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AIRPLANES USING CONVENTIONAL OR CRYOGENIC
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By

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SUMMARY

An analytical study has been conducted to evaluate the potential endurance of high-altitude airplanes operating as platforms for observation or communications-relay missions. These remotely piloted, propeller-driven configurations were designed with levels of technology assumed to be available in 1990. The turbine engines used either liquid hydrogen, liquid methane, or JP-7 fuel. Endurance was measured as the time spent between 60,000 feet and an engine-limited maximum altitude of 70,000 feet. Performance was calculated for a baseline vehicle and for configurations derived by varying aerodynamic, structural or propulsion parameters. Takeoff gross weight was constrained to be 3000 pounds. The computer program used in this study is documented in the Appendix.

Endurance is maximized by reducing wing loading and engine size. The level of maximum endurance for a given wing loading is virtually the same for all three fuels. Constraints due to winds aloft and propulsion system scaling produce maximum endurance values of 71 hours for JP-7 fuel, 70 hours for liquid methane, and 65 hours for liquid hydrogen. Endurance is shown to be strongly effected by structural-weight fraction, specific fuel consumption, and fuel load.

INTRODUCTION

Results from satellites and aircraft have already demonstrated the value of conducting communications-relay or observation tasks from high altitudes. Aircraft, such as the U-2, can provide several hours of continuous local coverage. The potential for greater endurance lies with remotely piloted aircraft that do not have to accommodate the needs of an on-board crew. Even further increases in endurance may be possible with the development of remotely powered systems (using photovoltaic cells or microwave-energy transmission) that can provide adequate levels of power.

Two programs for high-altitude, long-endurance, remotely piloted aircraft had progressed to the flight-demonstration phase by the 1970's (ref. 1). The Compass Dwell program was initiated in the late 1960's; it produced two vehicles that resembled propeller-driven sailplanes. One configuration, which had a piston engine, demonstrated endurance greater than 28 hours; however, it could not reach its desired operational altitude. The turboprop configuration reached 51,000 feet and had a cruise endurance of about 22 hours (ref. 2). Requirements for a higher cruise altitude and longer endurance terminated this program and led to the Compass Cope configurations. One of these two high-aspect-ratio, jet-powered vehicles reached an altitude of over 55,000 feet and achieved a total flight time of more than 24 hours.

The purpose of this study is to determine the potential performance of low-speed, high-altitude, remotely piloted vehicles developed with 1990-level technology. The basic design objective is to maximize flight time (cruise endurance) above 60,000 feet altitude. The baseline configuration is a glider-type airplane powered by a turboprop engine modified for high-altitude conditions. Liquid hydrogen, liquid methane, and JP-7 are each considered as fuel. Parametric analyses are used to show the effects of variations in aerodynamic, propulsion-system, and structural characteristics. Calculated performance is also used to define the limits of attainable cruise altitude and endurance. All calculations were performed with a computer program that is documented in the Appendix.

SYMBOLS

A	wing aspect ratio
$C_{D,o}$	profile-drag coefficient
C_L	vehicle lift coefficient
e	Oswald efficiency factor
P	power, hp
S	wing area, ft ²
W	weight, lbf
η_p	propeller efficiency

Abbreviations:

OWE	operating weight empty
sfc	specific fuel consumption, lbf/hp-hr
TOGW	takeoff gross weight

CONCEPT DESCRIPTION

Mission

The primary mission requires the vehicle to fly at altitudes between 60,000 and 70,000 feet for as long as possible. The minimum altitude reflects the need to obtain suitable range for observations or relay transmission as well as to remain above almost all air traffic. The maximum altitude results from estimated constraints on the engine operating envelope.

Baseline Vehicle

The baseline vehicle is a turboprop-powered configuration similar to conventional, motorized gliders. The vehicle description given in Table I is sufficiently general to apply to a variety of configurations. Two possible designs are suggested in figure 1. In each case, a single engine and the total fuel system are located within the fuselage. The detailed design of any such configuration can be expected to emphasize some conservatism and simplicity because of the need for a high level of reliability. A 200-pound payload is carried by all configurations.

Aerodynamic characteristics. - The baseline vehicle has aerodynamic performance that is at least comparable to conventional motorized gliders with non-retractable propulsion systems. The wing airfoil sections must operate at Reynolds numbers as low as 500,000 and at lift coefficients of .8 to 1.3. References 3, 4, and 5 show that some airfoils can meet these requirements and maintain constant, low profile drag over the required range of lift coefficient. The aspect-ratio 20 wing is conceived of as having an unswept leading edge and other features to enhance the conditions for laminar flow.

Propulsion system. - The engines of this study represent advanced conventional designs capable of operation at high altitude. The calculated engine performance reflects component performance anticipated for small engines by 1990 (ref. 6 and 7). Characteristics of the fuels (JP-7, liquid methane (CH₄), and liquid hydrogen (H₂)) and their associated tank and fuel-systems characteristics are given in Table II. The basic JP fuel selected is a high-thermal-stability, low-aromatic, high-flash-point kerosene. A judicious selection of blending stocks is required to maintain low viscosity and high volatility to assure the cold-soak operational capability for this fuel at high altitude. The basic turboshaft engine incorporates a multi-stage compressor driven by a single-stage turbine and a single-stage free turbine driving the output shaft through planetary reduction gears.

The calculated engine performance is described in figure 2 as a function of altitude for various power settings. The engines are designed to maintain an output of constant horsepower versus altitude (flat rated) up to an altitude of 10,000 feet. Flat rating allows a better horsepower match for the aircraft because of the inherent excess of available horsepower during low-speed, low-altitude operation of a turboprop engine. Specific fuel consumption is calculated as a function of horsepower and fuel flow.

The use of a cryogenic liquid fuel, such as methane or hydrogen, warrants design changes to the fuel systems, combustors, turbines, and cooling requirements. The fuel flow for either cryogenic fuel is obtained from figure 2(b) by using a ratio of the respective fuel heating values (ref. 8 and 9) to that of the basic JP-7 fuel. Shaft horsepower values for the cryogenic fuel have no adjustments for variations in fuel mass density or cooling flows. No component rematching nor engine weight changes are made as a result of fuel changes.

A constant-speed, variable-pitch propeller is assumed to operate at $\eta_p = 0.8$ at all altitudes. Such a propeller would be optimized for the low Reynolds-number environment at high altitude.

Fuel tank. - Fuel tank characteristics were defined after a separate study was conducted to determine the combined effects of tank weight, insulation characteristics, and operating pressure on vehicle endurance. The fuel tank for cryogenic fuels is

assumed to be an aluminum cylinder with hemispherical ends. The ratio of total length to diameter remains at a value of five. The tanks are maintained at a differential pressure of 50 lbf/in² by allowing fuel to vaporize and vent. The cryogenic tanks are surrounded by foam insulation (six inches for liquid hydrogen and three inches for liquid methane) which has thermal conductivity of 0.00867 Btu-ft/hr-F⁰-ft² and density of 2.3 lb/ft³. Heat transfer is assumed to occur only due to conduction from air at local ambient temperature through the wetted area of the tank (ref. 10).

Structural weight. - A simple set of structural weight parameters was chosen to represent a vehicle built with advanced fabrication methods and materials. The data of figure 3 are taken from references 11 to 13. This indicates that current motor-glider require about 50 percent of takeoff gross weight for structure. A weight fraction of less than 40 percent should be attainable if advanced materials and design features, such as lifting struts, are used in combination with reductions in design load factors (appropriate for unmanned, moderately flexible airplanes). Forty percent of takeoff gross weight was therefore allowed for structural and systems weights

Flight Profile

The vehicle flight profile consists of three segments, each flown at constant lift coefficient and constant power setting (Table I). This procedure reflects the concern for simplicity appropriate for this class of remotely piloted vehicles. The first segment is a climb from sea level to 40,000 feet altitude with a lift coefficient of 0.8 and with the engine operating at 25 percent of the maximum power available. The low power setting and the engine power-lapse with altitude combine to give adequate climb power at airspeeds that avoid dynamic-pressure limits for the structure. At 40,000 feet, the power is advanced to 100 percent, and the lift coefficient is changed to 1.0 until the rate of climb is zero. If the vehicle cannot climb to 60,000 feet in this configuration, the calculations are terminated. If zero climb rate is reached above that altitude, then vehicle lift coefficient is then changed to 1.2 and the power setting is adjusted to achieve trimmed, equilibrium flight. The vehicle continues in a simple cruise-climb mode unless it reaches 70,000 feet. At that point, the power setting is retarded to maintain 70,000 feet.

DISCUSSION OF RESULTS

All performance values presented herein were obtained with the computer program given in the Appendix. Flights terminated when the fuel was totally exhausted. This procedure provided a consistent, though extreme, point of comparison. Insufficient data exist to validate the present analysis with experimental flight tests.

Baseline Configuration and Nominal Flight Profile

The calculated performance of the baseline configuration, with either JP-7, liquid methane, or liquid hydrogen as fuel, is described by the sample program output in the Appendix and by computed results presented in Table III and figure 4. These flights include climb from sea level to the initial altitude for cruise-climb and then cruise to the point of fuel exhaustion.

Characteristics of the flight profiles from sea level to 60,000 feet are shown in figure 4 for the baseline configurations using each of the three fuels. At 60,000 feet the vehicle fueled with liquid hydrogen has the greatest percentage of remaining fuel for cruise. This fact and the greater weight of the liquid-hydrogen tank give that vehicle the heaviest wing loading at the start of cruise-climb flight.

As indicated in Table III, the cruise performance for the three fuels is remarkably similar. In each case endurance is about 43 hours and still-air range is about 6400 nautical miles. The greatest relative difference is in final altitude. The JP-7 fueled vehicle reaches 70,000 feet and has the lowest weight at fuel exhaustion; the liquid-hydrogen fueled configuration is limited to about 65,000 feet because of its significantly heavier fuel tank. The performance of the hydrogen-fueled vehicle is also affected by the loss of about 24 percent of the initial fuel load due to boil-off during the flight. (The fuel system design was developed to maximize endurance based on the effects of boil-off and the weight and complexity of tank insulation and pressurization.) Boil-off for the liquid methane is negligible.

Balloon-Assisted Launch

A slight advantage in endurance and range may be possible if the vehicle is launched from a balloon. The data of figure 5 is optimistic because fuel boil-off below the launch altitude is not considered. This could be large in the case of a lengthy balloon ascent with cryogenic hydrogen in the fuel tanks.

Power Loading and Wing Loading

Variations on the baseline configuration were considered in terms of simple variations in the relative engine size and wing size at constant vehicle weight. The baseline vehicle has a wing loading of 8 lbf/ft² and a power loading of 0.22 hp/lbf. Variations in engine size produce variations in power loading with consequent changes in engine and fuel weight. Changes in wing loading do not effect the structural-weight fraction; allowable load factor is therefore affected in an undefined manner. The resulting configurations are all considered to be individual designs rather than just modifications to the baseline vehicle. Extreme combinations of power loading and wing loading may not represent reasonable design points but can be used to define trends. All vehicles have the aerodynamic and structural characteristics of the baseline configuration and use the baseline schedule of throttle and lift-coefficient settings.

Each of the next three figures (figs. 6, 7, and 8) shows the effect of wing loading and power loading on performance for one of the fuels. In each figure, endurance increases with decreases in wing or power loading. For a given power loading, there are associated limits on wing loading that define the end points of the data curves. If wing loading is too high, the vehicle cannot meet the criteria of initiating cruise-climb at or above 60,000 feet. If wing loading is too low, the minimum throttle setting produces too much power at low altitudes. This, in turn, leads to airspeeds in excess of estimated structural limits.

Maximum endurance boundaries for configurations using the three fuels are presented in figure 9. They show that maximum endurance decreases with increased wing loading. These boundaries are all produced by the criterion requiring cruise-climb initiation at or above 60,000 feet. (The endurance limits would be increased if the criterion were relaxed.) Results show that vehicles using either JP-7 fuel or liquid methane can be designed to reach the same endurance limits. Configurations fueled with liquid hydrogen can be designed to have only slightly better values of

endurance at wing loadings above 7 lbf/ft². Based on considerations of the assumptions and analytical accuracy, the maximum endurance limits are virtually the same for all three fuels.

The effects of winds and other factors limit the combinations of power loading and wing loading that can be considered to be practical. The constant-endurance curves of figure 10 are intersected by several limiting lines. If reliability considerations dictate a single engine design, the limits of engine scaling produce power-loading limits of about 0.16 to 0.27 hp/lbf. The headwind limit is associated with the cruise airspeed of the vehicle. Data from reference 14 define values of windspeeds that are exceeded less than one percent of the time over the contiguous United States. At 60,000 feet, that windspeed is about 30 knots equivalent airspeed; at 70,000 feet, it is about 20 knots equivalent airspeed. During cruise, wing loading is reduced as fuel is consumed. The constant lift coefficient results in a reduction in airspeed for trimmed flight. The headwind limit on figure 10 denotes configurations that could not maintain station against these headwinds. Increasing vehicle airspeed by decreasing lift coefficient would move this boundary to lower values of takeoff wing loading. The requirement to maintain any given groundspeed against these headwinds (in order to change station) would result in a boundary at significantly higher values of takeoff wing loading.

Based on estimated wind and propulsion limits, maximum endurance for any fuel is achieved at the lowest allowable values of engine size (i.e., power loading) and wing loading. A lower limit for power loading of about 0.16 hp/lbf results from engine scaling considerations. At that limit, the maximum endurance values are approximately 71 hours for JP-7, 70 hours for liquid methane, and 65 hours for liquid hydrogen. The baseline configuration is conservatively designed and, consequently, has lower endurance (43 hours).

Parameter Sensitivity Studies

The relative significance of changes in the configuration is illustrated in figures 11 and 12. The computed results for JP-7 fueled vehicles in figure 11 indicate that the greatest improvements in endurance are achieved with decreases in structural weight fraction, decreases in specific fuel consumption, and increases in fuel-load. Most aerodynamic-performance parameters, such as cruise lift coefficient or profile-drag coefficient appear to have comparatively small effects. The more significant sensitivities for vehicles using JP-7 and cryogenic fuels are compared in figure 12. They indicate that the sensitivity trends are virtually the same, regardless of fuel type.

CONCLUSIONS

An analytical study has been conducted to evaluate the potential endurance of remotely piloted, low-speed, high-altitude, long-endurance airplanes designed with 1990 technology. The baseline configuration was propeller-driven, sailplane-like airplane powered by turbine engines that used JP-7, liquid methane, or liquid hydrogen as fuel. Endurance was measured from the time at which the vehicle reached 60,000 feet of altitude. Engine constraints were presumed to limit all configurations to 70,000 feet. Vehicle takeoff gross weight was constrained to be 3000 pounds. The results can be summarized as follows:

1. When engine size is adjusted to maximize endurance for a given wing loading, maximum endurance limits are virtually the same for all three fuels.
2. Sensitivity studies with the baseline configuration show that the three best ways to increase endurance are to reduce structural weight, to reduce specific fuel consumption, and to increase fuel load.
3. Maximum endurance is achieved by minimizing both engine size and wing loading. Constraints due to winds aloft and propulsion system scaling result in maximum endurance values of approximately 71 hours for JP-7 fuel, 70 hours for liquid methane, and 65 hours for liquid hydrogen.

APPENDIX - COMPUTER PROGRAM FOR PERFORMANCE CALCULATION

The computer program used in this paper is documented in this appendix. A listing of the program and sample sets of input and output data are given here. The sets of input and output variables are described in the output listing and by documentation within the program itself. Inputs are made by the unformatted "NAMELIST" method. The program was written in FORTRAN IV for use on a CDC 6600 computer system. The program contains all the interpolation methods and data tables required to make it independent of any special library subroutines of the host computer system.

Climbing flight starts at altitude HSTART at designated values of C_L and power settings ($CL1$ and $KPOW$, respectively). The climb equations determine a value of flight-path angle at an incremental increase in altitude. The vehicle weight is adjusted to allow for fuel consumption between specified altitudes. Iterative adjustments in both flight-path angle and weight lead to a consistent set of these parameters at each increment of altitude. At the second event altitude, $H2$, the throttle is changed to be full open and C_L is adjusted to the value for $CL2$. This procedure compensates for effects that decrease rate of climb with increases in altitude.

Cruise climb is initiated at either the input cruise altitude, $H3$, or the altitude at which the rate of climb is zero. The program uses $CL3$ as the CL for cruise-climb. The power setting is adjusted to achieve trimmed, equilibrium flight. Vehicle weight is computed for equilibrium flight at each altitude. If the vehicle could climb beyond 70,000 feet, the power setting is adjusted to maintain that ceiling for ten (10) identical increments of fuel weight.

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PROGRAM CHAAP(INPUT,OUTPUT,TAPE5=INPUT,TAPE6)
C
C PROGRAM FOR CALCULATION OF FLIGHT PROFILE AND ASSOCIATED PARAMETER
C
C
C DIMENSION ARC(5), ACB(3), SFCTANK(3)
C DIMENSION SFCVOL(3)
C
C COMMON/BL/BOIL,BOILT,ROILA
C COMMON /AERO/ CL,CD,RHO,S,D,THRUST,HA,HB,VA
C COMMON /ENG/ PAC,ETAP2,KPOW,SFCENG,SFC,SFCA,FLOW,FLOWA,POWSET,KFUE
C 1L,HMAX
C COMMON /WEIGHT/ WA,OW,WR,WFUFL,WFW,WD
C COMMON /START/ AGOLD,DFLH,GAMMA,KK,KC,KEC,RFUEL,RC,V,VX,VKT,T,TH,X
C 1,KODE,KALT,KG,KOUNT
C COMMON /ATMO/ ALTI(4),P1(15),P2(15),D1(15),D2(15),ALT(15),TK(4),
C . PROPT(2,9,6)
C COMMON/SYS/TA,RHA,TIN,RHIN,RADIUS,VOLTANK,ARFAT,RATIO,CONDUCT
C COMMON/PIC/PI
C
C NAMELIST /DF/ TOTALWF,MPAYLD,HSTART,CL1,H2,CL2,H3,CL3,CD0,AR,WOS,K
C 1FUEL,ENG SIZE,ETAP,PAC,KPOW,KGW,GW,KPOWCC,SWF,SFCTANK,DELTI,DELHI
C NAMELIST/IN/CONDUCT,PSI,RATIO,TA,RHA,TIN,RHIN,WSYS
C
C DESCRIPTION OF INPUT VARIABLES
C
C AR= ASPECT RATIO
C CL1,CL2,CL3= VEHICLE LIFT COEFFICIENTS SET AT ALTITUDES H1,H2,AND
C H3, RESPECTIVELY
C CD0= VEHICLE PROFILE-DRAG COEFFICIENT
C ENG SIZE= ENGINE SIZE, SHP
C ETAP= PROPELLER EFFICIENCY FACTOR ((THRUST*VELOCITY)/POWER)
C GW= GROSS WEIGHT, LB
C HSTART= STARTING ALTITUDE, FT
C H2,H3= EVENT ALTITUDES, FT
C PAC= PAYLOAD AND SYSTEMS POWER REQUIRED FROM ENGINE, SHP
C KFUEL= 1 FOR JP7, 2 FOR LIQUID CH4, 3 FOR LIQUID H2
C KGW= 1 FOR SPECIFIED GROSS WEIGHT AND NOT = 1 FOR SPECIFIED FUEL
C KPOW= 0 FOR OPEN OR AUTOMATICALLY SET THROTTLE, 1 FOR MAX POWER,
C 2 FOR 75% POWER, 3 FOR 50% POWER, AND 4 FOR 25% POWER
C KPOWCC= POWER CODE FOR CRUISE CLIMB
C SWF= STRUCTURAL WEIGHT FRACTION (WEIGHT OF STRUCTURE AND SYSTEMS/
C OF STRUCTURE, SYSTEMS, PAYLOAD, FUEL, FUEL SYSTEM, AND PROPULS
C SYSTEM)
C TOTALWF= TOTAL WEIGHT OF FUEL, LB
C WOS= WING LOADING, W/S, LB/FT2
C MPAYLD= PAYLOAD WEIGHT, LB
C
C CONDUCT= CONDUCTIVITY, BTU-FT/HR-DEGREE F-FT2
C PRESSURE= PSI
C RATIO= FINISS RATIO OF THE TANK L/D
C TIN= THICKNESS OF INSULATION, INCH
C TA= THICKNESS OF ALUMINUM, INCH
C RHIN= DENSITY OF INSULATION, LBF/FT2
C RHA = DENSITY OF ALUMINUM, LBF/FT2
```



```

DATA ((PROPT(2,I,J),J=1,6),I=1,9)/
,20.268,.1013,70.7864,1.3378,-256.2,189.3,
,21.,.1250,69.9403,1.6189,-248.8,193.,
,22.,.1634,68.7200,2.0711,-237.9,197.7,
,23.,.2096,67.4149,2.6119,-226.3,200.5,
,24.,.2645,66.0112,3.2548,-213.8,202.6,
,25.,.3288,64.4917,4.0171,-200.4,203.6,
,26.,.4035,62.8337,4.9214,-185.9,203.1,
. 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0./

C
DATA TA,TIN,RHA,RHIN,CONDUCT,PSI,RATIO/
. .15,6.0,172.8,2.3,0.00867,50.,4./

C
C
C CODES: KC = 1 FOR ALT. INCREMENT ENDING IN FUEL EXHAUSTION
C KEC- EVENT CODE; = 1 FOR CONFIGURATION CHANGE
C KALT- NUMBER OF ALTITUDE INCREMENTS
C KK- CYCLE COUNTER; CPITER ON FOR PRINT-OUT OF RESULTS
C

I=1
DO 62 I=1,7
C CHANGE UNIT DEGREE F, PSI, LB/FT3, BTU/LBM
PROPT(L,I,1)=PROPT(L,I,1)*1.8-459.67
PROPT(L,I,2)=PROPT(L,I,2)/6.894757
PROPT(L,I,3)=PROPT(L,I,3)*62.428
PROPT(L,I,4)=PROPT(L,I,4)*62.428
PROPT(L,I,5)=PROPT(L,I,5)/2.32597
PROPT(L,I,6)=PROPT(L,I,6)/2.32597
62 CONTINUE
C
L=2
DO 60 I=1,7
C CHANGE UNIT DEGREE F, PSI, LB/FT3, BTU/LBM
PROPT(L,I,1)=PROPT(L,I,1)*1.8-459.67
PROPT(L,I,2)=PROPT(L,I,2)*145.04
PROPT(L,I,3)=PROPT(L,I,3)*0.062428
PROPT(L,I,4)=PROPT(L,I,4)*0.062428
PROPT(L,I,5)=PROPT(L,I,5)/2.32597
PROPT(L,I,6)=PROPT(L,I,6)/2.32597
60 CONTINUE
PI=3.14159265
DO 10P KFL=2,3
CALL INTERP(PSI,PROPT,KFL,1)
CALL INTERP(14.69,PROPT,KFL,0)
10P CONTINUE
C
77 READ (5,42) ARC
IF (END(5)) 41,2
2 READ (5,DF)
READ (5,IN)
TA=TA/12.
TIN=TIN/12.
KPOVCC=3
C
FLOW=0.
THCM=0.
ENDU=0.
ROIL=0.

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ROILT=0.
ETAP2=ETAP

C
C
C
4

INITIALIZE PARAMETERS

CL=CL1
AGOLD=GAMMA=RFUEL=0.
PC=V=VX=0.
VKT=0.
T=TH=X=0.
DELH=DELTI
KK=-1
KC=KEC=KODE=KOUNT=0
KPOW=4

C
C
C

EMPIRICAL ADJUSTMENT TO OSTWALD EFFICIENCY FACTOR,

F=1.-.01*AP
SFCENG=FNGSIZE/650.
WPROPUL=(SFCENG*225.)*1.3+70.

C
C
C

WEIGHT CALCULATION

C
C

IF (KGM.NE.1) GO TO 5
GROSS WEIGHT SPECIFIED
WSYS=GM*(1.-SWF)-WPAYLD-WPROPUL
IF (KFUEL.EQ.1) GO TO 81
CALL SYSTEM(PROPT((KFUEL-1),9,3),WSYS,WFUEL,1)
GO TO 82

A1
A2

WFUEL=WSYS/(1.+SFC TANK(1))
VOLTANK=SFCVOL(KFUEL)*WFUEL
TOTALWF=WFUEL
WTOTAL=GM
GO TO 6

C
*

FUEL WEIGHT SPECIFIED
WFUEL=TOTALWF
IF (KFUEL.EQ.1) GO TO 90
VOLTANK=(WFUEL/PROPT((KFUEL-1),9,3))/0.9
R3=VOLTANK/(PI*(2.*RATIO+(4./3.)))
RADIUS=R3*(1./3.)
CALL SYSTEM(PROPT((KFUEL-1),9,3),WSYS,WFUEL,2)
WTANK=WSYS-WFUEL
GO TO 91

90
91
6

WTANK=WFUEL*SFC TANK(KFUEL)
VOLTANK=SFCVOL(KFUEL)*WFUEL
WTOTAL=(WPAYLD+WFUEL+WTANK+WPROPUL)/(1.-SWF)
WD=WTOTAL-WFUEL
WF=WD-WPAYLD
W1=WTOTAL
WF=TOTALWF

C
C

COMPUTE VOLUMES

C
92

VOLPAYL=WPAYLD/22.5
PAYLOAD DENSITY: 22.5 LB/CU FT.
VOLRN=0.

C

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IF (HSTART.EQ.0.) GO TO 7
CALL BALLOGN (HSTART,WTOTAL,VOLBN)
CONTINUE
VOLF=0.02831685
VTANKM=VOLTANK*VOLF
VOLBNM=VOLBN*VOLF
VPAYLM=VOLPAYL*VOLF

C
C
C   PREPARE VEHICLE DESCRIPTION DATA FOR HEADING

S=WTOTAL/WDS
ACK=1./(PI*AR*E)
SS=S*0.0929
SWPAYLD=WPAYLD*4.44822
SKWSL=ENG SIZE*0.7457
SWFUEL=WFUEL*4.44822
CC=0.0003048
HSTARTS=HSTART*CC
H2S=H2*CC
H3S=H3*CC
H4S=21.3
H4S=H3S
HHSTART=HSTART/1000.
HH2=H2/1000.
HH3=H3/1000.
HH4=70.
WDS=WD*47.98026
SWE=WE*4.44822
SPAC=PAC*0.7454
SWTOTAL=WTOTAL*4.44822
WRITE (6,44) ARC
WRITE (6,45) ACR(KFUEL),AR,S,WPAYLD,SWPAYLD,ENG SIZE,E,SS,WFUEL,SWF
IUEL,CL,HHSTART,HH2,HSTARTS,H2S,SKWSL,CDO,WDS,WE,SWE,CL2,HH2,HH3,H2
2S,H3S,PAC,SPAC,WDS,WTOTAL,SWTOTAL,CL3,HH3,HH4,H3S,H4S
WRITE (6,46) VOLPAYL,VPAYLM,VOLTANK,VTANKM,VOLBN,VOLBNM
CD=CDO*ACK*CL3**2
WDS=WD/S
CALL ALTMAX (WDS,CL3,CD,KFUEL,SFCENG,PAC,ETAP,WD,HMAX,KPOWCC,0.)

C
C
C   WRITE (6,43)

C
C
C   GAMMA=0.
KALT=0
H=HSTART-DELH

C
C
C   KALT IS 1 FOR INITIAL ALTITUDE
KALT=KALT+1
FLOW1=FLOW
ROIL1=BOIL
PC1=RC
V1=V
VX1=VX
```

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C
C CHANGE ALTITUDE
9 HO=H
IF (ARS(H-60000.).LT.50.) THEN=TH
10 H=H+DELH
HKM=H*CC
CALL FXPINT (ALT,D1,D2,15,HKM,SIGMA,KODE)
CD=CD0+ACK*CL**2
DOL=CD/CL
CALL ENGINE (H,KFUEL,KPOW,POWER,FLOW,SFC,KODE,SFCENG,POWSFT)
CALL PERTK(WFUEL,BOIL,H,KFUEL)
POWER=POWER-PAC
IF (KODE.EQ.1) GO TO 40

C
C ITERATE ON TOTAL WEIGHT
11 W=W1
KG=0

C
C KG IS NO. OF TIMES THROUGH GAMMA CYCLE AT EACH ALTITUDE
C ITERATE ON GAMMA
12 KG=KG+1
G1=GAMMA
O=W*COS(GAMMA)/(CL*S)
V=29.0*SQRT(O/SIGMA)
THRUST=FTAP*POWER*550./V

C
C TEST FOR KC= 1, WHICH INDICATES FUEL= 0
IF (KC.EQ.1) GO TO 17

C
C CORRECTION FOR ACCELERATION ALONG FLIGHT PATH
CF=1.0
IF (KALT.EQ.1.OR,KEC.EQ.1) GO TO 13
VAG=(V1+V)/2.
DELV=V1-V
CF=1.+VAG*DELV/(DELH*32.17)

C
C GAMMA IS ARCTAN OF ((T-D)/(L X ACCEL FACTOR))
C
13 RLIFT=CL*S*O
TOL=THRUST/RLIFT
VGAMMA=(TOL-DOL)/CF
IF (VGAMMA.LT..001.AND.VGAMMA.GT.-.001) GO TO 32
IF (VGAMMA.LT.0.) GO TO 15
GAMMA=ATAN(VGAMMA)
G2=GAMMA
AG12=ARS(G2-G1)

C
IF (KG.LT.15) GO TO 14
TFST=ABS(AG12-AGOLD)
IF (TFST.GT..00000001) GO TO 14
PRINT *, " ERROR OF AG12 = ",AG12
GO TO 16
14 IF (AG12.LT..001) GO TO 16
AGOLD=AG12
IF (KG.LT.30) GO TO 12
GO TO 30

```

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C
C   ADJUST TARGET ALTITUDE TO HAVE A POSITIVE GAMMA
15 IF (KALT.FO.1) GO TO 31
    H=H0
    DFLH=DELH/2.
    IF (DELH.LT.20.) GO TO 33
    GO TO 9

C
C   ADVANCE PARAMETER VALUES DUE TO ALTITUDE INCREMENT
16 RC=V*SIN(GAMMA)
    IF (KEC.EQ.1) GO TO 19
    DFLT=DFLH/((RC1+RC)/2.)
    DRDIL=(RDIL1+RDIL)*DELH/7200.
    DFLF=(FLOW1+FLOW)*DELH/7200.
    DELF=DFLF+DRDIL
    IF (WFUFL.GT.DELF) GO TO 18
    H=H0
    DELH=DELH*WFUFL/DELF
    IF (DELH.LT.20.) GO TO 33
    GO TO 9

C
C   END ADJUSTMENT FOR MAXIMUM ALTITUDE
C   DELT (DELTA TIME) GIVEN IN SECONDS
C
17 DELT=WFUFL*3600./(FLOW+RDIL)
    WFUFL=0.
    VX=V
    GO TO 19

C
C   CALCULATION OF ALL PERFORMANCE PARAMETERS FOR EACH ALTITUDE
C
18 RFUEL=WFUFL-DELF
    W1=WD+RFUEL
    ADELW=ABS(W1-W)
    IF (ADELW.GT.1) GO TO 11

C
    IF (KALT.FO.1) GO TO 19
    WFUFL=RFUEL
    VX=V+COS(GAMMA)

C
19 GAMMA0=GAMMA+57.295779
    RCM=RC*60.
    VKT=V*0.592484
    IF (KEC.EQ.1.AND.KC.EQ.1) GO TO 21
    IF (KALT.FO.1) GO TO 22
    IF (KFC.EQ.1) GO TO 24

C
20 X=X+((VX+VX1)/2.)*DELH/6076.115
    T=T+DELH
    TH=T/3600.
    IF (KC.EQ.1) GO TO 30
    GO TO 23

C
21 VX1=V
    GO TO 20

```


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```
C
22 KK=4
23 KK=KK+1
   BOILT=BOILT*DELT/3600.+BOILT
C   LIST RESULTS IF VEHICLE IS AT EVENT ALTITUDE, STANDARD ALTITUDE
C   OR INITIAL ALTITUDE
   ATEMP=ABS(H-H2)
   RTEMP=ABS(H-H3)
   IF (ATEMP.LT.1..OR.BTEMP.LT.1.) GO TO 24
   IF (KK.FO.5) GO TO 24
   VV=V
   IF (KALT.EQ.1) GO TO 24
   GO TO 8
C
24 PERCENT=WFUEL/TOTALWF*100.
   W2=WTOTAL-TOTALWF+WFUEL
   WDS2=W2/S
   WRITE (6,47) H,X,TH,V,VKT,RCM,GAMMAD,POWER,SFC,ETAP,THRUST,WFUEL,
1PERCENT,WDS2,CL,POWSET,BOILT
   KOUNT=KOUNT+KODF
   KODE=0
   IF (GAMMAD.LT.1.0) KPOW=1
C
   IF (KEC.EQ.1) GO TO 29
   IF (KK.FO.5) KK=0
   IF (KALT.FO.1) GO TO 28
   IF (ATEMP.GT.1.) GO TO 25
   CL=CL2
   KPOW=1
   KEC=1
   GO TO 27
25 IF (RTEMP.GT.1.) GO TO 26
   CL=CL3
   KPOW=0
   KFC=1
   GO TO 33
26 KEC=0
   GO TO 28
27 H=H-DELH
C   TEST FOR FUEL NEAR EXHAUSTION
28 IF (WFUEL.GT.0.1) GO TO 8
   GO TO 30
29 KEC=0
   IF (WFUEL.GT.0.1) GO TO 8
C
C   MAX H FOR GIVEN CONFIGURATION
C
30 PERCENT=WFUEL/TOTALWF*100.
   WRITE (6,47) H,X,TH,V,VKT,RCM,GAMMAD,POWER,SFC,ETAP,THRUST,WFUEL,
1PERCENT,WDS2,CL,POWSET,BOILT
   KOUNT=KOUNT+KODF
   KODF=0
   WRITE (6,48) DELF
C
C   VEHICLE CAN NOT CLIMB ANY HIGHER, THEREFORE CHANGE TO CRUISE HERE
   WRITE (6,49)
   GO TO 33
```

ORIGINAL PAGE 1
OF POOR QUALITY

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C
31 WRITE (6,50) TOL,DOL
32 CONTINUE
   H=H-DELH
   HKM=H*CC
   CALL EXPINT(ALT,D1,D2,15,HKM,SIGMA,KODE)
   V=VV
   PERCENT=WFUEL/TOTALWF*100.
   W2=WTOTAL-TOTALWF+WFUEL
   WDS2=W2/S
   VKT=V*0.592484
   IF(KK.EQ.0) GO TO 70
   WRITE (6,47) H,X,TH,V,VKT,RCM,GAMMAD,POWER,SFC,ETAP,THRUST,WFUEL,
1PERCENT,WDS2,CL,POWSET ,BOILT
70 WRITE (6,51)
   IF(H.LT.60000.) GO TO 200
   V=V1
33 KALT=KALT-1
   IF (KALT.EQ.1) GO TO 1
   VA=V
   VA=WD+WFUFL
   VA=V
   CL=CL3
   CD=CDO+ACK*CL**2
   RCM=0.
   GAMMAD=0.
   KG=1
   KPOW=KPOWCC
   KK=0
   KFC=1
   KG=0
   IF (HMAX.GE.70000.) HMAX=70000.
   IF ((HMAX-H).GT.500.) GO TO 34
   DELH=HMAX-H
   GO TO 35
34 DELH=DELHI
35 HA=H
   KPOW=0
   RHO=0.002376884*SIGMA
   V=SQRT((2.*WDS2)/(RHO*CL))
   VKT=V*0.592494
   D=0.5*RHO*V**2.
   D=C0*D*S
   THRUST=0
   POWER=(D*V)/(ETAP2*550.)
   POWER=POWER+PAC
   CALL ENGINE(HA,KFUEL,KPOW,POWER,FLOWA,SFCA,KODE,SFCENG,POWSET)
   CALL PEPTK(WFUEL,BOILA,HA,KFUEL)
   CALL ALTMAX(WDS,CL3,CD,KFUEL,SFCENG,PAC,ETAP,WD,HMAX,-1,POWSET)
   WRITE (6,47)H,X,TH,V,VKT,RCM,GAMMAD,POWER,SFCA,ETAP,THRUST,WFUEL,
1PERCENT,WDS2,CL,POWSET,BOILT
   CL=C1.3
   VA=V
   CD=CDO+ACK*CL**2
36 HR=HA+DELH
   IF (HR.GT.HMAX) HB=HMAX
   KPOW=-1
   CALL CRCH
   HA=HB

```

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```

KEC=0
WA=WR
IF ((WR-WD).LT.0.01) GO TO 39
IF (HR.GE.70000.) GO TO 37
IF (HB.FQ.HMAX) GO TO 39
GO TO 36
37 KFC=1
KPOW=0
HA=70000.
HKM=70000.*0.0003048
DW=WFUEL/10.
CALL EXPINT (ALT,D1,D2,15,HKM,SIGMA,KODE)
RHO=0.002376884*SIGMA
38 WR=WA-DW
WFUEL=WFUEL-DW
CALL CRUISE
IF (ABS(WR-WD).LT.0.01) GO TO 39
WA=WB
KEC=0
GO TO 38
39 IF (KOUNT.F0.0) GO TO 40
WRITE (6,52) KOUNT
1 CONTINUE
40 FNDU=TH-THCM
200 CONTINUE
GO TO 77
41 STOP
C
42 FORMAT (5A10)
43 FORMAT (//,2X,4X,4HALT.,3X,5HRANGE,3X,4HTIME,2X,13HTRUE AIRSPEED,3
1X,3HR/C,3X,5HGAMMA,2X,8HE. POWER,3X,3HSFC,3X,5HETA-P,2X,6HTHRUST,3
2X,13HFUEL IN TANKS,2X,3HW/S,5X,2HCL,2X,8HTHROTTLE,2X,7HB0ILOFF//
. 6X,4H(FT),4X,4HNM,
3 3X,4H(HR),3X,5H(FPS),2X,4H(KT),3X,5H(FPM),2X,5H(DFG),4X,4H(HP
4),2X,10H(LR/HP-HR),7X,4H(LB),5X,4H(LB),5X,1HZ,3X,5H(PSF),12X,1HZ,
6 6X,4H(LB)//)
44 FORMAT (141///2X,5A10//,2X,10HPROPULSION,20X,12HAERODYNAMICS,9X,4H
1WING,13X,15HWFIGTS, LB (N),10X,21HVEHICLE TRIM SCHEDULE)
45 FORMAT (/6X,5HFUEL:,1X,A10,11X,3HAR=,F6.2,9X,2HS=,F5.1,1X,3HFT2,4X
1,8HPAYLOAD:,F7.0,1X,1H(,F5.0,1H),4X,2HCL,5X,23HALTITUDE, FT/1000.
2(KM),/,4X,7HENGINE:,F6.0,1X,6HSHP-SL,10X,2HE=,F6.3,10X,1H=,F6.0,3H
3 M2,7X,5HFUEL:,F7.0,2H (,F5.0,1H),F7.2,F7.1,4H TO ,F4.1,2X,1H(,F4.
41,1X,2HTO,F5.1,1H),/11X,1H(,F5.0,6HKW-SL),9X,4HCDO=,F6.5,7X,4HW/S=
5,F5.1,4H PSF,8X,5HWEI:,F6.0,1H(,F6.0,1H),F7.2,F7.1,4H TO ,F4.1,2X
6,1H(,F4.1,4H TO ,F4.1,1H)/5X,6HAUX P:,F4.1,5H HP (,F4.2,4H KW),24X
7,,2H= ,F5.0,3H PA,7X,6HTOGW:,F6.0,1H(,F6.0,1H),F7.2,F7.1,4H TO ,F
84.1,2X,1H(,F4.1,4H TO ,F4.1,1H)//)
46 FORMAT (//2X,18HVOLUMES, FT3 (M3):,3X,8HPAYLOAD=,F6.2,1X,1H(,F6.4,
12H),,9X,5HTANK=,F6.2,1X,1H(,F6.4,2H),,9X,8HBALLOON=,F8.0,1X,1H(,F6
2.0,1H)//)
47 FORMAT (F11.1,F8.1,F7.2,F7.1,F6.1,F9.1,F5.1,F9.1,F9.4,F6.3,2F9.1,F
17.1,F6.2,F7.2,F8.1,F8.2)
48 FORMAT (20X,6HDELF= ,F20.3)
49 FORMAT (2X,32HVEHICLE CAN NOT CLIMB ANY HIGHER)
50 FORMAT (6X,4HT/L=,F10.5,6X,4HL/D=,F10.5//)
51 FORMAT (2X,18HCRUISE STARTS HERE)
52 FORMAT (30H INTERPOLATION OUT OF RANGE ,I4,7H TIMES!
END

```


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```
5 CONTINUE
  IF(PERCTP.GE.SETR(1)) GO TO 10
  KODE=1
  I=1
  GO TO 6
10 IF(PERCTP.LE.SETR(4)) GO TO 11
  I=4
  KODE=1
6 CALL LINEAR(ALT,SHP(1,I),15,H,HP,KODE)
  CALL LINEAR(ALT,FL(1,I),15,H,FLOW,KODE)
  GO TO 7
11 I=1
13 J=I+1
  IF(PERCTP.LE.SETR(I)) GO TO 12
  GO TO 13
12 I1=I
  I=I-1
  P(1)=SETR(I)
  P(2)=SETR(I1)
C
  CALL LINEAR(ALT,SHP(1,I),15,H,HPR(2),KODE)
  CALL LINEAR(ALT,SHP(1,I1),15,H,HPR(1),KODE)
  CALL LINEAR(ALT,FL(1,I),15,H,FLOWP(2),KODE)
  CALL LINEAR(ALT,FL(1,I1),15,H,FLOWR(1),KODE)
  CALL LINEAR(P,HPR,2,PERCTP,HP,KODE)
  CALL LINEAR(P,FLOWR,2,PERCTP,FLOW,KODE)
7 CONTINUE
  POWER=HP*SFCENG
  GO TO 2
C
  POWER SETS AT 100%,75%,50%,OR 25% OF MCR
C
1 CALL LINEAR (ALT,SHP(1,IPOW),15,H,HP,KODE)
  CALL LINEAR (ALT,FL(1,IPOW),15,H,FLOW,KODE)
  POWER=HP*SFCENG
  PERCTP=25.*(5.-IPOW)
C
  ADJUST FUEL FLOW FOR DIFFERENT FUEL.
C
2 CONTINUE
  FLOW=FLOW*SFCFL(IFUEL)*SFCENG
  SFC=FLOW/POWER
  RETURN
  FND
```

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```

SUBROUTINE ALTMAX (WDS,CL,CD,KFUEL,SFCENG,PAC,ETAP,W,HMAX,KPOW,
. POWSET)
COMMON /ATMO/ ALTT(4),P1(15),P2(15),D1(15),D2(15),ALT(15),TK(4)

C
C
C      CALCULATE MAXIMUM ATTAINABLE ALTITUDE
1      K=0
      H=55000.
      DFLH=5000.
2      H=H+DELH
      HKM=H*0.0003048
      CALL EXPINT (ALT,D1,D2,15,HKM,SIGMA,KODE)
      RHO=0.002376884*SIGMA
      K=K+1
      V=SQRT((2.*KJS)/(CL*RHO))
      DDL=CD/CL
      D=DDL*W
      CALL ENGINE (H,KFUEL,KPOW,POWER,FLOW,SFC,KODE,SFCENG,POWSET)
      POWER=POWER-PAC
      T=(POWER*ETAP*550.)/V
      IF (ABS(T-D).LT.0.01) GO TO 4
      IF (T.GT.D) GO TO 2
      IF (K.GT.1) GO TO 3
      K=0
      H=H-6000.
      GO TO 2
3      H=H-DFLH
      DFLH=DFLH/2.
      GO TO 2
4      HMAX=H
      IF (HMAX.LT.60000..AND.KPOW.GT.1) GO TO 5
      RETURN
5      KPOW=KPOW-1
      GO TO 1

C
      END

SUBROUTINE INTERP(PRESS,PROPT,LL,KCO)
DIMENSION PROPT(2,9,6)
C      INTERPOLATION -- DATA STORE IN PROPT(L,8,I), IF KCO=1
C      SEA LEVEL DATA STORE IN PROPT(L,9,I). IF KCO=0
C
      L=LL-1
      IF(L.EQ.0) RETURN
      K=8
      IF(KCO.EQ.0) K=9

C
      KODE=0
      IF(PROPT(L,1,2).LT.PRESS) GO TO 1
      DO 10 J=1,6
      PROPT(L,K,J)=PROPT(L,1,J)
10     CONTINUE
      KODE=1
      RETURN

```

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```
C
1  IF(PROPT(L,7,2).GT.PRESS) GO TO 2
   DO 11 J=1,6
   PROPT(L,K,J)=PROPT(L,7,J)
   KODE=2
11  CONTINUE
   RETURN
2   I=1
3   I=I+1
   IF(PROPT(L,I,2).GT.PRESS) GO TO 20
   GO TO 3
20  I2=I
   I1=I2-1
   DO 13 J=1,6
   PROPT(L,K,J)=-((PROPT(L,I1,J)-PROPT(L,I2,J))*(PROPT(L,I1,2)
   -PRESS)/(PROPT(L,I1,2)-PROPT(L,I2,2)))+PROPT(L,I1,J)
13  CONTINUE
   RETURN
   END
```

SUBROUTINE LINEAR (X,Y,N,AX,AY,KODE)

```
C
C   LINEAR INTERPOLATION ROUTINE
C
C   INPUT ARRAY X--INDEPENDENT VARIABLE; INPUT ARRAY Y--DEPENDANT VARI
C   N - SIZE OF ARRAY, MUST BE LESS THAN 100; AX - INPUT POINT;
C   AY - CORRESPONDING Y VALUE OUTPUT
C
C   DIMENSION X(100), Y(100)
C
C   IF (AX.GE.X(1)) GO TO 1
   AY=Y(1)
   KODE=1
   RETURN
C
1   IF (AX.LE.X(N)) GO TO 2
   AY=Y(N)
   KODE=1
   RETURN
C
2   I=1
3   I=I+1
   IF (AX.NE.X(I)) GO TO 4
   AX= X(I)
   AY=Y(I)
   RETURN
4   IF (AX.GE.X(I1)) GO TO 5
   X(I1)<AX<X(I1)
   AY=Y(I1)+(AX-X(I1))*(Y(I1)-Y(I))/(X(I1)-X(I))
   RETURN
5   I=I1
   GO TO 3
   END
```

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```
      SUBROUTINE EXPINT (X,Y1,Y2,N,AX,AY,KODE)
      DIMENSION X(100), Y1(100), Y2(100)
      EXPONENTIAL INTERPOLATION TO SUPPLY COEFFICIENTS FOR DENSITY
      AND PRESSURE RATIO EQUATION: AY= E**(Y1*X + Y2*X**2)
      IF (AX.GE.Y(1)) GO TO 1
      L=1
      KODE=1
      GO TO 5
1     IF (AX.LT.X(N)) GO TO 2
      L=N
      KODE=1
      GO TO 5
      X(1) <= AX <= X(N)
      I=1
      I1=I+1
      IF (AX.GE.X(I1)) GO TO 4
      L=I
      GO TO 5
4     I=I1
      GO TO 3
5     AY=EXP(-Y1(L)*AX-Y2(L)*AX*AX/100.)
      RETURN
      END
```

```
      SUBROUTINE BALLOON (H,WLIFT,VOLUME)
      CALCULATION OF BALLOON SIZE TO SUPPORT ITSELF AND RPV
      INPUT: ALTITUDE AND THE WEIGHT OF THE VEHICLE
      H-ALTITUDE(FT),WLIFT-WEIGHT OF THE VEHICLE(LBF),VOLUME-(CU FT)
      BALLOON IS 95% HELIUM AND 5% AIR.
      R-GAS CONSTANT 8.317 JOULE/KELVIN-MOLE
      COMMON /ATMOP/ ALTT(4),P1(15),P2(15),D1(15),D2(15),ALT(15),TK(4)
      HKM=H*0.0003048
      PO=101325.
      RHPO=1.2250
      CALL LINEAR (ALTT,TK,4,HKM,TA,KODE)
      CALL EXPINT (ALT,P1,P2,15,HKM,PRATIO,KODE)
      CALL EXPINT (ALT,D1,D2,15,HKM,SIGMA,KODE)
      PA=PRATIO*PO
      RHQ=SIGMA*RHPO
      WM=(4.002*.95+28.9644*.05)/1000.
      R=8.317
      TEMP=RHQ-(WM*PA)/(R*TA)
      VOLUME=WLIFT/TEMP/0.02831685
      RETURN
      END
```


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C SUBROUTINE SYSTEM (DENSITY,WSYS,WF,KCASE)
C COMMON/SYS/TA,RHA,TIN,RHIN,RADIUS,VOLTANK,AREAT,RATIO,CONDUCT
C CALCULATE FUEL SYSTEM WEIGHT,FUEL WEIGHT,TANK RADIUS,AND LENGTH,
C AT START OF FLIGHT.
C CONSIDER THICKNESS OF THE INSULATION AND ALUMINUM OF THE TANK.
C
C COMMON/PIC/PI

C
C

RATIO2=RATIO*2.
IF(KCASE.EQ.2) GO TO 20
R=WSYS-25.
C FUEL SYSTEM WEIGHT INCLUDES PUMP AND FUEL LINE.
R1=1.
GO TO 8
20 R1=RADIUS
8 CONTINUE
R2=R1+TA
R3=R2+TIN
PL=R1+RATIO2
V1=R1**2.*PI*(RL+4./3.*R1)
V2=R2**2.*PI*(RL+4./3.*R2)
V3=R3**2.*PI*(RL+4./3.*R3)
V1P=2.*R1*PI*(RL+4./3.*R1)+R1**2.*PI*(RATIO2+4./3.)
V2P=2.*R2*PI*(RL+4./3.*R2)+R2**2.*PI*(RATIO2+4./3.)
V3P=2.*R3*PI*(RL+4./3.*R3)+R3**2.*PI*(RATIO2+4./3.)
TWIN=(V3-V2)*RHIN
TWAL=(V2-V1)*RHA
TWLH2=V1*DENSITY*0.9
IF(KCASE.EQ.7) GO TO 21
X=8-TWIN-TWAL-TWLH2
IF(ABS(X).LE.0.0001) GO TO 10
DX=-((V3P-V2P)*RHIN+(V2P-V1P)*RHA+V1P*DENSITY*0.9)
P1=R1-X/DX
GO TO 8
10 RADIUS=P1
21 RLENGTH=RADIUS*RATIO2
AREAT=2.*PI*RADIUS**2.*(RATIO2+2.)
WIN=TWIN
WAL=TWAL
WF=TWLH2
WSYS=WIN+WAL+WF+25.
VOLTANK=RADIUS**3.*PI*(RATIO2+4./3.)
RETURN
END

C SUBROUTINE BOILOFF(AREAW,CONDUCT,TIN,DELT,BOIL,PROPT,L)
C
C CALCULATE OF BOILOFF FOR GIVEN FUEL AND FLUX
C
C INPUT AREAW,CONDUCTIVITY,THICKNESS OF INSULATION,TEMPERATURE
C GRADIENT,AND LH2 PROPERTIES.
C OUTPUT: BOILOFF, LBF/HR.
C
C DIMENSION PROPT(2,9,6)
O=CONDUCT*AREAW*DELT/TIN
BOIL=O/(PROPT(L,8,6)-PROPT(L,9,5))
RETURN
END

ORIGINAL PAGE IS
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SUBROUTINE CRCH

C

```
COMMON/BL/BOIL,BOILT,BOILA
COMMON /AERN/ CL,CD,RHO,S,D,THRUST,HA,HB,VA
COMMON /FNG/ PAC,ETAP2,KPDW,SFCENG,SFC,SFCA,FLOW,FLOWA,POWSET,KFUE
1L,HMAX
COMMON /WFIGHT/ WA,DW,WR,WFUEL,WF,WD
COMMON /START/ AGOLD,DELH,GAMMA,KK,KC,KEC,RFUEL,RC,V,VX,VKT,T,TH,X
1,KODE,KALT,KG,KOUNT
COMMON /ATM/ ALTT(4),P1(15),P2(15),D1(15),D2(15),ALT(15),TK(4)
```

C

C

C

CRUISE CLIMB CALCULATIONS

```
KK=KK+1
KALT=KALT+1
GO TO 2
1 HR=HR+DELH
IF (HR.GT.HMAX) HR=HMAX
2 HKM=HR*0.0003048
CALL EXPTNT (ALT,D1,D2,15,HKM,SIGMA,KODE)
RHO=0.002376RR4*SIGMA
CALL ENGINE (HB,KFUEL,KPDW,POWER,FLOWB,SFCB,KODE,SFCENG,POWSET)
CALL PFRTK(WFUFL,BOILA,HB,KFUEL)
POWER=POWER-PAC
IF (HR.NE.HMAX.OR.HMAX.EQ.70000.) GO TO 3
WR=WD
GO TO 4
3 WCU=(ETAP2*POWER*550.*CL/CD)**2.*S*RHO*CL/2.
WR=WCU**(1./3.)
4 DW=WA-WR
IF (DW.LT.0.) GO TO 1
VR=((2.*WR)/(CL*S*RHO))**.5
V=(VA+VR)/2.
FLOW=(FLOWA+FLOWR)/2.
ROIL=(ROILA+ROILR)/2.
DELTH=DW/(FLOW+ROIL)
DX=3600.*DELTH*V/6076.115
WDS=(WA+WR)/(2.*S)
X=X+DX
TH=TH+DELTH
ROIL=DELTH+ROIL
BOILT=BOILT+OBOIL
VKT=V*0.592494
SFC=(SFCA+SFCB)/2.
THRUST=ETAP2*POWER*550./V
WFUEL=WFUEL-DW
PERCENT=WFUEL/WF*100.
RCM=0
GAMMA=0
WRITE (6,5) HB,X,TH,V,VKT,RCM,GAMMA,POWER,SFC,ETAP2,THRUST,WFUEL
1,PERCENT,WDS,CL,POWSET,BOILT
KOUNT=KOUNT+KODE
KODE=0
SFCA=SFCB
FLOWA=FLOWR
ROILA=BOILR
```

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```
      VA=VB  
      RETURN  
C  
5  FORMAT (F11.1,F8.1,F7.2,F7.1,F6.1,F9.1,F5.1,F9.1,F9.4,F6.3,2F9.1,F  
17.1,F6.2,F7.2,F8.1,F8.2)  
      END  
  
      SUBROUTINE CRUISE  
      COMMON/BL/BOIL,BOILT,BOILA  
C  
C  CALCULATION OF CRUISE PERFORMANCE PARAMETERS AT CONSTANT ALTITUDE  
C  OPEN THROTTLE  
C  
      COMMON /AERG/ CL,CD,RHO,S,D,THRUST,HA,HR,VA  
      COMMON /ENG/ PAC,ETAP2,KPOW,SFCENG,SFC,SFCA,FLOW,FLOWA,POWSET,KFUE  
1L,HMAX  
      COMMON /WFIGHT/ WA,WB,WR,WFUEL,WF,WD  
      COMMON /START/ AGOLD,DELH,GAMMA,KK,KC,KEC,RFUEL,RC,V,VX,VKT,T,TH,X  
1,KODE,KALT,KG,KOUNT  
      COMMON /ATMO/ ALTT(4),P1(15),P2(15),D1(15),D2(15),ALT(15),TK(4)  
C  
C  
      RCM=0.  
      GAMMAD=0.  
      KPOW=0  
      WDS=(WA+WR)/(2.*S)  
      PERCENT=WFUEL/WF*100.  
      V=SQRT((2.*WDS)/(RHO*CL))  
      Q=0.5*RHO*V**2.  
      D=CD*Q*S  
      THRUST=D  
      POWER=(D*V)/(ETAP2*550.)  
      POWERP=POWER+PAC  
      CALL ENGINE (HA,KFUEL,KPOW,POWERP,FLOW,SFC,KODE,SFCENG,POWSET)  
      CALL PERTK (WFUEL,BOIL,HA,KFUEL)  
      DELTH=(WA-WB)/(FLOW+BOIL)  
      DY=DELTH*3600.*V/6076.15  
      X=X+DY  
      TH=TH+DELTH  
      DBOIL=DELTH*BOIL  
      BOILT=BOILT+DBOIL  
      VKT=V*0.592484  
      WRITE (6,1) HA,X,TH,V,VKT,RCM,GAMMAD,POWERP,SFC,ETAP2,THRUST,WFUEL  
1,PERCENT,WDS,CL,POWSET,BOILT  
      KOUNT=KOUNT+KODE  
      KODE=0  
      RETURN  
C  
1  FORMAT (F11.1,F8.1,F7.2,F7.1,F6.1,F9.1,F5.1,F9.1,F9.4,F6.3,2F9.1,F  
17.1,F6.2,F7.2,F8.1,F8.2)  
      END
```

```

SURROUTINE TANK(VFUEL,R,RL,HEIGHT,AREAW)
C
C CALCULATE HEIGHT OF THE FUEL AND THE WETTED AREA.
C
C
C
1 F(H)= VFUEL-((R**2*ACOS((R-H)/R)-(R-H)*A**.5)*RL+PI*R*H**2-
(1./3.)*PI*H**3)
DF(H)=-((2.*RL*A**.5+PI*A)
PI=3.14159265
C
C INPUTS: FUEL VOLUME, TANK RADIUS AND LENGTH.
C USES NEWTON-RALFSON FORMULA TO FIND HEIGHT
C
C INITIAL GUESS
C
H0= R
A= 2.*R*H0-H0**2
X= F(H0)
IF(ABS(X).LE.0.001) GO TO 10
DX= DF(H0)
H0= H0-X/DX
C=(R-H0)/R
IF(ABS(C).LE.1.) GO TO 10
STOP
10 HEIGHT= H0
AREAW= 2.*PI*R*HEIGHT+2.*R*RL*ACOS((R-HEIGHT)/R)
RETURN
END

SUBROUTINE PERTK(FUELV,BOIL,H,K)
C
C CALCULATE BOILOFF FOR GIVEN TANK AND AMBIENT CONDITIONS
C
C
COMMON /ATMO/ ALTT(4),P1(15),P2(15),O1(15),O2(15),ALT(15),TK(4),
PROPT(2,9,6)
COMMON /SYS/ TA, RHA, TIN, RHIN, RADIUS, VOLTANK, AREAT, RATIO, CONDUCT
L=K-1
BOIL=0.
IF(L.EQ.0.) RETURN
VFUEL=FUELV/PROPT(L,R,3)
PLENGTH=2.*RADIUS*RATIO
HM=0.0003048*H
CALL LINEAR(ALTT,TK,4,HM,T,KODE)
DIFFT=ABS(PROPT(L,R,1)-(T*1.8-459.67))
CALL TANK(VFUEL,RADIUS,PLENGTH,HEIGHT,AREAW)
CALL BOILOFF(AREAW,CONDUCT,TIN,DIFFT,BOIL,PROPT,L)
RETURN
END

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SAMPLE INPUT

BASELINE VEHICLE FUELED BY JP7
\$DF KFUEL=1 \$
\$IN TA=.15,TIN=6. \$
BASELINE VEHICLE FUELED BY LIQUID METHANE
\$DF KFUEL=2 \$
\$IN TA=.15,TIN=3.,RATIO=4. \$
BASELINE VEHICLE FUELED BY LIQUID HYDROGEN
\$DF KFUEL=3,DELHI=100. \$
\$IN TA=.15,TIN=6.,RATIO=4. \$
EXTREME JP7-FUELED CONFIGURATION
\$DF KFUEL=1,HSTART=10000.,AR=30.,WOS=5.,ENGSize=400.,
TOTALWF=500.,PAC=5.,KGW=0,SWF=.3 \$
\$IN \$

BASELINE VEHICLE FUELED BY JP7

PROPULSION

FUEL: JP7
 ENGINE: 640. SMP-SL
 AUX PI: 2.0 MP (1.49 KW)

AERODYNAMICS

AP=20.00
 E=.800
 COG=.01500

WING

S=375.0 FT2
 W/S= 8.0 PSF
 = 303. PA

WEIGHTS, LB (N)

PAYLOAD: 200. (890.)
 FUEL: 1136. (5093.)
 OWE: 1604. (7402.)
 TOW: 3000. (13345.)

VEHICLE TRIM SCHEDULE

CL ALTITUDE, FT/1000. (KM)
 .80 0.0 TO 40.0 (0.0 TO 12.2)
 1.00 40.0 TO 70.0 (12.2 TO 21.3)
 1.20 70.0 TO 100.0 (21.3 TO 30.5)

VOLUMES, FT3 (M3): P-YLOC= 0.00 (.2537) TANK= 26.01 (.7366) BALLOON= 0. (0.)

ALT.	RANGE	TIME	TRUE AIRSPEED	R/C	GAMMA	E. POWER	SFC	ETA-P	THRUST	FUEL IN TANKS	W/S	CL	THRITTLE	BOILOFF	
(FT)	MI	(MR)	(FPS)	(FPM)	(DEG)	(HP)	(LB/MP-HR)		(LB)	(LB)	(PSF)	%	%	(LB)	
0.0	0.0	0.00	80.0	1030.0	20.2	230.6	.6534	.000	1132.3	1135.9	100.0	.80	25.0	0.00	
5000.0	2.1	.04	95.8	1924.1	19.6	248.5	.5665	.000	1096.6	1128.5	99.4	.80	25.0	0.00	
10000.0	4.5	.09	103.8	1935.1	18.1	243.0	.5149	.000	1021.5	1123.9	98.9	.80	25.0	0.00	
15000.0	7.1	.13	112.9	1911.1	16.4	242.0	.4652	.000	935.1	1118.7	98.5	.80	25.0	0.00	
20000.0	10.1	.17	123.1	1862.9	14.6	239.4	.4239	.000	844.7	1114.0	98.1	.80	25.0	0.00	
25000.0	13.6	.22	134.8	1719.6	12.3	226.6	.4046	.000	726.4	1109.6	97.7	.80	25.0	0.00	
30000.0	17.0	.27	148.1	1510.5	9.8	203.9	.3763	.000	599.8	1105.2	97.3	.80	25.0	0.00	
35000.0	24.1	.34	163.4	1270.7	5.7	147.2	.4263	.000	391.1	1100.5	96.9	.80	25.0	0.00	
40000.0	35.0	.45	183.3	1084.6	616.7	32.2	.4607	.000	264.3	1094.5	96.4	.80	25.0	0.00	
45000.0	35.0	.45	183.3	96.7	1376.0	9.1	194.1	.4121	.000	517.6	1094.5	96.4	1.00	100.0	0.00
50000.0	42.4	.52	194.5	109.3	1957.9	5.0	149.5	.4365	.000	351.7	1089.3	95.9	1.00	100.0	0.00
55000.0	55.0	.63	208.0	123.2	602.1	2.8	115.7	.583	.000	240.4	1082.9	95.3	1.00	100.0	0.00
60000.0	79.4	.81	234.4	130.9	325.3	1.3	91.4	.6732	.000	167.0	1074.1	94.6	1.00	100.0	0.00
65000.0	150.9	1.29	283.7	156.2	76.2	.3	71.1	.4867	.000	115.3	1050.0	93.0	1.00	100.0	0.00
61000.0	197.6	1.59	289.5	159.7	36.5	.1	65.0	.4905	.000	100.4	1045.9	92.1	1.00	100.0	0.00
61000.0	197.6	1.59	246.2	145.8	0.0	0.0	61.2	.4910	.000	105.8	1045.9	92.1	1.20	63.0	0.00
61500.0	515.6	3.77	246.2	145.9	0.0	0.0	59.9	.4909	.000	103.5	981.1	86.4	1.20	63.0	0.00
62000.0	830.4	5.98	246.4	146.0	0.0	0.0	58.6	.4906	.000	101.2	916.8	80.7	1.20	63.0	0.00
62500.0	1166.3	8.22	246.5	146.0	0.0	0.0	57.4	.4904	.000	99.8	852.9	75.1	1.20	63.0	0.00
63000.0	1599.5	10.51	246.5	146.1	0.0	0.0	56.1	.4901	.000	96.5	789.5	69.5	1.20	63.0	0.00
63500.0	2102.5	12.82	246.6	146.1	0.0	0.0	54.8	.4898	.000	94.2	726.5	64.0	1.20	63.0	0.00
64000.0	2532.9	15.18	246.6	146.1	0.0	0.0	53.5	.4895	.000	92.0	664.0	58.5	1.20	63.0	0.00
64500.0	2889.6	17.58	246.5	146.1	0.0	0.0	52.3	.4892	.000	89.7	602.0	53.0	1.20	63.0	0.00
65000.0	3201.2	20.02	246.4	146.1	0.0	0.0	51.0	.4889	.000	87.4	540.3	47.6	1.20	63.0	0.00
65500.0	3516.7	22.16	246.5	146.2	0.0	0.0	49.4	.4883	.000	85.6	487.7	42.9	1.20	63.0	0.00
66000.0	3837.0	24.31	246.8	146.2	0.0	0.0	48.4	.4874	.000	83.7	435.7	38.4	1.20	63.0	0.00
66500.0	4162.5	26.59	247.0	146.3	0.0	0.0	47.9	.4865	.000	81.8	384.2	33.8	1.20	63.0	0.00
67000.0	4493.4	28.72	247.2	146.5	0.0	0.0	46.9	.4855	.000	79.9	333.0	29.3	1.20	63.0	0.00
67500.0	4833.4	30.98	247.3	146.5	0.0	0.0	45.9	.4845	.000	78.1	282.2	24.8	1.20	63.0	0.00
68000.0	5172.8	33.28	247.4	146.6	0.0	0.0	44.9	.4835	.000	76.2	231.0	20.4	1.20	63.0	0.00
68500.0	5521.8	35.62	247.5	146.6	0.0	0.0	43.9	.4824	.000	74.4	181.0	16.0	1.20	63.0	0.00
69000.0	5877.4	38.00	247.5	146.7	0.0	0.0	42.8	.4813	.000	72.6	132.1	11.6	1.20	63.0	0.00
69500.0	6240.0	40.42	247.5	146.6	0.0	0.0	41.8	.4801	.000	70.8	82.9	7.3	1.20	63.0	0.00
70000.0	6605.6	42.89	247.4	146.8	0.0	0.0	40.8	.4789	.000	69.0	33.9	3.0	1.20	63.0	0.00
70000.0	6265.4	43.07	247.3	146.5	0.0	0.0	40.8	.4783	.000	69.0	30.5	2.7	1.20	63.0	0.00
70000.0	6291.8	43.24	247.1	146.4	0.0	0.0	40.7	.4794	.000	68.9	27.1	2.4	1.20	62.6	0.00
70000.0	6316.5	43.42	246.9	146.3	0.0	0.0	40.6	.4785	.000	68.7	23.7	2.1	1.20	62.4	0.00
70000.0	6342.1	43.59	246.6	146.1	0.0	0.0	40.5	.4786	.000	68.6	20.3	1.8	1.20	62.1	0.00
70000.0	6367.7	43.77	246.4	146.0	0.0	0.0	40.4	.4785	.000	68.5	17.0	1.5	1.20	61.8	0.00
70000.0	6393.4	43.94	246.2	145.9	0.0	0.0	40.2	.4789	.000	68.4	14.2	1.2	1.20	61.6	0.00
70000.0	6419.2	44.12	246.0	145.7	0.0	0.0	40.1	.4790	.000	68.2	11.6	0.9	1.20	61.3	0.00
70000.0	6444.8	44.30	245.7	145.6	0.0	0.0	39.9	.4791	.000	68.1	8.8	0.6	1.20	61.1	0.00
70000.0	6470.4	44.47	245.5	145.5	0.0	0.0	39.8	.4793	.000	68.0	6.1	0.3	1.20	60.8	0.00
70000.0	6496.0	44.65	245.3	145.3	0.0	0.0	39.8	.4794	.000	67.9	3.4	0.0	1.20	60.6	0.00

ORIGINAL PARTS
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BASELINE VEHICLE FUELED BY LIQUID METHANE

PROPULSION
 FULL: METHANE
 ENGINE: 600. SMP-SL
 (492. KW-SL)
 AUX P: 2.0 MP (1.49 KW)
 AERODYNAMICS
 WING
 S=375.0 FT2
 AR= 20.00
 E= .800
 CDR=01500
 W/S= 0.0 PSF
 WING WEIGHTS, LB (N)
 PAYLOAD: 200. (890.)
 FUEL: 984. (4377.)
 OWE: 1816. (8078.)
 TOW: 3000. (13345.)
 ALTITUDE, FT/1000. (KM)
 CL 0.0 TO 40.0 (0.0 TO 12.2)
 40.0 TO 70.0 (12.2 TO 21.3)
 70.0 TO 70.0 (21.3 TO 21.3)
 VEHICLE TRIM SCHEDULE

VOLUMES, FT3 (M3): PAYLOAD= 8.09 (.2517); TANK= 41.30 (1.1694); BALLOON= 0. (0.1)

ALT.	RANGE	TIME	TRUE	AIRSPEED	R/C	GAMMA	E.	POWER	SFC	ETA-P	THRUST	FUEL	IN TANKS	W/S	CL	THRITTLE	BOILOFF
(FT)	N MI	(HR)	(FPS)	(KTS)	(FPM)	(DEG)	(MP)	(LB/MP-HR)	(MP)	(LB)	(ILR)	(LB)	%	(PSF)	%	(LS)	
0.0	0.0	0.00	88.8	52.6	1838.7	20.2	230.6	.5491	.800	1132.2	984.1	102.0	6.00	.80	25.0	.00	
5000.0	2.1	.04	95.8	56.8	1923.4	19.5	243.5	.4761	.800	1055.4	978.7	99.5	7.99	.80	25.0	.01	
10000.0	4.5	.09	103.9	61.5	1933.7	18.1	243.1	.4327	.800	1021.2	974.0	99.0	7.97	.80	25.0	.02	
15000.0	7.1	.13	113.0	66.9	1909.1	16.4	242.0	.3909	.800	934.6	969.6	98.5	7.96	.80	25.0	.03	
20000.0	10.1	.18	123.2	73.0	1868.4	14.6	238.4	.3563	.800	844.2	965.7	98.1	7.95	.80	25.0	.03	
25000.0	13.6	.22	134.9	79.9	1716.7	12.2	224.6	.3400	.800	725.9	961.9	97.7	7.94	.80	25.0	.04	
30000.0	17.6	.27	148.2	87.6	1507.4	9.8	203.9	.3163	.800	599.3	958.3	97.4	7.93	.80	25.0	.05	
35000.0	24.1	.36	163.5	96.9	1268.0	5.7	147.2	.2563	.800	390.8	954.3	97.0	7.92	.80	25.0	.05	
40000.0	35.1	.45	183.5	108.7	614.1	3.2	112.1	.2872	.800	264.0	949.2	96.5	7.91	.80	25.0	.06	
45000.0	42.5	.52	194.7	109.4	1371.9	8.0	149.1	.3463	.800	517.2	944.8	96.0	7.90	1.00	100.0	.07	
50000.0	55.2	.63	208.3	123.4	528.6	2.7	115.7	.3852	.800	240.1	939.4	95.5	7.88	1.00	100.0	.08	
55000.0	79.8	.82	234.8	139.1	321.8	1.3	91.4	.3977	.800	167.5	931.9	94.7	7.86	1.00	100.0	.10	
60000.0	153.3	1.31	268.2	156.5	72.3	.3	71.1	.4890	.800	115.8	916.2	93.1	7.82	1.00	100.0	.15	
61000.0	203.7	1.63	278.1	160.1	32.4	.1	65.0	.4122	.800	100.2	907.1	92.2	7.79	1.00	100.0	.18	
CRUISE STARTS HERE																	
61500.0	203.7	1.53	266.7	146.1	0.0	0.0	51.6	.4124	.800	104.3	907.1	92.2	7.79	1.20	63.7	.18	
61800.0	582.0	4.21	266.7	146.2	0.0	0.0	68.3	.4123	.800	104.0	841.8	85.5	7.71	1.20	63.7	.44	
62000.0	966.1	6.84	266.9	146.3	0.0	0.0	59.0	.4121	.800	101.6	777.0	79.0	7.53	1.20	63.7	.69	
62500.0	1356.2	9.50	247.0	146.3	0.0	0.0	57.7	.4119	.800	99.3	712.7	72.4	7.36	1.20	63.7	.92	
63000.0	1752.7	12.21	247.1	146.4	0.0	0.0	55.4	.4117	.800	96.9	648.8	65.9	7.19	1.20	63.7	1.15	
63500.0	2155.8	14.97	247.1	146.7	0.0	0.0	55.1	.4115	.800	94.6	585.4	59.5	7.02	1.20	63.7	1.36	
64000.0	2565.9	17.77	247.1	146.4	0.0	0.0	53.8	.4112	.800	92.3	522.4	53.1	6.85	1.20	63.7	1.57	
64500.0	2983.1	20.62	247.0	146.4	0.0	0.0	52.5	.4110	.800	90.0	459.9	46.7	6.69	1.20	63.7	1.76	
65000.0	3498.0	23.52	246.9	146.3	0.0	0.0	51.3	.4107	.800	87.8	397.8	40.4	6.52	1.20	63.7	1.95	
65500.0	3776.6	26.84	247.0	146.3	0.0	0.0	50.2	.4102	.800	85.9	345.2	35.1	6.37	1.20	63.7	2.10	
66000.0	4149.8	28.59	247.3	146.5	0.0	0.0	49.2	.4095	.800	84.0	293.2	29.8	6.23	1.20	63.7	2.25	
66500.0	4528.6	31.17	247.5	146.6	0.0	0.0	48.2	.4087	.800	82.1	241.6	24.6	6.09	1.20	63.7	2.38	
67000.0	4913.6	33.80	247.7	146.8	0.0	0.0	47.2	.4079	.800	80.3	190.4	19.4	5.95	1.20	63.7	2.51	
67500.0	5305.0	36.46	247.9	146.9	0.0	0.0	46.2	.4070	.800	78.4	139.7	14.2	5.82	1.20	63.7	2.63	
68000.0	5703.1	39.17	248.0	146.9	0.0	0.0	45.2	.4061	.800	76.6	89.3	9.1	5.68	1.20	63.7	2.73	
68500.0	6109.1	41.93	248.1	147.0	0.0	0.0	44.1	.4052	.800	74.8	39.2	4.0	5.55	1.20	63.7	2.82	
68996.5	6634.6	44.15	248.1	147.0	0.0	0.0	43.3	.4044	.800	73.3	.0	.0	5.43	1.20	63.7	2.88	

BASELINE VEHICLE FUELED BY LIQUID HYDROGEN

PROPULSION
 FUEL: HYDROGEN
 ENGINE: 650 SMP-SL
 AUX P: 2.0 MP (1.49 KM)
 PAYLOAD: 200. (.800.)
 FUEL: 568. (2529.)
 OME: 2232. (19226.)
 Y08W: 3000. (13345.)

AERODYNAMICS
 AR= 20.00
 E= 1.800
 CD0= .01500

WEIGHTS, LB (N)
 PAYLOAD: 200. (.800.)
 FUEL: 568. (2529.)
 OME: 2232. (19226.)
 Y08W: 3000. (13345.)

VEHICLE TRIM SCHEDULE
 CL ALTITUDE FT/1000 (KM)
 .80 0.0 TO 40.0 (.0 TO 12.2)
 1.00 40.0 TO 70.0 (12.2 TO 21.3)
 1.20 70.0 TO 100.0 (21.3 TO 30.3)

VOLUMES, FT3 (M3): PAYLOAD= 8.89 (.25171) TANK=162.93 (4.6474) BALLOON= 0. (0.)

ALT.	RANGE	TIME (HR)	TRUE AIRSPEED (FPS)	R/C (FPM)	GAMMA (DEG)	E. POWER (HP)	SFC (LB/HP-HR)	ETA-0	THRUST (LB)	FUEL IN TANKS (LB)	W (PSF)	M/S	CL	THROTTLE	BOILOFF (LB)
0.0	0.0	0.0	88.8	52.6	20.2	230.6	.2132	.800	1132.1	568.5	100.0	8.00	.80	25.0	.14
5000.0	2.1	.04	95.9	56.6	19.5	240.5	.1868	.800	1094.8	566.1	99.6	7.98	.80	25.0	.18
10000.0	4.5	.09	104.0	61.6	18.0	243.1	.1680	.800	1020.1	563.9	99.2	7.99	.80	25.0	.79
15000.0	7.1	.13	113.1	67.0	16.3	242.0	.1518	.800	939.2	561.9	98.8	7.98	.80	25.0	1.09
20000.0	10.1	.18	123.5	73.1	14.5	238.4	.1383	.800	842.6	560.1	98.5	7.98	.80	25.0	1.37
25000.0	13.6	.22	135.2	80.1	12.2	224.5	.1228	.800	724.3	558.3	98.2	7.97	.80	25.0	1.66
30000.0	17.9	.27	148.6	88.0	9.7	203.9	.1044	.800	597.8	556.6	97.9	7.97	.80	25.0	1.96
35000.0	24.2	.34	164.0	97.2	6.6	147.2	.0811	.800	389.7	554.7	97.6	7.96	.80	25.0	2.34
40000.0	35.4	.45	184.1	109.1	3.1	112.1	.0593	.800	263.2	552.1	97.1	7.96	.80	25.0	2.91
45000.0	50.4	.62	209.1	123.9	0.0	63.0	.0390	.800	150.3	550.0	96.3	7.95	1.00	100.0	3.29
50000.0	81.1	.82	235.6	139.7	0.0	31.2	.0244	.800	91.4	547.3	95.6	7.94	1.00	100.0	3.86
55000.0	101.1	1.05	261.7	157.4	0.0	15.6	.0158	.800	53.4	543.4	95.6	7.93	1.00	100.0	4.84
60000.0	160.8	1.35	275.7	161.0	0.0	8.1	.0117	.800	34.2	534.2	95.0	7.91	1.00	100.0	7.80
65000.0	224.9	1.76	281.8	161.0	0.0	4.1	.0076	.800	22.2	527.7	92.8	7.89	1.00	100.0	9.50
CRUISE STARTS HERE															
61000.0	224.9	1.76	248.2	147.1	0.0	62.7	.1599	.800	107.6	527.7	98.8	7.89	1.20	65.7	9.50
61500.0	356.9	2.65	248.2	147.1	0.0	62.4	.1598	.800	107.2	514.3	98.5	7.87	1.20	65.7	13.89
62000.0	489.7	3.56	248.2	147.1	0.0	62.2	.1599	.800	106.7	501.8	98.1	7.86	1.20	65.7	18.29
62500.0	624.1	4.47	248.3	147.1	0.0	61.9	.1598	.800	106.2	487.7	97.8	7.85	1.20	65.7	22.49
63000.0	759.9	5.39	248.3	147.1	0.0	61.6	.1598	.800	105.7	474.4	97.4	7.84	1.20	65.7	26.68
63500.0	897.0	6.33	248.3	147.1	0.0	61.4	.1598	.800	105.2	461.1	97.1	7.83	1.20	65.7	30.88
64000.0	1035.3	7.27	248.3	147.1	0.0	61.1	.1598	.800	104.7	447.8	96.8	7.82	1.20	65.7	34.88
64500.0	1175.0	8.21	248.4	147.2	0.0	60.8	.1598	.800	104.3	434.5	96.5	7.81	1.20	65.7	38.88
65000.0	1315.9	9.17	248.4	147.2	0.0	60.5	.1598	.800	103.8	421.4	96.1	7.80	1.20	65.7	42.79
65500.0	1457.9	10.14	248.4	147.2	0.0	60.3	.1598	.800	103.3	408.2	95.8	7.79	1.20	65.7	46.67
66000.0	1601.2	11.11	248.4	147.2	0.0	60.0	.1598	.800	102.8	395.0	95.5	7.78	1.20	65.7	50.49
66500.0	1745.6	12.09	248.4	147.2	0.0	59.8	.1597	.800	102.3	381.8	95.2	7.77	1.20	65.7	54.26
67000.0	1891.5	13.08	248.5	147.2	0.0	59.5	.1597	.800	101.9	368.7	94.9	7.76	1.20	65.7	57.98
67500.0	2038.4	14.08	248.5	147.2	0.0	59.2	.1597	.800	101.4	355.5	94.6	7.75	1.20	65.7	61.64
68000.0	2186.5	15.09	248.5	147.2	0.0	59.0	.1597	.800	100.9	342.4	94.2	7.74	1.20	65.7	65.26
68500.0	2335.8	16.10	248.5	147.2	0.0	58.7	.1597	.800	100.4	329.3	93.9	7.73	1.20	65.7	68.82
69000.0	2486.3	17.12	248.5	147.2	0.0	58.4	.1597	.800	99.9	316.3	93.5	7.72	1.20	65.7	72.32
69500.0	2638.1	18.15	248.5	147.2	0.0	58.2	.1597	.800	99.5	303.2	93.3	7.71	1.20	65.7	75.78
70000.0	2791.2	19.19	248.5	147.2	0.0	57.9	.1596	.800	99.0	290.2	93.0	7.70	1.20	65.7	79.18
70500.0	2945.5	20.24	248.5	147.2	0.0	57.6	.1596	.800	98.5	277.2	92.8	7.69	1.20	65.7	82.53
71000.0	3101.1	21.30	248.5	147.2	0.0	57.4	.1596	.800	98.1	264.2	92.5	7.68	1.20	65.7	85.82
71500.0	3258.1	22.36	248.5	147.2	0.0	57.1	.1594	.800	97.6	251.2	92.2	7.67	1.20	65.7	89.06
72000.0	3416.3	23.44	248.5	147.2	0.0	56.8	.1596	.800	97.1	238.2	91.9	7.66	1.20	65.7	92.24
72500.0	3576.0	24.52	248.5	147.2	0.0	56.6	.1596	.800	96.6	225.3	91.6	7.65	1.20	65.7	95.37
73000.0	3737.1	25.62	248.5	147.2	0.0	56.3	.1596	.800	96.2	212.4	91.4	7.64	1.20	65.7	98.44
73500.0	3899.6	26.72	248.5	147.2	0.0	56.0	.1595	.800	95.7	199.5	91.1	7.63	1.20	65.7	101.45
74000.0	4063.6	27.84	248.5	147.2	0.0	55.8	.1595	.800	95.2	186.6	90.8	7.62	1.20	65.7	104.40
74500.0	4229.2	28.96	248.5	147.2	0.0	55.5	.1595	.800	94.8	173.7	90.5	7.61	1.20	65.7	107.29
75000.0	4396.4	30.10	248.5	147.2	0.0	55.2	.1595	.800	94.3	160.9	90.3	7.60	1.20	65.7	110.11
75500.0	4565.2	31.24	248.5	147.2	0.0	55.0	.1595	.800	93.8	148.0	90.0	7.59	1.20	65.7	112.86

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PROPULSION	AERODYNAMICS				WING				WEIGHTS, LB (N)				VEHICLE TRIM SCHEDULE					
FUEL: JPT	AR=30.00	S=283.6 FT2	PAYLOAD: 200. (890.)	CL	ALTITUDE, FT/1000. (KMI)	FUEL: 400. SMP-SL	E= .700	M= 26. M2	FUEL: 500. (2224.)	CL	ALTITUDE, FT/1000. (KMI)	FUEL: 600. (3198.)	CL	ALTITUDE, FT/1000. (KMI)	FUEL: 700. (4392.)	CL	ALTITUDE, FT/1000. (KMI)	
ENGINE: (298. KU-SL)	CD0=.01500	W/S= 5.0 PSF	TOW: 1418. (6369.)	1.20	70.0 TO 70.0	AUX PI 5.0 MP (3.73 KM)			1.00	40.0 TO 70.0	1.20	70.0 TO 70.0	1.20	70.0 TO 70.0	1.20	70.0 TO 70.0	1.20	70.0 TO 70.0
64800.0	4735.7	32.40	248.5	147.2	0.0	0.0	54.7	.1595	.800	93.4	135.2	23.8	6.86	1.20	65.7	115.54		
64100.0	4908.1	33.57	248.4	147.2	0.0	0.0	54.4	.1595	.800	92.9	122.4	21.5	6.83	1.20	65.7	118.5		
64200.0	5082.3	34.76	248.4	147.2	0.0	0.0	54.2	.1594	.800	92.4	109.6	19.3	6.79	1.20	65.7	123.66		
64300.0	5256.6	35.95	248.4	147.2	0.0	0.0	53.9	.1594	.800	92.0	96.9	17.0	6.76	1.20	65.7	128.12		
64400.0	5437.0	37.17	248.4	147.2	0.0	0.0	53.6	.1594	.800	91.5	84.1	14.8	6.73	1.20	65.7	132.47		
64500.0	5617.6	38.39	248.3	147.1	0.0	0.0	53.4	.1594	.800	91.0	71.4	12.6	6.69	1.20	65.7	137.72		
64600.0	5800.8	39.64	248.3	147.1	0.0	0.0	53.1	.1594	.800	90.6	58.7	10.3	6.66	1.20	65.7	143.07		
64700.0	5986.7	40.90	248.3	147.1	0.0	0.0	52.8	.1594	.800	90.1	46.0	8.1	6.62	1.20	65.7	148.49		
64800.0	6175.6	42.19	248.3	147.1	0.0	0.0	52.6	.1593	.800	89.6	33.3	5.9	6.59	1.20	65.7	153.89		
64900.0	6368.1	43.49	248.2	147.1	0.0	0.0	52.3	.1593	.800	89.2	20.7	3.6	6.56	1.20	65.7	159.30		
65000.0	6564.9	44.83	248.2	147.1	0.0	0.0	52.0	.1593	.800	88.7	8.0	1.4	6.52	1.20	65.7	164.71		
65075.7	6693.8	45.71	248.2	147.1	0.0	0.0	51.9	.1593	.800	88.5	.0	.0	6.49	1.20	65.7	170.12		

EXTREME JPT-FUELED CONFIGURATION

ALT.	RANGE	TIME	TRUE AIRSPEED	R/C	GAMMA	E. POWER	SFC	ETA-P	THRUST	FUEL IN TANKS	W/S	CL	THROTTLE	BOILOFF
(FT)	N MI	(HR)	(FPS)	(KTS)	(DEG)	(HP)	(LB/HR)	(HR)	(LB)	(LB)	(PSF)	%	%	(LB)
10000.0	0.0	0.00	77.2	45.8	2529.6	33.1	147.3	.5149	.800	810.9	100.0	.80	25.0	0.00
15000.0	1.2	.03	85.2	50.5	2514.5	29.5	146.6	.4652	.800	731.4	99.5	.80	25.0	0.00
20000.0	2.8	.07	94.1	55.7	2461.2	25.9	146.5	.4239	.800	652.4	99.1	.80	25.0	0.00
25000.0	4.7	.10	104.2	61.8	2287.8	21.5	136.1	.4046	.800	553.4	98.7	.80	25.0	0.00
30000.0	7.1	.14	115.6	68.5	2032.7	17.0	123.6	.3763	.800	451.4	98.3	.80	25.0	0.00
35000.0	10.6	.19	128.7	76.3	1359.5	10.1	89.2	.4263	.800	287.9	97.9	.80	25.0	0.00
40000.0	16.5	.26	144.9	85.9	930.0	6.1	67.9	.4607	.800	191.1	97.4	.80	25.0	0.00
45000.0	24.5	.31	165.6	96.2	1831.9	14.3	117.7	.4121	.800	387.2	97.4	.80	25.0	0.00
50000.0	27.2	.39	164.6	97.5	1373.3	9.0	90.6	.4365	.800	258.7	96.9	.80	25.0	0.00
55000.0	38.3	.49	185.7	110.0	632.3	3.3	55.4	.4583	.800	174.0	96.4	.80	25.0	0.00
60000.0	50.7	.67	209.4	124.0	354.0	1.6	43.1	.4867	.800	119.4	95.8	.80	25.0	0.00
65000.0	108.1	1.04	235.6	139.6	128.3	.5	33.8	.4978	.800	80.0	95.0	.80	25.0	0.00
68000.0	216.1	1.78	252.4	149.5	27.6	.1	28.9	.4693	.800	40.7	93.6	.80	25.0	0.00

VOLUMES: FT3 (M3): PAYLOAD= 8.89 (.25171) TANK= 11.45 (.32421) BALLOON= 67619. (1915.)

CRUISE STARTS HERE														
ALT.	RANGE	TIME	TRUE AIRSPEED	R/C	GAMMA	E. POWER	SFC	ETA-P	THRUST	FUEL IN TANKS	W/S	CL	THROTTLE	BOILOFF
(FT)	N MI	(HR)	(FPS)	(KTS)	(DEG)	(HP)	(LB/HR)	(HR)	(LB)	(LB)	(PSF)	%	%	(LB)
68000.0	216.1	1.78	230.4	136.5	0.0	0.0	27.1	.4831	.800	42.2	91.3	1.20	62.6	0.00
65000.0	602.8	4.61	230.3	136.5	0.0	0.0	26.5	.4826	.800	41.0	83.9	1.20	62.6	0.00
69000.0	996.4	7.50	230.0	136.3	0.0	0.0	25.9	.4815	.800	39.9	76.7	1.20	62.6	0.00
69388.0	1397.3	10.45	229.6	136.0	0.0	0.0	25.2	.4803	.800	38.8	69.4	1.20	62.6	0.00
70000.0	1905.8	13.46	229.2	135.8	0.0	0.0	24.6	.4790	.800	37.7	62.2	1.20	62.6	0.00
70000.0	2166.7	16.14	227.5	134.8	0.0	0.0	24.3	.4791	.800	37.3	56.0	1.20	61.1	0.00
70000.0	2532.9	18.89	224.6	133.0	0.0	0.0	23.5	.4806	.800	36.3	49.8	1.20	58.1	0.00
70000.0	2904.6	21.72	221.6	131.3	0.0	0.0	22.8	.4822	.800	35.3	43.6	1.20	55.1	0.00
70000.0	3281.8	24.63	218.6	129.5	0.0	0.0	22.1	.4839	.800	34.4	37.3	1.20	52.2	0.00
70000.0	3663.1	27.62	215.5	127.7	0.0	0.0	21.4	.4875	.800	33.4	31.1	1.20	47.8	0.00
70000.0	4043.7	30.64	212.4	125.9	0.0	0.0	20.7	.4977	.800	32.5	24.9	1.20	38.4	0.00
70000.0	4423.3	33.71	209.3	124.0	0.0	0.0	20.0	.5084	.800	31.5	18.7	1.20	29.1	0.00
70000.0	4799.2	36.78	206.1	122.1	0.0	0.0	19.3	.5231	.800	30.6	12.4	1.20	25.0	0.00
70000.0	5169.2	39.86	202.8	120.2	0.0	0.0	18.7	.5420	.800	29.6	6.2	1.20	25.0	0.00
70000.0	5533.2	42.94	199.5	118.2	0.0	0.0	18.0	.5618	.800	28.7	.0	1.20	25.0	0.00

INTERPOLATION OUT OF RANGE 3 TIMES

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TABLE I - BASELINE VEHICLE CHARACTERISTICS

Aerodynamic characteristics

C_L schedule:

Sea level to 40,000 ft	0.8
40,000 to 70,000 ft	1.0
Cruise-climb or 70,000 ft	1.2

$C_{D,o}$	0.015
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Oswald efficiency factor	0.8
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Propulsion system

Engine power (sea level to 10,000 ft), hp	660.
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Power supplied to systems and payload, hp	2.
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Throttle schedule for climb, percent:

Sea level to 40,000 ft	25.
40,000 ft to 70,000 ft	100.

Vehicle P/W, hp/lbf	0.22
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Propeller efficiency factor, η_p	0.8
---	-----

Geometry and weights

Wing:

Aspect ratio	20.
Reference area, ft^2	375.
Span, ft	86.6

Weights, lbf:

Payload	200.
Engine, systems, and propeller	367.
Structure and systems	1200.
Fuel, fuel system and tank	1233.
Takeoff gross	3000.

Wing loading at takeoff gross weight, lbf/ft^2	8.
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TABLE II. - FUEL AND FUEL-SYSTEM CHARACTERISTICS

FUEL	JP-7	LIQUID METHANE	LIQUID HYDROGEN
Heating value, Btu/lbf	18604	21518	51593
Storage temperature, OF	ambient	-259	-423
Storage pressure, PSI		50	50
Heat of vaporization, Btu/lbf.		3271	172
Fuel specific volume, ft ³ /lbf.	.023	.042	.251
Specific weight of tank and fuel system lbf/lbf-fuel	.086	0.25	1.17
Usable tank volume, percent	100	90	90

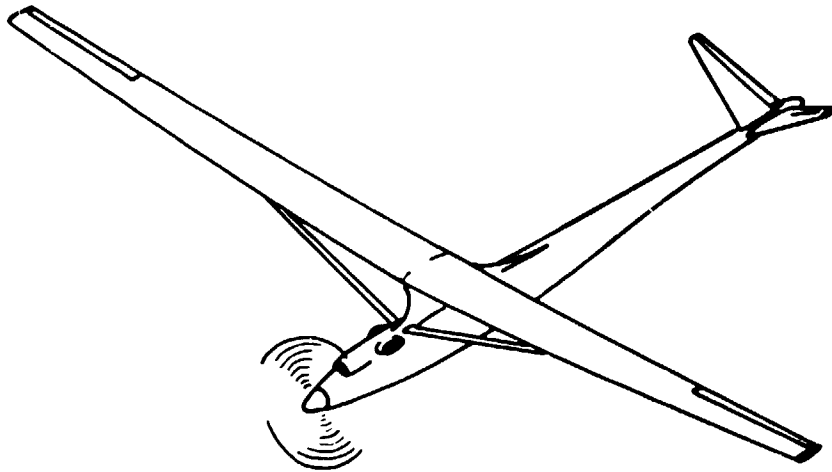
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TABLE III - FLIGHT PROFILE AND PERFORMANCE OF BASELINE CONFIGURATION

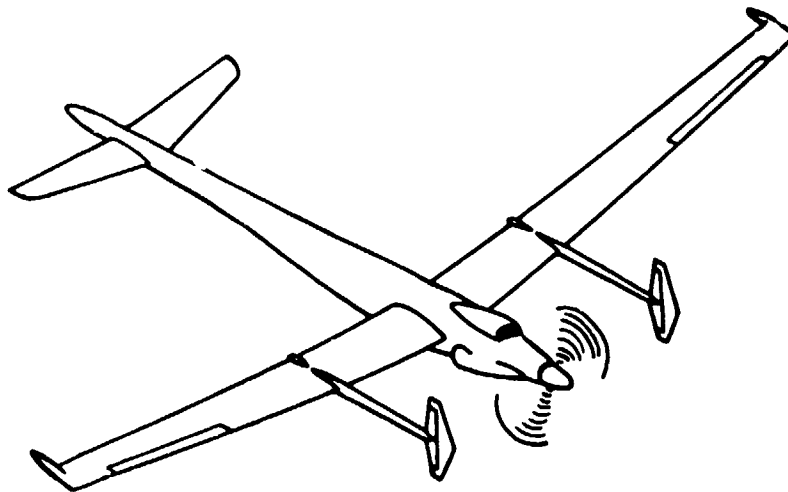
FUEL	JP-7	LIQUID METHANE	LIQUID HYDROGEN
Takeoff:			
Wing loading, lbf/ft ²	8.0	8.0	8.0
Fuel weight, lbf	1136.	984.	568.
60,000 feet:			
Wing loading, lbf/ft ²	7.8	7.8	7.9
Fuel remaining, percent	93.	93.	94.
Elapsed time, hr.	1.3	1.3	1.4
Initiation of cruise-climb, ft.	61,000	61,000	61,000
Fuel-exhaustion point:			
Wing loading, lbf/ft ²	5.0	5.4	6.5
Altitude, ft	70000.	68896.	65075.
Cruise segment:*			
Endurance, hr.	43.36	42.85	44.36
Range, n.mi.	6346.	6283.	6533.

*Note: endurance and range after vehicle reaches 60,000 feet altitude.

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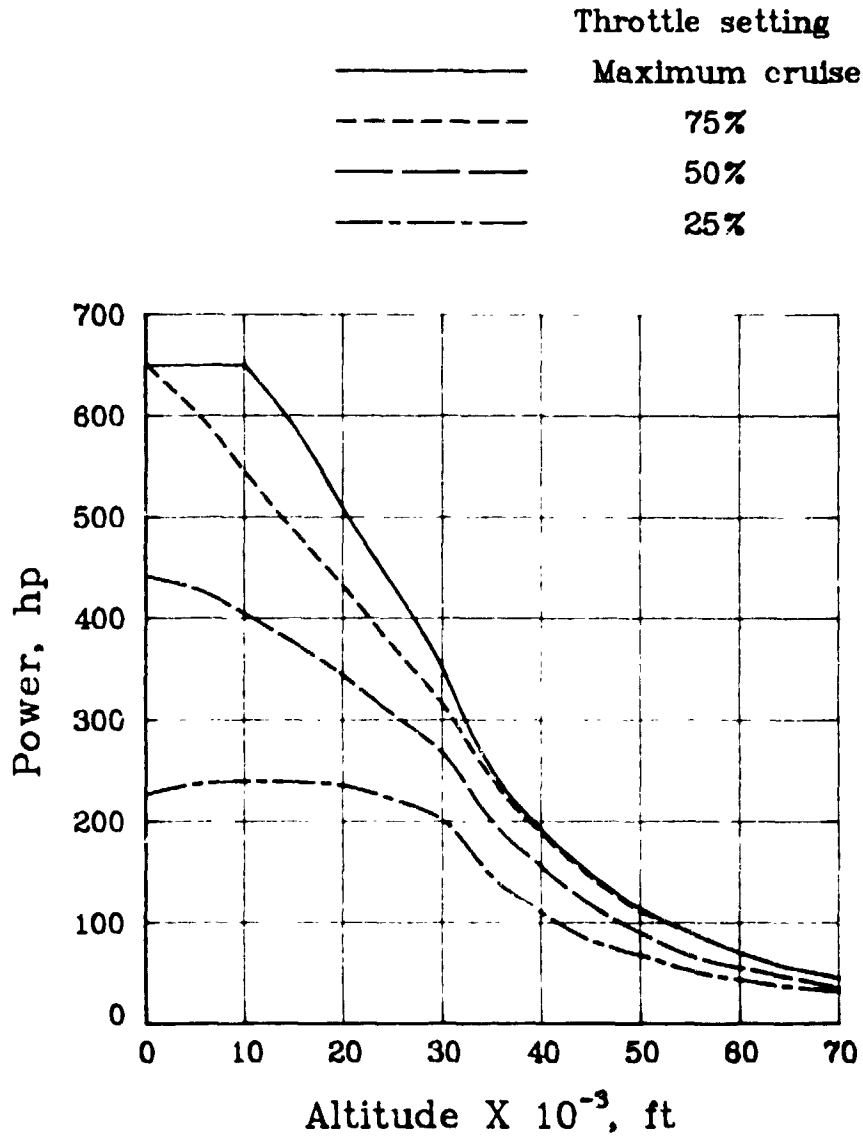
(a) Tractor-propeller configuration



(b) Pusher-propeller configuration

Figure 1.- Representative vehicle designs that correspond to baseline configuration specifications.

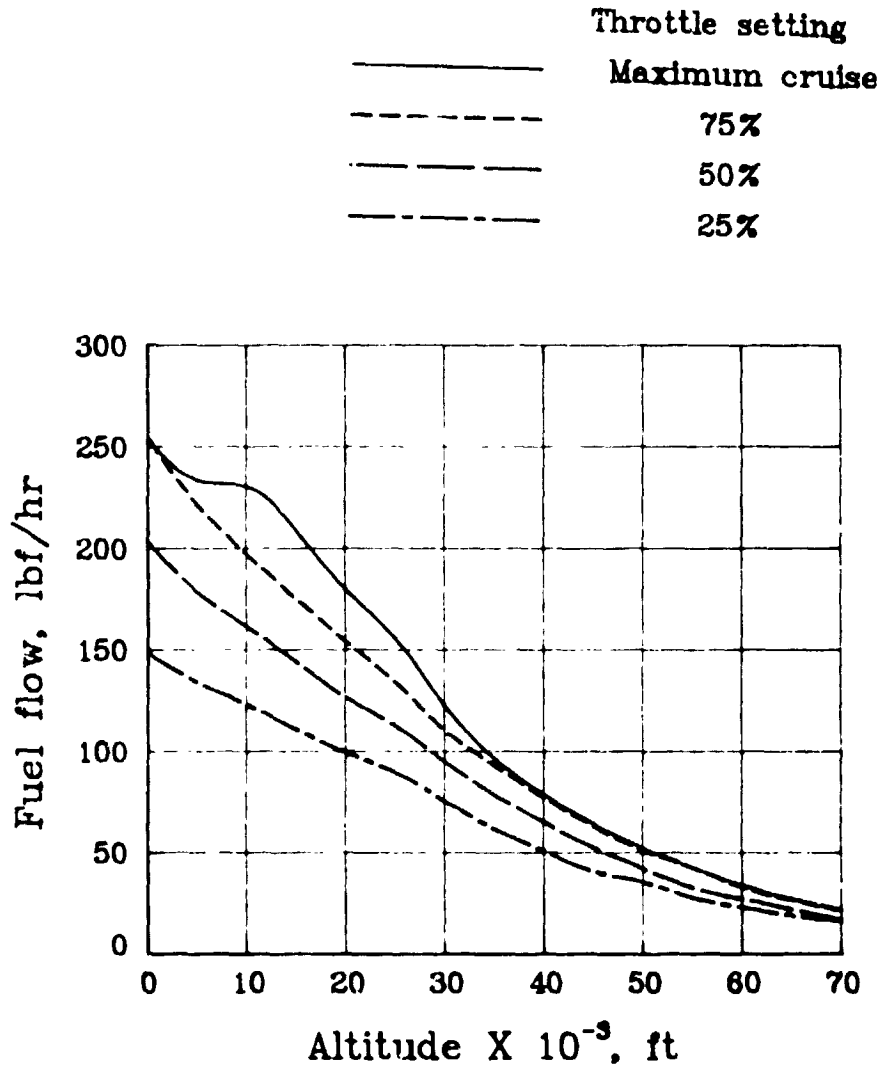
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(a) Available engine power for all fuels.

Figure 2. - Performance of 550 horsepower engine.

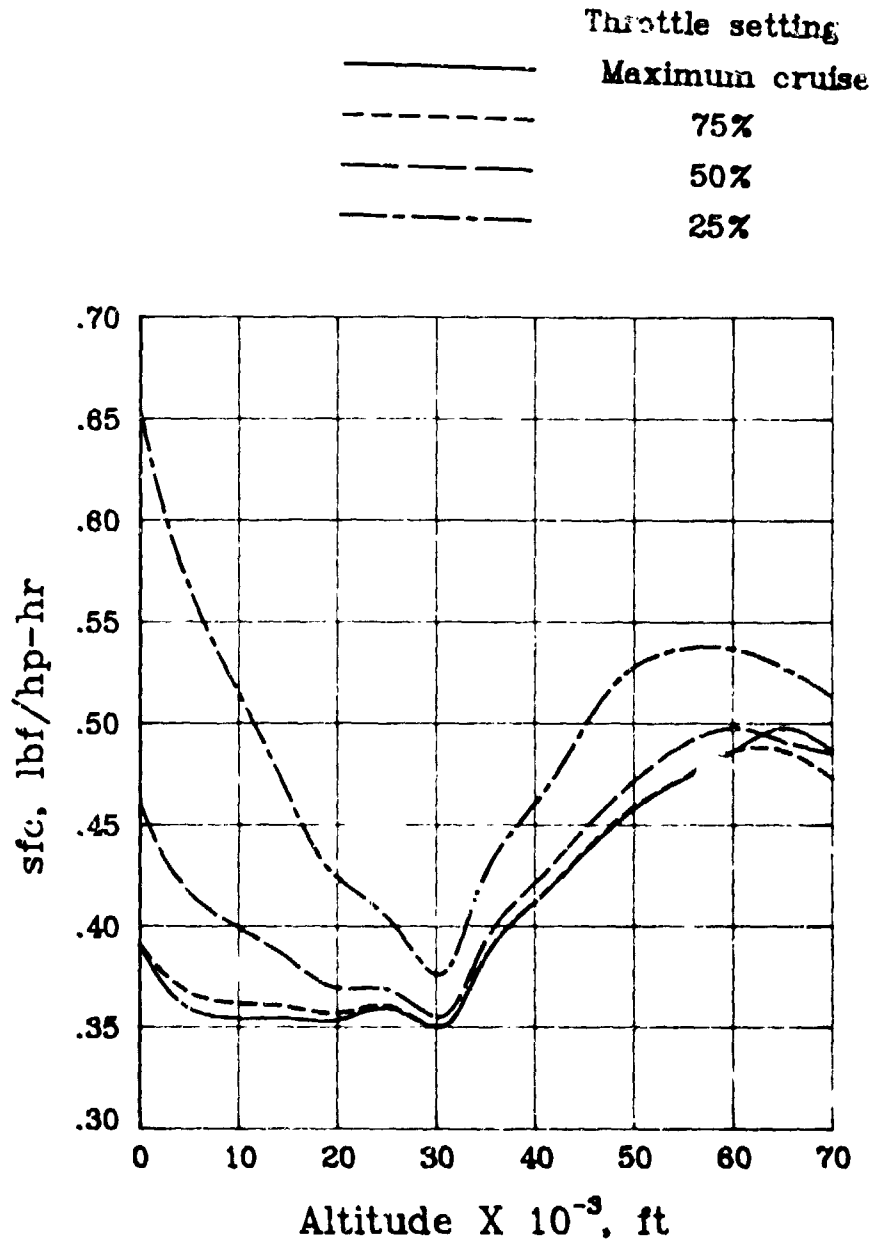
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(b) Fuel flow for JP-7 fuel. (Fuel flow for other fuels is proportional to heating value.)

Figure 2. - Continued.

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(c) Specific fuel consumption for JP-7 fuel. (Specific fuel consumption for other fuels is proportional to heating values.)

Figure 2. - Concluded.

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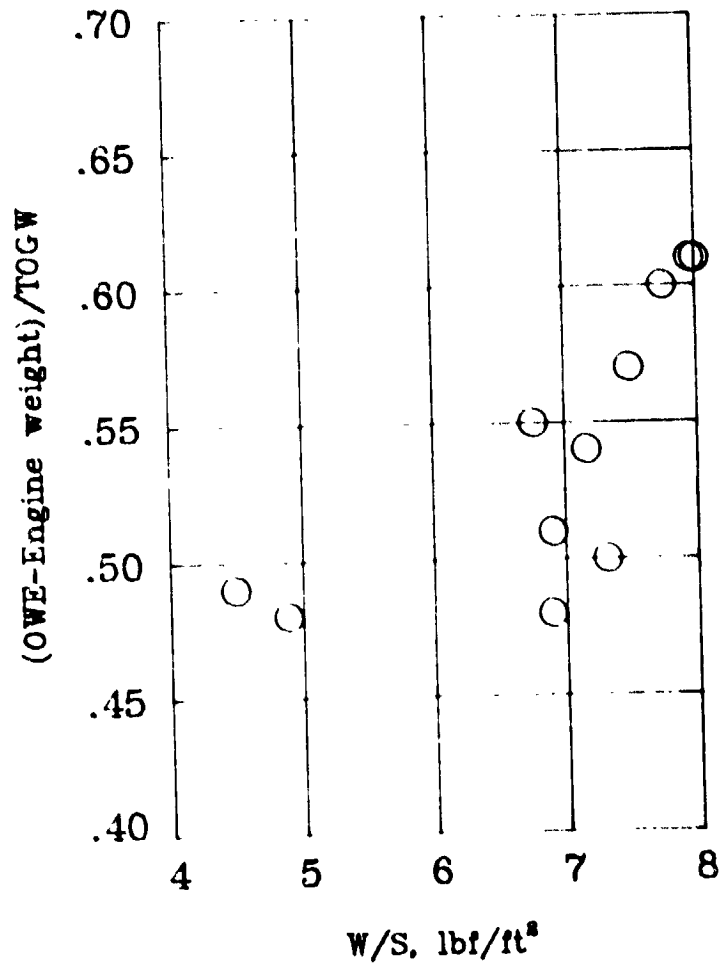


Figure 3. - Weight data for current conventional motor gliders.

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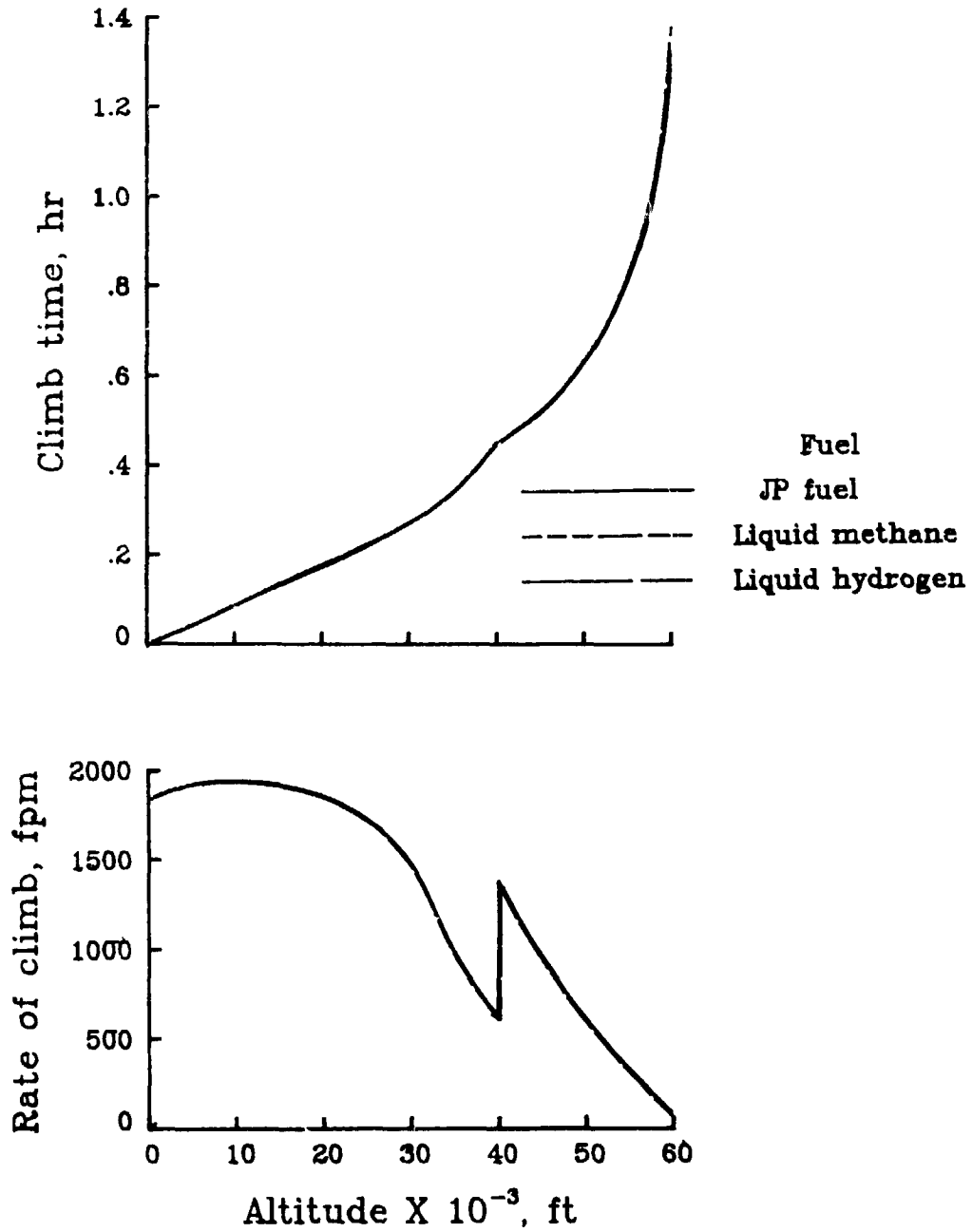


Figure 4. - History of flight parameters for baseline configuration.

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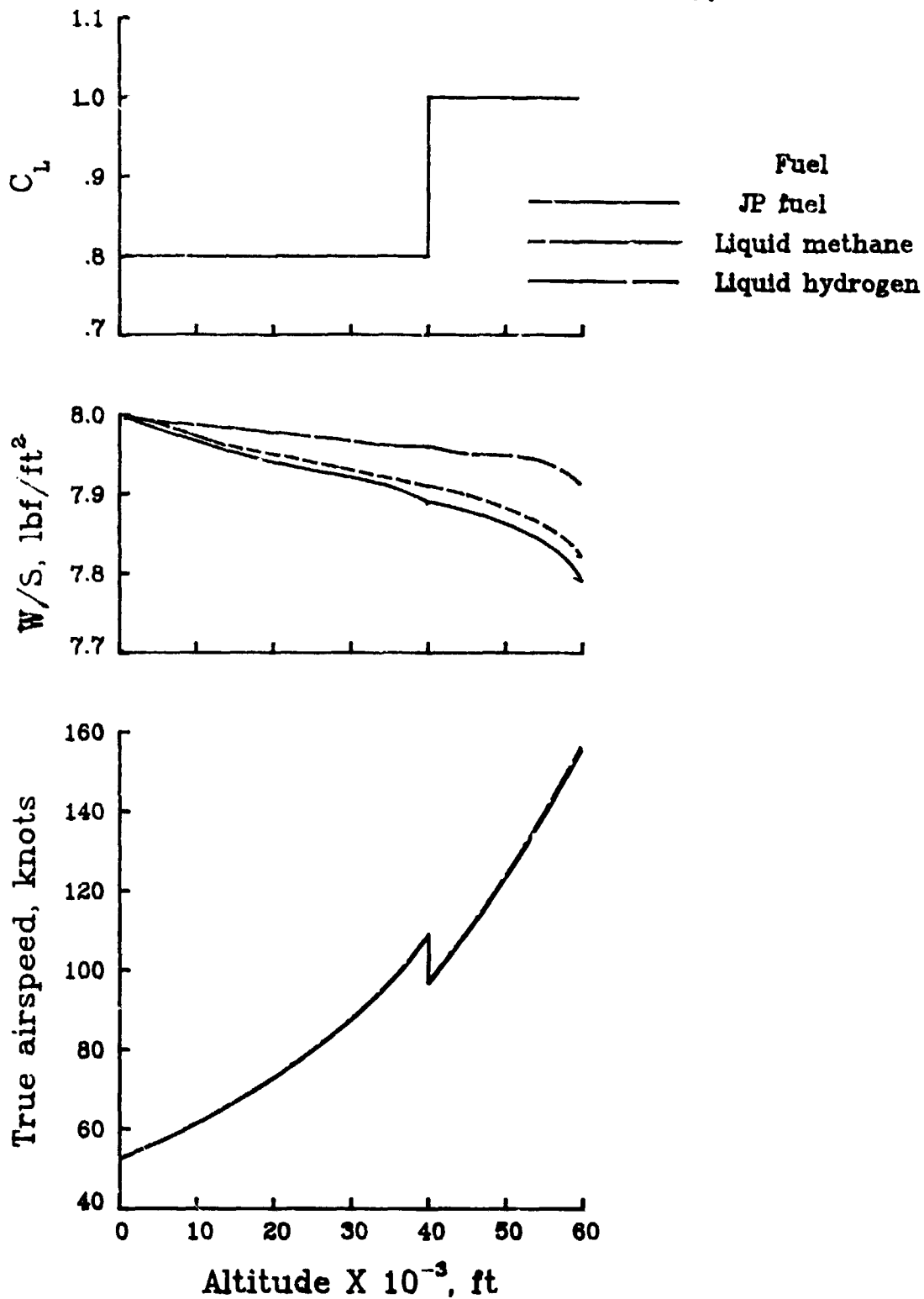


Figure 4. - Continued.

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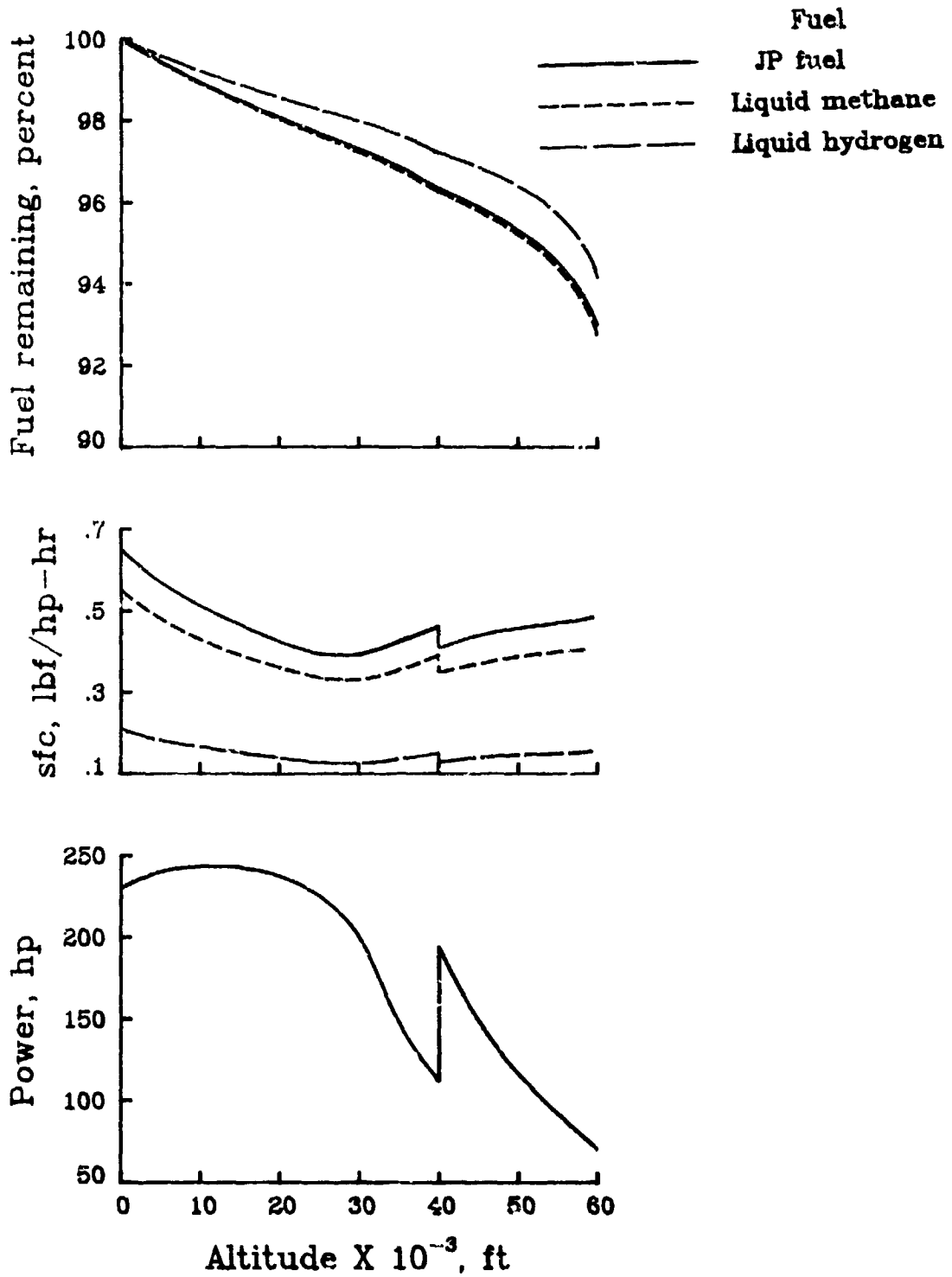


Figure 4. - Concluded.

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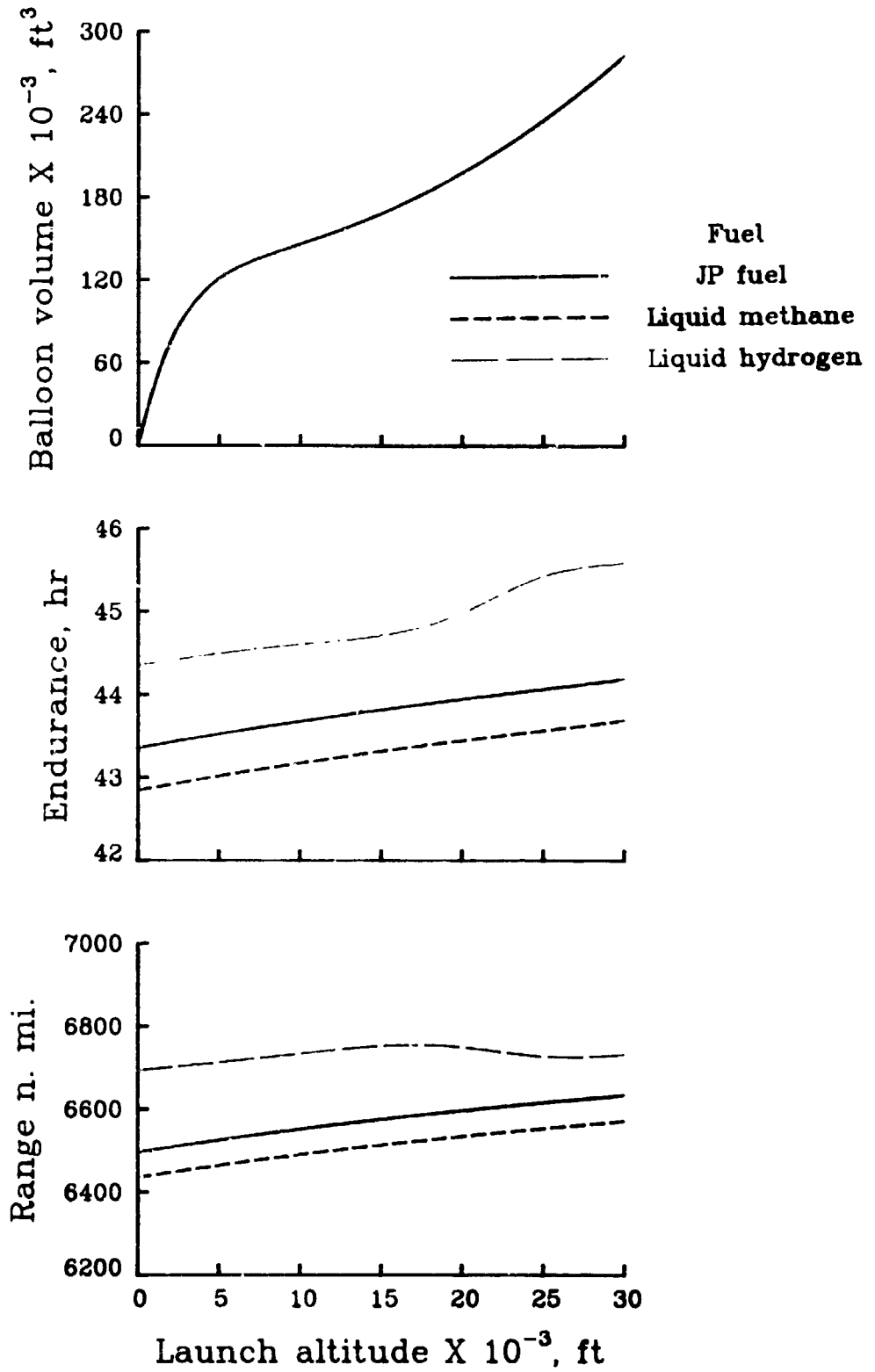


Figure 5. - Effect of balloon assisted launch.

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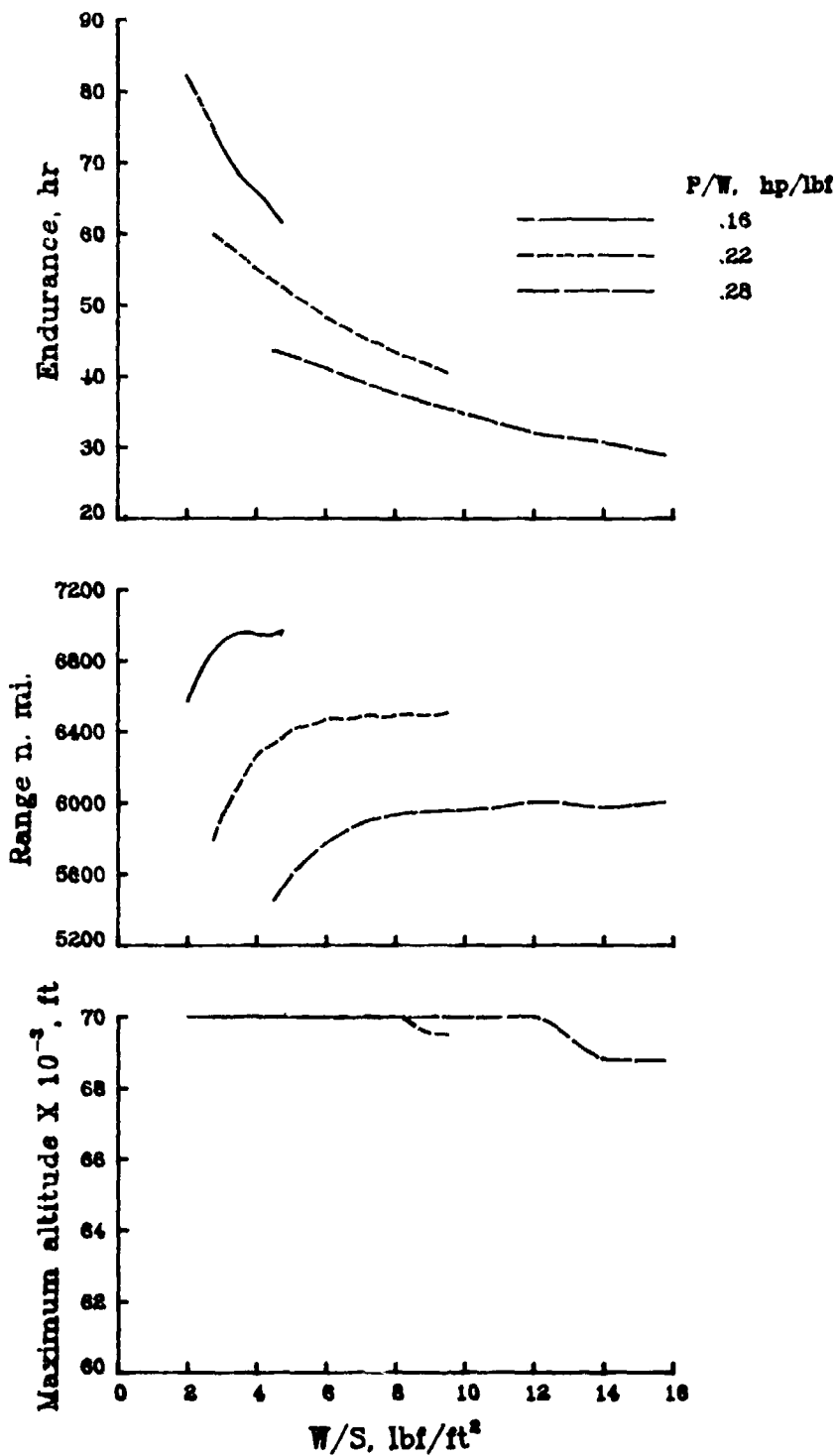


Figure 6.- Variation of endurance, range and maximum attainable altitude with both power loading and wing loading for JP-7 fueled vehicles. TOGW = 3000 lbf.

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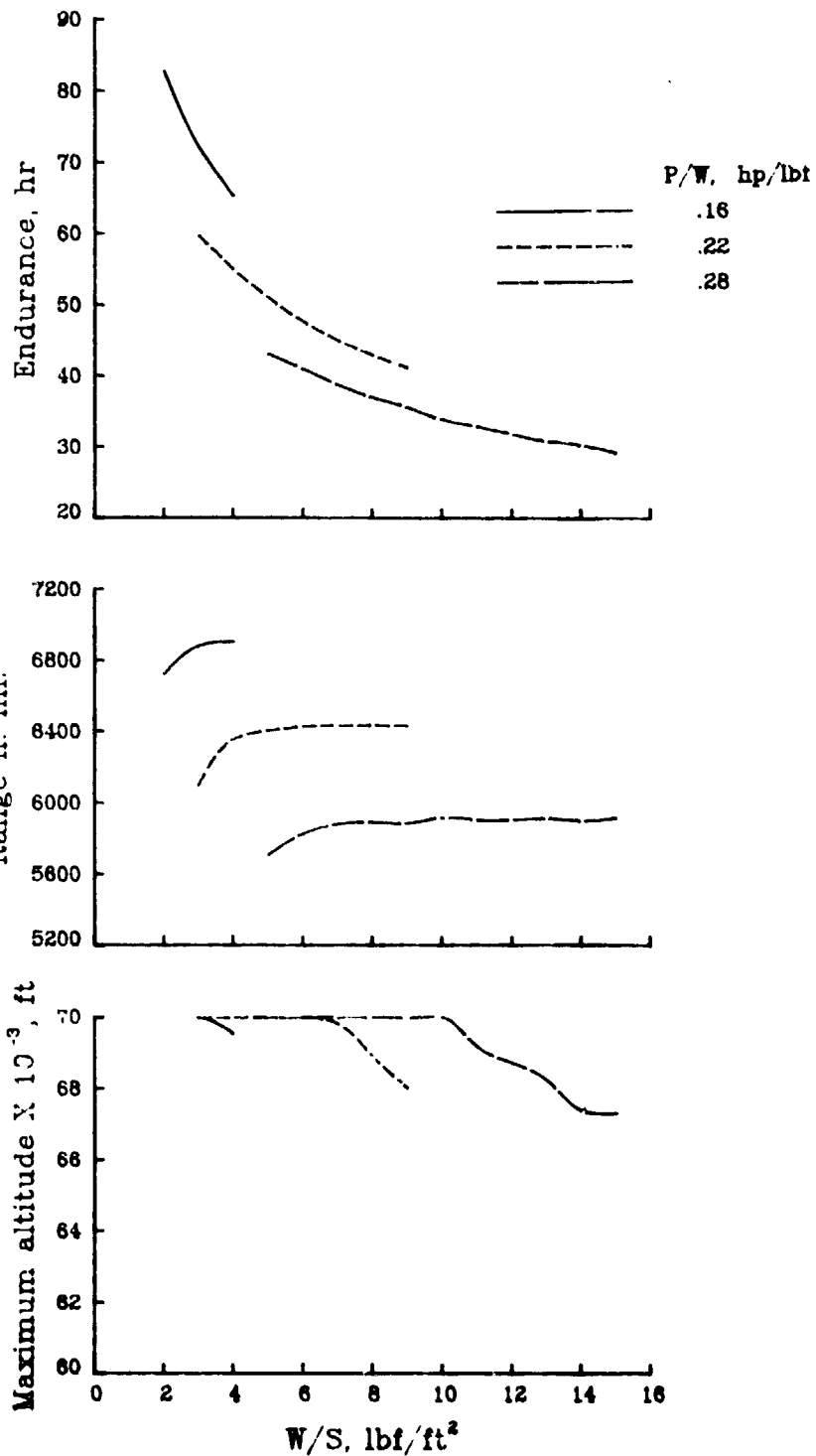


Figure 7.- Variation of endurance, range and maximum attainable altitude with both power loading and wing loading for liquid-methane fueled vehicles. TOGW = 3000 lbf.

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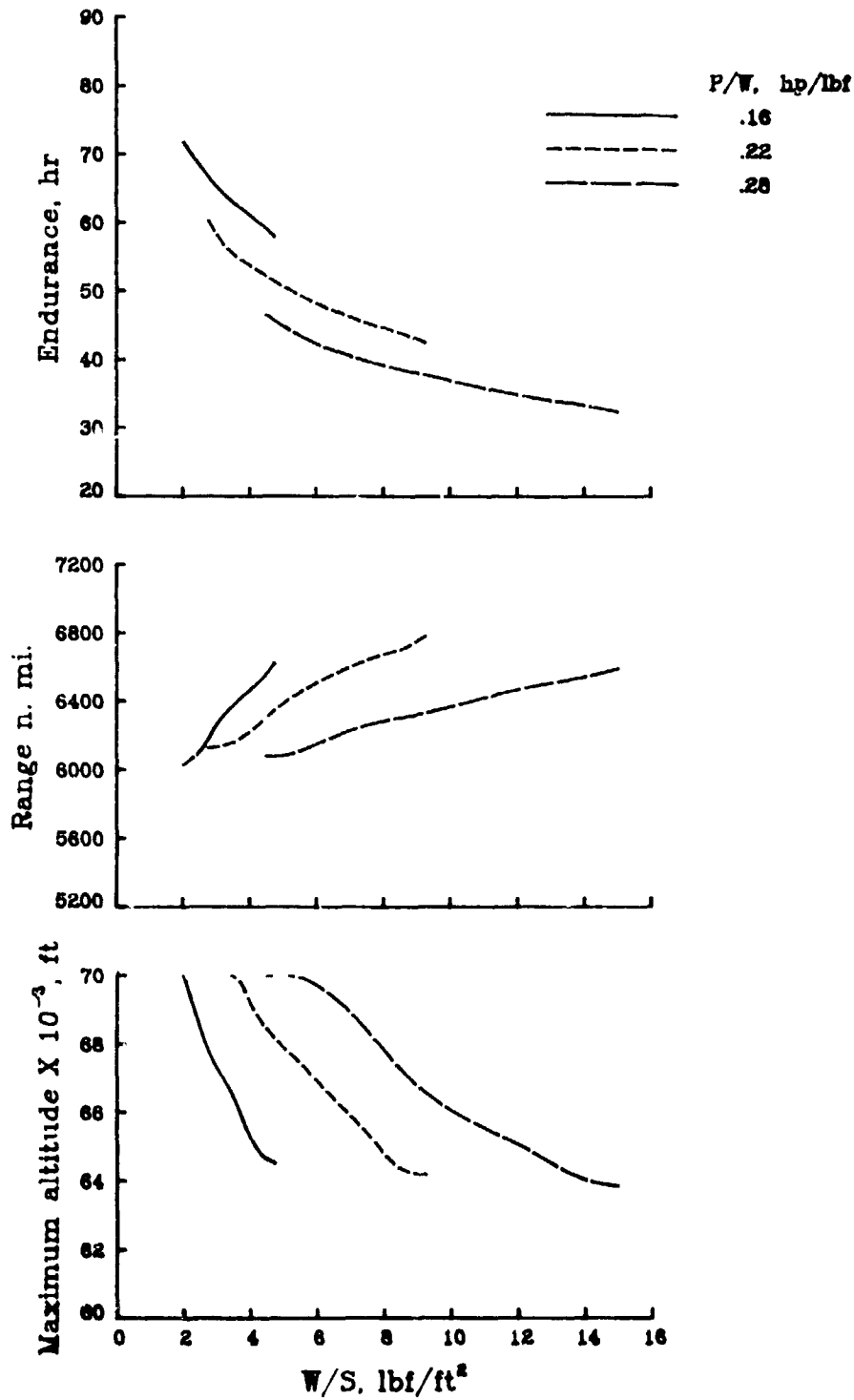


Figure 8.- Variation of endurance, range and maximum attainable altitude with both power loading and wing loading for liquid-hydrogen fueled vehicles. TOGW = 3000 lbf.

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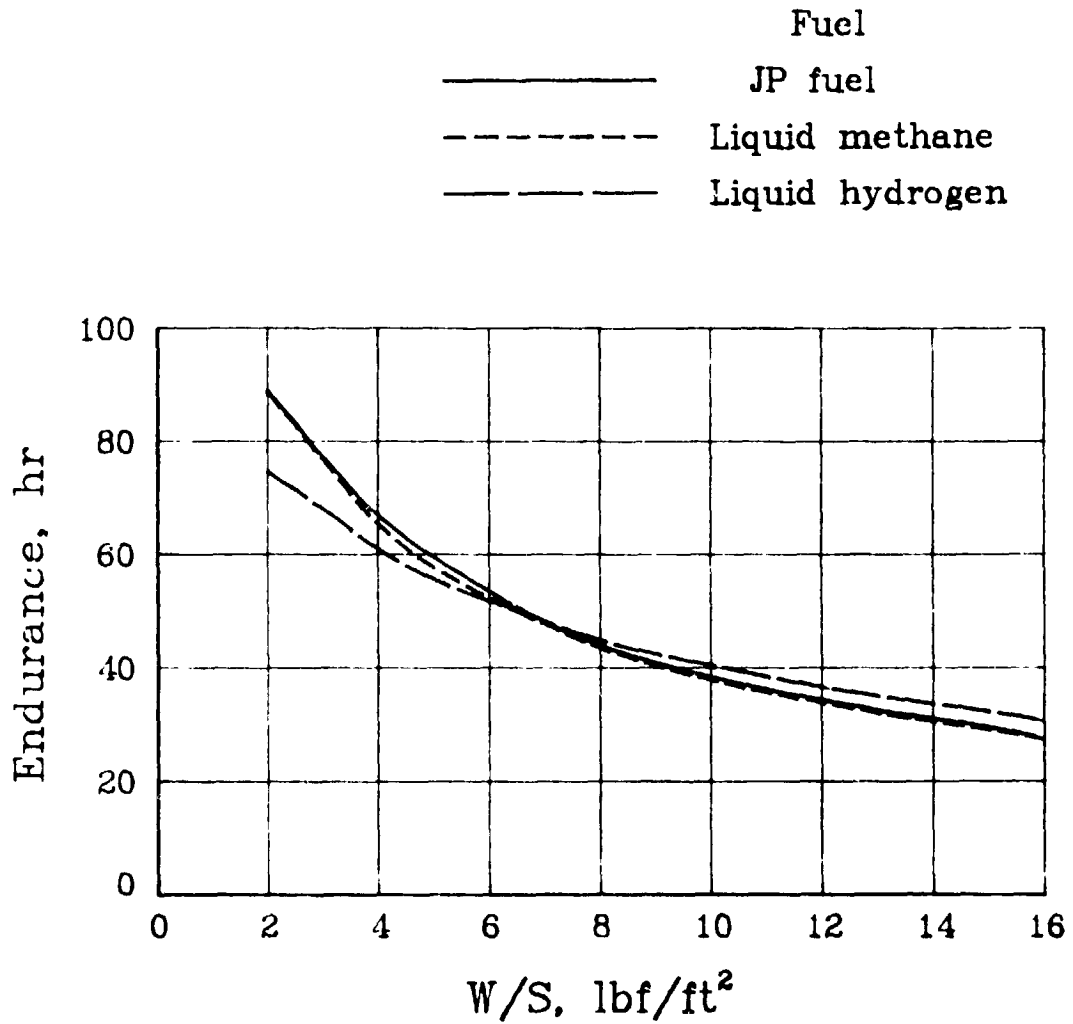
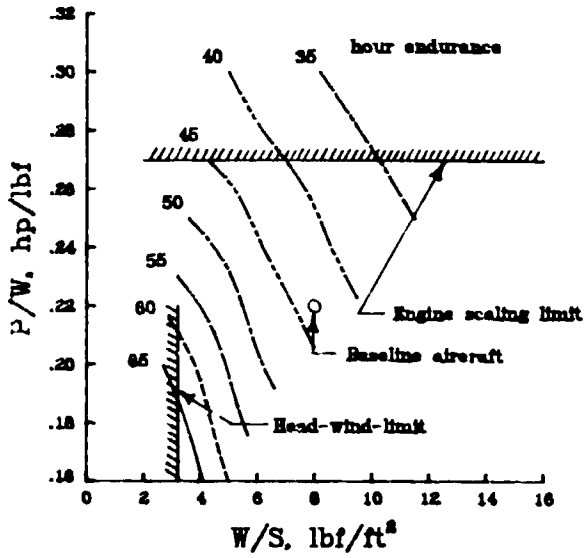
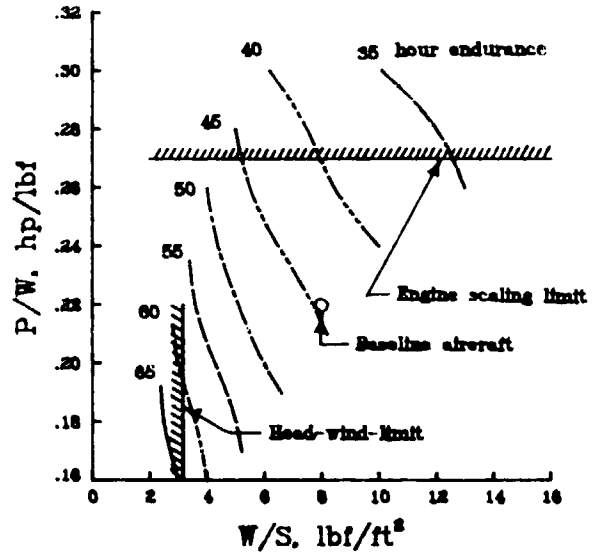


Figure 9.- Variation of maximum endurance with wing loading for three different fuel systems.

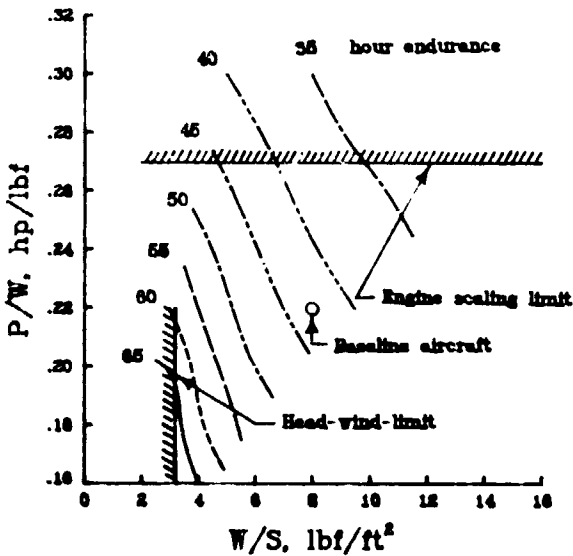
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(a) JP-7 fuel



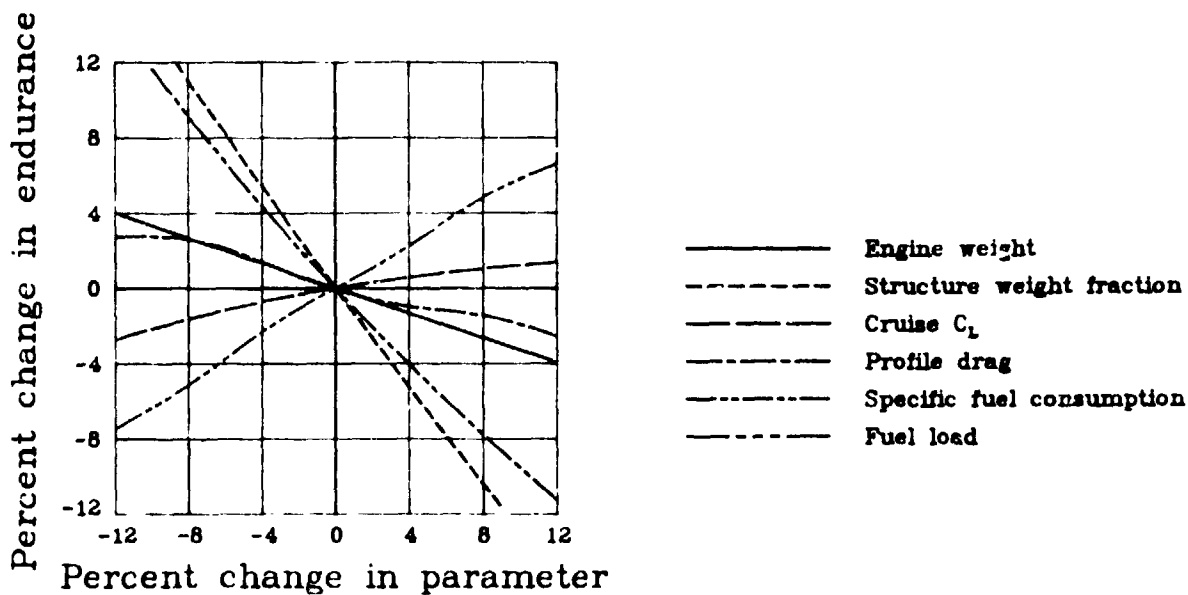
(c) Liquid hydrogen



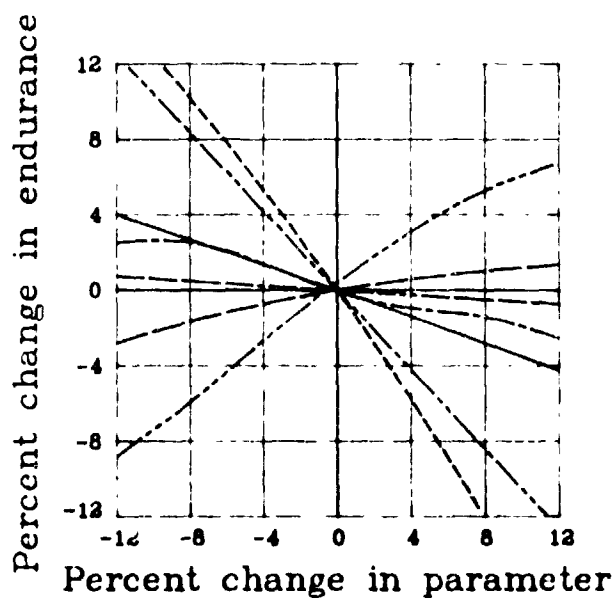
(b) Liquid methane

Figure 10.- Effect of variation in takeoff wing loading and power loading on endurance. TOGW = 3000 lbf.

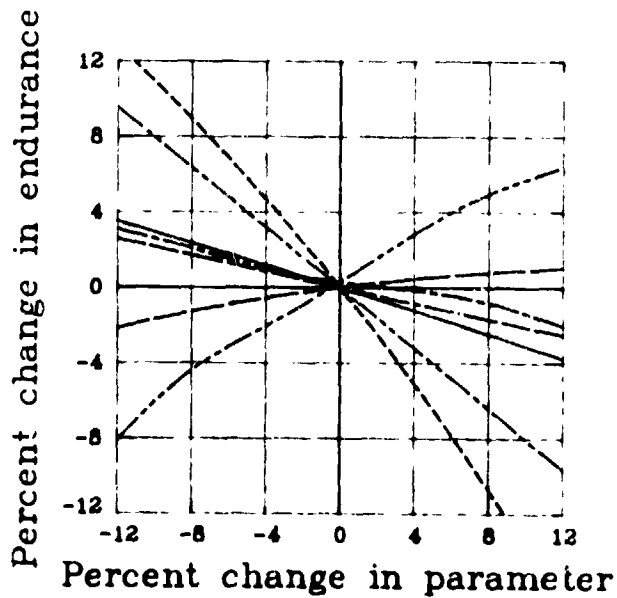
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(a) JP-7 fuel



(b) Liquid methane



(c) Liquid hydrogen

Figure 11.- Effect on endurance of changes in various parameters from baseline values.

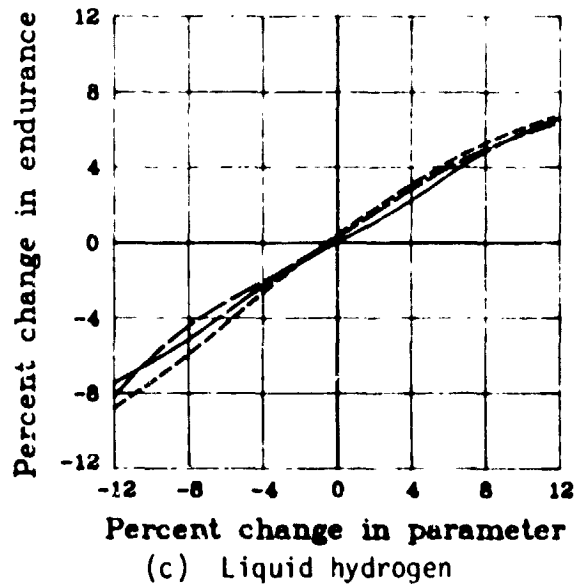
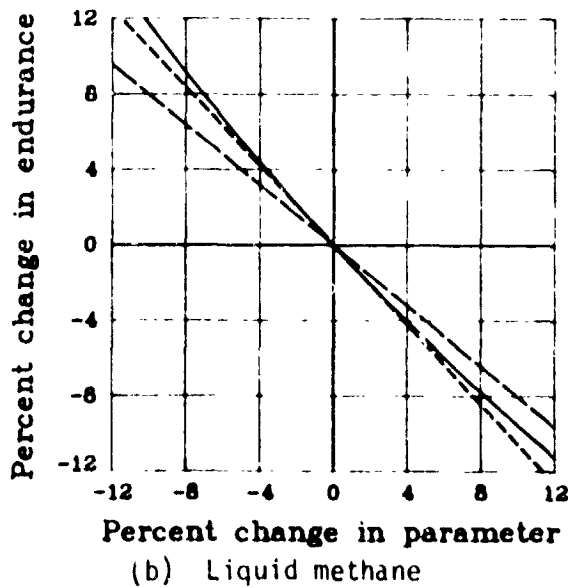
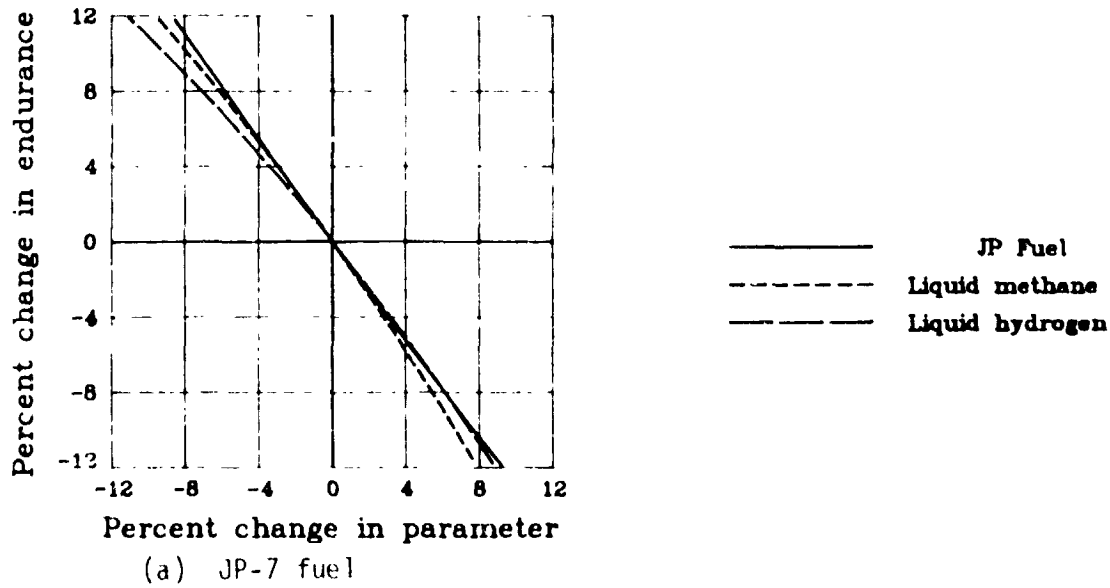


Figure 12.- Effect on endurance of changes in various parameter for three different fuel systems.