 4HRS MANEUVERING @ LIMIT 73.4 KTS STATION FUEL WT = 85.12
        * * * * * DSCENT PROFILE,  AUXAWAY AND DSCENT AT THRESHOLD * * * * *
POWERED DESCENT AT 150 M/MIN
TIME TO DESCEND FROM 15 KM=1.66666667 HRS
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FUEL FOR BLOWER = 2.13649184 KGS
FUEL FOR LANDING 4HR AT THRESHOLD PWR(SL 29.8KT)=17.7005967 KGS
FUEL USED FOR DESCENT OPS INCL 8HR LANDING = 33.7762929 KG
                 * * * * * SUMMARY * * * * *
TOTAL FUEL WT FOR MISSION = 149.498381
```

APPENDIX B

APPENDIX B

This Appendix in Section 1 gives results of a brief survey of engine possibilities for the HAPP Demonstrator.

Section 2 is a presentation by Thunder Engines, Inc., on the possibilities for development of a suitable turbocharged reciprocating engine for the HAPP Project.

APPENDIX B

SECTION 1

HAPP DEMONSTRATOR

ELECTRIC * Motor

Battery

Lithium

NiCad

Fuel Cell

Reciprocating Generator

RECIPROCATING

* { Supercharged
Turbocharged }

* { Air cooled
Liquid cooled }

* { Hydrogen
Fossil Fuel
Hydrazine }

TURBINE

Turbojet

Turboshaft

ELECTRIC

An electric drive motor propulsion system can be configured several different ways. In all cases, the drive motor is a DC Samarium Cobolt electric drive.

Drive Motor

Inland Motor Co.

Samarium Cobolt

250 - 300 VDC

30 HP per motor @ 10000 rpm

Liquid Cooled

.80 - .90 efficiency off the shelf

Battery

Nickle - Cadmium

Union Carbide and RCA Astro Electronics

Long Shelf Life

$\sim$ 25 $\frac{\text{Watt - hrs}}{\#}$

550 Kw - hrs → 22000 lbs

Lithium

RCA Astro Electronics and NASA Goddard

Non-rechargable (primary)

2.4 - 3.3 volts/cell

Usually deliver power @ slow rates

$\sim$ 100 $\frac{\text{Watt - hrs}}{\#}$

550 Kw - hrs → 5500 lbs

ELECTRIC (cont'd)

Fuel Cell

Westinghouse Advanced Energy Systems

Englehrad Industrial and United Technologies

Electro chemical reaction

Can be wired for just about any voltage

Can constantly adjust to power demanded

30 $\frac{\text{Watts}}{\#}$

37 kw → 1230 lbs

40 Std ft^3 of hydrogen/kw-hr

May require oxygen or compressor to meet oxygen demanded, $H_2 + O \rightarrow H_2O$

$100K - 500K w/controller electronics

Generator

Inland Motor/RPM Development

Samarium Cobolt Generator

Turbocharged Reciprocating (See Recip. Power Plant Section)

Will require development for generator

TURBINE

A turbine based system may be difficult to start at altitude. The turbine power output capability decreases with inlet air density. To provide 50 hp at altitude, the engine must be sized to provide ten times that at sea level.

TURBINE (cont'd)

Turbojet

High velocity exhaust gas inappropriate for use with slow flying vehicle.

Turboshaft

Williams Research and Pratt and Whitney

PT-6-A25, 550 shp @ SL output 2200 rpm

.60 lb/HP-hr

303 lbs

Fuel wt ≅ 450 lbs for 15 hrs at 50 hp.

Requires an additional gearbox to output 100 rpm from 2200 rpm output

This engine has been operated at 55000 feet.

Vertical operation during launch potential problem.

Must start engine at low altitude.

RECIPROCATING

Due to the low air density at 50000 feet, the inlet air to the engine must be compressed. This can be accomplished with a gear driven (supercharger) or exhaust powered (turbocharged) compressor. To obtain a wide range of power levels at altitude, the compressor as a minimum must have two stages. An additional consideration is engine cooling. Due to the low air density, air cooling, in any conventional sense, is not adequate and the engine must be liquid cooled. Aviation engine manufacturer expertise generally apply to air cooled engines. A liquid cooled, high altitude reciprocating engine is a special development item.

RECIPROCATING (cont'd)

Three possible fuels are considered.

1. Hydrogen - Requires insulated tank.

   Potential handling problems.

2. Fossil Fuel - Well understood

3. Hydrazine - Not pursued because it was felt

   too hazerdous for this mission.

RPM Development

165 in^3 4 cylinder

170 hp.

SFC = ?

Will require turbocharger and gear box development.

Engine $50 K

Gearbox $50 K

Turbo $100 K

Rotoway

4 cylinder, opposed

Water cooled block

100 hp at SL

Used in small helicopter

Development costs unknown

THUNDER ENGINES INC.

PROPULSION SYSTEM PROPOSAL

FOR I.L.C./HAP PROJECT

Prepared by Thunder Engines, Inc.
501 Reservation Road
Marina, California 93933
(408) 384-3063

October 1982

THUNDER ENGINES INC.

November 3, 1982

I. L. C. Dover, Inc.
P. O. Box 266
Frederica, Delaware 19946

Attn: James Thiele

Dear Mr. Thiele:

Please find enclosed the propulsion system description for your proposal on the HAP project.

In summary, this material comprises:

1.) The Problem Statement.
2.) The Design Approach of Thunder Engines.
3.) An approach to engine sizing.
4.) Description of two candidate engines.
5.) The turbosystem analysis.
6.) Heat exchanger design and sizing calculations.
7.) Sketch of the layshaft-type gearbox.
8.) A weight summary.
9.) A cost overview.
10.) A brief description of Thunder Engines facility and staff structure.

I trust this material is of use in your report, and it may interest you to know we have aimed for the maximum amount of duplication between this proposal and the Lockheed HI-SPOT with regard to the candidate engine and parts of the turbosystem.

Thunder Engines is, we believe, uniquely equipped by reason of company size, recent experience and industry contact to be a very effective sub-contractor on your propulsion system. Please consider our company very seriously if the contract for a flight demonstrator is awarded.

Yours sincerely,

W.M Waide.

W. Martin Waide
Vice President Engineering

WMW:lah

7120 HAYVENHURST AVE., SUITE 321, VAN NUYS, CA 91406 / (213) 997-0117

The Problem Statement

Thunder Engines R & D staff have been approached for an initial appraisal of a propulsion system with the following characteristics.

Rated Power at Altitude - 70 B.H.P. at 50,000 feet.

Minimum practical installed system weight.

Emphasis on minimum fuel consumption.

Reduction drive for large, slow-turning propeller.

A turbocharged, liquid cooled, four-cycle engine can be produced with these characteristics. Extensive supporting data exists from similar automotive and aircraft designs, and as a result, the following description is seen as a low-risk approach.

A brief outline of the analytical approach to engine, turbocharger and intercooler sizing is provided in subsequent paragraphs.

The Design Approach of Thunder Engines

Thunder Engines capability includes the design, prototype build and testing skills necessary to produce a lightweight engine of the required displacement.

However, a brief survey of existing liquid cooled, light, large displacement 4 cylinder engines shows that the Lotus 907 is a possible candidate. This British engine is constructed from aluminum die castings, and as 70 B.H.P. at 4000 rpm is a considerable de-rating from its designed power, a bore and stroke increase to 4.1 x 3.25 is feasible. These modifications give a swept volume of 165 cubic inches. An assembled engine dry weight of 155 lbs. can be achieved.

One other alternative is the recently constructed 4 cylinder Weslake engine, which would produce its rated power at 4000 rpm from a displacement of 236 cubic inches, but which would require a conversion to liquid cooling. This is already a minimum-weight design, being intended for large motor gliders.

Both the above engines feature four valves per cylinder giving high combustion efficiency and a 70% power B.S.F.C. of 0.40 lbs. per H.P. hour. Depending on the time and budget constraints of the subject program, the modification of an existing proven engine would merit further study. (Thunder Engines could, however, rapidly produce a candidate engine which properly meets the unique requirements.*)

*i.e. we could build from a fresh design, but it makes more sense to use the most applicable, existing, cylinder block as a basis for a flight engine.

THUNDER ENGINES INC.

Photographs of various components of the in-line 4-cylinder engine are enclosed. Please understand that the engine will be re-configured with a lightweight crankshaft, and a light, single camshaft cylinder head.

One other candidate engine, still in development by General Motors, but undoubtedly intended for production, is the Buick lightweight V-6 engine.

This die cast, integral crankcase, cylinder block and cylinder liner component is currently being produced in small batches for prototype use. A considerable investment has been made in the tooling, and the beautiful result represents the "state of the art" in thin-wall Reynolds 390 aluminum cylinder blocks. Weighing 38 pounds, the 160 to 180 cubic inch displacement block is close to the weight of some experimental graphite/ glass/epoxy blocks, yet avoids the expense and risk of that approach. An adequate supply of these blocks could almost certainly be negotiated with G.M. senior management when the time came to build a propulsion system in '83.

Photographs of this block are enclosed, and some of the automotive features amounting to 15 cubic inches of material not required for the flight application could be removed, saving 1.4 pounds. At a rated power of 70 B.H.P., the engine is conservatively stressed and represents a low-risk, fast response approach for an available candidate engine. Again, the crankshaft, cylinder heads and accessories would be re-configured in flight weight form. A small scale drawing showing this v-6 engine with manifolding is enclosed, as are some full scale block drawings to enable you to get an appreciation of relative sizes.

The design and development of lightweight high-efficiency turbochargers is a complex subject, and Thunder Engines is currently contracted to a small California company (THERMO MECHANICAL SYSTE specializing in this field. In the areas of analysis, prototype build and sub-system test, Thunder Engines would be properly supported in the turbocharger aspects of the program.

With regard to the propeller reduction gearing, Thunder Engines has successfully designed, built and tested a series of reduction gear boxes. Complete responsibility could be taken for this part of the project, with actual gear manufacture being sub-contracted to one of three Los Angeles gear specialists.

THUNDER ENGINES INC.

Engine Sizing

Cubic Inch displacement is determined as follows:

1. B.S.F.C. is assumed to be .41 at altitude, thus
   $\dot{m}$ fuel = 70 B.H.P. X 0.41 lb/hp-hour
   = 28.7 lb/hour = 0.478 lb/min fuel (gasoline)

2. F/A ratio is assumed to be 0.067

$$\frac{\dot{m}\text{ fuel}}{F/A} = \frac{0.478\text{ lb.fuel/min.}}{0.067\text{ lb. fuel/lb.air}} = 7.134\text{ lb/min engine airflow.}$$

3. Manifold Pressure is given to be 15 "HgA
   Manifold air temperature to be 85°F., and
   volumetric efficiency to be 100%

$$\text{C.I.D.} = \frac{7.134\text{ lb/min}\times 0.37\,\frac{ft^3\cdot psia}{lb.m.{}^\circ R}(460+85)^\circ R.\left(\frac{12in}{1ft}\right)^3}{\frac{15.3}{2.036}\text{ p.s.i.a.}(4000\text{ r.p.m.})\left(\frac{1\text{ cycle}}{2\text{ rev.}}\right)}$$

$$= \underline{165\text{ CUBIC INCHES}}$$

4. Brake Mean Effective Pressure is given by $\frac{\text{B.H.P. X 33,000}}{\text{L.A.N/2}}$

   where L = length of stroke in feet
   A = total piston area in square inches
   N/2 = no. of firing strokes per minute.

$$\text{B.M.E.P.} = \frac{70 \times 33{,}000 \times 12}{3.25 \times 52.8 \times 2{,}000}$$

$$= \underline{80.8\text{ P.S.I.}}$$

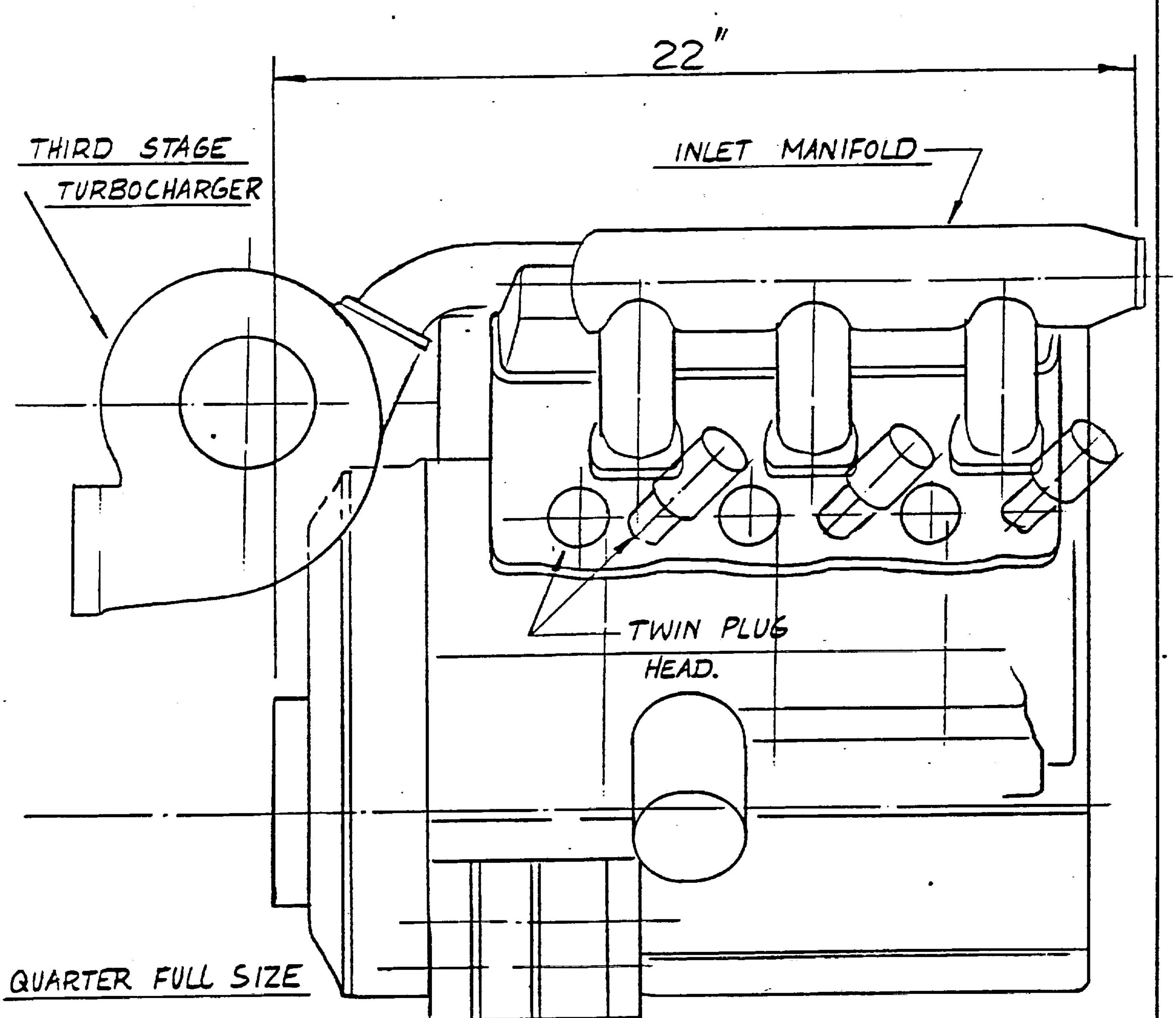
There are some specific reasons for selecting a low B.M.E.P., a relatively low manifold pressure and correspondingly large swept volume.

The low B.M.E.P. gives modest engine stresses and allows light components to be used.

The low manifold pressure permits a two-stage* compressor, operating at a modest pressure ratio and hence allowing a broad range of powers.

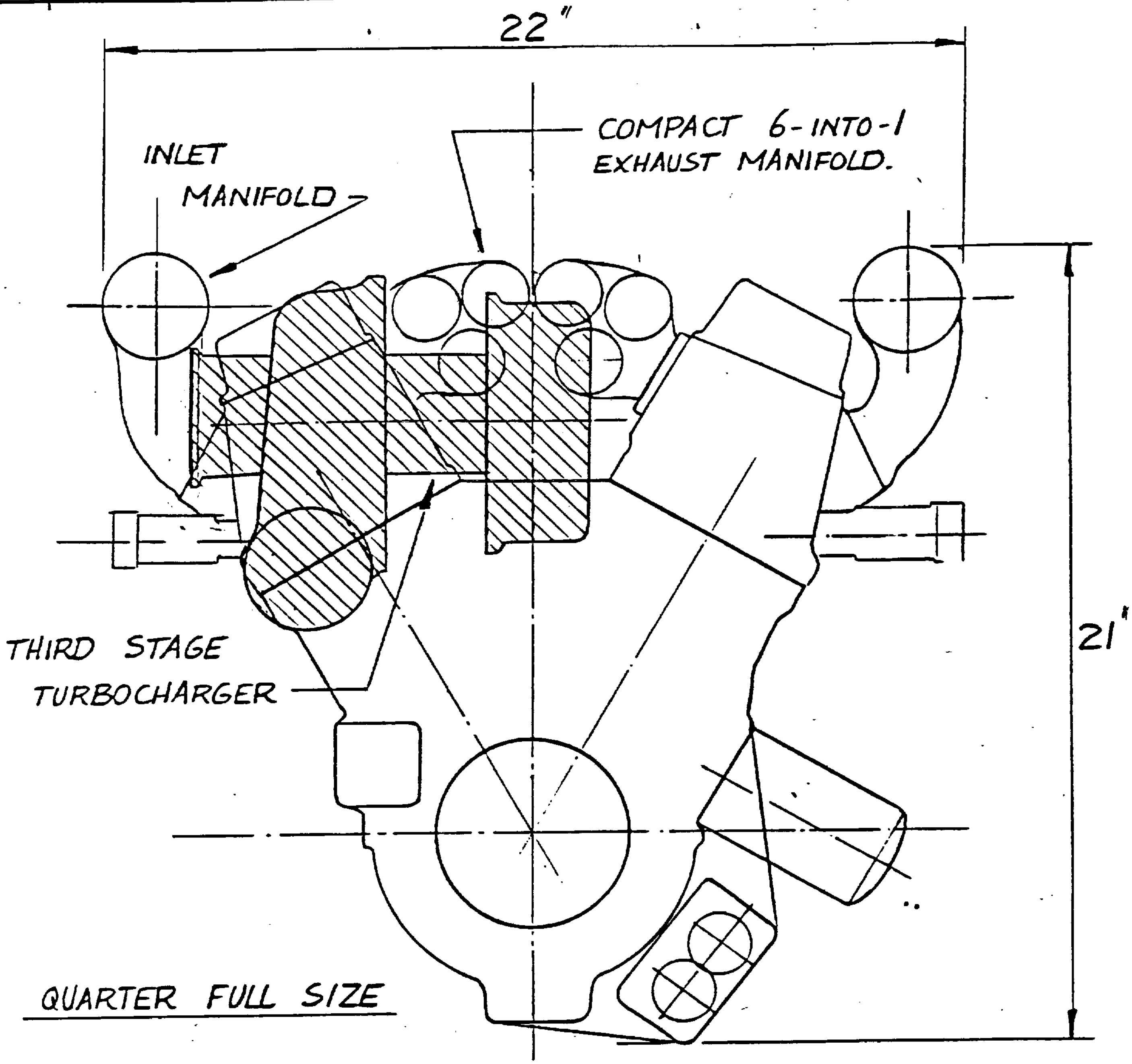
* For the 50,000 ft. demonstration.
3-stages req'd. for 70 K ft.

REVISIONS			10-19-82
LTR	DESCRIPTION	APPROVED	DATE

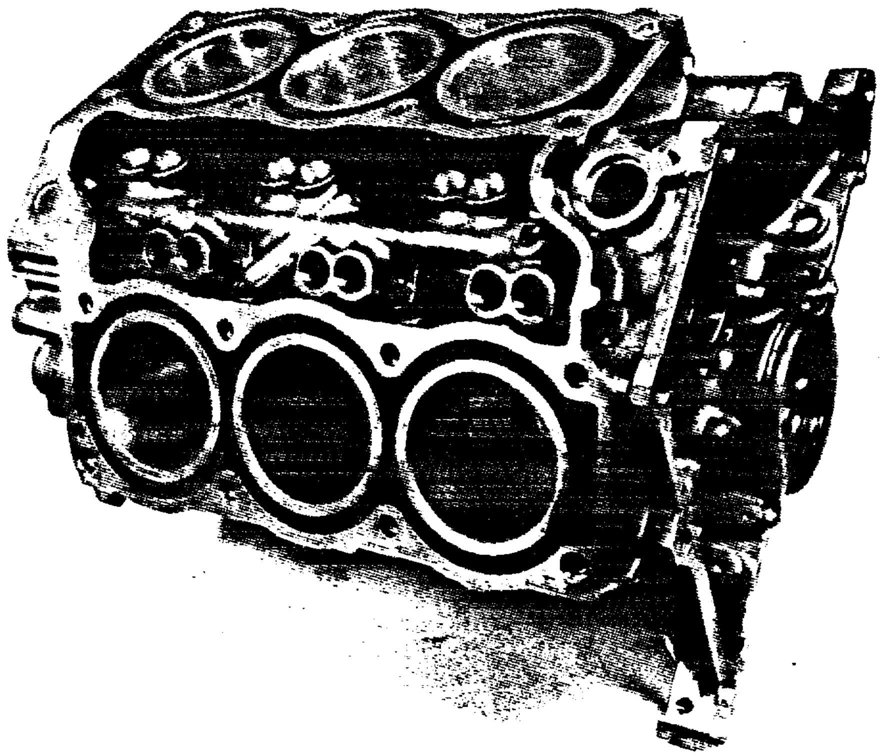


FIRST USED ON MODEL:	DR		**THUNDER ENGINES INC.**
	CHK		
	ENGR		TITLE COMPACT 165 C.I.D. V-6 SIDE VIEW
NEXT ASSY	PROJ ENGR		
	STRESS		
	DOC CONT		
	MATL		SIZE A / DWG NO: / REV
	FINISH		SCALE / SHT OF

REVISIONS			10-19-62
LTR	DESCRIPTION	APPROVED	DATE



FIRST USED ON MODEL:	DR		**THUNDER ENGINES INC.**
	CHK		
	ENGR		
NEXT ASSY	PROJ ENGR		TITLE COMPACT 165 C.I.D. 60° ALUMINUM V-6 ENGINE
	STRESS		
	DOC CONT		
	MATL		SIZE A · DWG NO: · REV
	FINISH		SCALE · SHT OF



EXPERIMENTAL ENGINE BLOCK
V6 ALUMINUM ALLOY
WEIGHT 38 POUNDS

THUNDER ENGINES INC.

TURBO-SYSTEM PROPOSAL FOR THE I.L.C. PROPULSION SYSTEM.

Prepared for Thunder Engines Inc. by:-

Thermo Mechanical Systems Co.
Canoga Park,
California.

1.0 OVERVIEW/OBJECTIVES

This proposal presents the TMS approach for developing a turbocharger system for the TE high altitude propulsion system. Propulsion system performance goals, at the design 70,000 ft altitude, are:

- Maximum power of 70 BHP at about 4000 RPM and 17"Hga boost pressure
- Minimum power of about 15 BHP at about 2000 RPM and 7.3"Hga boost pressure

The proposed TE engine is of about 165 in^3 displacement and, with about 94% volumetric efficiency, gives maximum and minimum power air flow rates of .124 lb/sec and .0266 lb/sec respectively. For best efficiency (i.e. lowest fuel consumption) over this broad operating range (i.e. 15 to 70 hp) it was decided to use a 3 stage turbocharger system with maximum per stage compressor pressure ratio of about 2.4 to 1. This low per stage compressor pressure ratio will provide significantly better fuel economy over the required broad range than a 2 stage system.

The following sections present i) the system preliminary analyses/design, ii) the proposed development program (i.e. Statement of Work), and iii) the estimated program time. Also included as an attachment to this proposal is a TMS report giving a brief summary of experience capabilities, facilities, personnel and related contracts.

2.0 SYSTEM PRELIMINARY ANALYSES AND DESIGN

A preliminary analyses was performed to determine 1) compressor design requirements, 2) turbine design requirements, and 3) turbo/engine matching requirements, over the range of engine operating conditions.

With respect to item (1), the performance goals dictate a three stage turbocharger system having first, second, and third stage compressor impeller diameters of about 6.25 inches, 5.0 inches, and 3.0 inches, respectively. These impellers will be machined using existing TMS tooling and will be of an existing design which has demonstrated high efficiency over a broad range. However, due to the relatively low compressor pressure ratios per stage (compared to previous TMS compressor designs) the outlet area from each impeller must be increased (by as much as 50%) over that of previous TMS impellers.

With respect to item (2), preliminary analyses indicates that off-the-shelf commercial turbine wheels can be used for all three stages. The first stage will utilize the Howmet fabricated VAT turbine rotor with a tip diameter of about 6.4 inches; the second stage will utilize the AID T18A40 turbine rotor with a tip diameter of about 5.1 inches; and the third stage will utilize the Schwitzer 4LE303 turbine rotor with a tip diameter of about 3.6 inches.

With respect to item (3), Figures 1 and 2 present the results of the turbo/engine matching at the maximum and minimum power conditions, respectively, at the 70,000 ft design altitude. It should be noted that these results are the final results of many iterations in which turbine nozzle areas were matched i) to provide the required 7.3"Hga boost at minimum power conditions while ii) providing equal compressor pressure ratios of about 2.41 at maximum power conditions. As noted in Figure 1, the maximum horsepower (70 BHP) propulsion system operating conditions are:

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- an engine speed of 4000 RPM
- an air flow rate of .124 lb/sec
- a boost pressure of 17.0"Hga } giving an engine ΔP of +8.5"Hga
- an exhaust pressure of 8.5"Hga }
- an engine exhaust gas temperature of 2110°R
- 30% wastegate flow
- equal compressor pressure ratios of 2.41
- 1st, 2nd, and 3rd stage turbo speeds of 42,903, 59,141, and 98,550 RPM respectively
- 1st, 2nd, and 3rd stage turbo shaft horsepowers of 7.0, 9.0, and 9.0 hp respectively, with 3% bearing losses
- assumed intercooler ΔP's of 4% and outlet temperatures of 545°R
- compressor and turbine efficiencies between 70 to 75%

Similarly, from Figure 2 the minimum horsepower (15 BHP) propulsion system operating conditions are:

- an engine speed of 2000 RPM
- an air flow rate of .0266 lb/sec
- a boost pressure of 7.33"Hga } giving an engine ΔP of +4.4"Hga
- an exhaust pressureof 2.94"Hga }
- an engine exhaust gas temperature of 2110°R
- 3% wastegate flow (due to leakage only)
- 1st, 2nd, and 3rd stage compressor pressure ratios of 1.41, 1.75, and 2.30 respectively
- 1st, 2nd, and 3rd stage turbo speeds of 25,719, 46,051, and 95,278 RPM respectively
- 1st, 2nd, and 3rd stage turbo shaft horsepowers of .52, 1.14, and 1.8 hp respectively, again with 3% bearing losses
- assumed intercooler ΔP's of 1% and outlet temperatures of 545°R

- compressor and turbine efficiencies between 70 to 75%

As shown in Figures 1 and 2, only the 2nd and 3rd stage air coolers are needed as the combination of i) the low ambient temperature (392°R) and ii) the low stage pressure ratio, eliminates the need for the first stage air cooler. As shown, the 2nd and 3rd stage air cooler heat rejection rates are 6.2 Btu/sec each at the maximum power condition, and .80 Btu/sec and 1.24 Btu/sec respectively, at the minimum power condition . Furthermore, the preliminary control system analyses indicates that a single wastegate between the engine and the 3rd stage turbine will provide the required operating range control. As indicated, this wastegate will be essentially closed (i.e. except for leakage), at the minimum power condition and will be approximately 30% open at the maximum power condition. This 30% wastegate flow is necessary to keep from overboosting the engine (i.e. beyond 17.0"Hga) at the maximum power condition.

3.0 PROPOSED PROGRAM (STATEMENT OF WORK)

The development/demonstration of the propulsion system identified in the previous section will be accomplished via the following specific tasks:

Task 1 - Configuration Cycle and System Analysis, Detailed Design and Interface Requirements

Task 2 - Fabrication and Procurement of Turbochargers and Ancillary Equipment

Task 3 - Test Program Preparation

Task 4 - Test Facility Preparation

Task 5 - Testing and Development of Turbocharger and Engine System

Task 6 - Reporting

A brief summary of the effort proposed for each of these tasks is as follows:

Task 1 - Configuration Cycle and System Analysis, Detailed Design and Interface Requirements

The configuration cycle and system analysis, detailed design and interface requirements will further detail and expand on the preliminary analysis and design presented in the previous section. Analysis subtasks to be performed in this task include (but are not limited to):

1. To determine engine BMEP, BSFC, and BHP at required engine operating conditions. TMS has available turbocharger and engine matching computer programs that can be used to determine such critical parameters as compressor and turbine efficiencies, required turbine nozzle areas, wastegate settings, engine ΔP, etc. These computer programs allow determination of propulsion system performance as a function of individual component performance parameters (e.g. turbine efficiency, engine volumetric efficiency, heat exchanger pressure drops, etc.). As a result of this computer program capability, TMS, in close coordination with the engine manufacturer, can suggest/utilize engine design parameters to optimize overall powerplant performance.

2. To evaluate potential control systems for optimizing propulsion system performance. Potential control techniques include: exhaust system

wastegate, variable-pitch propeller, engine throttling, and intercooler bypass. It is very possible that several of these controls will be required for optimum powerplant performance.

3. To evaluate and to determine the matching parameters (e.g. flow rate, pressure ratio, speed, efficiency, compressor surge) of the three turbochargers as they relate to engine parameters (e.g. flow rate, pressure and temperature at exhaust opening) at required engine operating conditions. This will include final sizing i) the inducers and diffusers for the compressor rotors and ii) the nozzles and exducers for the turbine rotors. In addition, close coordination with the engine manufacturer will be maintained so that engine design options (e.g. valve timing, valve sizes) will be made to give overall highest propulsion system performance.

4. To determine/estimate the weight of all turbocharger system components and to reevaluate, if necessary, to meet program goals.

5. To evaluate intake manifold, exhaust stack, and interconnecting duct designs and associated losses (e.g. friction, turning, and thermal losses) and to determine acceptable designs to meet overall performance objectives. At the cold environmental temperatures (e.g. -65°F) it may be important to insulate the exhaust stacks and turbine housings to reduce energy losses.

6. To evaluate and specify the turbocharger lubrication system design. It is anticipated that the turbochargers will utilize the engine oil lubricant system.

With respect to the detailed design of the turbocharger system, all necessary design effort to define the turbocharger system hardware for fabrication will be performed. This will include showing turbocharger system connections to the engine, heat exchangers and airframe as coordinated with the engine and airframe contractors. As indicated in the previous preliminary analyses section, the estimated compressor impeller diameters are 6.25, 5.0, and 3.0 inches for the 1st, 2nd, and 3rd stages respectively. The turbine rotors will be from available commerical units; the VAT for the 1st stage, the AID T18A40 for the second stage, and the Schwitzer 4LE303 for the third stage. Low friction ball bearing assemblies will be designed for each turbocharger. In addition, adjustable geometry compressor diffuser and turbine nozzle vanes will be used on all stages to insure optimum turbo/eninge matching. This adjustable geometry can/will be eliminated in the final flight hardware. The estimated flight weight for the complete turbocharger system (including wastegate, ducting, insulation, etc.) is about 50 lbs with the first prototype demonstration version weight being about twice that. The additional weight of this first prototype version is due to i) the adjustable geometry and associated heavier hardware, ii) the flanged and bolted heavy duty ducting, and iii) the heavier weight materials for test development durability considerations.

Task 2 - Fabrication and Procurement of Turbochargers and Ancillary Equipment

Based upon the results of Task 1 above, TMS will fabricate or procure the hardware for two complete turbocharger sets (3 stages each) with an additional set of critical spare parts (impellers, rotors, bearings, etc.).

TMS presently has the tooling to manufacture all three compressor impellers. It is anticipated that the turbine rotors will be rotors from existing turbochargers (third stage from the Schwitzer 4LE303, second stage from the AiResearch T18A40, and the first stage from the VAT) with slight modifications. TMS utilizes several local machine shops to fabricate/modify turbocharger components. The turbocharger housings will be fabricated using sheet metal and all components will be designed with weight and reliability as critical design criteria. Other turbocharger system components (controls, ducting, bearings) will be fabricated or procured as appropriate.

Task 3 - Test Program Preparation

The detailed test plan and test data computational procedures will be formulated for testing the complete turbocharger and engine system.

Task 4 - Test Facility Preparation

Turbocharger Test Facilities

Initial turbocharger testing will first be performed in the TMS blockhouse test facility. This will permit developmental testing of individual turbocharger stages under steady flow conditions necessary for generating accurate compressor impeller performance maps. This facility will be modified as necessary to accommodate the turbochargers developed in the previous tasks. The turbocharger will be mounted on a test bench and monitored by operators at a console outside the blockhouse via an observation window. All instrumentation readouts will be located in instrumentation panels at the console location.

Turbine drive air will be supplied by two series-connected centrifugal compressors driven by an Allison aircraft engine located just outside the lab facility. The pressurized air will be ducted through the blockhouse wall to a J-33 jet combustor which can add additional energy to the air if required. This configuration can supply six pounds of turbine drive air per second at 60 psia and up to 1500^{o}F. Air pressure will be controlled primarily by varying the speed of the Allison engine. Turbine exhaust air will be vented unthrottled to ambient through a muffler.

Figure 3 shows a typical turbocharger installation on the TMS test cart. The moveable test cart incorporates an oil tank, oil pump, oil coolers and an oil safety system. Air drawn into the compressor is metered by a venturi connected to a 60 inch vertical water manometer. Compressor pressure ratio is controlled by reducing inlet pressure with a remotely-controlled, electrically-operated butterfly valve while exhausting compressor air to ambient pressure.

Propulsion System Test Facilities

Layout. Figure 4 presents a very simplified schematic of the TMS high altitude propulsion system test facility which will be used in this program. This facility will be modified as necessary to accommodate the propulsion system developed in this program. The altitude chamber encompasses the engine, turbochargers, dynomometer and the sensing portions of the instrumentation. The functions external to the chamber are the display and recording instrumentation, the safety monitors, and the environment generation and control.

System level testing under altitude conditions will be accomplished as shown diagrammatically by Figure 5. The tank (2) is mounted on tracked wheels and attached to a tooling plate with quick release toggles so that it can be quickly rolled away from the enclosed test components (i.e. engine, turbos) which remain supported by the heavy tooling plate. This provides easy access to those components without requiring disconnection of the many plubming or electrical connections which pass through the tooling plate.

Air enters the system through the expander (1) located at the front of the tank (2), first passing through a throttling valve which controls tank pressure, and then through the expander wheel which provides the required temperature drop. From the expander, the cold, low pressure air enters the tank and is ducted to the turbocharger compressors, passes through the engine, the turbocharger turbines and exits the tank through the exhaust duct (3). To allow for thermal expansion, the duct takes an upward angle after leaving the tank and forms an expansion loop as it curves back down to the exhaust precooler inlet (4). Leaving the precooler, the exhaust passes through a throttling valve (5) before entering the first Roots blower (6). From the blower exit it flows to the intercooler (7) prior to entering the second Roots blower (8). Leaving that blower it goes through intercooler (9) and then to four rotary piston pumps (10) before being exhausted to ambient through a ventilation duct (11). The exhaust precooler and the intercoolers are all water-cooled as are the pumps and blowers. Two of the water-cooled turbo intercoolers, (12) and (13), are located immediately adjacent to the tank to reduce pressure losses. The first turbo intercooler (14), being much larger, was placed on the floor immediately to the rear of (12) and (13).

<u>Instrumentation</u>. The turbocharger instrumentation will be read out on specially fabricated instrumentation consoles located just outside the vacuum chamber. The engine related parameters will be read out on the dynomometer console gages and digital displays, and will be permanently recorded on the console printer whenever a data point is taken. Figure 6 presents a copy of the permanent printout which will be provided by the Superflow dynomometer. Recorded there are:

<u>Engine</u>
Speed
Exhaust Temp (Each Cylinder)
Airflow Volume
Fuel Flow
Torque
Horsepower
Brake Specific Fuel Consumption
and Air to Fuel Ratio

<u>Safety System</u>. To prevent damage to the engine, turbochargers, or vacuum system during a malfunction, a safety system will be incorporated to shutdown the engine if certain limits are exceeded.

Previous experience has shown that where a safety system can be activated by any of several parameters, determining the deviant parameter can be difficult if the system does not include an over limit call out. Therefore, the present system will include an over limit indicator light for each monitored parameter.

The following parameters will be monitored by the safety system:

<u>Engine</u>
Speed
Coolant Level
Coolant Temp (out)
Crankcase Pressure
Oil Temp Out (engine sump)
Oil Pressure (includes turbo oil pressure)
Oil Tank Level

<u>Turbochargers</u>
Speed
Oil Out Temp
Bearing Temp
Turbine Inlet Temp, 3rd Stage Only

<u>Dyno</u>
Cooling Water Out

Figure 7 presents a photograph of the TMS high altitude vacuum chamber closed on the tooling plate, while Figure 8 presents a photograph of the high altitude test facility instrumentation consoles.

<u>Task 5 - Testing and Development of Turbocharger and Engine System</u>

TMS will provide the personnel, facilities and the equipment necessary for complete development and endurance testing of the turbocharger and engine system. A description of the proposed turbocharger and engine test facility, and its operation, has been given in the previous section. This facility will have all the necessary controls, instrumentation, and data taking capability to completely define the turbocharger and engine system performance. During this testing, hardware design changes necessary to accomplish performance goals will be made and development testing repeated as necessary.

<u>Task 6 - Reporting</u>

During conduct of this program reporting will be accomplished by telephone conversations, personal visits/discussions, and monthly letter progress reports to (1) relate the program status in general and (2) point out any specific factors that may affect the program plan or otherwise be of immediate interest. This arrangement will provide the opportunity to review information acquired during the program in a timely fashion and to suggest changes in program direction, if desired. A detailed Final Report will be submitted at the end of the program documenting all efforts, results, conclusions, and recommendations.

4.0 ESTIMATED PROGRAM TIME AND COSTS

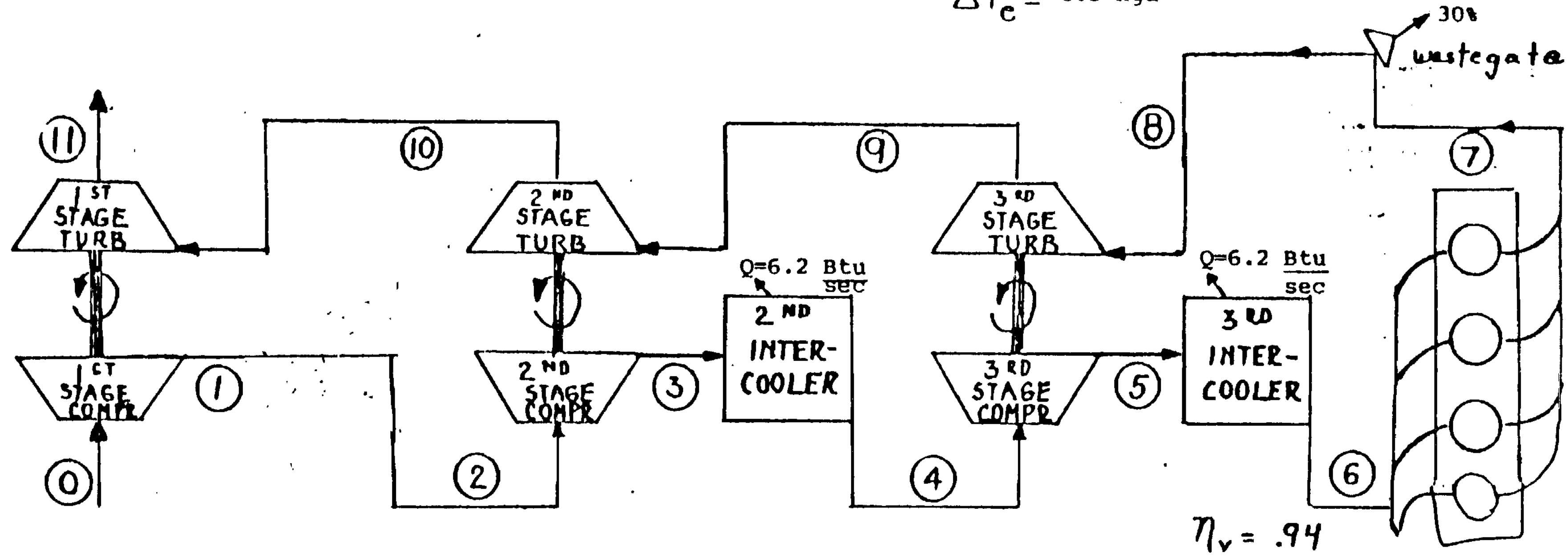
Figure 9 presents the proposed task and time schedule with major milestones for this program. As indicated there, the major program milestones are:

End of 5th month -	Analysis, configuration and design of complete turbocharger system completed
End of 6th month -	Test Program Plan completed
End of 9th month	Turbocharger System Fabrication completed Test Facility Preparation completed
End of 11th month-	Turbocharger System Development completed (Bench Test)
End of 17th month-	Engine/Turbocharger System Development completed (Including redesign, retest)
End of 18th month-	Detailed Final Report submitted

It is estimated that this program can be completed in seventeen months, with the Final Report being submitted at the end of the eighteenth month.

POSITION	0	1	2	3	4	5	6	7	8	9	10	11
TEMPERATURE (°R)	392	552	545	752	545	752	545	2110	2060	1805	1551	1363
PRESSURE ("Hga)	1.322	3.19	3.19	7.68	7.37	17.76	17.0	8.53	8.53	4.72	2.40	1.322

$\Delta P_c = 8.5"Hga$



$\eta_v = .94$

TURBOCHARGER SPECIFICATIONS

STAGE	1	2	3
TURBO SPEED RPM	42903	59141	98550
COMPR PRESSURE RATIO	2.41	2.41	2.41
COMPR EFFICIENCY		.70-.75	
TURBINE EFFICIENCY		.70-.75	
SHAFT HP	7.0	9.0	9.0

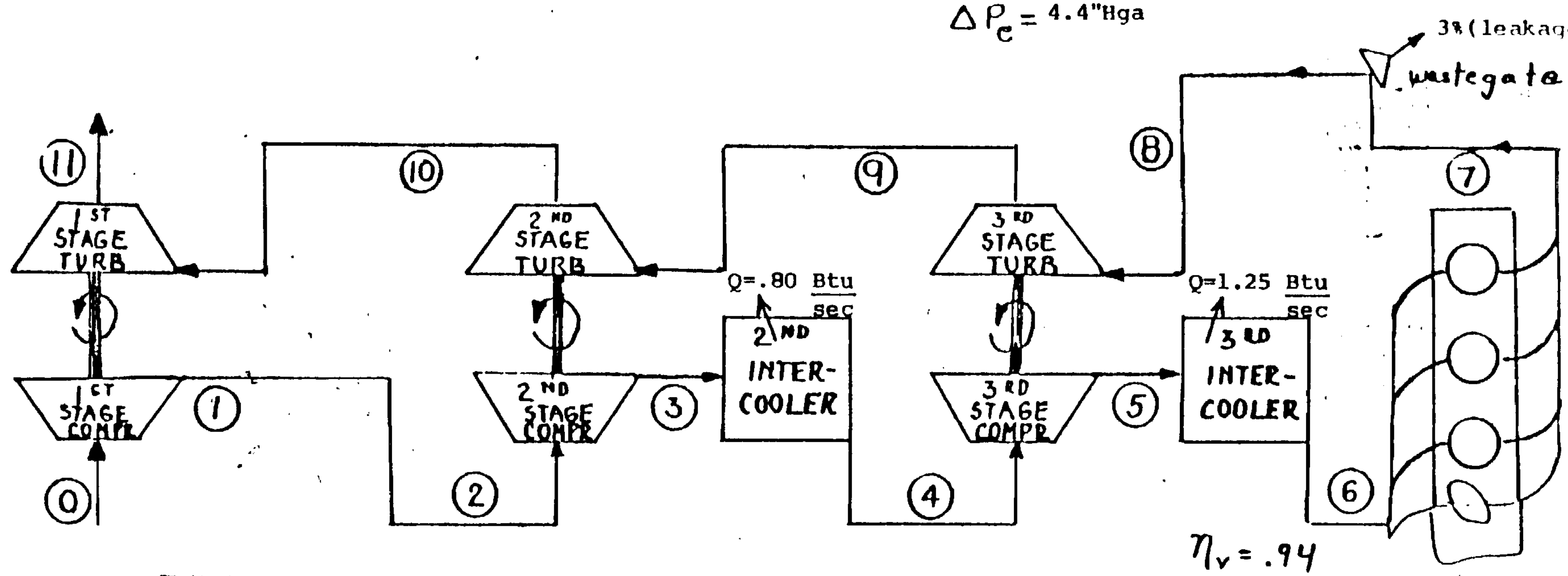
FIXED PARAMETERS

CYCLE FLOW RATE Lb/Sec	.124
INTERCOOLER ΔP, %	4
INTER COOLER OUTLET TEMP °R	545
TURBO BEARING LOSSES %	3
ENGINE EXHAUST TEMP °R	2110
F/A RATIO	.06

FIGURE 1: Propulsion System Operating Parameters at maximum power conditions (70 BHP and 4000 RPM at 70,000 ft altitude)

POSITION	0	1	2	3	4	5	6	7	8	9	10	11
TEMPERATURE (°R)	392	449	449-545	671	545	740	545	2110	2060	1874	1735	1660
PRESSURE ("Hga)	1.322	1.86	1.86	3.26	3.24	7.45	7.33	2.94	2.94	2.0	1.53	1.34

$\underbrace{\qquad\qquad}_{\Delta P_c = 4.4\text{"Hga}}$



$\eta_v = .94$

TURBOCHARGER SPECIFICATIONS

STAGE	1	2	3
TURBO SPEED RPM	25719	46051	95278
COMPR PRESSURE RATIO	1.41	1.75	2.30
COMPR EFFICIENCY		.70-.75	
TURBINE EFFICIENCY		.70-.75	
SHAFT HP	.52	1.14	1.8

FIXED PARAMETERS

CYCLE FLOW RATE Lb/Sec	.0266
INTERCOOLER ΔP, %	1.0
INTERCOOLER OUTLET TEMP °R	545
TURBO BEARING LOSSES %	3
ENGINE EXHAUST TEMP °R	2110
F/A RATIO	.06

FIGURE 2: Propulsion System Operating Parameters at minimum power conditions (15 BHP and 2000 RPM at 70,000 ft altitude)

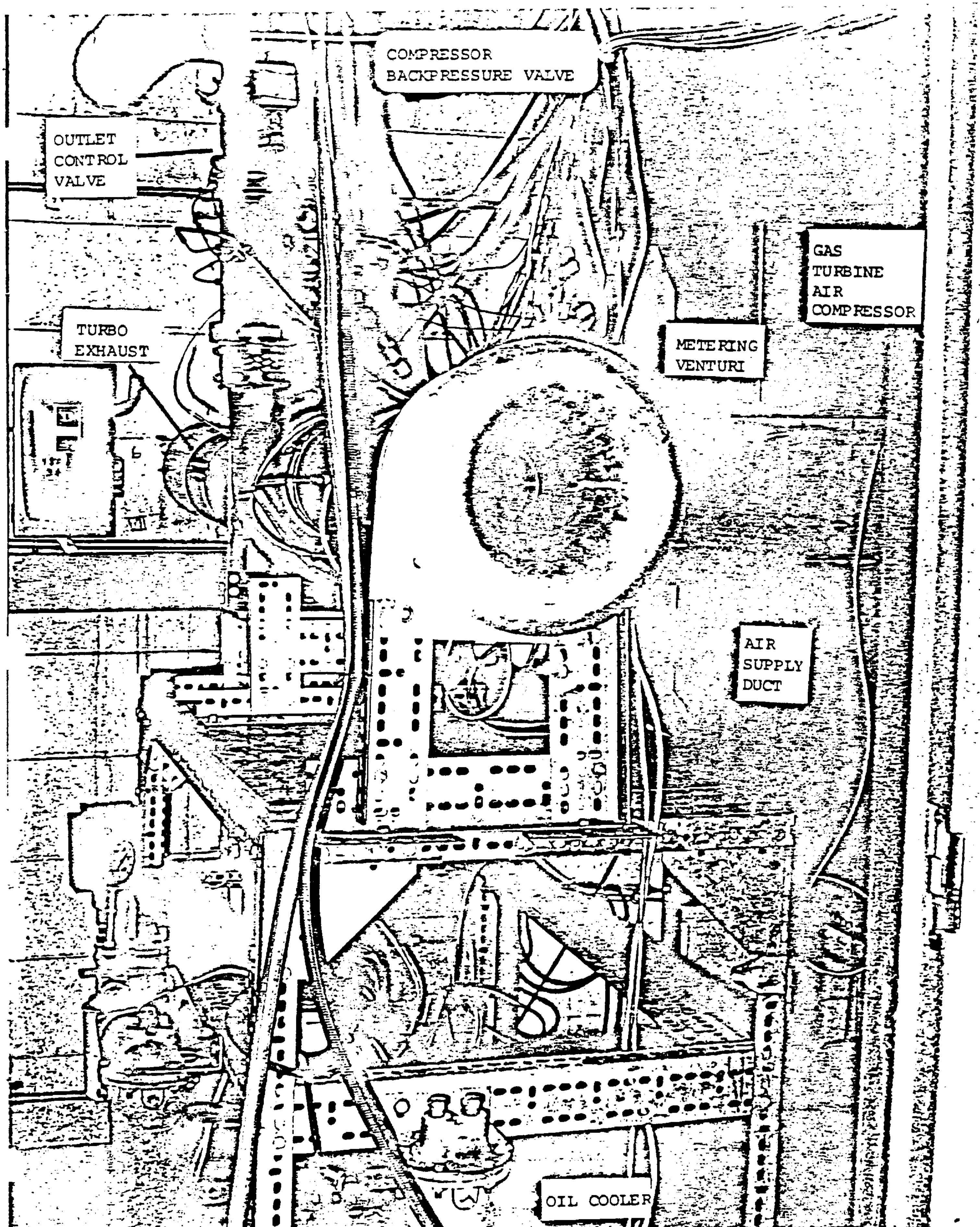


Figure 3: Photograph of the turbocharger on the turbo test stand.

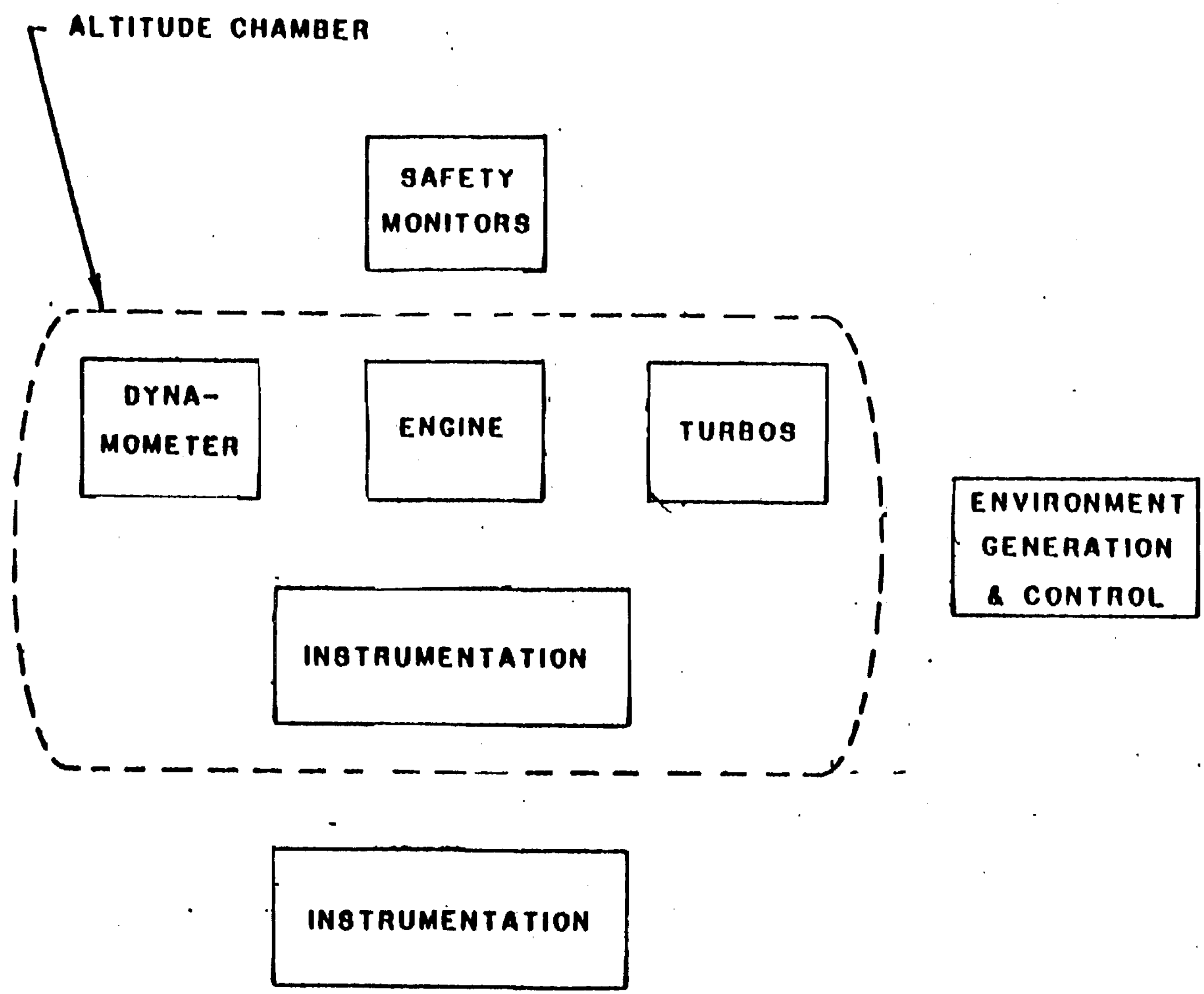


Figure 4: Simplified schematic of TMS high altitude test facility.

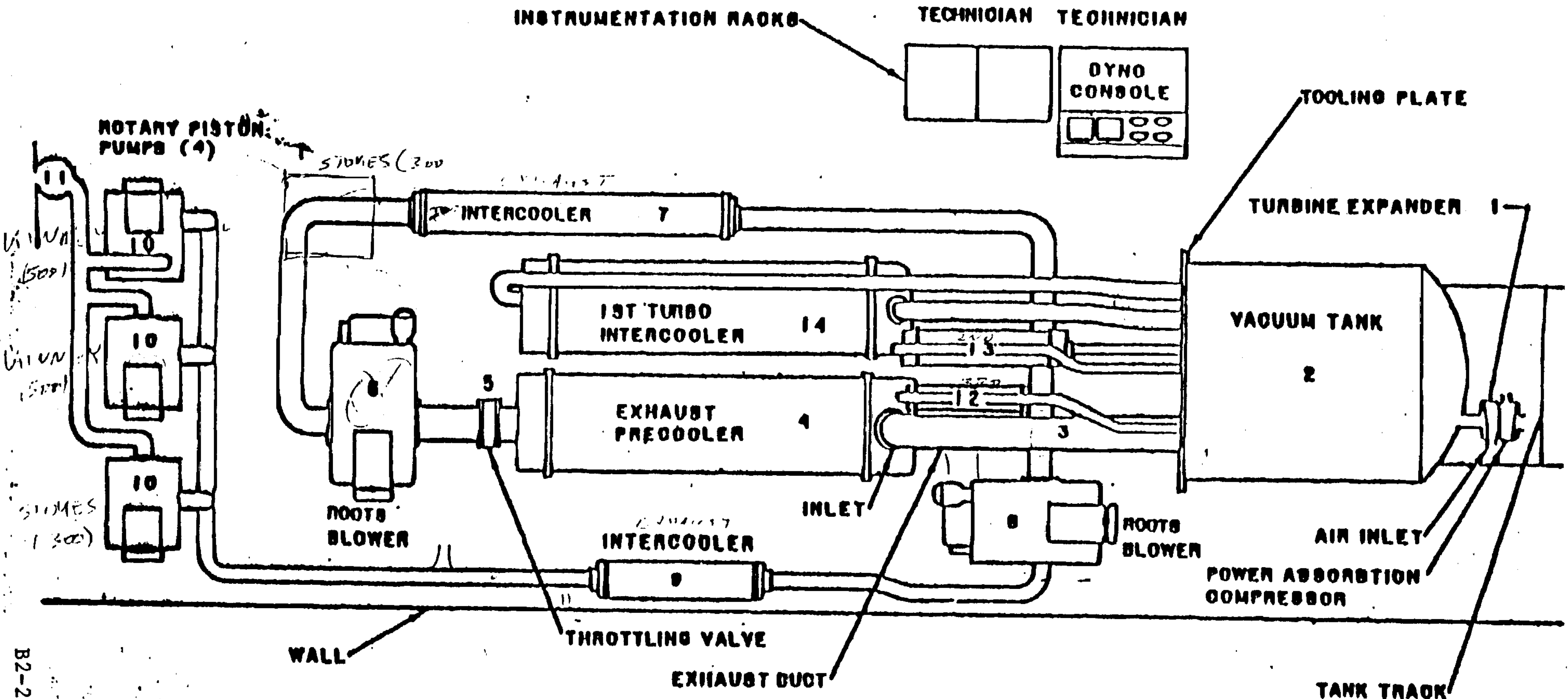


Figure 5: TMS High Altitude Test Facility Layout

ENGINE DYNAMOMETER TEST
ON SUPERFLOW SF-8[illegible]

DATE: ______________ TEST NO. ______________

ENGINE: ______________________________

____

TEST DESCRIPTION: ______________________

____

____

TEST DATA

RPM	T	HP	FA	FB	A1	A2	A/F	BSFC
	LB-FT		LBS/HR		SCFM			LB/HP-HR
0	0	0	0	0	0	0	0.0	0.00
0	0	0	0	0	0	0	0.0	0.00
0	0	0	0	0	0	0	0.0	0.00
0	0	0	0	0	0	0	0.0	0.00
0	0	0	0	0	0	0	0.0	0.00

EXHAUST TEMPERATURE

CYL1	CYL2	CYL3	CYL4	CYL5	CYL6	CYL7	CYL8
136	128	136	72	72	72	72	72
136	128	136	72	72	72	72	72
136	128	136	72	72	72	72	72
136	128	136	72	72	72	72	72
136	128	136	72	72	72	72	72

Figure 6: Copy of permanent data printout which will be provided by Superflow Dynomometer Console.

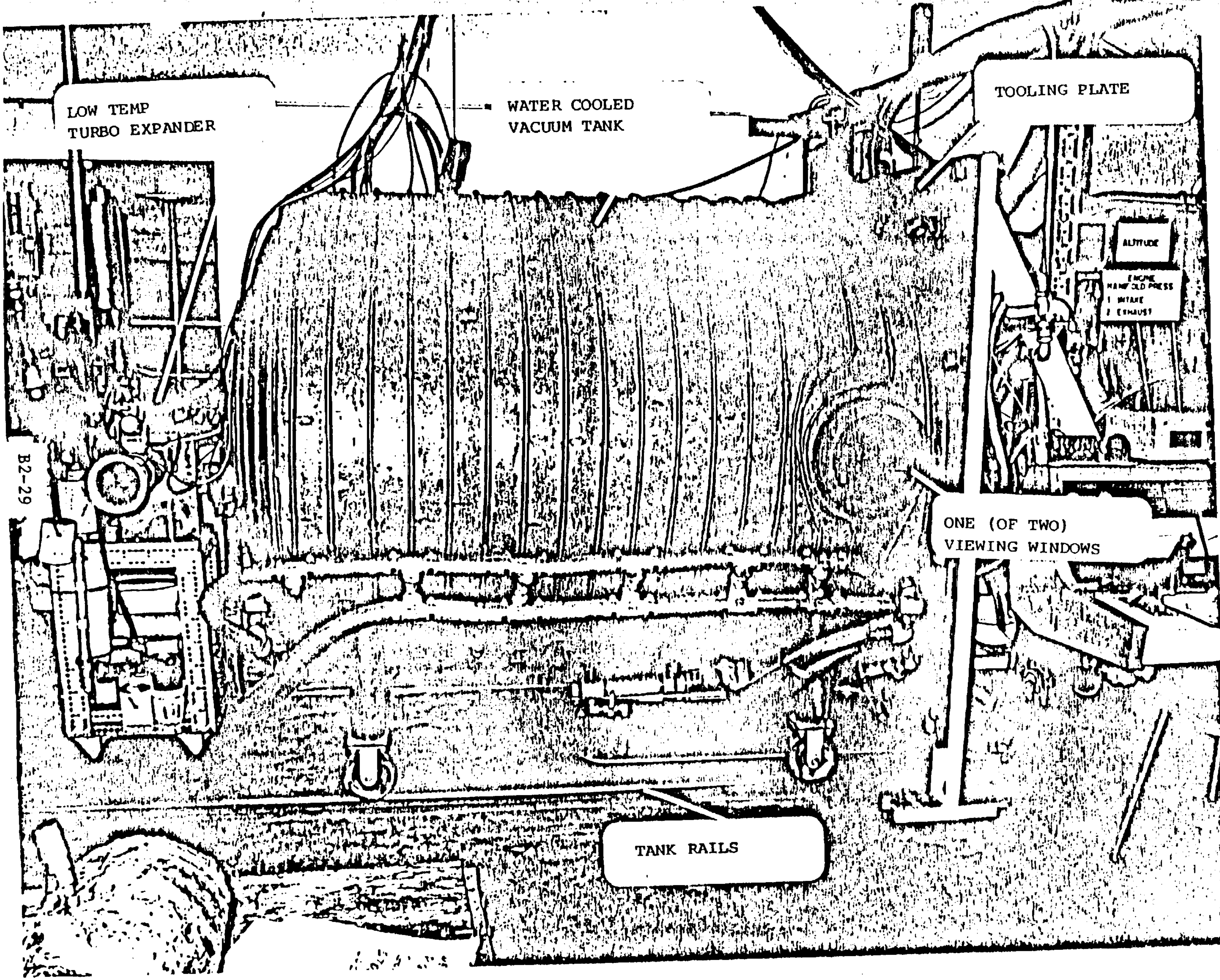


Figure 7: Photograph of high altitude vacuum chamber closed on tooling plate.

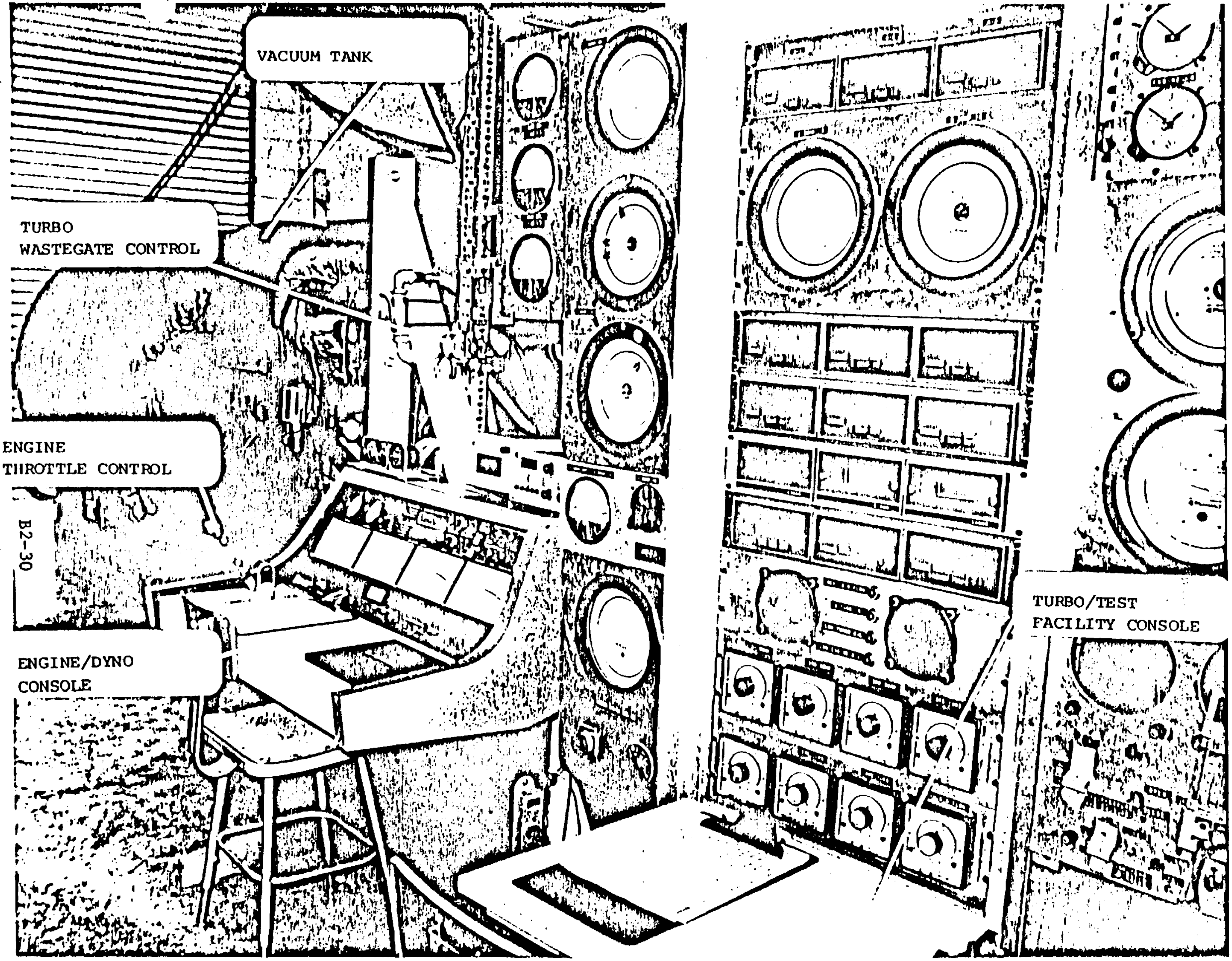


Figure 8: Photograph of high altitude test facility instrumentation console.

TASK	DESCRIPTION
1	Configuration, cycle and system analysis, detailed design and interface requirements
2	Fabricate turbochargers and ancillary equipment
3	Prepare a Test Program including test procedures and test matrix
4	Prepare test facilities including ancillary equipment and instrumentation
5	Conduct testing and development of the turbocharger and turbocharger engine system
6	Reporting
	. Monthly Progress Reports
	. Detailed Final Report

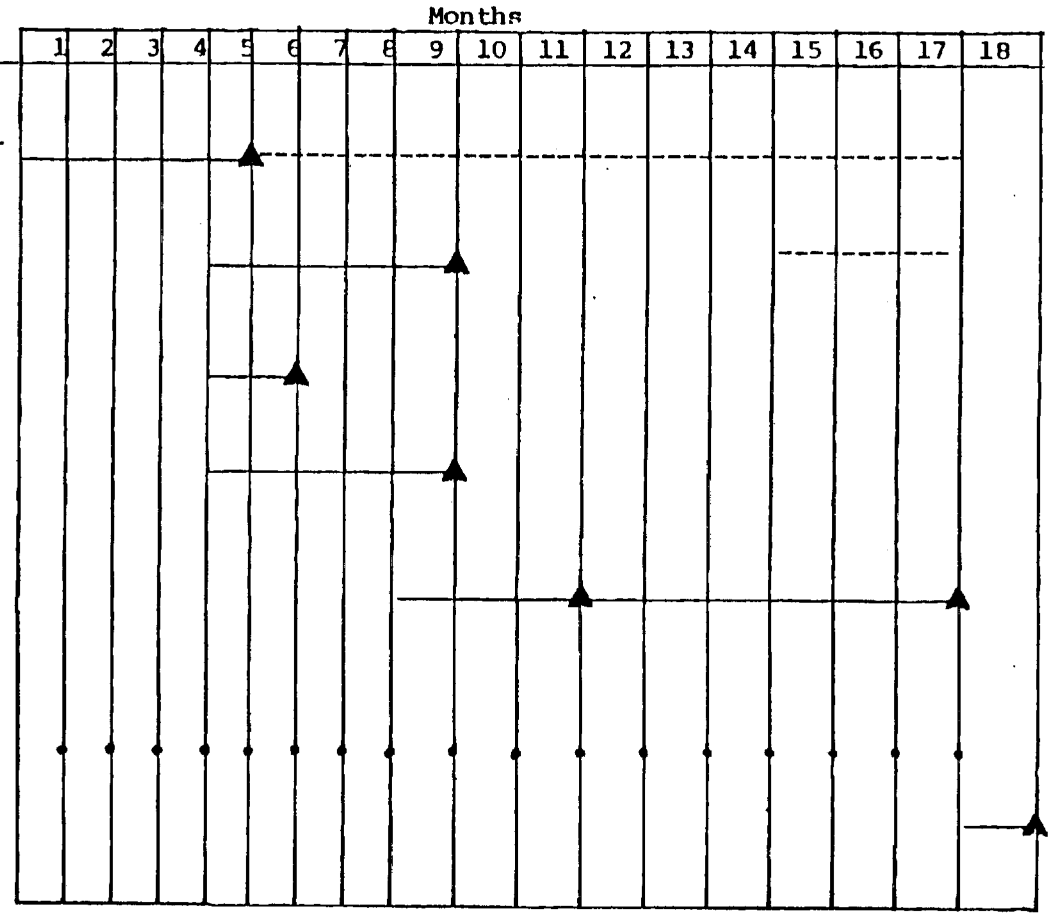


FIGURE 9: Proposed Task and Time Schedule with Major Milestones (*)

*See Section 4.0 of Text for Milestone Identification

Heat Exchanger Design

The charge air intercooler is to have two sections. The aft section accepts 2ND stage discharge air at 292°F and removes 372 BTU/min from that stream to provide 3RD stage inlet air at 85°F. The forward section accepts 3RD stage discharge air at 292°F and removes 372 BTU/min to deliver inlet manifold air at 85°F.

The heat exchanger is of counter-flow configuration with cooling air flowing the entire length from front to rear in designated tubes. The hot charge air streams flow forward in interstitial tubes which are manifolded together at the ends of their respective sections.

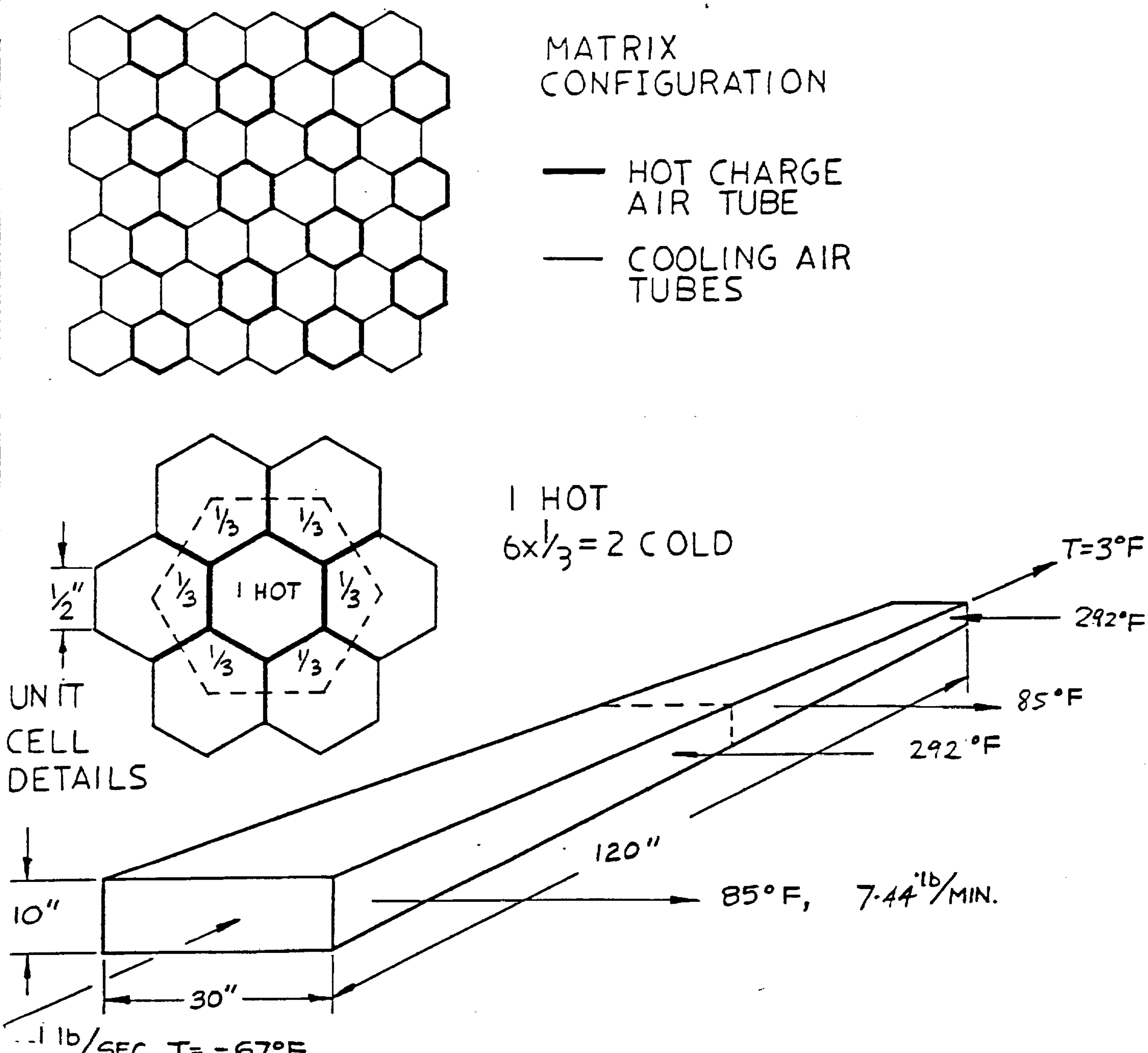
The tubes are to be constructed of graphite/polyamid material and would have a hexegonal cross section, one-half inch on a side. This design allows the tubes to be nested together so that every "hot" tube is completely surrounded by "cold" tubes in solid contact with all of its sides. (as detailed in Appended Sketch). In the final analysis this comes to 160 hot tubes and 320 cold tubes.

Note that if a conventional aluminum gas-to-gas heat exchanger was scaled up to provide adequate surface area on the atmosphere side of the fins, the assembly would be unacceptably heavy. The proposed design is fabricated from graphite/polyamid sheet.

The intercooler performance would benefit from using the energy of the air downstream of the propeller to overcome the the pumping work of the heat exchanger. Whilst the propeller parameters are not fully known at this time, a cooler intake velocity of 170 ft/sec. at rated power has been assumed.

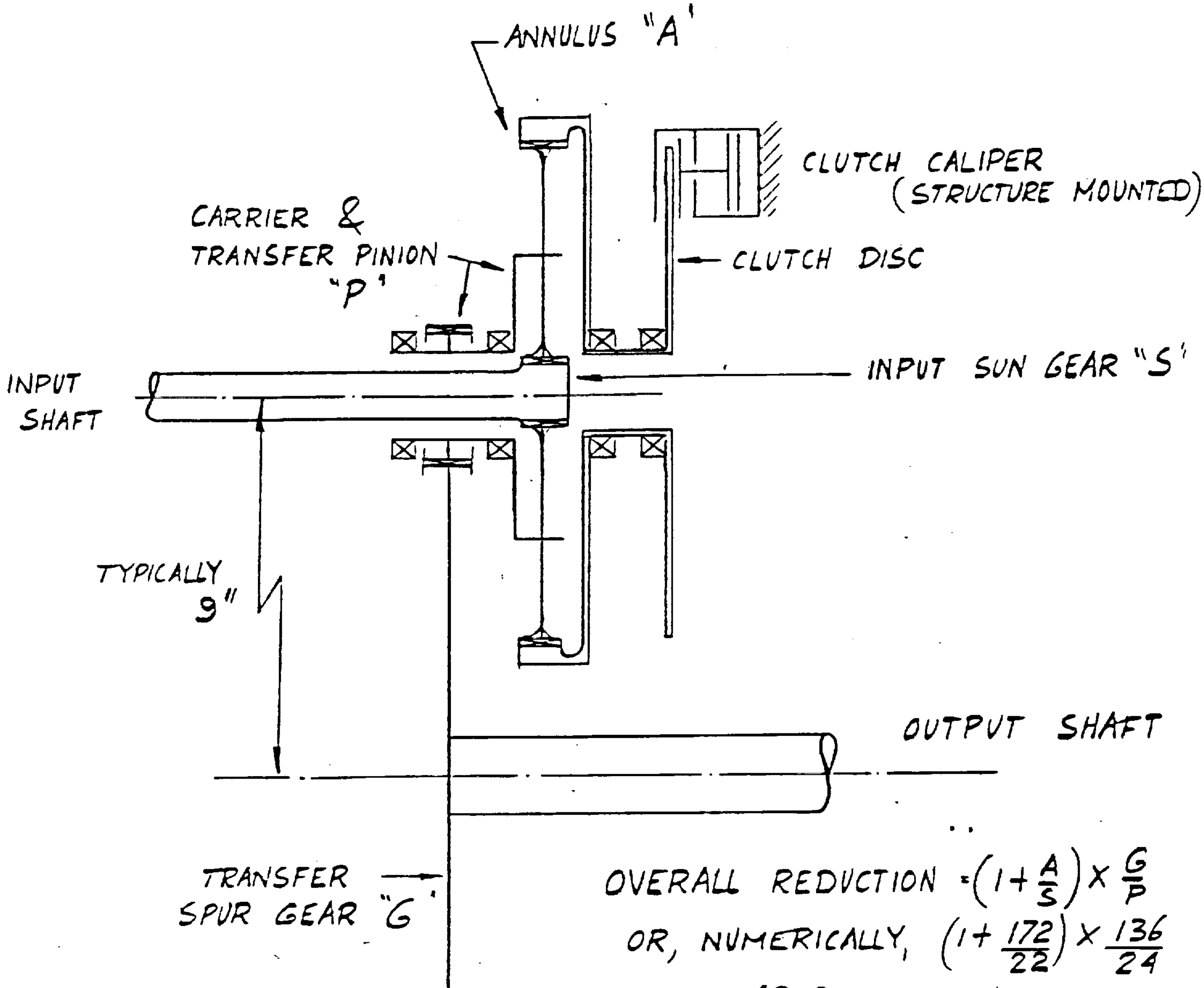
The resulting assembly of both cooler stages weighs from 65 to 75 lbs. and is intended to be an independently-mounted unit with an overall length of 10 feet.

REVISIONS			
LTR	DESCRIPTION	APPROVED	DATE



FIRST USED ON MODEL:	DR		THUNDER ENGINES INC.
	CHK		
	ENGR		
NEXT ASSY	PROJ ENGR		TITLE GAS-TO-GAS INTERCOOLER CONCEPT
	STRESS		
	DOC CONT		
	MATL		SIZE A | DWG NO: | REV
	FINISH		SCALE | SHT OF

REVISIONS			10/10/82
LTR	DESCRIPTION	APPROVED	DATE



OVERALL REDUCTION $= \left(1+\frac{A}{S}\right) \times \frac{G}{P}$

OR, NUMERICALLY, $\left(1+\frac{172}{22}\right) \times \frac{136}{24}$

$= 49.97:1$

FIRST USED ON MODEL:	DR		THUNDER ENGINES INC.
	CHK		
	ENGR		
NEXT ASSY	PROJ ENGR		TITLE INTEGRATED REDUCTION GEAR AND ENGINE CLUTCH. (USING LIGHT, NON-ROTATING FRICTION ELEMENT)
	STRESS		
	DOC CONT		
	MATL		SIZE A; DWG NO:; REV
	FINISH		SCALE; SHT OF

THUNDER ENGINES INC.

Weight breakdown of flight-weight in-line 4 Cyl.

CYLINDER BLOCK, WITH LINERS.	47.5 lb.
MAIN BEARING FRAME.	10.5
CRANKSHAFT	27.0
RODS. & PISTONS	9.6
CYLINDER HEAD WITH VALVES	21.0
CAMSHAFT & DRIVE	9.1
OIL PUMP & DRIVE	8.4
WATER PUMP & DRIVE	5.0
INLET MANIFOLD	4.0
IGNITION (8 COILS)	12.6
	154.7 lbs.

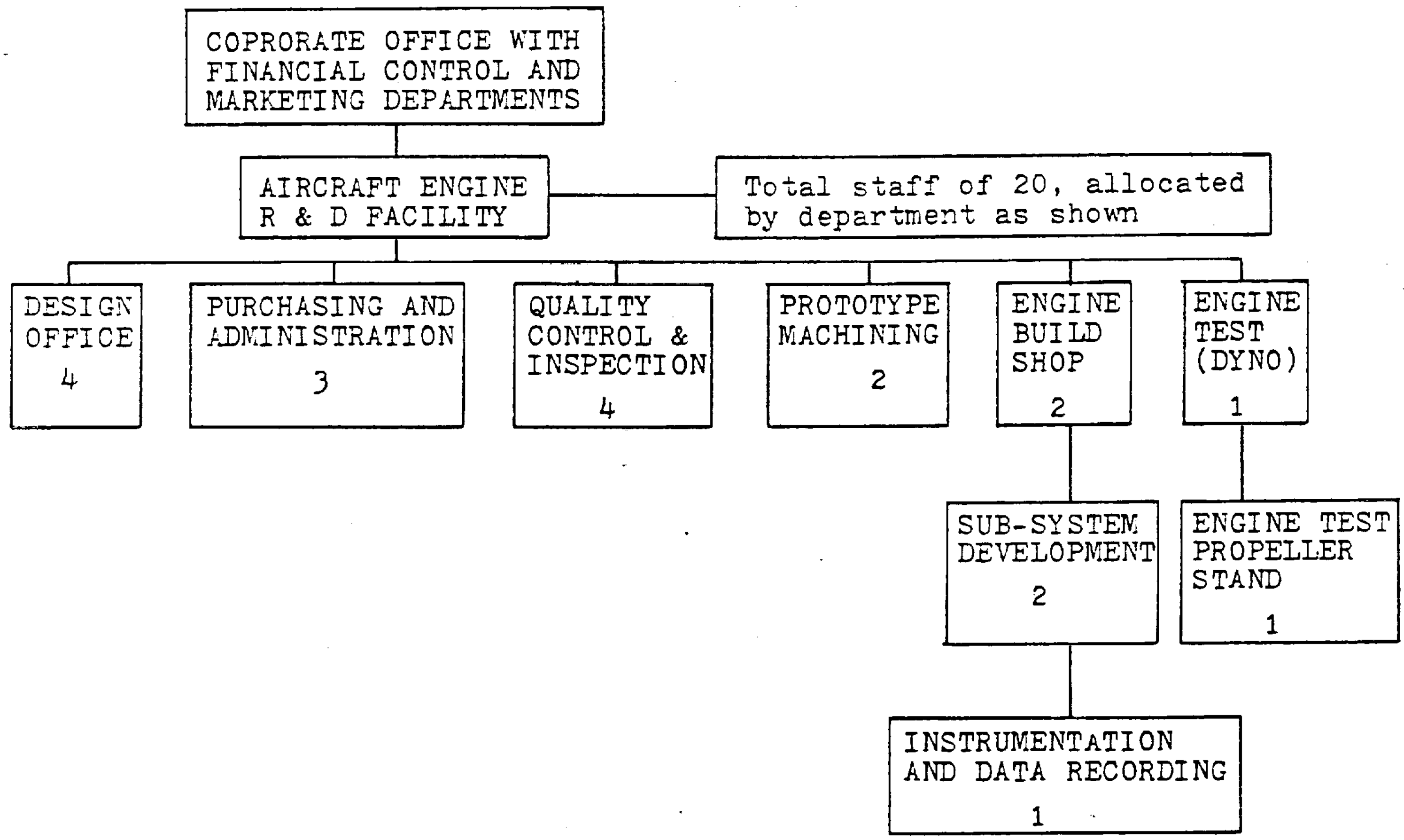
For V-6 Configuration.

			Difference
BLOCK		38 lbs.	−9.5
MAIN BRGS.		7	−3.5
CRANKSHAFT		24	−3.0
RODS & PISTONS		12.5	+2.9
2 HEADS	@	16 lbs.	+9.0
IGNITION (12 COILS)		18.9 lbs.	+6.3

Nett Difference +2.2 for V-6

V-6 TOTAL 156.9 lbs.

THE STAFF AND FACILITIES STRUCTURE OF THUNDER ENGINES



APPENDIX C

TM DEVELOPMENT, INC.

I.L.C. REPORT INSERT

PROPELLER DESCRIPTION

Functions Provided

The propeller subsystem is designed to perform the dual functions of propulsion and control

Aerodynamic Configuration

The propeller is to be configured primarily for high propulsive efficiency in the low-speed environment. Airfoil selection, blade planform taper and twist are selected for this efficiency requirement, since the chosen methods of manufacture provide total design freedom of aerodynamic shape factors.

Control Functions

The control function is achieved by a gimballing action of the hub permitting a $\pm 25^{\circ}$ tilt of the rotational plane and thrust vector in both vertical and horizontal directions.

This feature gives the capability of applying powerful pitching and yawing moments to the vehicle whether it is at rest or underway.

In addition, the propeller is designed with the capability of negative pitch settings, thru beta control, which will allow reverse thrust maneuvering.

Structural Features

Because of the extremely light propeller weight required, the construction will be primarily of composite materials with a minimum of fasteners and fittings made of metal.

Primary blade and hub structures will utilize Kevlar-epoxy prepreg laminating materials and honeycomb sandwich techniques.

Figures 1 thru 4 show some of the specific structural properties of Kevlar laminates as compared with the conventional lightweight materials, aluminum alloy and titanium.

An additional weight advantage of designing the propeller in Kevlar material is that the usual gage-thickness limitations of sheet metal are eliminated. Serviceable sandwich facings of .008 inch or even down to .004 are practical.

Where localized exceptional stiffness/strength is required in the blade or hub, graphite fibers will be used.

Fatigue and Fail-Safe Features

The laboratory and operational experience with well-designed fiberglass and Kevlar laminate structures has demonstrated their exceptional tolerance to conditions which are often fatal to metal structures. Corrosion, accidental scratches or other "notch" damage and minor manufacturing defects are all critical to lightweight metal structures but generally have no adverse effect on the composite structures proposed for this propeller.

Multiply-redundant load paths are designed into the propeller structural and materials configuration, giving a highly mission-reliable subsystem with a negligible maintenance burden.

Propeller Structural Dynamics

This very lightweight and flexible propeller and vehicle mounting must be designed and analyzed for dynamic stability.

Some items for analytical consideration include:

Propeller rotating natural frequencies and resonance points.

Aeroelastic behaviour, such as flutter and divergence.

Propeller mounting stiffness related to whirl mode phenomena.

A three blade propeller configuration is planned, which will provide for good aerodynamic efficiency and minimal vibration tendencies.

Special propeller design features are planned which will allow a minimum weight propeller by virtue of structural simplicity and absolute minimal steady and vibratory loadings. These design features will also tend to minimize any vibrations transmitted to the flight vehicle

High Altitude Tolerance

Special design attention will be given to high altitude functioning of the propeller. This will include:

Low temperature dimensional behaviour of structural and mechanical elements, such as bearings.

Atmospheric pressure cycling and appropriate venting of hollow compartments.

Lubrication requirements for trouble-free operation of pitch change mechanisms.

Change in structural properties of materials at low temperatures.

SPECIFIC MATERIALS PROPERTIES

FIGURE 1

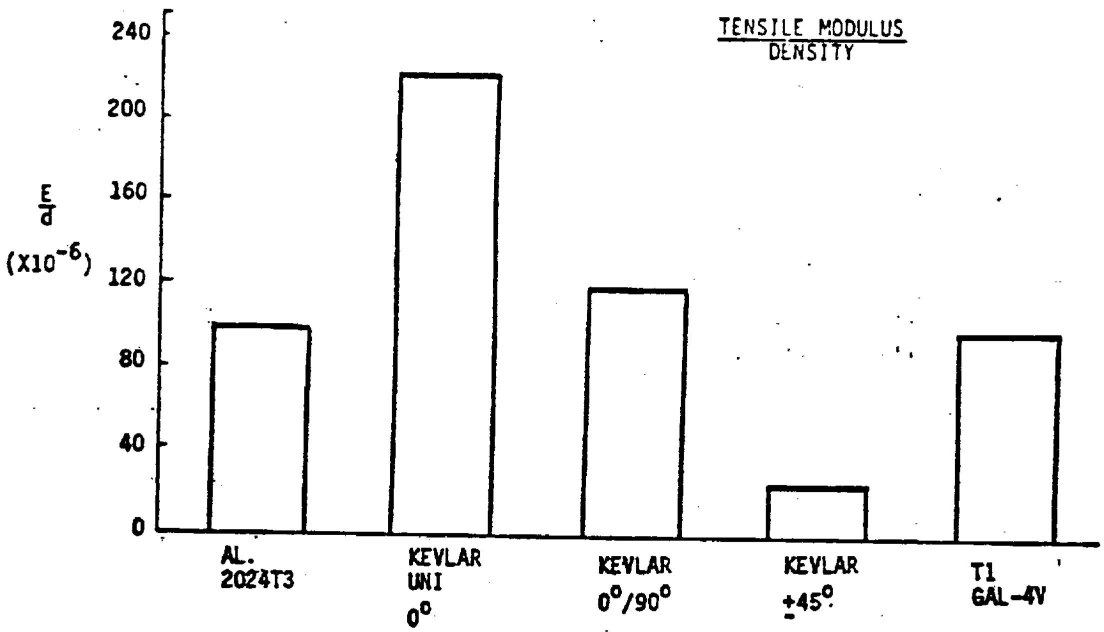
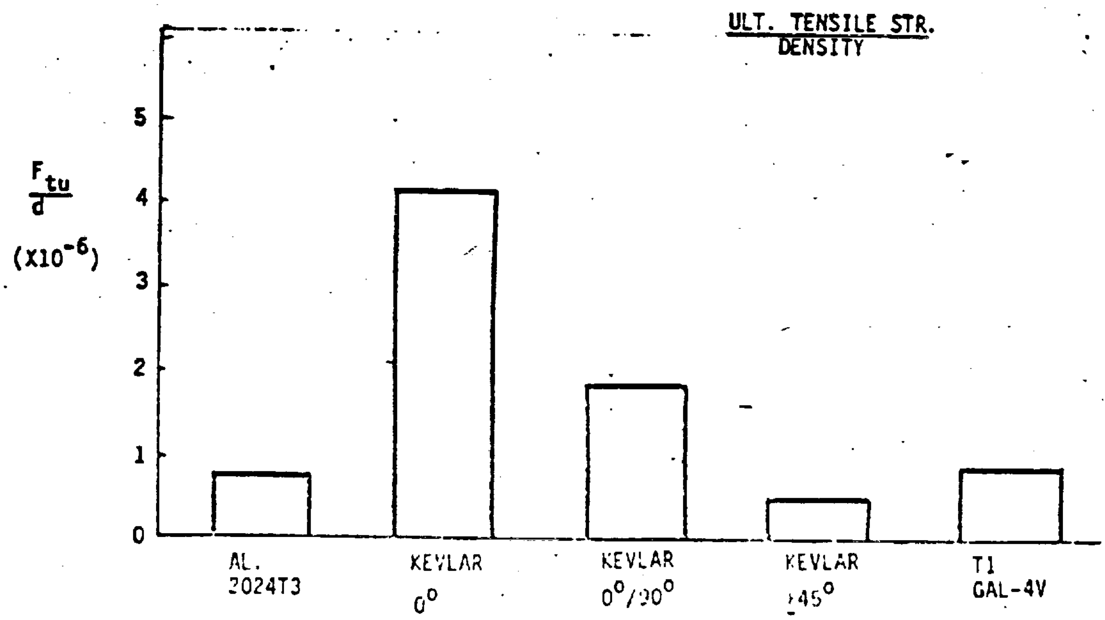


FIGURE 2



APPENDIX D

COMMAND AND TELEMETRY SUBSYSTEM FOR A
LINE-OF-SIGHT AIR SHIP CONTROL LINK

Presented to

ICL Industries

31 August 1982

Prepared by T. G. Hall

T. G. Hall

Approved by P. A. Bartholomew

P. A. Bartholomew

MOTOROLA • Government Electronics Division • 8201 E. McDOWELL ROAD, SCOTTSDALE, ARIZ. 85252

1.0 INTRODUCTION

Motorola is pleased to submit this response to ILC Industries for an air-to-ground telemetry link and a ground-to-air command link. The communication links are part of an air ship system concept study for NASA Wallops Flight Center under Contract Number NAS-6-3131.

This response contains a technical description of both terminals and ROM size, weight and power estimates for the air ship terminal.

2.0 SYSTEM DESCRIPTION

The functional block diagram for the communication subsystems is shown in Figure 1. The air ship is located overhead at a line-of-sight range of approximately 70,000 feet. Approximately 100 sensor outputs are telemetered down to a microprocessor, which displays air ship status to a pilot and encodes the pilot's responses for transmission to the air ship control junctions.

The following sections develop the communication requirements and discuss the hardware approach. Section 2.1 develops the data rates. Section 2.2 presents the link analysis and the transmit power and receiver sensitivity requirements. Section 2.3 describes the telemetry system and Section 2.4 describes the command system. Section 3.0 contains the size, weight and power estimates.

2.1 DATA RATE REQUIREMENTS

2.1.1 Telemetry (Down Link)

The telemetry data consists of 100 analog voltages from air ship sensors. The time constant associated with each sensor is on the order of 30 seconds; therefore, the 20 dB information bandwidth is less than 0.05 Hz and a sample of 1 in 10 seconds is adequate. The telemetry encoder will sequentially select each sensor output, quantize the voltage to a precision of 8 bits and insert the digital data into the telemetry format. The data rate, without format overhead, is 80 bits per second (100 sensors x 8 bits/sample x 0.1 sample/second). Since

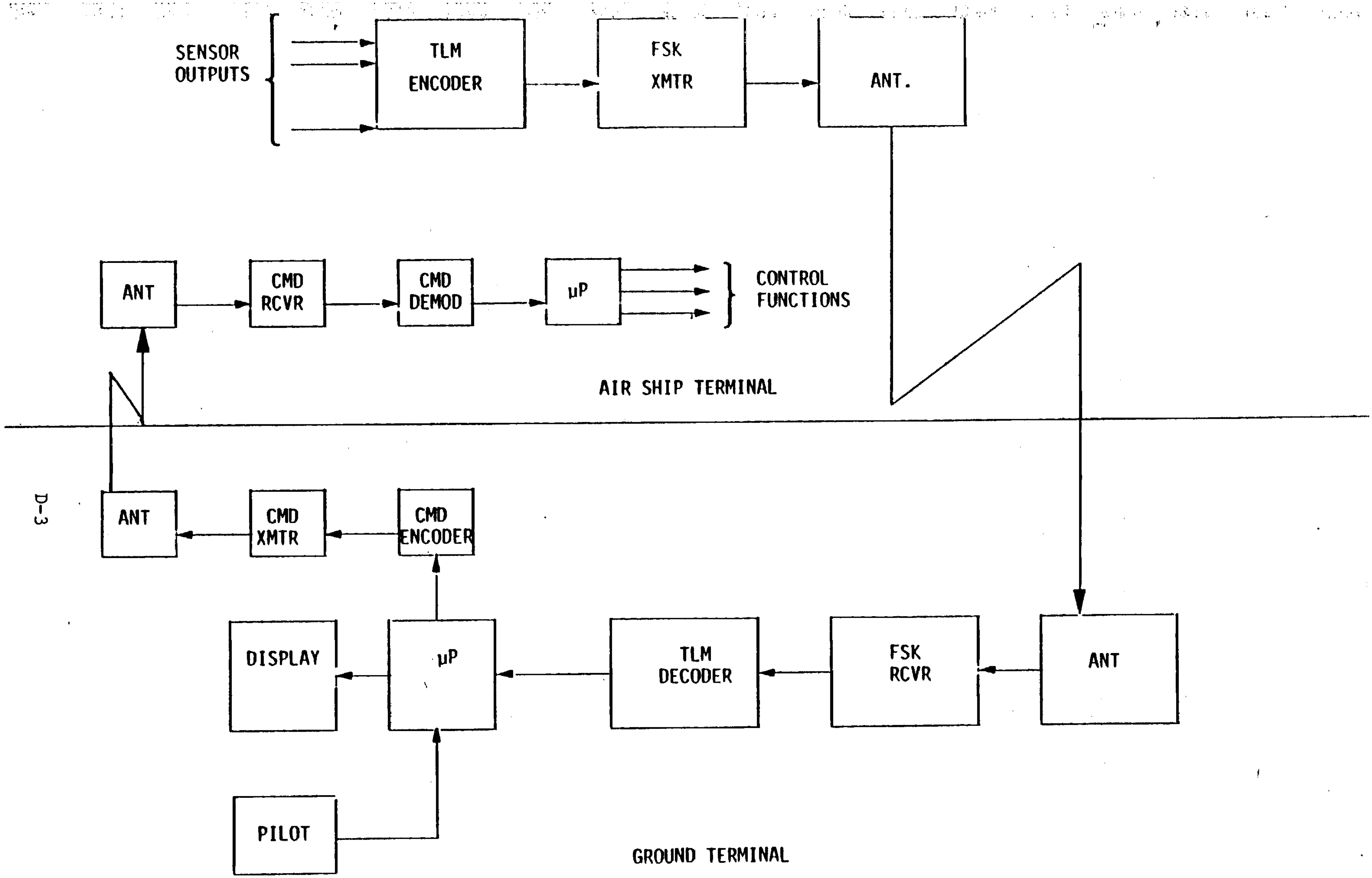


Figure 1. Functional Block Diagram of the Telemetry and Control System

the bit rate is so low, a Manchester code can be used with essentially no penalty and will simplify the telemetry frame synchronization. This code encodes a binary ONE as the symbol pair 01 and encodes a binary ZERO as the symbol pair 10. The symbol pairs 11 and 00 do not appear in the data stream and can be used for unambiguous telemetry frame synchronization. Eight bit words are encoded into 16 symbols; therefore, a 16-symbol sequence of eight ONE symbols followed by eight ZERO symbols is selected for frame synchronization. Frame synchornization is guaranteed at the first complete telemetry frame received. The Manchester encoding plus the frame sync data will raise the telemetry data rate to 176 bps.

2.1.2 Command (Up Link)

There are 6-8 commandable functions for the up link with time constants on the order of 30 seconds during station-keying and 5 seconds during ascent and descent. Assuming 8-bit precision, the maximum data rate is 8 functions x 8 bits/function ÷ 5 seconds/function a 64 bps. Again, Manchester encoding with a 16-symbol frame sync word only increases the data rate to 144 bps and provides rapid and positive synchronization.

2.2 LINK ANALYSIS

The data rates for these links are low and the communication range is short. Therefore, there is considerable flexibility in selecting antenna gains, transmitted power levels and receiver sensitivities. The criteria used in selecting these parameters was to provide large margin to preclude loss of an air ship due to marginal communications and to simplify air ship hardware. These factors led to the selection of non-coherent frequency shift key (FSK) modulation with a transmitter power of 0.1 watts and a receiver noise figure of 10 dB. The air ship antenna gains are specified at -10dBi and the ground terminal antennas are specified at +6 dBi. These parameters provide a BER of less than $1x10^{-7}$ and the system margin exceeds 26 dB.

Additional margin for the command link can be provided at low cost by increasing the ground transmitter to a watt.

3.0 MECHANICAL

31. AIR SHIP TERMINAL

The air ship terminal is composed of the telemetry encoder-transmitter and the command receiver-decoder. Since a command link failure will compromise air ship safety, two command receiver-decoders and two telemetry encoder transmitters are proposed for 100 percent redundancy of major control functions. Table 1 presents the size, weight and power budgets for a single system .

Table 1. Size, Weight and Power Estimate for the Air Ship Telemetry

Function	Volume (in^3)	Power (Watts)	Weight (lbs)
TLM Encoder	27	2.0	1.4
TCM XMTR/CMD REC/ANT.	767	30.0	24.0
CMD Decoder/μP	24	2.3	1.2
Housing/Thermal Control		5.0	2.0
Totals	818	39.3	28.6

Therefore, two complete sets of electronics will be less than 60 pounds and will require less than 40 watts, depending on whether all redundant units are powered simultaneously. The unit will be enclosed with an insulating material for thermal control.

3.2 GROUND TERMINAL

The ground terminal will be housed in a standard relay rack and will use commercial power supplies. Since size, weight and power are not significant parameters, no estimates for these parameters have been prepared.