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TL.114-59/01

DC Ferguson

THE AVROCAR DESIGN

AVRO/SPG/TR 254

DECLASSIFIED

DATE...... INT. ....

AVRO AIRCRAFT LIMITED

SECRET

I. D. No. 59RDZ-2885

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SPECIAL PROJECTS GROUP
Technical Report No. 254

THE AVROCAR DESIGN

January 1959

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The number of pages in this report, including Security Warning, Title page, Table of Contents, List of Illustrations and the Appendix is 108.

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PART 1

INTRODUCTION

3419-802-2

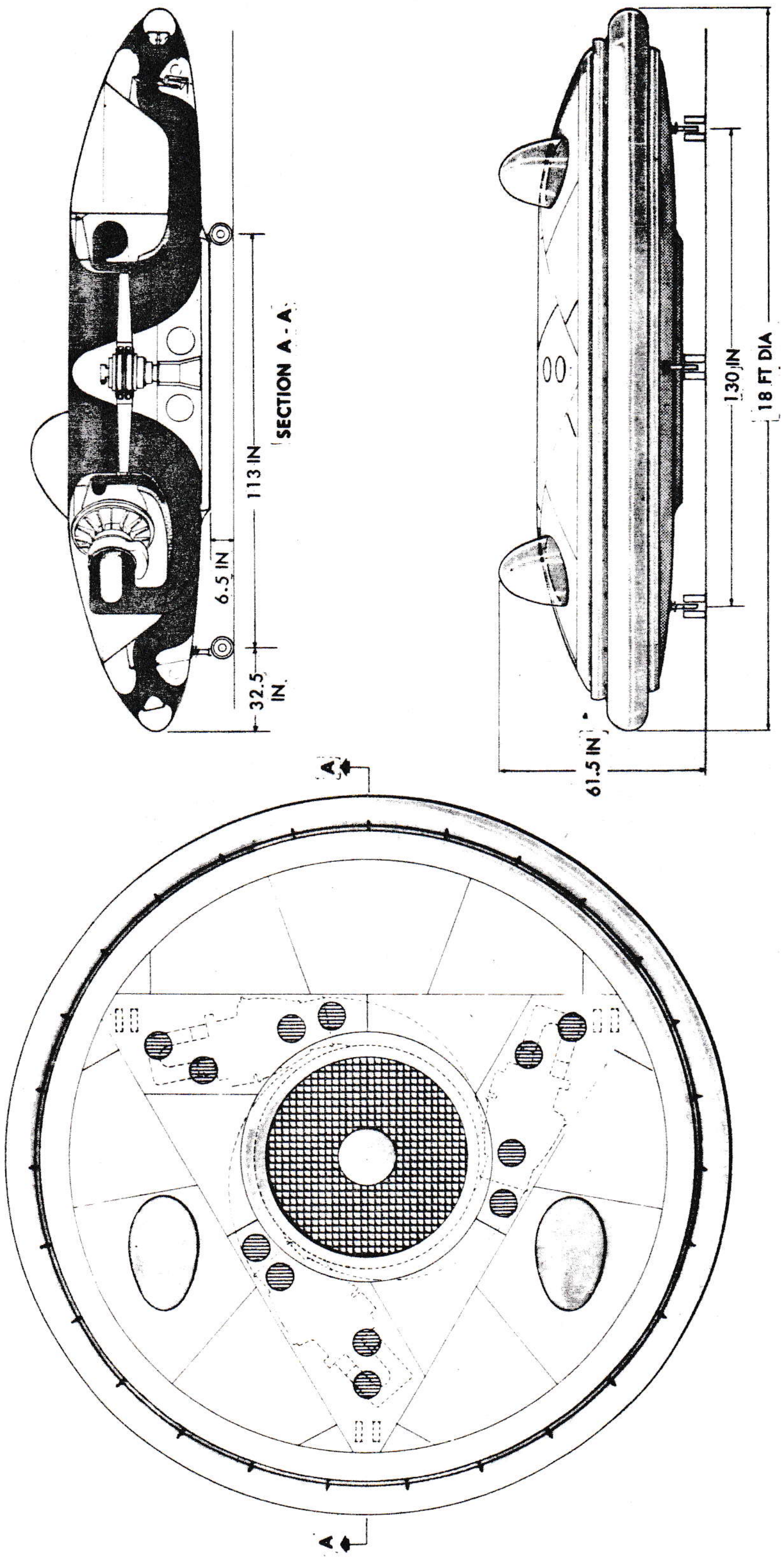

FIG. 1 GENERAL ARRANGEMENT

The current design and manufacture of the Avrocar involves a light, all wing, experimental vehicle of circular planform with VTOL capability.

Crew accommodation consists of two single-seat cabs, each enclosed by a transparent canopy. The pilot's cab is located at the forward left hand side of the vehicle, and the other at the forward right hand side. The vehicle provides for the stowage of cargo and equipment in trunks enclosed by detachable panels.

The powerplant of the vehicle consists of three small gas turbine engines which act as gas generators to drive a centrally located turbine compressor combination, known as the turborotor. The engines are arranged tangentially and symmetrically in plan. The exhaust gases are directed onto the turbine blades of the turborotor.

Propulsion, flight control and hovering are derived from the turborotor air being fed into diffuser ducts, formed by the primary structure and expelled from annular nozzles at the wing periphery and in the undersurface of the vehicle. The direction in which the air is deflected at the wing tip is controlled by positioning spoiler rings located in the throat of the peripheral nozzle.

For hovering, close to the ground and in free air, the peripheral air flow is directed vertically downwards. Transition from hovering to forward flight is accomplished by changing the direction of the airflow from vertical to near horizontal thereby inducing a forward motion to the vehicle. As the velocity of the vehicle increases, conventional airfoil lift is developed and the thrust used for hovering is employed for propulsion and flight control.

At the present stage of development the Avrocar is committed to meet the minimum performance requirements defined in the Preliminary Statement of Work which are as follows.

1. The vehicle shall take-off and hover at a minimum height of six feet above the ground for a minimum duration of ten minutes with a payload of 1000 lb. including the pilot and crew.

2. The vehicle shall take-off, accomplish transition to forward flight, carry the above payload a distance of 25 nautical miles, and land with the payload under sea level standard conditions.

3. The vehicle shall attain a minimum forward airspeed of 25 knots in zero wind.

In design provisions were made to enable further development of the vehicle. When developed the vehicle is intended for operation within 400 ft. of the ground over terrain of not more than 10,000 ft. altitude, with a speed range from 0 to 270 knots.

An outline of development to date has been integrated with the description of the design contained in this report. Further development will be dependent upon future contractual provisions.

PART 2

ESTIMATED AIRPLANE PERFORMANCE

2.1 General

The estimated performance for the Avrocar, when developed, is shown by Figs. 2 to 11 and is based on:-

(i) Powerplant performance specified in Section 5.7, and Figs. 17 to 23.

(ii) Weights detailed in Part 3.

(iii) "Ground cushion" and thrust augmentation data specified in Technical Report Avro/SPG/TR 266.

(iv) Drag coefficient, $C_D = 0.016 + 0.312\ C_L^2$.

(v) Inlet pressure recovery data contained in Technical Report Avro/SPG/TR 266.

(vi) Net thrust obtained by reducing gross thrust by 10% to allow for jet drag and nozzle losses.

(vii) Fuel transfer capability or in flight engine start, during two engine performance.

2.1.1 Flight Limitations

In order to maintain the aircraft weight and the contingent stressing considerations within prescribed estimates the following performance limitations have been imposed on the vehicle:-

Maximum level flight speed	225 Knots EAS
Maximum diving speed	270 Knots EAS
Maximum load factor in manoeuvre at 225 Knots EAS	4.0
Minimum load factor in manoeuvre at 225 Knots EAS	-2.0
Ceiling (above sea level)	10,000 feet

Load factors at other speeds are given in Fig. 36.

In flight starting of the engines is not presently provided, nor is fuel transfer from any tank to any engine. These features can be incorporated in a later development.

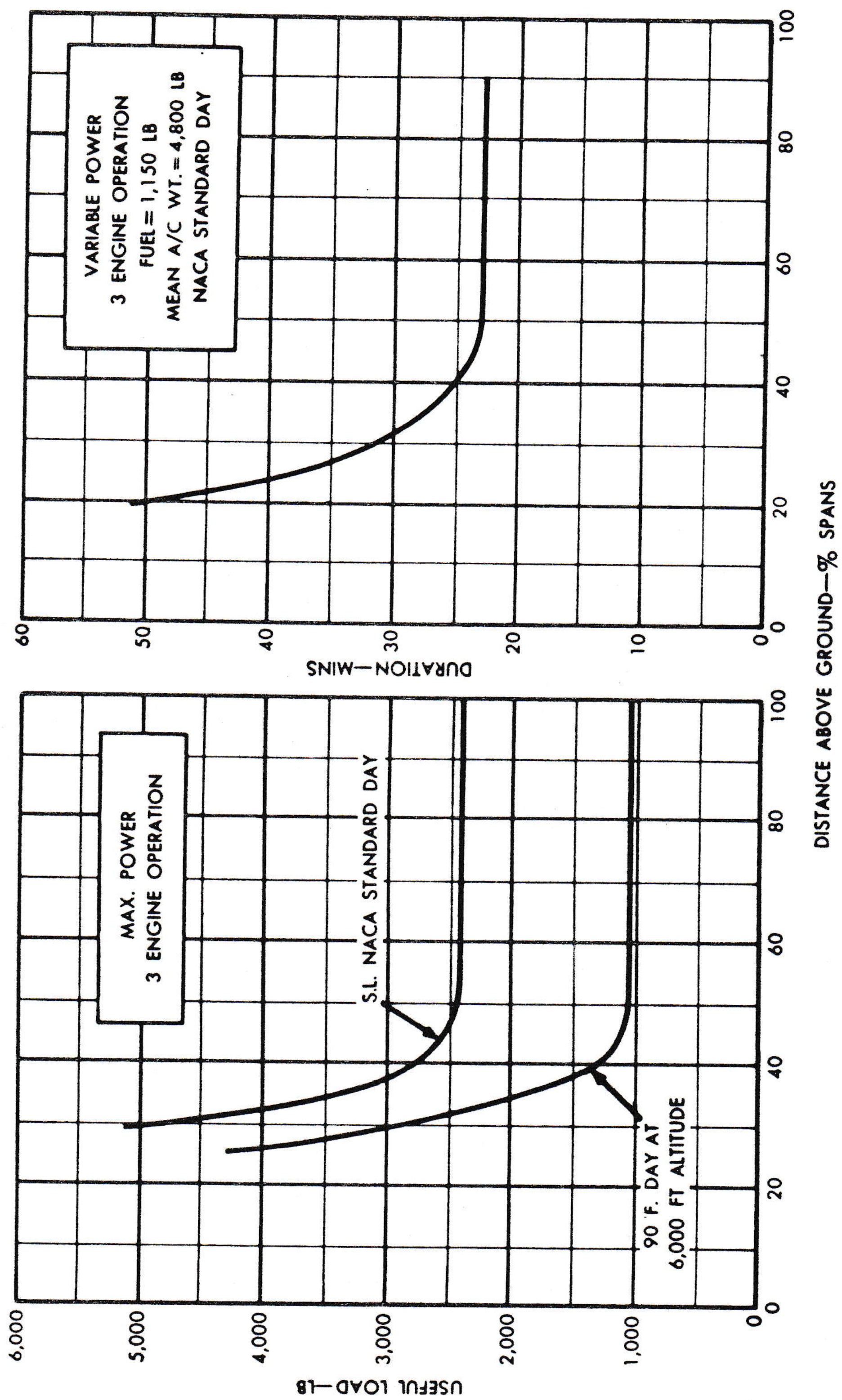

FIG. 2 ESTIMATED HOVERING PERFORMANCE
TEST VEHICLE - WITH CENTRAL NOZZLE

4230-802-1

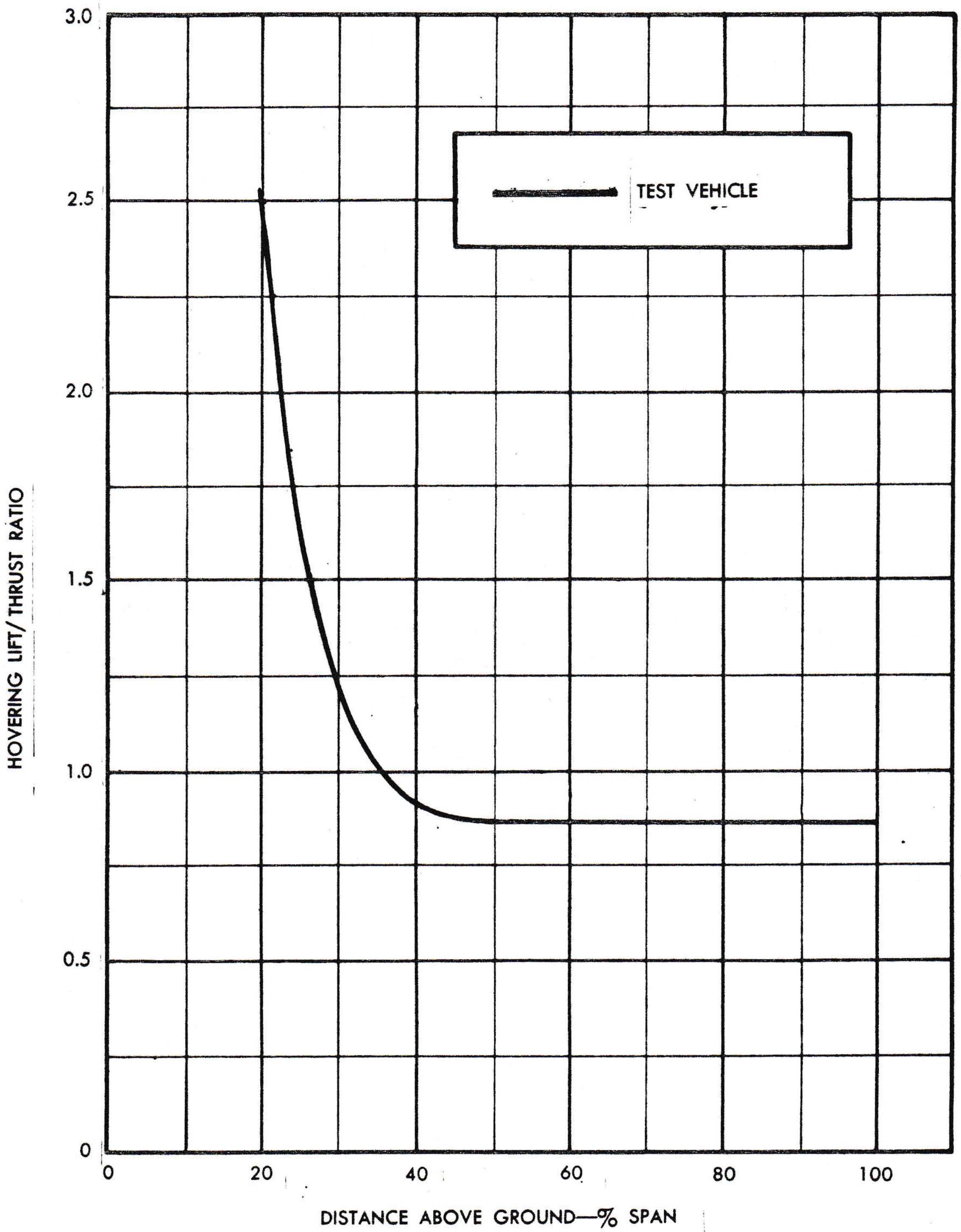

FIG. 3 ESTIMATED HOVERING THRUST LIFT EFFICIENCY

4235-802-1

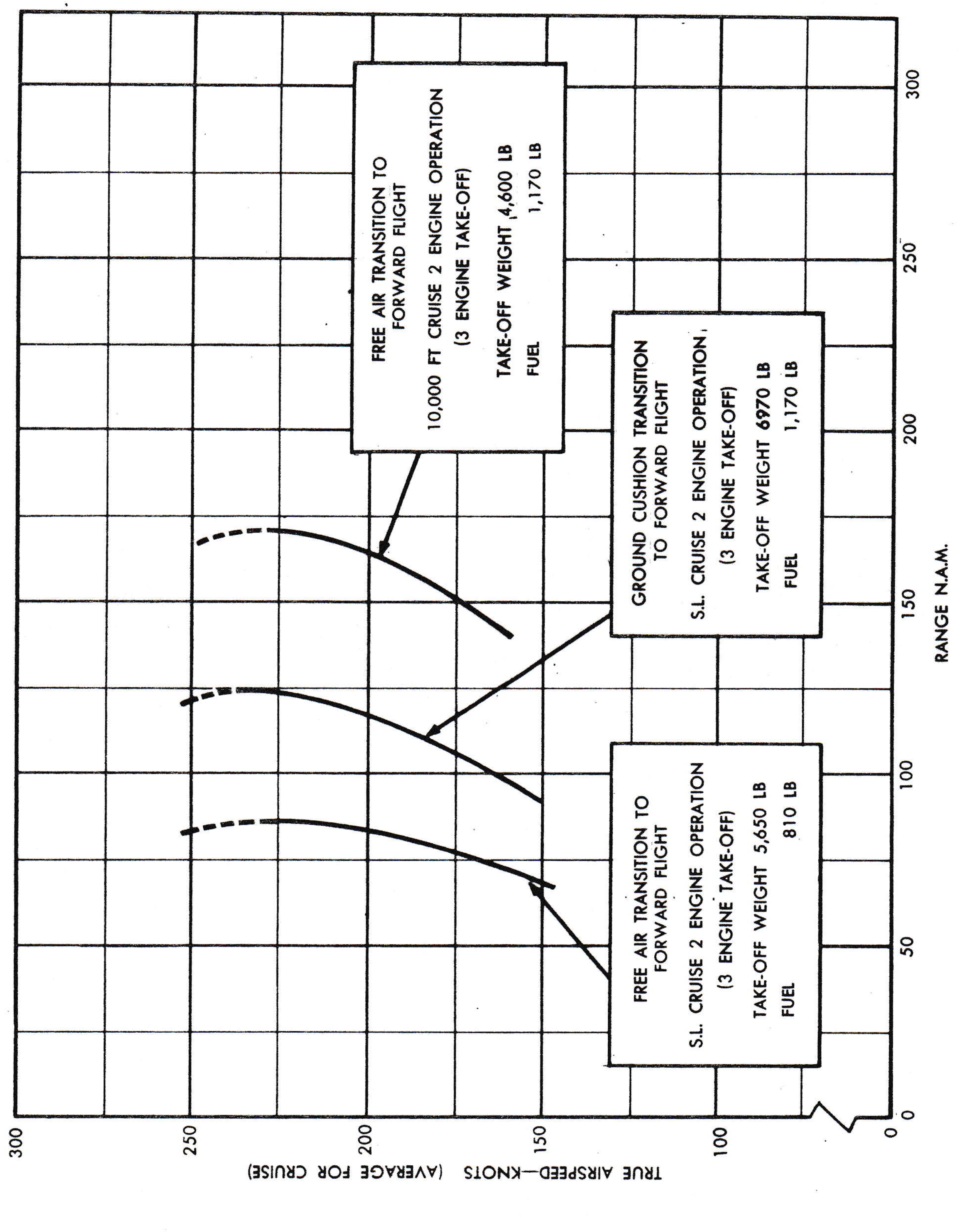

FIG. 4 ABSOLUTE AIR RANGE

4234-802-1

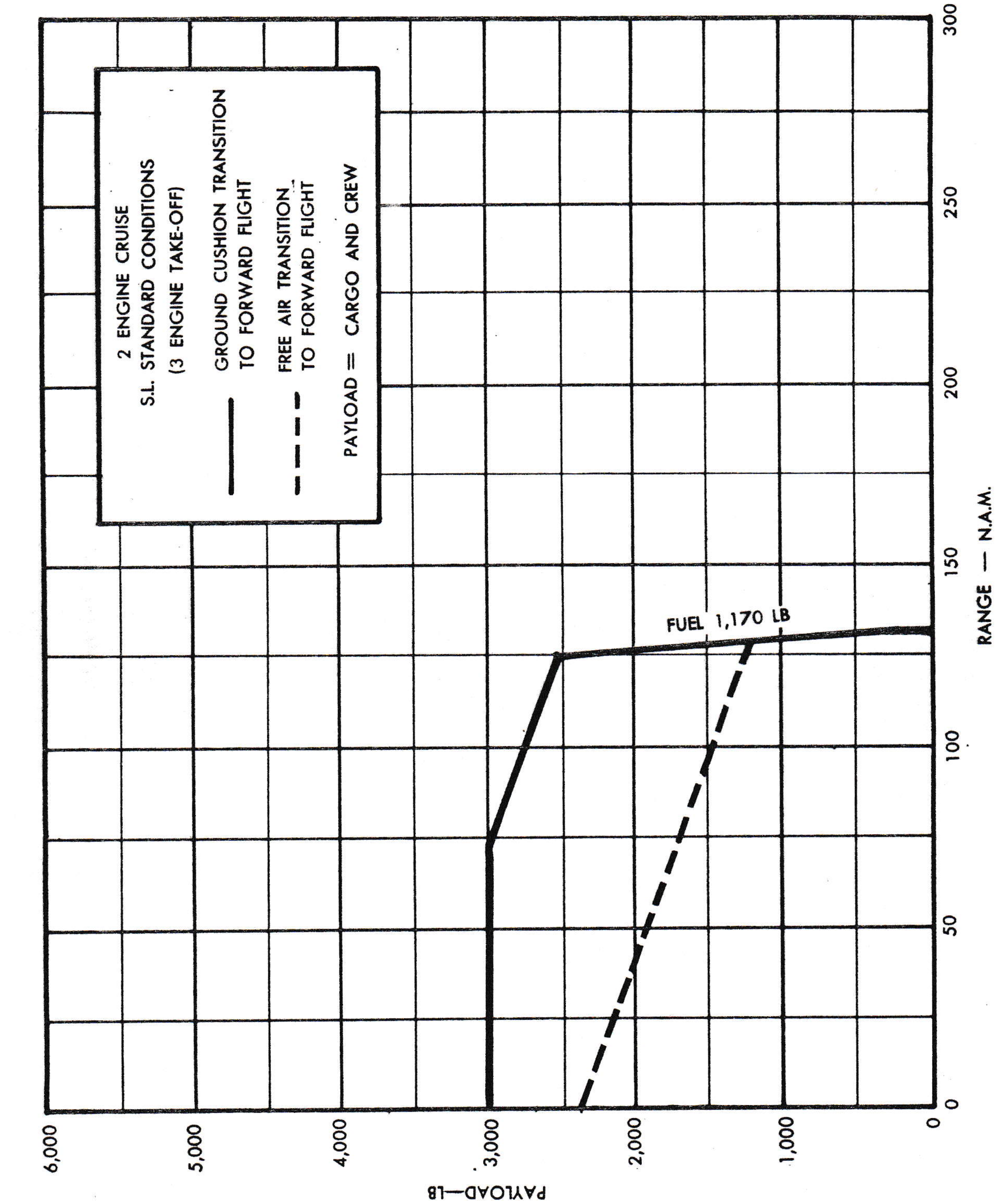

FIG. 5 PAYLOAD V ESTIMATED RANGE

4156-802-1

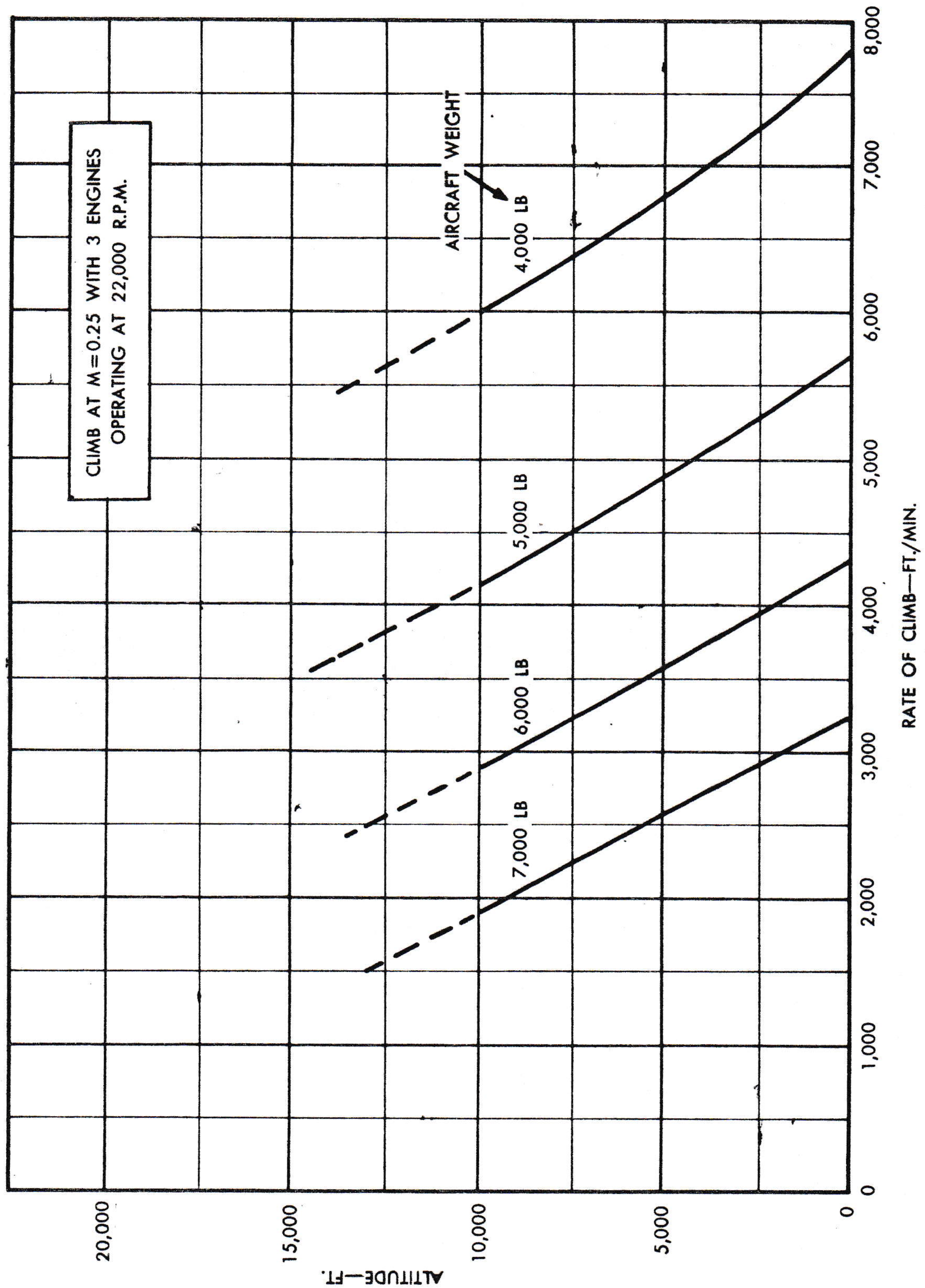

FIG. 6 ESTIMATED RATE OF CLIMB

4157-802-1

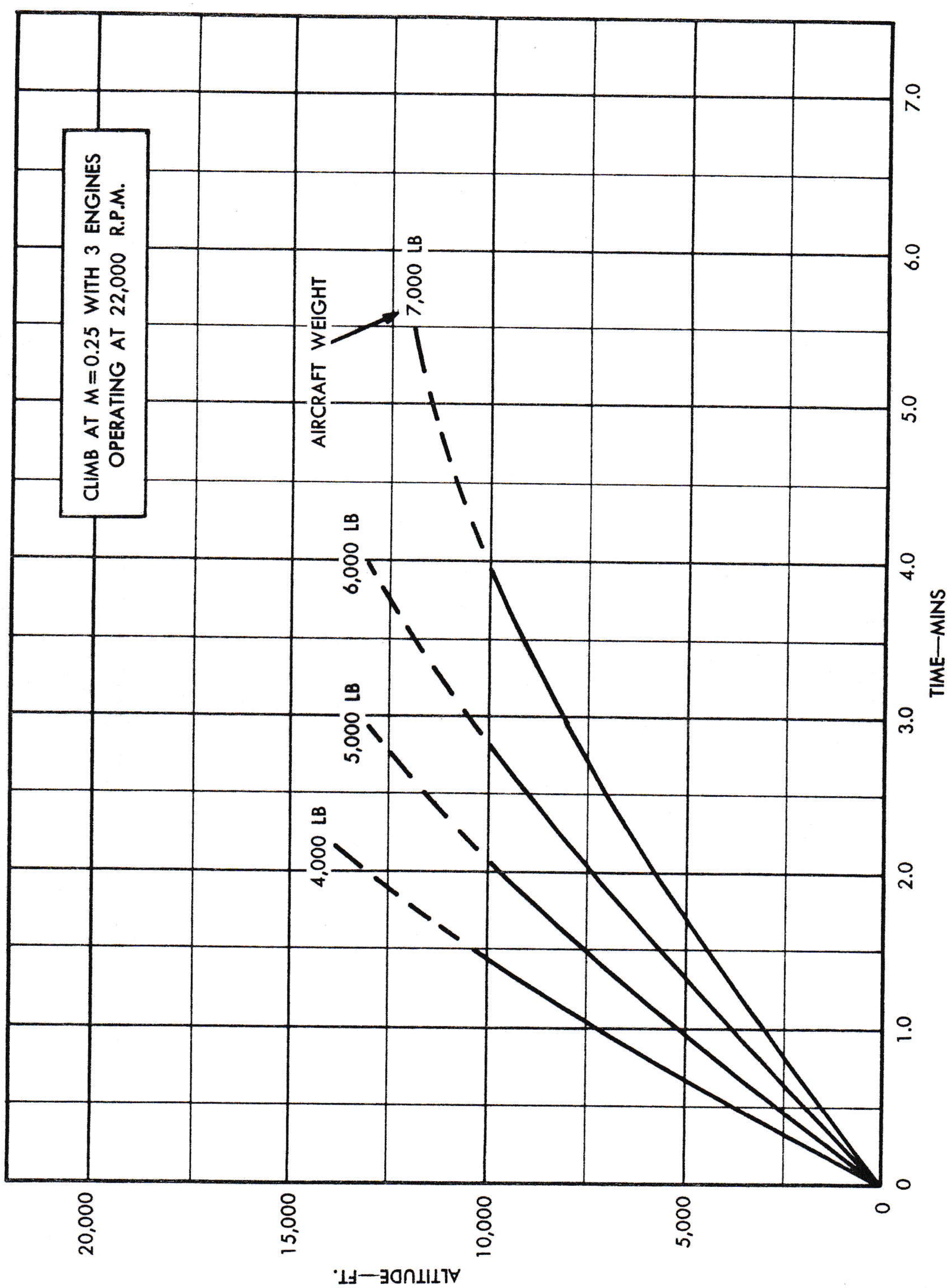

FIG. 7 ESTIMATED TIME TO HEIGHT

4231-802-1

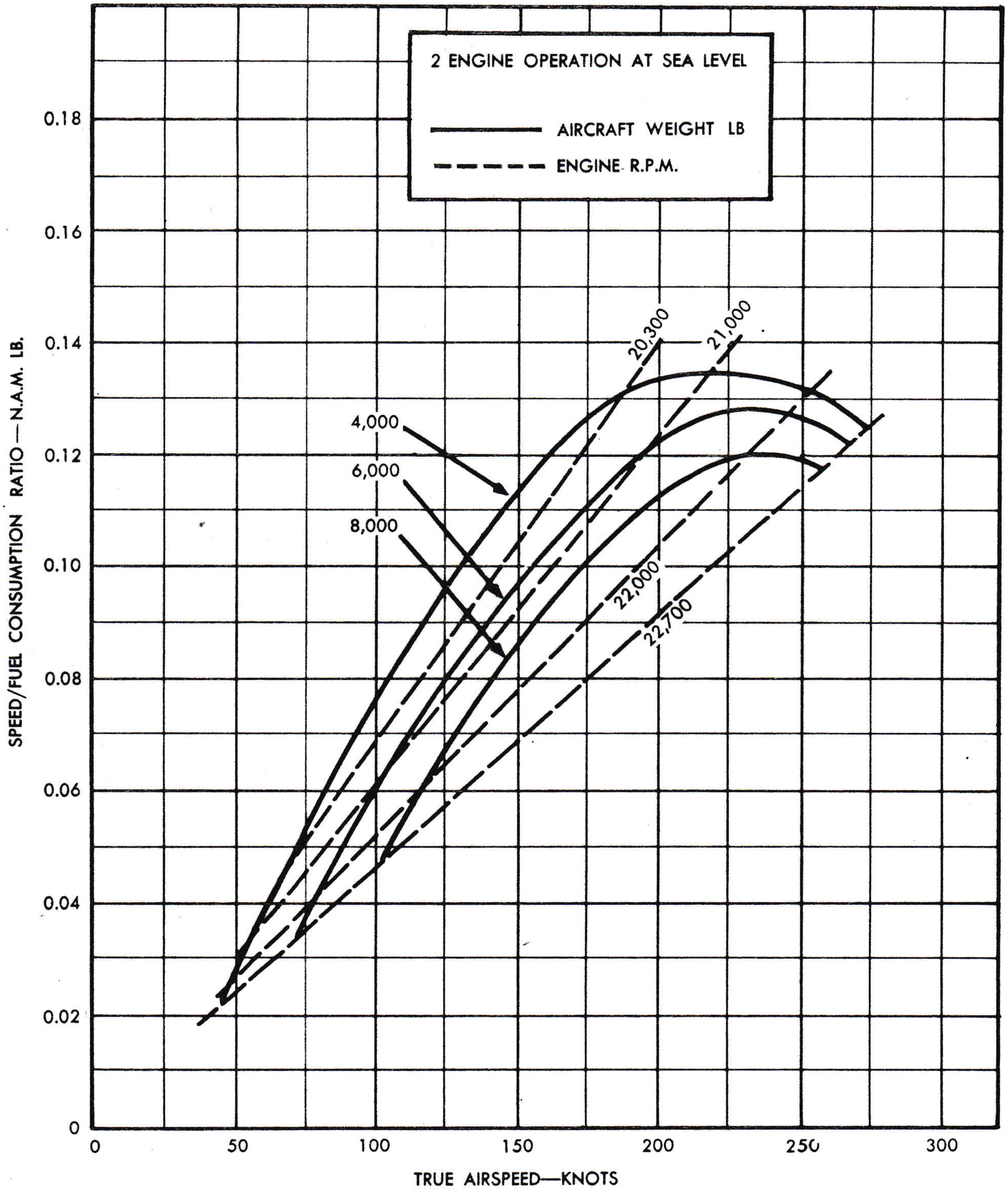

FIG. 8 SPECIFIC AIR RANGE-SEA LEVEL-2 ENGINE OPERATION

4233-802-1

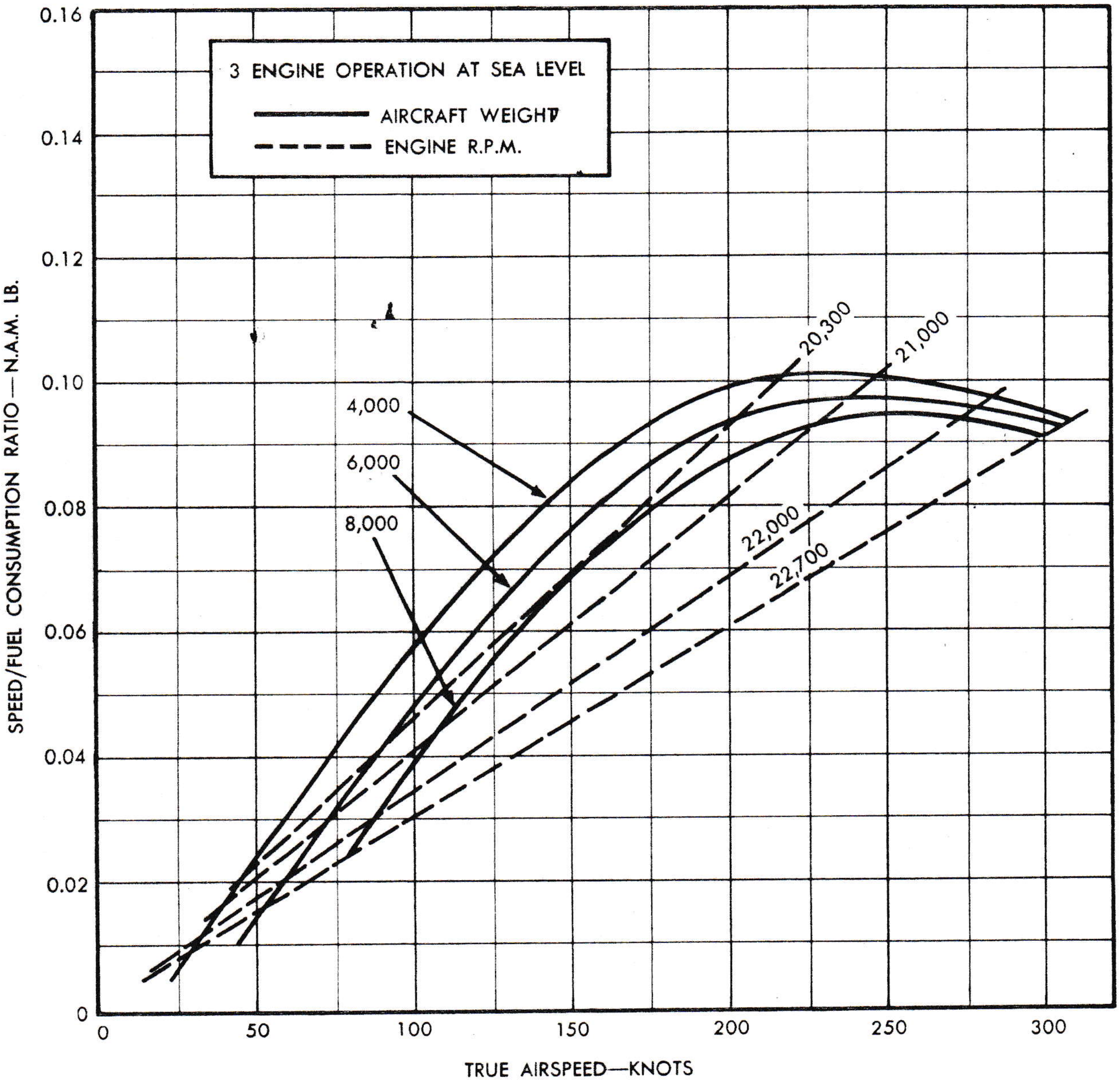

FIG. 9 SPECIFIC AIR RANGE-SEA LEVEL-3 ENGINE OPERATION

4159-802-1

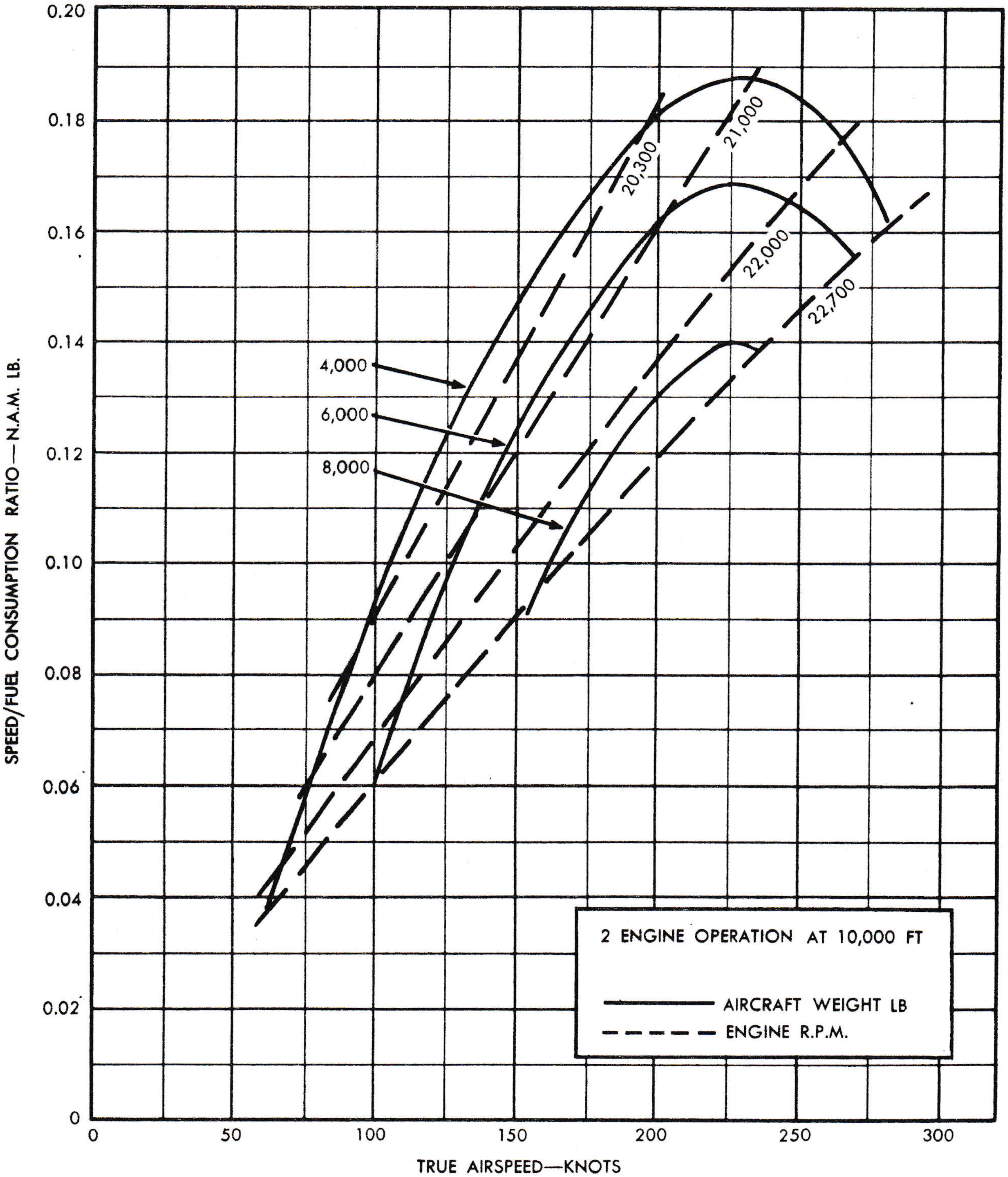

FIG. 10 SPECIFIC AIR RANGE-10,000 FT. -2 ENGINE OPERATION

4232-802-1

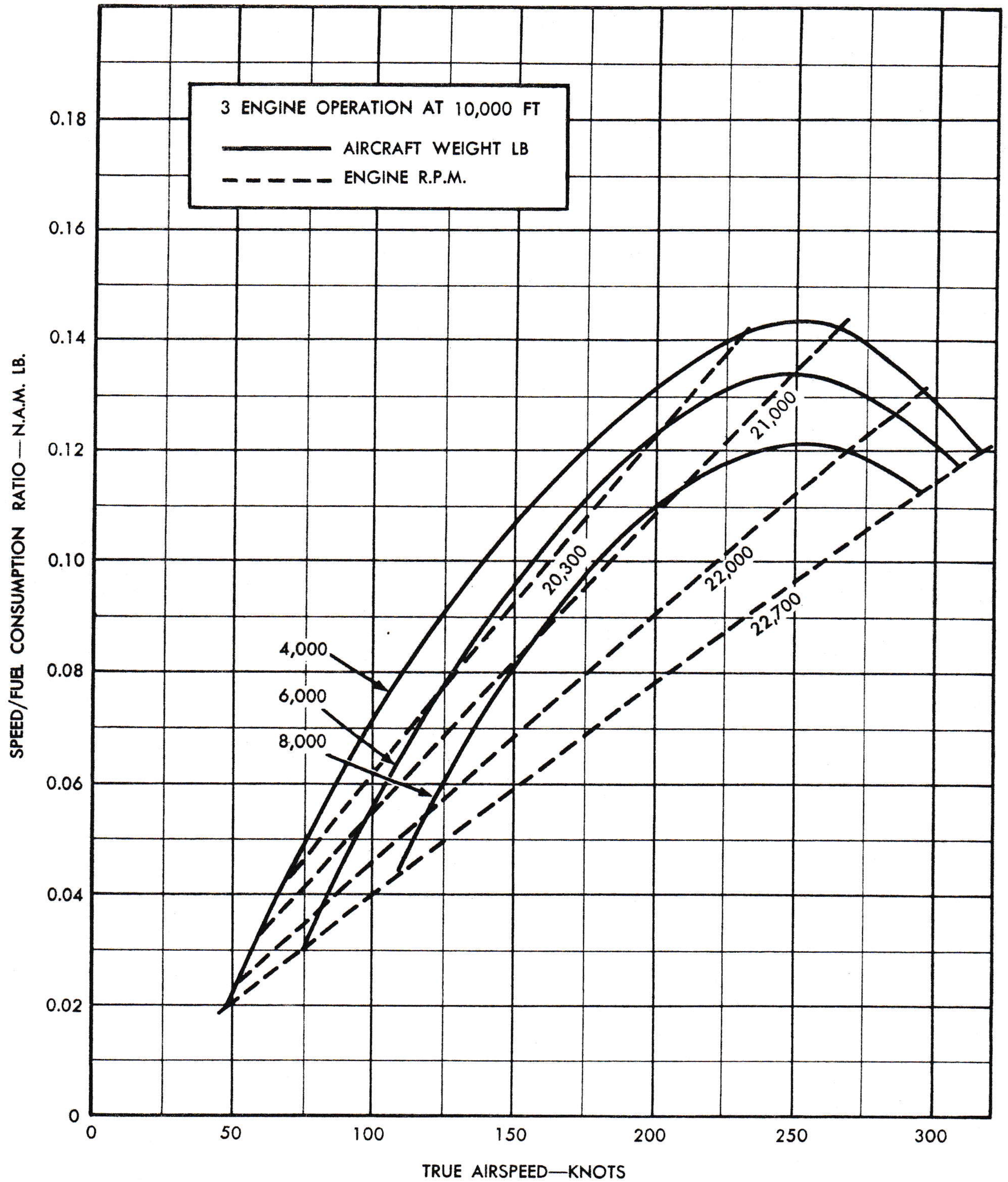

FIG. 11 SPECIFIC AIR RANGE-10,000 FT. -3 ENGINE OPERATION

PART 3

ESTIMATED AIRPLANE WEIGHT

AN-9103-D
NAME [illegible]
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GROUP WEIGHT STATEMENT
WEIGHT EMPTY

PAGE 18
MODEL VZ-9AV
REPORT AVRO/SPG/TR 254

1	WING GROUP						726
2	CENTER SECTION - BASIC STRUCTURE					548	
3	INTERMEDIATE PANEL - BASIC STRUCTURE						
4	OUTER PANEL - BASIC STRUCTURE (INCL. TIPS 111 LBS.)					111	
5	HATCHES					67	
6	SECONDARY STRUCTURE (INCL. WINGFOLD MECHANISM LBS.)						
7	AILERONS (INCL. BALANCE WEIGHT LBS.)						
8	FLAPS - TRAILING EDGE						
9	- LEADING EDGE						
10	SLATS						
11	SPOILERS						
12	SPEED BRAKES						
13							
14							
15	TAIL GROUP						—
16	STABILIZER - BASIC STRUCTURE						
17	FINS - BASIC STRUCTURE (INCL. DORSAL LBS.)						
18	SECONDARY STRUCTURE (STAB. & FINS)						
19	ELEVATOR (INCL. BALANCE WEIGHT LBS.)						
20	RUDDERS (INCL. BALANCE WEIGHT LBS.)						
21							
22							
23	BODY GROUP						—
24	FUSELAGE OR HULL - BASIC STRUCTURE						
25	BOOMS - BASIC STRUCTURE						
26	SECONDARY STRUCTURE - FUSELAGE OR HULL						
27	- BOOMS						
28	- SPEEDBRAKES						
29	- DOORS, PANELS & MISC.						
30							
31	ALIGHTING GEAR GROUP - LAND (TYPE: Wheels)						70
32–33		LOCATION	WHEELS, BRAKES TIRES, TUBES, AIR	STRUCTURE	CONTROLS		
34		Wing	22.2	47.8	—		
35							
36							
37							
38							
39							
40	ALIGHTING GEAR GROUP - WATER						—
41		LOCATION	FLOATS	STRUTS	CONTROLS		
42							
43							
44							
45							
46	SURFACE CONTROLS GROUP						117
47	COCKPIT CONTROLS					14	
48	AUTOMATIC PILOT						
49	SYSTEM CONTROLS (INCL. POWER & FEEL CONTROLS LBS.)					103	
50							
51	ENGINE SECTION OR NACELLE GROUP						40
52	INBOARD						
53	CENTER						
54	OUTBOARD						
55	DOORS, PANELS & MISC.					40	
56							
57	TOTAL (TO BE BROUGHT FORWARD)						953

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NAME [signature]
DATE December, 1958

GROUP WEIGHT STATEMENT
WEIGHT EMPTY

PAGE 19
MODEL VZ-9AV
REPORT AVRO/SPG/TR254

		AUXILIARY		MAIN		
1	PROPULSION GROUP					1851
2						
3	ENGINE INSTALLATION				1174	
4	AFTERBURNERS (IF FURN. SEPARATELY)					
5	ACCESSORY GEAR BOXES & DRIVES					
6	SUPERCHARGERS (FOR TURBO TYPES)					
7	AIR INDUCTION SYSTEM				32	
8	EXHAUST SYSTEM				138	
9	COOLING SYSTEM					
10	LUBRICATING SYSTEM				34	
11	TANKS			18		
12	COOLING INSTALLATION			—		
13	DUCTS, PLUMBING, ETC.			16		
14	FUEL SYSTEM				100	
15	TANKS - PROTECTED			—		
16	- UNPROTECTED			25		
17	PLUMBING, ETC.			75		
18	WATER INJECTION SYSTEM					
19	ENGINE CONTROLS				16	
20	STARTING SYSTEM				See Elect	
21	PROPELLER INSTALLATION					
22	TURBOROTOR				357	
23						
24	AUXILIARY POWER PLANT GROUP					
25	INSTRUMENTS & NAVIGATIONAL EQUIPMENT GROUP					29
26	HYDRAULIC & PNEUMATIC GROUP (For Flight Control Operation Only)					26
27						
28						
29	ELECTRICAL GROUP					262
30						
31						
32	ELECTRONICS GROUP (Communications)					32
33	EQUIPMENT				28	
34	INSTALLATION				4	
35						
36	ARMAMENT GROUP (INCL. GUNFIRE PROTECTION LBS.)					
37	FURNISHINGS & EQUIPMENT GROUP					54
38	ACCOMMODATIONS FOR PERSONNEL					
39	MISCELLANEOUS EQUIPMENT					
40	FURNISHINGS				54	
41	EMERGENCY EQUIPMENT					
42						
43	AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP					3
44	AIR CONDITIONING				3	
45	ANTI-ICING					
46						
47	PHOTOGRAPHIC GROUP					
48	AUXILIARY GEAR GROUP					12
49	HANDLING GEAR				12	
50	ARRESTING GEAR					
51	CATAPULTING GEAR					
52	ATO GEAR					
53						
54						
55	MANUFACTURING VARIATION					
56	TOTAL FROM PG. 2					953
57	WEIGHT EMPTY					3222

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GROUP WEIGHT STATEMENT
USEFUL LOAD & GROSS WEIGHT

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MODEL VZ-9AV
REPORT AVRO/SPG/TR 254

1	LOAD CONDITION BASIC MISSION TAKE OFF GROSS WEIGHT (Ref. AVRO/SPG/TR 125/5)						
2							
3	CREW (NO. 1)						200
4	PASSENGERS (NO. 1)						200
5	FUEL	Type	Gals.				
6	UNUSABLE	JP-4	1.85				12
7	INTERNAL	JP-4	124.61				810
8							
9							
10	EXTERNAL						
11							
12	BOMB BAY						
13							
14	OIL (For Turborotor and Engines)						44
15	TRAPPED 1					8	
16	ENGINE					36	
17							
18	FUEL TANKS (LOCATION Wing)						
19	WATER INJECTION FLUID (GALS)						
20							
21	BAGGAGE						
22	CARGO (Payload)						1162
23							
24	ARMAMENT						
25	GUNS (Location)	Fix. or Flex.	Qty.	Cal.			
26							
27							
28							
29							
30							
31							
32	AMMUNITION						
33							
34							
35							
36							
37							
38							
39	INSTALLATIONS (BOMB, TORPEDO, ROCKET, ETC.)						
*40	BOMB OR TORPEDO RACKS						
41							
42							
43							
44							
45							
46	EQUIPMENT						
47	PYROTECHNICS						
48	PHOTOGRAPHIC						
49							
*50	OXYGEN						
51							
52	MISCELLANEOUS						
53							
54							
55	USEFUL LOAD						2428
56	WEIGHT EMPTY						3222
57	GROSS WEIGHT						5650

*If not specified as weight empty.

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GROUP WEIGHT STATEMENT
DIMENSIONAL & STRUCTURAL DATA

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MODEL VZ-9AV
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1	LENGTH - OVERALL (FT.) 18			HEIGHT - OVERALL - STATIC (FT.) 4.95				
2		Main Floats	Aux. Floats	Booms	Fuse or Hull	Nacelles Inboard	Nacelles Center	Nacelles Outboard
3	LENGTH - MAX. (FT.)							
4	DEPTH - MAX. (FT.)							
5	WIDTH - MAX. (FT.)							
6	WETTED AREA (SQ. FT.)							
*7	FLOAT OR HULL DISPL. - MAX (LBS.)							
8	FUSELAGE VOLUME (CU. FT.) 520		PRESSURIZED			TOTAL 520		

		Wing	H. Tail	V. Tail
9				
10	GROSS AREA (SQ. FT.)	254		
11	WEIGHT/GROSS AREA (LBS./SQ. FT.)	22.2		
12	SPAN (FT.)	18.0		
13	FOLDED SPAN (FT.)			
14				
15	SWEEPBACK - AT 25% CHORD LINE (DEGREES)			
16	- AT % CHORD LINE (DEGREES)			
**17	THEORETICAL ROOT CHORD - LENGTH (INCHES)	216		
18	- MAX. THICKNESS (INCHES)	43.2		
**19	CHORD AT PLANFORM BREAK - LENGTH (INCHES)			
20	- MAX. THICKNESS (INCHES)			
**21	THEORETICAL TIP CHORD - LENGTH (INCHES)	0		
22	- MAX. THICKNESS (INCHES)			
23	DORSAL AREA, INCLUDED IN (FUSE.) (HULL) (V. TAIL) AREA (SQ. FT.)	0		
24	TAIL LENGTH - 25% MAC WING TO 25% MAC H. TAIL (FT.)			

25	AREAS (SQ. FT.) Flaps	L.E.	T.E.	
26	Lateral Controls	Slots	Spoilers	Ailerons
27	Speed Brakes	Wing	Fuse. or Hull	
28				
29				

30	ALIGHTING GEAR (Fixed) (LOCATION) (Wing)	
31	LENGTH - OLEO EXTENDED - [illegible] (INCHES)	22
32	OLEO TRAVEL - FULL EXTENDED TO FULL COLLAPSED (INCHES)	3.5
33	FLOAT OR SKI STRUT LENGTH (INCHES)	
34	ARRESTING HOOK LENGTH - ℄ HOOK TRUNNION TO ℄ HOOK POINT (INCHES)	
35	HYDRAULIC SYSTEM CAPACITY (GALS.)	

		Location	No. Tanks	****Gals. Protected	No. Tanks	****Gals. Unprotected
36	FUEL & LUBE SYSTEMS					
37	Fuel - Internal	Wing			3	176 (MAX)
38		Fuse. or Hull				
39	- External					
40	- Bomb Bay					
41						
42	Oil (1 Tank Integral with Turborotor Shaft)				4	5.8
43	(3 Tanks, one for each Engine)					
44						

		Fuel in Wings (Lbs.)	Stress Gross Weight	Ult. L.F.
45	STRUCTURAL DATA - CONDITION			
46	FLIGHT	822	5650	
47	LANDING (1/2 Useable Fuel)	405	5233	
48				
49	MAX. GROSS WEIGHT WITH ZERO WING FUEL		4828	
50	CATAPULTING			
51	MIN. FLYING WEIGHT		3442	
52	LIMIT AIRPLANE LANDING SINKING SPEED (FT./SEC.) At WLN		6.0	
53	WING LIFT ASSUMED FOR LANDING DESIGN CONDITION (%W)		70%	
54	STALL SPEED - LANDING CONFIGURATION - POWER OFF (KNOTS)		Not Appl.	
55	PRESSURIZED CABIN - ULT. DESIGN PRESSURE DIFFERENTIAL - FLIGHT (P.S.I.)			
56				
57	AIRFRAME WEIGHT (AS DEFINED IN AN-W-11) (LBS.)			

*Lbs. of sea water @ 64 lbs./cu. ft.
**Parallel to ℄ at ℄ airplane.
***Parallel to ℄ airplane.
****Total usable capacity.

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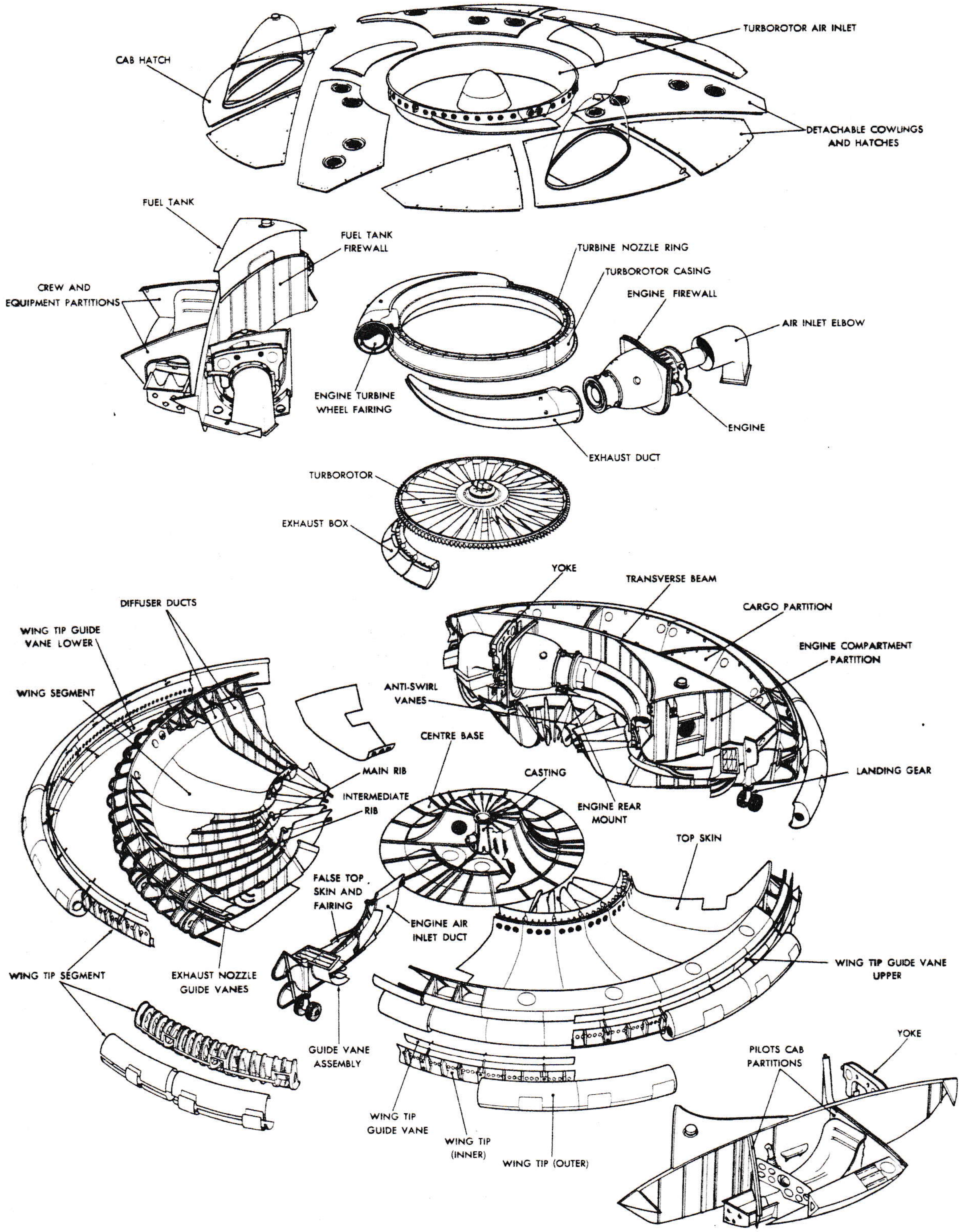

FIG. 12 AIRFRAME STRUCTURE EXPLODED VIEW

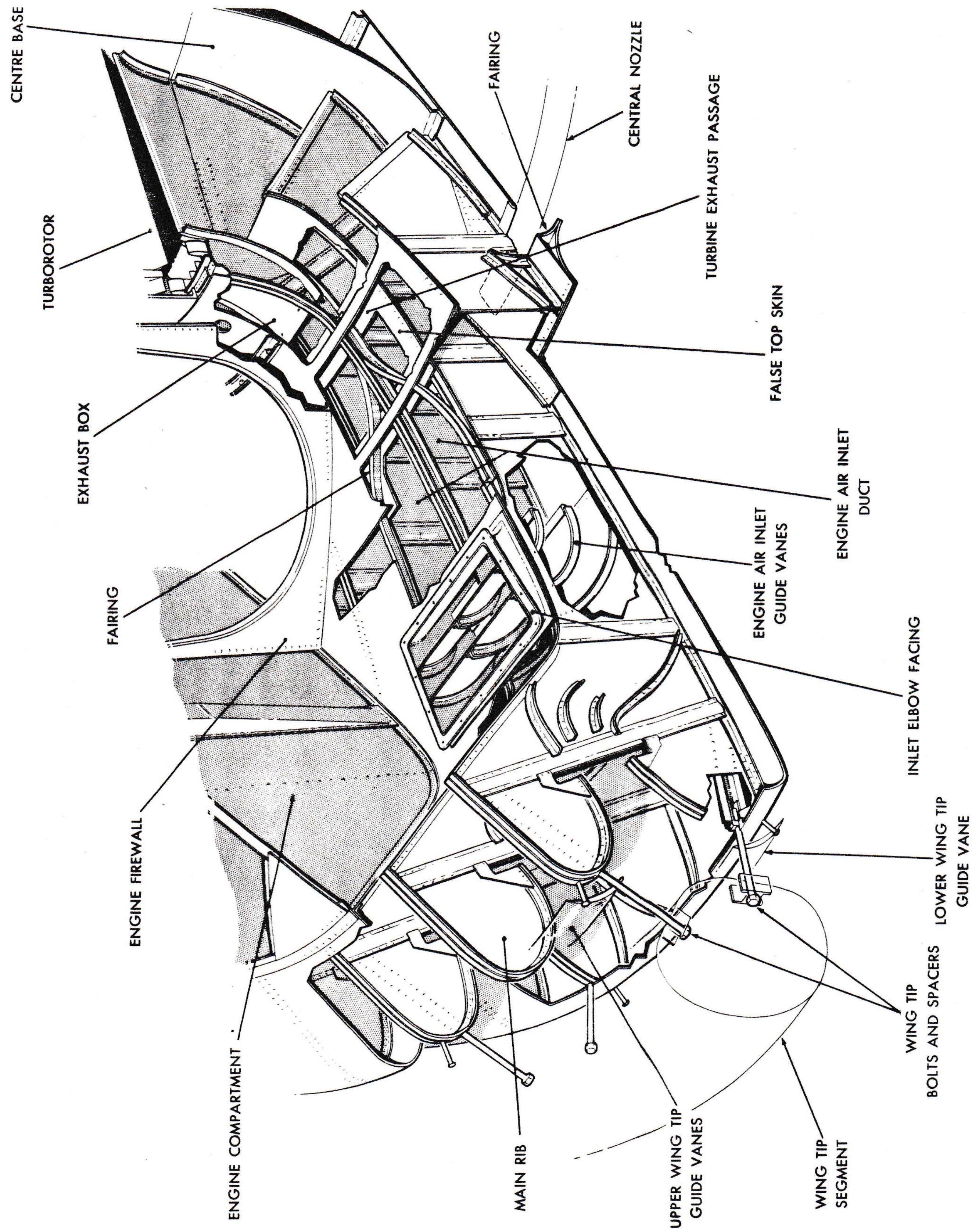

FIG. 13 ENGINE AIR INLET STRUCTURE

4.1 General

The airframe of the Avrocar, see Fig. 12, is an assembly of two types of structure, primary and secondary, supported on the ground by a fixed tricycle type alighting gear. The primary structure consists of a center base and three wing segments married into a single platform which carries the secondary structure and equipment. The secondary structure consists of a wing tip, turborotor casing, turborotor air inlet, compartment partitions, doors and cowlings.

4.2 Primary Structure

4.2.1 Center Base

The center base forms the hub of the vehicle and is a fabricated structure of aluminum alloy. It consists of a pedestal shaped spinning reinforced by six equidistant sheet metal ribs radiating from a cast cyclinder, and twelve riblets. The structure is covered by top and bottom skins of aluminum alloy. The casting provides the mounting for the turborotor shaft assembly while the radial ribs and skins provide for the transfer of loads between the three wing segments.

4.2.2 Wing Segments

Each of the three wing segments consists of five main radial ribs and twelve intermediate radial ribs. The ribs are covered by a top and bottom skin to form separate channels or diffuser ducts through which air from the turborotor is moved. The inboard end of each main rib carries an anti-swirl vane located between the wing segment and the upper contour of the center base, (beneath the compressor blades of the turborotor). The outboard ends of the ribs terminate in two toroidal shaped rims formed by the skins and the rib ends. Two exhaust nozzle guide vanes are attached between the rims. An upper and a lower wing tip guide vane are located between the wing rims and the wing tip at the nozzle outlet.

An engine inlet duct is formed between each segment upon marrying the center base structure, the wing segments, and three additional main ribs. Each duct is centrally divided by one of the three ribs.

A guide vane assembly is incorporated in the downstream end of each duct. These vanes turn the inlet air into the elbow which connects with the engine compressor casing in the engine compartment located above. To prevent contamination of the engine inlet air, a false top skin and fairing is incorporated in the roof at the upstream end of the duct. The skin and fairing provide a separate bifurcated passage which carries the engine exhaust gas to adjacent ducts.

The outboard end of the main rib in each engine air inlet duct, outboard of the guide vane assembly, is reinforced to carry a landing gear leg.

The bottom skins of the vehicle incorporate a centrally located annulus, together with a fairing, which form a central nozzle.

4.2.2 Wing Segments (Continued)

The top skins of the segments form the floor of the secondary structure. These skins and the bifuracted exhaust passages are of stainless steel, the remainder of the wing segment structure is fabricated from aluminum alloy.

4.3 Secondary Structure

4.3.1 Wing Tip

The wing tip, which surrounds the vehicle, is divided into nine segments each of which is a fabricated box construction of aluminum alloy ribs and skins. Each wing tip segment consists of an inner tip, (with a series of air inlet holes) and an outer tip bolted together to form a plenum with upper and lower air outlet slots. The inner part of each tip segment is attached to the wing segments by bolts and spacers to form a bifurcated outlet for the diffuser ducts. The bolts and spacers also carry the wing tip guide vanes.

4.3.2 Torborotor Casing

The turborotor casing assembly is a continuous stainless steel ring fabricated from rolled angles and sheet metal. The lower angle of the casing is secured to a collar surrounding the entry to the diffuser ducts. The turborotor casing assembly, which segregates the turbine shroud from the three engine compartments, is protected from thermal radiation by fibrous silica blankets.

4.3.3 Turborotor Air Inlet

The turborotor air inlet assembly is a continous ring fabricated from ribs and skins of aluminum alloy. The assembly is attached to the rotor casing by turnbuckles and to the engine compartment structure by support brackets, nuts and bolts.

4.3.4 Compartments

The well formed in the primary structure above the floor is sub-divided into compartments by three beams and a number of smaller partitions.

The three transverse beams of aluminum alloy, form a triangular enclosure for the engines, exhaust ducts, turborotor and fuel tanks. The fuel tanks are protected from the exhaust ducts by stainless steel firewalls and fibrous silica blankets, and from the cold zone of the engine by an aluminum alloy partition. The hot and cold zones of the engine compartments are divided at the engine compressor flange by a stainless steel firewall.

The transverse beams are laterally supported by the subsidiary partitions in the left, right and rear of the vehicle, which form the crew, equipment and cargo compartments, and by the walls of the fuel tank and engine compartments.

4.3.5 Hatches and Cowlings

The various compartments are enclosed by hatches and cowlings which form the upper surface of the vehicle.

The hatch of each crew compartment is of double skin aluminum alloy, reinforced by stiffeners and angles and fitted with a plexiglas canopy. Each hatch is hinged at the rear and is secured at the front by two latches interconnected by a torque tube. The hatches may be operated from within the cab and externally.

The three engine compartments are enclosed by cowlings constructed of double skin aluminum alloy. Each cowling incorporates four louvered air vents to provide cooling air and ventilation. See Section 6.6.

The cargo and equipment compartment hatches are of double skin aluminum alloy reinforced by stiffeners and edge members. The hatches are secured around their edges by quick release fasteners.

4.4 Alighting Gear

The vehicle is fitted with three landing gear legs, each incorporating an integral pneumatic shock absorber and solid twin wheels which are free to castor. The landing gear legs are equidistantly spaced around the vehicle, one at the front and two at the rear.

Each shock absorber consists of a piston retained within a cylinder by a stop integral with the piston, and a retaining ring. An axle carrying the twin wheels is attached to the lower end of the piston.

The upper end of the cylinder is attached to the reinforced outer end of the main rib which divides the engine air inlet duct.

A charging valve on the top of the cylinder permits ground charging of the shock absorber to 500 psi and is accessible through the engine compartment.

PART 5

POWERPLANT

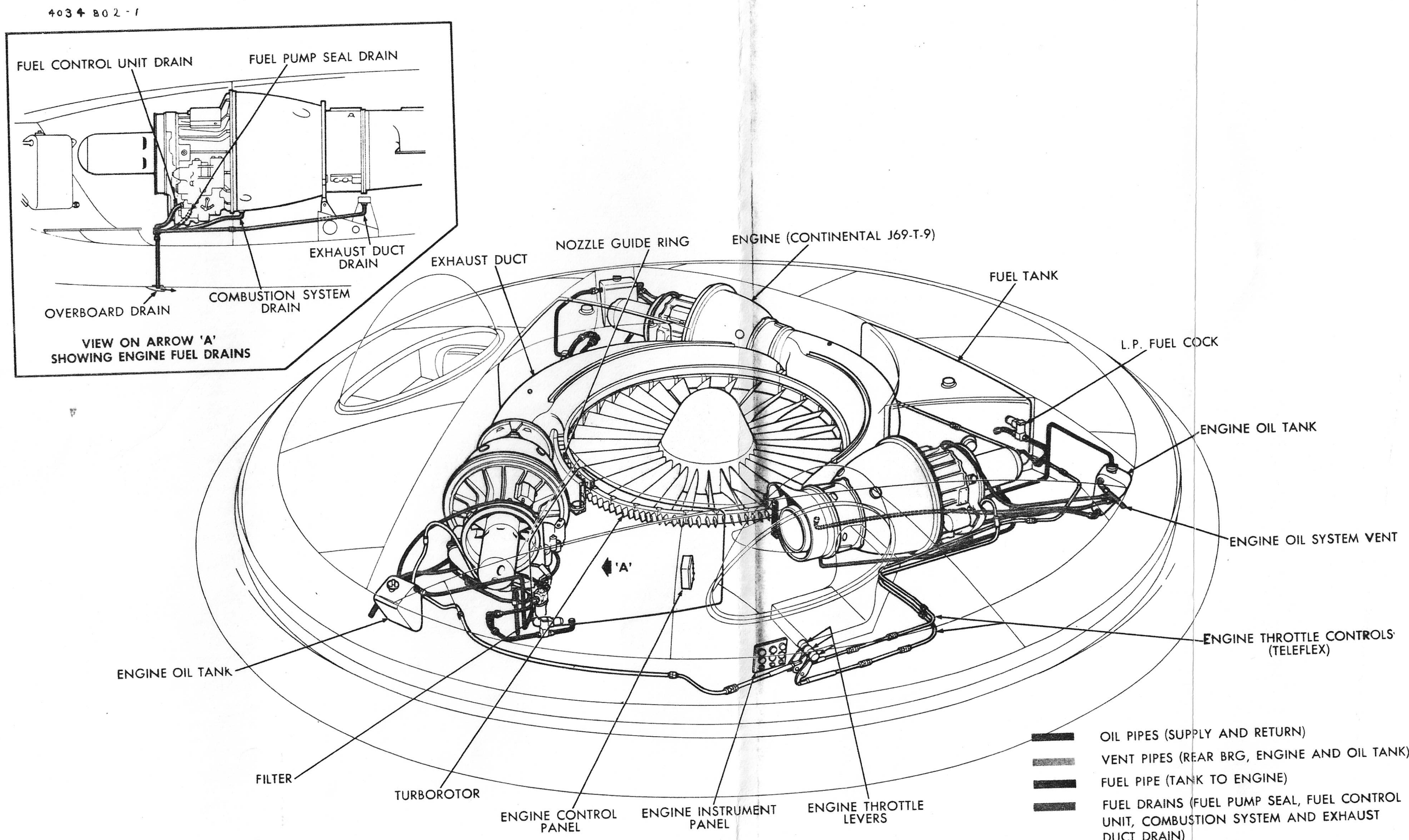

FIG. 14 POWERPLANT INSTALLATION

5.1 General

The powerplant of the Avrocar, see fig. 14 , consists of three conventional gas turbine engines; three exhaust ducts; a turbine driven compressor, known as a turborotor; three fuel tanks with fuel cocks and piping; three engine oil tanks with piping; a turborotor oil tank, three engine air inlet elbows; and the engine controls.

The three gas turbine engines perform as gas generators to drive the turborotor which supplies compressed air to the nozzles at the periphery of the wing and in the undersurface of the vehicle.

5.2 General Arrangement

Three Continental J69-T-9 turbojet engines, with a military thrust rating of 920 lb at 22,700 r.p.m., are arranged tangentially and symmetrically in plan about the turborotor. Three tusk-shaped ducts convey the exhaust gases to a turbine nozzle ring assembly located above the turbine blades of the turborotor. The nozzle ring directs the exhaust gases onto the turbine blades to drive the turborotor.

The compressor section of the turborotor provides for the induction of ambient air through the inlet in the upper surface of the vehicle. The diffuser ducts, within the primary wing structure, provide for the delivery of air from the turborotor to the nozzles, and to the engine compressors through the engine air inlet ducts.

A fuel tank is located between each engine compartment and the turborotor air inlet. Each tank is protected by an aluminum alloy partition and a stainless steel firewall.

An engine oil tank is located in each engine compartment and is mounted on the structure between the ends of the transverse bulkheads. A turborotor oil tank is mounted on the turborotor shaft assembly.

5.2.1 Engine Mounting

Each engine, installed within an engine compartment, is secured at the main trunnions by a yoke, see fig. 12, and at the rear by a fitting secured to the floor to the vehicle.

Each yoke is a fabricated box construction of aluminum alloy. The shoulders of each yoke incorporate hinge pins and spherical bearings which are supported on two adjacent compartment partitions by capped housings mounted on reinforced structural supports. The housing caps are detachable to facilitate engine removal. The legs of each yoke incorporate plain bearings which carry the two engine main support trunnions. The right hand trunnion is free to permit transverse expansion of the engine.

The rear anchorage for each engine consists of a stainless steel fabricated box which is attached to the floor structure and carries a steel fork end fitting. The steel fork accommodates a male fitting, attached to the underside of the engine turbine inlet flange, which

5.2.1 Engine Mounting

is secured by a pin. To facilitate engine removal the pin is inserted through a recessed aperture in the adjacent compartment.

5.2.2 Engine Firewall

The hot and cold zone of each engine compartment is separated by a transverse firewall of stainless steel. The firewall is fitted with a silicone rubber seal around its outside edge which locates against metal rubbing strips provided on the adjacent structure. The firewall is attached to the engine compressor casing flange by brackets.

5.2.3 Engine Air Inlet Elbow

Each engine air inlet elbow, see Fig. 12, conveys clean air from the air inlet ducts, integral with the primary structure, to the engine compressor, see paragraph 4.2.2. Each elbow is fabricated of resin filled glass cloth with an angle attachment for securing the elbow to the floor of the vehicle. A metal ribbing strip on each engine compressor engages a rubber seal attached to the elbow to permit longitudinal expansion of the engine.

5.2.4 Exhaust Ducts.

A tusk shaped duct provides for the transmission of hot gas from each engine turbine to the turbine nozzle ring surrounding the turborotor. The ducts are of stainless steel with an internal engine turbine wheel fairing, and a machined ring for clamping the inlet end flange to the engine turbine shroud. The exit of the duct is reinforced with two external flanges which engage in circumferential grooves, provided in the upper surfaces of the nozzle guide .ring to permit heat expansion.

5.2.5 Turbine Nozzle Ring

The stainless steel turbine nozzle ring assembly consists of 18 segments, each of which incorporates 8 blades. The assembly forms a nozzled duct to guide the exhaust gases from the exhaust duct onto the turbine baldes of the turborotor. Each segment is attached to the upper flange of the turborotor casing, see paragraph 4.3.2, while the lower edges are fitted with metal seals to minimize pressure leakage at both the inner and outer walls of the ring. The attachments are designed to permit differential heat expansion.

5.2.6 Turbine Shroud

The turbine shroud is a stainless steel machined ring which encases the rotor turbine blades. The shroud consists of nine segments supported on brackets and attached to the inboard ends of the eighteen main structural ribs. The attachment of the segments to the brackets provides for differential heat expansion.

5.2.7 Turbine Exhaust

The hot gas exhausting from the turbine flows into 18 exhaust boxes located in the entry to the diffuser ducts in the primary structure. The stainless steel exhaust boxes incorporate radial inlet guide vanes and a series of six outlet ducts. The boxes are attached to the underside of the turbine shroud segments and to the inboard portion of the floor skin between the main ribs. The attachments provide for differential heat expansion. A series of holes are located circumferentially in the upper skin at the diffuser ducts for cooling purposes. See fig.30 , and paragraph 6.6.1

5.3 Fuel System

5.3.1 General

The fuel system incorporates three individual fuel tanks, three electrically actuated low pressure fuel cocks, and the respective fuel lines and filters. Each tank provides for the supply of fuel to one engine through its respective fuel cock, which is mounted on an adjacent compartment partition in a protective sheet metal box. From the L.P. fuel cock, fuel is delivered by fire resistant hose to the inlet connection of the engine fuel control unit. This unit incorporates a fuel filter and fuel pump.

5.3.2 Fuel Tanks

Each fuel tank has a useable capacity of approximately 57 U.S. gallons and is constructed of welded aluminum skins which are braced internally by stiffeners and baffle plates. External supports are provided for attaching the tanks to the adjacent compartment partition. Each tank is provided with a filler neck, a strainer and a filler cap which is vented to atmosphere but incorporates a float valve to prevent fuel leakage. An outlet connection is located in a recessed panel near the bottom of the tank with an internal low level delivery pipe. On the bottom of each tank a drain valve is provided which is operated by a spring loaded plunger located in the top surface of the tank.

Each tank houses a sealed, float type fuel quantity transmitter which may be removed for servicing through a panel in the side of the tank. A rectangular access panel is also provided in one side of the tank for inspection purposes.

5.3.3 Engine Fuel Drains

Drain pipes from the engine fuel pump seal, the engines combustion system, and the exhaust duct in each engine compartment are connected to an overboard drain.

5.4 Engine Oil System

Each engine is provided with an independent oil system. A tank with an oil capacity of 1.8 U.S. gallons and an expansion volume of 1.2 U.S. gallons is installed in each engine compartment.

A vent pipe from each tank is connected to the throat of the diffuser ducts in the primary structure. These pipes are interconnected with the front and rear engine breather pipes.

Each tank is provided with a combined filler cap and dipstick.

5.5 Engine Controls

5.5.1 Throttles

The engine control consists of three throttle levers mounted in a throttle box assembly located on the left hand console of the pilot's cab. Each lever is connected mechanically with an engine fuel control unit by a teleflex cable and conduit. A quick disconnect coupling is provided at each engine compartment partition.

Each throttle lever is provided with an adjustable stop at the maximum engine r.p.m. position and a gate at the idling r.p.m. position. Rearward movement of each lever through the gate closes the H.P. fuel cock in the engine control unit which cuts the fuel supply to the engines. The box is engraved to indicate maximum, idle, and off positions.

5.6 Turborotor Assembly

The turborotor assembly comprises the turborotor and a stationary compound shaft assembly consisting of an external shaft, an internal shaft and a central control shaft. See fig.16 . The top of the shaft assembly is faired by a bullet.

5.6.1 Turborotor

The turborotor, see fig.15 , is fabricated of stainless steel with a hub carried on two taper roller bearings which are secured on the external shaft by an interposing spacer and retaining nut. Radially disposed about the hub are 31 compressor blades with an outer rim carrying 124 turbine blades. The turbine blades are made up in segments of four to facilitate replacement.

5.6.2 Shaft Assembly

The external shaft, on which the rotor is mounted, is connected at the upper end with the central control shaft by a flexural diaphragm while the lower end is flared to accommodate a spherical bearing carried by the internal shaft.

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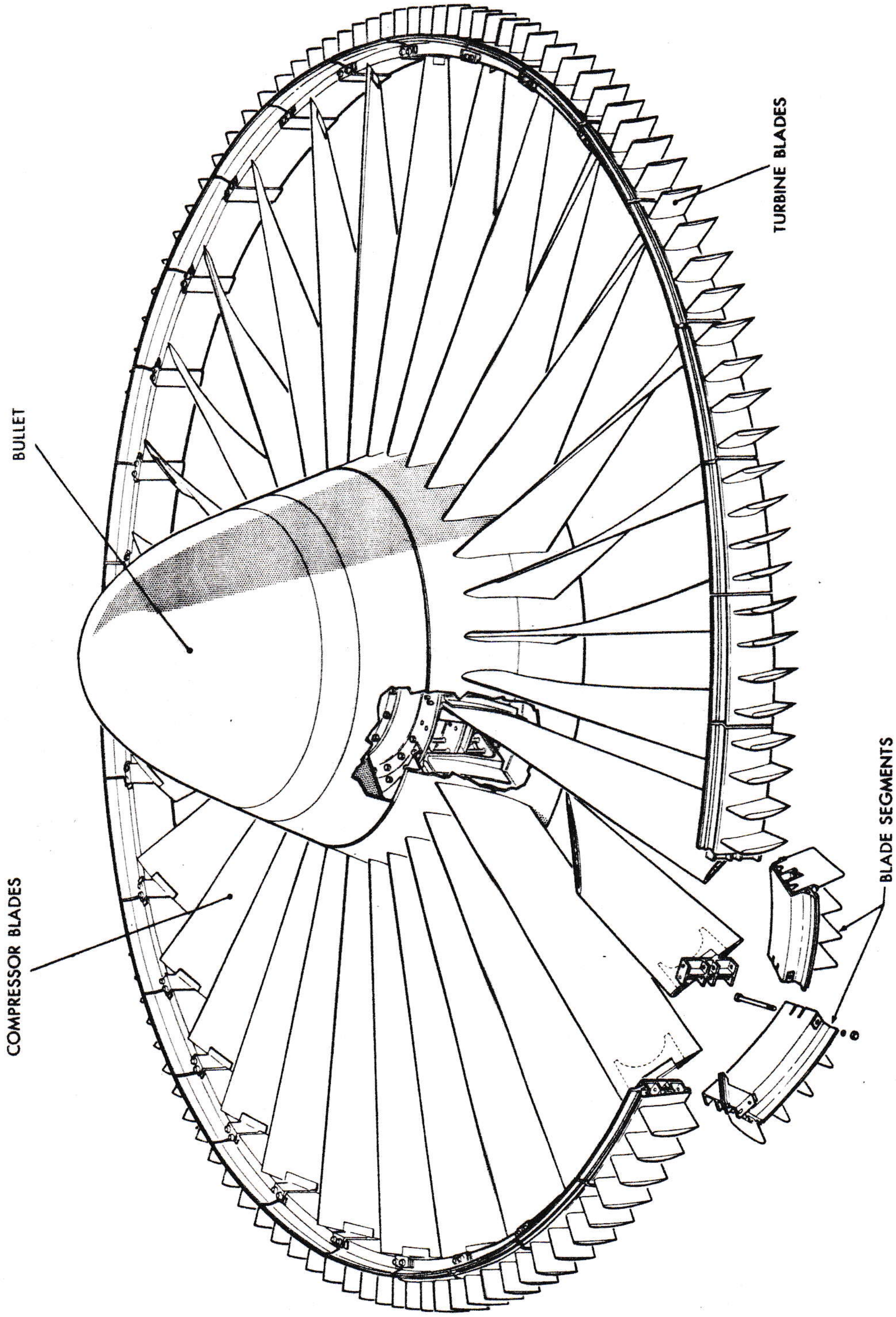

FIG. 15 TURBOROTOR ASSEMBLY

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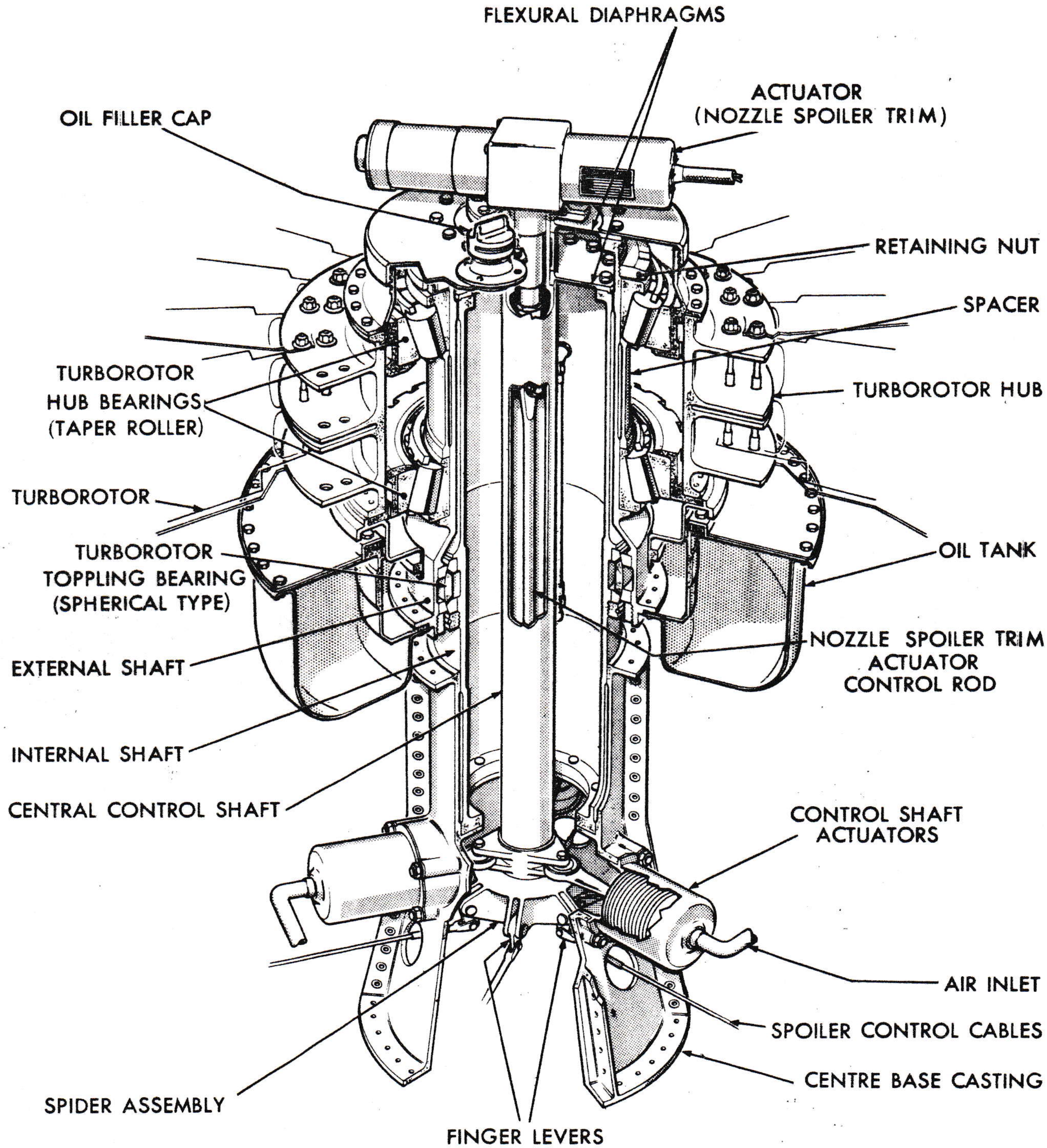

FIG. 16 TURBOROTOR SHAFT ASSEMBLY

5.6.2 Shaft Assembly (Continued)

The internal shaft is located in the bore of the external shaft and is also connected at its upper end with the central control shaft by a flexural diaphragm. The lower end of the internal shaft is located and secured in the center base casting of the vehicle primary structure.

The central control shaft is housed in the bore of the internal shaft. The inner ends of the two flexural diaphragms are located on this shaft by a step, spacer, collar and retaining nut. The lower end of the control shaft accommodates a spider assembly incorporating two groups of integral lugs. One group forms the attachment for three control shaft actuators while the other group forms the attachment pivots for six finger levers to which are coupled 18 control cables for operating the nozzle spoilers.

A collar at the upper end of the central control shaft forms the mounting for the nozzle spoiler trim control actuator. Connected to the actuator and housed within the bore of the central control shaft, is a control rod, the lower end of which carries a spool to locate the tips of the six finger levers so that movement of the actuator may be transferred to the control cables collectively.

5.6.3 Turborotor Lubrication

A sheet metal doughnut type oil tank is mounted at the lower end of the external shaft with a graphite seal located between the tank and the rotor hub. A cover with windback seal is attached to the top of the external shaft above the rotor bearings at the hub. An oil filler cap is located in the cover. An overflow pipe leads from the tank to discharge at the bottom of the vehicle. A submerged mechanical pump driven by the hub injects oil via an internal pipe system to a spray device located between the bearings.

5.7 Powerplant Performance Estimates

5.7.1 Leading Dimensions of Engine

The following constitute the principle dimensions and aerodynamic quantities at the design point for the engine.

Turborotor Temperature Rise	9.11°C
Turborotor Mass Flow	544 lb./sec.
Turborotor Speed (maximum rating)	2570 R.P.M.
Turborotor Inner Diameter	20.18 ins.
Turborotor Outer Diameter	60.00 ins.
Engine Speed (maximum rating)	22,700 R.P.M.
Engine Mass Flow	53.72 lb/sec.

5.7.1 Leading Dimensions of Engine

Central Annular Nozzle Area	(actual)	700 ins.^{2}
Peripheral Nozzle Area	(actual)	2318 ins.^{2}
Central Annular Nozzle Area	(effective)	665.28 ins.^{2}
Peripheral Nozzle Area	(effective)	1865 ins.^{2}

5.7.2 Assumptions

In order to avoid a lengthy program of matching calculations, three basic assumptions were made

(a) For vertical take-off and hovering both central and peripheral nozzles are in operation. In forward flight the central nozzle is closed with only the peripheral nozzle in operation.

(b) The horsepower developed by the power plant varies with the thrust and inlet pressure of the J69 engine, and the turborotor R.P.M. This may be written as follows:

$$\frac{HP}{P_3} = K.X.N.$$

Where X is the thrust developed by the J69 engine; P_3, the pressure at the turborotor outlet; N, the turborotor R.P.M; K, a similarity constant; and HP the developed horsepower of the engines.

(c) For the duct flow losses it was assumed that $\Delta P/1/2\,\rho V^2$ remained constant for all values of flow. The actual values used in this calculation are

$$(P_3 - P_6)\ /1/2\ \rho V_3^2 = 0.34419$$

and

$$(P_3 - P_4)\ /1/2\ \rho V_3^2 = 0.10542$$

These are based respectively on effective areas of 1869.5 in.^{2} and 521.7 in.^{2}

5.7.3 Summary of Sea Level Static Performance

Ratings at standard Sea Level Conditions:

Rating	Thrust lb.	Turborotor R.P.M.	Engine R.P.M.	S.F.C. lb./lb./hr.
Maximum	6,500	2,570	22,700	0.4798
Military	5,840	2,380	22,000	0.5272
Normal	5,040	2,120	21,000	0.5539
90% Normal	4,560	1,940	20,300	0.6184

5.7.4 Off Design Performance

The off design performance is presented in the form of non-dimensional curves in Figs. 20,21 & 22 and the turborotor operating characteristics in Fig. 23. The sea level performance shown in Figs. 18 &19 was calculated for the pressure recovery shown in Fig. 17.

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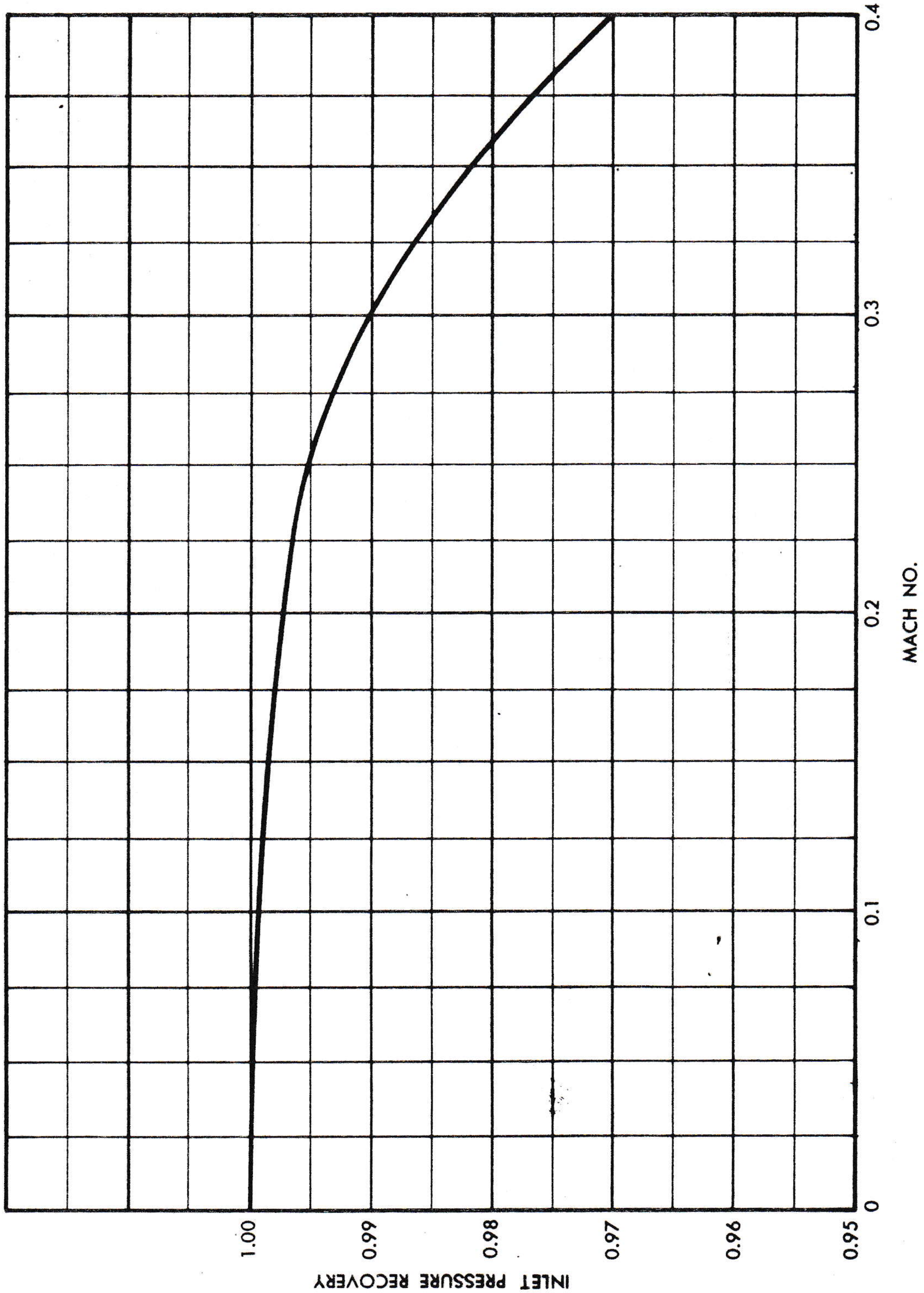

FIG. 17 INLET PRESSURE RECOVERY

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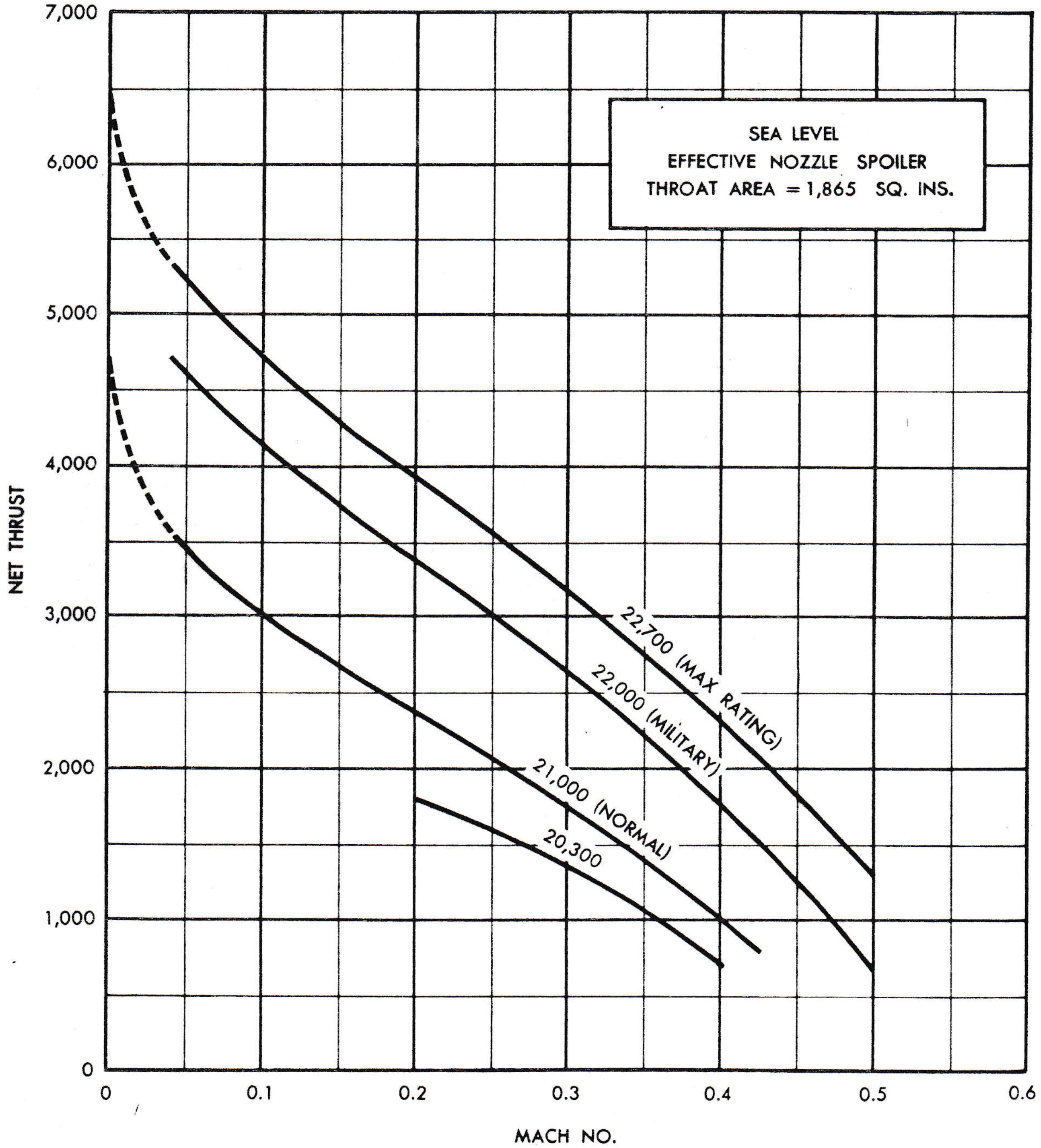

FIG. 18 NET THRUST

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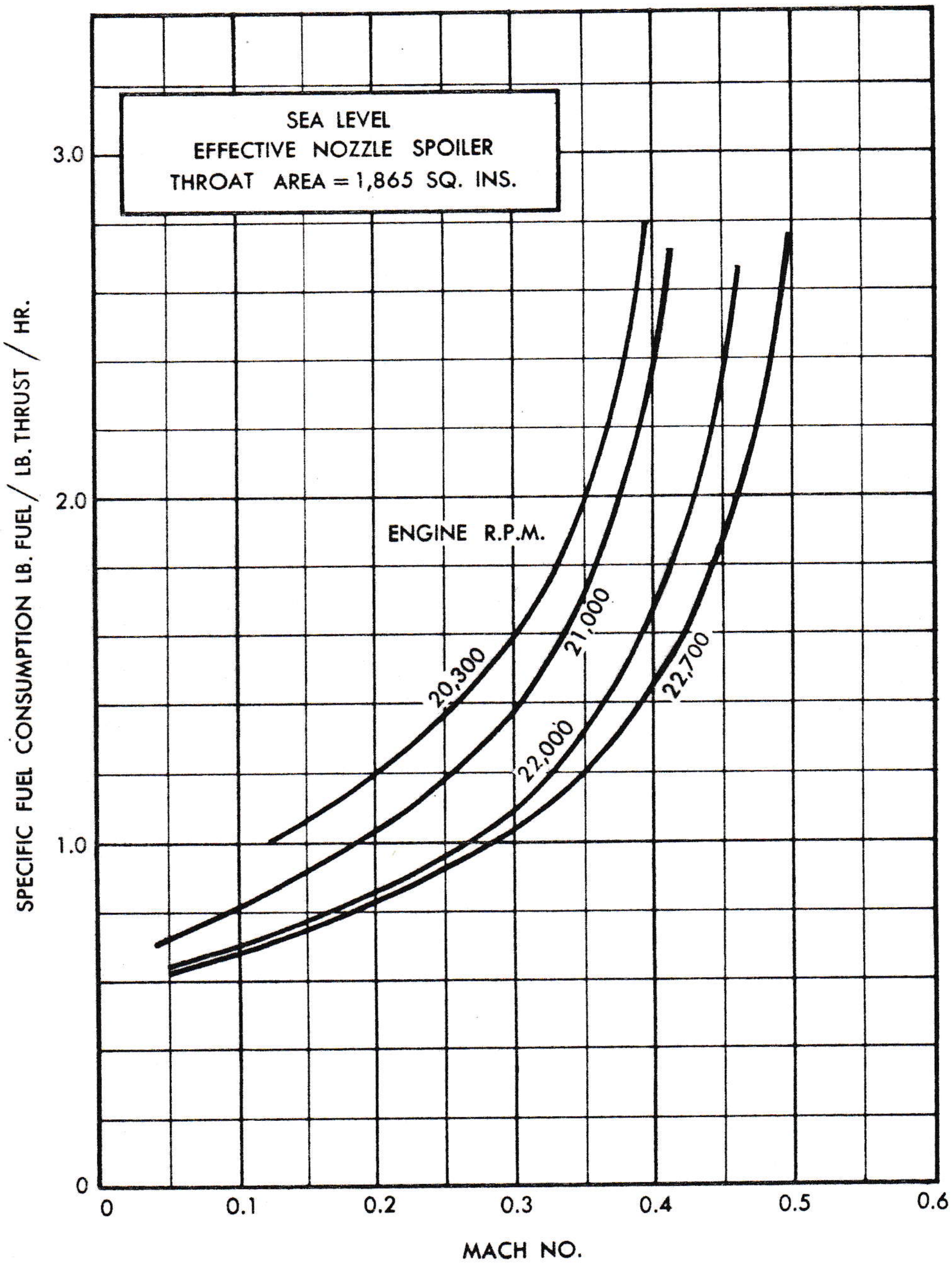

FIG. 19 SPECIFIC FUEL CONSUMPTION

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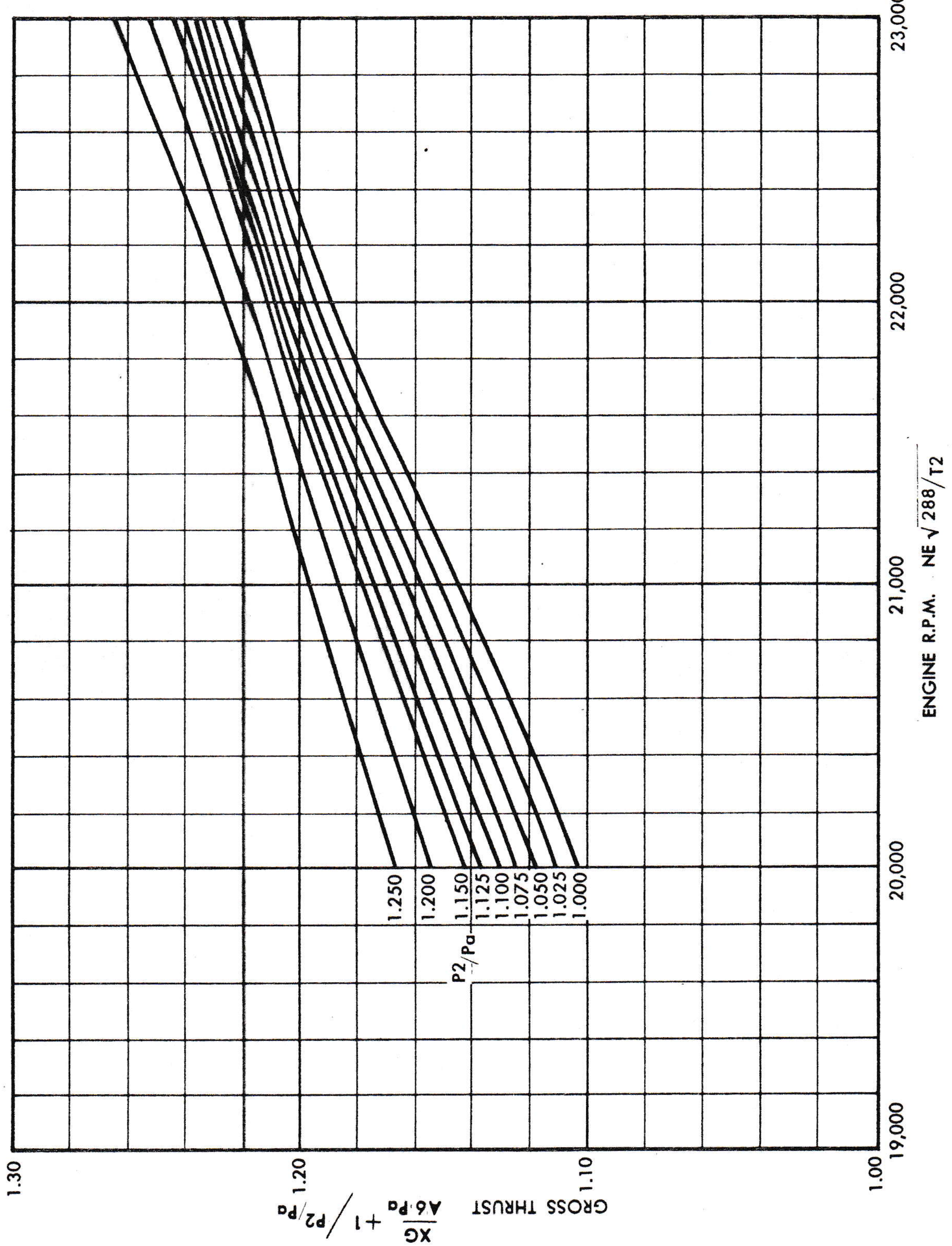

FIG. 20 NON DIMENSIONAL GROSS THRUST

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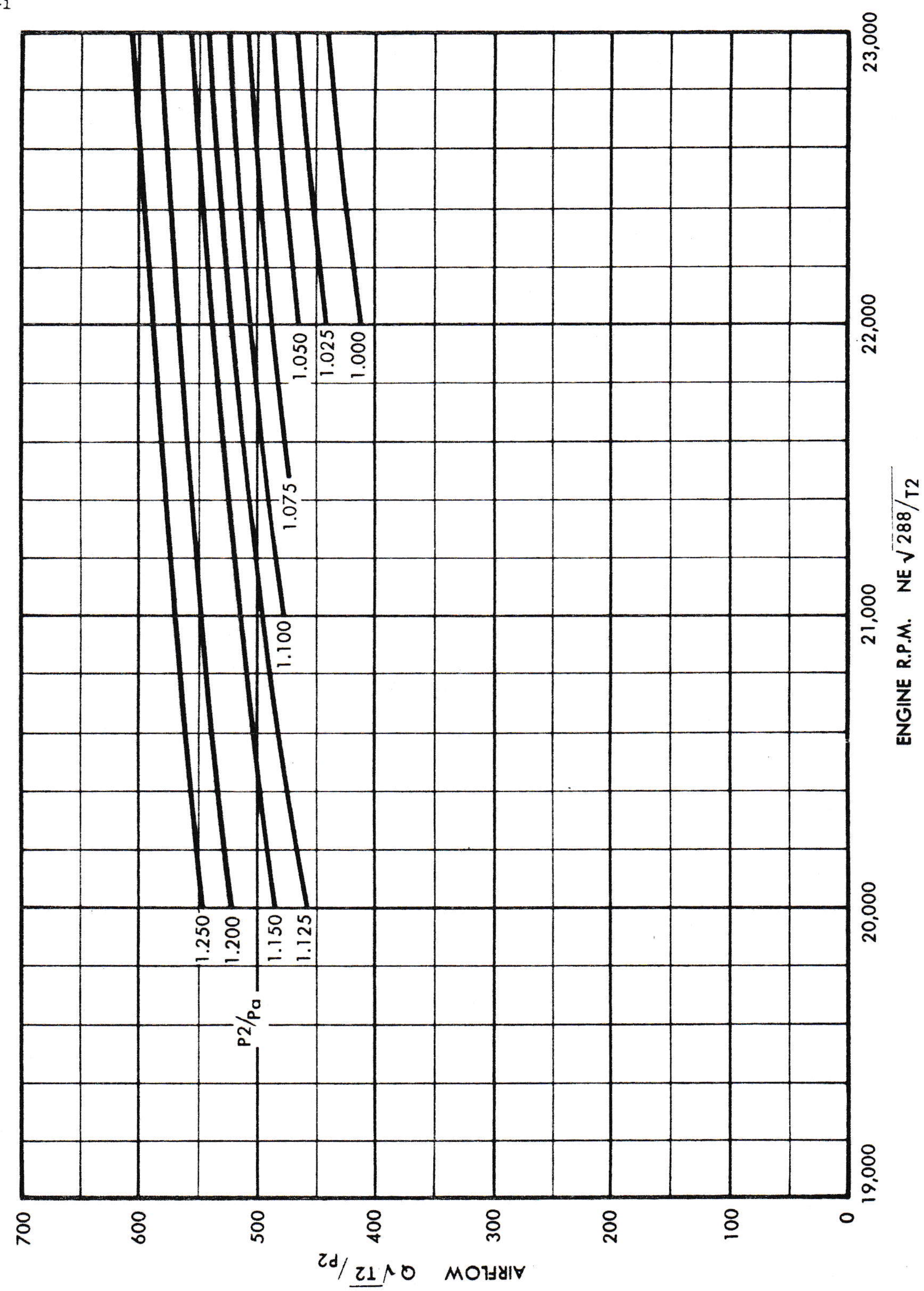

FIG. 21 NON DIMENSIONAL AIR FLOW

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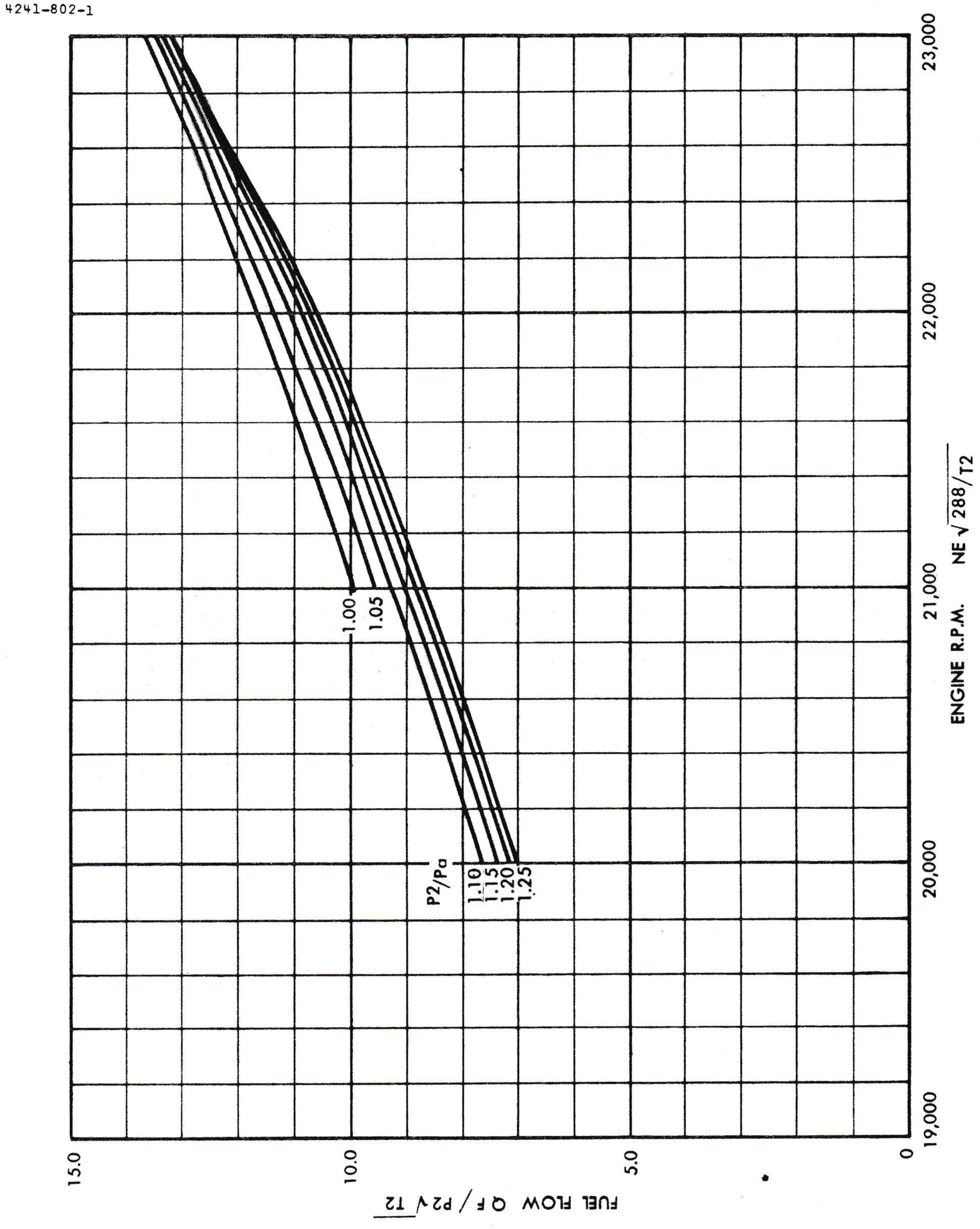

FIG. 22 NON DIMENSIONAL FUEL FLOW

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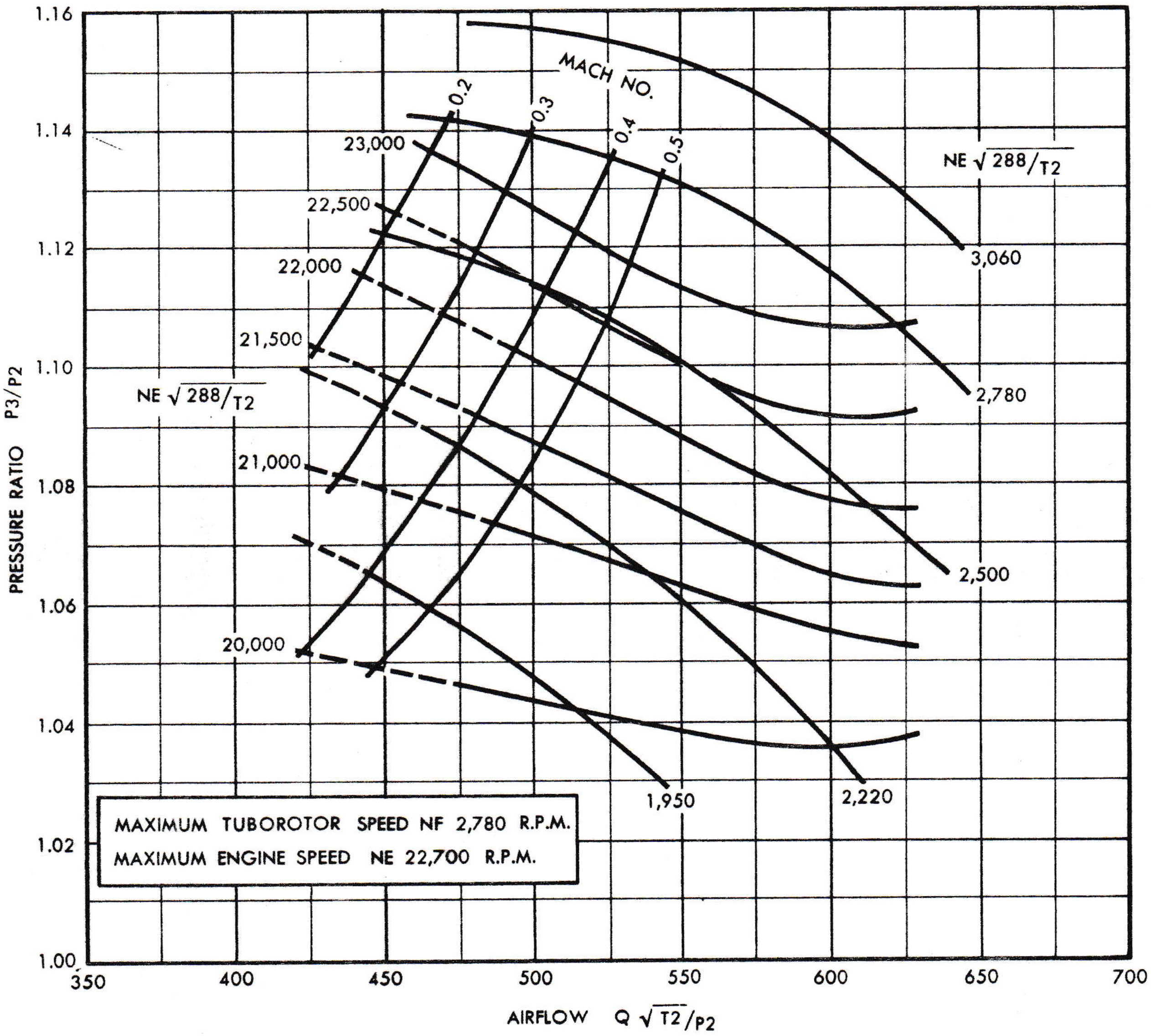

FIG. 23 TURBOROTOR PRESSURE RATIO

PART 6

SERVICES

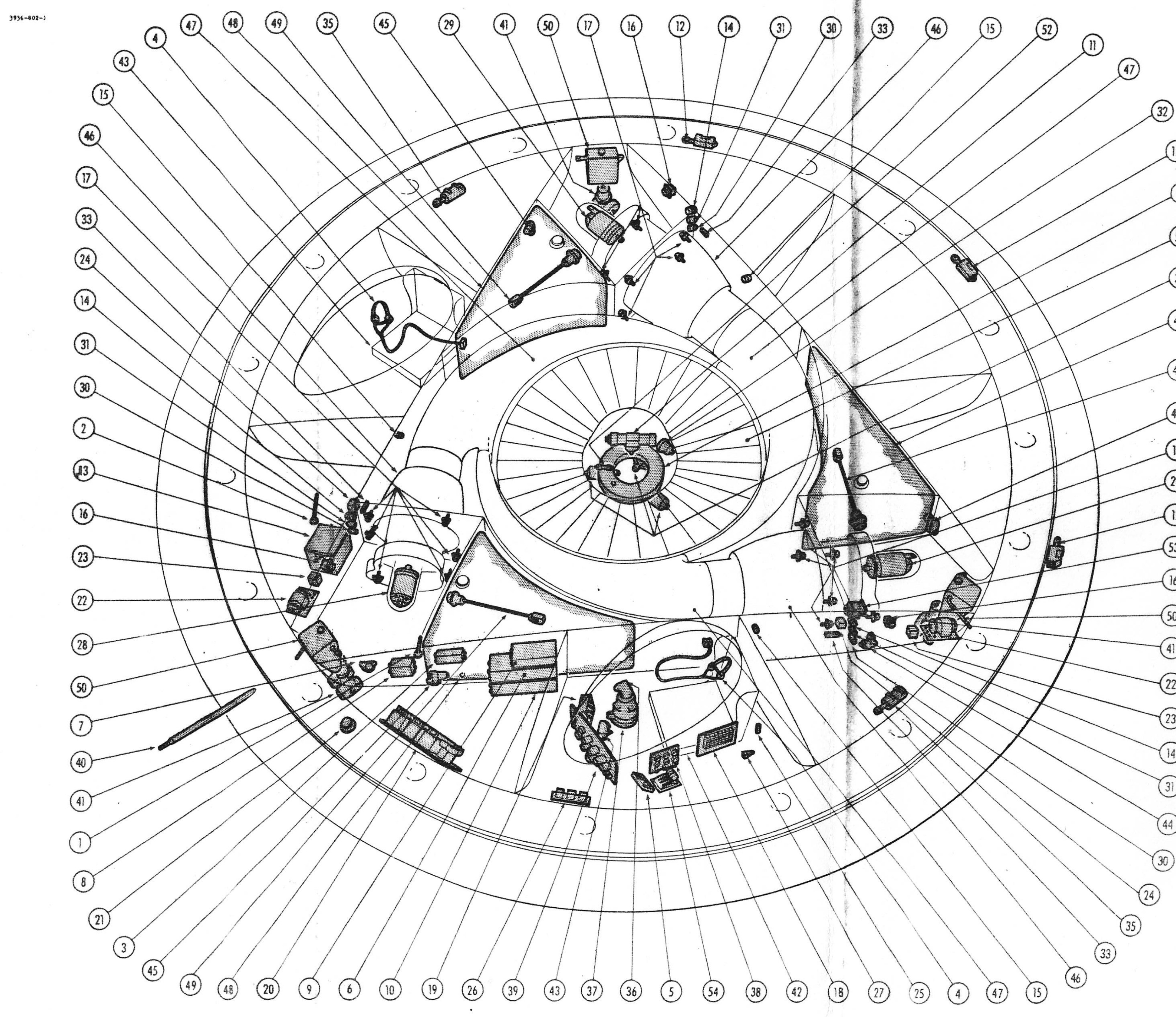

FIG. 24 GENERAL ARRANGEMENT OF EQUIPMENT

COMMUNICATIONS

1 Antenna, U.H.F.
2 Antenna, V.H.F.
3 Box, junction, transmitter-receiver
4 Intercom, headsets and jack
5 Panel, communication
6 Receiver
7 Relay, power supply
8 Relay, receiver, oscillator
9 Transmitter
10 Transverter

ELECTRICAL

11 Actuator, nozzle spoiler trim
12 Actuator, wing tip slide
13 Battery
14 Connector, engine services
15 Connector, exhaust thermocouple
16 Connector, starter/generator
17 Detectors, fire
18 Panel, circuit breaker
19 Panel, engine control
20 Panel, relay, and limiter
21 Receptacle, external power supply
22 Regulator, voltage
23 Relay, generator
24 Relay, generator change-over
25 Relay, wing tip slide actuator
26 Resistor, exhaust thermocouple
27 Shunt, ammeter
28 Starter/generator
29 Starter/generator (used as starter only)
30 Switch, engine oil pressure
31 Switch, fuel pressure
32 Switch, turborotor oil pressure
33 Terminal block, engine electrics

FLIGHT EQUIPMENT

34 Actuators, control shaft
35 Actuators, yaw control
36 Column, control
37 Control, pneumatic
38 Panel, engine instrument
39 Panel, main instrument
40 Probe, pitot-static

FURNISHINGS AND MISC. EQUIPMENT

41 Landing gear
42 Seats, (pilot and observer)
43 Valve, external charging
44 Valve, vacuum relief

POWER PLANT EQUIPMENT

45 Cocks, L. P. Fuel
46 Engine
47 Exhaust ducts
48 Fuel tanks
49 Indicators, fuel contents
50 Oil Tank, engine
51 Oil tank, turborotor
52 Pick-up, magnetic, turborotor R. P. M.
53 Pump, vacuum
54 Throttles, engines
55 Turborotor

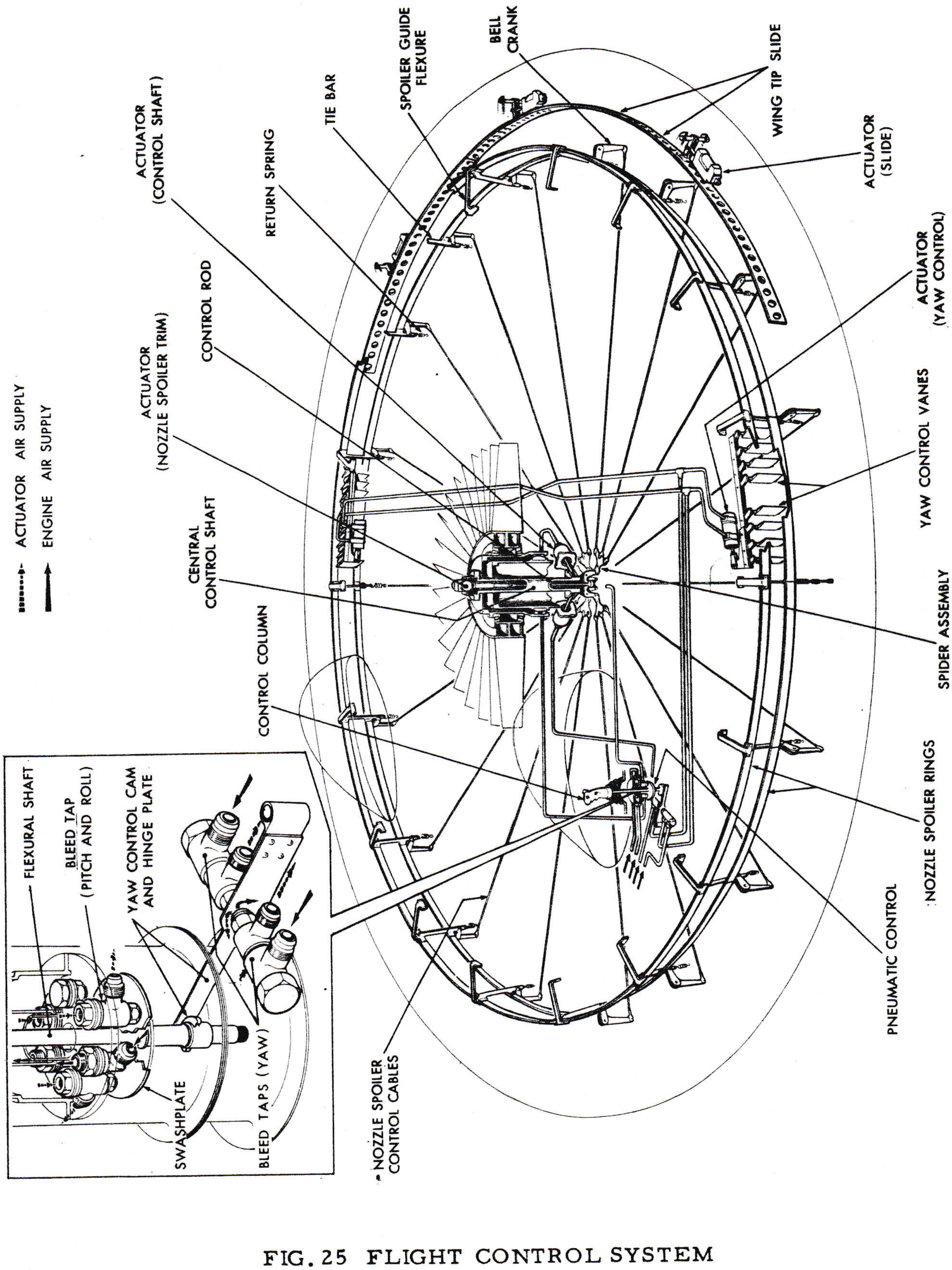

FIG. 25 FLIGHT CONTROL SYSTEM

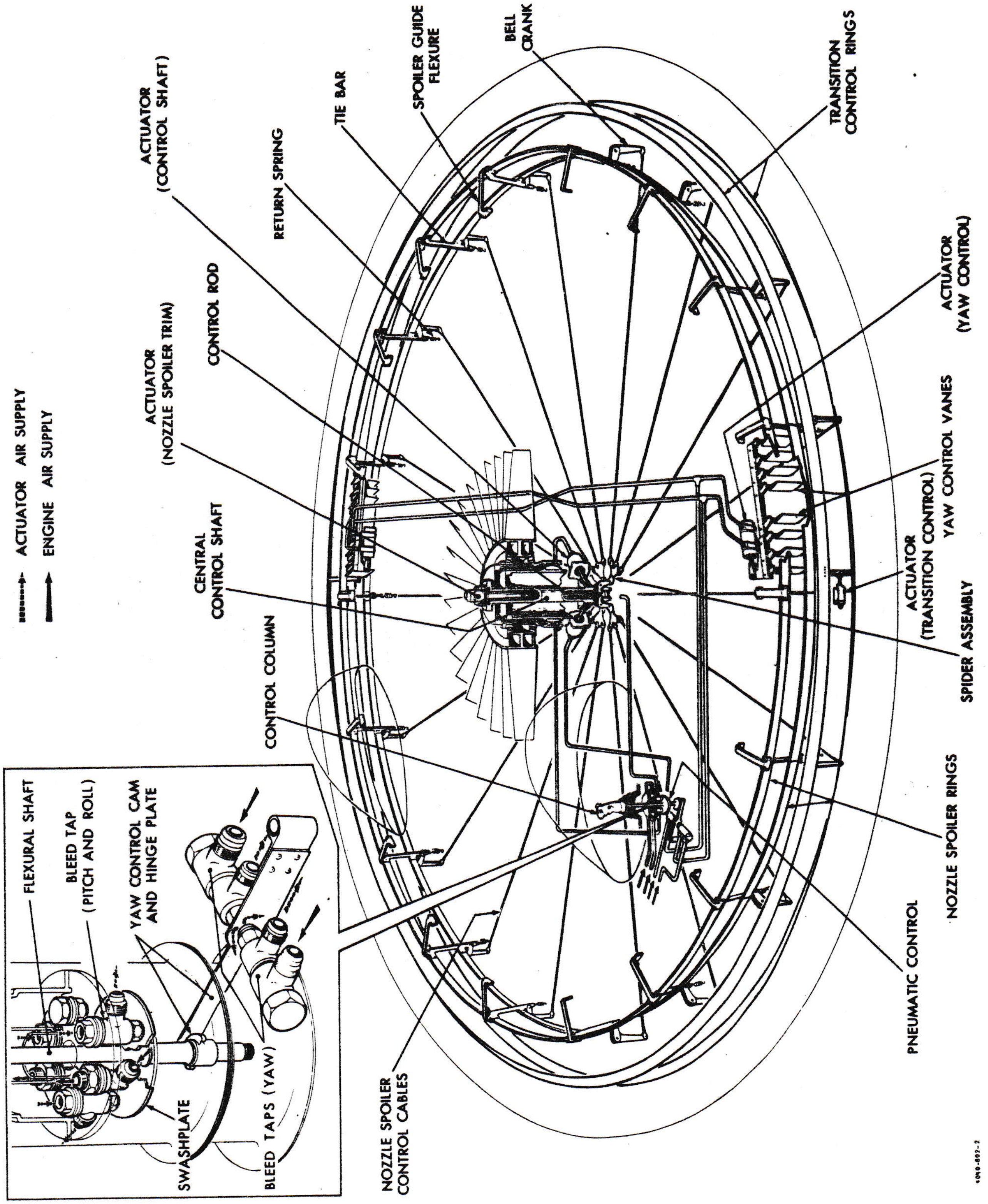

FIG. 26 FLIGHT CONTROL SYSTEM (MODIFIED)

6.1 Flight Control System

6.1.1 General

Flight control in hovering and forward flight is derived from an appropriately directed stream of air expelled through annular nozzles around the periphery of the vehicle. These nozzles are designed to utilize the Coanda principle of jet deflection in conjunction with a boundary layer detachment control which is provided by nozzle spoiler rings in the throat of the nozzles. See Fig. 25. The spoiler rings are connected to the turborotor, see Part 5, which, in turn, is connected with the control column in the pilot's cab.

For description of the pneumatic system and the pneumatic control at the base of the control column see Section 6.5.

6.1.2 Pitch and Roll

The pilot's control column consists of a hand grip connected by a flexural shaft to a pneumatic control at its base. (See Fig. 25-detail)

Deflection of the control column in a fore, aft or lateral direction alters the pneumatic pressure in three lines supplying air for operating the control shaft actuators. As a result of these pressure changes in the lines, the actuators displace the base of the control shaft simultaneously producing a differential movement to eighteen spoiler control cables through the finger levers attached to the spider assembly.

The control cables are connected to the spoiler rings by bell cranks and tie bars so that the differential movement of the cables effects a lateral swashplate action (in the plane) of the rings, deflecting the air flow in the appropriate direction to obtain the required amount of pitch and/or roll.

6.1.3 Trim

In order to apply trim to the spoiler ring mechanism in pitch and roll, conventional control wheels are provided on the Pilot's left hand console with flexible drives to bias the neutral position of the pneumatic control, by tipping the top assembly against the swashplate. (See Fig. 25 - detail)

6.1.4 Yaw

Directional control of the vehicle is accomplished by twisting the hand grip on the control column. Partial rotation of the flexural shaft alters the pressure in the pneumatic lines which supply air for operating an actuator at the left and right sides of the vehicle. Each actuator positions a set of yaw control vanes in the throat of the peripheral nozzles located below the actuator. The vanes deflect the airflow at these points to produce the required amount of yaw.

6.1.4 Independent trimming of the yaw control may be incorporated at a later date for high speed flight. Meanwhile, the hand grip provides for inching the controls.

6.1.5 Hovering and Transition

The hand grip of the control column incorporates three switches for selecting hovering and for transition to, and from, forward flight.

A pair of push button type inching switches is located on the open side of the hand grip. These are connected to a nozzle spoiler trim actuator mounted on top of the turborotor shaft, see fig. 16. The actuator is connected to a control rod, housed in the central control shaft, which carries a spool at its lower end supporting the tips of the six finger levers. When the lower switch is depressed the actuator lowers the spool and allows the spoiler return springs to move the spoiler rings into the hovering position. When the upper switch is depressed the actuator lifts the spool, and the finger levers and control cables move the spoiler rings to the forward flight position.

A toggle type inching switch, located on the top of the grip, is connected with three electrical actuators which control the position of a wing tip slide housed in the three rear inner wing tip segments. For hovering the switch is selected rearwards and the wing tip slide is moved to uncover the series of holes (see paragraph 4.3.1) which allow part of the peripheral air flow to enter a plenum chamber in the wing tip. From the plenum the air escapes through two slots, one near the top of the inner wing tip, the other near the bottom, to form air spoilers which assist the vertical deflection of the air for hovering.

For forward flight the toggle switch is selected forward and the wing tip slide is returned to the closed position to permit rearward flow of the jet.

In addition to the peripheral air flow a central stream of air is provided through an inner annulus in the bottom of the vehicle. This central air stream provides a column about which the air from the peripheral nozzles may stabilize and coalesce.

Future development of the vehicle will include replacement of the wing tip slide and air spoilers with two transition control rings, see fig. 26, located in the wing tip slots.

For hovering the control rings will be centrally located to assist in downward deflection of the annular jet.

For forward flight the control rings will be displaced aft, resulting in rearward deflection of the annular jet.

Two electric actuators, together with suitable cockpit controls will be installed for actuation of the transition control rings.

6.2 Radio Communication

6.2.1 General

Radio communication is provided by Aircraft Radio Corporation type 12 equipment. The installation provides for communication by amplitude modulated signals on 5 channels in the VHF band and 8 channels in the UHF band.

6.2.2 Equipment

The installation consists of the components listed below according to location, followed by an account of modifications to standard items:

Equipment Compartment

VHF Transmitter	T-11B
VHF Receiver	R-19 (With dynamotor)
UHF/VHF Transverter (Transmitter-receiver-converter)	TV-10
Oscillator and Relay Unit	K-13
Junction Box	J-13A
Power Relay	AN-3350-1

Cabs

Control Unit (Pilot's cab only)	C-53 (modified)
Jack Box	J-10
Headset (high impedance) with boom microphone (carbon)	RH-46

Antennas

VHF Antenna	A-12
UHF Antenna	A-16 (modified)

Crystals - to local requirements. A card listing allocated radio frequencies is located in the pilot's cab.

Control Unit C-53 is mounted in an inverted position, to afford clearance for manipulation of the tuning handle, and is fitted with a re-arranged face plate.

To improve performance the UHF Antenna used in the vehicle is a modified version of the A-16 Antenna in which the A-16 base assembly is retained but the L-shaped rod is replaced by a straight rod of aluminum giving an overall length from the vehicle skin of approximately 11 inches. The UHF and VHF antennas are located to the left and right respectively on the upper surface at the front of the vehicle.

6.2.3 Controls

Control Unit C-53 is located at the left of the pilot's cab and provides the pilot with control of tuning for both transmission and reception.

Selection of the required VHF or UHF channel for transmission is by a rotary switch on the Control Unit selecting positions 1 to 8 for UHF transmission and positions A to E for VHF transmission. Positions F to O, which are available for additional VHF frequency transmissions, and position P for interphone, are not utilized.

Receiver tuning for both the VHF and UHF signals is by means of a cranked handle which rotates an associated calibrated dial and drives the tuning mechanism in the VHF receiver via a flexible cable. Depression of the tuning handle brings into effect a head-set whistle tone which permits tuning of the receiver to the transmitter frequency previously selected.

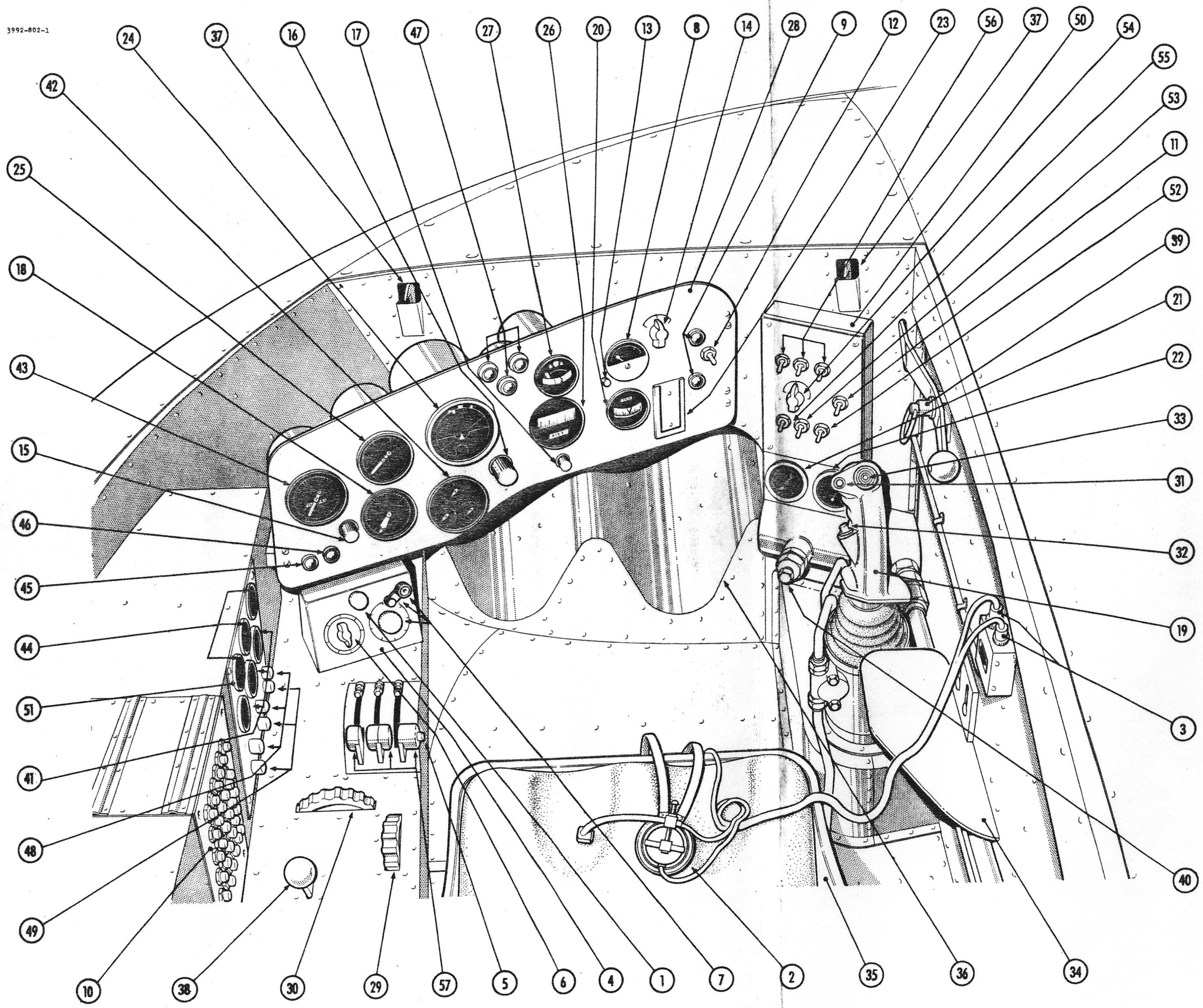

FIG. 27 PILOT'S CAB ARRANGEMENT

COMMUNICATIONS

1 Control, volume
2 Headset, pilot's intercommunication
3 Jacks, intercommunication headset
4 Panel, communication
5 Switch, microphone (Press to speak)
6 Switch, selector, transmitter frequency
7 Tuner, receiver

ELECTRICAL

8 Galvanometer
9 Lights, warning, generator failure
10 Panel, circuit breaker
11 Switch, ground/flight
12 Switch, selector, generator power (Generator No. 1 or 2)
13 Switch, selector, volt/amp
14 Switch, selector, galvanometer reading (Main bus, Gen. No. 1 or 2)

FLIGHT CONTROLS, EQUIPMENT AND INSTRUMENTS

15 Adjustment, altimeter
16 Adjustment, gyro horizon
17 Adjustment, direction indicator
18 Altimeter
19 Column, pilot's control
20 Compass, standby
21 Gauge, pneumatic pressure
22 Gauge, vacuum
23 Holder, compass card
24 Indicator, gyro horizon
25 Indicator, air speed
26 Indicator, direction
27 Indicator, turn and bank
28 Panel, main instrument
29 Wheel, pitch trim
30 Wheel, roll trim
31 Switch, selector, nozzle spoiler position, forward flight
32 Switch, selector, nozzle spoiler position, hovering
33 Switch, selector, wing tip slide position

FURNISHINGS, MISC. CONTROLS AND EQUIPMENT

34 Armrest
35 Seat, pilot's
36 Footrest
37 Latches, canopy locking
38 Lever, pilot's harness release
39 Lever and locking ring, canopy release
40 Valve, external charging, (pneumatic system)

POWER PLANT INSTRUMENTS AND CONTROLS

41 Gauges, exhaust temperature
42 Indicator, fuel contents
43 Indicator, turborotor R.P.M.
44 Indicators, Engine R.P.M.
45 Light, warning, turborotor oil level
46 Light, warning, turborotor oil pressure
47 Lights, warning, fire
48 Lights, warning, fuel pressure (not installed)
49 Lights, warning, oil pressure
50 Panel, engine control
51 Panel, engine instrument
52 Switch, engine ignition
53 Switch, engine priming
54 Switch, engine selector
55 Switch, engine starter
56 Switches, L.P. fuel cocks
57 Throttles, engine

6.3 Instrumentation

6.3.1 General

The following instruments are installed in the pilot's cab. See Fig. 27

Instrument	Type	Range	Location
Air-speed Indicator	Kollsman Type K3	40 - 400 mph.	Main Instr. Panel
Altimeter	AN 5760-4B	0 -50,000 ft.	Main Instr. Panel
Gyro Horizon Indicator	AN 5736, air driven gyro	-	Main Instr. Panel
Direction Indicator	AN 5735-2A air driven gyro	-	Main Instr. Panel
Turn and Bank Indicator	MS 28041-1, 28V D.C.	-	Main Instr. Panel
Standby Compass (with deviation card)	AN 5766-4, magnetic	0° - 360°	Main Instr. Panel
Volt/Ammeter	NAF 1091-A-120	24V-120 amp.	Main Instr. Panel
Exhaust Temp. Gauges	MS 28006-2	0° - 1,000°C	Eng. Instr. Panel Left hand console
Engine RPM Indicators	MS 28000-1	Percentage	Eng. Instr. Panel, Left hand console
Turborotor RPM Indicator	Orenda 400066	0 - 3,000rpm	Main Instr. Panel
Fuel Gauge (Triple)	100541	-	Main Instr. Panel

6.3.2 Pitot-Static System

A conventional pitot-static system is installed in the vehicle. The pitot-static probe is located in the end of a boom projecting from the front centre of the vehicle.

The probe lines are connected by flexible hose to the air-speed indicator and altimeter on the main instrument panel. Drainage points are provided in both pitot and static lines.

6.3.3 Vacuum System

A conventional vacuum system is provided in the vehicle utilizing a dry air-vacuum pump installed in No. 1 engine. From the pump a pipe line connects with the flexible hoses from the gyro horizon indicator and the direction indicator. A suction relief valve, set at -3.75 in. to -4.25 in. Hg, is installed in the pipe line, together with a gauge

6.3.3 Vacuum System (Continued)

located beneath the engine control panel.

6.3.4 Turborotor R.P.M. Sensor

The turborotor rpm sensor consists of a magnetic pick-up on the turborotor which feeds impulses to the indicator through an amplifier-rectifier system.

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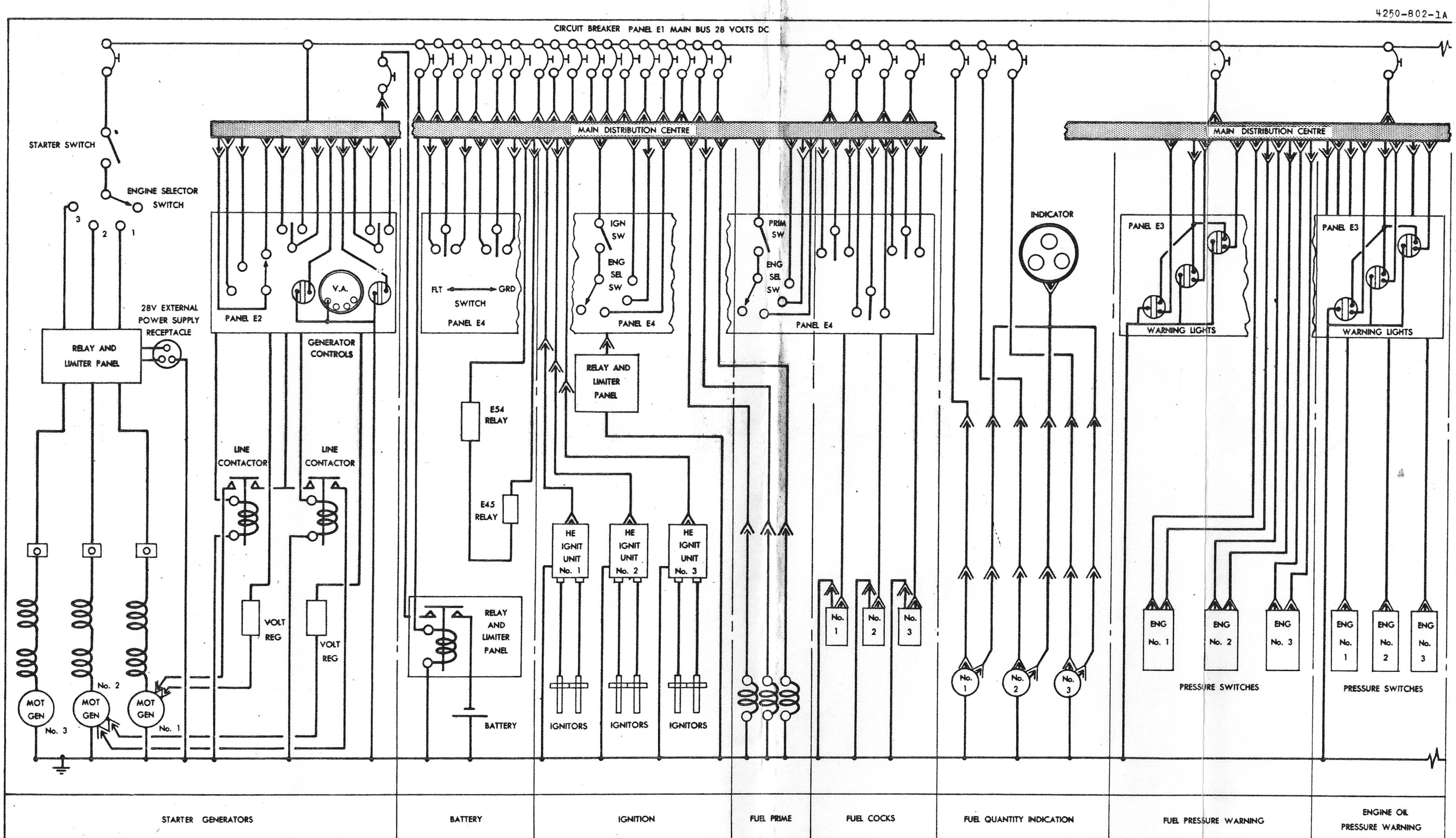

FIG. 28A WIRING DIAGRAM

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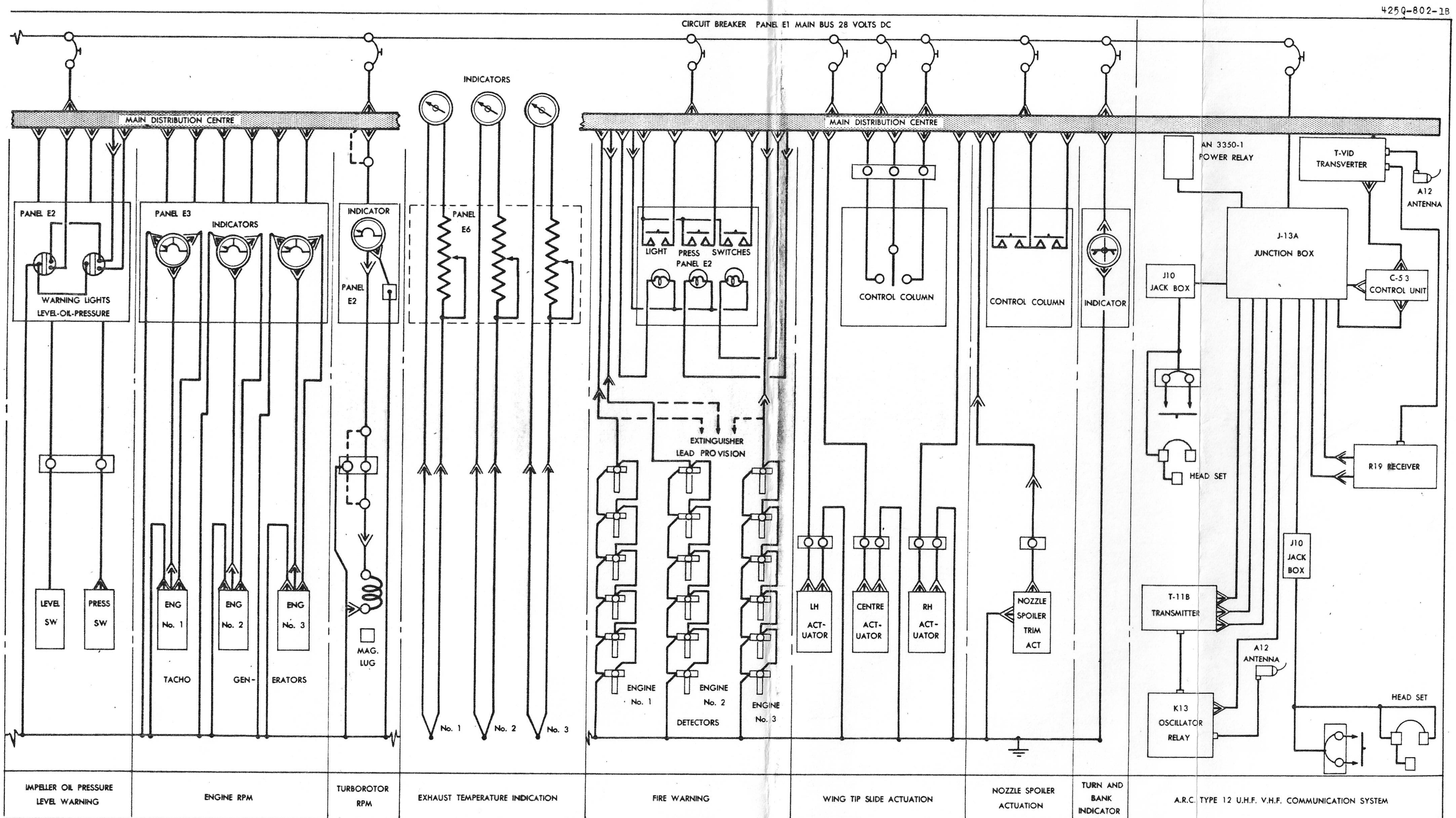


FIG. 28B WIRING DIAGRAM

6.4 Electrical System

6.4.1 General

The vehicle electrical supply consists of a 28V D.C. system with automatic successive changeover, under failure conditions, from main to standby generator and thence to standby battery. Engine starting is from an external source. For electrical wiring diggrams see Fig.28 .

6.4.2 Power Supply

The electrical system draws approximately 35 amps at 28V D.C. under maximum operating load conditions and is supplied from a 100 amp combined starter-generator mounted coaxially at the air inlet end of No. 1 engine. In the event of generator failure, all electric loads will be automatically transferred to an identical generator mounted on No. 2 engine. Generator failure will be indicated by two warning lights, (one for each generator) located on the main instrument panel. Failure of both generators will cause automatic switching to a 28V 10 AH silver-zinc alkaline battery which provides an emergency supply at maximum load for approximately 15 minutes.

A toggle switch on the main instrument panel permits manual selection of the generators as an alternative to automatic changeover. A galvanometer on the same panel is selected by a rotary switch to read generator-supplied load current and also generator and bus voltages. A switch associated with the instrument sets it to read volts or amps as required.

Voltage regulation is provided by a carbon-pile voltage regulator in each generator circuit. The carbon-pile regulators are located in the compartments adjacent to No. 1 and No. 2 engines.

6.4.3 Ground Supply

A receptacle is installed in the leading edge of the wing to provide for connection with an external electrical ground power supply source. The ground/flight switch on the engine control panel, and a relay on the relay and limiter panel in the equipment compartment connect the supply to the vehicle D.C. bus.

6.4.4 Engine Control Panel

An engine control panel is located to the right of the main instrument panel. In addition to the ground/flight supply switch which, for engine starting, is set for the external ground supply, it incorporates a start, a fuel prime and an ignition switch. These are switched to the three engines in turn by an engine selection rotary switch. The start condition energizes three start relays, one for each engine, located on the relay and limiter panel in the equipment compartment. Peak engine starting current is

6.4.4 Engine Control Panel (Continued)

approximately 800 amps. Three switches control the LP fuel cocks for the three engines.

6.4.5 Engine Instrument Panel

On the engine instrument panel are provided, for each engine, warning indications of low oil pressures by indicator lamps with integral press-to-test facility. In addition, gauges show engine RPM (detected by tacho-generators) and exhaust temperatures (sensed by thermocouples via adjusting resistors). A gauge reading turborotor rpm is located on the main instrument panel, see sec. 6.3, and on this panel indicator lamps with pres-to-test facility give warnings for turborotor oil level and pressure.

6.4.6 Flight Control

Switches for flight control are located on the control column. A three position toggle switch, when set to the forward flight and the hover position, energizes two relays, one for each position, which control the wing tip slide actuators, see paragraph 6.15. The upper of two press switches completes a circuit direct to the nozzle spoiler trim actuator at the top of the turborotor shaft to set it to the forward flight position, and the lower press switch reverses this actuator to the hovering position.

6.4.7 Fuel Indication

A float-type fuel quantity transmitter is installed in each of the three fuel tanks and is connected with a triple fuel contents gauge mounted on the main instrument panel.

6.4.8 Fire Detection

Six fire detectors are located in each engine compartment; four are mounted on the rear face of the firewall and are set to detect 500°C, and two are located in front of the firewall, adjacent to the fuel pump and the fuel ratio control valve, and are set to 250°C.

Warnings are given by combined lamp press-switch units (one for each engine compartment) which are located on the main instrument panel. From the press switches connections are available for control of an extinguisher system (if such an installation is authorized).

6.4.9 Circuit Breaker Panel

At the left of the pilot's cab is located a main distribution centre and circuit breaker panel on which are arranged manual reset circuit breakers for the electrical distribution system.

6.4.10 Bonding

An extended coil spring attached to each landing gear leg provides for discharge of static electricity on landing the vehicle.

For bonding during servicing an appropriately grounded standard alligator clamp may be attached to any one of the wing tip spacers. During refueling a similar clamp may be attached to the filler cap attachment clip.

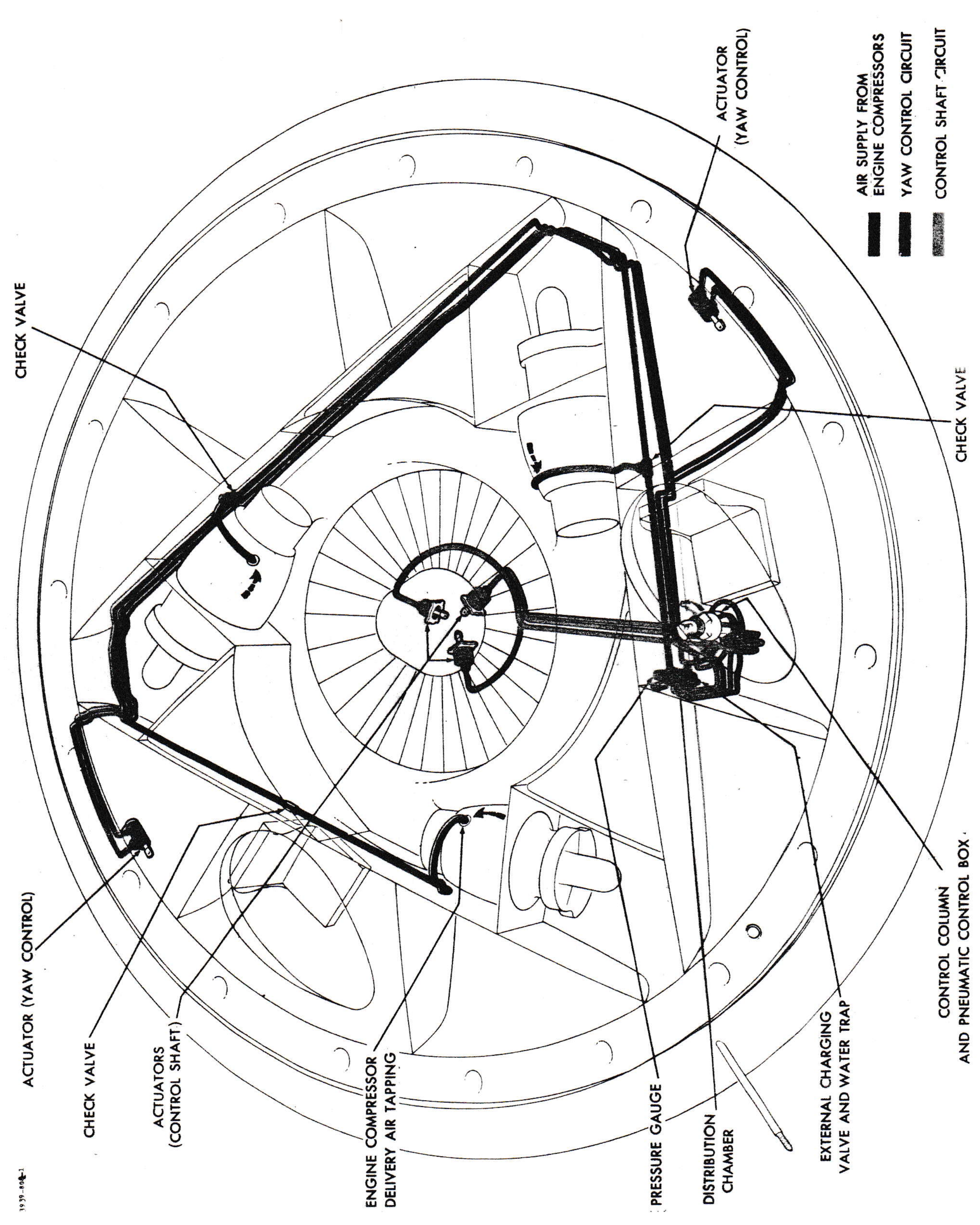


FIG. 29 PNEUMATIC SYSTEM

6.5 Pneumatic System

6.5.1 General

A pneumatic system, see Fig. 29, is installed in the vehicle to provide air pressure for actuating the flight control system.

Each engine compressor section feeds air through a tapping into a gallery pipe which terminates at a distribution chamber located to the right of the main instrument panel. Three check valves are fitted into the gallery pipe. The distribution chamber incorporates an external charging valve and water trap and is also connected with a pneumatic pressure gauge located above the chamber.

Air from the chamber is fed by four pipes to a pneumatic control attached to the floor at the base of the pilot's control column. Two of these pipes supply pressurized air for pitch and roll operation, and two for yaw operation.

The pilot's control column consists of a hand grip which is connected by a flexural shaft to the pneumatic control which incorporates two bleed tap and plate assemblies. One assembly comprises three bleed taps and a swashplate which control the pressure supplied to three control shaft actuators for pitch and roll. The other assembly comprises two horizontally opposed bleed taps, and a cam and hinge plate assembly which control the pressure supplied to two yaw control actuators.

When the control column is in the neutral position the location of the plates, relative to the bleed taps, permits a continuous bleed of air from the taps thereby maintaining equal pressure in the lines to the actuators.

6.5.2 Pitch and Roll Control

Deflection of the control column in a fore, aft or lateral direction, (for pitch and roll) changes the position of the swashplate thereby altering the tap outlet areas. As a result, the relative pressures in the lines to the three control shaft actuators, which displace the nozzle spoiler rings, (see paragraph 6.1.2), are changed.

Trim, in pitch and roll, is provided by two cams in the pneumatic control at the base of the control column. Each cam is connected by a teleflex cable to a trim wheel in the pilot's cab. Operation of either trim wheel rotates the respective cam, repositioning the bleed tap assembly relative to the swashplate.

6.5.3 Yaw Control

Twisting of the control column grip, (for yaw) rotates the cam on the hinge plate assembly. Movement of the hinge plate increases the air bleed from one tap, and decreases the bleed from the other, thereby changing the relative pressures in the lines to the two yaw control actuators. The pipe line from each tap is connected with a tee piece. One line from each tee piece is connected to the rod end of one actuator, while the other line is connected to the opposite end of the other actuator. By cross connecting the lines in this manner the actuators provide a differential movement for positioning the yaw control vanes on the left and right hand side of the vehicle. (See paragraph 6.1.4)

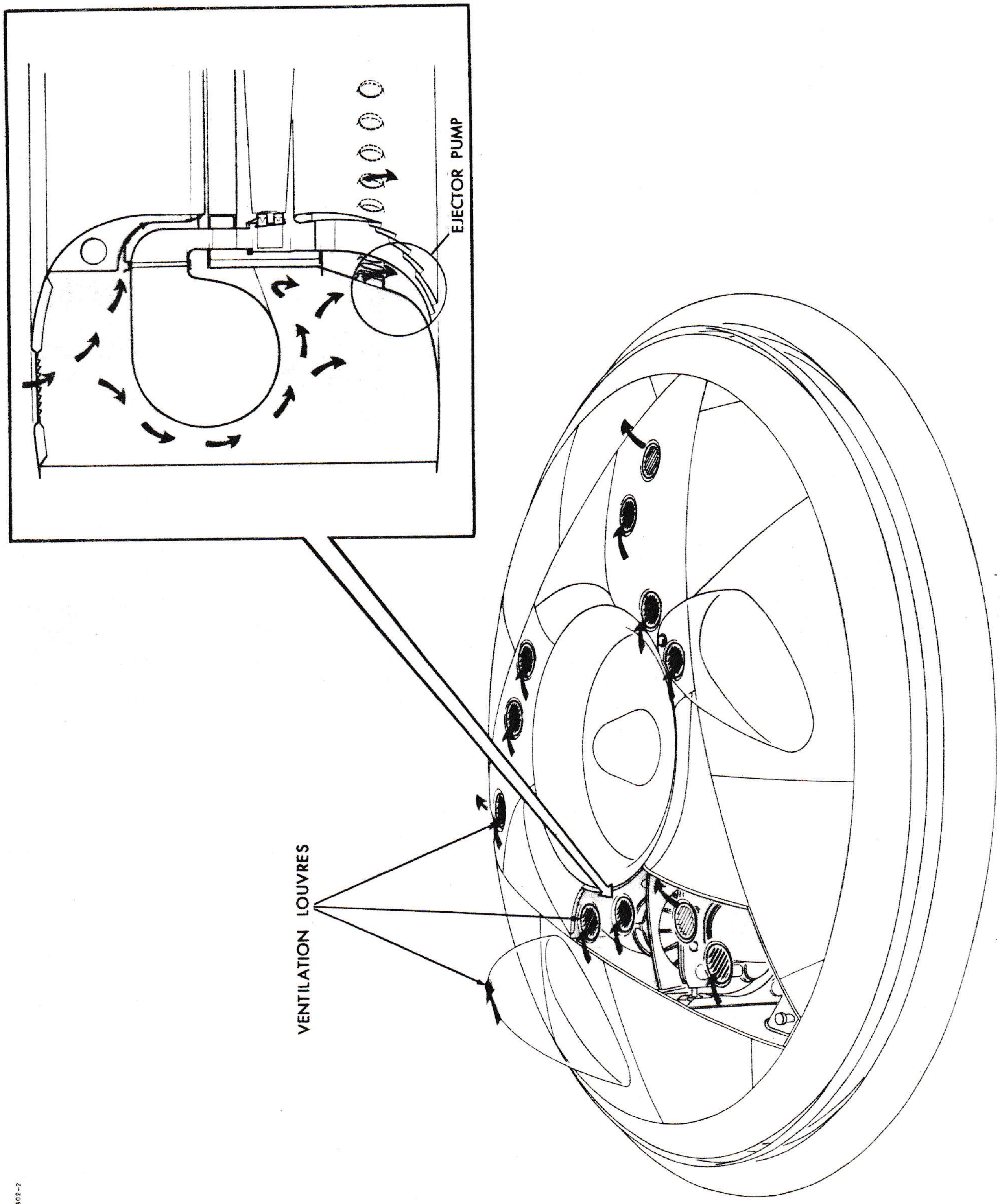


FIG. 30 COOLING AND VENTILATION

6.6 Ventilation

6.6.1 General

Ventilation and cooling of particular areas in the vehicle is provided for by louvres in the cowlings of the engine compartments, and in the canopies. See Fig.30 .

An inlet and an exit louvre are installed in the cowling of the cold zone of each engine compartment for ventilating and cooling the compartment.

Two inlet louvres are installed in the cowling of the hot zone of each engine compartment to provide cooling air for the compartment and for a series of holes located circumferentially in the upper skin of the primary structure at the diffuser ducts. By ejector pump action, these holes draw in the air to cool the compartment and to cool and insulate the upper skin of the diffuser ducts downstream of the turborotor. To provide cooling of the turborotor air inlet some air is also circulated between the exhaust duct and the turborotor air inlet.

A manually adjustable louvre is located in each transparent canopy above the occupants head. The rotary louvre may be positioned as an inlet or an exit for air in flight, or for ventilation to prevent misting when the vehicle is parked.

6.7 Crew Furnishings

6.7.1 Seat Installation

Each seat, which is designed to accommodate a back pack parachute, is made of aluminum alloy. Four attachment lugs located beneath the seat pan are secured by quick release pins to four fork fittings mounted on reinforcing girders built into the vehicle structure.

6.7.2 Safety Equipment

A standard lap-type quick release safety belt is anchored to the rear seat girder. A standard shoulder harness is attached to an inertia reel which is installed at the base of the compartment rear partition. The harness anchorage cable passes over a guide rail at the top of the partition, with a release lever located on the base of the console to the left of the seat pan.

6.7.3 Footrest and Armrest

A double trough of aluminum alloy is installed in the floor at the front of each compartment to provide a footrest.

A fixed armrest is provided in the pilot's cab. It is mounted on the transverse beam to the right of the seat.

6.7.4 Cab Entrance

The hatch of each crew compartment is secured by two spring latches interconnected by a torque tube. A lever which may be locked to prevent inadvertent operation in flight, is installed in each cab for realease of the latches. The latches may also be released by an external lever attached to the torque tube.

Supports are provided to hold the hatches in the open position.

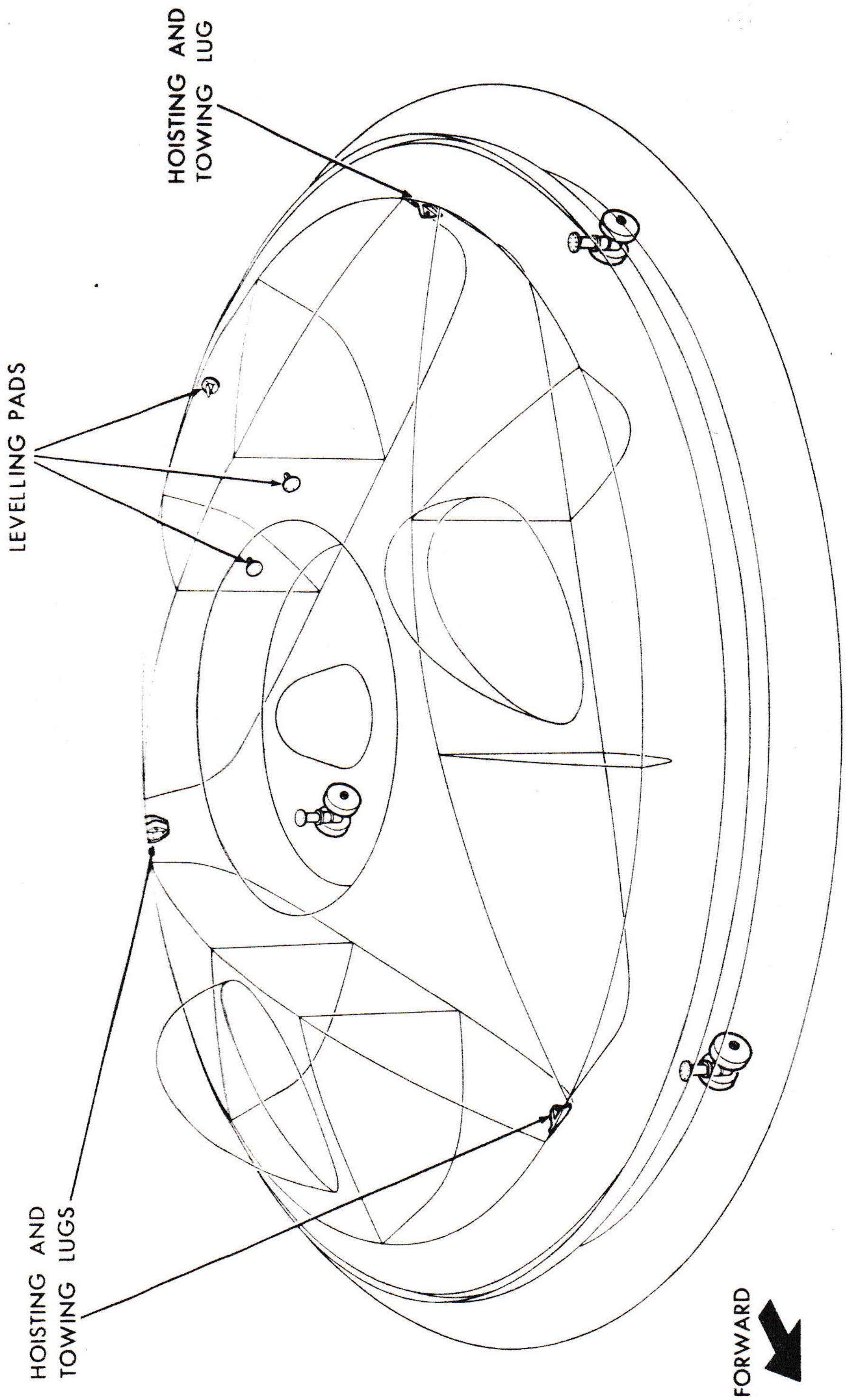


FIG. 31 TOWING, HOISTING AND LEVELING PROVISIONS

6.8 Ground Handling Provisions

6.8.1 Towing, Hoisting and Mooring

Three lugs are fitted on the reinforced structure at the outboard rim of the engine compartments for the attachment of special hinged shackles for towing, hoisting and mooring. (See Fig. 31).

For towing purposes a shackle and towing cable may be attached to any one of the three lugs. The vehicle may be hoisted by lifting vertically at all three lugs, using a triangular swinglebar and special shackles. The three lugs and shackles are also used for mooring the vehicle.

6.8.2 Levelling Pads

Three fixed levelling pads are fitted inside the rear compartment of the vehicle, two are located on the transverse bulkhead and one below the outer rim on the longitudinal center line. These pads are positioned on a plane parallel to, and 14.35 inches above, the design horizontal datum line of the vehicle.

Longitudinal and lateral levels may be checked using a tee-shaped level bar, placed on the pads, and an inclinometer.

6.8.3 Powerplant Hoisting

The turborotor assembly is provided with lifting lugs at its upper extremity to facilitate installation and removal with conventional hoisting equipment.

The engine assembly is provided with a lifting eye at the top center of the turbine inlet flange and two lifting eyes equi-spaced transversely on the upper segment of the compressor outlet flange. A tee-shaped lifting beam is used for slinging the engine.

6.8.4 Bonding

See paragraph 6.4.10.

PART 7

STABILITY AND CONTROL CHARACTERISTICS

7.1 General

Because the c.g. of the vehicle is centrally located, a system to sense out-of-balance conditions and to introduce corrective bias into the flight control system is required in flight. The gyroscopic characteristic of the turborotor is used to sense the rate of imbalance in pitch and roll and to appropriately bias the flight control system to stabilize the vehicle. A separate yaw sensing device, not yet designed, or a small fixed fin will be installed later to improve control at high speeds.

The flight control system is described in Sect. 6.1.

7.2. Stability Modes

The motion of the Avrocar is characterized in general by several oscillatory modes which may be described on a basis of the relative frequencies. The high frequency mode is basically a control oscillation which is normally heavily damped by any reasonable amount of direct rotor damping. The frequency of this mode varies directly with the control system spring constant. The intermediate frequency mode appears in the control system, the pitch and roll angles and the normal acceleration, and is generally lightly damped for zero rotor phasor angle. (Rotor Phasor Angle - Angular displacement, about the vertical axis of the vehicle, between the toppling axis of the turborotor and the spoiler). The damping improves progressively as the rotor phasor angle increases from 0° to 90°. The frequency of this mode varies inversely with the system spring constant and excessive rotor damping will result in instability. An increase in forward speed increases the frequency and decreases the damping of the intermediate frequency mode. Values for the frequency of the high and intermediate frequency modes are approximately 17 and 1.5. cycles per second respectively for a Mach Number of 0.15; and 19 and 5.5 cycles per second respectively for a Mach Number of 0.4 with a spring constant of 500,000 ft. lb/rad. The results show a trend towards a decrease in frequency with increase in rotor phasor angle for both modes. A relatively slow oscillation is introduced from the yawing motion with a frequency controlled by the directional stabilizer gain, and damping controlled mainly by the yaw damper gain, this mode affects pitch and roll slightly. Finally a lightly damped long period mode dominates pitch and roll after the initial transient motions. Fig. 32 shows typical responses to a sharp edged gust for a Mach Number of 0.15 with 30° rotor phasor angle, and 0.4 with 20° rotor phasor angle.

7.3 Gust Tolerance

Since the aircraft is stabilized by a device which has limited power (the jet), it is to be expected that very large disturbances will result in divergent tendencies out of proportion to the size of the disturbance. If a given type of disturbance is introduced to the steady flight condition several times with gradually increasing magnitude, the responses for a while will have the same shapes with amplitudes proportional to the magnitude of the disturbance. Eventually a point will be reached where one control parameter reaches the limit.

7.3 Gust Tolerance (Continued)

Subsequently, the response will exhibit increasing nonlinearities, and amplitudes in general will begin increasing out of proportion to the disturbance. Finally a limit will be reached beyond which the aircraft diverges. Thus, this aircraft, in contrast to conventional aircraft, possesses (for example) a gust tolerance dictated by stability considerations in addition to the normal strength limitation.

The maximum vertical gust velocity that the Avrocar can withstand without rapid divergence (the gust tolerance) has been determined for several flight conditions. Three gust types have been considered, the first being a sharp edged gust, the gust velocity having an instantaneous value at the gust onset, and maintaining this value; the second type is a graded gust, the gust velocity following a (1-cos) curve from zero to its maximum value and then remaining constant; for the third type the gust velocity follows 1 cycle of a (1-cos) curve starting with zero velocity and terminating with zero velocity. This latter case is referred to as a complete sinusoid gust. In general the gust tolerance varies inversely with control system spring constant. Changes in weight have no consistent effect, and changes in gust tolerance due to rotor phasor angle are small. A typical curve showing the variation of gust tolerance with gust gradient distance is given in Fig.34 . The minimum value of gust tolerance for sharp edged gusts for a Mach Number of 0.15 is 35 ft./sec. and for a Mach Number if 0,4 is 54 ft./sec. within the normal range of the spring constant. The gust tolerance varies linearly with gradient distance for graded gusts, the values corresponding to the sharp edged tolerance above, for a gradient distance of 200 ft., being 47 ft./sec. for a Mach Number of 0.15 and 88 ft./sec. for a Mach Number of 0.4. In the case of full simusoid gusts, the gust tolerance is very large for short gusts decreasing with increasing gust length to a minimum, and increasing again with further increase in gust length. The minimum value occurs for gusts of gradient distance between 20 ft. and 140 ft. The lowest value obtained for this minimum point is 55 ft./sec. with a gradient distance of 110 ft.

7.4 Normal Load Factor

The normal load factor obtained from stability work on the Avrocar was based on a study of the motion of the aircraft in the three types of vertical gust referred to in the previous section. The normal load factor shows a considerable decrease in value with increase in gust gradient distance, for constant gust velocity. The nonlinearity of the system due to control limits at high gust velocity does not have a large effect on the load factor, the load factors being slightly less than the linear value for short gusts, the trend being reversed for long gusts. An increase in load factor occurs with increasing spring constant, this effect being less pronounced for gusts with long gradient distance. No simple relation exists between the load factors obtained for different aircraft weights, and the effect of changing the control system phase angle is small. The normal load factor increment is approximately proportional to the aircraft forward speed, for a given gust velocity and configurations.

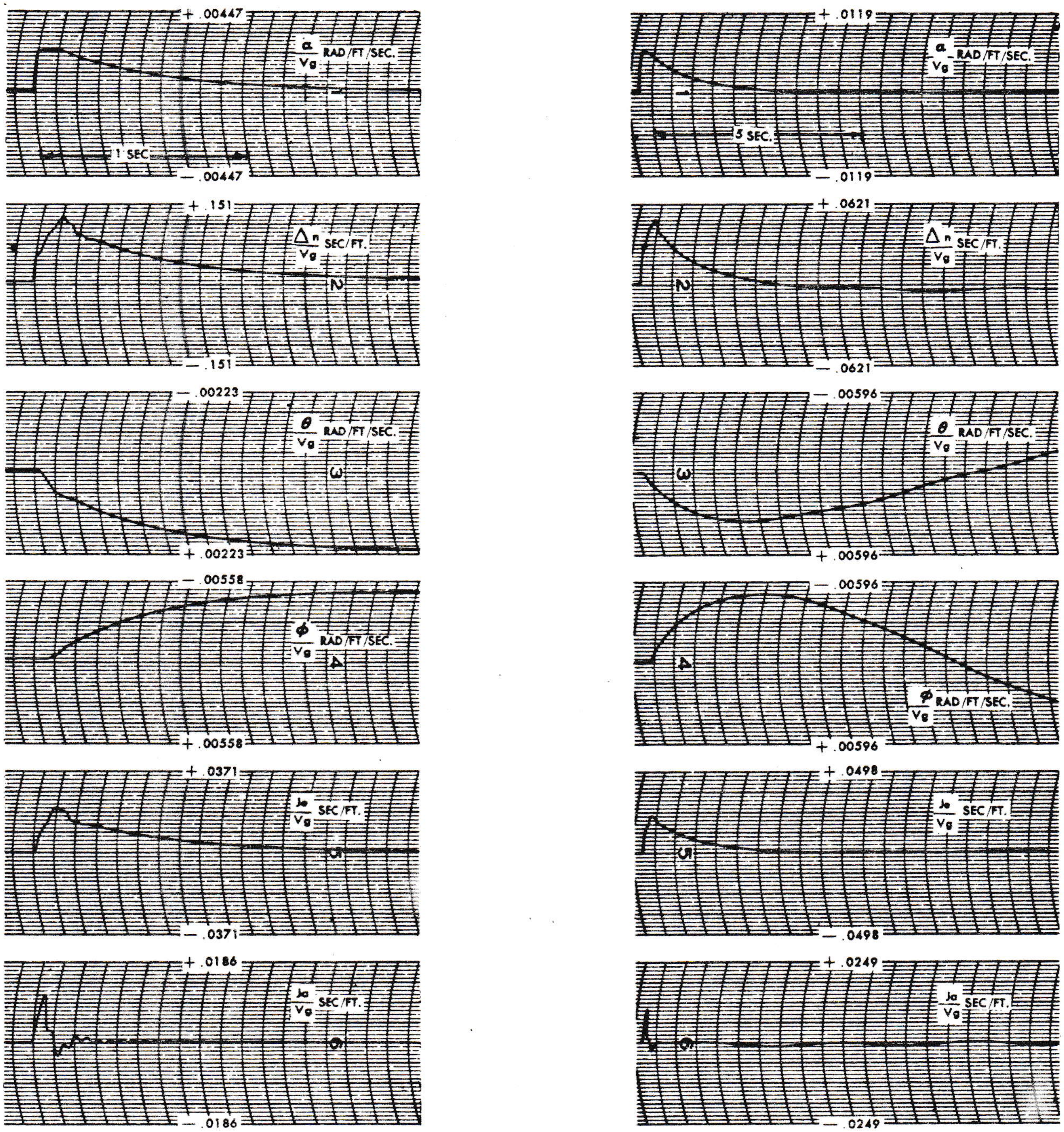
7.4 Normal Load Factor (Continued)

At a Mach Number of 0.15 the value of load factor increment for a gust velocity of 40 ft./sec. is approximately 2.2. g for a sharp edged gust and 1.6 g for a gust of gradient distance 150 ft. For a Mach Number of 0.40 and the same gust velocity the values are 4.4 g and 3.1 g respectively. Both are for a value of a spring constant of 500,000 ft. lb/rad. A typical curve showing the variation of load factor with gust gradient distance is given in Fig. 33.

7.5 Handling Qualities

A rotor phasor angle of 20° and a pilot phasor angle (angular displacement about the vertical axis of the airplane, between the toppling axis of the turborotor and the pilot's control column) of -90° presently appears to be most satisfactory for vehicle control.

The response to pilot control shows negligible cross coupling between longitudinal and lateral motion. The intermediate frequency mode is quite heavily damped and the pilot can easily control the long period oscillation in pitch. Without automatic stabilization in yaw, the pilot would experience difficulty in controlling the aircraft at high speed. A yaw damper, with a sufficiently high gain enables the pilot to stabilize the aircraft easily. With a directional stabilizer, but without the yaw damper, the pilot cannot stabilize the relatively long period oscillations in yaw, evenn with a high gain on the directional stabilizer, although within the limits imposed by the aircraft stability boundaries, increasing the gain tends to help the pilot slightly.



$M = 0.4$

$T_s = 500{,}000$ FT/LB/RAD.

$\Gamma_R = 20°$

$M = 0.15$

$T_s = 250{,}000$ FT LB./RAD.

$\Gamma_R = 30°$

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FIG. 32 LINEAR RESPONSE TO A SHARP EDGED VERTICAL GUST

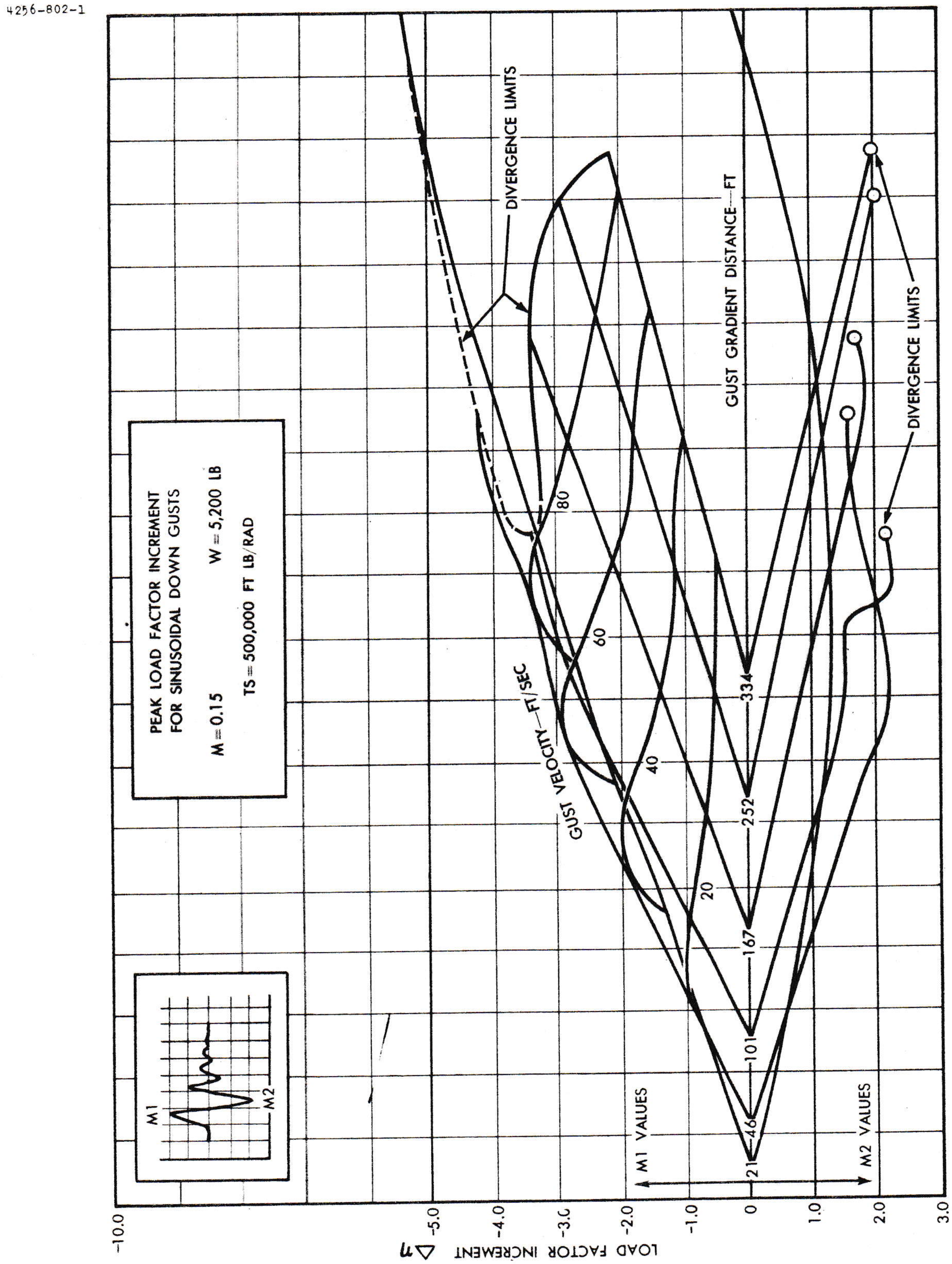

FIG. 33 PEAK LOAD FACTOR INCREMENT FOR SINUSOIDAL DOWN GUSTS

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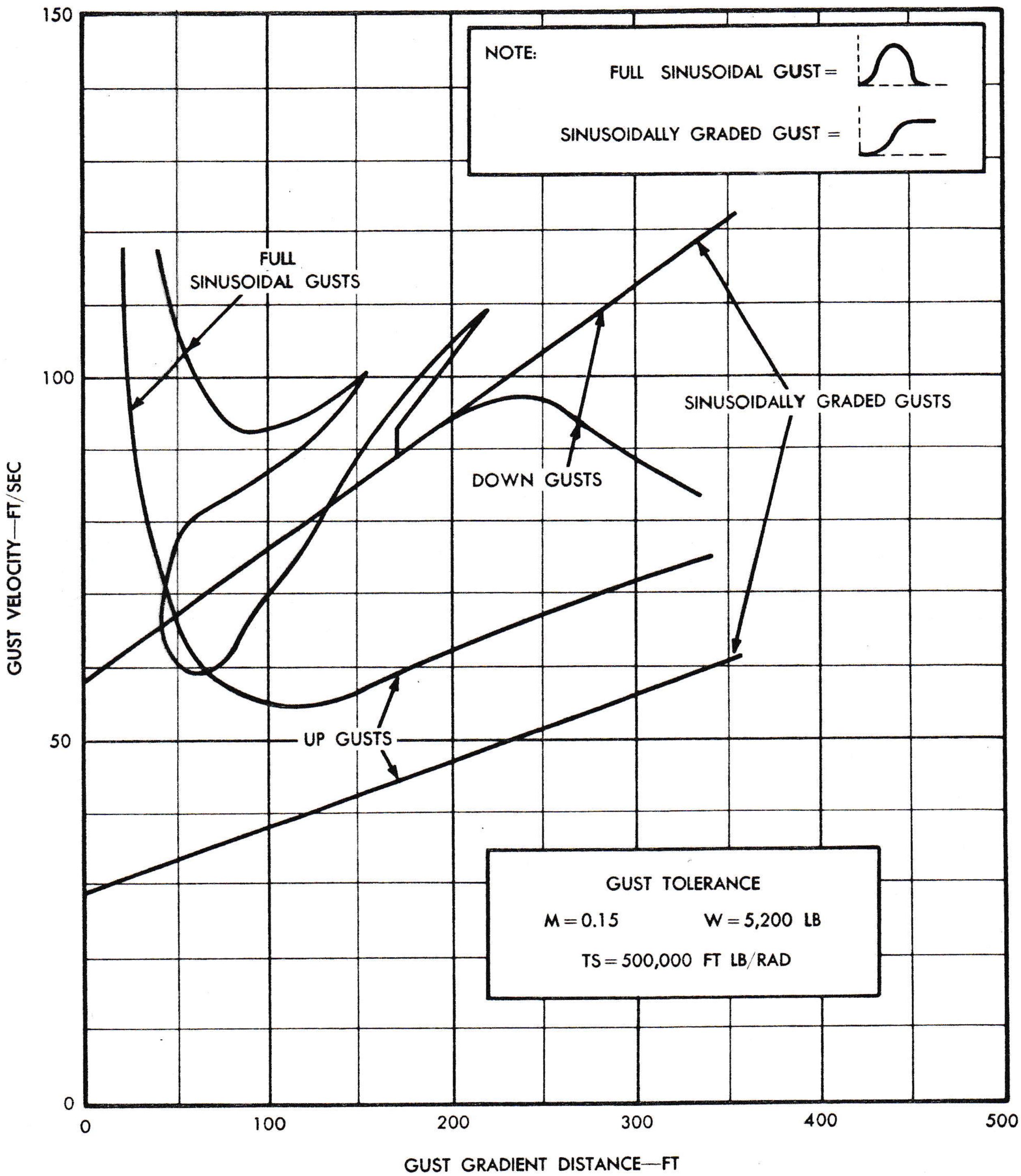

FIG. 34 GUST TOLERANCE

PART 8

STRESS

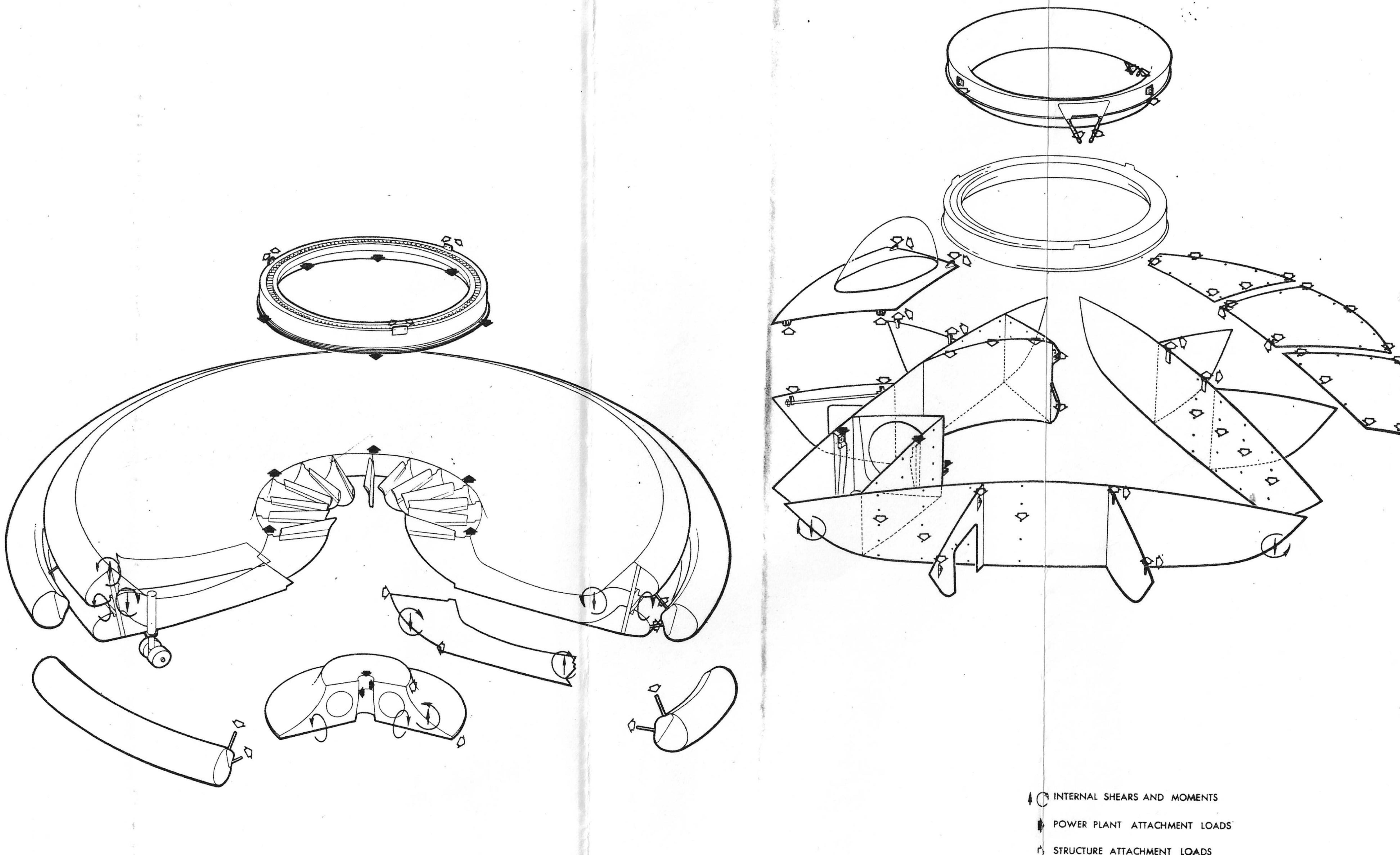

FIG. 35 STRUCTURAL LOAD PATHS

8.1 General

The analysis of the vehicle structure was based on the preliminary load data outlined in Part 9, on preliminary but detailed scheme drawings issued prior to the detailed design. In this way, it was possible to keep the structural analysis in step with detailed design progress and to provide maximum support to the design effort. However, it meant that some latitude had to be used in applying the attachment loads and in determining the internal load paths, see Fig. 35, in order to reduce the redundancies involved to a manageable level.

In the Avrocar, there are two major structural units, each capable of carrying the applied loading. The first consists of the center base, radial ribs with top and bottom skins, and a wing perimeter which form the hub, disc and rim respectively of the wheel-like structure. The second consists of the inner wing tip, and the triangular system of beams and compartment partitions. Together they form a very rigid, but highly redundant structure.

In order to simplify the problem, the wheel-like structure was considered to be the primary structural unit with the support offered by the triangular system of beams neglected, as a first approximation. The transverse beams and compartment partitions were defined as secondary structure providing support for the fuel tank, engine, fairing, cowling and hatch loads. (See Figure 35). The turborotor air inlet, turborotor casing and outer wing tip were also defined as secondary structure. The complete secondary structure is supported by the radial ribs and wing rim.

As a further simplification, the concentrated load reactions from the secondary structure in the well formed by the wing were treated as distributed loads over the radial ribs in the analysis of the primary structure. This was necessary since the geometry of these bulkheads was not firmly established in time for the initial analysis.

8.2 Primary Structure

8.2.1 Center Base

The center base was analysed as a thick wing subjected to the fixing moments and reactions of the wing ribs plus moments, thrust and inertial forces from the tuborotor. Local conditions due to the introduction of the rib forces were also considered.

8.2.2 Wing Ribs

Due to the thin skins employed, the stiffness of the top and bottom skins in acting as the web of a disc-type wheel was ignored. Instead, the radial ribs and effective widths of top and bottom skins were considered as light spokes joining a stiff rim and hub. The eighteen main ribs were considered to be encastré in both the wing rim and center base with a sinking support due to the deflection of the base relative to the wing rim. The thirty-six intermediate ribs were considered as propped cantilevers fixed to the wing rim and simply

8.2.2 Wing Ribs (Continued)

supported at the center base, again with a sinking support. The critical loading case was taken to be that due to a symmetrical manoeuvre at 4.0 g for the basic mission take-off gross weight.

8.2.3 Wing Rim

Fixing moments from the radial ribs were applied to the two boxes forming the wing rim as equal and opposite radial loads applied at the respective shear centers. The rims were considered as continuous beams in carrying the loads from the intermediate ribs to the main ribs and as complete rings under concentrated radial loads in carrying the net rib moments.

8.3 Secondary Structure

8.3.1 Wing Tip

The tip of the wing was considered as a ring supported by a system of radial spokes. Both fixed ended and pinned conditions for the spokes were examined. The ring was assumed to be loaded by uniformly distributed vertical and radial pressures corresponding to the maximum intensity of air loading anticipated on forward segments of the ring.

8.3.2 Transverse Beams and Compartment Partitions

The beams and compartment partitions were assumed to be loaded by structure and power plant reactions as shown in Fig. 35 . The engine partitions and fuel tank fire-walls receive end support from the turborotor casing and transverse beams, the others by the beams, the radial ribs and the upper rim of the wing.

Under the simplifying assumptions used in the analysis of the primary structure, interaction loads between the transverse beams and the radial wing ribs could not be determined with any degree of reliability. However, it was felt that due to the flexibility of the radial ribs and the ribs to bulkhead joints, these loads would be small.

The beams were analysed both as single span, fixed ended, and as three-span continuous beams. The latter were considered to be fixed at each end to the upper wing rim, and supported at two intermediate positions by compartment partitions. Both analyses were somewhat severe since they did not provide for the support deflections which would relieve the heavily loaded joints but they did provide an indication of the upper limits of internal stress and reaction loads.

8.3.3 Turborotor Air Inlet and Turborotor Casing

The turborotor air inlet was analysed as a ring on six supports under loads normal to the plane of the ring, and as a ring with a sinusoidal shear reaction and three radial restraints under loads in the plane of the ring. Three of the six supports were turnbuckles attached to the turborotor casing. The other three supports were also attached to the casing through two sets of brackets on the end of the engine partition.

The turborotor casing was analysed as a circular beam on an elastic foundation formed by the radial ribs. In addition to the turborotor air inlet loads, engine loads and temperature effects were also considered.

8.4 Alighting Gear

Landing loads were developed, and the gear and local attachments analysed using the criteria given in Appendix I, section 10.4. The loads were derived on the basis of the energy absorbed by the shock struts during a landing at the basic mission take-off weight of 5,650 lb.

The critical items in the landing gear assembly were the axle support tube and the outer support tube in bending. Stress levels and minimum margins of safety are detailed in report AVRO/SPG/TR 205.

PART 9

EXTERNAL LOADS

9.1 General

In order to facilitate accomplishment of a telescoped program, airplane ground, air and inertia loads and pressure distributions for the Avrocar were determined using simplified conditions. Later, theoretical distributions of pressures and air loads were evaluated for a limited number of cases in flight. The theoretical distributions proved that whilst the simplified conditions assumed were conservative, considerable work would have to be carried out to refine the loads to a point where all initial conditions could be considered. Time and funds for such an evaluation were not catered for in the present program since it was not believed to be essential at this period of development.

The basic load criteria used in the design of the vehicle is set forth in Appendix I.

PART 10

APPENDIX 1

STRUCTURAL DESIGN CRITERIA

10.1 General

When developed the vehicle is intended for operation within 400 ft. of the ground over terrain of not more than 10,000 ft. altitude, with a speed range from 0 to 270 knots.

Due to departures from conventional aircraft design U.S. Military Specifications are applied only to a limited extent, as specified herein. Additional data have been raised to cover conditions peculiar to the vehicle and to provide load criteria where flight experience and reliable test data are lacking.

The outline is intended to serve as a basis for the establishment of complete criteria.

The contractor, however, reserves the right to modify these criteria without prior notification if, at the discretion of the contractor, such modifications are warranted by design developments.

10.2 Structural Criteria - General

The primary and secondary structure of the Avrocar 1 is designed in accordance with the requirements of MIL-S-5700 with the following modifications:
(references are to the appropriate sections of MIL-S-5700).

10.2.1 Applicable Documents (Ref. Section 2)

The applicable documents listed in MIL-S-5700 apply only to the extent specified herein.

10.2.2 Flight Load Diagram (Ref. Section 3.5)

V-n diagrams are prepared in accordance with the requirements of MIL-S-5702 as modified in section 10.3 of this Appendix.

10.2.3 Flight Design Criteria (Ref. Section 4.2)

For stressing purposes, the Avrocar 1 is classified as a Class 1 reconnaisance aircraft. The maximum altitude is 10,000 ft. (Ref. Table 1 MIL-S-5700).

Yawing conditions (Ref. 4.2.4) do not apply due to peculiarities of the configuration. Special criteria to cover this requirement will be formulated when control characteristics in yaw are established.

Flight conditions, other than yawing are in accordance with the requirements of MIL-S-5702 as modified in section 10.3 of this Appendix.

10.2.3 Flight Design Criteria (Ref. Section 4.2) (Cont'd.)

Pitching and rolling velocities are limited to 2.0 radians per second.

10.2.4 Ground Loads Criteria (Ref. Section 4.3)

Ground loads are in accordance with the requirements of MIL-S- 8698 (ASG) as modified in section 10.4 of this Appendix, and with the requirements of ANC-2 to the extent specified in section 10.4 of this Appendix.

10.2.5 Wing, Fuselage, Engine Mount and Nacelle Loads (Ref. Sections 4.4. 4.5

The wing and fuselage of the Avrocar 1 are an integral structure. The loads acting on and within this structure are in accordance with the requirements of MIL-S-5704, MIL-S-5705, MIL-S-5822 and section 10.3 of this Appendix to the extent specified in section 10.5 of this Appendix.

10.2.6 Empennage and Control Surface Loads (Ref. 4.6)

Not applicable.

10.2.7 Control System Loads (Ref. 4.7)

The control system is designed in accordance with the requirements of the model specification and portions of MIL-S-5707 as indicated in section 10.6 of this Appendix.

10.2.8 Armament Loads (Ref. 4.8)

Not Applicable.

10.2.9 Structural Tests (Ref. 5.2, 5.3)

Not Applicable.

10.3 <u>Flight Design Criteria</u>

10.3.1 Applicable Documents

Flight criteria are in accordance with the requirements of MIL-S-5702 to the extent specified and as modified herein. Subsidiary specifications and documents called up in MIL-S -5702 do not apply except as noted.

10.3.2 Criteria - General

The aircraft is analysed for the flight conditions outlined below. The resulting loads have been carried sufficiently far into the main structure to assure that the maximum load for each member of the aircraft structure has been obtained. References are to the applicable section of MIL-S-5702.

10.3.2.1 Airplane Configuration (Ref. 3.1)

Only the basic or clean configuration is applicable.

10.3.2.2 Weights and Center of Gravity Positions (Ref. 3.2, 3.3).

The following weight conditions are considered:

W_{B_M} = Basic Mission Take-Off Gross Weight - 5,650 lb.

W_{A_1} = Alternate Mission Weight 1 (Design Payload, maximum Fuel) - 6,010 lb.

W_{A_2} = Alternate Mission Weight 11 (Max. Take-off Gross Weight) - 6,970 lb.

W_{A_3} = Alternate Mission Weight 111 (Min. Flying Gross Weight) - 3,600 lb.

W_{A_4} = Alternate Mission Weight IV (Min. Flying Weight, full fuel) - 4,410 lb.

The center of gravity position and aircraft inertias are in accordance with AVRO/SPG/TR 125.

10.3.2.3 Power Settings (Ref. 3.4)

Unless otherwise specified military rated power setting is assumed for all loading conditions.

10.3.2.4 Design Speeds (Ref. 3.5)

The investigation covers the following speeds:

Hover Speed	-	V_{hov_e}	- 0	knots EAS
Transition Speed	-	V_{tr_e}	0 to 76	knots EAS
Gust & Slow Down Speed	-	V_{ge}	120	knots EAS
Max. Level Flight Speed	-	V_{he}	225	knots EAS
Max. Dive Speed	-	$V_{max._e}$	270	knots EAS

10.3.2.5 Design Altitude (Ref. 3.6)

Only the sea level case is considered for stressing purposes.

10.3.2.6 Mach Number and Aero-Elastic Effects (Ref. 3.7)

Due to the low speeds, the relatively rigid structure, and the lack of test data, section 3.7 of MIL-S-5702 does not apply.

10.3.2.7 Thermal Effects (Ref. 3.8)

The effect of temperature changes due to exhaust gases is considered.

10.3.2.8 Maximum Normal Force Coefficient V Mach Number (Ref. 3.9)

Due to the low speeds, incompressible flow is assumed hence the maximum normal force coefficient is considered invariant with Mach number.

10.3.2.9 Flight Envelopes (Ref. 3.10)

Due to lack of information on the low speed characteristics of the Avrocar 1, the design manoeuvre envelope is assumed to coincide with the minimum flight weight gust envelope. Gust envelopes have been drawn using the gust load formula of section 4.1.2.1 MIL-S-5702 to meet the requirements of section 3.10.2 MIL-S-5702 when applicable.

These are presented in the form of a complete design envelope in fig. 36 and were used for the maximum design flight conditions imposed on the Avrocar 1.

10.3.3 Flight Conditions (Ref. 4.0)

The flight conditions outlined below were considered according to the availability of aerodynamic data and time allowed. Of these conditions, only those considered to be most critical were examined in detail.

10.3.3.1 Symmetrical Flight Conditions

10.3.3.1.1 Steady Pitching Manoeuvre (Ref. 4.1.1.1)

Steady pitching manoeuvre conditions for the combinations of aircraft weights and speeds laid down in paragraph 10.3.2 of this Appendix are given in Table I. The pitching velocity ($\dot{\theta}$) is assumed to be $\frac{n\,g}{V}$ radian per second

(note - $\dot{\theta}$max. = 2 rad. per sec. ref. para 4.3)

10.3.3.1.1 Steady Pitching Manoeuvre (Ref. 4.1.1.1) (Cont'd)

where n = Aircraft load factor

v = Aircraft velocity in feet/second

$g = 32.2$ ft./sec.^{2}

10.3.3.1.2 Manoeuvre with Pitching Acceleration (Ref. 4.1.1.2)

Due to lack of data, dynamic lift coefficients cannot be determined at this time.

10.3.3.1.3 Gust (Ref. 4.1.2)

The aircraft is considered in steady level flight and subjected to the gust intensities of fig. 2A MIL-S-5702.

The gust load formula given in section 4.1.2.1 MIL-S-5702 is employed. The cases considered are given in Table II.

The pitching acceleration due to gust is assumed to be:

$$\ddot{\theta} = \frac{4.46\, W\, (n-1)}{I_y} \text{ radians/sec.}^2$$

where W = Aircraft weight (lb).

n = Applicable load factor

I_y = Inertia of the aircraft about the y axis (slugs ft.^{2})

10.3.3.2 Unsymmetrical Flight Conditions

Due to lack of data, the rolling pull-out manoeuvre specified in MIL-S-5702 section 4.2.1.1 cannot be evaluated at this time. In lieu of this requirement, an abrupt rolling condition with a rolling moment being balanced by aircraft inertia force, and a steady rolling condition was examined. An unsymmetrical gust condition was also examined.

10.3.3.2.1 Abrupt Rolling Manoeuvre

The maximum available control moment in roll is estimated to be $M_x = .227\ F_u\ C_r$

where F_u = Jet momentum thrust of the applicable speed (lb).

C_r = Length of root chord (feet)

10.3.3.2.1 Abrupt Rolling Manoeuvre (Cont'd.)

This moment was used to assess the maximum rolling acceleration to which the aircraft may be subjected. It was compared with the accelerations resulting from an unbalanced wing loading of 125 - 75 percent as allowed in the alternate condition given in section 4.2.1.3 MIL-S-5702, and the critical condition applied to the flight cases given in Table 3, a positive load factor of $1 + 2/3\Delta n$ was considered applicable where Δn is based on the symmetrical load factor for the weight and speed under consideration.

10.3.3.2.2 Steady Rolling Manoeuvre

The aircraft is considered to be in a steady rolling manoeuvre at a rate of roll of 2.0 radians per second and a positive load factor of $1 + 2/3\Delta n$ where Δn is as defined above. Since the control moments required and aerodynamic forces involved cannot be evaluated at this time, the conditions apply to the power plant and the installation of fixed services and equipment only. The flight conditions to be considered are outlined in Table IV.

10.3.3.2.3 Gust (Ref. 4.2.2)

Unsymmetrical gust was considered as required by section 4.2.2 MIL-S-5702 for the cases shown in Table V. An elliptical spanwise loading distribution with a discontinuity at $y = 0$ was assumed.

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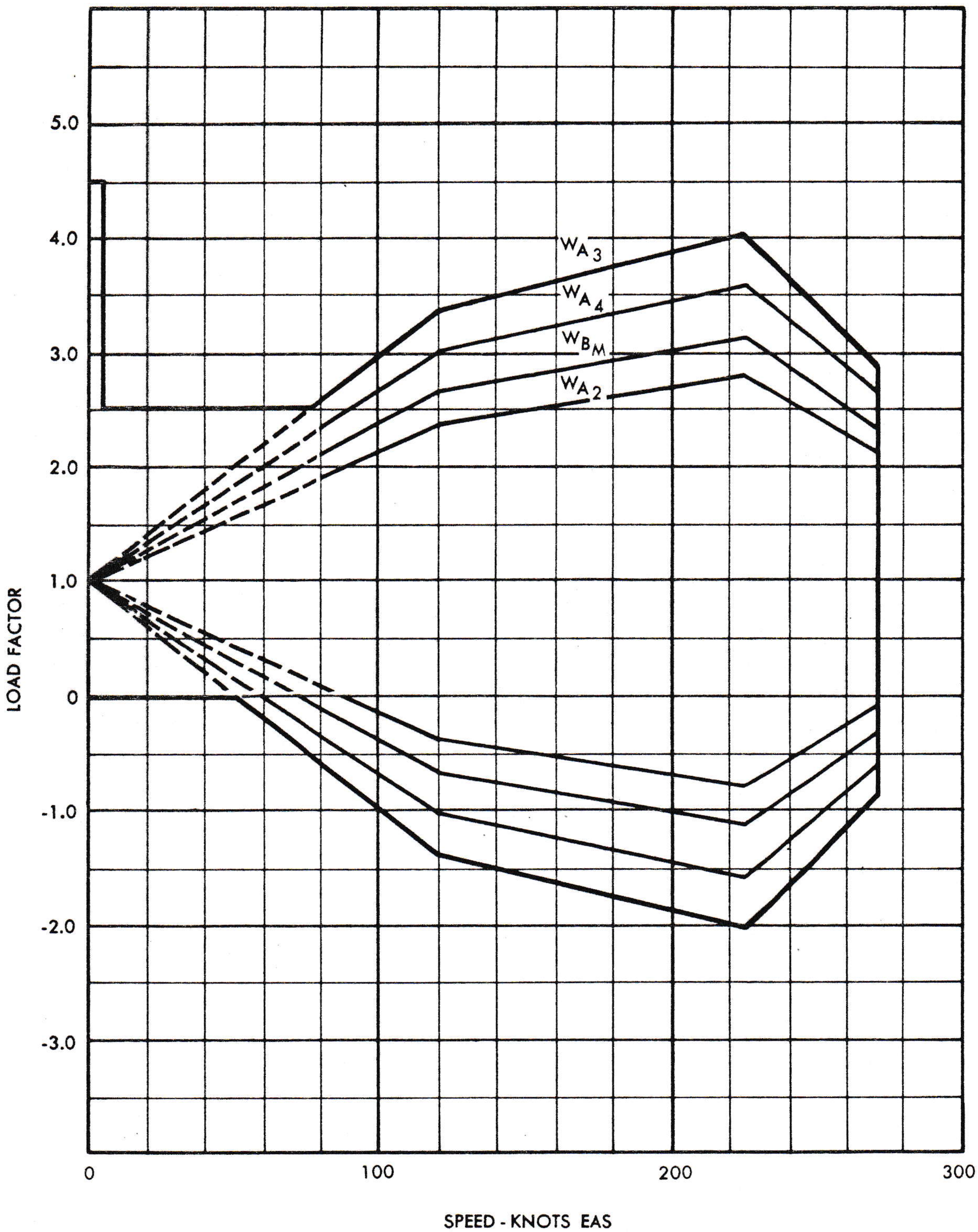


FIG. 36 DESIGN ENVELOPE

STRUCTURAL DESIGN CRITERIA - AVROCAR 1

TABLE I - BALANCED PITCHING MANOEUVRE CASES

CASE	WEIGHT		ATTDE.	SPEED		INERTIA FACTORS			POWER	ROLLING		PITCHING	
	Condn.	lb.		Code	Knots	Vertl.	Fwd.	Side	R.P.M.	Accl. rad/sec²	Vel. rad/sec	Accl. rad/sec²	Vel. rad/sec
1	W_{BM}	5650	Level @ S.L.	V_{tr_e}	4-76 0-52	+2.5 -0	To be Det'd.	0	22,000	0	0	0	To be Det'd.
2	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
3	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
4	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
5	W_{BM}	5650	"	V_{ge}	120	+3.36 -1.36	"	"	"	"	"	"	"
6	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
7	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
8	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
9	W_{BM}	5650	"	V_{h_e}	225	+4.02 -2.02	"	"	"	"	"	"	"
10	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
11	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
12	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
13	W_{bM}	5650	Dive or Upset <	V_{max_e}	270	+2.90 -0.90	"	"	"	"	"	"	"
14	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
15	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
16	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"

TABLE II - SYMMETRICAL GUST CASES

CASE	WEIGHT		ATTDE.	SPEED		INERTIA FACTORS			POWER	ROLLING		PITCHING	
	Condn.	lb.		Code	Knots	Vertl.	Fwd.	Side	R.P.M.	Accl. rad/sec²	Vel. rad/sec	Accl. rad/sec²	Vel. rad/sec
17	W_{BM}	5650	Level @ S.L.	V_{tre}	4-76 0-52	+2.05 +0.28	To be Det'd.	0	22,000	0	0	To be Det'd	0
18	W_{A2}	6970	"	"	"	+1.86 +0.41	" "	" "	"	"	"	"	"
19	W_{A3}	3600	"	"	"	+2.5 0	"	"	"	"	"	"	"
20	W_{A4}	4410	"	"	"	+2.25 +0.15	"	"	"	"	"	"	"
21	W_{BM}	5650	"	V_{Be}	120	+2.66 -0.66	"	"	"	"	"	"	"
22	W_{A2}	6970	"	"	"	+2.38 -0.38	"	"	"	"	"	"	"
23	W_{A3}	3600	"	"	"	+3.36 -1.36	"	"	"	"	"	"	"
24	W_{A4}	4410	"	"	"	+3.02 -1.02	"	"	"	"	"	"	"
25	W_{BM}	5650	"	V_{he}	225	+3.13 -1.13	"	"	"	"	"	"	"
26	W_{A2}	6970	"	"	"	+2.78 -0.78	"	"	"	"	"	"	"
27	W_{A3}	3600	"	"	"	+4.02 -2.02	"	"	"	"	"	"	"
28	W_{A4}	4410	"	"	"	+3.59 -1.59	"	"	"	"	"	"	"
29	W_{BM}	5650	Dive or Upset <	V_{max_e}	270	+2.33 -0.33	"	"	"	"	"	"	"
30	W_{A2}	6970	"	"	"	+2.11 -0.11	"	"	"	"	"	"	"
31	W_{A3}	3600	"	"	"	+2.90 -0.90	"	"	"	"	"	"	"
32	W_{A4}	4410	"	"	"	+2.64 -0.64	"	"	"	"	"	"	"

TABLE 111 - MANOEUVRE CASES WITH ROLLING ACCELERATION

CASE	WEIGHT		ATTDE.	SPEED		INERTIA FACTORS			POWER	ROLLING		PITCHING	
	Condn.	lb.		Code	Knots	Vertl.	Fwd.	Side	R.P.M.	Accl. rad/sec²	Vel. rad/sec	Acel. rad/sec²	Vel. rad/sec
33	W_{BM}	5650	Level @ S.L.	V_{tr_e}	4-76 0-52	+2.0	To be Det'd.	0	22,000	To be Det'd.	0	0	0
34	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
35	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
36	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
37	W_{BM}	5650	"	V_{g_e}	120	+2.58	"	"	"	"	"	"	"
38	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
39	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
40	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
41	W_{BM}	5650	"	V_{h_e}	225	+3.02	"	"	"	"	"	"	"
42	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
43	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
44	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
45	W_{BM}	5650	Dive or Upset<	V_{max_e}	270	+2.27	"	"	"	"	"	"	"
46	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
47	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
48	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"

TABLE 1V - MANOEUVRE CASES WITH ROLLING VELOCITY

CASE	WEIGHT		ATTDE.	SPEED		INERTIA FACTORS			POWER	ROLLING		PITCHING	
	Condn.	lb.		Code	Knots	Vertl.	Fwd.	Side	R.P.M.	Accl. rad/sec²	Vel. rad/sec	Accl. rad/sec²	Vel. rad/sec
49	W_{BM}	5650	Level @ S.L.	V_{tre}	4-76 0-52	+2.0	To be Det'd.	0	22,000	0	2.0	0	0
50	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
51	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
52	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
53	W_{BM}	5650	"	V_{ge}	120	+2.58	"	"	"	"	"	"	"
54	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
55	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
56	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
57	W_{BM}	5650	"	V_{he}	225	+3.02	"	"	"	"	"	"	"
58	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
59	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
60	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"
61	W_{BM}	5650	Dive or Upset <	V_{max_e}	270	+2.27	"	"	"	"	"	"	"
62	W_{A2}	6970	"	"	"	"	"	"	"	"	"	"	"
63	W_{A3}	3600	"	"	"	"	"	"	"	"	"	"	"
64	W_{A4}	4410	"	"	"	"	"	"	"	"	"	"	"

STRUCTURAL DESIGN CRITERIA - AVROCAR 1

TABLE V - UNSYMMETRICAL GUST CASES

CASE	WEIGHT		ATTDE.	SPEED		INERTIA FACTORS			POWER	ROLLING		PITCHING	
	Condn.	lb.	.	Code	Knots	Vertl.	Fwd.	Side	R.P.M.	Accl. rad/sec²	Vel. rad/sec	Accl. rad/sec²	Vel. rad/sec
65	W_{3M}	5650	Level @ S.L.	V_{tre}	4-76 0-52	+1.92 +0.37	To be Det'd.	0	22,000	To be Det'd.	0	To be Det'd.	0
66	W_{A2}	6970	"	"	"	+1.75 +0.48	"	"	"	"	"	"	"
67	W_{A3}	3600	"	"	"	+2.31 +0.12	"	"	"	"	"	"	"
68	W_{A4}	4410	"	"	"	+2.09 +0.26	"	"	"	"	"	"	"
69	W_{3M}	5650	"	V_{Ee}	120	+2.45 -0.45	"	"	"	"	"	"	"
70	W_{A2}	6970	"	"	"	+2.21 -0.21	"	"	"	"	"	"	"
71	W_{A3}	3600	"	"	"	+3.07 -1.07	"	"	"	"	"	"	"
72	W_{A4}	4410	"	"	"	+2.77 -0.77	"	"	"	"	"	"	"
73	W_{3M}	5650	"	V_{he}	225	+2.86 -0.86	"	"	"	"	"	"	"
74	W_{A2}	6970	"	"	"	+2.56 -0.56	"	"	"	"	"	"	"
75	W_{A3}	3600	"	"	"	+3.64 -1.64	"	"	"	"	"	"	"
76	W_{A4}	4410	"	"	"	+3.27 -1.27	"	"	"	"	"	"	"
77	W_{BM}	5650	Dive or Upset <	V_{max_e}	270	+2.16 -0.16	"	"	"	"	"	"	"
78	W_{A2}	6970	"	"	"	+1.97 +0.03	"	"	"	"	"	"	"
79	W_{A3}	3600	"	"	"	+2.66 -0.66	"	"	"	"	"	"	"
80	W_{A4}	4410	"	"	"	+2.44 -0.44	"	"	"	"	"	"	"

10.4 Ground Load Criteria

10.4.1 Take-off Loads

Take-off loads for this aircraft are to be determined.

Their intensity is expected to be such that they will not provide a design condition for the airframe structure in general.

10.4.2 Landing Loads

The landing loads are based on the requirements of MIL-S-8698: MILITARY SPECIFICATION, STRUCTURAL DESIGN REQUIREMENTS, HELICOPTERS, the appropriate paragraphs of which are modified for this aircraft as follows:

10.4.2.1 Landing Parameters

The airplane limit sinking speed, on initial contact with the ground, is six feet/second at an airplane lift equal to its weight, at the basic mission take-off gross weight (Ref. MIL-S-8698 para. 3.4.2).

10.4.2.2 Reserve Engergy Requirements

Failure of the structure will not occur in a drop with a sinking speed equal to the limit value of sinking speed associated with the landing weight specified above times the square root of 1.5 (Ref. MIL-S-8698 para. 3.4.4).

10.4.2.3 Main Gear Obstruction Loads

The alighting gear components are assumed to contact the ground simultaneously. The forward velocity is zero. The vertical components of the ground reactions are those which would result from contact with the specified sinking speed and lift. A load equal to one-half of the maximum vertical reaction, (at the centroid of each contact surface) but not exceeding the aircraft weight, is applied in a forward, aft, inboard and outboard direction, each in combination with the vertical load, considering each landing gear independently. Under this condition transverse loads on the other units are assumed zero. (Ref. MIL-S-8698 para. 3.4.5.1).

10.4.3 Crash Landing

Paragraph 3.4.7 MIL-S-8698 (ASG) applies with the ultimate inertia-load factors as specified below:

Fore and Aft	$\pm$	6g
Lateral	$\pm$	4g
Up		4g
Down		8g

10.4.4 Ground Handling Loads

Loads for the design of the Avrocar 1 in connection with towing, hoisting and mooring are in accordance with the requirements of ANC.2 chapter 4, dated October 1952.

10.5 Wing and Fuselage Load Criteria

The wing-fuselage structure is designed in accordance with the requirements of MIL-S-5704, MIL-S-5705 and MIL-S-5822 to the extent specified herein. Subsidiary documents called up do not apply except as noted:

10.5.1 General (Ref. MIL-S-5704 Sections 3.1, 3.2
MIL-S-5705 Sections 3.1, 3.2)

The structure is designed for the loads resulting from the flight conditions outlined in section 10.3, the ground conditions outlined in section 10.4 and the engine conditions outlined herein.

The loads include the factors of safety specified in MIL-S-5700.

10.5.2 Pressure Distributions (Ref. MIL-S-5704 Sections 3.3 & 3.4
MIL-S-5705 Sections 4.2.4. & 4.2.6)

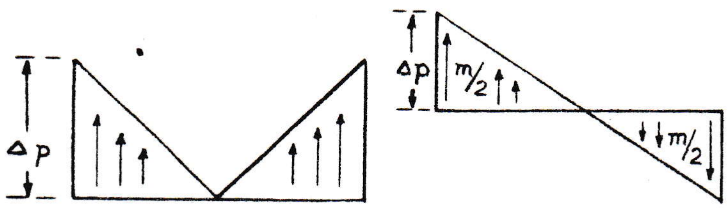
10.5.2.1 Distribution of Aerodynamic Loads

The magnitude of aerodynamic coefficients and the spanwise and chordwise distribution of the resulting loads was based on the results of wind tunnel tests performed on models of an earlier aircraft design designated the PV.704. The initial estimates were approximations only for preliminary design purposes based on the most critical of the flight conditions outlined in section 10.3 of this Appendix.

The lift load distribution was based on strip theory using a triangular section saddle back type loading, assuming a constant Δp, at the periphery and $\Delta p = 0$ at mid chord stations. The pitching moment load contribution was assumed to vary linearly along the chord, the loads at the periphery varying sinusoidally according to the relation $\Delta p = \Delta p_{root} \cos \theta$. The rolling moment load contribution was assumed to vary linearly along the

10.5.2.1 Distribution of Aerodynamic Loads (Continued)

span, the loads at the periphery varying sinusoidally according to the relation $\Delta p = \Delta p_{tip} \sin \theta$. In the above p denotes loading and θ the angle between the radius vector and the root chord station.



Pitch: $\Delta p = \Delta p_{root} \cos \theta$

Roll: $\Delta p = \Delta p_{tip} \sin \theta$

10.5.2.2 Surface Pressures - External

10.5.2.2.1 Wing - Leading and Trailing Edge

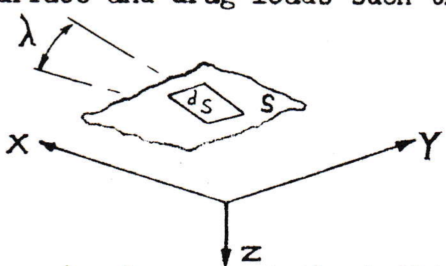
The maximum external surface pressures acting on the wing at stations between 0 and 20% and between 80% and 100% of the local wing chord were assumed to be 4.0q.

10.5.2.2.2 Wing - Central Portions

The maximum pressures on the exterior surface of the fuel tanks, the duct walls and the lower surface of the airplane at chord stations from 20 to 80% of the chord at span stations from $2y/b = -.80$ to $+.80$ are $\pm 1.5q$.

10.5.2.2.3 Wing - Hatches

The hatches on the upper surface of the Avrocar are designed to withstand an arbitrary airload of $\pm$ 80 psf. normal to the surface and drag loads such that



$$D = 80 \int \sin \lambda \, dS + .0035qS$$

In order to prevent the build up of differential pressures between compartments covered by the hatches on the upper surface, suitable venting provisions are incorporated.

10.5.2.3 Surface Pressures - Internal

The internal bursting pressures acting within the radial ducts are equal to the difference between the internal total pressure and the external ambient pressure.

10.5.3 Weight Distribution (Ref. MIL-S-5704 Section 3.5)

The distribution of weights for the cases given in section 10.3 are as detailed in AVRO/SPG/TR 125, modified to distribute concentrated weight items over wing areas supported by ribs.

10.5.4 Loads - Basic Structure (Ref. MIL-S-5704 Section 4.1.2, 4.2.0
MIL-S-5705 Section 4.1)

10.5.4.1 Wing Tip

The wing tip is designed for the unit loads specified in 10.5.2.2, and 10.5.2.3 distributed in the most adverse manner.

10.5.4.2 Wing Rims

The wing rims are designed for loads arising from the distribution given in 10.5.2.1, for internal loads from the ribs and wing tip, and for loads arising from 10.5.2.2. and 10.5.2.3.

10.5.4.3 Wing Ribs

The radial ribs are designed for loads resulting from the distributions given in 10.5.2.1, in combination with inertia loads based on the weight distribution 10.5.3, and for ground reactions resulting from the conditions outlined in 10.4. The requirements of MIL-S-5704, section 4.1.2.2. apply.

10.5.4.4 Center Base

The center base structure is designed for loads resulting from the analysis of the radial ribs and for loads resulting from the analysis of the main rotor and control mechanisms.

10.5.4.5 Transverse Beams and Partitions

The beams and partitions separating powerplant, crew and cargo compartments are considered as secondary structure. They are designed to carry the panel loads resulting from the distributions given in 10.5.2.2 and loads resulting from rib deflections.

10.5.5 Loads - Secondary Items (Ref. MIL-S-5705 Section 4.7)

10.5.5.1 Crew Seats

Structural provisions for the installation of pilot's and observer's seats are in accordance with the requirements of MIL-S-5705, section 4.7.1.1 and MIL-S-5822.

10.5.5.2 Canopy Loads - (Ref. MIL-S-5705 Section 4.2.4)

On the frontal surface of the canopy, an elliptical pressure distribution varying from p = q at the leading edge to zero at the normal transverse plane through the vertex is assumed. On the rear surface, a constant pressure distribution approximating that on the rear portions of a sphere is used.

10.5.5.3 Air Data Probe and Antenna Installations

The air data probe and antenna installations are designed for loads occurring at the maximum flight speed and/or the highest load factors either together or independently whichever is critical. Buffeting is not considered.

10.5.5.4 Radio and Electrical Installations

Radio and electrical installations are designed for the flight conditions outlined in section 10.3 of this Appendix. For items located in or adjacent to the pilot's compartment loads resulting from the crash landing conditions outlined in paragraph 10.4.3 also apply.

10.5.5.5 Miscellaneous Equipment

The installation of miscellaneous equipment is in accordance with the requirements of MIL-S-5705, section 4.7.7.

10.5.6 Power Plant Loads (Ref. MIL-S-5705 Section 4.6)

10.5.6.1 Turborotor Inlet

Loads on the turborotor inlet, inlet grid and nose bullet are based on an inlet full condition at the critical speed for the inlet.

10.5.6.2 Engine Cowlings

Loads on the engine cowlings are in accordance with the surface pressures outlined in paragraph 10.5.2.2 of this Appendix.

10.5.6.3 Turborotor

The turborotor is designed in accordance with AVRO/SPG/TR 126: DESIGN SPECIFICATION FOR AVROCAR TURBOROTOR, dated March, 1958.

10.5.6.4 Engine Installation

Installation of the engines is in accordance with MIL-S-5705, sections 4.5.2 and 4.6.3.

The loads on the engine inlet, jet pipe bullet and engine exhaust duct are those due to the pressure and momentum of the flow through the engine at military rated power in hovering flight.

10.6 Control System Criteria

10.6.1 General

The control system of the Avrocar is designed to meet the requirements outlined in the model specification. For stressing purposes, the following criteria are used for the components indicated:

10.6.2 Gyro Stabilizer System

The system is designed to provide full control deflection under a rate of roll or pitch of 10 degree per second at maximum rotor speed. Stops are incorporated to support the loads resulting from a rate of roll or pitch of 2.0 radians per second.

The loads to be applied are those resulting from the required control deflection, gyroscopic moment and forces on the turborotor and aircraft inertia factors.

10.6.3 Pilot's Controls

The pilot's control column is designed to provide a 2.0 inch travel in both fore and aft, and lateral directions under the application of a 50 lb. force for full control. In addition, the applied pilot's stick loads given in Table 1 MIL-S-5707 apply.

Yaw control is provided by a twist grip on the control column.

The twist grip is designed to provide an angular movement of $\pm 25^{\circ}$ under a 10 inch pound moment for full control.

10.6.4 Operating Mechanisms

Loads on control slides, spoiler mechanism and pilot controlled items are in accordance with the required displacements and-or actuator output available.

10.6.5 Guide Vanes and Yaw Control Vanes

Guide vanes and yaw control vanes are designed for the aerodynamic loads resulting from the critical internal flow condition.