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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 (CH_4), and liquid hydrogen (H_2)) 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, combusters, 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/in^2 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-F^o-ft^2 and density of 2.3 lb/ft^3. 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-gliders 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 consistant, 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/ft^2 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/ft^2. 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.

```
      PROGRAM CHAAP(INPUT,OUTPUT,TAPE5=INPUT,TAPE6)
C
C     PROGRAM FOR CALCULATION OF FLIGHT PROFILE AND ASSOCIATED PARAMETER
C
C
C
      DIMENSION ABC(5), ACB(3), SFCTANK(3)
      DIMENSION SFCVOL(3)
C
      COMMON/BL/BOIL,BOILT,BOILA
      COMMON /AERO/ CL,CD,RHO,S,D,THRUST,HA,HB,VA
      COMMON /ENG/ PAC,ETAP2,KPOW,SFCENG,SFC,SFCA,FLOW,FLOWA,POWSET,KFUE
     1L,HMAX
      COMMON /WEIGH1/ WA,DW,WB,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),
     .  PROPT(2,9,6)
      COMMON/SYS/TA,RHA,TIN,RHIN,RADIUS,VOLTANK,AREAT,RATIO,CONDUCT
      COMMON/PIC/PI
C
      NAMELIST /DE/ TOTALWF,WPAYLD,HSTART,CL1,H2,CL2,H3,CL3,CDO,AR,WOS,K
     1FUEL,ENGSIZE,ETAP,PAC,KPOW,KGW,GW,KPOWCC,SWF,SFCTANK,DELTI,DELHI
      NAMELIST/IN/CONDUCT,PSI,RATIO,TA,RHA,TIN,RHIN,WSYS
C
C     DESCRITION 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     CDO= VEHICLE PROFILE-DRAG COEFFICIENT
C     ENGSIZE= 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     WPAYLD= PAYLOAD WEIGHT, LB
C
C     CONDUCT= CONDUCTIVITY,BTU-FT/HR-DEGREE F-FT2
C     PRESSURE= PSI
C     RATIO= FINESS 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
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ORIGINAL PAGE
OF POOR QUALITY

```
C
      DATA TOTALWF,WPAYLD,HSTART,CL1,H2,CL2,H3,CL3,CDO,AR,WOS,KFUEL,ENGS
     1IZF,ETAP,PAC,KPOW,KGW,GW,KPOWCC,SWF/1000.,200.,0.0,.80,40000.,1.0,
     270000.,1.2,.015,20.,8.,1,660.,.8,2.,3,1,3000.,3,.4/
      DATA DELTI,DELHI/1000.,500./
C
      DATA ACB/10HJP7        ,10HMETHANE   ,10HHYDROGEN  /
C
C     SECTANK= TANK WEIGHT PER UNIT FUEL WEIGHT
C     SECVOL= FUEL VOLUME PER UNIT FUEL WEIGHT, FT3/LB
C     ....FOR JP7,CH4,THEN H2
C
      DATA SECTANK/0.0855,0.2441,1.241/
      DATA SECVOL/0.0229,0.0418,0.2509/
C
C     DATA DESCRIBING 1962 ATMOSPHERE (IN METRIC UNITS)
C
C     TEMPERTURES, TK, GIVEN IN DEGREES K AT ALTITUDES, ALTT, GIVEN IN K
C     PRESSURES AND DENSITY DATA FOR EXPONENTIAL CURVE-FIT METHOD LISTED
C     IN TABLES P1,P2,D1, AND D2 FOR ALTITUDES (ALT) GIVEN IN KM
C
      DATA ALTT/0.,11.,20.,32./
      DATA TK/288.15,216.65,216.65,228.65/
      DATA P1/.118382401,.118382401,.117983950,.117313461,.116307412,.11
     15262468,.116634912,.121226411,.126132247,.129873961,.132819468,.13
     25855970,.139009744,.141631531,.14384007/
      DATA P2/.1468131,.1468131,.1567744,.1679492,.1805248,.1909742,.178
     14975,.1402350,.1051933,.0818076,.0654437,.0502612,.0359258,.025001
     27,.0165073/
      DATA D1/.0958648,.0958648,.09553324,.094992534,.094171454,.0933534
     18,.066937005,.07707,.087963845,.09618994,.102713697,.104454366,.11
     2078 9734,.116073981,.120579001/
      DATA D2/.11869,.11869,.1269793,.1359911,.1462546,.1544343,.3945841
     1,.3101418,.2323292,.1809161,.144673,.1359697,.1071724,.0851547,.06
     278277/
      DATA ALT/0.,2.,4.,6.,8.,10.,11.,12.,14.,16.,18.,20.,22.,24.,26./
C
C     PROPT= THERMODYNAMIC PROPERTIES OF LIQUID HYDROGEN,
C     AND LIQUID METHANE .
C     PROPT FOR LIQUID METHANE,TEMPERATURE DEGREE K,PRESSURE KN/M2,
C     DENSIDTY KG/CM3,ENTHALPY KJ/KG.
C     PROPT FOR LIQUID HYDROGEN DEGREE K,PRESSURE MPA,DENSITY KG/M3
C     (LIQUID,GAS), ENTHALPY KJ/KG (LIQUID, GAS).
C
      DATA((PROPT(1,I,J),J=1,6),I=1,9) /
     . 100.,34.856,.441,.000685,3963.1,12469.2,
     . 105.,57.249,.433,.000825,4235.9,12621.0,
     . 110.,89.267,.426,.001611,4511.2,12754.9,
     . 115.,133.648,.419,.002334,4789.,12878.4,
     . 120.,193.024,.412,.003274,5070.2,12994.7,
     . 125.,270.436,.404,.004466,5355.5,13104.3,
     . 130.,368.924,.397,0.005977,5645.5,13208.1,
     . 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0./
```

```
      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,-237.9,197.2,
     ,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.,.4035,62.8337,4.9215,-185.9,203.1,
     . 0.,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; CRITER ON FOR PRINT-OUT OF RESULTS
C
      L=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 108 KFL=2,3
      CALL INTERP(PSI,PROPT,KFL,1)
      CALL INTERP(14.69,PROPT,KFL,0)
108   CONTINUE
C
77    READ (5,42) ABC
      IF (EOF(5)) 41,2
2     READ (5,DF)
      READ (5,IN)
      TA=TA/12.
      TIN=TIN/12.
      KPOWCC=3
C
      FLOW=0.
      THCM=0.
      ENDU=0.
      ROIL=0.
```

```
      BOILT=0.
      ETAP2=ETAP
C
C      INITIALIZE PARAMETERS
C
4     CL=CL1
      AGOLD=GAMMA=RFUEL=0.
      RC=V=VX=0.
      VKT=0.
      T=TH=X=0.
      DELH=DELTI
      KK=-1
      KC=KEC=KODE=KOUNT=0
      KPOW=4
C
C      EMPIRICAL ADJUSTMENT TO OSTWALD EFFICIENCY FACTOR,
C
      E=1.-.01*AR
      SFCENG=ENGSIZE/650.
      WPROPUL=(SFCENG*225.)*1.3+70.
C
C      WEIGHT CALCULATION
C
      IF (KGW.NE.1) GO TO 5
C      GROSS WEIGHT SPECIFIED
      WSYS=GW*(1.-SWF)-WPAYLD-WPROPUL
      IF(KFUEL.EQ.1) GO TO 81
      CALL SYSTEM(PROPT((KFUEL-1),9,3),WSYS,WFUEL,1)
      GO TO 82
81    WFUEL=WSYS/(1.+SFCTANK(1))
      VOLTANK=SFCVOL(KFUEL)*WFUEL
82    TOTALWF=WFUEL
      WTOTAL=GW
      GO TO 6
C      FUEL WEIGHT SPECIFIED
5     WFUEL=TOTALWF
      IF(KFUEL.EQ.1) GO TO 90
      VOLTANK=(WFUEL/PROPT((KFUEL-1),9,3))/.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    WTANK=WFUEL*SFCTANK(KFUEL)
      VOLTANK=SFCVOL(KFUEL)*WFUEL
91    WTOTAL=(WPAYLD+WFUEL+WTANK+WPROPUL)/(1.-SWF)
6     WD=WTOTAL-WFUEL
      WE=WD-WPAYLD
      W1=WTOTAL
      WF=TOTALWF
C
C      COMPUTE VOLUMES
C
92    VOLPAYL=WPAYLD/22.5
C      PAYLOAD DENSITY:  22.5LB/CU FT.
      VOLRN=0.
```

```
      IF (HSTART.EQ.0.) GO TO 7
      CALL BALLOON (HSTART,WTOTAL,VOLBN)
7     CONTINUE
      VOLF=0.02831685
      VTANKM=VOLTANK*VOLF
      VOLBNM=VOLBN*VOLF
      VPAYLM=VOLPAYL*VOLF
C
C      PREPARE VEHICLE DESCRIPTION DATA FOR HEADING
C
      S=WTOTAL/WOS
      ACK=1./(PI*AR*E)
      SS=S*0.0929
      SWPAYLD=WPAYLD*4.44822
      SKWSL=ENGSIZE*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.
      WOSS=WOS*47.88026
      SWF=WF*4.44822
      SPAC=PAC*0.7454
      SWTOTAL=WTOTAL*4.44822
      WRITE (6,44) ARC
      WRITE (6,45) ACB(KFUEL),AR,S,WPAYLD,SWPAYLD,ENGSIZE,E,SS,WFUEL,SWF
     1UEL,CL,HHSTART,HH2,HSTARTS,H2S,SKWSL,CDO,WOS,WF,SWE,CL2,HH2,HH3,H2
     2S,H3S,PAC,SPAC,WOSS,WTOTAL,SWTOTAL,CL3,HH3,HH4,H3S,H4S
      WRITE (6,46) VOLPAYL,VPAYLM,VOLTANK,VTANKM,VOLBN,VOLBNM
      CD=CDO+ACK*CL3**2
      WDOS=WD/S
      CALL ALTMAX (WDOS,CL3,CD,KFUEL,SFCENG,PAC,ETAP,WD,HMAX,KPOWCC,0.)
C
      WRITE (6,43)
C
      GAMMA=0.
      KALT=0
      H=HSTART-DELH
C
C       KALT IS 1 FOR INITIAL ALTITUDE
8     KALT=KALT+1
      FLOW1=FLOW
      BOIL1=BOIL
      RC1=RC
      V1=V
      VX1=VX
```

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```
C
C       CHANGE ALTITUDE
9       HO=H
        IF (ABS(H-60000.).LT.50.) THCM=TH
10      H=H+DELH
        HKM=H*CC
        CALL EXPINT (ALT,D1,D2,15,HKM,SIGMA,KODE)
        CD=CDO+ACK*CL**2
        DOL=CD/CL
        CALL ENGINE (H,KFUEL,KPOW,POWERT,FLOW,SFC,KODE,SFCENG,POWSFT)
        CALL PERTK(WFUEL,BOIL,H,KFUEL)
        POWER=POWERT-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
        Q=W*COS(GAMMA)/(CL*S)
        V=29.0*SQRT(Q/SIGMA)
        THRUST=ETAP*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*Q
        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=ABS(G2-G1)
C
        IF (KG.LT.15) GO TO 14
        TEST=ABS(AG12-AGOLD)
        IF (TEST.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
```

```
C
C       ADJUST TARGET ALTITUDE TO HAVE A POSITIVE GAMMA
15     IF (KALT.EQ.1) GO TO 31
       H=H0
       DELH=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
       DELT=DELH/((RC1+RC)/2.)
       DBOIL=(BOIL1+BOIL)*DELT/7200.
       DELF=(FLOW1+FLOW)*DELT/7200.
       DELF=DELF+DBOIL
       IF (WFUEL.GT.DELF) GO TO 18
       H=H0
       DELH=DELH*WFUEL/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=WFUEL*3600./(FLOW+BOIL)
       WFUEL=0.
       VX=V
       GO TO 19
C
C       CALCULATION OF ALL PERFORMANCE PARAMETERS FOR EACH ALTITUDE
C
18     RFUEL=WFUEL-DELF
       W1=WO+RFUEL
       ADELW=ABS(W1-W)
       IF (ADELW.GT..1) GO TO 11
C
       IF (KALT.EQ.1) GO TO 19
       WFUEL=RFUEL
       VX=V*COS(GAMMA)
C
19     GAMMAD=GAMMA*57.295779
       RCM=RC*60.
       VKT=V*0.592484
       IF (KEC.EQ.1.AND.KC.EQ.1) GO TO 21
       IF (KALT.EQ.1) GO TO 22
       IF (KEC.EQ.1) GO TO 24
C
20     X=X+((VX+VX1)/2.)*DELT/6076.115
       T=T+DELT
       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=BOIL*DELT/3600.+BOILT
C      LIST RESULTS IF VEHICLE IS AT EVENT ALTITUDE, STANDARD ALTITUDE
C                 OR INITIAL ALTITUDE
      ATEMP=ABS(H-H2)
      BTEMP=ABS(H-H3)
      IF (ATEMP.LT.1..OR.BTEMP.LT.1.) GO TO 24
      IF (KK.EQ.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
      WOS2=W2/S
      WRITE (6,47) H,X,TH,V,VKT,RCM,GAMMAD,POWERT,SFC,ETAP,THRUST,WFUEL,
     1PERCENT,WOS2,CL,POWSET,BOILT
      KOUNT=KOUNT+KODE
      KODE=0
      IF (GAMMAD.LT.1.0) KPOW=1
C
      IF (KEC.EQ.1) GO TO 29
      IF (KK.EQ.5) KK=0
      IF (KALT.EQ.1) GO TO 28
      IF (ATEMP.GT.1.) GO TO 25
      CL=CL2
      KPOW=1
      KEC=1
      GO TO 27
25    IF (BTEMP.GT.1.) GO TO 26
      CL=CL3
      KPOW=0
      KEC=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,POWERT,SFC,ETAP,THRUST,WFUEL,
     1PERCENT,WOS2,CL,POWSET,BOILT
      KOUNT=KOUNT+KODE
      KODE=0
      WRITE (6,48) DELE
C
C      VEHICLE CAN NOT CLIMB ANY HIGHER, THEREFORE CHANGE TO CRUISE HERE
      WRITE (6,49)
      GO TO 33
```

```
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
      WOS2=W2/S
      VKT=V*0.592484
      IF(KK.EQ.0) GO TO 70
      WRITE (6,47) H,X,TH,V,VKT,RCM,GAMMAD,POWERT,SFC,ETAP,THRUST,WFUEL,
     1PERCENT,WOS2,CL,POWSET ,BOILT
70    WRITE (6,51)
      IF(H.LT.60000.) GO TO 200
      V=V1
      KALT=KALT-1
33    IF (KALT.EQ.1) GO TO 1
      VA=V
      WA=WD+WFUEL
      VA=V
      CL=CL3
      CD=CDO+ACK*CL**2
      RCM=0.
      GAMMAD=0.
      KG=1
      KPOW=KPOWCC
      KK=0
      KEC=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.*WOS2)/(RHO*CL))
      VKT=V*0.592484
      Q=0.5*RHO*V**2.
      D=CD*Q*S
      THRUST=D
      POWER=(D*V)/(ETAP2*550.)
      POWERT=POWER+PAC
      CALL ENGINE(HA,KFUEL,KPOW,POWERT,FLOWA,SFCA,KODE,SFCENG,POWSET)
      CALL PERTK(WFUEL,BOILA,HA,KFUEL)
      CALL ALTMAX(WOOS,CL3,CD,KFUEL,SFCENG,PAC,ETAP,WD,HMAX,-1,POWSET)
      WRITE (6,47)H,X,TH,V,VKT,RCM,GAMMAD,POWERT,SFCA,ETAP,THRUST,WFUEL,
     1PERCENT,WOS2,CL,POWSET,BOILT
      CL=CL3
      VA=V
      CD=CDO+ACK*CL**2
36    HB=HA+DELH
      IF (HB.GT.HMAX) HB=HMAX
      KPOW=-1
      CALL CRCM
      HA=HB
```

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```
      KEC=0
      WA=WB
      IF ((WB-WD).LT.0.01) GO TO 39
      IF (HB.GE.70000.) GO TO 37
      IF (HB.EQ.HMAX) GO TO 39
      GO TO 36
37    KEC=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    WB=WA-DW
      WFUEL=WFUEL-DW
      CALL CRUISE
      IF (ABS(WB-WD).LT.0.01) GO TO 39
      WA=WB
      KEC=0
      GO TO 38
39    IF (KOUNT.EQ.0) GO TO 40
      WRITE (6,52) KOUNT
1      CONTINUE
40    ENDU=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,7HBOILOFF//
     .  6X,4H(FT),4X,4HN MI,
     3      3X,4H(HR),3X,5H(FPS),2X,4H(KT),3X,5H(FPM),2X,5H(DEG),4X,4H(HP
     4),2X,10H(LB/HP-HR),7X,4H(LB),5X,4H(LB),5X,1H%,3X,5H(PSF),12X,1H%,
     6 6X,4H(LB)/)
44     FORMAT (1H1///2X,5A10//,2X,10HPROPULSION,20X,12HAERODYNAMICS,9X,4H
     1WING,13X,15HWEIGHTS, 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,5HOWE: ,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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```
      SUBROUTINE ENGINE(H,IFUEL,IPOW,POWER,FLOW,SFC,KODE,SFCENG,PERCTP)
C
C     CALCULATION OF ENGINE PERFORMANCE
C
C     INPUT:  H-ALTITUDE,FT
C             IFUEL: 1-JP6,2-CH4,3-H2
C             IPOW:1-MCR,2-.75MCR,3-.50MCR,4-.25MCR,0-OPEN THROTTLE
C     OUTPUT:  FLOW-FUEL FLOW,LB/HR
C              SFC-SPECIFIC FUEL CONSUMPTION,LB/HP-HR
C
C     IF IPOW EQUAL ZERO, OPEN THROTTLING POWER IS INPUT
C     IF IPOW NOT EQUAL ZERO, POWER IS OUTPUT
C
C     DATA ALT(FT),FL(LB/HR),SHP(HP)
C
      DIMENSION ALT(15), FL(15,4), SHP(15,4), FLOWR(4), HPR(4), SETR(4)
      DIMENSION SFCFL(3),P(2)
C
      DATA ALT/0.,5.E3,10.E3,15.E3,20.E3,25.E3,30.E3,35.E3,40.E3,45.E3,5
     10.E3,55.E3,60.E3,65.E3,70.E3/
      DATA ((SHP(I,J),I=1,15),J=1,4)/650.0,650.0,650.1,589.1,508.2,432.2
     1,350.5,250.4,191.2,147.2,113.9,90.,70.,55.,45.,650.0,604.2,544.7,4
     266.0,431.3,371.6,315.4,241.3,187.5,144.3,111.4,90.,70.,55.,45.,441
     3.2,428.8,404.3,375.2,343.3,305.3,266.8,200.0,154.3,117.1,89.6,67.,
     455.,45.,35.,227.1,236.9,239.4,238.3,234.8,221.2,200.8,145.0,110.4,
     581.9,67.5,52.,43.,36.,32./
      DATA ((FL(I,J),I=1,15),J=1,4)/417.7,384.0,378.9,343.4,295.8,255.6,
     1201.8,158.6,129.5,105.6,85.8,70.,56.,45.,36.,417.7,364.8,324.2,288
     2.0,253.4,220.5,181.7,153.0,127.1,103.7,84.1,70.0898,56.0207,44.,35
     3.,334.4,293.6,265.3,237.0,208.5,185.1,155.9,129.3,106.9,86.3,69.5,
     453.9612,45.,36.3388,27.9126,243.9,220.6,202.6,182.2,163.6,147.1,12
     54.2,101.6,83.6,67.1,58.5911,45.9145,37.9395,31.2367,27./
      DATA SETR/25.,50.,75.,100./
      DATA SFCFL/0.6084,0.5113,0.1985/
C
      IF (IFUEL.GT.3.OR.IPOW.GT.4) RETURN
      IF (IPOW.GT.0) GO TO 1
      IF(IPOW.EQ.-1) GO TO 5
      HP=POWER/SFCENG
      CALL LINEAR (ALT,SHP(1,1),15,H,HPR(4),KODE)
      CALL LINEAR (ALT,SHP(1,2),15,H,HPR(3),KODE)
      CALL LINEAR (ALT,SHP(1,3),15,H,HPR(2),KODE)
      CALL LINEAR (ALT,SHP(1,4),15,H,HPR(1),KODE)
C
      CALL LINEAR (ALT,FL(1,1),15,H,FLOWR(4),KODE)
      CALL LINEAR (ALT,FL(1,2),15,H,FLOWR(3),KODE)
      CALL LINEAR (ALT,FL(1,3),15,H,FLOWR(2),KODE)
      CALL LINEAR (ALT,FL(1,4),15,H,FLOWR(1),KODE)
C
      CALL LINEAR (HPR,SETR,4,HP,PERCTP,KODE)
      CALL LINEAR (SETR,FLOWR,4,PERCTP,FLOW,KODE)
      GO TO 2
C  GIVEN PERCTP, FIND FLOW,SFC,HP
C
```

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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      I=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,FLOWR(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
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
C        ADJUST FUEL FLOW FOR DIFFERENT FUEL.
C
2       CONTINUE
        FLOW=FLOW*SFCFL(IFUEL)*SFCENG
        SFC=FLOW/POWER
        RETURN
        END
```

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```
      SUBROUTINE ALTMAX (WOS,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       CALCULATE MAXIMUM ATTAINABLE ALTITUDE
C
1     K=0
      H=55000.
      DELH=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.*WOS)/(CL*RHO))
      DOL=CD/CL
      D=DOL*W
      CALL ENGINE (H,KFUEL,KPOW,POWERT,FLOW,SFC,KODE,SFCENG,POWSET)
      POWER=POWERT-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-DELH
      DELH=DELH/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
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
```

```
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 - CORRESPENDING Y VALUE OUTPUT
C
      DIMENSION X(100), Y(100)
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     I1=I+1
      IF (AX.NE.X(I)) GO TO 4
C      AX= X(I)
      AY=Y(I)
      RETURN
4     IF (AX.GE.X(I1)) GO TO 5
C      X(I)<AX<X(I1)
      AY=Y(I)+(AX-X(I))*(Y(I1)-Y(I))/(X(I1)-X(I))
      RETURN
5     I=I1
      GO TO 3
      END
```

```
      SUBROUTINE EXPINT (X,Y1,Y2,N,AX,AY,KODE)
C
      DIMENSION X(100), Y1(100), Y2(100)
C
C      EXPONENTIAL INTERPOLATION TO SUPPLY COEFFICIENTS FOR DENSITY
C      AND PRESSURE RATIO  EQUATION: AY= E**(Y1*X + Y2*X**2)
C
C
      IF (AX.GE.X(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
C
C      X(1)<= AX<= X(N)
C
2     I=1
3     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)
C
C       CALCULATION OF BALLOON SIZE TO SUPPORT ITSELF AND RPV
C      INPUT: ALTITUDE AND THE WEIGHT OF THE VEHICLE
C      H-ALTITUDE(FT),WLIFT-WEIGHT OF THE VEHICLE(LBF),VOLUME-(CU FT)
C      BALLOON IS 95% HELIUM AND 5% AIR.
C      R-GAS CONSTANT 8.317 JOULE/KELVIN-MOLE
C
C
      COMMON /ATMO/ ALTT(4),P1(15),P2(15),D1(15),D2(15),ALT(15),TK(4)
C
      HKM=H*0.0003048
      P0=101325.
      RHO0=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*P0
      RHO=SIGMA*RHO0
      WM=(4.002*.95+28.9644*0.05)/1000.
      R=8.317
      TEMP=RHO-(WM*PA)/(R*TA)
      VOLUME=WLIFT/TEMP/0.02831685
      RETURN
      END
```

```
      SUBROUTINE SYSTEM (DENSITY,WSYS,WF,KCASE)
      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
      COMMON/PIC/PI
C
C
      RATIO2=RATIO*2.
      IF(KCASE.EQ.2) GO TO 20
      B=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
      RL=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.2) GO TO 21
      X=B-TWIN-TWAL-TWLH2
      IF(ABS(X).LE.0.0001) GO TO 10
      DX=-((V3P-V2P)*RHIN+(V2P-V1P)*RHA+V1P*DENSITY*0.9)
      R1=R1-X/DX
      GO TO 8
10    RADIUS=R1
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

      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
      DIMENSION PROPT(2,9,6)
      Q=CONDUCT*AREAW*DELT/TIN
      BOIL=Q/(PROPT(L,8,6)-PROPT(L,8,5))
      RETURN
      END
```

```
      SUBROUTINE CRCM
C
      COMMON/BL/BOIL,BOILT,BOILA
      COMMON /AERO/ CL,CD,RHO,S,D,THRUST,HA,HB,VA
      COMMON /ENG/ PAC,ETAP2,KPOW,SFCENG,SFC,SFCA,FLOW,FLOWA,POWSET,KFUE
     1L,HMAX
      COMMON /WEIGHT/ WA,DW,WB,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      CRUISE CLIMB CALCULATIONS
C
      KK=KK+1
      KALT=KALT+1
      GO TO 2
1     HB=HB+DELH
      IF (HB.GT.HMAX) HB=HMAX
2     HKM=HB*0.0003048
      CALL EXPINT (ALT,D1,D2,15,HKM,SIGMA,KODE)
      RHO=0.002376884*SIGMA
      CALL ENGINE (HB,KFUEL,KPOW,POWERT,FLOWB,SFCB,KODE,SFCENG,POWSET)
      CALL PFPTK(WFUEL,BOILB,HB,KFUEL)
      POWER=POWERT-PAC
      IF (HB.NE.HMAX.OR.HMAX.EQ.70000.) GO TO 3
      WB=WD
      GO TO 4
3     WCU=(ETAP2*POWER*550.*CL/CD)**2.*S*RHO*CL/2.
      WB=WCU**(1./3.)
4     DW=WA-WB
      IF (DW.LT.0.) GO TO 1
      VB=((2.*WB)/(CL*S*RHO))**0.5
      V=(VA+VB)/2.
      FLOW=(FLOWA+FLOWB)/2.
      BOIL=(BOILA+BOILB)/2.
      DELTH=DW/(FLOW+BOIL)
      DX=3600.*DELTH*V/6076.115
      WOS=(WA+WB)/(2.*S)
      X=X+DX
      TH=TH+DELTH
      DBOIL=DELTH*BOIL
      BOILT=BOILT+DBOIL
      VKT=V*0.592494
      SFC=(SFCA+SFCB)/2.
      THRUST=ETAP2*POWER*550./V
      WFUEL=WFUEL-DW
      PERCENT=WFUEL/WF*100.
      RCM=0
      GAMMAD=0
      WRITE (6,5) HB,X,TH,V,VKT,RCM,GAMMAD,POWERT,SFC,ETAP2,THRUST,WFUEL
     1,PERCENT,WOS,CL,POWSET,BOILT
      KOUNT=KOUNT+KODE
      KODE=0
      SFCA=SFCB
      FLOWA=FLOWB
      BOILA=BOILB
```

```
      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 /AERO/ CL,CD,RHO,S,D,THRUST,HA,HB,VA
      COMMON /ENG/ PAC,ETAP2,KPOW,SFCENG,SFC,SFCA,FLOW,FLOWA,POWSET,KFUE
     1L,HMAX
      COMMON /WEIGHT/ WA,DW,WB,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
      WOS=(WA+WB)/(2.*S)
      PERCENT=WFUEL/WF*100.
      V=SQRT((2.*WOS)/(RHO*CL))
      Q=0.5*RHO*V**2.
      D=CD*Q*S
      THRUST=D
      POWER=(D*V)/(ETAP2*550.)
      POWERT=POWER+PAC
      CALL ENGINE (HA,KFUEL,KPOW,POWERT,FLOW,SFC,KODE,SFCENG,POWSET)
      CALL PERTK(WFUEL,BOIL,HA,KFUEL)
      DELTH=(WA-WB)/(FLOW+BOIL)
      DX=DELTH*3600.*V/6076.15
      X=X+DX
      TH=TH+DELTH
      DBOIL=DELTH*BOIL
      BOILT=BOILT+DBOIL
      VKT=V*0.592484
      WRITE (6,1) HA,X,TH,V,VKT,RCM,GAMMAD,POWERT,SFC,ETAP2,THRUST,WFUEL
     1,PERCENT,WOS,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
      F(H)= VFUEL-((R**2*ACOS((R-H)/R)-(R-H)*A**.5)*RL+PI*R*H**2-
     1      (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
      HO= R
    8 A= 2.*R*HO-HO**2
      X= F(HO)
      IF(ABS(X).LE.0.001) GO TO 10
      DX= DF(HO)
      HO= HO-X/DX
      C=(R-HO)/R
      IF(ABS(C).LE.1.) GO TO 8
      STOP
   10 HEIGHT= HO
      AREAW= 2.*PI*R*HEIGHT+2.*R*RL*ACOS((R-HEIGHT)/R)
      RETURN
      END


      SUBROUTINE PERTK(FUELW,BOIL,H,K)
C
C     CALCULATE BOILOFF FOR GIVEN TANK AND AMBIENT CONDITIONS
C
      COMMON /ATMO/ ALTT(4),P1(15),P2(15),D1(15),D2(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=FUELW/PROPT(L,8,3)
      RLENGTH=2.*RADIUS*RATIO
      HM=0.0003048*H
      CALL LINEAR(ALTT,TK,4,HM,T,KODE)
      DIFFT=ABS(PROPT(L,8,1)-(T*1.8-459.67))
      CALL TANK(VFUEL,RADIUS,RLENGTH,HEIGHT,AREAW)
      CALL BOILOFF(AREAW,CONDUCT,TIN,DIFFT,BOIL,PROPT,L)
      RETURN
      END
```

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  $
```

ORIGINAL PAGE IS
OF POOR QUALITY

BASELINE VEHICLE FUELED BY JP7

PROPULSION	AERODYNAMICS	WING	WEIGHTS, LB (N)	VEHICLE TRIM SCHEDULE	
				CL	ALTITUDE, FT/1000, (KM)
FUEL: JP7	AP= 20.00	S=375.0 FT2	PAYLOAD: 200. (890.)	.80	0.0 TO 40.0 (0.0 TO 12.2)
ENGINE: 660. SHP-SL	E= .800	= 35. M2	FUEL: 1136. (5053.)	1.00	40.0 TO 70.0 (12.2 TO 21.3)
(492.KW-SL)	CD0=.01500	W/S= 8.0 PSF	OWE: 1664.(7402.)	1.20	70.0 TO 70.0 (21.3 TO 21.3)
AUX P: 2.0 HP (1.49 KW)		= 383. PA	TOGW: 3000.(13345.)		

VOLUMES, FT3 (M3): PAYLOAD= 8.87 (.2517); TANK= 26.01 (.7366); BALLOON= 0. (0.)

ALT. (FT)	RANGE N MI	TIME (HR)	TRUE AIRSPEED (FPS)	TRUE AIRSPEED (KT)	R/C (FPM)	GAMMA (DEG)	E. POWER (HP)	SFC (LB/HP-HR)	ETA-P	THRUST (LB)	FUEL IN TANKS (LB)	FUEL IN TANKS %	W/S (PSF)	CL	THROTTLE %	BOILOFF (LB)
0.0	0.0	0.00	88.8	52.6	1838.8	20.2	230.6	.6534	.800	1132.3	1135.9	100.0	8.00	.80	25.0	0.00
5000.0	2.1	.04	95.8	56.8	1924.1	19.6	240.5	.5665	.800	1095.6	1129.5	99.4	7.98	.80	25.0	0.00
10000.0	4.5	.09	103.8	61.5	1935.1	18.1	243.1	.5149	.800	1021.5	1123.9	98.9	7.97	.80	25.0	0.00
15000.0	7.1	.13	112.9	65.9	1911.1	16.4	242.0	.4652	.800	935.1	1118.7	98.5	7.95	.80	25.0	0.00
20000.0	10.1	.17	123.1	73.0	1862.9	14.6	238.4	.4239	.800	844.7	1114.0	98.1	7.94	.80	25.0	0.00
25000.0	13.6	.22	134.8	79.9	1719.6	12.3	224.6	.4046	.800	726.4	1109.6	97.7	7.93	.80	25.0	0.00
30000.0	17.8	.27	148.1	87.7	1510.5	9.8	203.9	.3763	.800	590.8	1105.2	97.3	7.92	.80	25.0	0.00
35000.0	24.1	.34	163.4	96.8	970.7	5.7	147.2	.4263	.800	391.1	1100.5	96.9	7.91	.80	25.0	0.00
40000.0	35.0	.45	183.3	108.6	616.7	3.2	112.1	.4607	.800	264.3	1094.5	96.4	7.89	.80	25.0	0.00
40000.0	35.0	.45	163.3	96.7	1376.0	8.1	194.1	.4121	.800	517.8	1094.5	96.4	7.89	1.00	100.0	0.00
45000.0	42.4	.52	184.5	109.3	957.9	5.0	149.5	.4365	.800	351.7	1089.3	95.9	7.88	1.00	100.0	0.00
50000.0	55.0	.63	208.0	123.2	602.1	2.8	115.7	.4583	.800	240.4	1082.9	95.3	7.86	1.00	100.0	0.00
55000.0	79.4	.81	234.4	138.9	325.3	1.3	91.4	.4732	.800	167.8	1074.1	94.6	7.84	1.00	100.0	0.00
60000.0	150.9	1.29	263.7	156.2	76.2	.3	71.1	.4867	.800	115.3	1056.0	93.0	7.79	1.00	100.0	0.00
61000.0	197.6	1.59	269.5	159.7	36.5	.1	65.0	.4905	.800	100.4	1045.9	92.1	7.76	1.00	100.0	0.00
CRUISE STARTS HERE																
61000.0	197.6	1.59	246.1	145.8	0.0	0.0	61.2	.4910	.800	105.8	1045.9	92.1	7.76	1.20	63.0	0.00
61500.0	515.6	3.77	246.2	145.9	0.0	0.0	59.9	.4909	.800	103.5	981.1	86.4	7.67	1.20	63.0	0.00
62000.0	838.4	5.98	246.4	146.0	0.0	0.0	58.6	.4906	.800	101.2	916.8	80.7	7.50	1.20	63.0	0.00
62500.0	1166.3	8.22	246.5	146.0	0.0	0.0	57.4	.4904	.800	98.8	852.9	75.1	7.33	1.20	63.0	0.00
63000.0	1499.5	10.51	246.5	146.1	0.0	0.0	56.1	.4901	.800	96.5	789.5	69.5	7.16	1.20	63.0	0.00
63500.0	1836.1	12.82	246.6	146.1	0.0	0.0	54.8	.4898	.800	94.2	726.5	64.0	6.99	1.20	63.0	0.00
64000.0	2182.5	15.18	246.6	146.1	0.0	0.0	53.5	.4895	.800	92.0	664.0	58.5	6.83	1.20	63.0	0.00
64500.0	2532.9	17.58	246.5	146.1	0.0	0.0	52.3	.4892	.800	89.7	602.0	53.0	6.66	1.20	63.0	0.00
65000.0	2889.6	20.02	246.4	146.0	0.0	0.0	51.0	.4889	.800	87.4	540.3	47.6	6.49	1.20	63.0	0.00
65500.0	3201.2	22.16	246.5	146.1	0.0	0.0	50.0	.4883	.800	85.6	487.7	42.9	6.34	1.20	63.0	0.00
66000.0	3516.7	24.31	246.8	146.2	0.0	0.0	48.9	.4874	.800	83.7	435.7	38.4	6.20	1.20	63.0	0.00
66500.0	3837.0	26.50	247.0	146.3	0.0	0.0	47.9	.4865	.800	81.8	384.2	33.8	6.06	1.20	63.0	0.00
67000.0	4162.5	28.72	247.2	146.5	0.0	0.0	46.9	.4855	.800	79.9	333.0	29.3	5.93	1.20	63.0	0.00
67500.0	4493.4	30.98	247.3	146.5	0.0	0.0	45.9	.4845	.800	78.1	282.2	24.8	5.79	1.20	63.0	0.00
68000.0	4830.1	33.28	247.4	146.6	0.0	0.0	44.9	.4835	.800	76.2	231.8	20.4	5.66	1.20	63.0	0.00
68500.0	5172.8	35.62	247.5	146.6	0.0	0.0	43.9	.4824	.800	74.4	181.8	16.0	5.52	1.20	63.0	0.00
69000.0	5521.8	38.00	247.5	146.7	0.0	0.0	42.8	.4813	.800	72.6	132.1	11.6	5.39	1.20	63.0	0.00
69500.0	5877.4	40.42	247.5	146.6	0.0	0.0	41.8	.4801	.800	70.8	82.9	7.3	5.26	1.20	63.0	0.00
70000.0	6240.0	42.89	247.4	146.6	0.0	0.0	40.8	.4789	.800	69.0	33.9	3.0	5.13	1.20	63.0	0.00
70000.0	6265.4	43.07	247.3	146.5	0.0	0.0	40.8	.4783	.800	69.0	30.5	2.7	5.06	1.20	62.9	0.00
70000.0	6291.0	43.24	247.1	146.4	0.0	0.0	40.7	.4784	.800	68.9	27.1	2.4	5.05	1.20	62.6	0.00
70000.0	6316.5	43.42	246.9	146.3	0.0	0.0	40.6	.4785	.800	68.7	23.7	2.1	5.04	1.20	62.4	0.00
70000.0	6342.1	43.59	246.6	146.1	0.0	0.0	40.5	.4786	.800	68.6	20.3	1.8	5.03	1.20	62.1	0.00
70000.0	6367.7	43.77	246.4	146.0	0.0	0.0	40.4	.4788	.800	68.5	17.0	1.5	5.02	1.20	61.8	0.00
70000.0	6393.4	43.94	246.2	145.9	0.0	0.0	40.2	.4789	.800	68.4	13.6	1.2	5.01	1.20	61.6	0.00
70000.0	6419.1	44.12	246.0	145.7	0.0	0.0	40.1	.4790	.800	68.2	10.2	.9	5.00	1.20	61.3	0.00
70000.0	6444.8	44.30	245.7	145.6	0.0	0.0	40.0	.4791	.800	68.1	6.8	.6	4.99	1.20	61.1	0.00
70000.0	6470.6	44.47	245.5	145.5	0.0	0.0	39.9	.4793	.800	68.0	3.4	.3	4.98	1.20	60.8	0.00
70000.0	6496.4	44.65	245.3	145.3	0.0	0.0	39.8	.4794	.800	67.9	0.0	0.0	4.98	1.20	60.6	0.00

BASELINE VEHICLE FUELED BY LIQUID METHANE

PROPULSION	AERODYNAMICS	WING	WEIGHTS, LB (N)	VEHICLE TRIM SCHEDULE	
FUEL: METHANE	AR= 20.00	S=375.0 FT2	PAYLOAD: 200. (890.)	CL	ALTITUDE, FT/1000. (KM)
ENGINE: 660. SHP-SL	E= .800	= 35. M2	FUEL: 984. (4377.)	.80	0.0 TO 40.0 (0.0 TO 12.2)
(492.KW-SL)	CDO=.01500	W/S= 8.0 PSF	OWE: 1816.(8078.)	1.00	40.0 TO 70.0 (12.2 TO 21.3)
AUX P: 2.0 HP (1.49 KW)		= 383. PA	TOGW: 3000.(13345.)	1.20	70.0 TO 70.0 (21.3 TO 21.3)

VOLUMES, FT3 (M3): PAYLOAD= 8.89 (.2517): TANK= 41.30 (1.1694): BALLOON= 0. (0.)

ALT. (FT)	RANGE N MI	TIME (HR)	TRUE AIRSPEED (FPS)	TRUE AIRSPEED (KT)	R/C (FPM)	GAMMA (DEG)	E. POWER (HP)	SFC (LB/HP-HR)	ETA-P	THRUST (LB)	FUEL IN TANKS (LB)	FUEL IN TANKS %	W/S (PSF)	CL	THROTTLE %	BOILOFF (LB)
0.0	0.0	0.00	88.8	52.6	1838.7	20.2	230.6	.5491	.800	1132.2	984.1	100.0	8.00	.80	25.0	.00
5000.0	2.1	.04	95.8	56.8	1923.4	19.5	240.5	.4761	.800	1095.4	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	1860.4	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	17.8	.27	148.2	87.8	1507.4	9.8	203.9	.3163	.800	599.3	958.3	97.4	7.93	.80	25.0	.05
35000.0	24.1	.34	163.5	96.9	968.0	5.7	147.2	.3583	.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	.3872	.800	264.0	949.2	96.5	7.91	.80	25.0	.06
40000.0	35.1	.45	163.5	96.8	1371.9	8.0	194.1	.3463	.800	517.2	949.2	96.5	7.91	1.00	100.0	.06
45000.0	42.5	.52	184.7	109.4	954.2	4.9	149.5	.3668	.800	351.3	944.8	96.0	7.90	1.00	100.0	.07
50000.0	55.2	.63	208.3	123.4	598.6	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	264.2	156.5	72.3	.3	71.1	.4090	.800	115.8	916.2	93.1	7.82	1.00	100.0	.15
61000.0	203.7	1.63	270.1	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																
61000.0	203.7	1.63	246.7	146.1	0.0	0.0	51.6	.4124	.800	106.3	907.1	92.2	7.79	1.20	63.7	.18
61500.0	582.0	4.21	246.7	146.2	0.0	0.0	60.3	.4123	.800	104.0	841.8	85.5	7.71	1.20	63.7	.44
62000.0	966.1	6.84	246.9	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	56.4	.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.[illegible]	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	3408.0	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	5305.2	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	5703.6	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.[illegible]
68896.5	6434.6	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

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BASELINE VEHICLE FUELED BY LIQUID HYDROGEN

PROPULSION	AERODYNAMICS	WING	WEIGHTS, LB (N)	VEHICLE TRIM SCHEDULE
FUEL: HYDROGEN ENGINE: 660. SHP-SL (492.KW-SL) AUX P: 2.0 HP (1.49 KW)	AR= 20.00 E= .800 CD0=.01500	S=375.0 FT2 = 35. M2 W/S= 8.0 PSF = 383. PA	PAYLOAD: 200. (890.) FUEL: 568. (2529.) OWE: 2232.(9926.) TOGW: 3000.(13345.)	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 70.0 (21.3 TO 21.3)

VOLUMES, FT3 (M3): PAYLOAD= 8.89 (.2517); TANK=142.93 (4.0474); BALLOON= 0. (0.)

ALT. (FT)	RANGE N MI	TIME (HR)	TRUE AIRSPEED (FPS)	(KT)	R/C (FPM)	GAMMA (DEG)	E. POWER (HP)	SFC (LB/HP-HR)	ETA-P	THRUST (LB)	FUEL IN TANKS (LB)	%	W/S (PSF)	CL	THROTTLE %	BOILOFF (LB)
0.0	0.0	0.00	88.8	52.6	1838.3	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	56.8	1921.3	19.5	240.5	.1848	.800	1094.8	566.1	99.6	7.99	.80	25.0	.48
10000.0	4.5	.09	104.0	61.6	1929.6	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	1903.2	16.3	242.0	.1518	.800	933.2	561.9	98.8	7.98	.80	25.0	1.09
20000.0	10.1	.18	123.5	73.1	1852.9	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	1708.1	12.2	224.6	.1320	.800	724.3	558.3	98.2	7.97	.80	25.0	1.66
30000.0	17.9	.27	148.6	88.0	1498.2	9.7	203.9	.1228	.800	597.9	556.6	97.9	7.97	.80	25.0	1.96
35000.0	24.3	.34	164.0	97.2	960.1	5.6	147.2	.1391	.800	389.7	554.7	97.6	7.96	.80	25.0	2.34
40000.0	35.4	.45	184.1	109.1	606.7	3.1	112.1	.1503	.800	263.2	552.1	97.1	7.96	.80	25.0	2.91
40000.0	35.4	.45	164.0	97.2	1360.1	7.9	194.1	.1344	.800	515.5	552.1	97.1	7.96	1.00	100.0	2.91
45000.0	42.9	.52	185.4	109.8	943.5	4.9	149.5	.1424	.800	350.0	550.0	96.8	7.95	1.00	100.0	3.29
50000.0	55.9	.63	209.1	123.9	588.7	2.7	115.7	.1495	.800	239.1	547.3	96.3	7.94	1.00	100.0	3.86
55000.0	81.1	.82	235.8	139.7	312.1	1.3	91.4	.1544	.800	166.8	543.4	95.6	7.93	1.00	100.0	4.84
60000.0	160.8	1.35	265.7	157.4	61.7	.2	71.1	.1588	.800	114.4	534.2	94.0	7.91	1.00	100.0	7.50
61000.0	224.9	1.76	271.8	161.0	21.1	.1	66.5	.1597	.800	103.2	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	0.0	62.7	.1599	.800	107.6	527.7	92.8	7.89	1.20	65.7	9.50
61100.0	356.9	2.65	248.2	147.1	0.0	0.0	62.4	.1599	.800	107.2	514.3	90.5	7.87	1.20	65.7	13.89
61200.0	489.7	3.56	248.2	147.1	0.0	0.0	62.2	.1599	.800	106.7	501.0	88.1	7.84	1.20	65.7	18.23
61300.0	624.1	4.47	248.3	147.1	0.0	0.0	61.9	.1598	.800	106.2	487.7	85.8	7.80	1.20	65.7	22.49
61400.0	759.9	5.39	248.3	147.1	0.0	0.0	61.6	.1598	.800	105.7	474.4	83.4	7.77	1.20	65.7	26.68
61500.0	897.0	6.33	248.3	147.1	0.0	0.0	61.4	.1598	.800	105.2	461.1	81.1	7.73	1.20	65.7	30.80
61600.0	1035.3	7.27	248.3	147.1	0.0	0.0	61.1	.1598	.800	104.7	447.8	78.8	7.70	1.20	65.7	34.86
61700.0	1175.0	8.21	248.4	147.2	0.0	0.0	60.8	.1598	.800	104.3	434.6	76.5	7.66	1.20	65.7	38.85
61800.0	1315.9	9.17	248.4	147.2	0.0	0.0	60.6	.1598	.800	103.8	421.4	74.1	7.63	1.20	65.7	42.79
61900.0	1457.9	10.14	248.4	147.2	0.0	0.0	60.3	.1598	.800	103.3	408.2	71.8	7.59	1.20	65.7	46.67
62000.0	1601.2	11.11	248.4	147.2	0.0	0.0	60.0	.1598	.800	102.8	395.0	69.5	7.55	1.20	65.7	50.49
62100.0	1745.6	12.09	248.4	147.2	0.0	0.0	59.8	.1597	.800	102.3	381.8	67.2	7.52	1.20	65.7	54.26
62200.0	1891.5	13.08	248.5	147.2	0.0	0.0	59.5	.1597	.800	101.9	368.7	64.9	7.48	1.20	65.7	57.98
62300.0	2038.4	14.08	248.5	147.2	0.0	0.0	59.2	.1597	.800	101.4	355.5	62.5	7.45	1.20	65.7	61.64
62400.0	2186.5	15.09	248.5	147.2	0.0	0.0	59.0	.1597	.800	100.9	342.4	60.2	7.41	1.20	65.7	65.26
62500.0	2335.8	16.10	248.5	147.2	0.0	0.0	58.7	.1597	.800	100.4	329.3	57.9	7.38	1.20	65.7	68.82
62600.0	2486.3	17.12	248.5	147.2	0.0	0.0	58.4	.1597	.800	99.9	316.3	5.6	7.34	1.20	65.7	72.32
62700.0	2638.1	18.15	248.5	147.2	0.0	0.0	58.2	.1597	.800	99.5	303.2	3.3	7.31	1.20	65.7	75.78
62800.0	2791.2	19.19	248.5	147.2	0.0	0.0	57.9	.1596	.800	99.0	290.2	51.0	7.28	1.20	65.7	79.18
62900.0	2945.5	20.24	248.5	147.2	0.0	0.0	57.6	.1596	.800	98.5	277.2	48.8	7.24	1.20	65.7	82.53
63000.0	3101.1	21.30	248.5	147.2	0.0	0.0	57.4	.1596	.800	98.1	264.2	46.5	7.21	1.20	65.7	85.82
63100.0	3258.1	22.36	248.5	147.2	0.0	0.0	57.1	.1596	.800	97.6	251.2	44.2	7.17	1.20	65.7	89.06
63200.0	3416.3	23.44	248.5	147.2	0.0	0.0	56.8	.1596	.800	97.1	238.2	41.9	7.14	1.20	65.7	92.24
63300.0	3576.0	24.52	248.5	147.2	0.0	0.0	56.6	.1596	.800	96.6	225.3	39.6	7.10	1.20	65.7	95.37
63400.0	3737.1	25.62	248.5	147.2	0.0	0.0	56.3	.1596	.800	96.2	212.4	37.4	7.07	1.20	65.7	98.44
63500.0	3899.6	26.72	248.5	147.2	0.0	0.0	56.0	.1595	.800	95.7	199.5	35.1	7.03	1.20	65.7	101.45
63600.0	4063.6	27.84	248.5	147.2	0.0	0.0	55.8	.1595	.800	95.2	186.6	32.8	7.00	1.20	65.7	104.40
63700.0	4229.2	28.96	248.5	147.2	0.0	0.0	55.5	.1595	.800	94.8	173.7	30.6	6.96	1.20	65.7	107.29
63800.0	4396.4	30.10	248.5	147.2	0.0	0.0	55.2	.1595	.800	94.3	160.9	28.3	6.93	1.20	65.7	110.11
63900.0	4565.2	31.24	248.5	147.2	0.0	0.0	55.0	.1595	.800	93.8	148.0	26.0	6.90	1.20	65.7	112.86

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64000.0	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.[illegible]
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	120.68
64300.0	5258.6	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	123.12
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	125.47
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	127.72
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	129.87
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	131.89
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	133.78
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	135.50
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	137.01
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	137.79

EXTREME JP7-FUELED CONFIGURATION

PROPULSION	AERODYNAMICS	WING	WEIGHTS, LB (N)	VEHICLE TRIM SCHEDULE	
				CL	ALTITUDE, FT/1000. (KM)
FUEL: JP7	AR= 30.00	S=283.6 FT2	PAYLOAD: 200. (890.)	.80	10.0 TO 40.0 (3.0 TO 12.2)
ENGINE: 400. SHP-SL	E= .700	= 26. M2	FUEL: 500. (2224.)	1.00	40.0 TO 70.0 (12.2 TO 21.3)
(298.KW-SL)	CD0=.01500	W/S= 5.0 PSF	OWE: 718.(3195.)	1.20	70.0 TO 70.0 (21.3 TO 21.3)
AUX P: 5.0 HP (3.73 KW)		= 239. PA	TOGW: 1418.(6309.)		

VOLUMES, FT3 (M3): PAYLOAD= 8.89 (.2517); TANK= 11.45 (.3242); BALLOON= 67619. (1915.)

ALT. (FT)	RANGE N MI	TIME (HR)	TRUE AIRSPEED (FPS)	TRUE AIRSPEED (KT)	R/C (FPM)	GAMMA (DEG)	E. POWER (HP)	SFC (LB/HP-HR)	ETA-P	THRUST (LB)	FUEL IN TANKS (LB)	FUEL IN TANKS %	W/S (PSF)	CL	THROTTLE %	BOILOFF (LB)
10000.0	0.0	0.00	77.2	45.8	2529.6	33.1	147.3	.5149	.800	810.9	500.0	100.0	5.00	.80	25.0	0.00
15000.0	1.2	.03	85.2	50.5	2514.5	29.5	146.6	.4652	.800	731.4	497.6	99.5	4.99	.80	25.0	0.00
20000.0	2.8	.07	94.1	55.7	2461.2	25.9	144.5	.4239	.800	652.4	495.5	99.1	4.98	.80	25.0	0.00
25000.0	4.7	.10	104.2	61.8	2287.8	21.5	136.1	.4046	.800	553.4	493.4	98.7	4.98	.80	25.0	0.00
30000.0	7.1	.14	115.6	68.5	2032.7	17.0	123.6	.3763	.800	451.4	491.5	98.3	4.97	.80	25.0	0.00
35000.0	10.6	.19	128.7	76.3	1359.5	10.1	89.2	.4263	.800	287.9	489.4	97.9	4.96	.80	25.0	0.00
40000.0	16.5	.26	144.9	85.9	930.0	6.1	67.9	.4607	.800	191.1	486.8	97.4	4.95	.80	25.0	0.00
40000.0	16.5	.26	128.0	75.8	1891.9	14.3	117.7	.4121	.800	387.2	486.8	97.4	4.95	1.00	100.0	0.00
45000.0	20.6	.31	145.6	86.2	1373.3	9.0	90.6	.4365	.800	258.7	484.6	96.9	4.95	1.00	100.0	0.00
50000.0	27.2	.39	164.6	97.5	949.9	5.5	70.1	.4583	.800	174.0	482.0	96.4	4.94	1.00	100.0	0.00
55000.0	38.3	.49	185.7	110.0	632.3	3.3	55.4	.4732	.800	119.4	478.9	95.8	4.93	1.00	100.0	0.00
60000.0	58.7	.67	209.4	124.0	354.0	1.6	43.1	.4867	.800	80.0	474.9	95.0	4.91	1.00	100.0	0.00
65000.0	108.1	1.04	235.6	139.6	128.3	.5	33.8	.4978	.800	53.9	468.0	93.6	4.89	1.00	100.0	0.00
68000.0	216.1	1.78	252.4	149.5	27.6	.1	28.9	.4893	.800	40.7	456.4	91.3	4.85	1.00	100.0	0.00
CRUISE STARTS HERE																
68000.0	216.1	1.78	230.4	136.5	0.0	0.0	27.1	.4831	.800	42.2	456.4	91.3	4.85	1.20	62.6	0.00
68500.0	602.8	4.61	230.3	136.5	0.0	0.0	26.5	.4826	.800	41.0	419.7	83.9	4.78	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	383.3	76.7	4.65	1.20	62.6	0.00
69500.0	1397.3	10.45	229.6	136.0	0.0	0.0	25.2	.4803	.800	38.8	347.2	69.4	4.52	1.20	62.6	0.00
70000.0	1805.8	13.46	229.2	135.8	0.0	0.0	24.6	.4790	.800	37.7	311.2	62.2	4.40	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	280.1	56.0	4.28	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	249.0	49.8	4.17	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	217.9	43.6	4.06	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	186.7	37.3	3.95	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	155.6	31.1	3.84	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	124.5	24.9	3.73	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	93.4	18.7	3.62	1.20	29.1	0.00
70000.0	4799.2	36.78	206.1	122.1	0.0	0.0	19.3	.5233	.800	30.6	62.2	12.4	3.51	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	31.1	6.2	3.40	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	-.0	3.29	1.20	25.0	0.00

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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
Oswald efficiency factor	0.8
Propulsion system	
Engine power (sea level to 10,000 ft), hp	660.
Power supplied to systems and payload, hp	2.
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
Propeller efficiency factor, ηp	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, °F	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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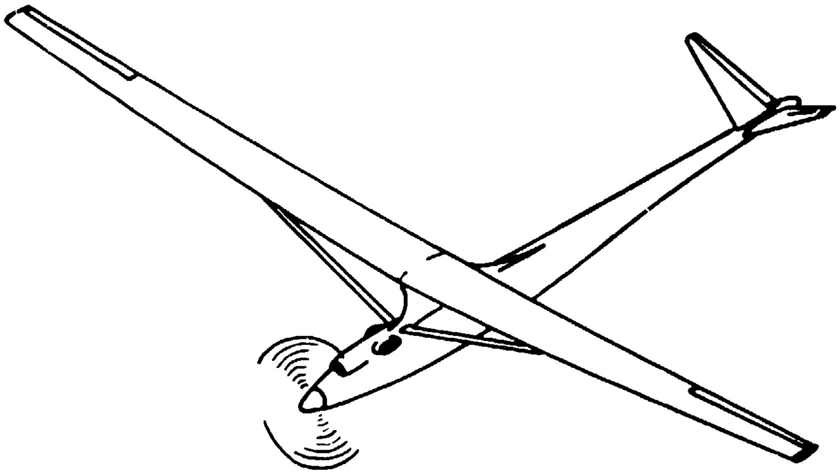
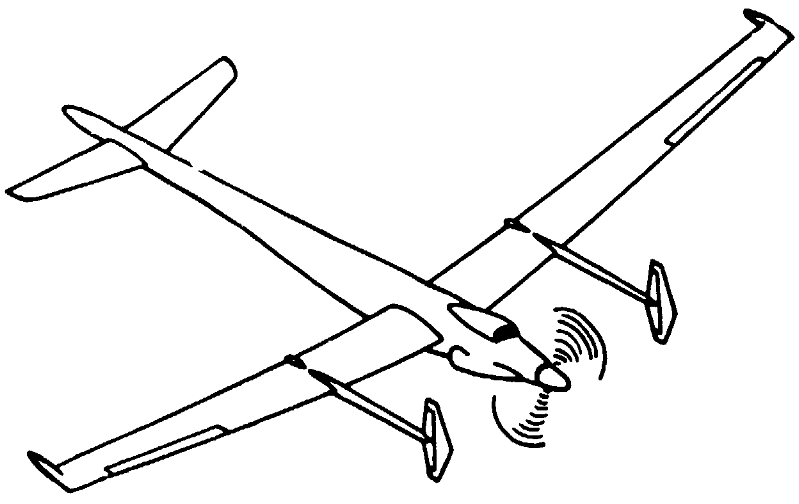


(a) Tractor-propeller configuration



(b) Pusher-propeller configuration

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

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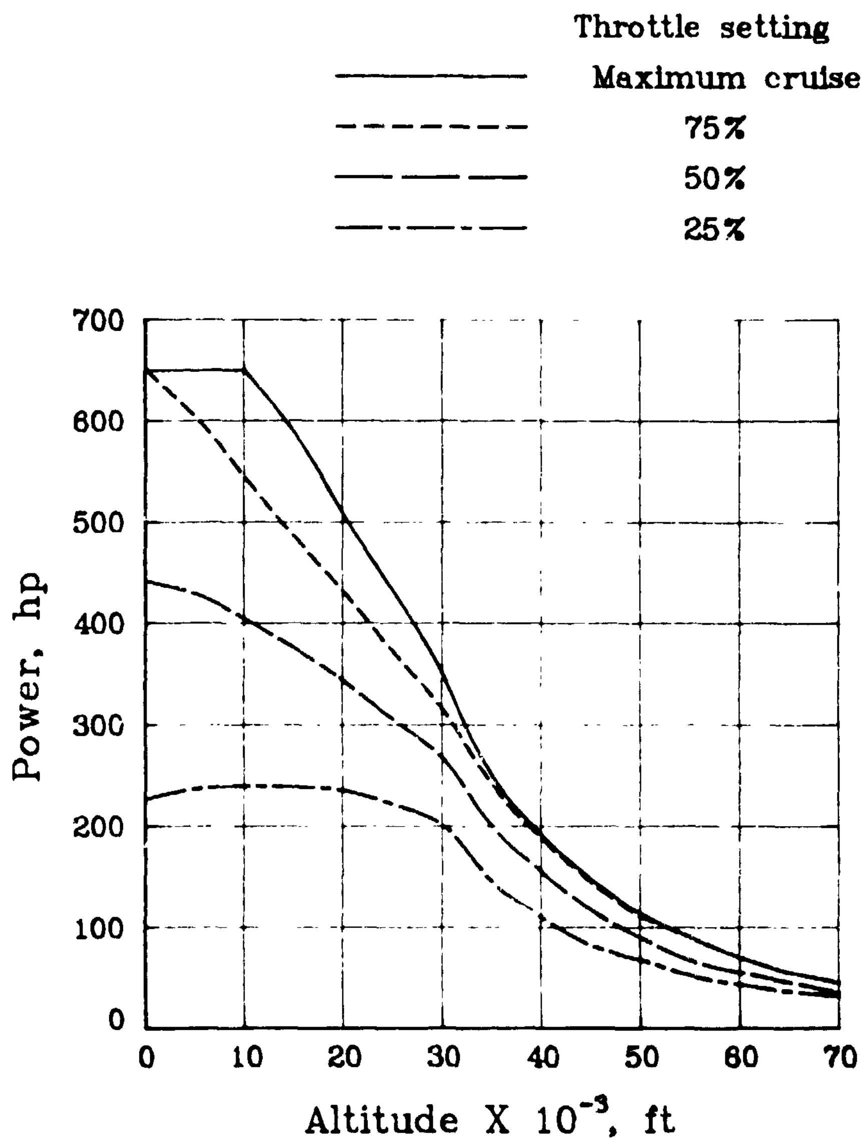

(a) Available engine power for all fuels.

Figure 2. - Performance of 650 horsepower engine.

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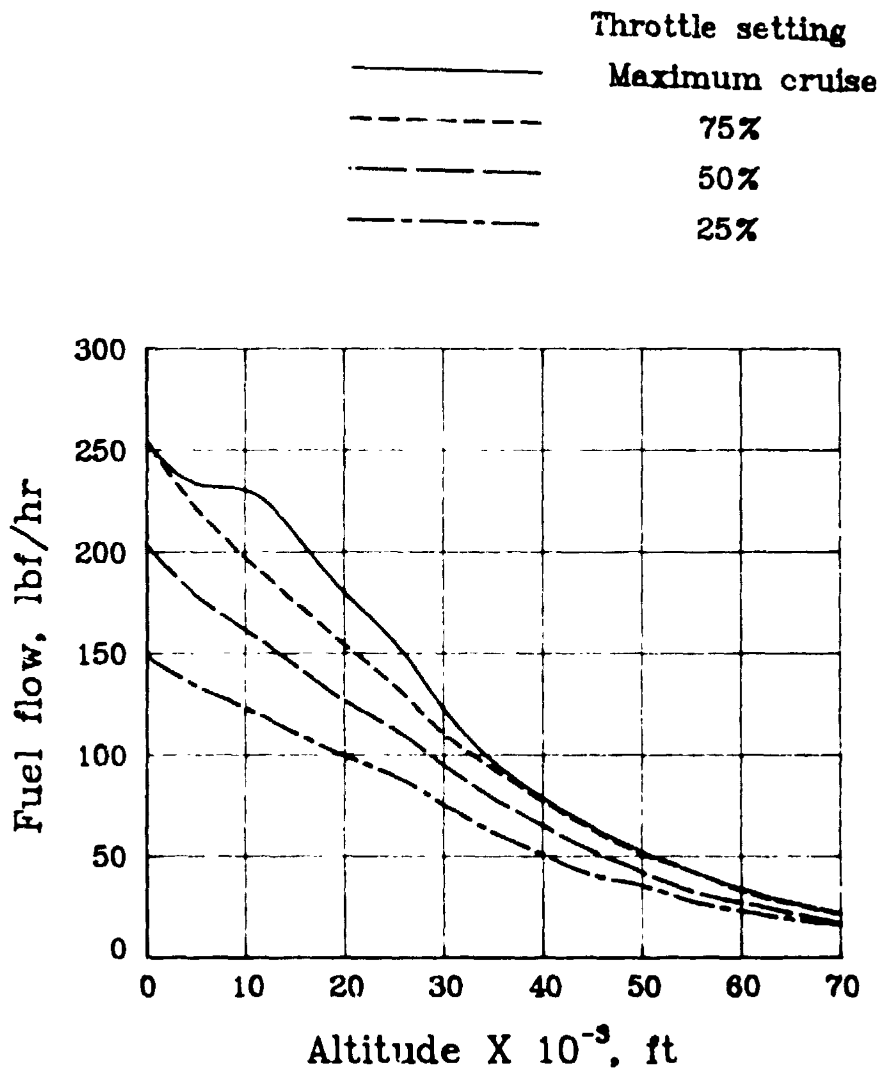
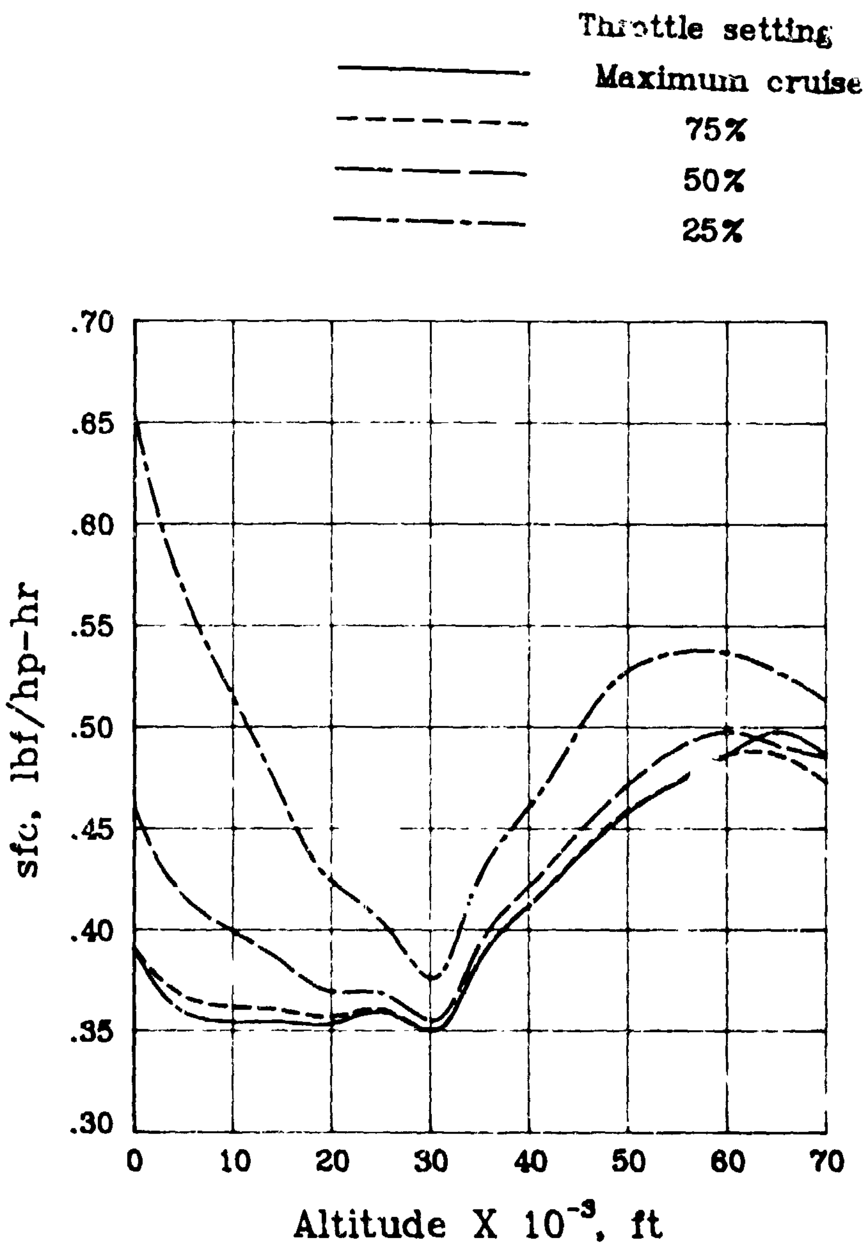


(b) Fuel flow for JP-7 fuel. (Fuel flow for other fuels is proportional to heating value.)

Figure 2. - Continued.



(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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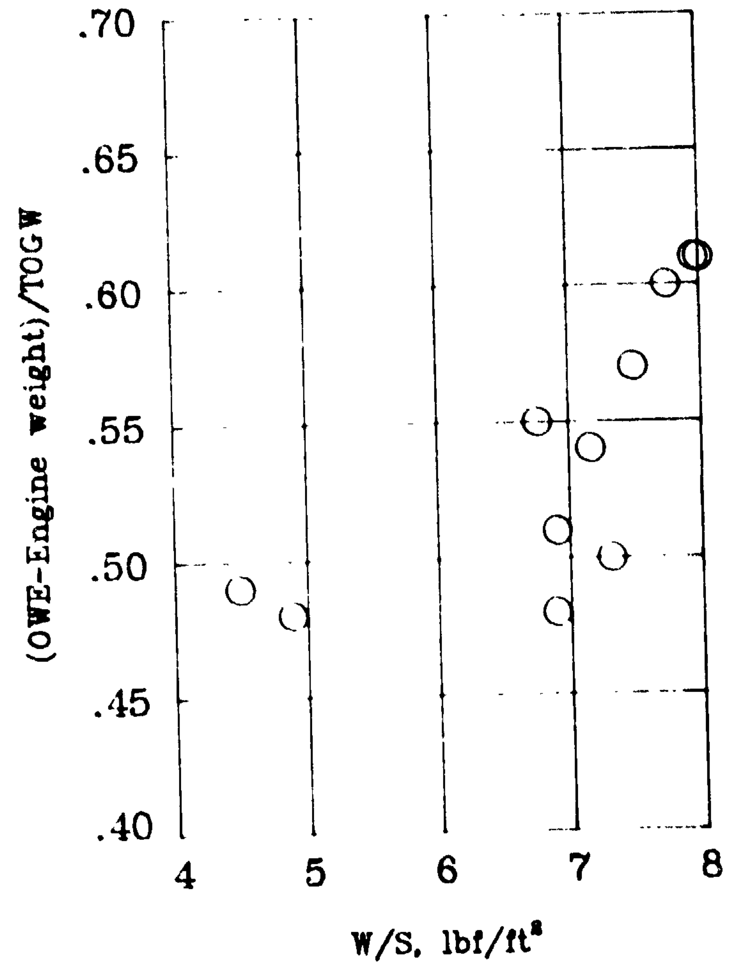

Figure 3. - Weight data for current conventional motor gliders.

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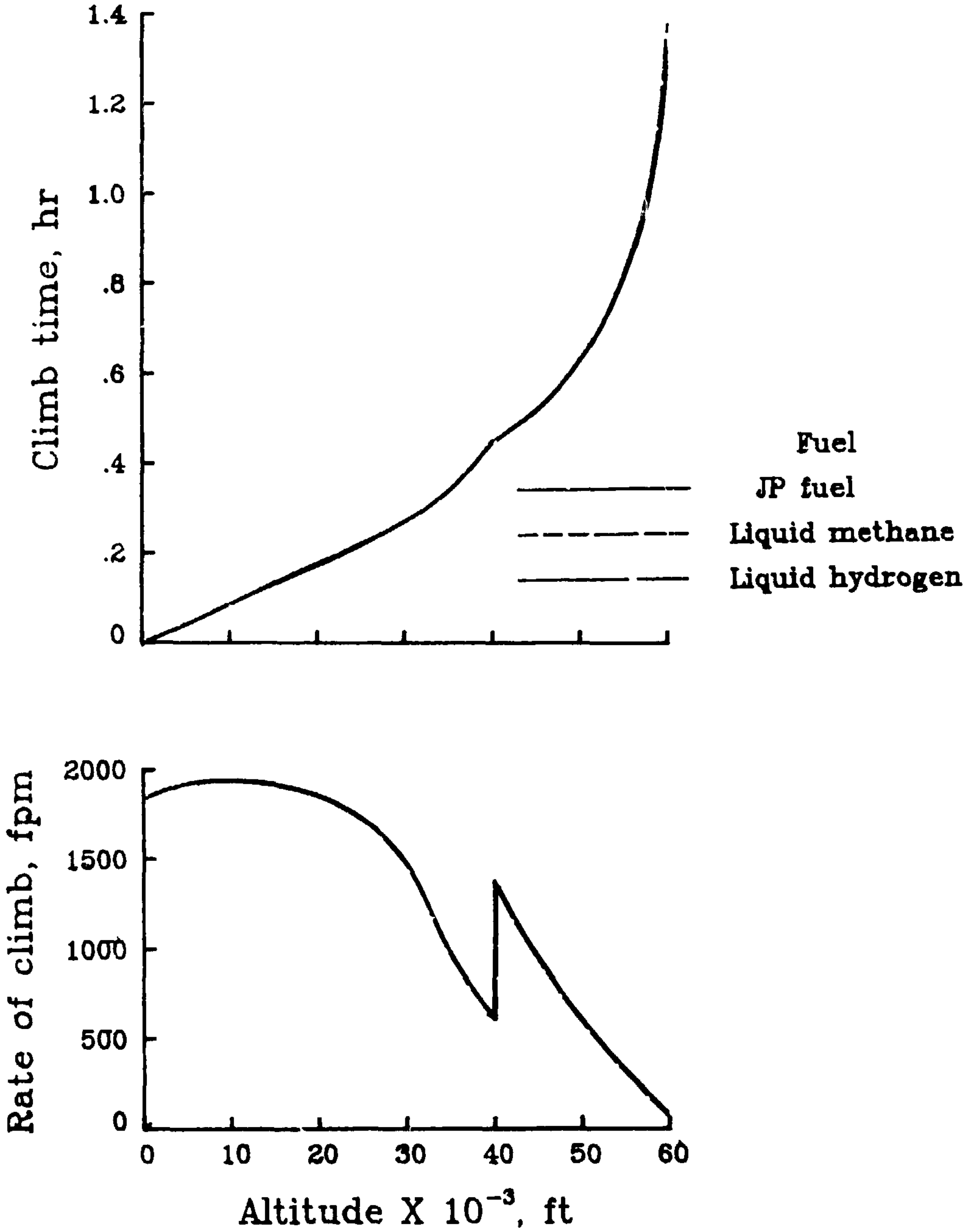

Figure 4. - History c. flight parameters for baseline configuration.

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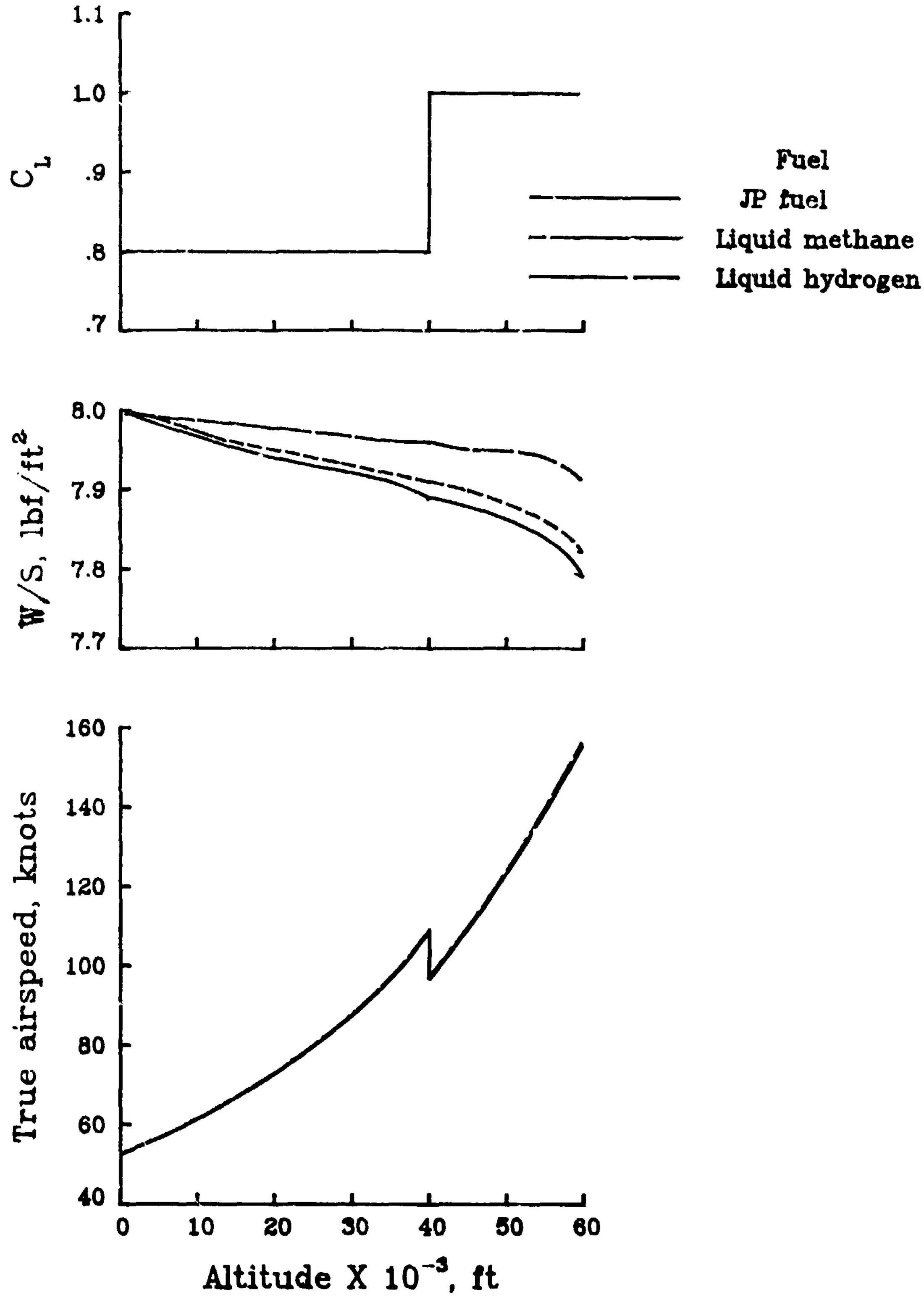

Figure 4. - Continued.

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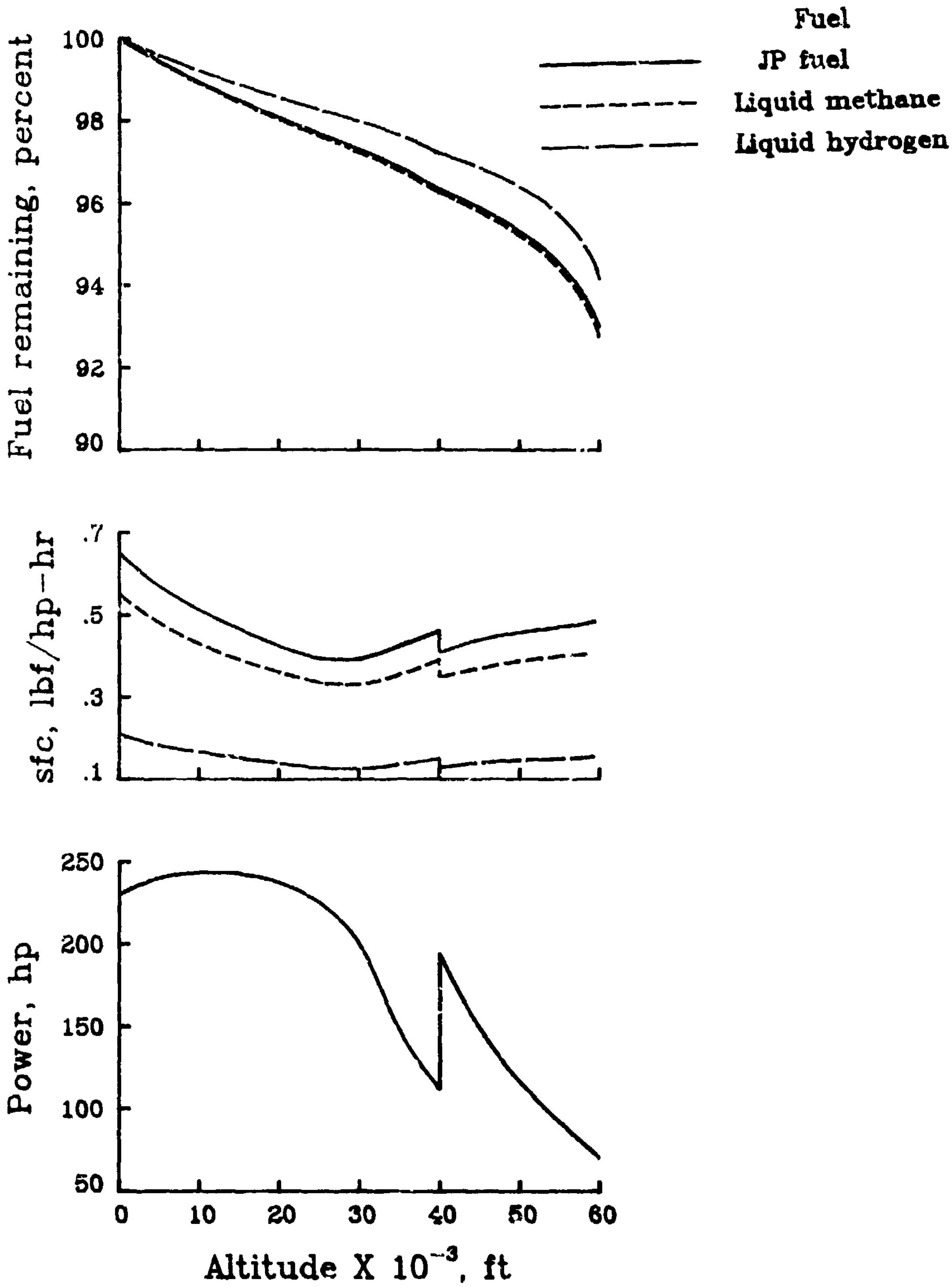

Figure 4. - Concluded.

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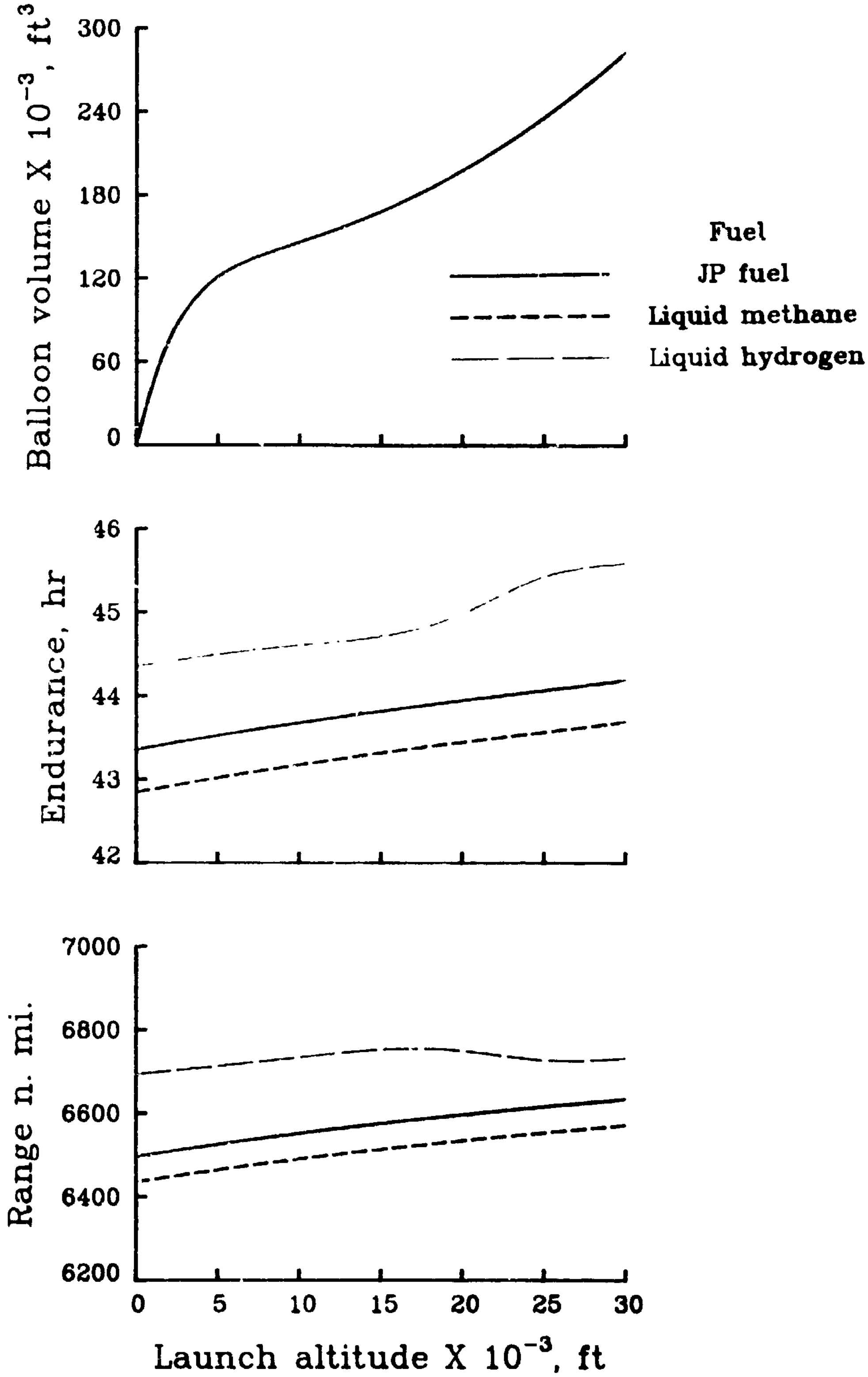

Figure 5. - Effect of balloon assisted launch.

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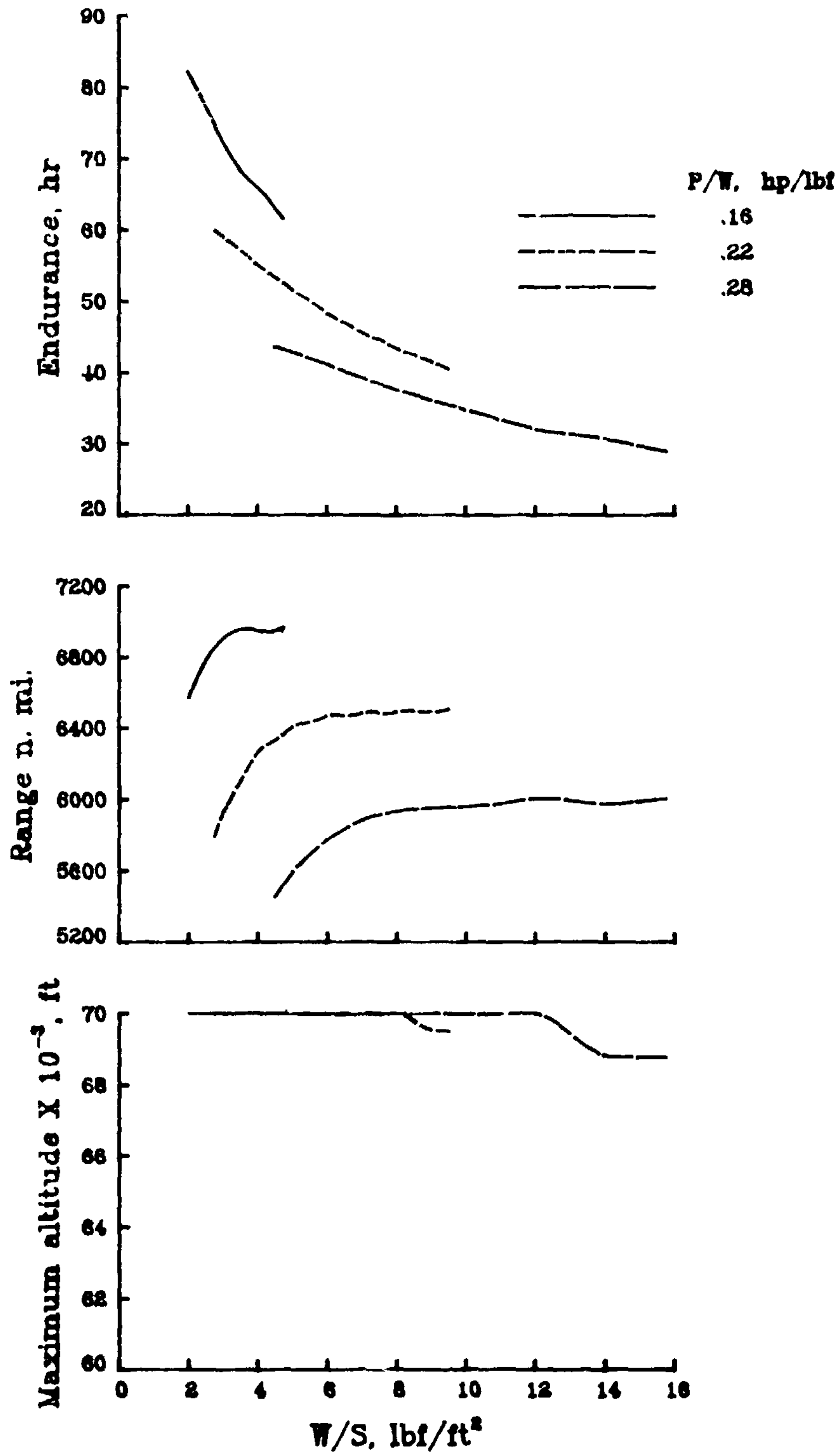

Figure 6.- Variation of endurance, range and maximum attainable altitude with both power loading and wing loading for JP-7 fueled vehicles. TOGW = 3000 lbf.

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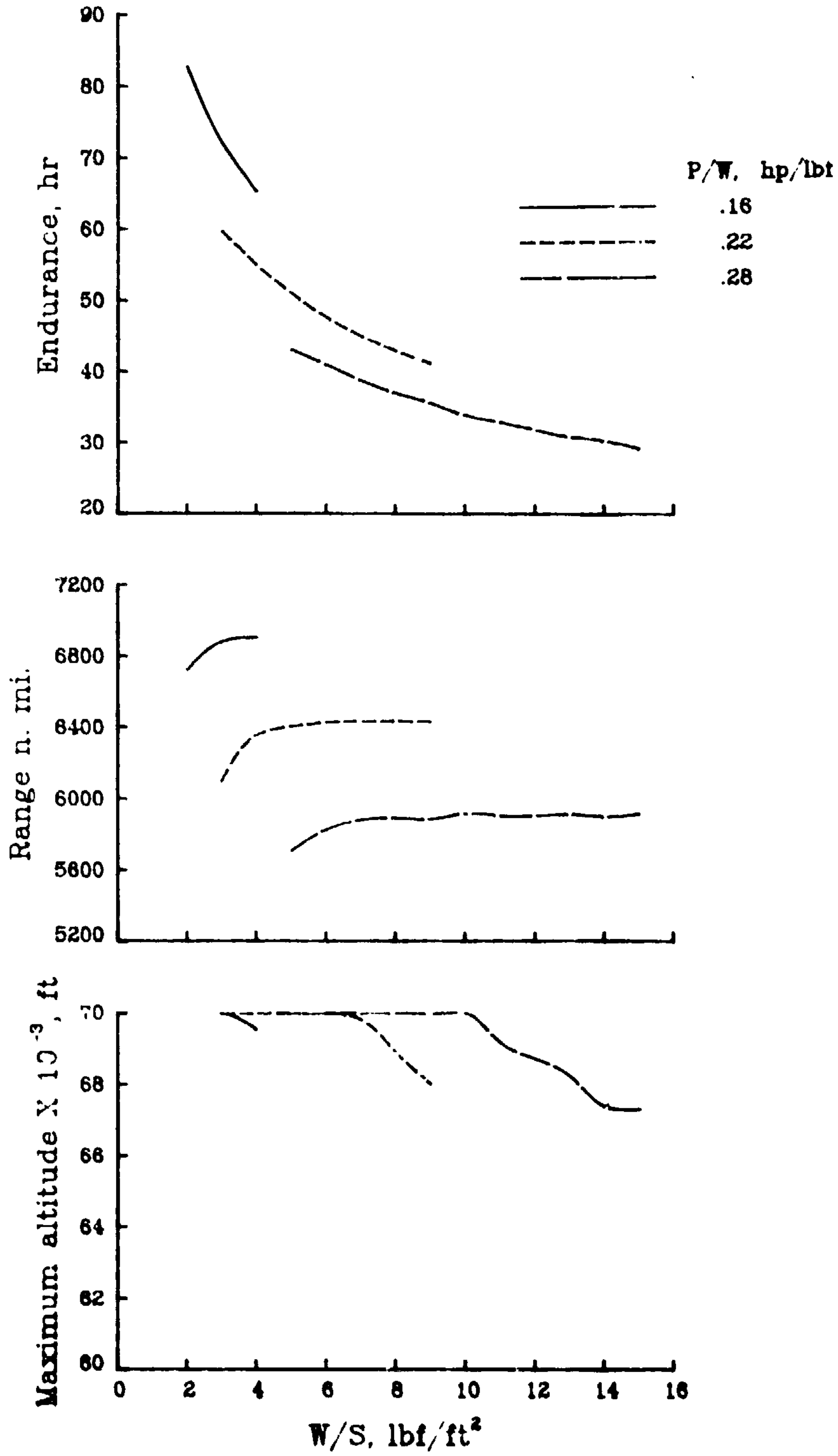


Figure 7.- Variation of endurance, range and maximum attainable altitude with both power loading and wing loading for liquid-methane fueled vehicles. TOGW = 3000 lbf.

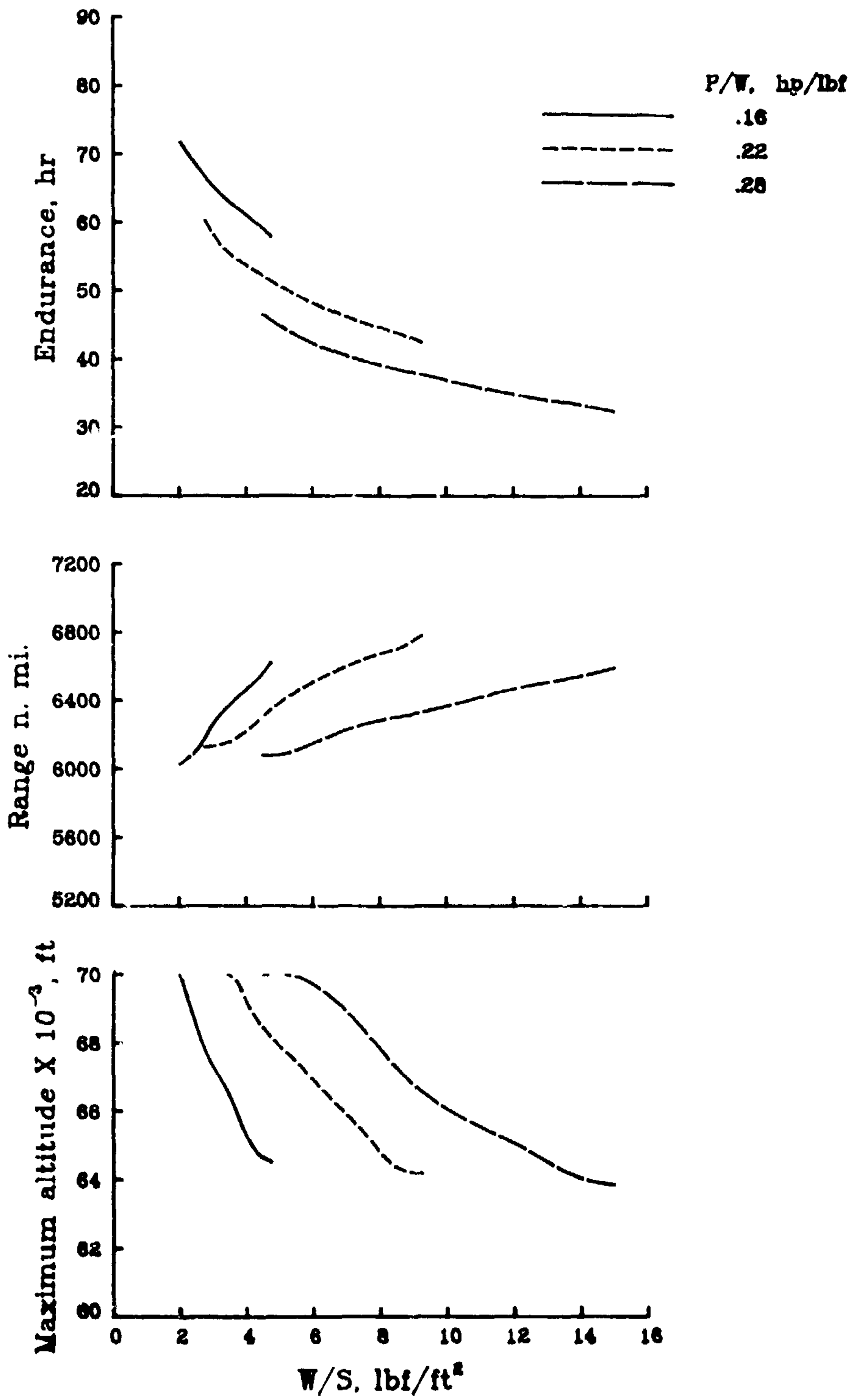


Figure 8.- Variation of endurance, range and maximum attainable altitude with both power loading and wing loading for liquid-hydrogen fueled vehicles. TOGW = 3000 lbf.

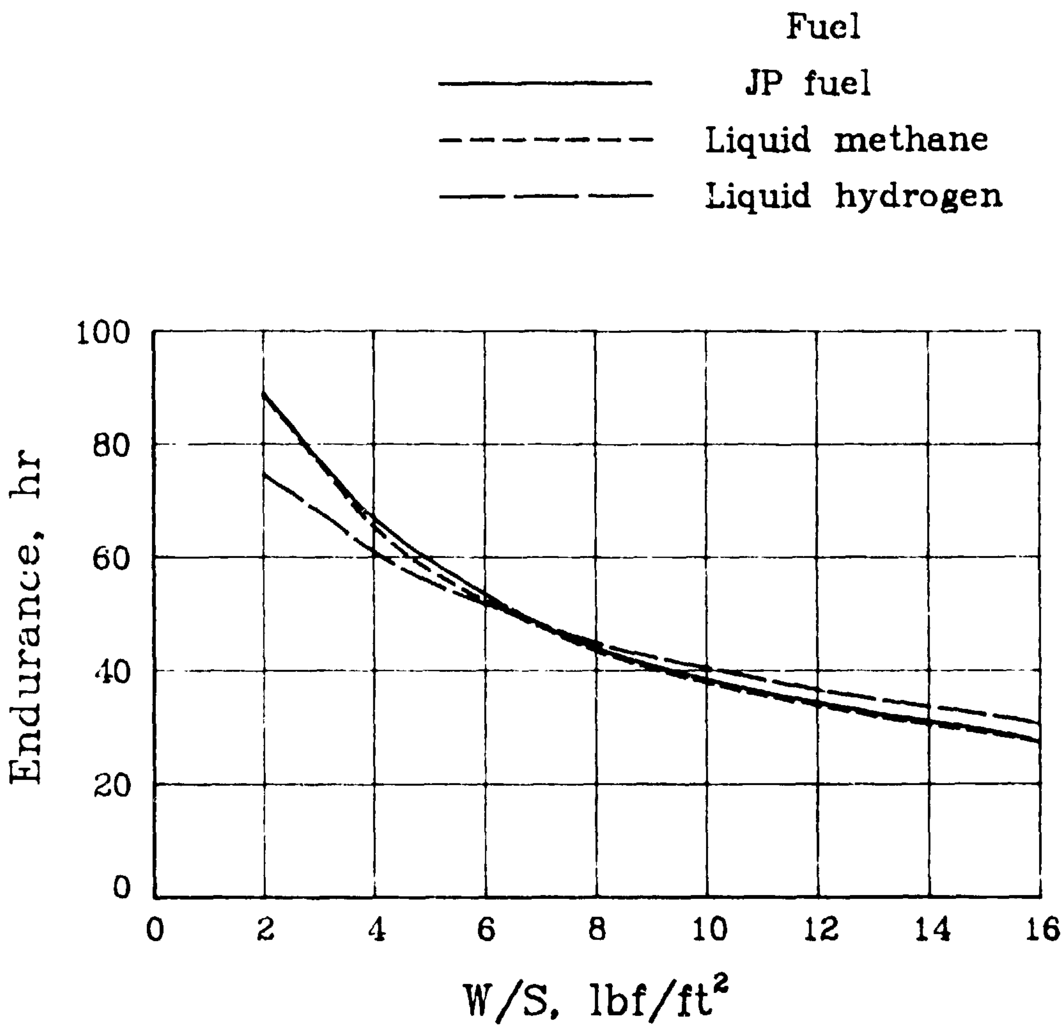
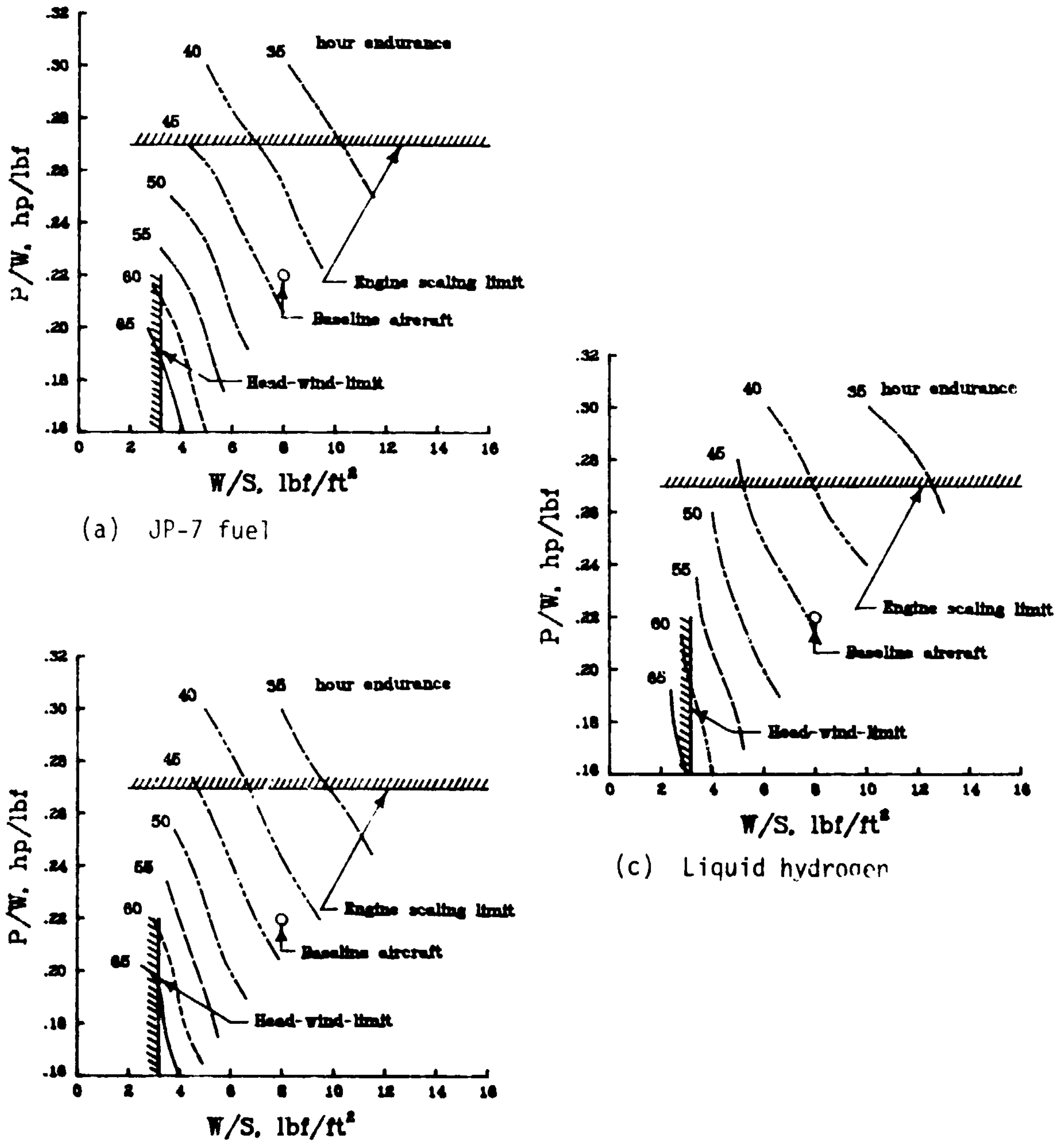


Figure 9.- Variation of maximum endurance with wing loading for three different fuel systems.



(a) JP-7 fuel

(b) Liquid methane

(c) Liquid hydrogen

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

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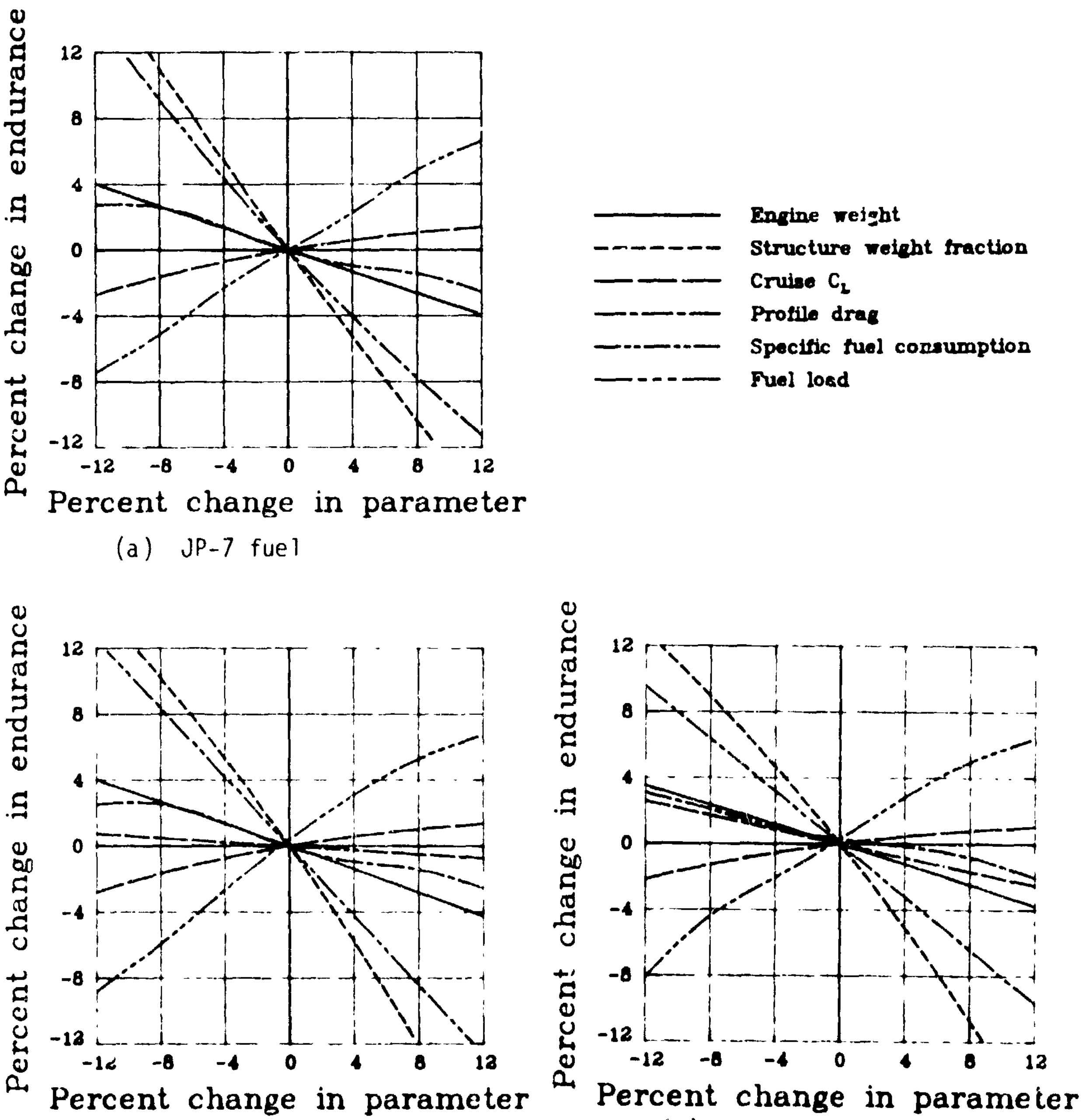

(a) JP-7 fuel

(b) Liquid methane

(c) Liquid hydrogen

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

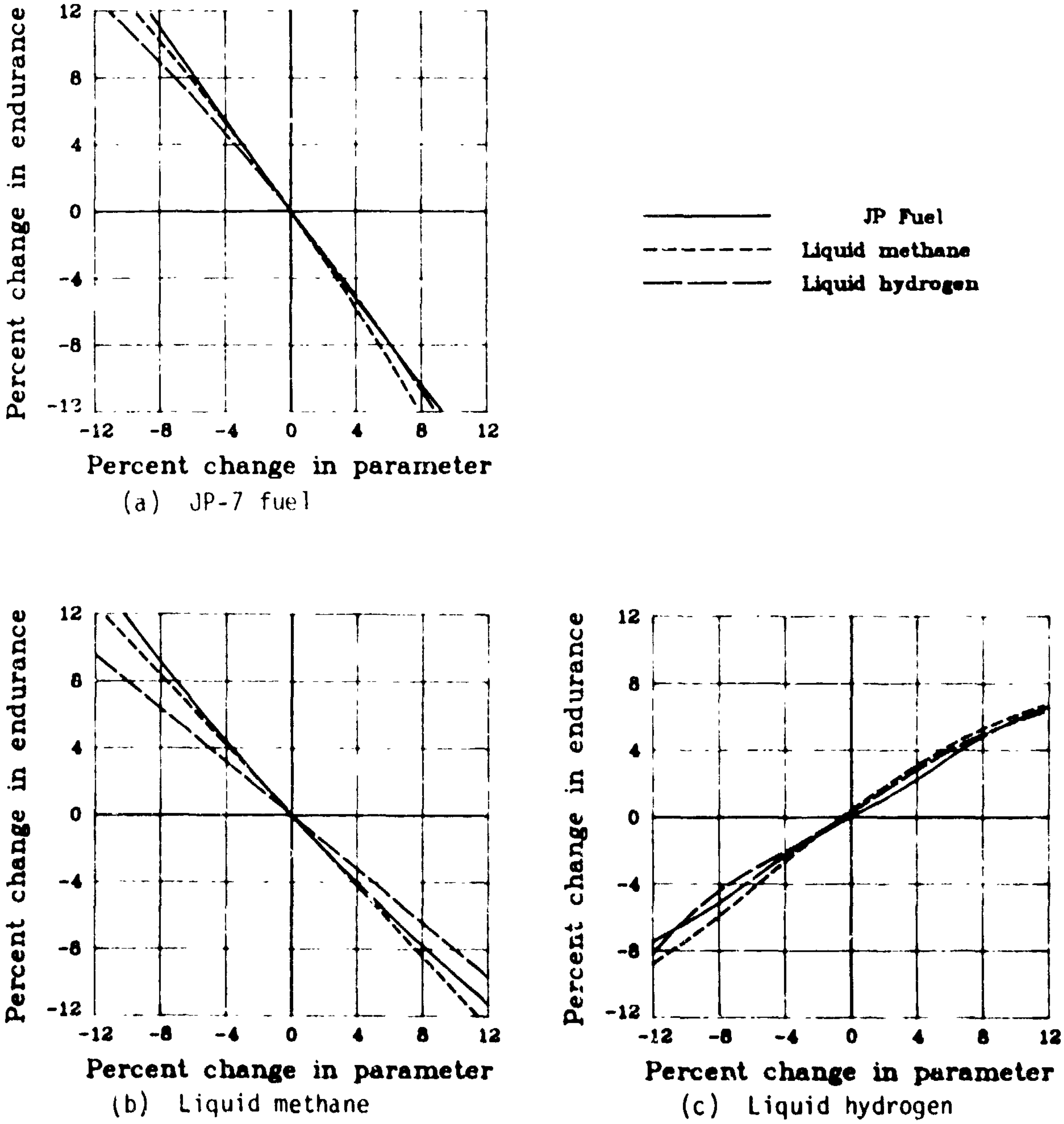

Figure 12.- Effect on endurance of changes in various parameter for three different fuel systems.