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CONTROL POWER REQUIREMENTS OF VTOL AIRCRAFT

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DATE: January 1970

TO: NASA
Office of Scientific and
Technical Information
Code US
Washington, D.C. 20546

FROM: Professor Myron A. Hoffman
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SUBJECT: Progress Report on NASA Grant NGR 05-004-051

- (1) The VTOL performance and D.O.C. (direct operating cost) computer program has been modified for the pure jet lift short-haul transports. This new design, based on the proposals of several aerospace companies, has been adopted as our reference vehicle for the VTOL control power studies. In this design concept, the jet lift engines are removed from the fuselage and put in pods attached to the outer portions of the wings. Fig. 1 (taken from Ref. 1)* shows a representative aircraft configuration of this type.
- (2) This vehicle has cruising speed of 520 mph and a maximum range of 600 miles. It is designed for 100 passengers in the VTOL mode and 150 passengers in the STOL mode (400 ft. takeoff field length).
- (3) Three computer runs for this design at three different levels of control power, 15%, 25% and 35% of the required thrust horsepower, are attached. The program printouts include vehicle dimensions, performance, D.O.C. and moments of inertia.
- (4) This reference design will be used in the lateral hover control-power studies now in progress as soon as satisfactory stability derivatives are in hand.

*Ref. 1 A.J.K. Carline, "Design Problems of a Commercial Jet Lift VTOL Transport", USAF Technology and Planning Conference, Las Vegas, Sept. 1969.

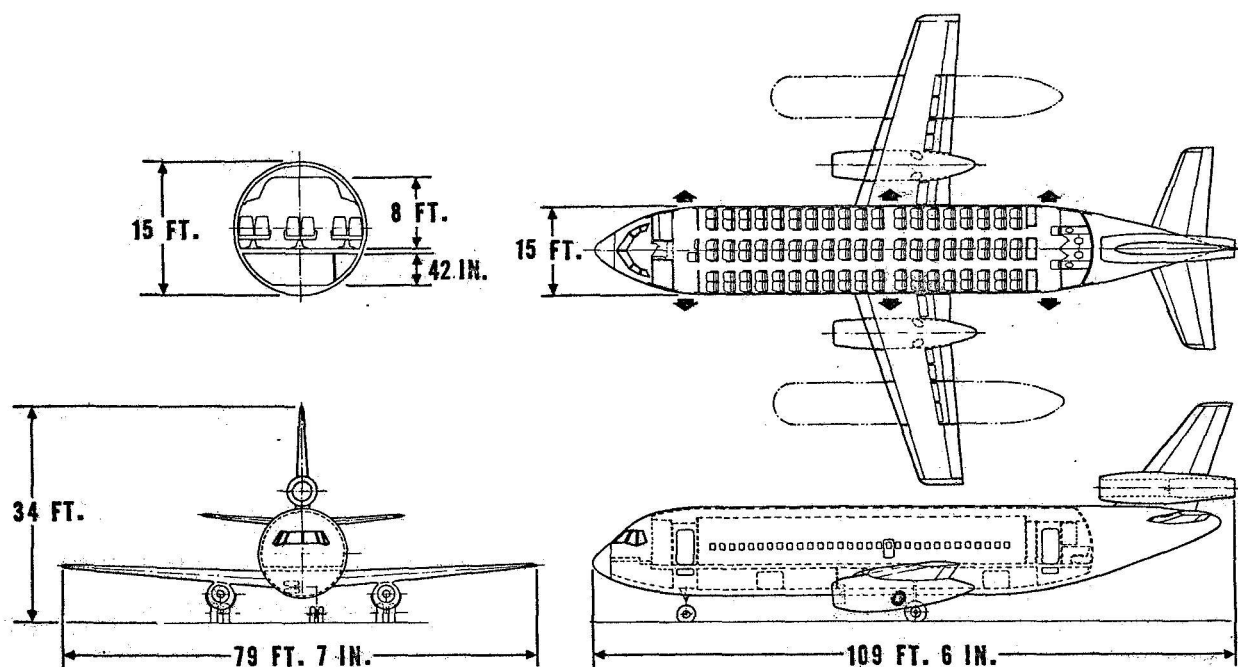
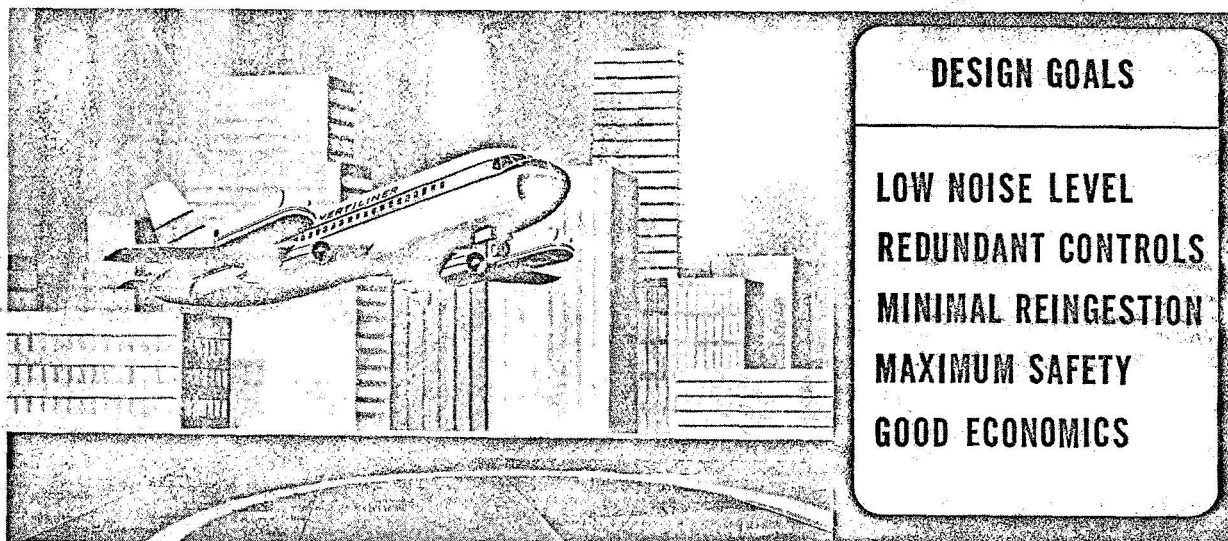
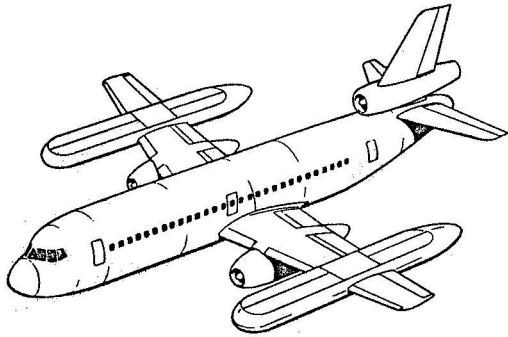
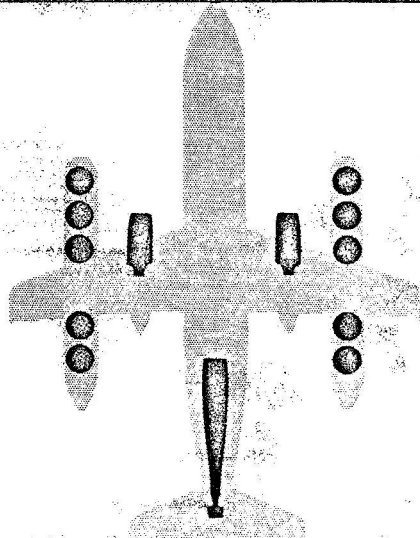


Fig. 1a (Ref. 1)



TAKEOFF WEIGHTS

VERTICAL	GROSS	103,000 LB.
	PAYLOAD	20,000 LB.
400 FT. T.O. FIELD LENGTH	GROSS	108,000 LB.
	PAYLOAD	25,000 LB.
PASSENGER SEATS	114 TO 147	
V CRUISE AT 20,000 FT.	450 KNOTS	
RANGE (MAXIMUM PAYLOAD)	300 S.M.	
MAXIMUM RANGE	600 S.M.	



TYPE	CRUISE	LIFT
NUMBER	3	10
BY-PASS RATIO	3:1	12:1
THRUST/ENGINE	10,000 LB.	14,000 LB.

COMMENTS:

CRUISE ENGINES-DESIGNED FOR SHORT HAUL AND
VECTORED

LIFT ENGINES- SIMPLE FUEL CONTROL-SHORT DURATION-
PARTIAL POWER OPERATION

Fig. 1b (Ref. 1)

DESIGN PROJECT INPUT DATA

PILOT SALARY	35000.00	DOLLARS/YEAR
COPILOT SALARY	21000.00	DOLLARS/YEAR
PILOT AND COPILOT FLIGHT TIME	960.00	HOURS/YEAR
FLEET SIZE	20	AIRCRAFT
PRODUCTION RUN (AIRFRAME)	300	
AVERAGE AIRCRAFT AGE	36.00	MONTHS
DEPRECIATION TIME	12.00	YEARS
TIME BETWEEN OVERHAUL - ENGINES	4000.00	FLIGHT HOURS
VEHICLE UTILIZATION	3000.00	HOURS/YEAR
ENGINE COST	150.00	DOLLARS/LB
ELECTRONIC EQUIPMENT COST	150000.00	DOLLARS
NUMBER OF PASSENGERS (CAPACITY)	150	
PASSENGER LOAD	67	PERCENT
NUMBER OF SEATS ABREAST	6	
NUMBER OF DOORS	2	
NUMBER OF TOILETS	2	
NUMBER OF ISLES	2	
NUMBER OF CREW MEMBERS	3	
NUMBER OF CRUISE ENGINES	3	
NUMBER OF LIFT ENGINES	10	
CRUISE ENGINE DEFLECTOR EFFICIENCY	90	PERCENT
THRUST SPECIFIC FUEL CONSUMPTION		
LIFT ENGINES	0.70	
CRUISE ENGINES	0.55	
THICKNESS TO CHORD RATIO - WING	0.10	
OSWALD WING EFFECT FACTOR	0.80	
AIR DENSITY - SEA LEVEL STANDARD DAY	0.0023769	SLUGS/CU. FT.
AIR TEMPERATURE - SEA LEVEL STANDARD DAY	519.00	DEG. RANKINE
AIR TEMPERATURE - SEA LEVEL HOT DAY	550.00	DEG. RANKINE
KINEMATIC VISCOSITY OF AIR - S.L. HOT DAY	0.00015723	SQ. FT./SEC
STRUCTURAL LOAD FACTOR	4.50	
CRUISE VELOCITY	520.00	MPH
HEAD WIND VELOCITY	0.00	MPH

NOTES

- 1) AIRCRAFT ASSUMED TO BE OPERATING ON A HOT DAY
- 2) TOTAL GROSS WEIGHT INCLUDES FUEL
- 3) LIFT ENGINES ASSUMED TO DELIVER 16.0 LB PER LB
CRUISE ENGINES ASSUMED TO DELIVER 9.2 LB PER LB
- 4) WEIGHT OF RESERVE FUEL NOT CONSIDERED IN DIRECT OPERATING COSTS
- 5) RESERVE TIME NOT CONSIDERED IN TOTAL TIME FOR CALCULATING BLOCK SPEED
- 6) VEHICLE WILL CRUISE AT A LIFT COEFFICIENT OF 0.30
- 7) IN CRUISE VEHICLE MUST FLY AGAINST A HEAD WIND OF 0.0 MPH

REFERENCE DESIGN

AVAILABLE CONTROL POWER = 15.0 PERCENT
OF REQUIRED THRUST HORSEPOWER

COMPONENT WEIGHTS - LBS

FUSELAGE	13729.28
WING	9046.31
EMPENNAGE	2677.42
ENGINES	
LIFT-TEN AT 745. LBS EACH	7446.90
CRUISE-THREE AT 1067. LBS EACH	3200.08
NACELLES PLUS PODS	11242.74
ENGINE OIL	490.00
UNDERCARRIAGE	3212.90
FURNISHINGS	6550.00
AIR CONDITIONING	2450.00
HYDRAULICS	1371.14
ELECTRICAL EQUIPMENT	940.16
ELECTRONIC EQUIPMENT	642.00
FLIGHT CONTROLS	2141.93
FUEL TANKS	918.96
PAYLOAD	20000.01
CREW	600.00
FUEL (WITH RESERVES)	20523.44

TOTAL GROSS WEIGHT	107183.28
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WING DIMENSIONS

SPAN	77.03	FT
MEAN CHORD	12.84	FT
TAPER RATIO	0.25	
MEAN SWEEPBACK ANGLE	30.00	DEG
ASPECT RATIO	6.00	
WING LOADING	108.31	LBS/SQ.FT.
WING AREA	988.84	SQ.FT.
POD LOCATION (PERCENT SPAN FROM C.G.)	33	PERCENT

FUSELAGE DIMENSIONS

TOTAL LENGTH	114.65	FT
OUTSIDE DIAMETER	14.87	FT
INSIDE DIAMETER	14.20	FT
LENGTH OF POD	37.11	FT
NUMBER OF SEATS ABREAST	6	

ENGINE SPECIFICATIONS

NORMAL RATED THRUST PER LIFT ENGINE	11915.04	LBS
NORMAL RATED THRUST PER CRUISE ENGINE	8177.99	LBS

CLIMB PHASE

RATE OF CLIMB	5000.00	FT/MIN
VELOCITY OF CLIMB	441.37	MPH

CRUISE PHASE

LIFT/DRAG	8.81
LIFT COEFFICIENT	0.30
PARASITIC DRAG COEFFICIENT	0.028
INDUCED DRAG COEFFICIENT	0.006

DESCENT PHASE

RATE OF DESCENT	7467.92	FT/MIN
VELOCITY OF DESCENT	515.67	MPH

TABLE OF PERFORMANCE (INCLUDING RESERVE TIME AND FUEL)

PHASE	FUEL-LBS	RANGE-MI	TIME-MIN
STARTUP AND CHECKOUT	968.99	0.00	0.60
VERTICAL ASSENT	193.80	0.00	0.10
ACCELERATION AND TRANSITION	776.17	0.00	0.67
CLIMB	1253.35	26.99	3.70
CRUISE	10690.37	551.72	63.66
DESCENT	1905.77	21.29	2.48
DECELERATION AND RETRANSITION	1158.23	0.00	1.00
VERTICAL DESCENT	218.16	0.00	0.10
RESERVE	3358.60	0.00	20.00
TOTALS	20523.44	600.00	92.31
	POUNDS	MILES	MINUTES

VEHICLE CENTER OF GRAVITY
(AS MEASURED FROM NOSE OF AIRCRAFT
AND LONGITUDINAL AXIS OF FUSELAGE)

XBAR = 44.58 FEET

YBAR = 0.00 FEET

ZBAR = -0.16 FEET

VEHICLE MOMENTS OF INERTIA
(ABOUT AIRCRAFT C.G.)

IXX = 908568. LB-FT-SEC**2

IYY = 2131961. LB-FT-SEC**2

IZZ = 2890561. LB-FT-SEC**2

VEHICLE PRODUCT OF INERTIA
(ABOUT AIRCRAFT C.G.)

JXZ = -41242.70 LB-FT-SEC**2

DIRECT OPERATING COSTS TABLE

STAGE LENGTH (MILES)	50.0	100.0	200.0	400.0	600.0
CRUISE ALTITUDE (FT)	5000.0	10000.0	20000.0	20000.0	20000.0
FUEL BURNED (LBS)	4810.9	7696.0	9949.6	13513.9	17340.6
BLOCK SPEED (MI/HR)	438.6	354.1	431.1	487.5	497.9
FLIGHT OPERATIONS (C/MI)					
PILOT	8.3	10.3	8.5	7.5	7.3
COPILOT	5.0	6.2	5.1	4.5	4.4
FUEL	162.8	130.2	84.2	57.2	48.9
OIL	0.0	0.0	0.0	0.0	0.0
INSURANCE	21.5	25.8	20.6	17.5	16.3
PUBLIC LIABILITY	0.9	0.9	0.9	0.9	0.9
TOTAL	198.6	173.4	119.3	87.5	77.8
DIRECT MAINTENANCE (C/MI)					
LABOR AIRFRAME	24.2	25.3	19.4	15.8	14.3
MATERIAL AIRFRAME	4.9	5.1	3.8	3.1	2.8
LABOR ENGINES	12.6	14.7	11.9	10.4	10.1
MATERIAL ENGINES	10.2	11.8	9.5	8.3	8.1
TOTAL	51.9	56.9	44.6	37.6	35.4
MAINTENANCE BURDEN (C/MI)	66.2	72.0	56.3	47.1	44.0
DEPRECIATION (C/MI)					
AIRFRAME	28.4	33.6	26.6	22.2	20.3
ENGINES	8.9	11.1	9.1	8.0	7.9
ELECTRONICS	2.3	2.8	2.3	2.1	2.0
AIRFRAME SPARES	2.8	3.4	2.7	2.2	2.0
ENGINE SPARES	6.7	8.3	6.8	6.0	5.9
TOTAL	49.1	59.2	47.5	40.5	38.1
TOTAL D.O.C. (C/MI)	299.6	289.5	211.4	165.6	151.2
(\$/BLOCK HR)	1314.0	1025.0	911.3	807.3	752.9
(C/AVE SEAT MI)	2.5	2.4	1.8	1.4	1.3

TOTAL COST OF AIRCRAFT = 6.08 MILLION

REFERENCE DESIGN

AVAILABLE CONTROL POWER = 25.0 PERCENT
OF REQUIRED THRUST HORSEPOWER

COMPONENT WEIGHTS - LBS

FUSELAGE	13814.49
WING	9485.76
EMPENNAGE	2790.16
ENGINES	
LIFT-TEN AT 854. LBS EACH	8537.07
CRUISE-THREE AT 1090. LBS EACH	3270.90
NACELLES PLUS PODS	12490.94
ENGINE OIL	490.00
UNDERCARRIAGE	3348.19
FURNISHINGS	6550.00
AIR CONDITIONING	2450.00
HYDRAULICS	1445.48
ELECTRICAL EQUIPMENT	961.73
ELECTRONIC EQUIPMENT	642.00
FLIGHT CONTROLS	2232.13
FUEL TANKS	966.61
PAYLOAD	20000.01
CREW	600.00
FUEL (WITH RESERVES)	21587.73

TOTAL GROSS WEIGHT	111663.21
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WING DIMENSIONS

SPAN	78.63	FT
MEAN CHORD	13.11	FT
TAPER RATIO	0.25	
MEAN SWEEPBACK ANGLE	30.00	DEG
ASPECT RATIO	6.00	
WING LOADING	108.31	LBS/SQ.FT.
WING AREA	1030.48	SQ.FT.
POD LOCATION (PERCENT SPAN FROM C.G.)	33	PERCENT

FUSELAGE DIMENSIONS

TOTAL LENGTH	114.65	FT
OUTSIDE DIAMETER	14.87	FT
INSIDE DIAMETER	14.20	FT
LENGTH OF POD	39.10	FT
NUMBER OF SEATS ABREAST	6	

ENGINE SPECIFICATIONS

NORMAL RATED THRUST PER LIFT ENGINE	13659.31	LBS
NORMAL RATED THRUST PER CRUISE ENGINE	8358.98	LBS

CLIMB PHASE

RATE OF CLIMB	5000.00	FT/MIN
VELOCITY OF CLIMB	441.37	MPH

CRUISE PHASE

LIFT/DRAG	8.98
LIFT COEFFICIENT	0.30
PARASITIC DRAG COEFFICIENT	0.027
INDUCED DRAG COEFFICIENT	0.006

DESCENT PHASE

RATE OF DESCENT	7310.49	FT/MIN
VELOCITY OF DESCENT	515.67	MPH

TABLE OF PERFORMANCE (INCLUDING RESERVE TIME AND FUEL)

PHASE	FUEL-LBS	RANGE-MI	TIME-MIN
STARTUP AND CHECKOUT	1094.07	0.00	0.60
VERTICAL ASSENT	218.81	0.00	0.10
ACCELERATION AND TRANSITION	868.48	0.00	0.67
CLIMB	1293.36	26.99	3.70
CRUISE	10917.87	551.26	63.61
DESCENT	2218.36	21.75	2.53
DECELERATION AND RETRANSITION	1295.98	0.00	1.00
VERTICAL DESCENT	247.87	0.00	0.10
RESERVE	3432.92	0.00	20.00
TOTALS	21587.73	600.00	92.31
	POUNDS	MILES	MINUTES

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VEHICLE CENTER OF GRAVITY
(AS MEASURED FROM NOSE OF AIRCRAFT
AND LONGITUDINAL AXIS OF FUSELAGE)

XBAR = 44.31 FEET

YBAR = 0.00 FEET

ZBAR = -0.16 FEET

VEHICLE MOMENTS OF INERTIA
(ABOUT AIRCRAFT C.G.)

IXX = 1019446. LB-FT-SEC**2

IYY = 2192047. LB-FT-SEC**2

IZZ = 3043937. LB-FT-SEC**2

VEHICLE PRODUCT OF INERTIA
(ABOUT AIRCRAFT C.G.)

JXZ = -43294.80 LB-FT-SEC**2

DIRECT OPERATING COSTS TABLE

STAGE LENGTH (MILES)	50.0	100.0	200.0	400.0	600.0
CRUISE ALTITUDE (FT)	5000.0	10000.0	20000.0	20000.0	20000.0
FUEL BURNED (LBS)	5328.5	8386.6	10795.9	14434.4	18338.6
BLOCK SPEED (MI/HR)	438.6	354.1	431.1	487.5	497.9

FLIGHT OPERATIONS (C/MI)

PILOT	8.3	10.3	8.5	7.5	7.3
COPILOT	5.0	6.2	5.1	4.5	4.4
FUEL	180.3	141.9	91.4	61.1	51.7
OIL	0.0	0.0	0.0	0.0	0.0
INSURANCE	22.8	27.3	21.8	18.5	17.3
PUBLIC LIABILITY	0.9	0.9	0.9	0.9	0.9
TOTAL	217.3	186.6	127.6	92.4	81.6

DIRECT MAINTENANCE (C/MI)

LABOR AIRFRAME	25.1	26.2	20.1	16.3	14.9
MATERIAL AIRFRAME	5.1	5.2	4.0	3.2	2.9
LABOR ENGINES	13.2	15.4	12.4	10.9	10.6
MATERIAL ENGINES	11.3	13.1	10.6	9.2	9.0
TOTAL	54.7	60.0	47.0	39.7	37.3

MAINTANENCE BURDEN (C/MI)

	68.9	74.9	58.5	49.0	45.8
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DEPRECIATION (C/MI)

AIRFRAME	29.5	34.9	27.6	23.0	21.0
ENGINES	10.0	12.4	10.2	9.0	8.8
ELECTRONICS	2.3	2.8	2.3	2.1	2.0
AIRFRAME SPARES	2.9	3.5	2.8	2.3	2.1
ENGINE SPARES	7.5	9.3	7.7	6.8	6.6
TOTAL	52.2	62.9	50.5	43.1	40.6

TOTAL D.O.C. (C/MI)

	324.2	309.5	225.1	175.2	159.5
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(\$/BLOCK HR)

	1422.1	1095.7	970.5	854.1	794.3
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(C/AVE SEAT MI)

	2.7	2.6	1.9	1.5	1.3
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TOTAL COST OF AIRCRAFT =6.45 MILLION

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REFERENCE DESIGN

AVAILABLE CONTROL POWER = 35.0 PERCENT
OF REQUIRED THRUST HORSEPOWER

COMPONENT WEIGHTS - LBS

FUSELAGE	13902.38
WING	9958.36
EMPENNAGE	2910.66
ENGINES	
LIFT-TEN AT 972. LBS EACH	9715.58
CRUISE-THREE AT 1115. LBS EACH	3346.44
NACELLES PLUS PODS	13839.27
ENGINE OIL	490.00
UNDERCARRIAGE	3492.79
FURNISHINGS	6550.00
AIR CONDITIONING	2450.00
HYDRAULICS	1525.86
ELECTRICAL EQUIPMENT	984.36
ELECTRONIC EQUIPMENT	642.00
FLIGHT CONTROLS	2328.53
FUEL TANKS	1018.35
PAYLOAD	20000.01
CREW	600.00
FUEL (WITH RESERVES)	22743.18

TOTAL GROSS WEIGHT	116497.77
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WING DIMENSIONS

SPAN	80.31	FT
MEAN CHORD	13.39	FT
TAPER RATIO	0.25	
MEAN SWEEPBACK ANGLE	30.00	DEG
ASPECT RATIO	6.00	
WING LOADING	108.31	LBS/SQ.FT.
WING AREA	1074.98	SQ.FT.
POD LOCATION (PERCENT SPAN FROM C.G.)	33	PERCENT

FUSELAGE DIMENSIONS

TOTAL LENGTH	114.65	FT
OUTSIDE DIAMETER	14.87	FT
INSIDE DIAMETER	14.20	FT
LENGTH OF POD	41.11	FT
NUMBER OF SEATS ABREAST	6	

ENGINE SPECIFICATIONS

NORMAL RATED THRUST PER LIFT ENGINE	15544.93	LBS
NORMAL RATED THRUST PER CRUISE ENGINE	8552.01	LBS

CLIMB PHASE

RATE OF CLIMB	5000.00	FT/MIN
VELOCITY OF CLIMB	441.37	MPH

CRUISE PHASE

LIFT/DRAG	9.16
LIFT COEFFICIENT	0.30
PARASITIC DRAG COEFFICIENT	0.027
INDUCED DRAG COEFFICIENT	0.006

DESCENT PHASE

RATE OF DESCENT	7155.30	FT/MIN
VELOCITY OF DESCENT	515.67	MPH

TABLE OF PERFORMANCE (INCLUDING RESERVE TIME AND FUEL)

PHASE	FUEL-LBS	RANGE-MI	TIME-MIN
STARTUP AND CHECKOUT	1229.25	0.00	0.60
VERTICAL ASSENT	245.85	0.00	0.10
ACCELERATION AND TRANSITION	968.22	0.00	0.67
CLIMB	1336.08	26.99	3.70
CRUISE	11160.44	550.79	63.55
DESCENT	2566.37	22.22	2.59
DECELERATION AND RETRANSITION	1444.81	0.00	1.00
VERTICAL DESCENT	279.97	0.00	0.10
RESERVE	3512.20	0.00	20.00
TOTALS	22743.18	600.00	92.31
	POUNDS	MILES	MINUTES

VEHICLE CENTER OF GRAVITY
(AS MEASURED FROM NOSE OF AIRCRAFT
AND LONGITUDINAL AXIS OF FUSELAGE)

XBAR = 44.03 FEET

YBAR = 0.00 FEET

ZBAR = -0.16 FEET

VEHICLE MOMENTS OF INERTIA
(ABOUT AIRCRAFT C.G.)

IXX = 1144035. LB-FT-SEC**2

IYY = 2257473. LB-FT-SEC**2

IZZ = 3213350. LB-FT-SEC**2

VEHICLE PRODUCT OF INERTIA
(ABOUT AIRCRAFT C.G.)

JXZ = -45433.38 LB-FT-SEC**2

DIRECT OPERATING COSTS TABLE

STAGE LENGTH (MILES)	50.0	100.0	200.0	400.0	600.0
CRUISE ALTITUDE (FT)	5000.0	10000.0	20000.0	20000.0	20000.0
FUEL BURNED (LBS)	5890.8	9139.2	11720.3	15437.5	19424.3
BLOCK SPEED (MI/HR)	438.6	354.1	431.1	487.5	497.9

FLIGHT OPERATIONS (C/MI)

PILOT	8.3	10.3	8.5	7.5	7.3
COPILOT	5.0	6.2	5.1	4.5	4.4
FUEL	199.4	154.7	99.2	65.3	54.8
OIL	0.0	0.0	0.0	0.0	0.0
INSURANCE	24.1	28.9	23.1	19.6	18.3
PUBLIC LIABILITY	0.9	0.9	0.9	0.9	0.9
TOTAL	237.7	200.9	136.7	97.8	85.7

DIRECT MAINTENANCE (C/MI)

LABOR AIRFRAME	26.0	27.2	20.8	16.9	15.4
MATERIAL AIRFRAME	5.3	5.4	4.1	3.3	3.0
LABOR ENGINES	13.9	16.1	13.0	11.4	11.1
MATERIAL ENGINES	12.5	14.5	11.7	10.2	9.9
TOTAL	57.7	63.3	49.6	41.9	39.5

MAINTANENCE BURDEN (C/MI)

71.8	78.0	60.8	51.0	47.7
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DEPRECIATION (C/MI)

AIRFRAME	30.6	36.2	28.6	23.9	21.9
ENGINES	11.2	13.9	11.4	10.1	9.9
ELECTRONICS	2.3	2.8	2.3	2.1	2.0
AIRFRAME SPARES	3.1	3.6	2.9	2.4	2.2
ENGINE SPARES	8.4	10.4	8.6	7.6	7.4
TOTAL	55.6	67.0	53.8	46.0	43.3

TOTAL D.O.C. (C/MI)

350.9	331.1	240.0	185.6	168.5
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(\$/BLOCK HR)

1539.3	1172.4	1034.7	904.7	839.1
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(C/AVE SEAT MI)

2.9	2.8	2.0	1.5	1.4
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TOTAL COST OF AIRCRAFT =6.84 MILLION