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CANADIAN GOVERNMENT PROGRAM FOR THE AVROCAR PHASE 1

WEIGHT AND BALANCE REPORT

500/WTS/1

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CANADIAN GOVERNMENT PROGRAM FOR THE AVROCAR

PHASE 1

WEIGHT AND BALANCE REPORT

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TO:
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LIST OF REFERENCE REPORTS

Report No.	Title	Author
S.A.W.E.#3	Selection of Optimum Wing Configuration for Minimum Weight	Davidson and McWhorter
Vickers - Armstrong W28	Tail Unit Weight Prediction	Pavelin
S.A.W.E.# 126	Fuselage Weight Prediction	Green
R.A.E.#80	Prediction of Undercarriage Weights	Burt and Ripley
R.A.E.# 198	A Method of Undercarriage Weight Prediction	Phillips
P & W TDM-1569	Preliminary Performance Estimates of Lifting Fans	Pratt & Whitney
GEN/WTS/44	Lifting Fan Weights	Avro Aircraft Limited
S.A.W.E.# 158	Preliminary Design Weight Estimation	Weinberg
J.R.Ae.Soc.	Gear Box Design	October 1954
PB 121097	Weights and Balance, Rotary Wing Aircraft, Vol. 5	Liberatore
R.A.E. 94	A Simple Method for Tail Unit Structure Weight Prediction	Ripley
J.R.Ae.Soc.	Aircraft Design Analysis	Driggs

1.0 FOREWORD

Phase I appertains to the Avrocar development in its present general configuration.

Since there was not a rigid specification to adhere to and most configurations were unconventional, the estimating processes outlined for Phase 2 could not be applied.

The general Avrocar structural layout was used as a design basis for the discus shaped portion of each configuration, raising the gauges of the material to meet the speed and load factor requirements. The wings, tail planes, fins and rudders were estimated in the conventional manner outlined in Estimating Methods section of this report.

As the various design configurations evolved, a weight estimate of each was prepared except for a few configurations which were discarded as impractical before a weight estimate commenced. The Design Diving Speed and the Ultimate Load Factor were set for each configuration at the G.A. drawing completion stage by the Project Engineer, and the Weight Statement prepared on this information. Subsequent information from the Performance Group has not been incorporated in the Weight Statements and could alter the Weight Estimates appreciably. The assumed values for each configuration are shown on each Weight Statement.

Where horizontal c.g. positions have been calculated, the rotor centerline is used as the datum. No detailed moments of inertia have been calculated but where approximate values were required for performance estimates, Avrocar data was extrapolated for the Discus vehicles, and empirical data used for more conventional configurations.

2.0 WEIGHT ESTIMATION METHODS

The weight estimates for the various configurations considered in this program are based on present state-of-the-art levels with no significant optimization attempts. In general, the configuration weight estimate was conducted on an "as drawn" basis using equipment and materials available 'off the shelf'. Certain areas of current aircraft development, particularly in the gear box and propeller field, give promise of significant weight reducation in the near future. It is felt, therefore, that the weights quoted in this report are realistic and possibly slightly conservative.

The weight estimates are based on a design diving speeds, and an Ultimate Load Factors, set by the Project Engineer at the completion of the G.A. drawings.

2.1 Structure

2.1.1 Wing

The Davidson-McWhorter method of wing weight prediction (S.A.W.E. Report #33) was used exclusively for conventional wing/fuselage structures using ultimate load factor, aspect ratio, wing area, taper ratio, thickness/chord ratio, and design diving speed as the major parameters.

Wherever the Avrocar discus shape appeared in its true form the components weight was calculated using the Avrocar basic structure with increased material gauges to suit the requirements.

2.1.2 Fin and Rudder

The fin and rudder weights were established by the Pavelin method (Vickers Armstrong Report W28) using design diving speed, area, structural sweep, span and taper ratio as parameters. An additional 10% allowance for mass balance weight is included. Where applicable, a previous Avrocar fin design was used being modified slightly to suit the new area requirement.

2.1.3 Tailplane

The Pavelin method was also used for tailplane estimates and is essentially the same as the vertical tail method using different constants. Here again an additional 10% was added for mass balancing. A previously designed Avrocar tailplane was used as a basis for applicable configurations.

2.1.4 Fuselage

Fuselages for the conventional configurations were estimated by the Green method, (S.A.W.E. #126) and Driggs (Aircraft Design Analysis) which uses maximum speed, wetted area, and tail length (1/4 c wing to 1/4 c tailplane) as parameters. Some discus shaped vehicles are considered under wing group only with no separate allowance for fuselage and are generally based on Avrocar design with increased material gauges.

2.1.5 Undercarriage

R.A.E. Structures Reports 80 and 198 were used to establish weights of the retractable conventional undercarriage assuming a sinking speed of 9 ft/sec. An extrapolation of the Avrocar undercarriage was used on applicable configurations.

2.2 Powerplant

The weights for the engine and engine accessories were generally obtained from the engine manufacturer's brochures.

The lifting fan weights were derived from Avro Report GEN/WTS/44 which is a collection of curves relating fan diameter, horsepower, pressure ratio etc, based on information obtained from Pratt & Whitney Report TDM 1569 and checked with data based on our own experience with the Avrocar and other vehicles. Propeller weights were estimated from a method outlined in S.A.W.E. Report # 158 after checking the method with known actual weights of aircraft propellers.

The Journal of the Royal Aeronautical Society published an article on Gear Design which was used as the basis for the gear box weights. It was found that this method was reliable for spur gears, but did not reflect the weight savings possible through use of planetary gearing. Several examples of planetary gear box were plotted against the general curve and all fell below the curve, however, it was deemed insufficient data to warrant a change in method and the heavier gear box weights are carried throughout the study.

Shafting weight was determined in each case by sizing according to accepted machinery practice. The ducting was sized by simple hoop tension and allowance made for hangers, joints, etc.

The clutch weights were obtained from a clutch weight vs torque curve produced from data obtained on a great number of clutches.

The fuel system and tankage, engine control system, and fire extinguishing system weights were established from empirical data based on experience.

2.3 Equipment

Since time did not permit the detail layout of equipment and the general specification did not list mandatory communication and navigation equipment it was decided to use the Avrocar equipment modified where necessary by design considerations.

2.4 Operational Load

Fuel loads were established arbitrarily depending mainly on available volume, and oil weights were obtained from the engine manufacturer's brochures. Residual fuel (unusable) is considered to be 1.5% of the usable fuel.

A standard allowance of 200 lb. per crewman is carried assuming a crew of two. The cargo allowance was established arbitrarily.

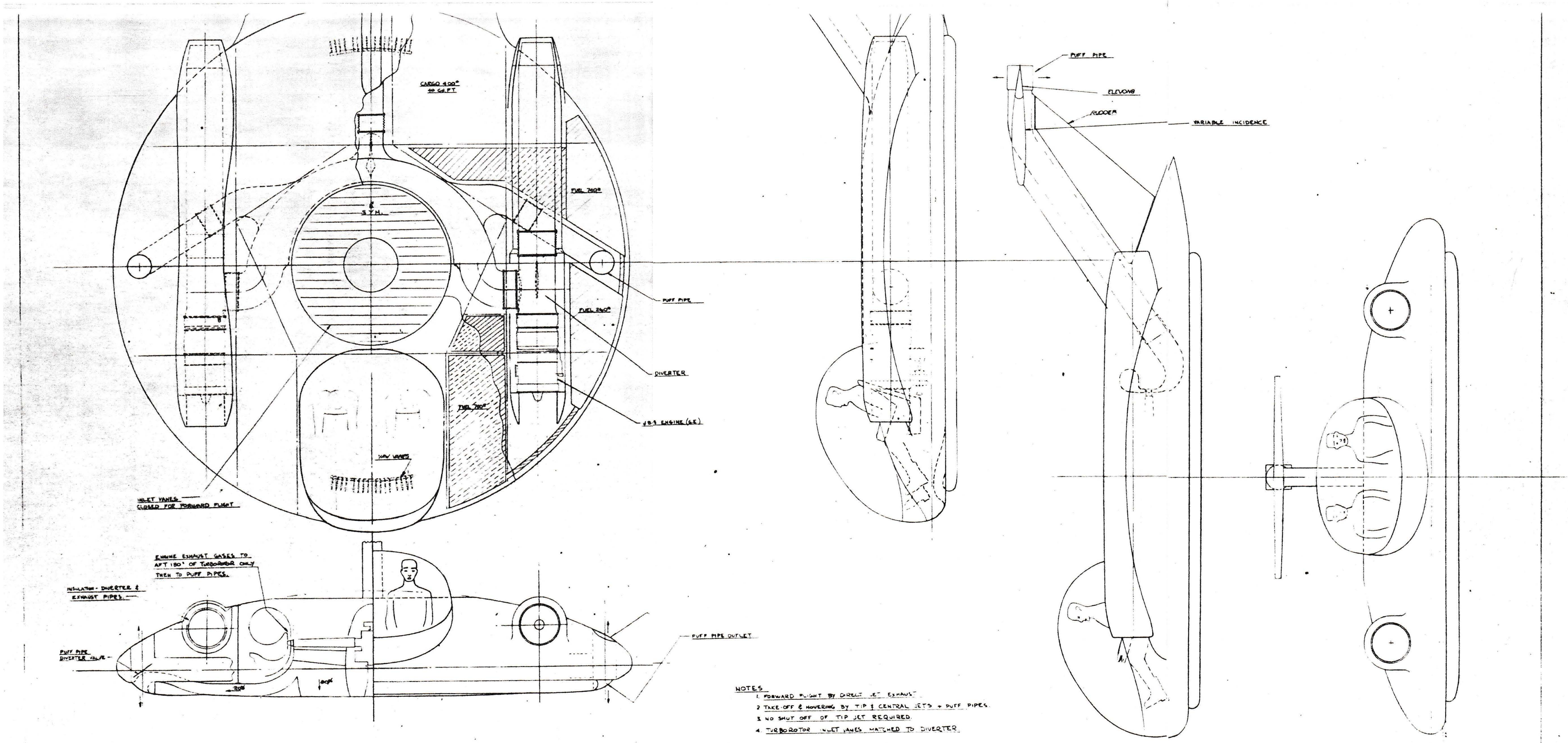
CARGO 400#
40 CU. FT
℄ SYM.
FUEL 740#
PUFF PIPE
FUEL 240#
DIVERTER
FUEL 780#
J85 ENGINE (G.E.)
YAW VANES
INLET VANES
CLOSED FOR FORWARD FLIGHT
ENGINE EXHAUST GASES TO
AFT 180° OF TURBOROTOR ONLY
THEN TO PUFF PIPES.
INSULATION - DIVERTER &
EXHAUST PIPES.
PUFF PIPE
DIVERTER VALVE
PUFF PIPE OUTLET
PUFF PIPE
ELEVONS
RUDDER
VARIABLE INCIDENCE
NOTES
1. FORWARD FLIGHT BY DIRECT JET EXHAUST
2. TAKE-OFF & HOVERING BY TIP & CENTRAL JETS + PUFF PIPES.
3. NO SHUT OFF OF TIP JET REQUIRED.
4. TURBOROTOR INLET VANES MATCHED TO DIVERTER.

FIG. 1

WEIGHT ESTIMATE (Fig. 1)

COMPONENT	Wt. (lb.)	H. Arm (in.)
Structure	1104	- 15
Wing	960	2
Tailplane	72	-145
Fin	72	-110
Undercarriage	60	0
Powerplant	1921	13
Rotor, stator and shroud	548	0
Engines, J85-7	650	38
Engine installation	22	38
Engine controls	10	52
Fuel system and tanks	290	20
Engine jet pipes and diverters	205	- 26
Rotor and puffer pipes	88	- 41
Insulation	78	6
Firewalls	30	40
Flying Controls	200	- 35
Equipment	366	49
Radio and intercom.	35	80
Instruments	26	80
Electrics	218	40
Pneumatics	23	0
Cockpit furnishings	64	65
Trapped fuel		
Weight Empty	3651	5
Useful Load	4855	8
Crew	400	60
Residual fuel	54	40
Rotor oil	9	0
Engine oil	12	45
Fuel	3580	20
Cargo	800	- 75
Gross Weight	8506	7

V = 350 knots
Ultimate load factor = 6

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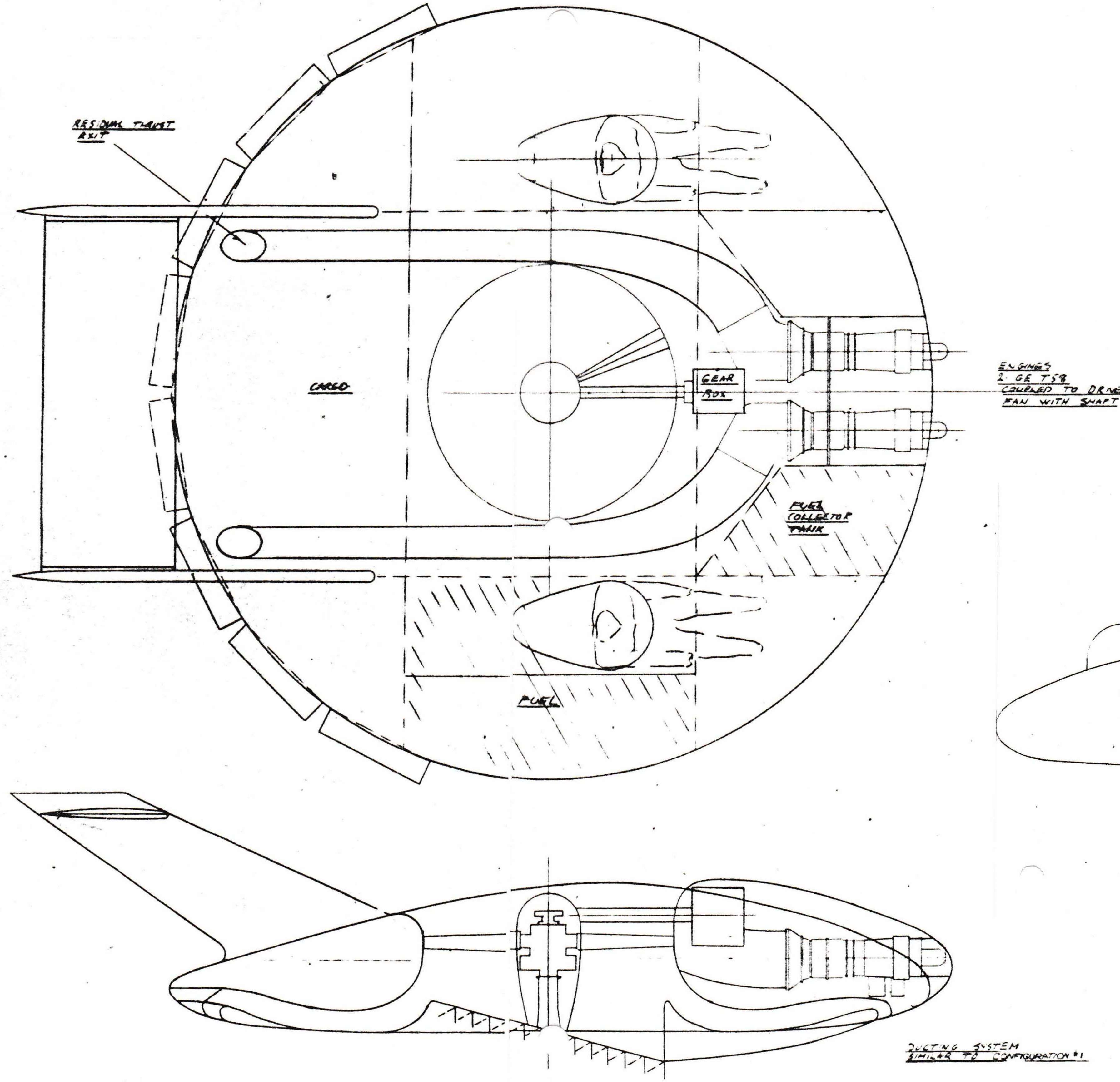


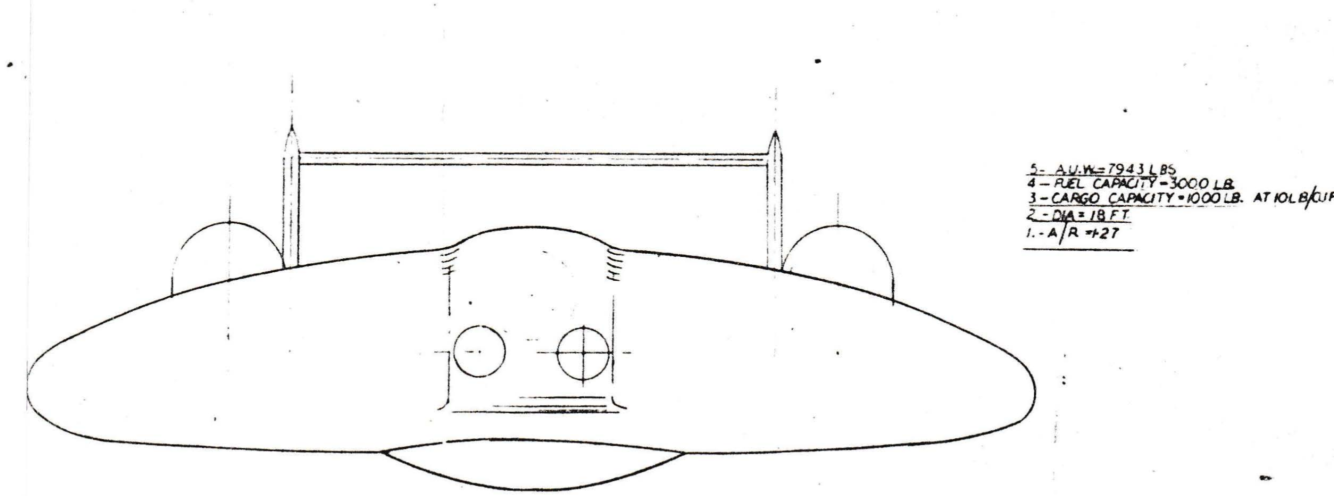


FIG. 2

WEIGHT ESTIMATE (Fig. 2)

COMPONENT	Wt. (lb.)	H. Arm (in.)
Structure	1179	- 16
Wing	980	2
Tailplane	85	-124
Fin	114	- 95
Undercarriage	60	0
Powerplant	1608	45
Rotor, stator and shroud	490	0
Gear boxes and shaft	258	40
Engine, T-58	542	92
Engine mounts	22	92
Engine controls	10	40
Fuel system and tanks	115	38
Exhaust pipes	85	- 15
Firewalls	30	79
Engine intakes	10	105
Fire extinguishers	28	80
Insulation	18	85
Flying Controls	204	- 40
Equipment	396	41
Radio and intercom.	35	30
Instruments	26	52
Electrics	218	50
Pneumatics	23	50
Cockpit furnishings	64	30
Weight Empty	3447	17
Useful Load	4466	- 13
Crew	400	21
Residual fuel	45	0
Rotor oil	9	0
Engine oil	12	95
Fuel	3000	0
Cargo	1000	- 70
Gross Weight	7913	0

V_D = 290 knots

Ultimate load factor = 6

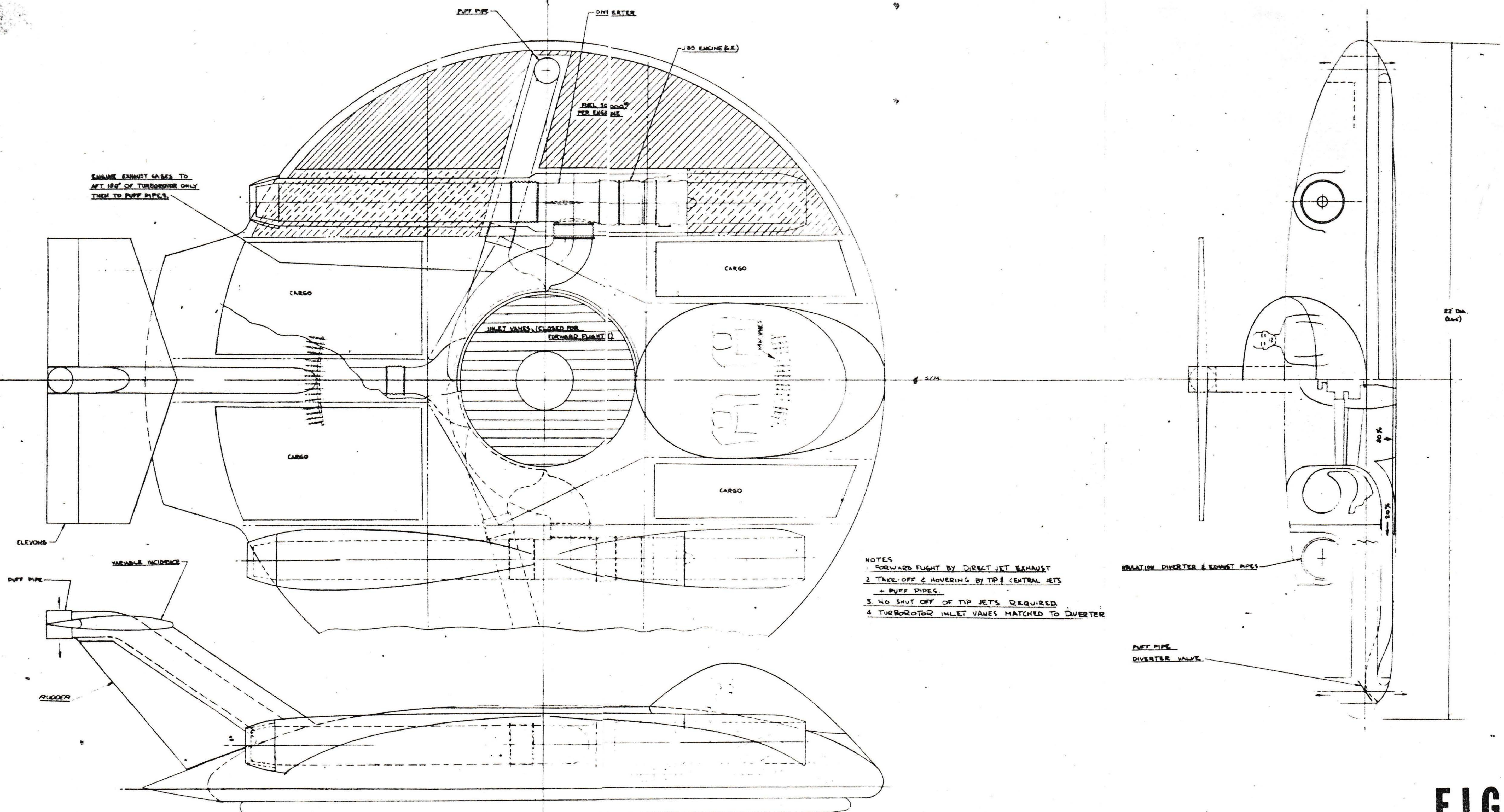

PUFF PIPE
DIVERTER
J85 ENGINE (G.E.)
FUEL 50,000# PER ENGINE
ENGINE EXHAUST GASES TO AFT 180° OF TURBOROTOR ONLY THEN TO PUFF PIPES.
CARGO
CARGO
CARGO
CARGO
INLET VANES (CLOSED FOR FORWARD FLIGHT)
S/M
ELEVONS
VARIABLE INCIDENCE
PUFF PIPE
RUDDER
NOTES
1 FORWARD FLIGHT BY DIRECT JET EXHAUST
2 TAKE-OFF & HOVERING BY TIP & CENTRAL JETS + PUFF PIPES.
3 NO SHUT OFF OF TIP JETS REQUIRED
4 TURBOROTOR INLET VANES MATCHED TO DIVERTER
22' DIA.
80%
20%
DIVERTER & EXHAUST PIPES
PUFF PIPE
DIVERTER VALVE

FIG. 3

WEIGHT ESTIMATE (Fig. 3)

COMPONENT	Wt. (lb.)	H. Arm (in.)
Structure	1489	- 12
Wing	1330	5
Tailplane	81	-170
Fin	78	-135
Undercarriage	80	0
Powerplant	2115	4
Rotor, stator and shroud	548	0
Engines, J85-7	650	36
Engine installation	22	36
Engine controls	10	60
Fuel system and tanks	333	9
Engine jet pipes and diverters	246	- 36
Rotor and puffer pipes	101	- 49
Insulation	175	- 40
Firewalls	30	41
Flying Controls	200	- 50
Equipment	426	49
Radio and intercom.	35	88
Instruments	26	90
Electrics	218	45
Pneumatics	23	20
Cockpit furnishings	64	76
Trapped fuel	60	7
Weight Empty	4310	0
Useful Load	7511	- 1.
Crew	400	76
Residual fuel	90	7
Rotor oil	9	0
Engine oil	12	43
Fuel	6000	7
Cargo	1000	- 80
Gross Weight	11821	- 1

V_D = 290 knots

Ultimate load factor = 6

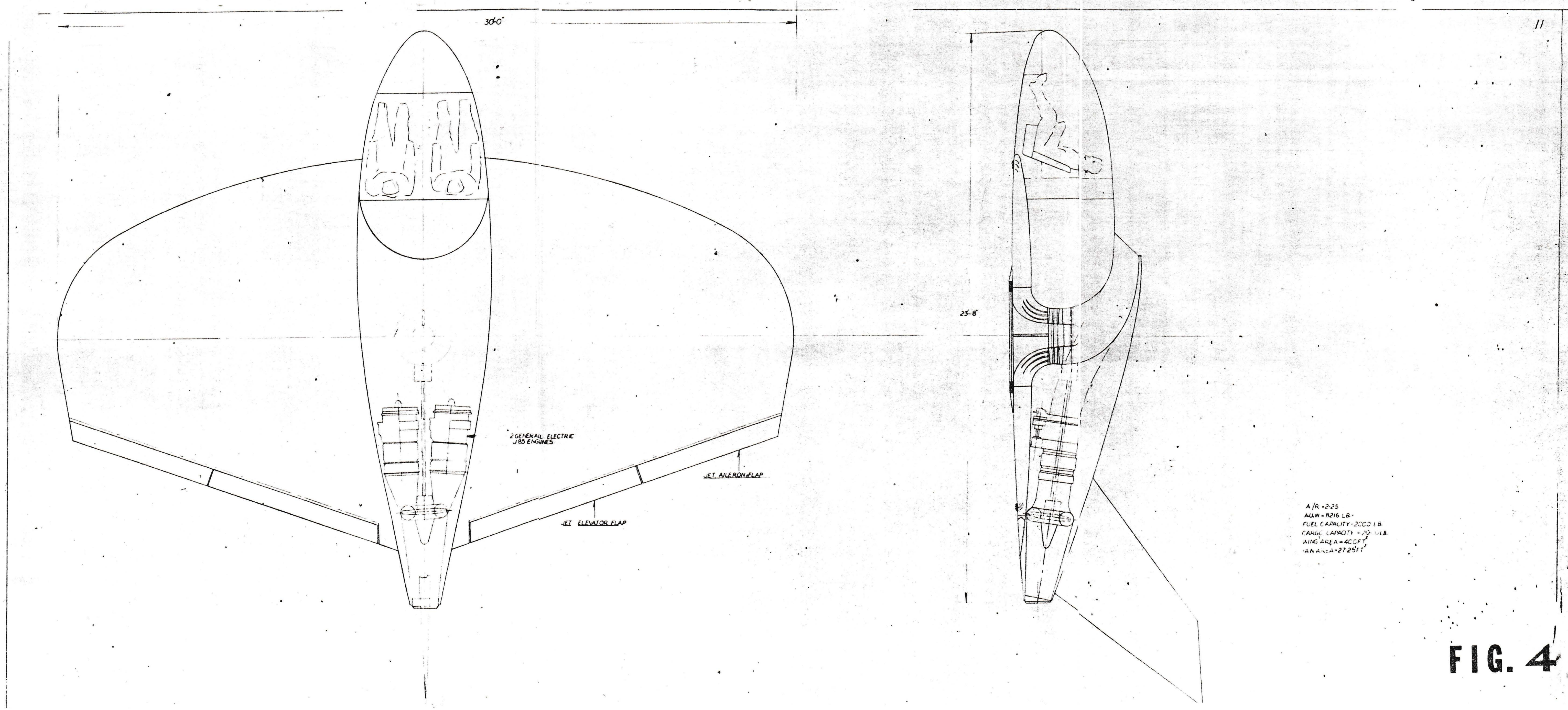

30'-0"
2 GENERAIL ELECTRIC
J 85 ENGINES
JET AILERON FLAP
JET ELEVATOR FLAP
23'-8"
A/R = 2.25
AUW = 8216 LB.
FUEL CAPACITY = 2000 LB.

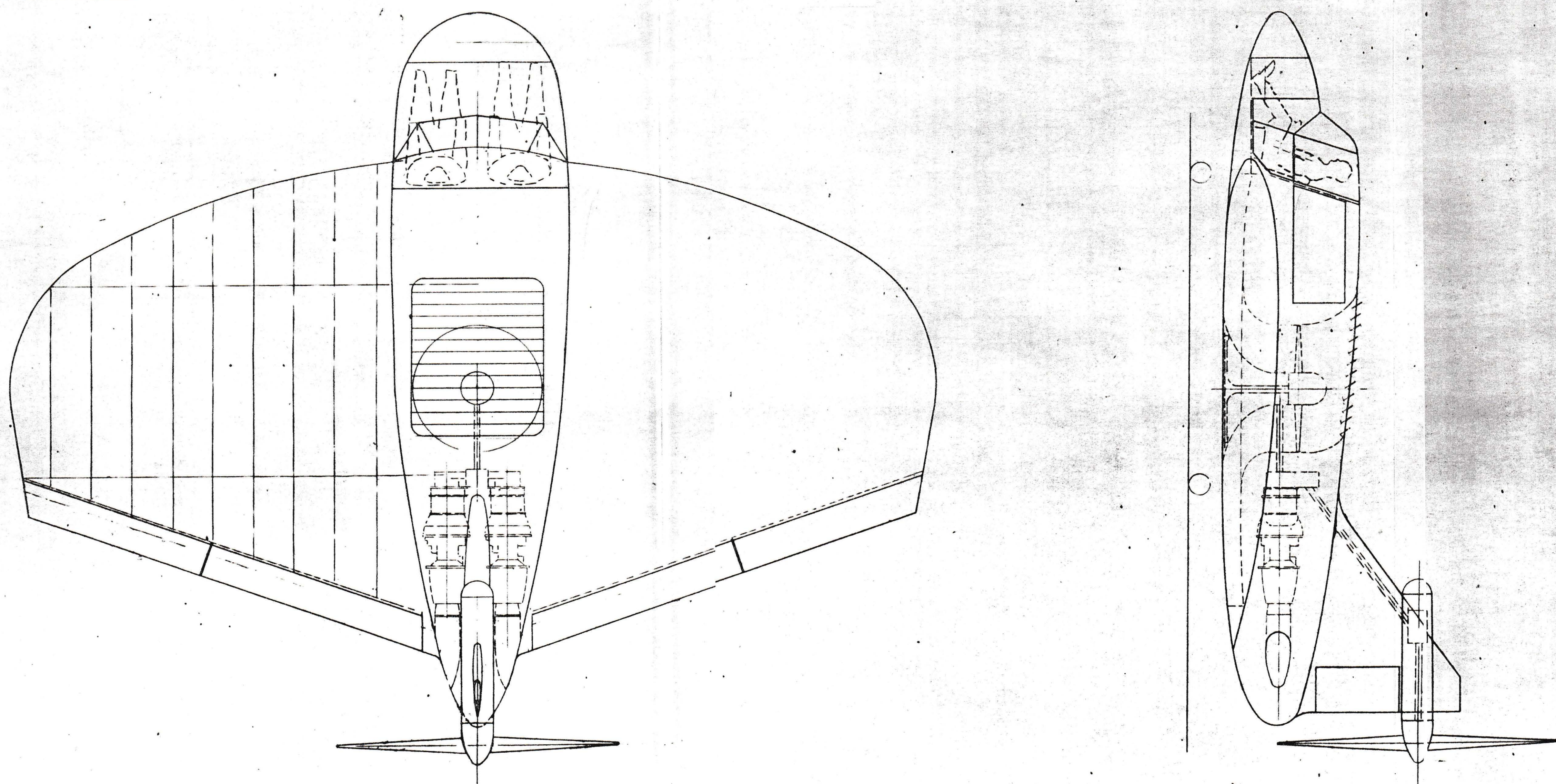
FIG. 4

WEIGHT ESTIMATE (Fig. 4)

COMPONENT	Wt. (lb.)
Structure	2072
Wings	777
Fin and Rudder	126
Fuselage	1169
Undercarriage	180
Powerplant	3254
Engines and free turbine	1931
Fan	650
Jet pipes	18
Insulation	15
Ducting	374
Fuel system and tanks	124
Intakes	86
Engine mounts	30
Engine controls	26
Flying Controls	130
Equipment	360
Weight Empty	5996
Operational Load	3726
Crew (2)	400
Oil	60
Residual fuel	66
Fuel	3000
Cargo	200
Gross Weight	9722

V_D = 684 mph

Ultimate load factor = 4



ENGINES-2 ASTAZOU II 522 S.H.P. EACH
FUEL CAPACITY-920 LB
CARGO-200 LB
A.U.W.=5892 LB
WING AREA-400 SQ. FT.
ASPECT RATIC=2·25

FIG. 5

WEIGHT ESTIMATE (Fig.5)

COMPONENT	Wt. (lb.)
Structure	1036
Wings	461
Fin, rudder and nacelle	65
Fuselage	510
Undercarriage	50
Powerplant	2713
Engines (2) Astazou II	550
Fan	42
Case and stator	66
Gear box and shafting	534
Propeller	232
Jet pipes	16
Insulation	12
Ducting	374
Fuel system and tanks	111
Intakes	30
Engine mounts	20
Engine controls	26
Gyro allowance	700
Flying Controls	130
Equipment	360
Weight Empty	4289
Operational Load	1603
Crew (2)	400
Oil	60
Residual fuel	23
Fuel	920
Cargo	200
Gross Weight	5892

V_D = 250 mph

Ultimate load factor = 7.27

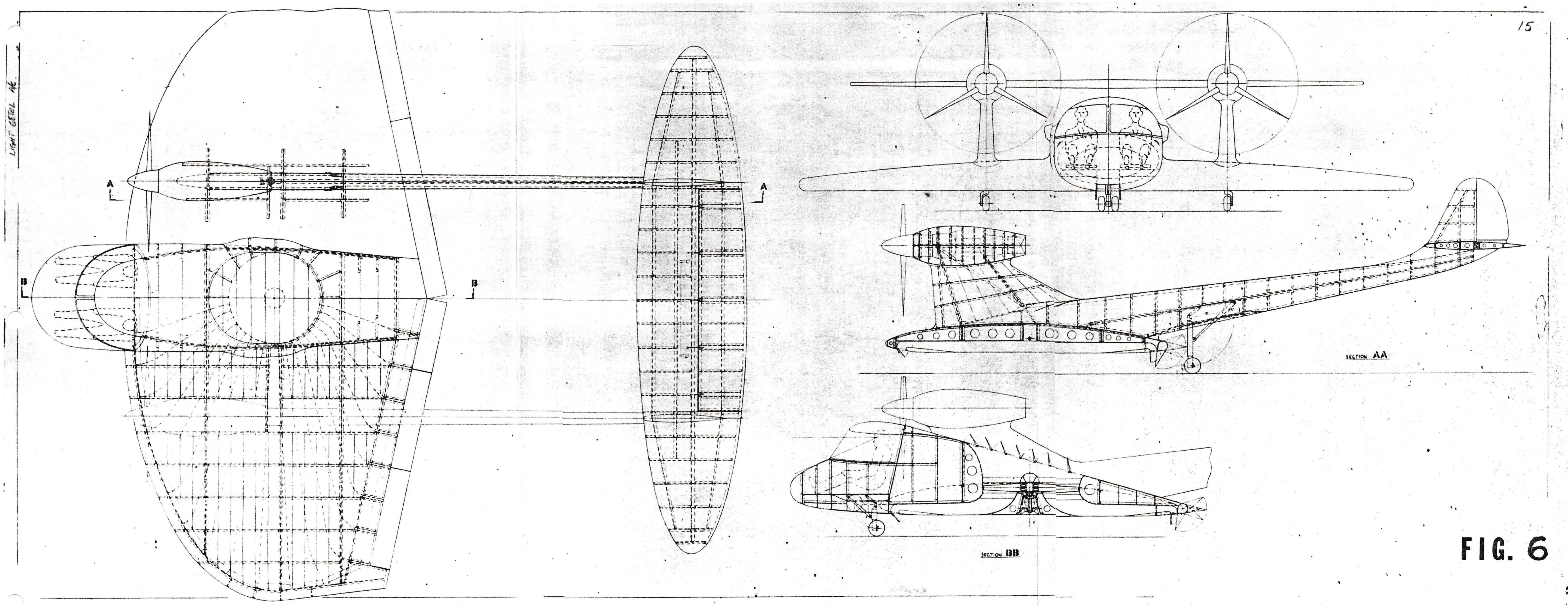


FIG. 6

WEIGHT ESTIMATE (Fig. 6)

COMPONENT	Wt. (lb.)
Structure	2423
Fuselage	1281
Wing	560
Fin and rudder	63
Tailplane	173
Nacelle	217
Pylons	129
Undercarriage	180
Powerplant	2022
Engines, Astazou II	580
Fan	60
Case and stator	70
Gear boxes and shafting	618
Propeller	284
Jet pipes & insulation	12
Ducting	137
Fuel system and tanks	60
Fan clutch (2)	116
Intakes	45
Engine mounts	20
Controls	20
Flying Controls	65
Equipment	480
Weight Empty	5170
Operational Load	1652
Crew	400
Oil	60
Residual fuel	32
Fuel	960
Cargo	200
Gross Weight	6822

V_D = 345 mph

Ultimate load factor = 7

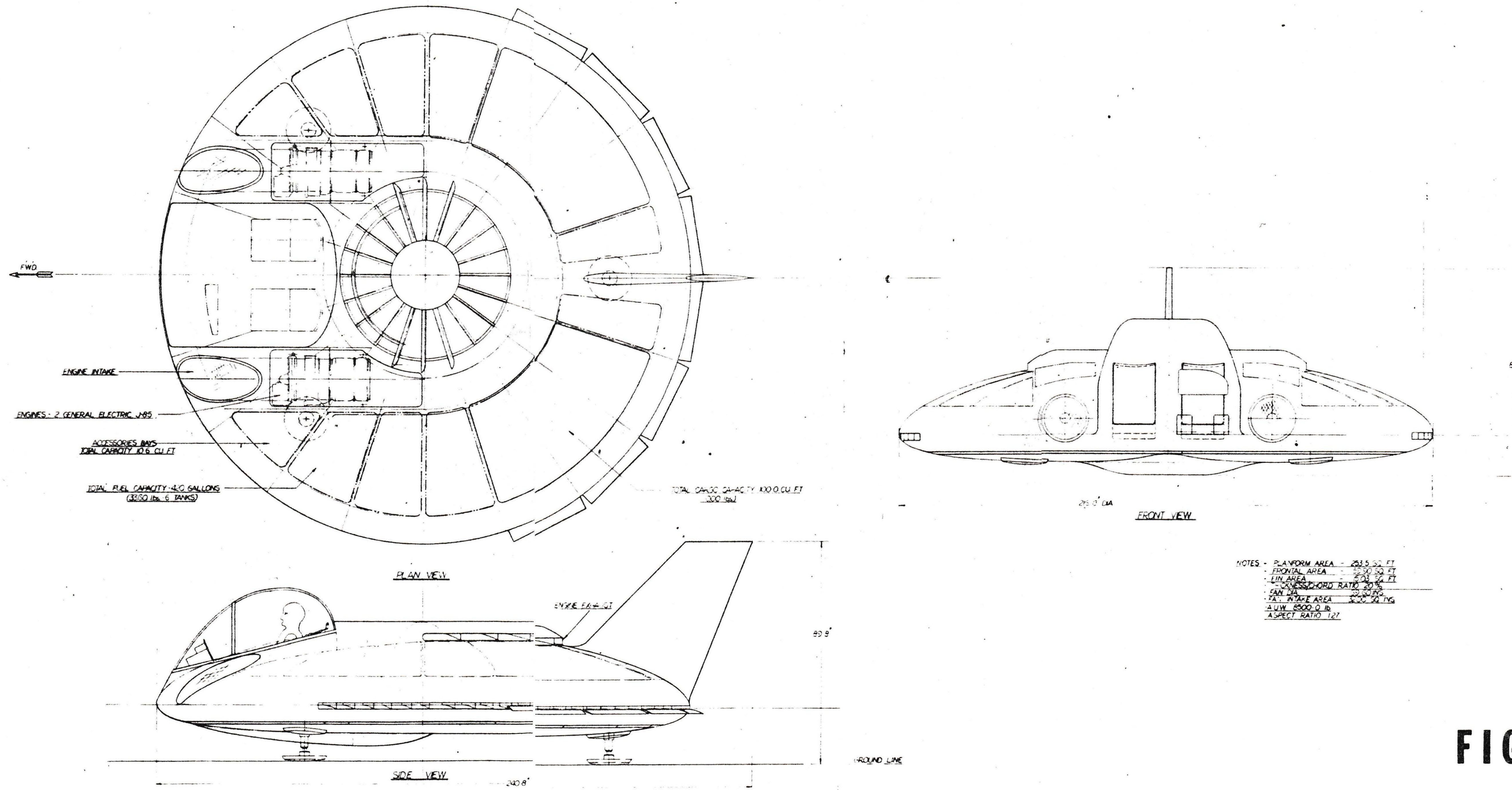

FWD
ENGINE INTAKE
ENGINES - 2 GENERAL ELECTRIC J-85
ACCESSORIES BAYS
TOTAL CAPACITY 10.6 CU FT
TOTAL FUEL CAPACITY 420 GALLONS
(3360 lbs 6 TANKS)
PLAN VIEW
FRONT VIEW
SIDE VIEW
GROUND LINE
NOTES - PLANFORM AREA - 253.5 SQ FT
ASPECT RATIO 127

FIG. 7

WEIGHT ESTIMATE (Fig. 7)

COMPONENT	Wt. (lb.)	H. Arm (in.)
Structure	1051	- 5
Wing	980	3
Fin	71	-100
Undercarriage	60	0
Powerplant	1651	18
Rotor, stator and shroud	621	0
Engines, J85-7	650	41
Engine mounts	22	39
Engine controls	10	64
Fuel system and tanks	115	15
Jet pipes	89	- 20
Exhaust outlet	58	- 29
Firewalls	30	39
Engine intakes	10	83
Fire extinguishers	28	40
Insulation	18	- 29
Flying Controls	234	- 10
Equipment	366	50
Radio and intercom.	35	80
Instruments	26	90
Electrics	218	40
Pneumatics	23	0
Cockpit furnishings	64	65
Weight Empty	3362	12
Useful Load	4832	2
Crew	400	60
Residual fuel	51	10
Rotor oil	9	0
Engine oil	12	50
Fuel	3360	10
Cargo	1000	- 48
Gross Weight	8194	

V_D = 290 knots

Ultimate load factor = 6

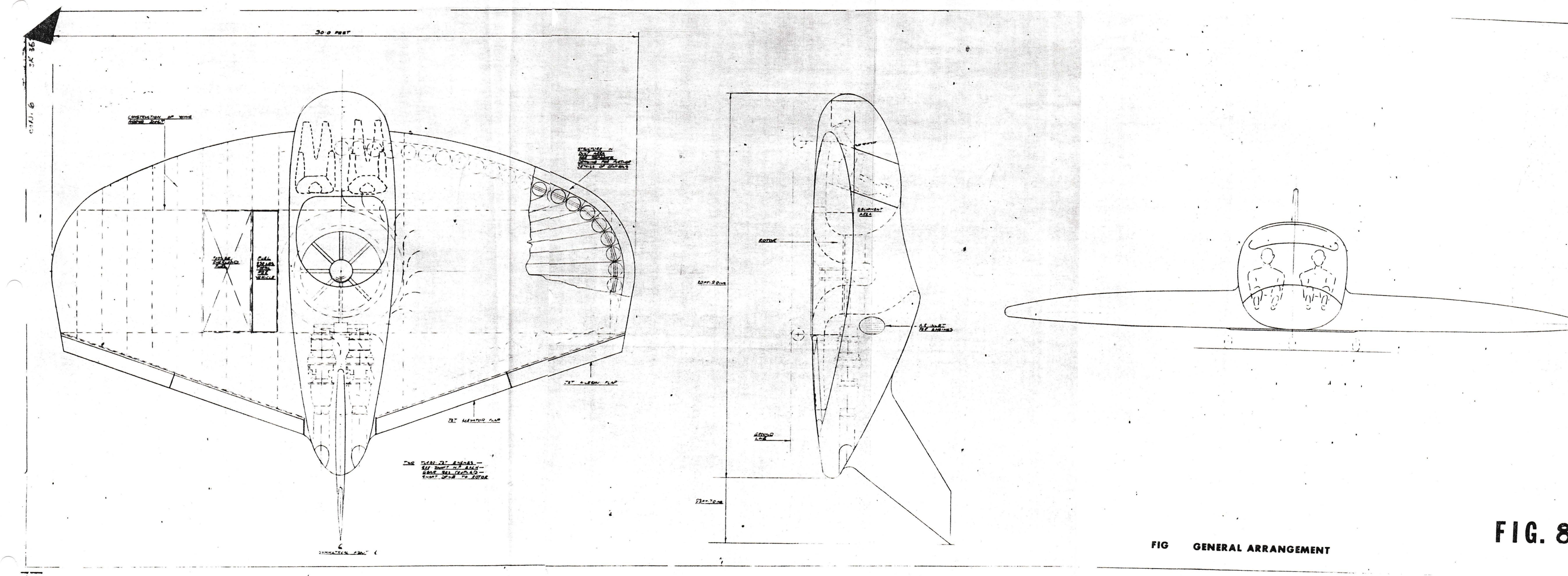


FIG GENERAL ARRANGEMENT

FIG. 8

WEIGHT ESTIMATE (Fig. 8)

COMPONENT	Wt. (lb.)
Structure	919
Wings	461
Fin and rudder	42
Fuselage	416
Undercarriage	50
Powerplant	2124
Engines (2) Astazou II	550
Fan	42
Case and stator	66
Gear box and shaft	177
Jet pipe	16
Insulation	12
Ducting	374
Fuel system and tanks	111
Intakes	30
Engine mounts	20
Engine controls	26
Gyro allowance	700
Flying Controls	130
Equipment	360
Weight Empty	3583
Operational Load	1603
Crew (2)	400
Oil	60
Residual fuel	23
Fuel	920
Cargo	200
Gross Weight	5186

V_D = 250 mph

Ultimate load factor = 7.27

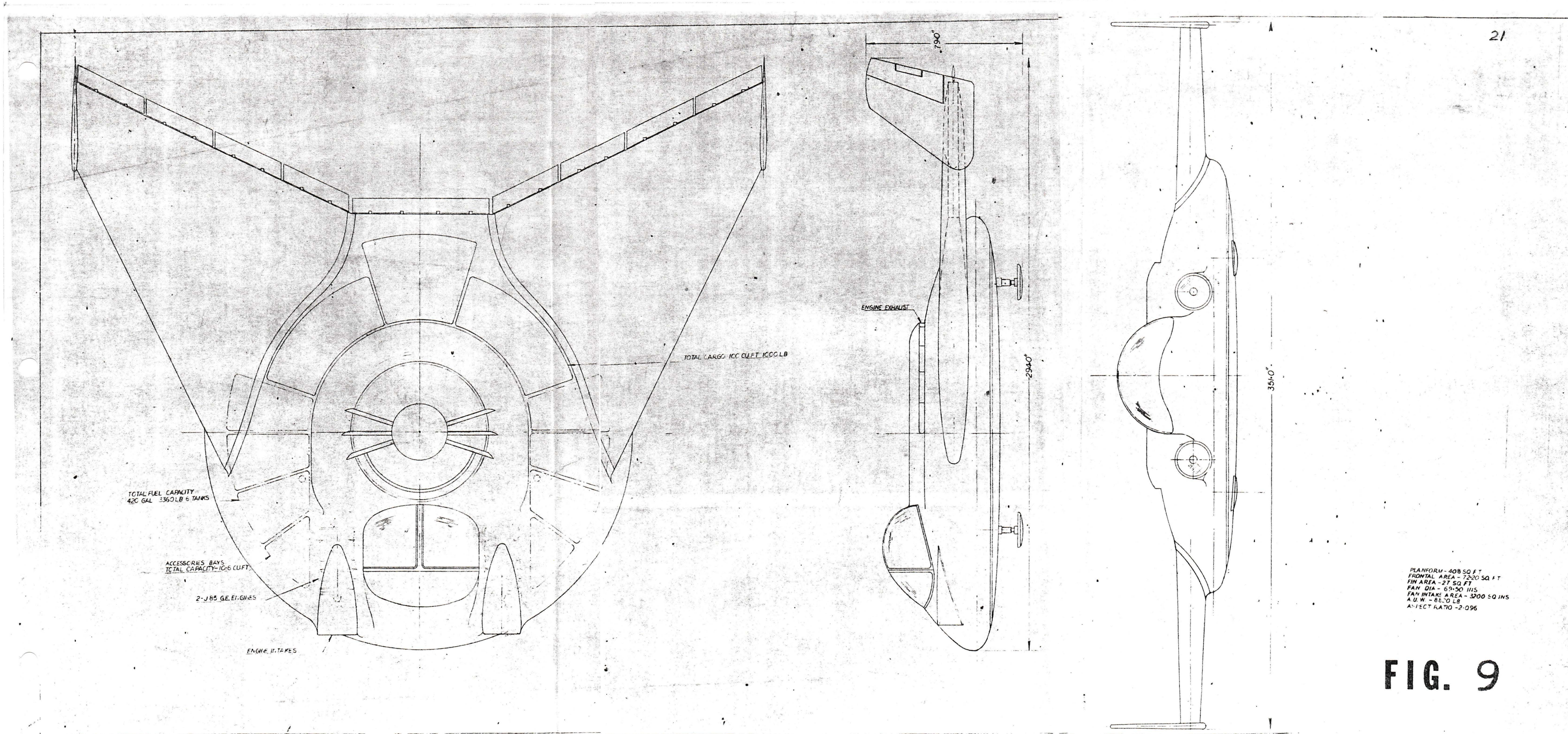

TOTAL CARGO 100 CU.FT 1000 LB
TOTAL FUEL CAPACITY
420 GAL 3360 LB 6 TANKS
ACCESSORIES BAYS
TOTAL CAPACITY - 10·6 CU.FT
2-J85 GE. ENGINES
ENGINE INTAKES
ENGINE EXHAUST
19'0"
29'0"
35'0"
PLANFORM - 408 SQ FT
FRONTAL AREA - 72·20 SQ FT
FIN AREA - 27 SQ FT
FAN DIA - 69·50 INS
FAN INTAKE AREA - 3200 SQ INS
A.U.W. - 8820 LB
ASPECT RATIO - 2·096

FIG. 9

WEIGHT ESTIMATE (Fig. 9)

COMPONENT	Wt. (lb.)
Structure	1643
Wings	413
Fin and rudders	250
Fuselage	980
Undercarriage	60
Powerplant	1651
Rotor, stator and shroud	621
Engines (2) J85-7	650
Engine mounts	22
Engine controls	10
Fuel system and tanks	115
Jet pipes	89
Exhaust outlet	58
Firewalls	30
Engine intakes	10
Fire extinguishers	28
Insulation	18
Flying Controls	234
Equipment	365
Radio and intercom.	35
Instruments	26
Electrics	217
Pneumatics	23
Cockpit furnishings	64
Weight Empty	3953
Useful Load	4831
Crew	400
Residual fuel	50
Rotor oil	9
Engine oil	12
Fuel	3360
Cargo	1000
Gross Weight	8784

V_D = 350 mph

Ultimate load factor = 6

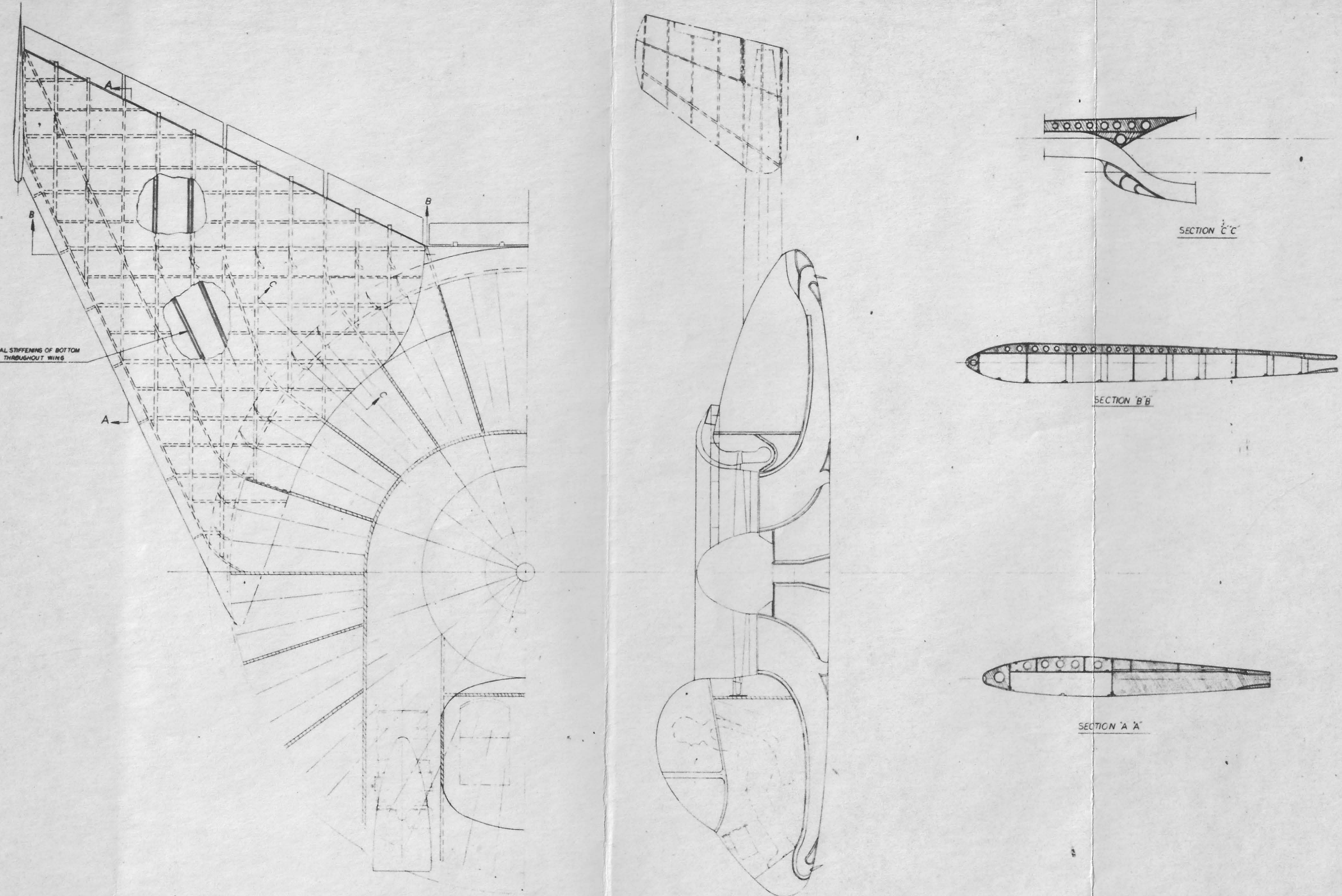

A
B
C
TYPICAL STIFFENING OF BOTTOM SKIN THROUGHOUT WING
SECTION 'C' 'C'
SECTION 'B' 'B'
SECTION 'A' 'A'

FIG. I.6