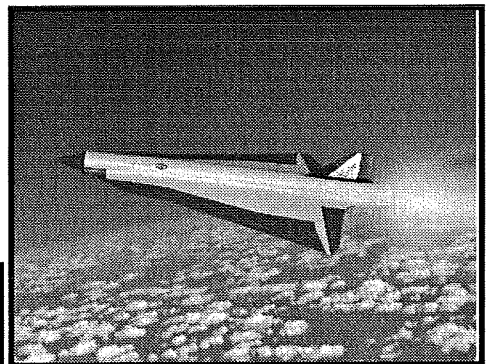
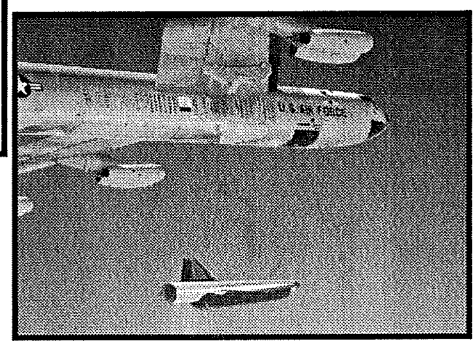
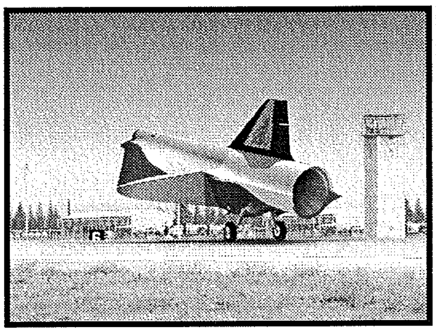
D-21B RBCC Modification Feasibility Study Final Report

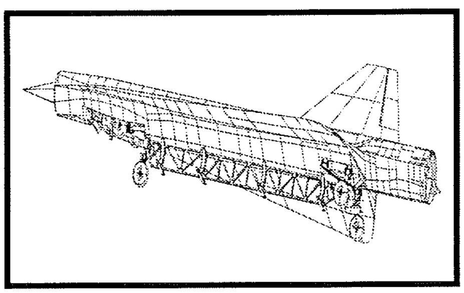


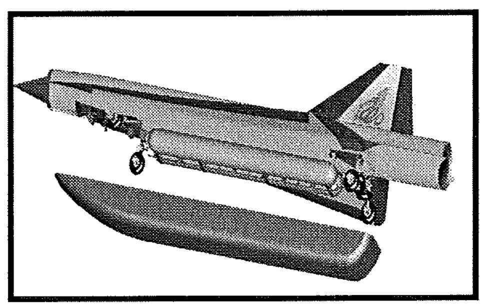


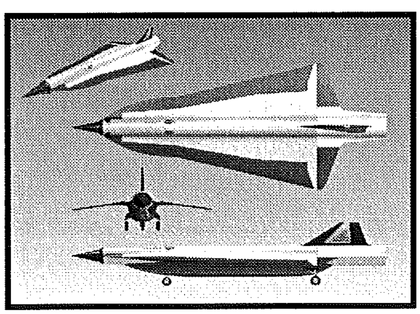


DRACO

D-21







25 October 1999

This final report includes the material presented in the interim and final reviews

Orbital

D-21B RBCC MODIFICATION

FEASIBILITY STUDY

FINAL REPORT

DRACO

D-21

25 OCTOBER 1999

PREPARED BY

Orbital Sciences Corporation
Launch Systems Group
CAGE Code 9X711

ORIGINAL ISSUE DATE
25 OCTOBER 1999

TM-15296 REV -
25 OCTOBER 1999
CODE A1-0-C7

Orbital Sciences Corporation
Launch Systems Group

TM-15296

D-21B RBCC MODIFICATION
FEASIBILITY STUDY
FINAL REPORT

DRACO
D-21
25 OCTOBER 1999

APPROVED BY: Mark D. Hamache 10/27/99
DRACO STUDY LEAD DATE

APPROVED BY: Manoj Mittal 10/25/99
DRACO SYSTEMS & ELEC. STUDY LEAD DATE

APPROVED FOR RELEASE BY: Patrick Dof 10/25/99
CONFIGURATION MANAGEMENT DATE

REVISION SUMMARY

REV	DATE	CHANGE	PAGE

Table of Contents

Tasks And Objectives

- Orbital's SOW Tasks Include:
  - Task #1: Description Of Required Vehicle Modifications
  - Task #2: Estimated Vehicle Performance With RBCC Engine
  - Task #3: Performance Required Of The Engine To Achieve Aforementioned Vehicle Performance
  - Task #4: Cost And Schedule To Achieve The Vehicle Modifications

- SOW Was Funded By MSFC At $100,000. Orbital Provided Internal Funds To Increase The Depth Of The Study.

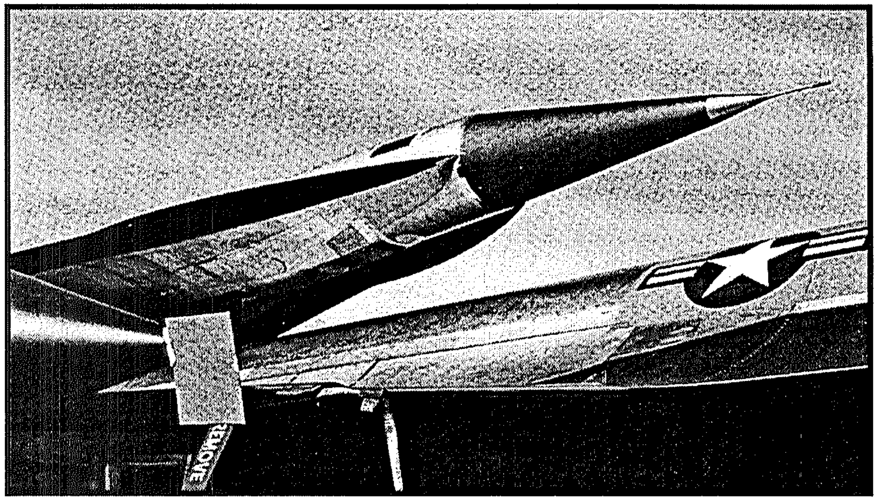
- Period Of Performance Was 45 Days +

- This Objective Of This Final Review Is To Present Results From All Tasks And Make Recommendations On Potential Follow-on Work

Review of RBCC Testbed Requirements

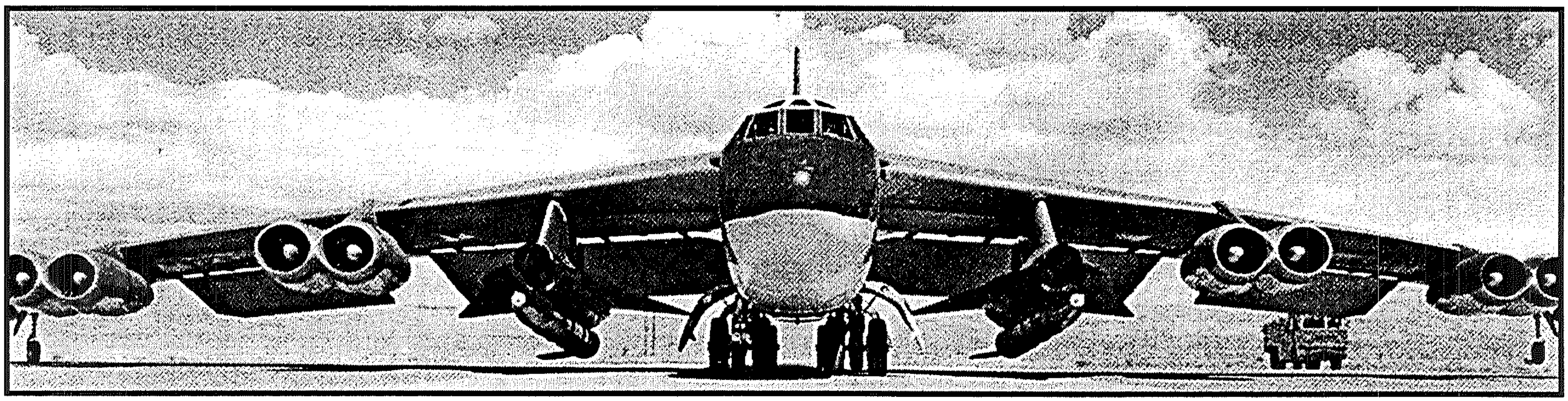
- Not a New Vehicle Development. Use Minimal Modifications in a "Design to Cost" to Achieve As Much Testing As Possible.
- NASA Has Interest in Regime From Mach 0 Through Mach 6 As a Demonstration of a RBCC based Advanced Space Transportation System.
  - Transition From Air Augmented Rocket (AAR) to Ramjet at Approximately M=2.5-M3 of Primary Interest
  - Low-speed Acceleration From Takeoff (or Airdrop) to Mach 2.5 of Secondary Interest
  - Transition From Ramjet Back to Rocket at Some Mach Number Between M=3 and M=6 of Tertiary Interest
- Low Cost, Minimal Mods and Recovery / Quick Turnaround of Primary Importance
  - Secondary And Tertiary Performance Goals Less Important Than Cost
- Study to Be Conducted at a "Feasibility Level." Maximum Attention Provided to "Show Stoppers" and Minimum Attention Provided to Elements Known to Be Low Cost or Easily Within State-of-the-art.
- Cost And Schedule For The RBCC Test-bed Calculated To ROM Level Of Fidelity

D-21 Operational Configurations



SR-71 With D-21

Launched At
M=3+



B-52H With 2 D-21Bs

Lauched At M=0.8 And 43,000 Ft With Large Solid Rocket Booster

D-21B Operational Configuration

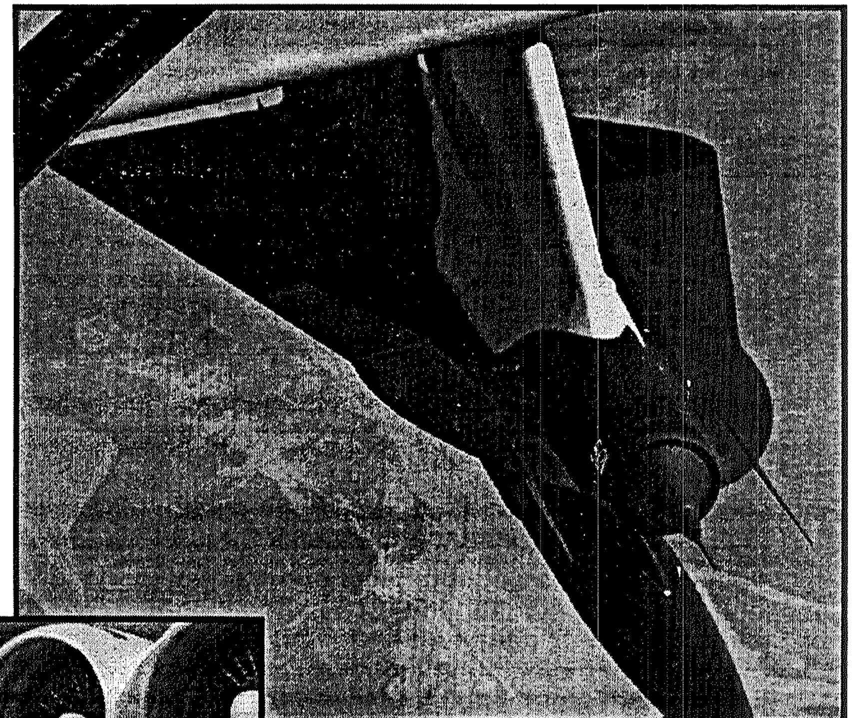
D-21B Drone On B-52H

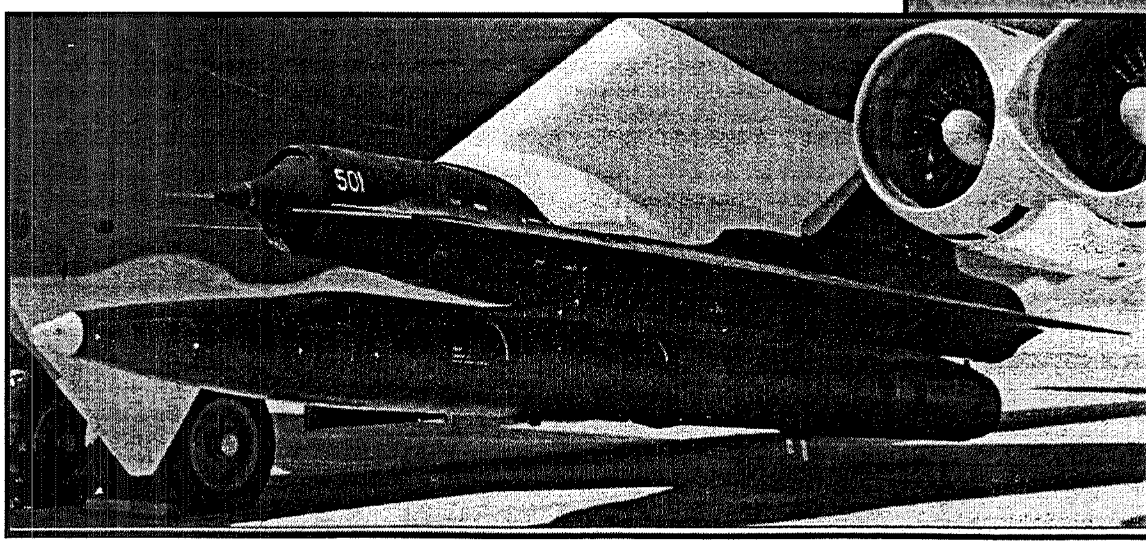
Length = 43 Ft   Span = 19 Ft

M=3.5 Cruise @ 95,000 ft

D-21B = 11,000 Lb Wet

RJ-43 Ramjet ~ 4,000 Lb Thrust

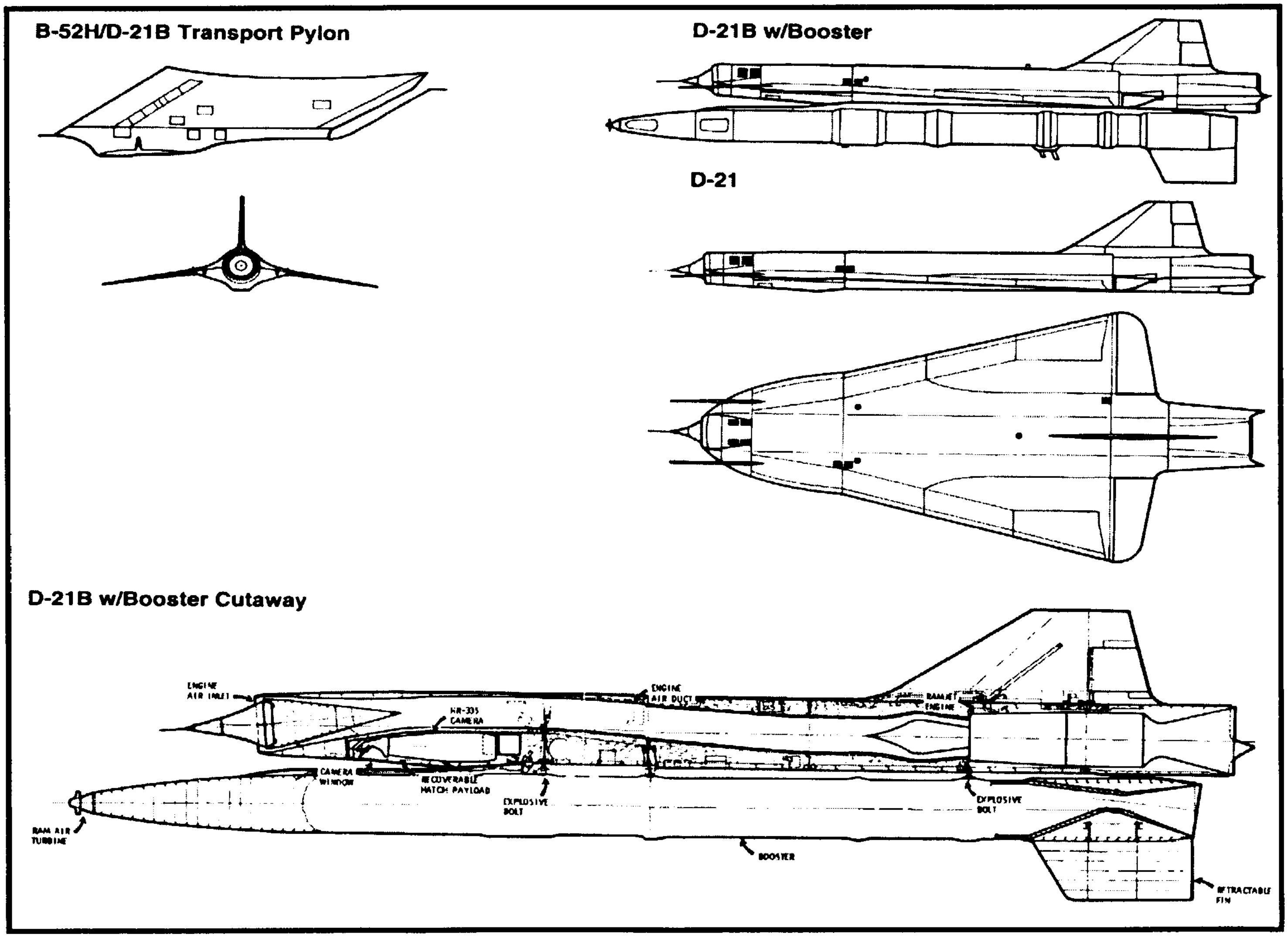




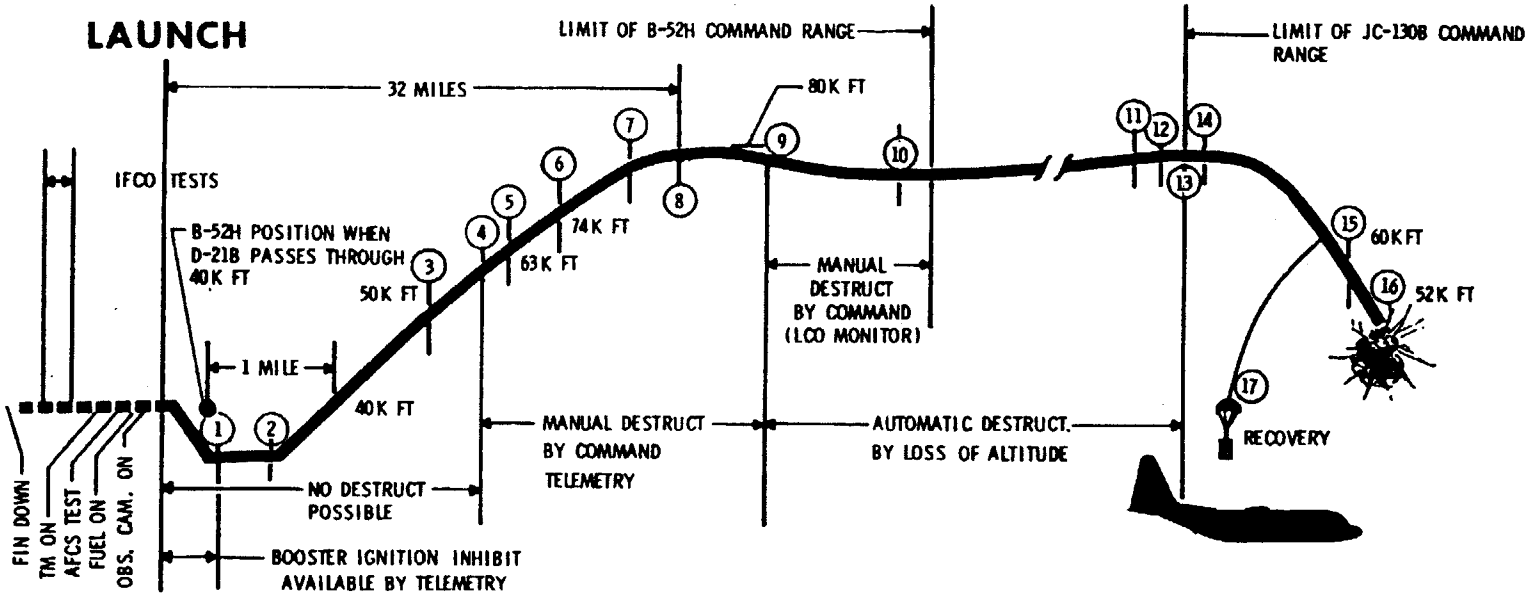
SRB = 14,000 Lb GW

27,000 Lb Thrust

D-21B Description



D-21B Operational Flight Profile



D-21B Sequence of Events

BOOSTER IGNITION-

5° PITCH-UP, FOLLOWED BY 1°/SEC PULL-UP

TRANSITION TO FINAL CLIMB TRAJECTORY

MANUAL DESTRUCT CIRCUIT COMPLETE

5 DESTRUCT ALTITUDE SWITCH OPEN

6 ENGINE IGNITION: AUTO DESTRUCT CIRCUIT COMPLETE

7 APU LOAD TAKE-OVER

8 BOOSTER JETTISON, AFCS TO MACH HOLD

9 AUTOMATIC DESTRUCT CIRCUITRY ARM

10 COMMAND AND T/M "OFF"

11 COMMAND "ON"

12 BEACONS "ON" AND T/M "ON"

13 DESTRUCT DISABLE

14 FUEL "OFF"

15 EJECT HATCH

16 AUTOMATIC DESTRUCT

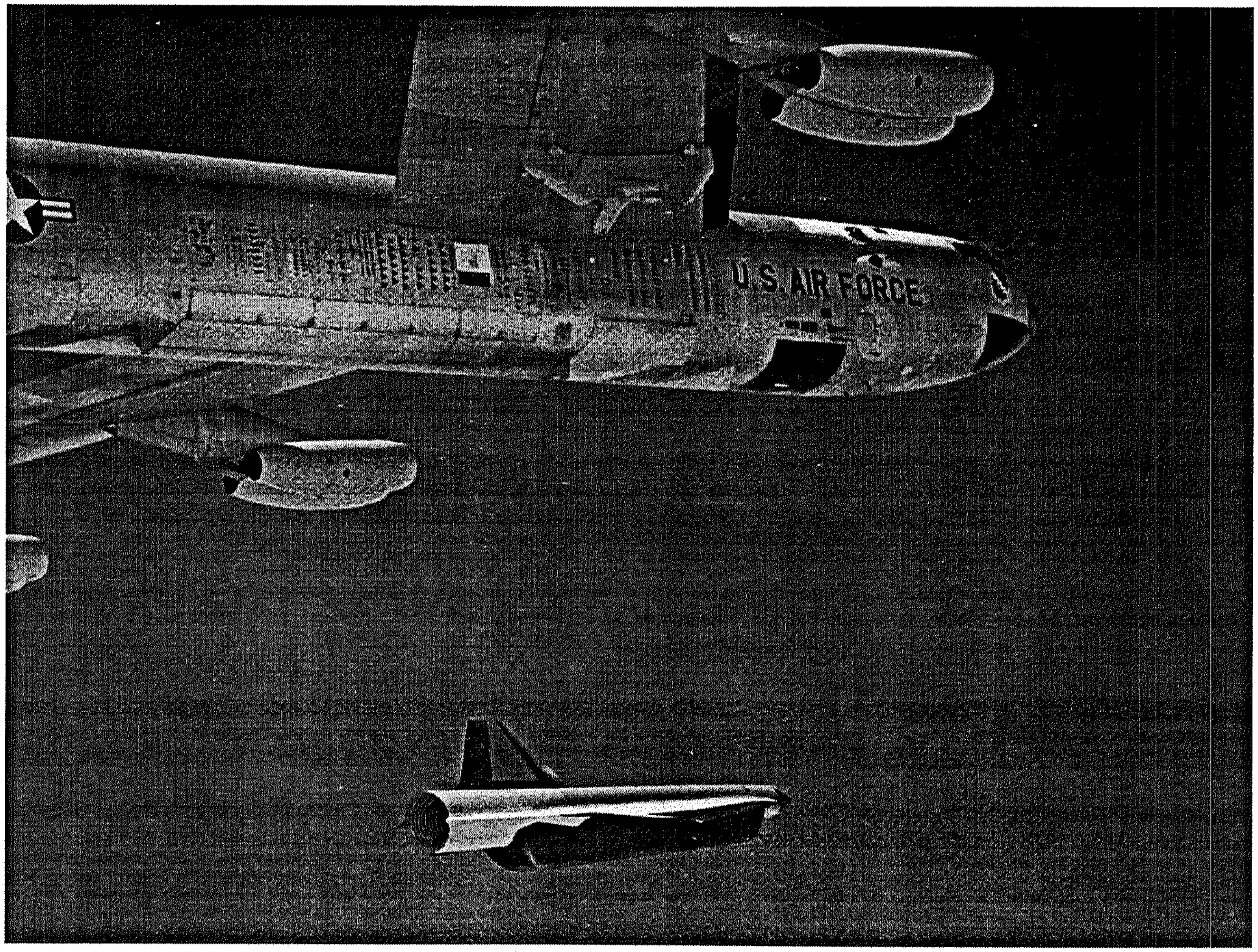
17 HATCH RECOVERY

Background: Previous Northrop Grumman Work

- Over The Past Four Years Northrop Grumman Had Investigated Several Hypersonic Test-bed Concepts That Could Utilize The D-21B Airframe Including: X-34, Future-X, And RBCC Test-beds
- The D-21B Airframe Was A Logical Candidate Because It Was Designed To Cruise At Relatively High Mach With High Skin Temperatures And Could Save Time And Development Cost By Utilizing An Existing Airframe
- Orbital Sciences And NGC Have Cooperated Over The Past Two Years On Several Projects Including CRV And “Space Transportation Architecture Study”
- NGC And Orbital Have Proprietary Information Exchange Agreements And Contracts In Place That Allow The Two Companies To Share NGC Data From Previous D-21B Studies

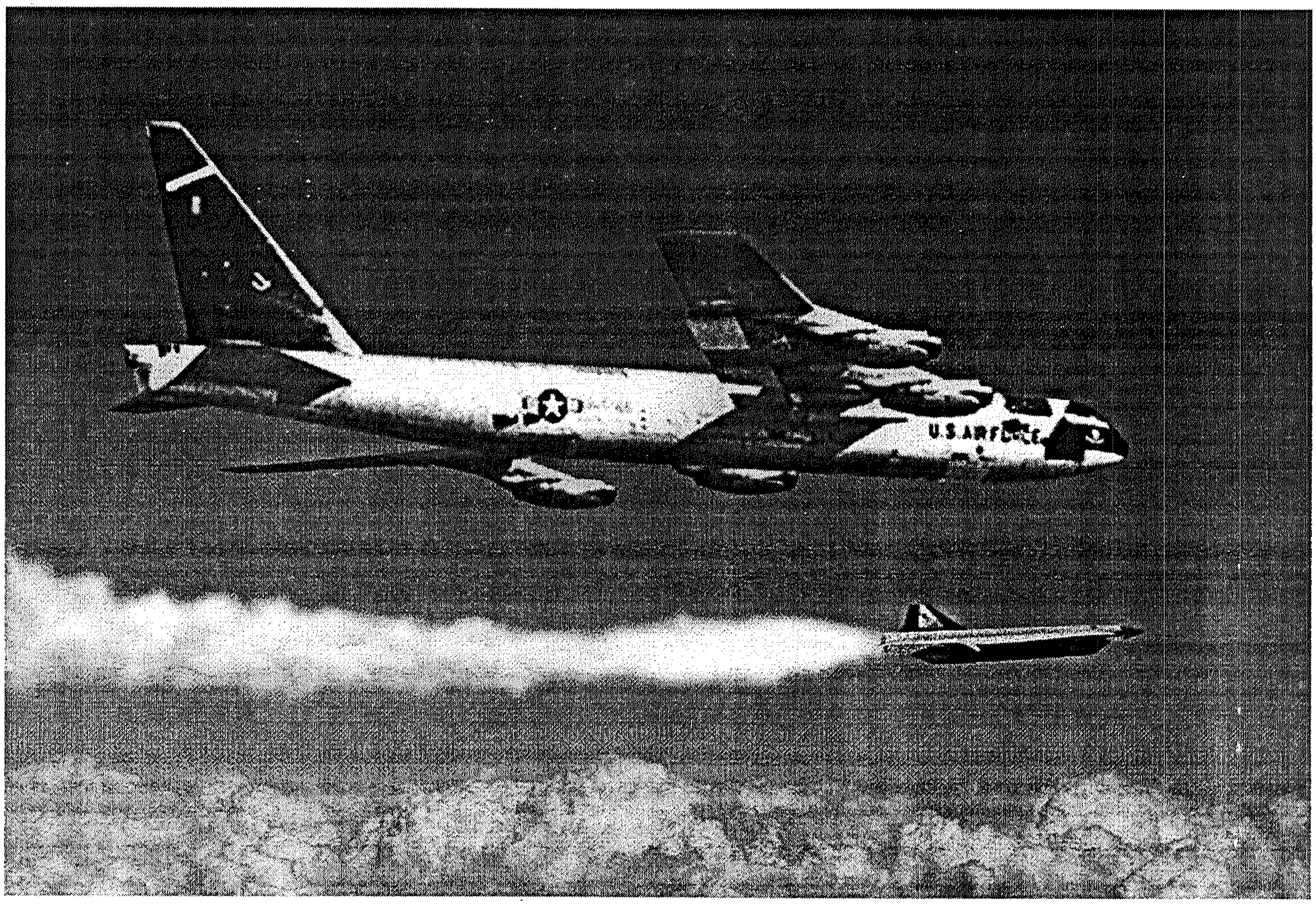
Configuration Trades Performed

- RBCC Engine Compatibility Examined
  - Physical Fit
  - Inlet Compatibility
    - NASA Baselined Translating Cone Type Variable Inlet
    - Flow And Aerothermal Compatibility
  - Duct Compatibility
    - Flow And Aerothermal Compatibility
- Aerothermal Analysis Of Airframe
- Structural Loads Analysis
- Landing Gear And External Tank Configuration
- Analysis Of Compatibility Of Propane With D-21 Internal Tanks
- Avionics / Flight Controls / Instrumentation Using Pegasus / X-34 Baseline
- Low Speed Stability And Control And Runway Landing Analysis



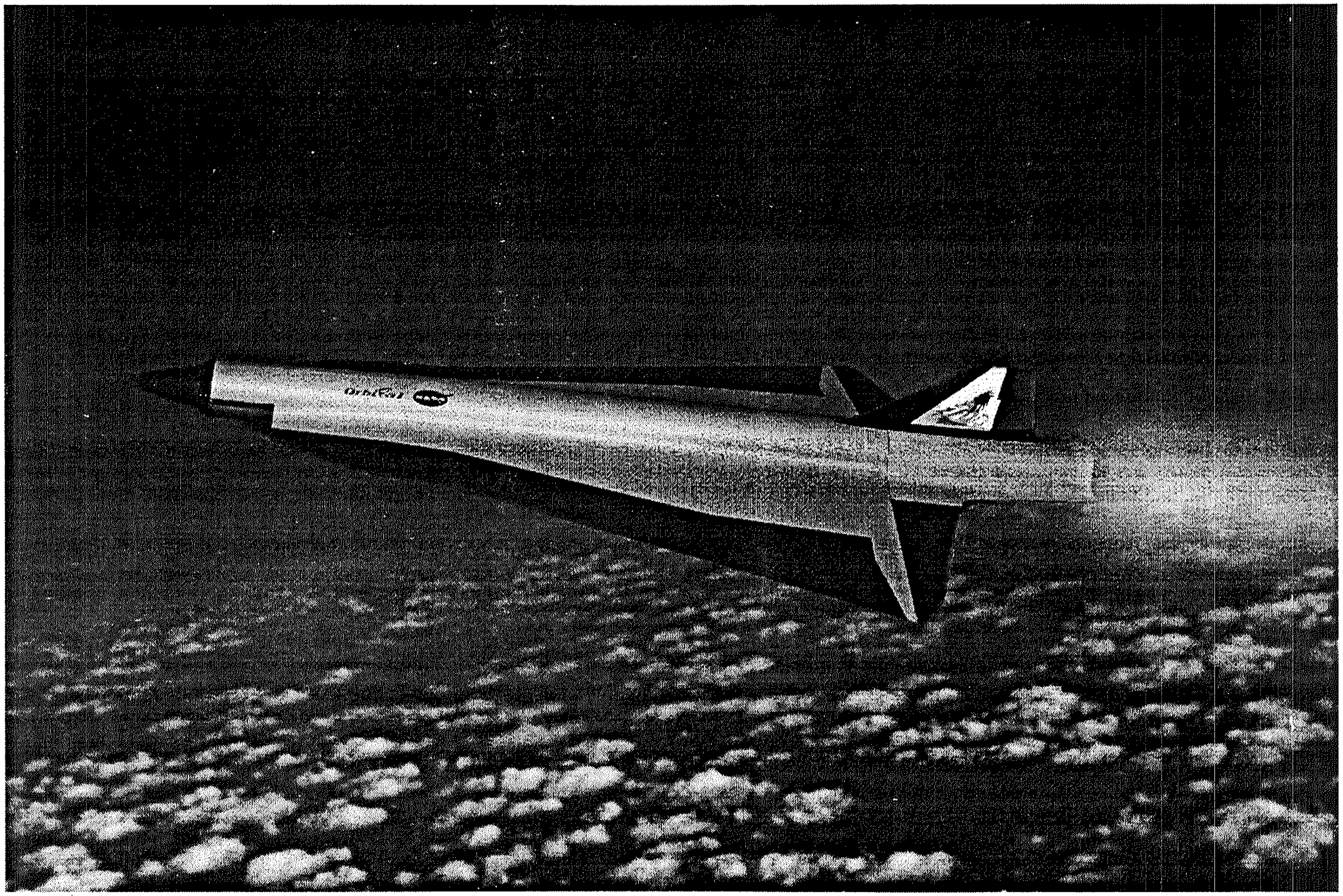
B-52 (008) Air Launch From 43,000 Ft And M=0.8.
B-52 Will Have LOX Top-off Capability For D-21B.

DRACO D-21B With RBCC Modifications



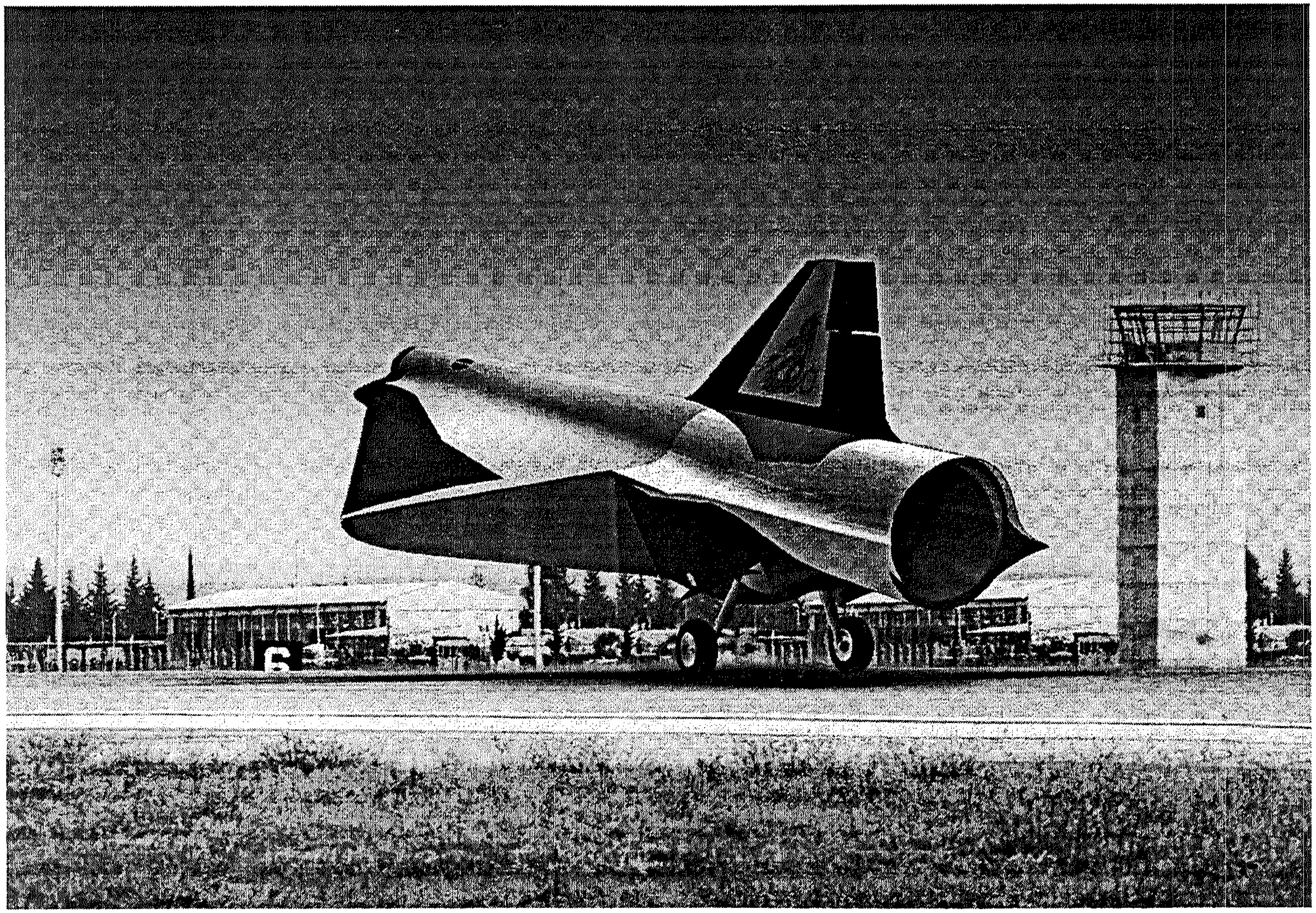
B-52 (008) Air Launch From 43,000 Ft And M=0.8.
B-52 Will Have LOX Top-off Capability For D-21B.

DRACO D-21B With RBCC Modifications



Mach = 3.5+ RBCC Engine Demonstration Test-bed

DRACO D-21B With RBCC Modifications



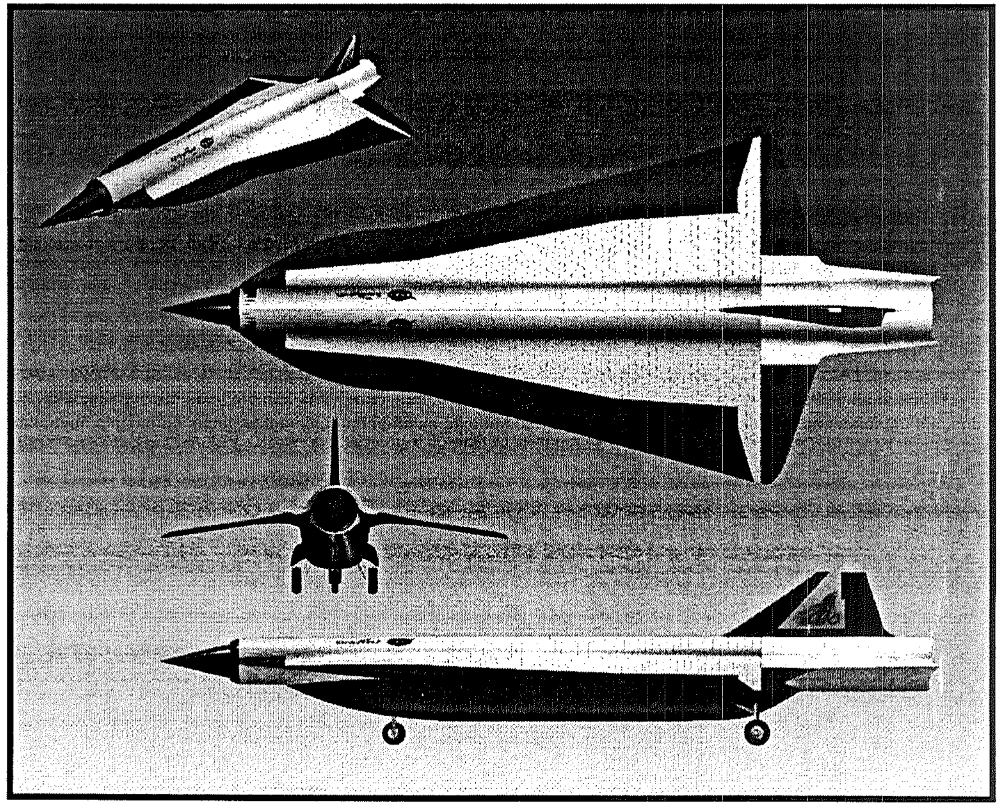
Runway Landing On Wheeled Gear Is The Preferred Recovery Technique

DRACO D-21B With RBCC Modifications

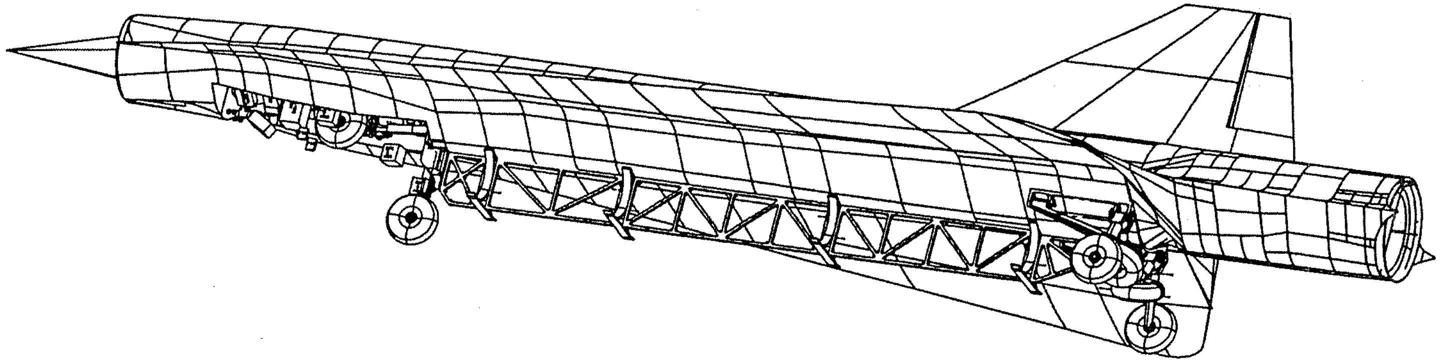
Length = 44+ Ft
Span = 19.5 Ft
GLOW = 11,850 Lbs
Landing W t= 6,480 Lbs

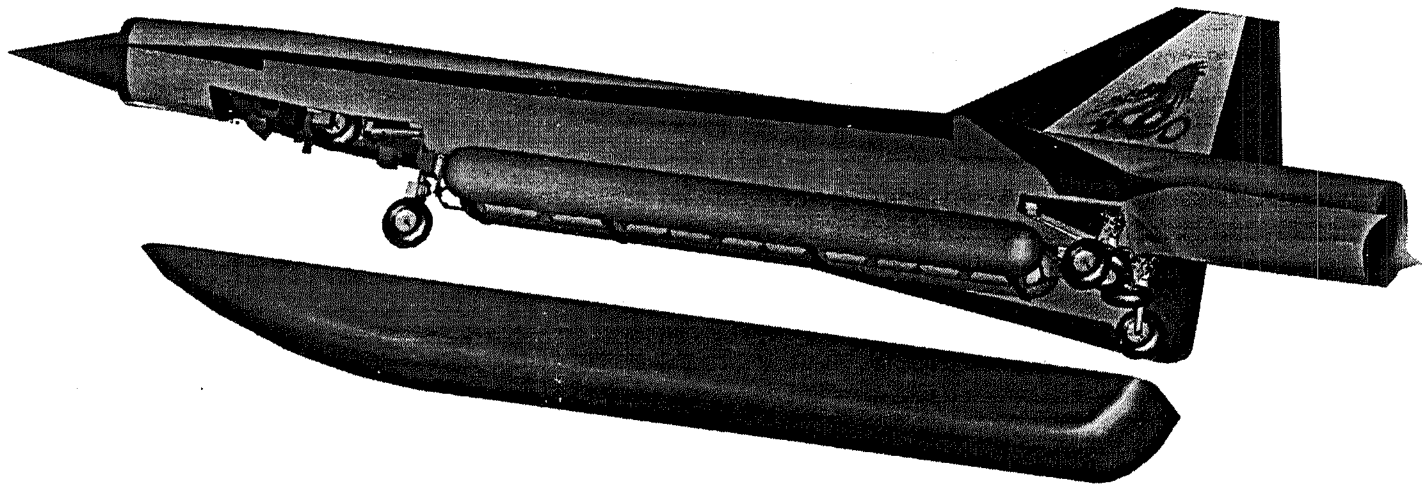
With LOX/JP Config:
Max Mach = 3.5+
Max Altitude= 85,200 Ft
Max Q = 1300 PSF

DRACO Engine Max Thrust:
Ejector Mode: ~ 12,000 Lb
Ramjet Mode: ~ 2,500 Lb



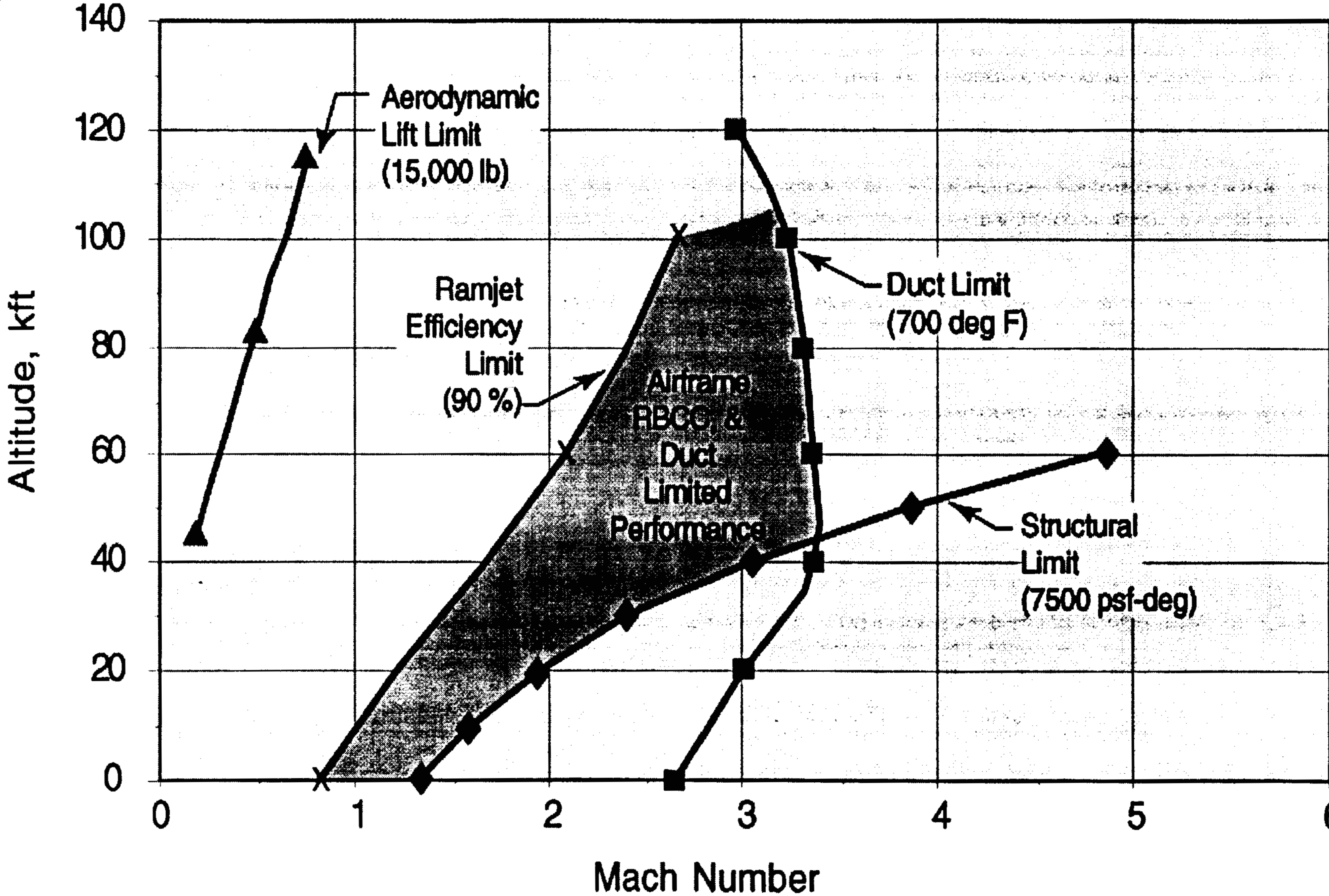
DRACO D-21B CAD Model





LOX Tanks, Landing Gear, And "Canoe" Fairing Modifications

DRACO D-21B Operational Envelope With Unmodified Airframe and Duct



Summary Of Performance Trajectory Tools

- A Comprehensive Database Of Aerodynamic Parameters Was Developed
- Engine And Inlet Performance Data Estimates Were Provided By The NASA DRACO Team And Iterated With Vehicle Performance
- Mass Properties Were Updated Including All Additional Avionics, Systems, Landing Gear, Propellant Tanks, And TPS
- Drag Estimates For The Unmodified D-21B Were Updated To Include External Tanks And The “Canoe” Structural Modification
- Three Degree Of Freedom (3DOF) Trajectories Were Run At Two Different Dynamic Pressure (Q) Conditions With Each Flight Beginning From A B-52 Air Launch At 40,000 Ft And M=0.8
- Once The Desired Maximum Dynamic Pressure Was Reached, It Was Maintained Until All Fuel Was Exhausted
- Three Different Propellant Combinations Were Evaluated:
  - LOX/JP, LOX/Propane, And Peroxide/JP
  - At Two Dynamic Pressure Levels: 650 PSF, And 1300 PSF

Verification Of Trajectory Tools

- 3 DOF Trajectories Were Run For The Propellant Combinations And Dynamic Pressures Shown Below Using USAF AFFTC-TIH-95-01, "Computer Program For Aerospace Vehicle Trajectory Simulation For Operation On A PC(PCSIM6D)
- This Program Does Not Explicitly Optimize End Conditions, But Flies To A Table Of Attitude And Thrust Commands. These Commands Are Manually Entered Based On User Experience.
- Approximately 100 Engineering Manhours Were Spent To Verify This Program Against The NASA 6DOF POST Code That Is The Industry Standard For Trajectory Analysis.
- The "Manual" Optimization Was Found To Be As Effective As The POST Optimization Techniques For This Study And Substantially Increased The Number Of Trades That Could Be Evaluated Within The Study Time And Cost Restrictions
- The Following Parameters Are Plotted Vs Time For Each Of The Three Propellant Combinations (LOX/JP, LOX/Propane, Peroxide/JP):

  Altitude, Mach, Thrust, Drag, Excess Thrust, Dynamic Pressure, Pitch Angle, Angle Of Attack, Q*AOA, and Nose Stagnation Temperature

D-21 Aerodynamic Data

- Lift and Drag Data Developed by Northrop-Grumman For Another Program
- Lockheed "Aerodynamic Characteristics" Report SP-507 Used As Basis
- Data Extended Into Unknown Areas Using Standard Advanced Design Methods.`
- Program VORLAX Used to Predict Aerodynamic Center Data
  - Found Unstable Static Longitudinal Stability Below M=1.0
- Inlet Drag Not Included in Drag Predictions
  - Charged to Engine
- Clean D-21 Drag from Northrop Used in this Analysis
- Clean D-21 Frontal Area Estimated to be 10.9 ft^2
- Addition of External LOX Tanks Increased Estimated Frontal Area to 15.4 ft^2

Summary of Results

- Performance Analysis Conducted at Two Dynamic Pressures, 650 psf and 1300 psf
- Higher Dynamic Pressures Generally Achieved Better Performance, (ie Higher Mach Number)
- JP-5/LOX Fuel Achieved Slightly Better Performance Than Other Fuels
- JP-5/Hydrogen Peroxide Had Nearly Equal Performance
- Propane/LOX Was The Worst Because Internal Fuel Tanks Were Very Heavy (1400 lb) and Because Small Volume Was Available When Tanks Installed Internally
- Most Trajectories Flown With Only Partial Internal JP Fuel Volume Used
  - 50% to 61%
- Ramjet Excess Thrust Was Low For All Three Fuels

Summary of Results (Continued)

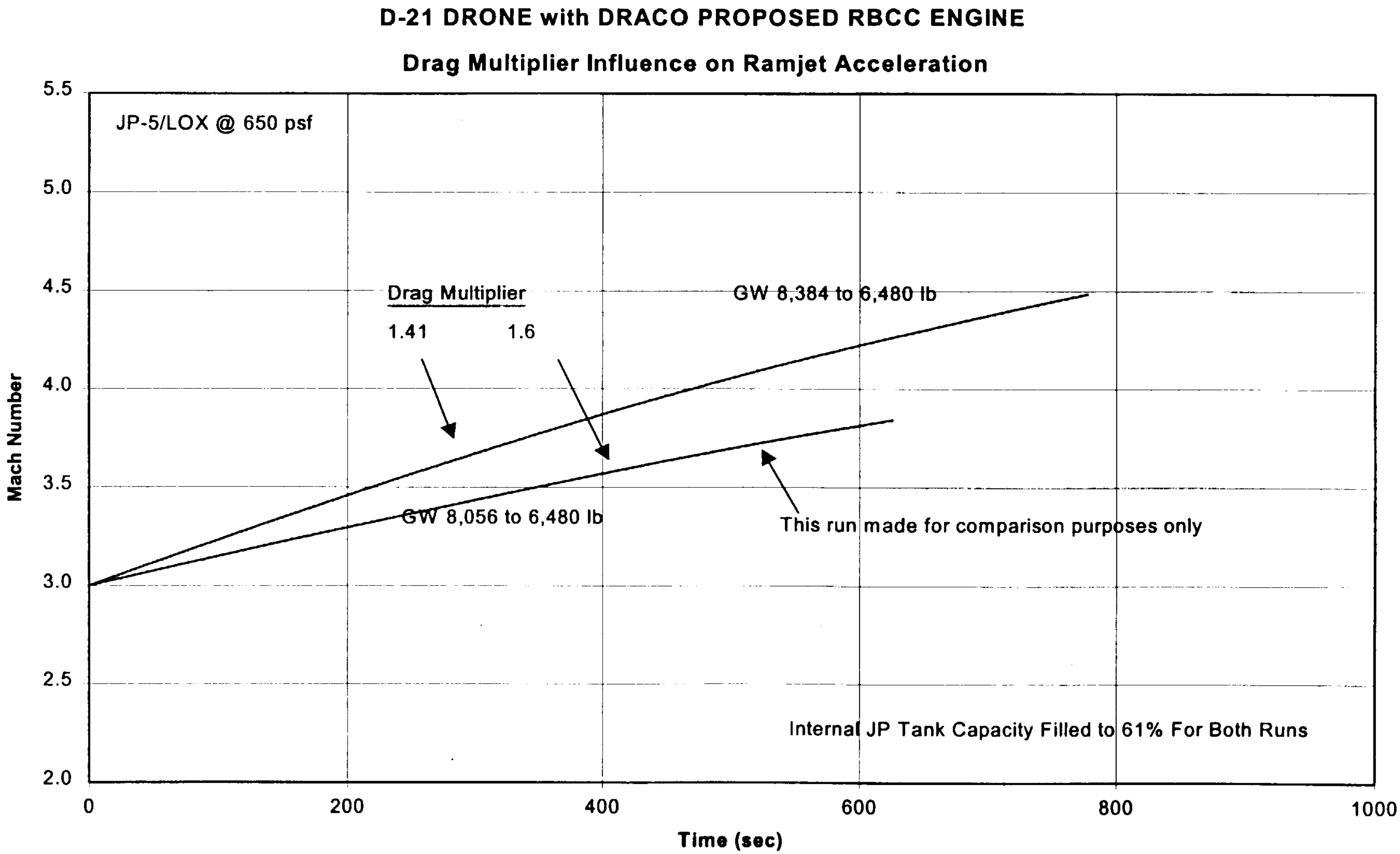
- Increasing Gross Weight and/or High Drag Multiplier Greatly Reduced Excess Thrust Available
  - F_{ex} As Low As 148 lb (N_{xw} = 0.024 "g") For Some Configurations With Full Fuel Load (see following graphs)
  - Multiplier Increase From 1.38 to 1.5 Cut Ramjet Excess Thrust By Half Just Prior to Fuel Burn-Out
- Because of Low Ramjet Excess Thrust In All Three Fuel Configuration, Managing Gross Weight and Drag Will Be A Major Design Challenge

Summary of Results

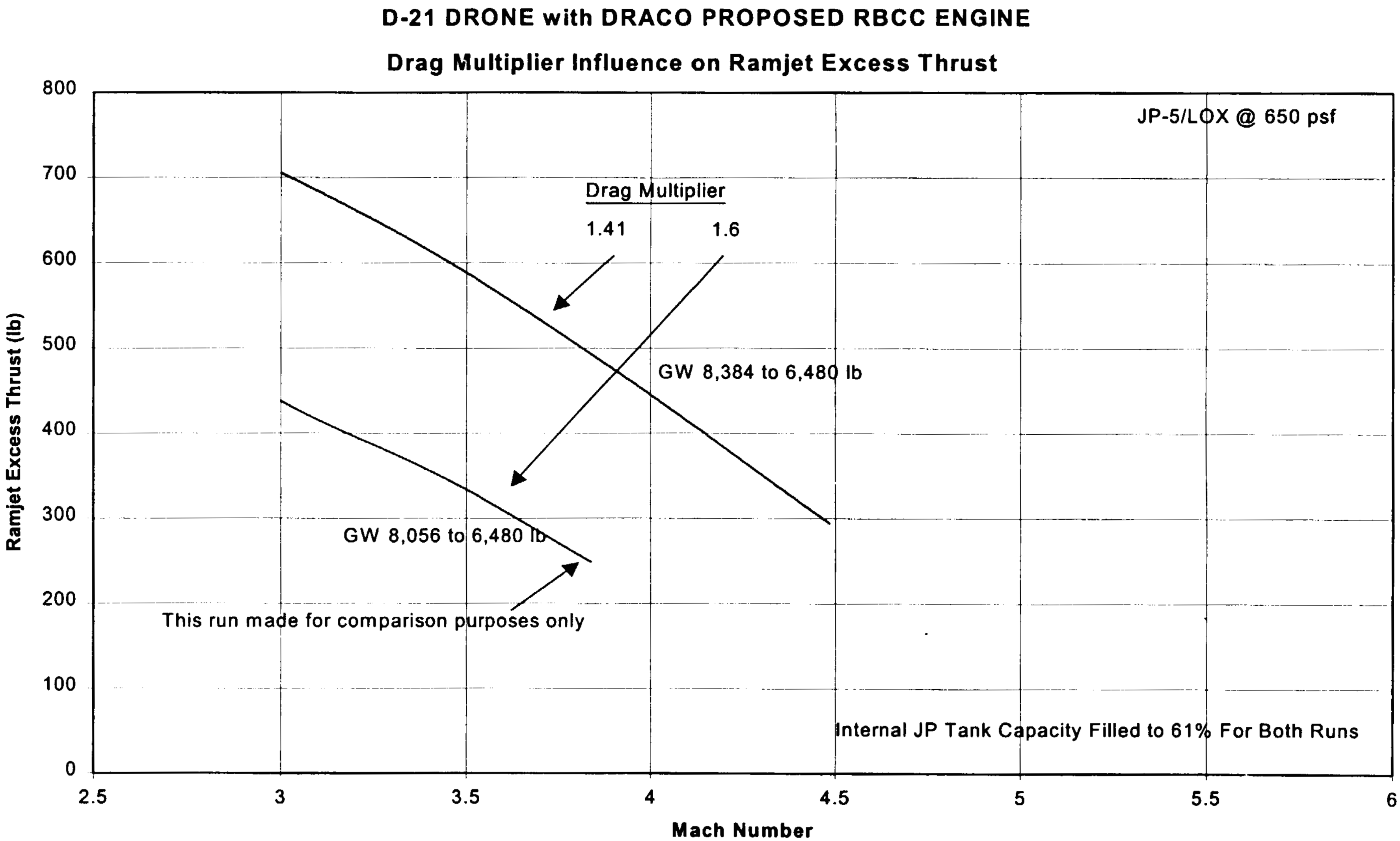
	JP/LOX 650 psf	JP/H_2O_2 650 psf	C_3H_8/LOX 650 psf	JP/LOX 1300 psf	JP/H_2O_2 1300 psf	C_3H_8/LOX 1300 psf
Drag Multiplier	1.41	1.5	1.42	1.41	1.5	1.42
Start GW (lb)	11,849	13,117	13,035	11,425	12,647	13,035
End GW (lb)	6,480	6,453	7,378	6,945	6,701	7,378
Relight Fuel (lb)	506	416	none	975	664	none
Zero Fuel W (lb)	5,974	6,037	7,378	5,970	6,037	7,378
Ejector Fuel (lb)	1,043	560	823	1,043	560	823
Oxidizer (lb)	2,712	3,920	2,798	2,712	3,920	2,798
Ramjet Fuel (lb)	2,120	2,600	2,036	1,700	2,130	2,036
Tank Vol Used[1]	61%	61%	100%	53%	52%	100%
Max. Mach	4.49	4.33	4.2	4.52	4.49	4.68
Max. Altitude	85,200	83,700	82,380	70,670	70,420	72,210
Max Possible Mach[2]	4.86	4.55	4.2	5.26	5.02	4.68

Note: 1. Maximum capacity of 5700 lb.
2. Assumes full internal tank volume used.

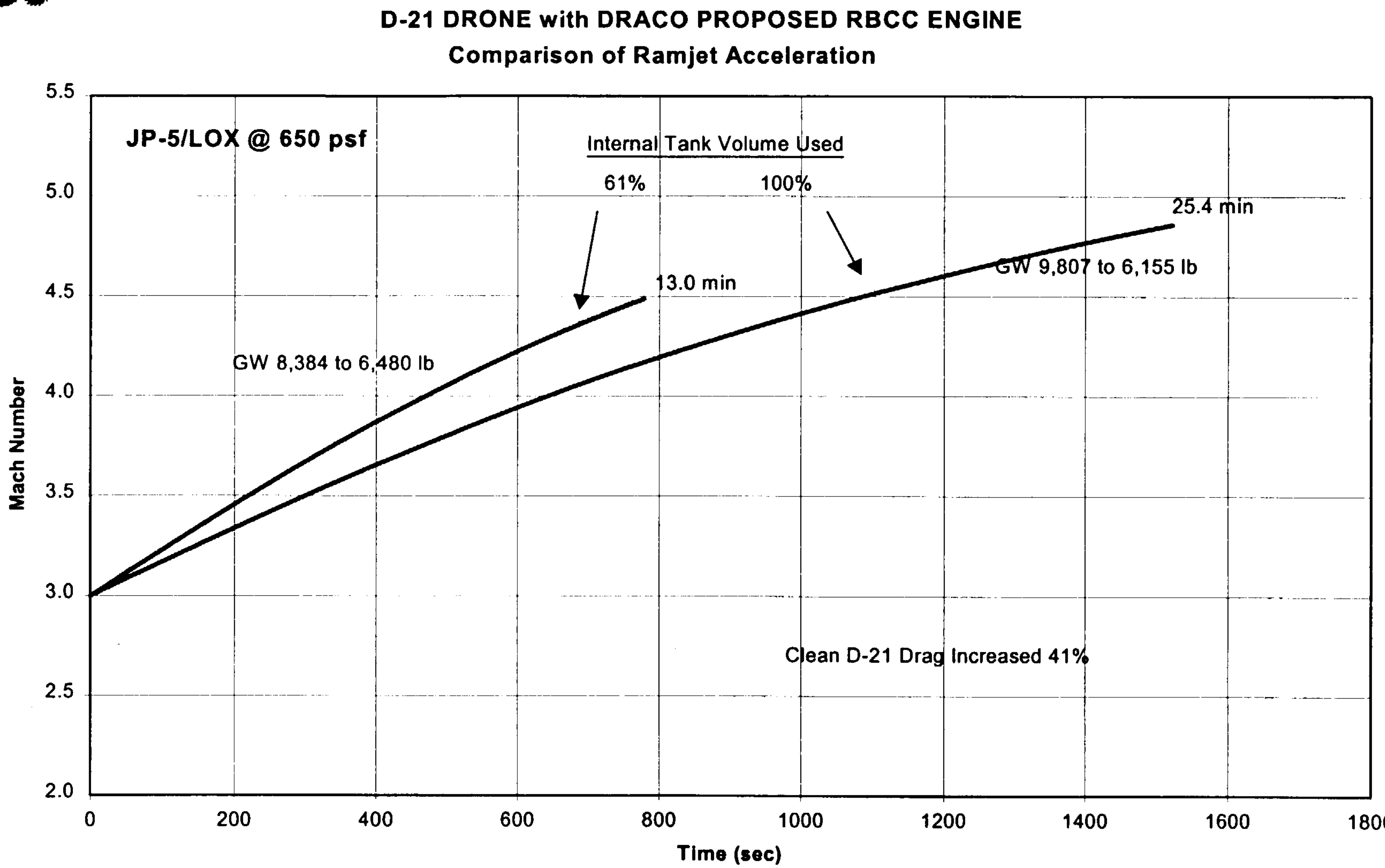
Drag Influence on Ramjet Performance



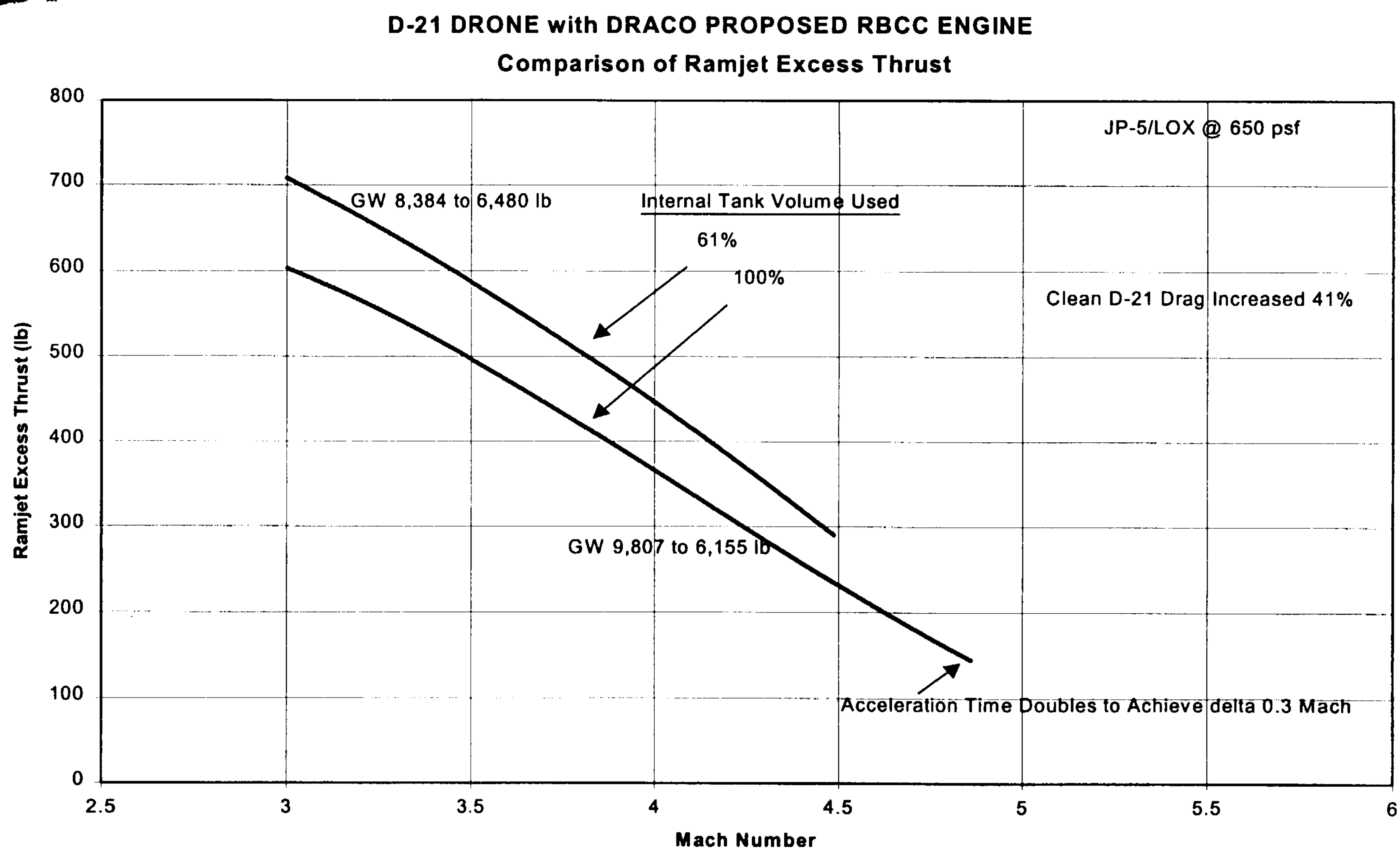
Drag Influence on Ramjet Performance



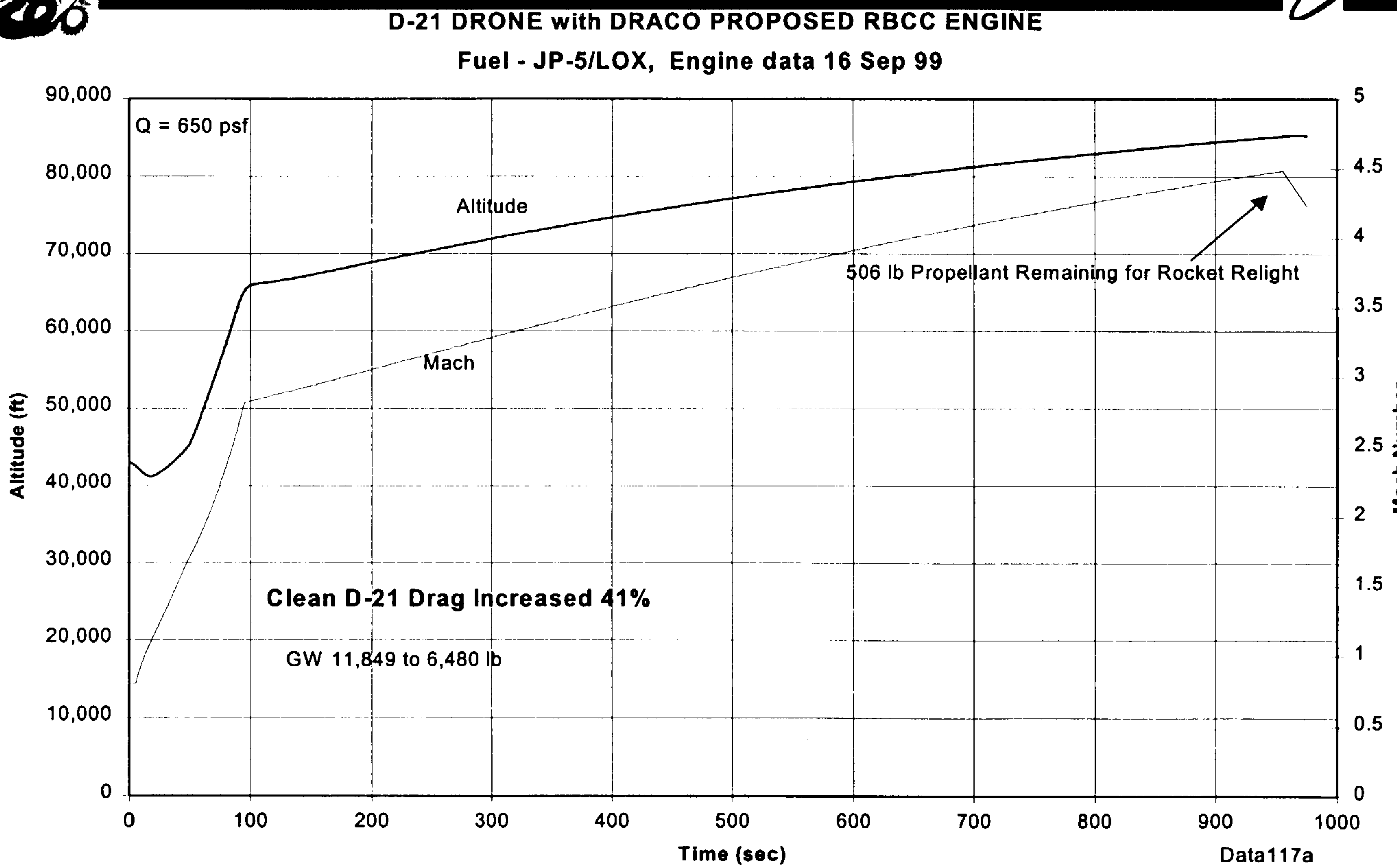
Ramjet Acceleration



Ramjet Excess Thrust

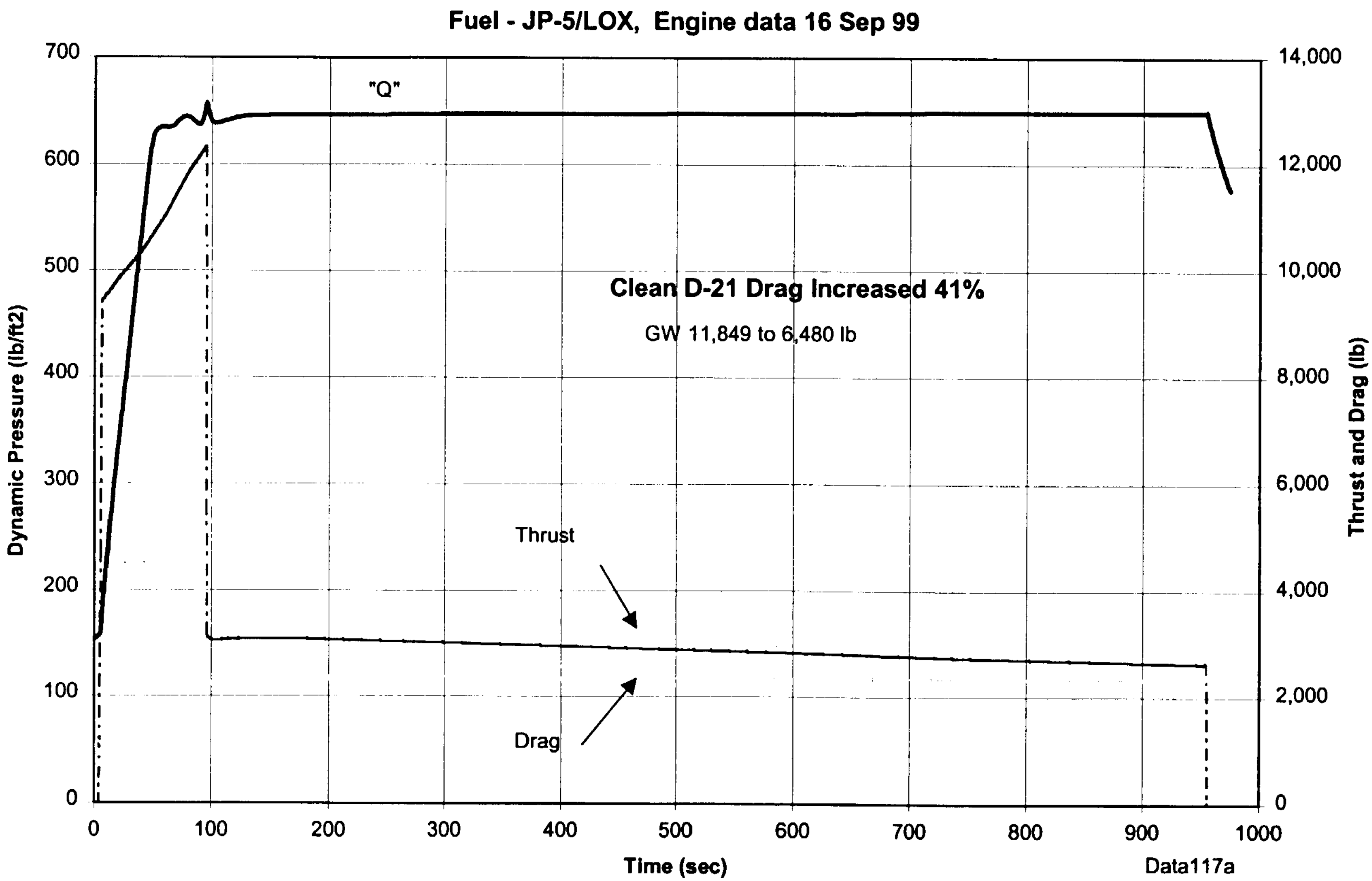


JP-5/LOX, 650 psf



JP-5/LOX, 650 psf

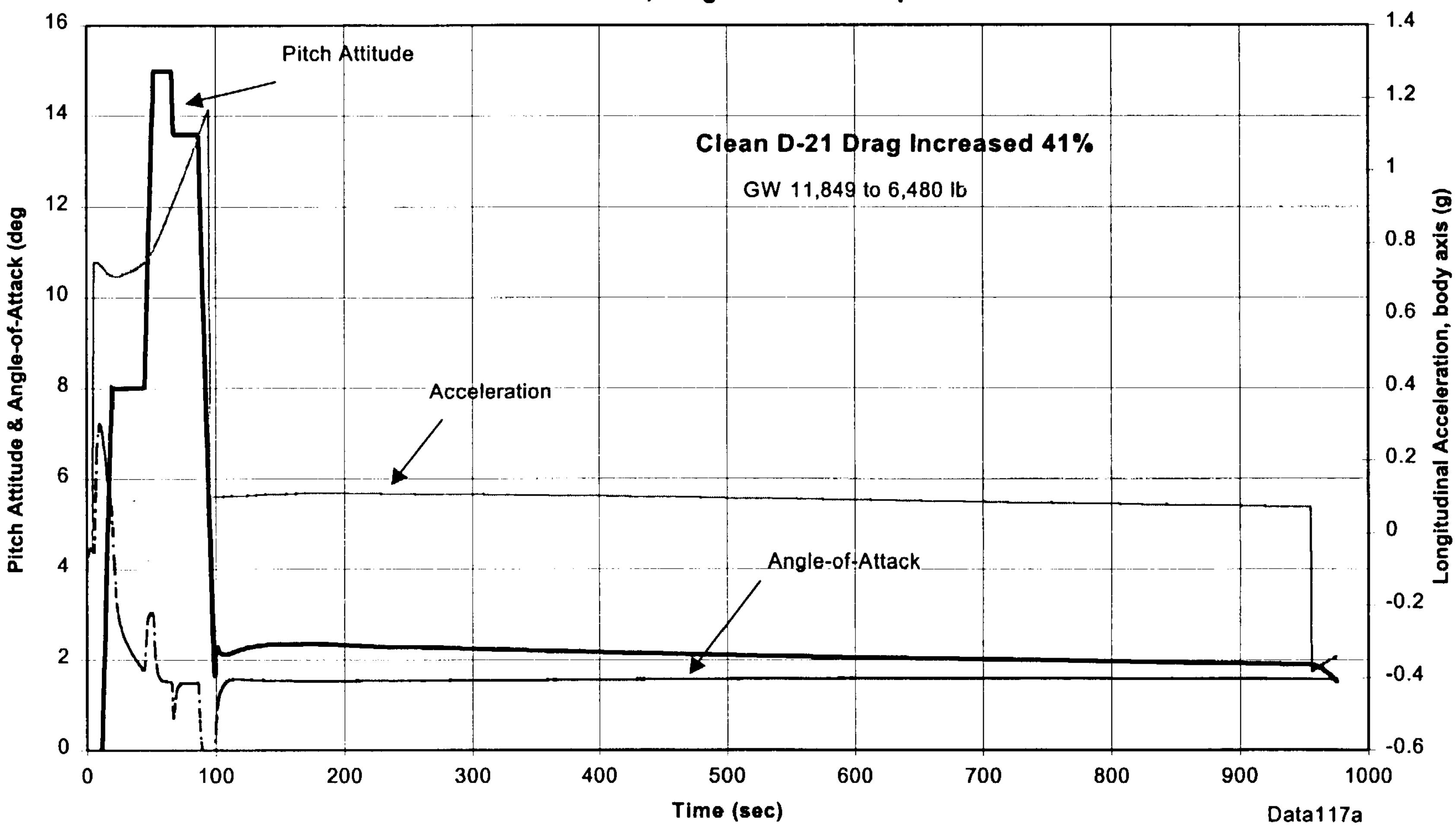
D-21 DRONE with DRACO PROPOSED RBCC ENGINE



JP-5/LOX, 650 psf

D-21 DRONE with DRACO PROPOSED RBCC ENGINE

Fuel - JP-5/LOX, Engine data 16 Sep 99

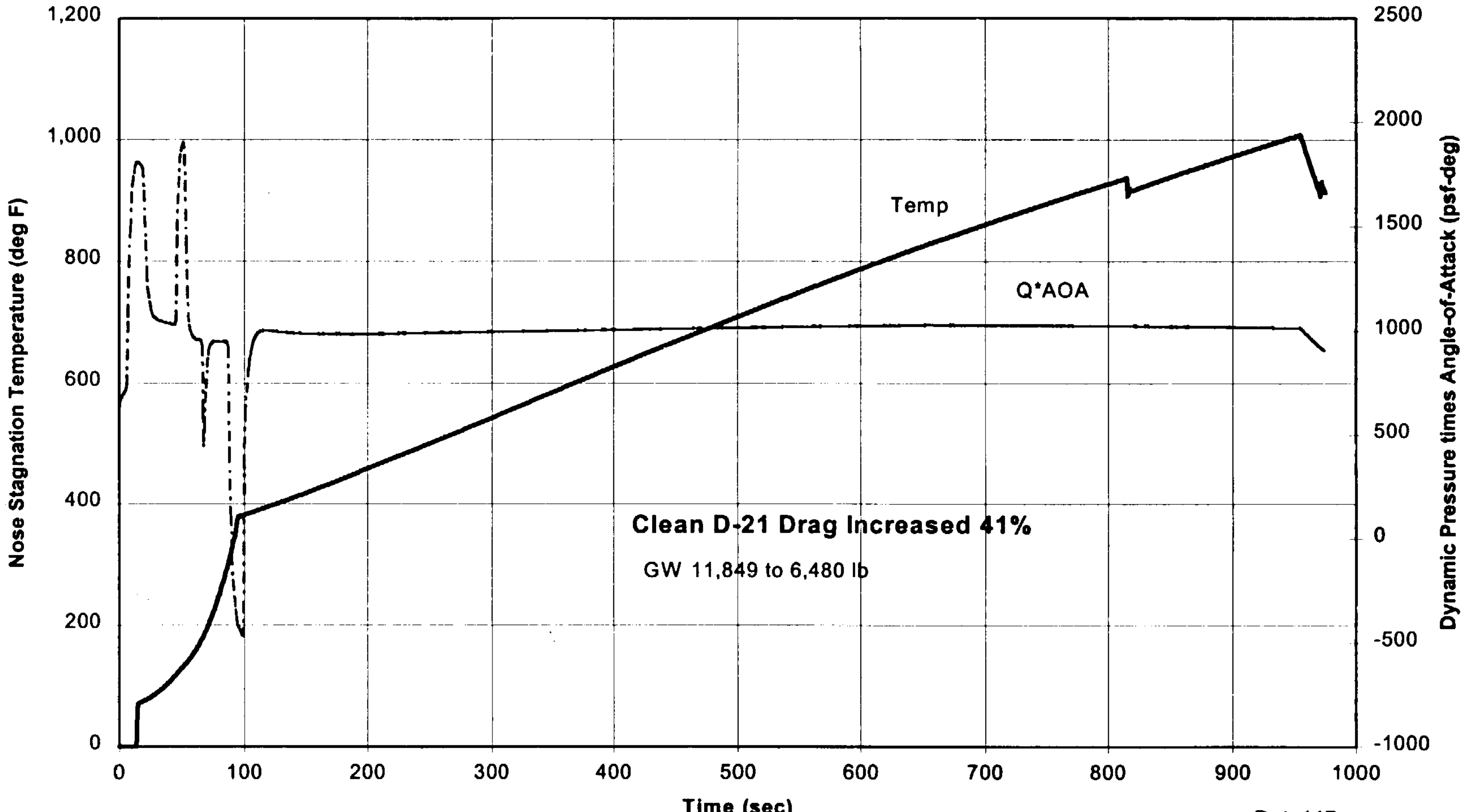


Data117a

JP-5/LOX, 650 psf

D-21 DRONE with DRACO PROPOSED RBCC ENGINE

Fuel - JP-5/LOX, Engine data 16 Sep 99

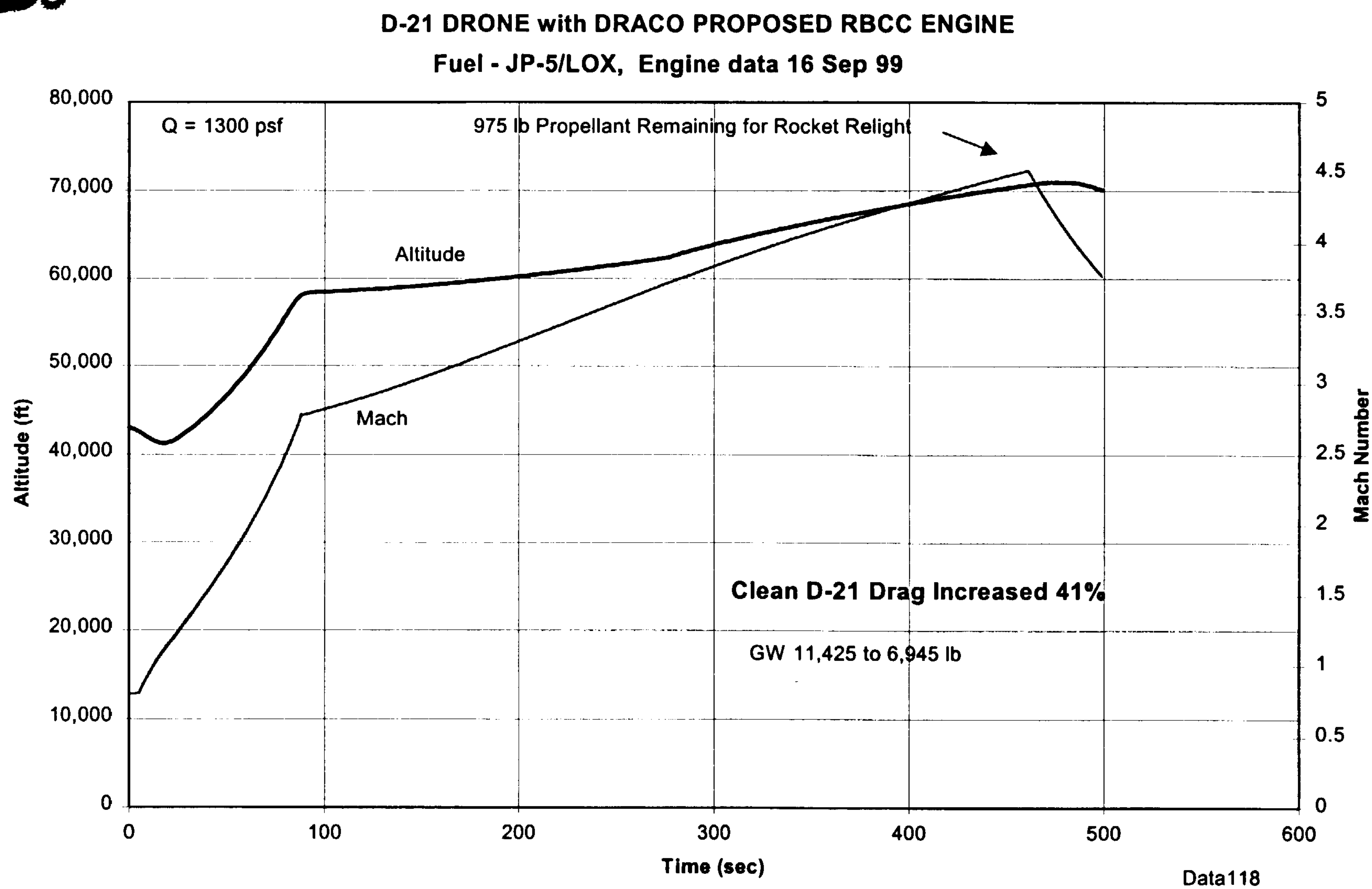


Data117a

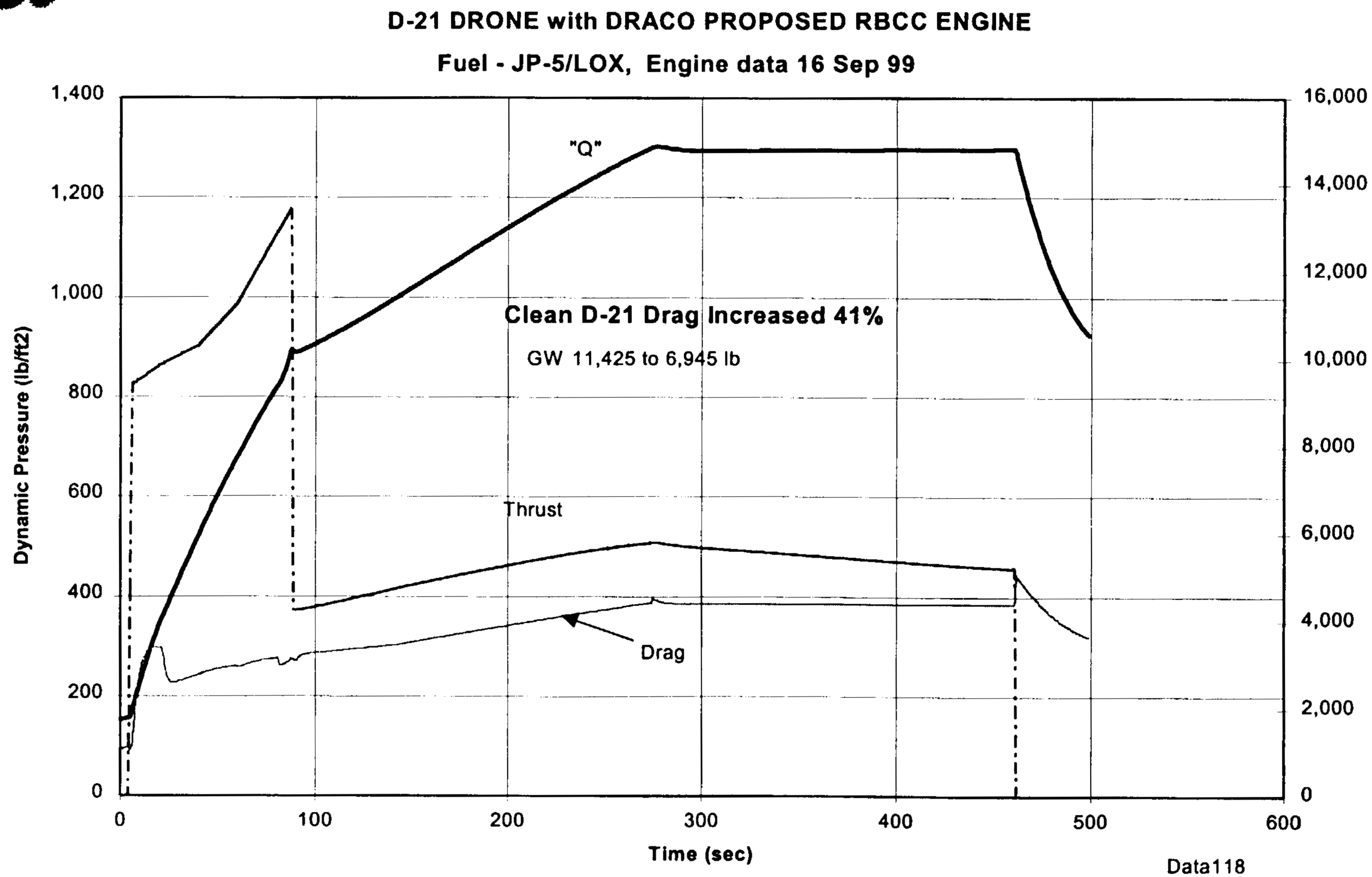
JP/LOX, 650 psf, Gross Weight

ORBITAL SCIENCES - DRACO - 28 September 1999 - Data117			sheet12
Fuel JP-5/LOX, engine data 16 Sep, LOX top=off from B-52			
D-21B Drone with DRACO Ejector Ramjet Installed	Weight (lb)	Weight (lb)	Weight (lb)
Drone as weighed @ Mojave			4145
Items Deleted			
Ramjet	-510		
Hydraulic Systems/Actuators/Pumps	-100		
APU/Generator/etc.	-250		
Vertical Tail	-326		
Miscellaneous (Avionics)	-50	-1236	2909
Baseline Structure Added			
Forward fuselage (incl avionics bay)	82		
Mid fuselage (incl conformal tanks)	460		
Aft fuselage (incl engine bay)	125		
Vertical tail	374		
Landing gear	350		
Movable Air Inlet Spike	100	1491	4400
Propulsion			
DRACO Ejector Ramjet- includes pumps, fuellines,			
fuel system, etc.	900	900	5300
Systems & Equipment			
Avionics Mass Properties, APU Power Option, 9/18/99	471		
Equipment Cooling, including nitrogen tank	39		
Nitrogen	45		
Drouge Chute	50		
Engine Residual Fluid	10		
Unusable Propellant, 1% of 5875 lb	59		
Payload - none		674	
Zero Propellant Weight			5974
Fuel			
JP-5 for ejector	1043		
LOX - O/F 2.6 for JP-5/LOX	2712		
JP-5 for ramjet- (5200 lb available)	2120	5875	
Gross Weight at Engine Start			11849
506 lb Propellant Reserved at Ramjet Burn-out for Rocket Relight			
Drag multiplier 1.41			

JP-5/LOX, 1300 psf



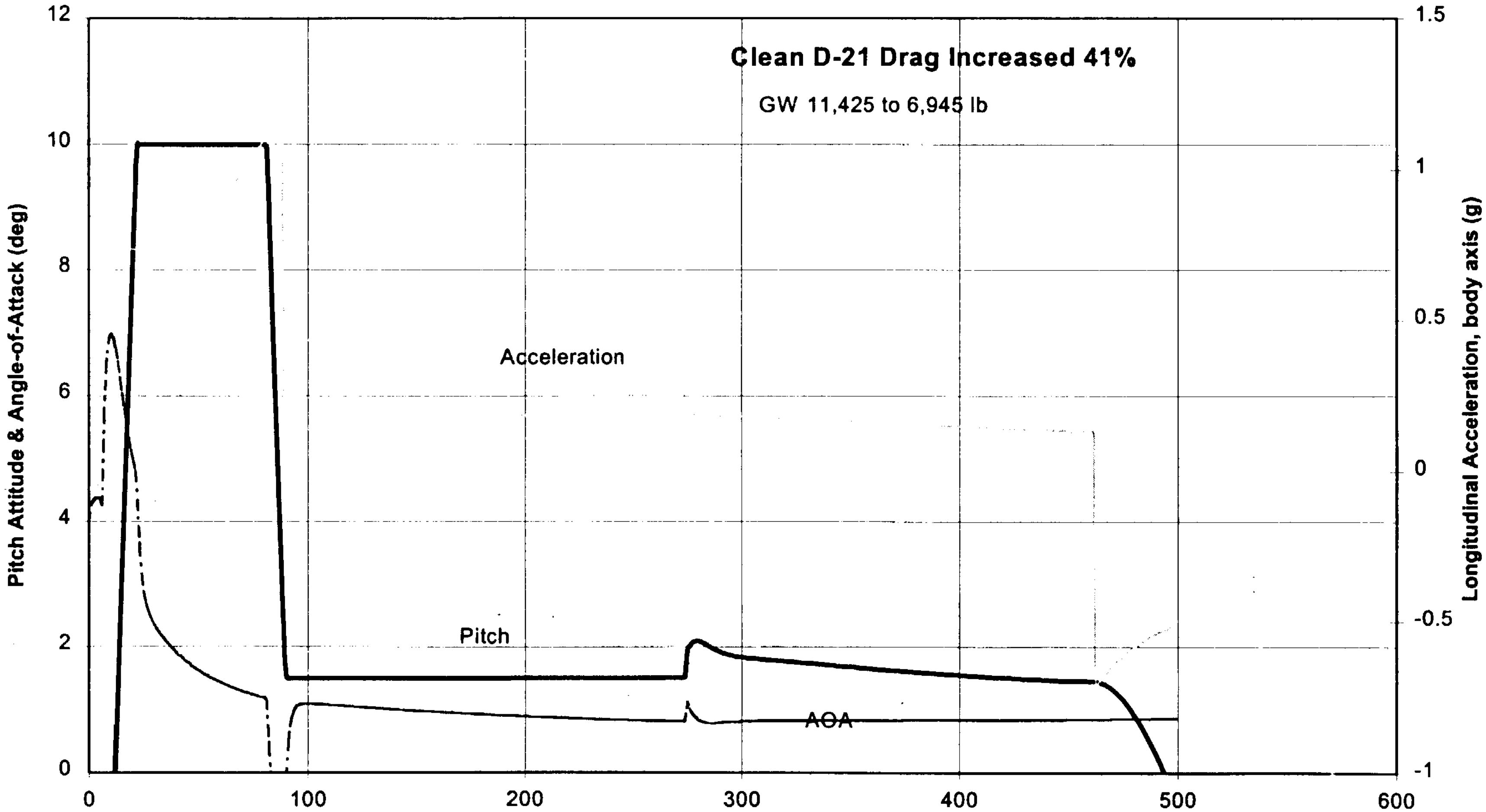
JP-5/LOX, 1300 psf



JP-5/LOX, 1300 psf

D-21 DRONE with DRACO PROPOSED RBCC ENGINE

Fuel - JP-5/LOX, Engine data 16 Sep 99

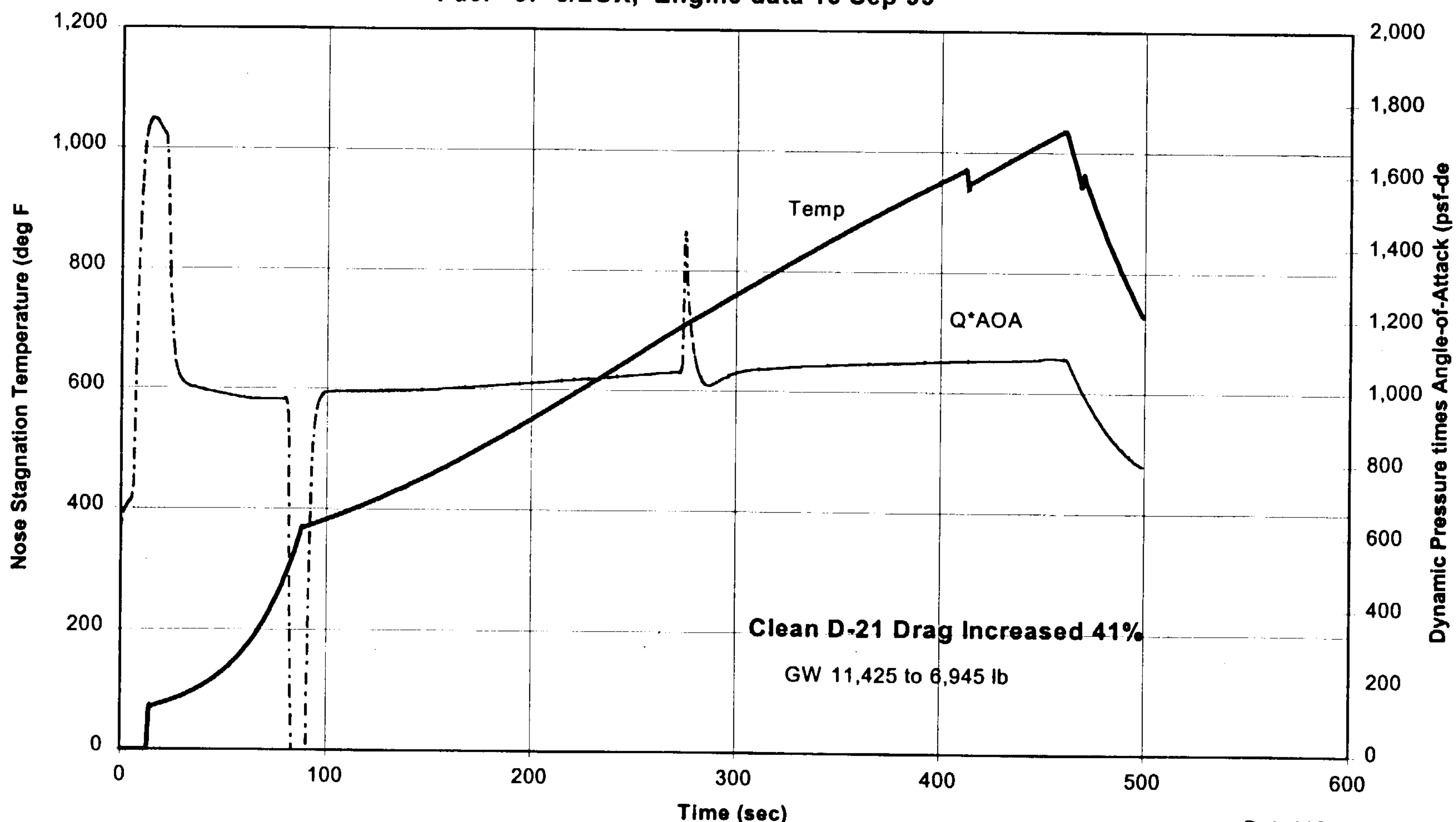


Data118

JP-5/LOX, 1300 psf

D-21 DRONE with DRACO PROPOSED RBCC ENGINE

Fuel - JP-5/LOX, Engine data 16 Sep 99



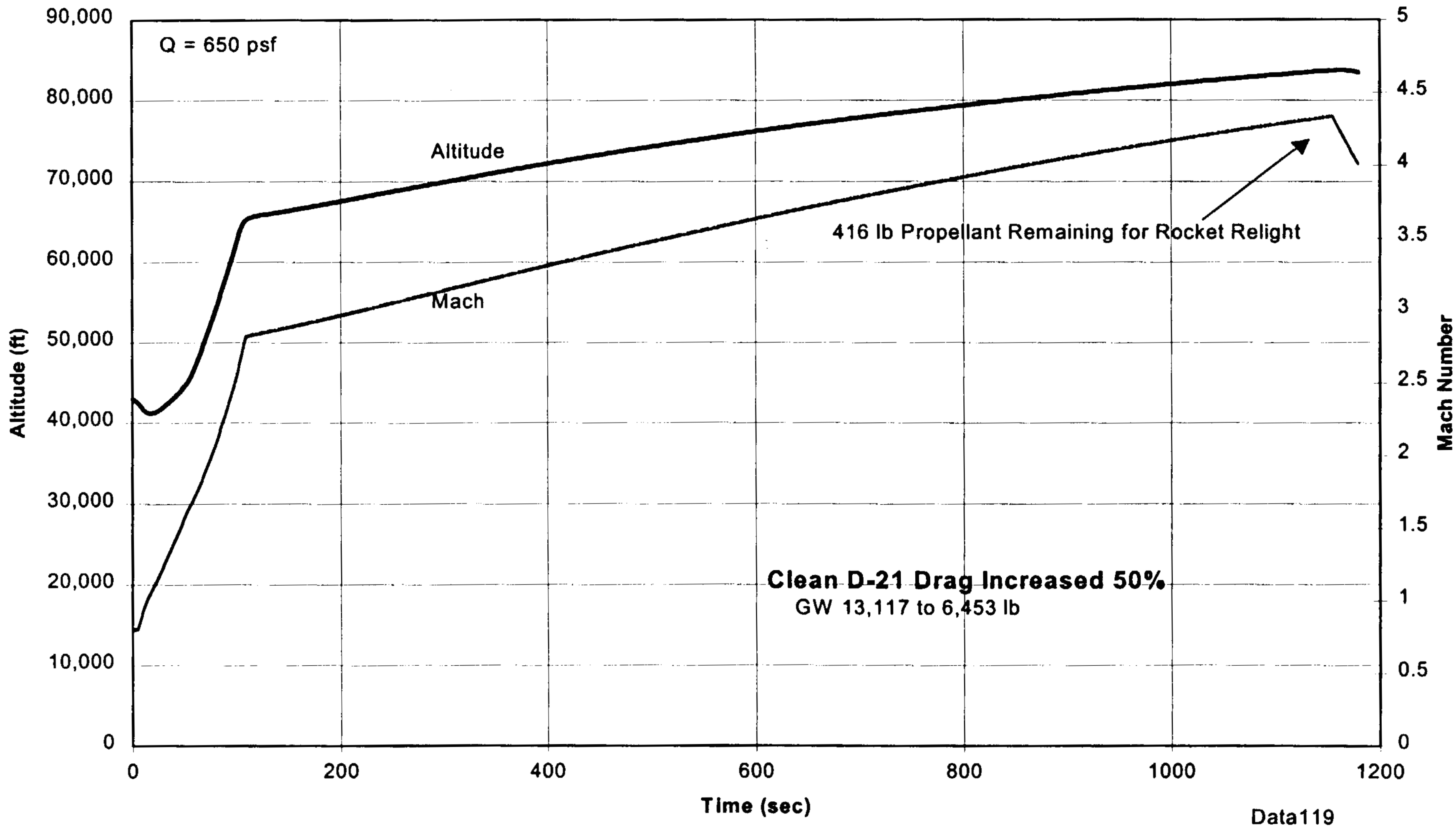
Data118

JP/LOX, 1300 psf, Gross Weight

ORBITAL SCIENCES - DRACO - 30 September 1999 - Data118			sheet13
Fuel JP-5/LOX, engine data 16 Sep, LOX top=off from B-52			
D-21B Drone with DRACO Ejector Ramjet Installed	Weight (lb)	Weight (lb)	Weight (lb)
Drone as weighed @ Mojave			4145
Items Deleted			
Ramjet	-510		
Hydraulic Systems/Actuators/Pumps	-100		
APU/Generator/etc.	-250		
Vertical Tail	-326		
Miscellaneous (Avionics)	-50	-1236	2909
Baseline Structure Added			
Forward fuselage (incl avionics bay)	82		
Mid fuselage (incl conformal tanks)	460		
Aft fuselage (incl engine bay)	125		
Vertical tail	374		
Landing gear	350		
Movable Air Inlet Spike	100	1491	4400
Propulsion			
DRACO Ejector Ramjet- includes pumps, fuellines,			
fuel system, etc.	900	900	5300
Systems & Equipment			
Avionics Mass Properties, APU Power Option, 9/18/99	471		
Equipment Cooling, including nitrogen tank	39		
Nitrogen	45		
Drouge Chute	50		
Engine Residual Fluid	10		
Unusable Propellant, 1% of 5455 lb	55		
Payload - none		670	
Zero Propellant Weight			5970
Fuel			
JP-5 for ejector	1043		
LOX - O/F 2.6 for JP-5/LOX	2712		
JP-5 for ramjet- (5200 lb available)	1700	5455	
Gross Weight at Engine Start			11425
975 lb Propellant Reserved at Ramjet Burn-out for Rocket Relight			
Drag multiplier 1.41			

JP-5/H_2O_2, 650 psf

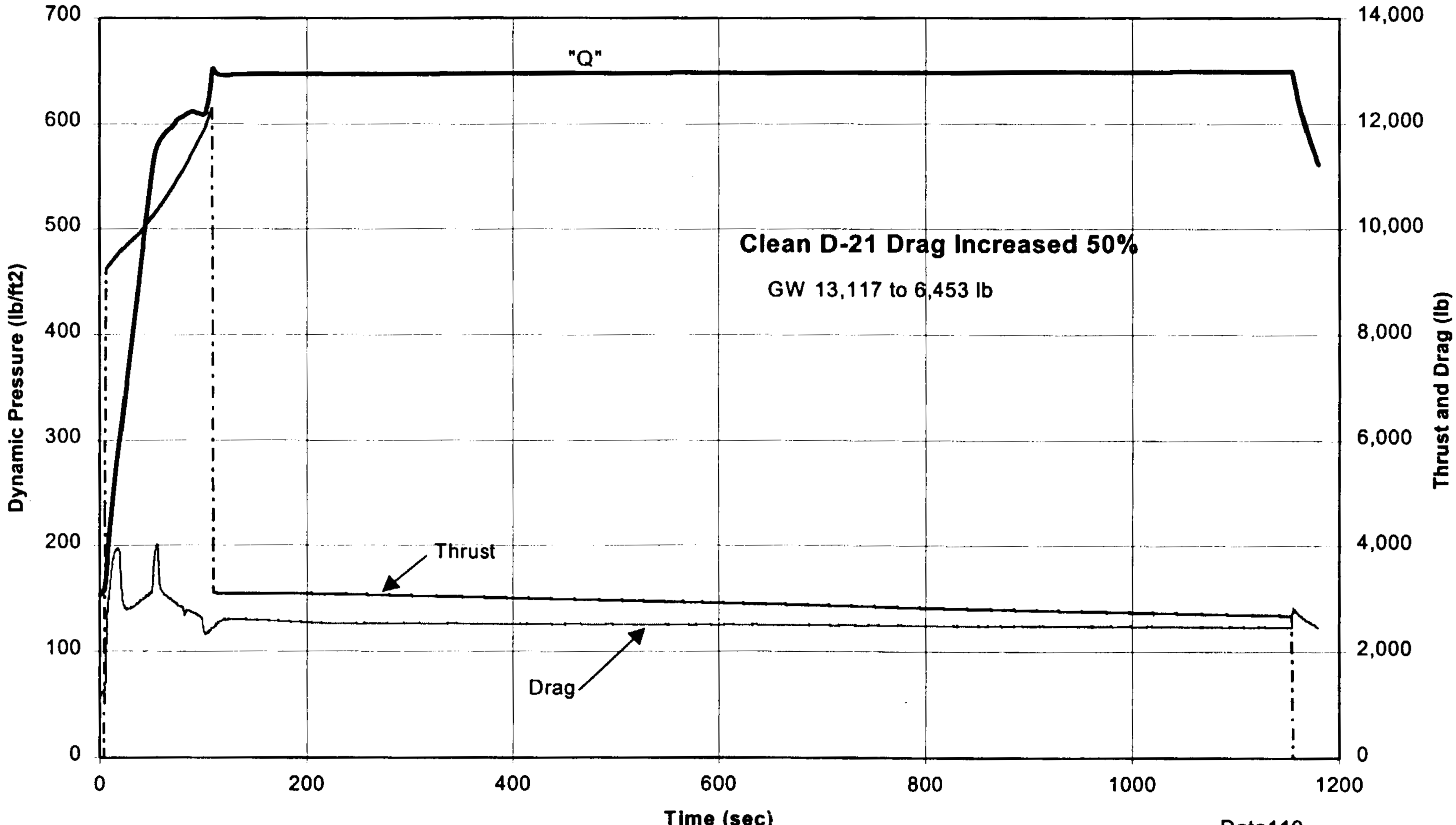
D-21 DRONE with DRACO PROPOSED RBCC ENGINE
Fuel - JP-5/H_2O_2, Engine data 16 Sep 99



Data119

$JP\text{-}5/H_2O_2$, 650 psf

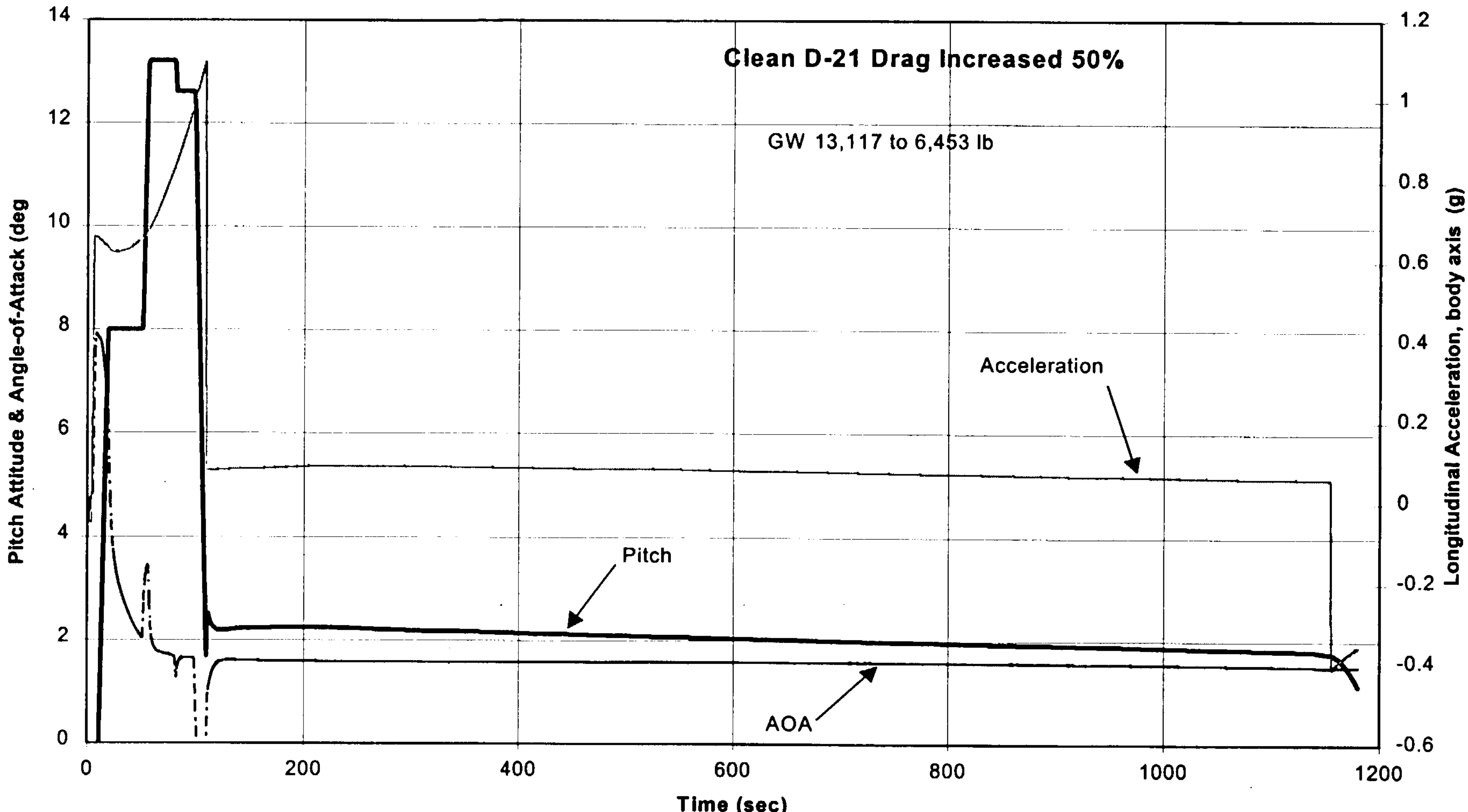
D-21 DRONE with DRACO PROPOSED RBCC ENGINE
Fuel - $JP\text{-}5/H_2O_2$, Engine data 16 Sep 99



Data119

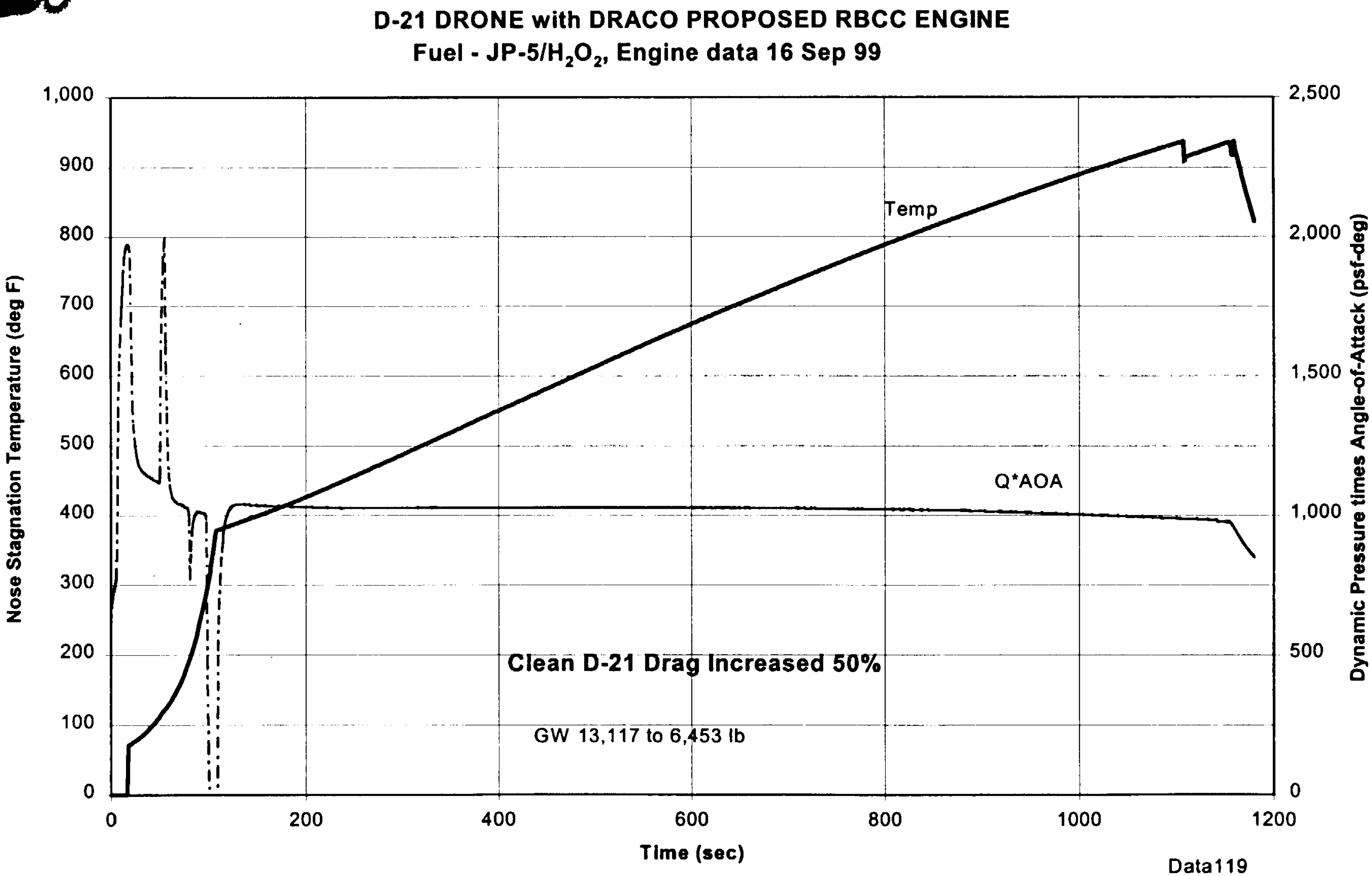
JP-5/H_2O_2, 650 psf

D-21 DRONE with DRACO PROPOSED RBCC ENGINE
Fuel - JP-5/H_2O_2, Engine data 16 Sep 99



Data119

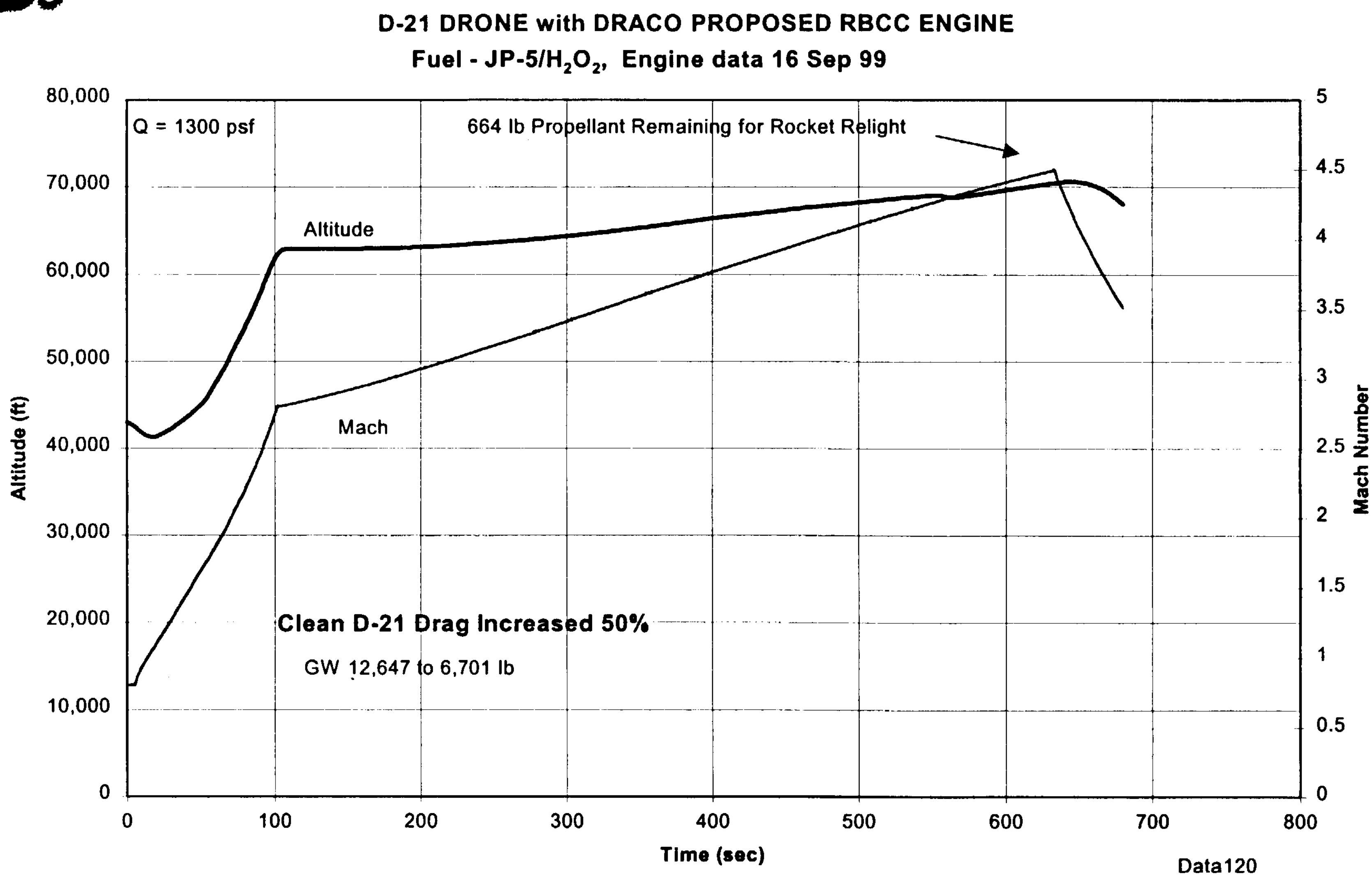
JP-5/H_2O_2, 650 psf



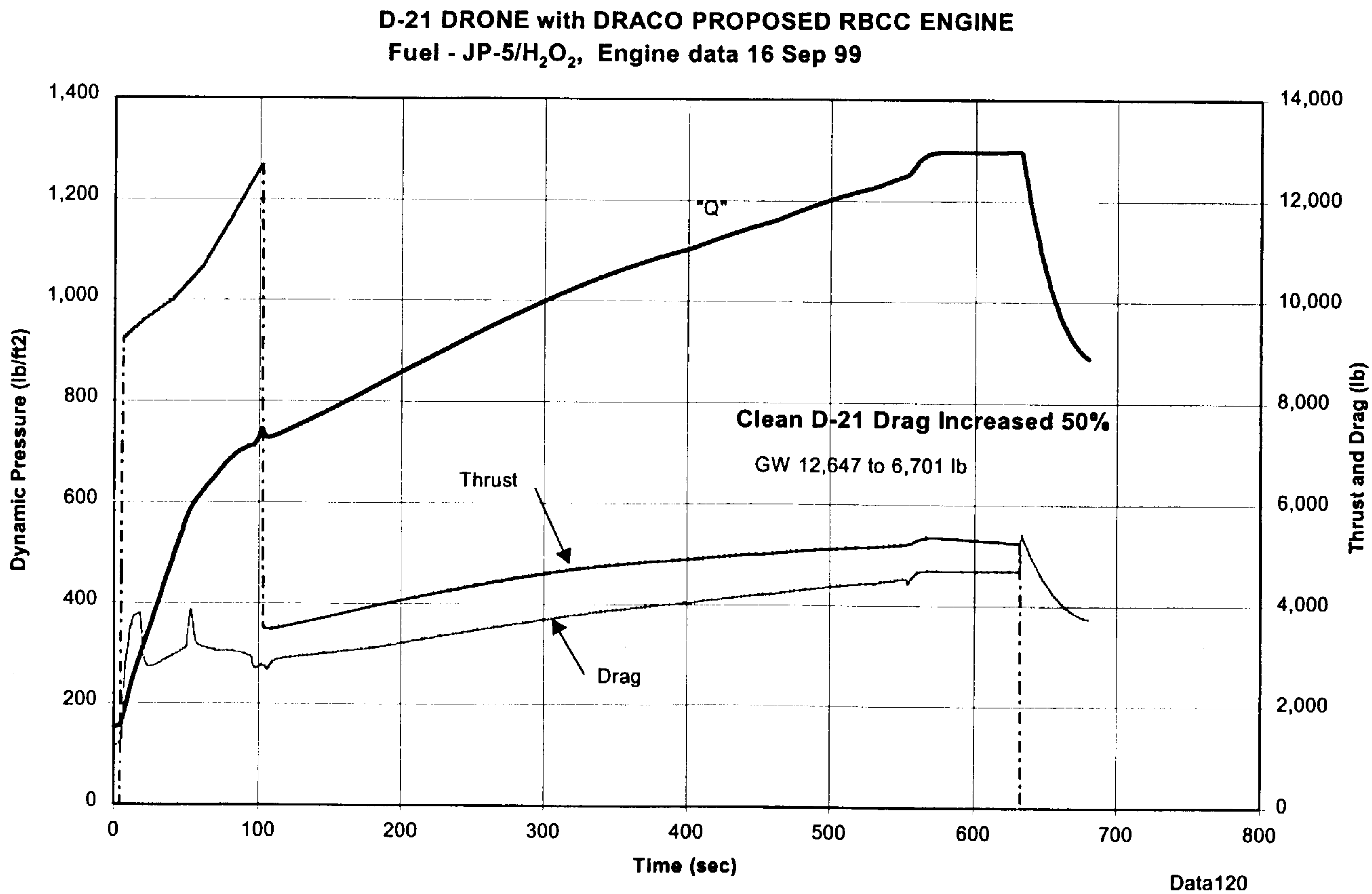
JP-5/H_2O_2, 650 psf, Gross Weight

ORBITAL SCIENCES - DRACO - 30 September 1999 - Data119			sheet14
Weights for JP-5/H2O2, engine data 16 Sep			
D-21B Drone with DRACO Ejector Ramjet Installed	Weight (lb)	Weight (lb)	Weight (lb)
Drone as weighed @ Mojave			4145
Items Deleted			
Ramjet	-510		
Hydraulic Systems/Actuators/Pumps	-100		
APU/Generator/etc. 250 lb	-250		
Vertical Tail	-326		
Miscellaneous (Avionics)	-50	-1236	2909
Baseline Structure Added			
Forward fuselage (incl avionics bay)	82		
Mid fuselage (incl conformal tanks)	511		
Aft fuselage (incl engine bay)	125		
Vertical tail	374		
Landing gear	350		
Movable Air Inlet Spike	100	1542	4451
Propulsion			
DRACO Ejector Ramjet- includes pumps, fuellines, etc.	900		
Fuel System - 200 lb		900	5351
Systems & Equipment			
Avionics Mass Properties, APU Power Option, 9/18,99	471		
Equipment Cooling, including nitrogen tank	39		
Nitrogen	45		
Drouge Chute	50		
Engine Residual Fluid	10		
Unusable Propellant, 1% of 7080 lb	71	686	
Payload - none			
Zero Propellant Weight			6037
Fuel			
JP-5 for ejector	560		
H2O2 - O/F 7.0 for JP-5/H2O2	3920		
JP-5 for ramjet	2600	7080	
Gross Weight at Engine Start			13117
416 lb Propellant set aside for rocket relight			

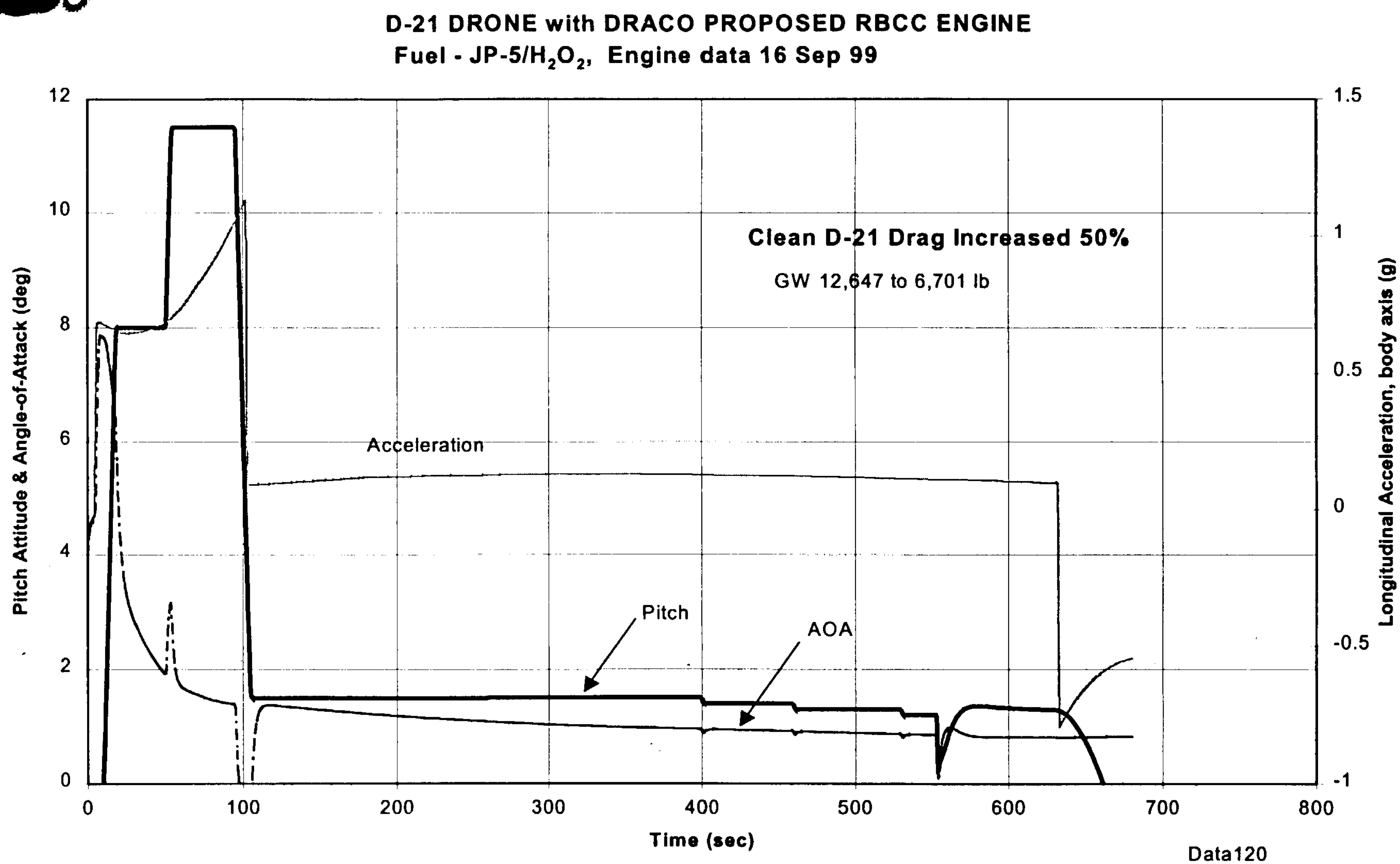
JP-5/H_2O_2, 1300 psf



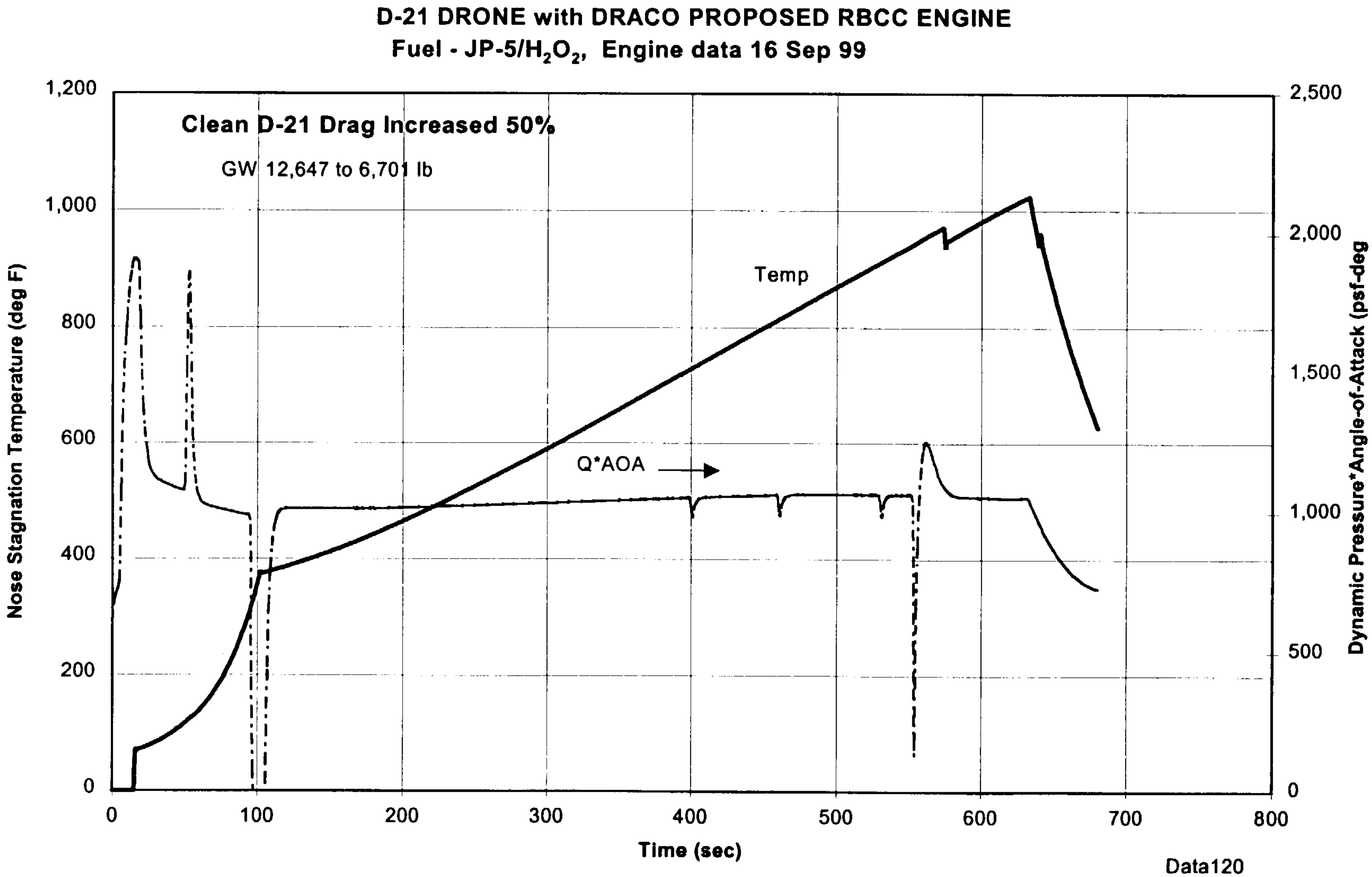
JP-5/H_2O_2, 1300 psf



JP-5/H_2O_2, 1300 psf



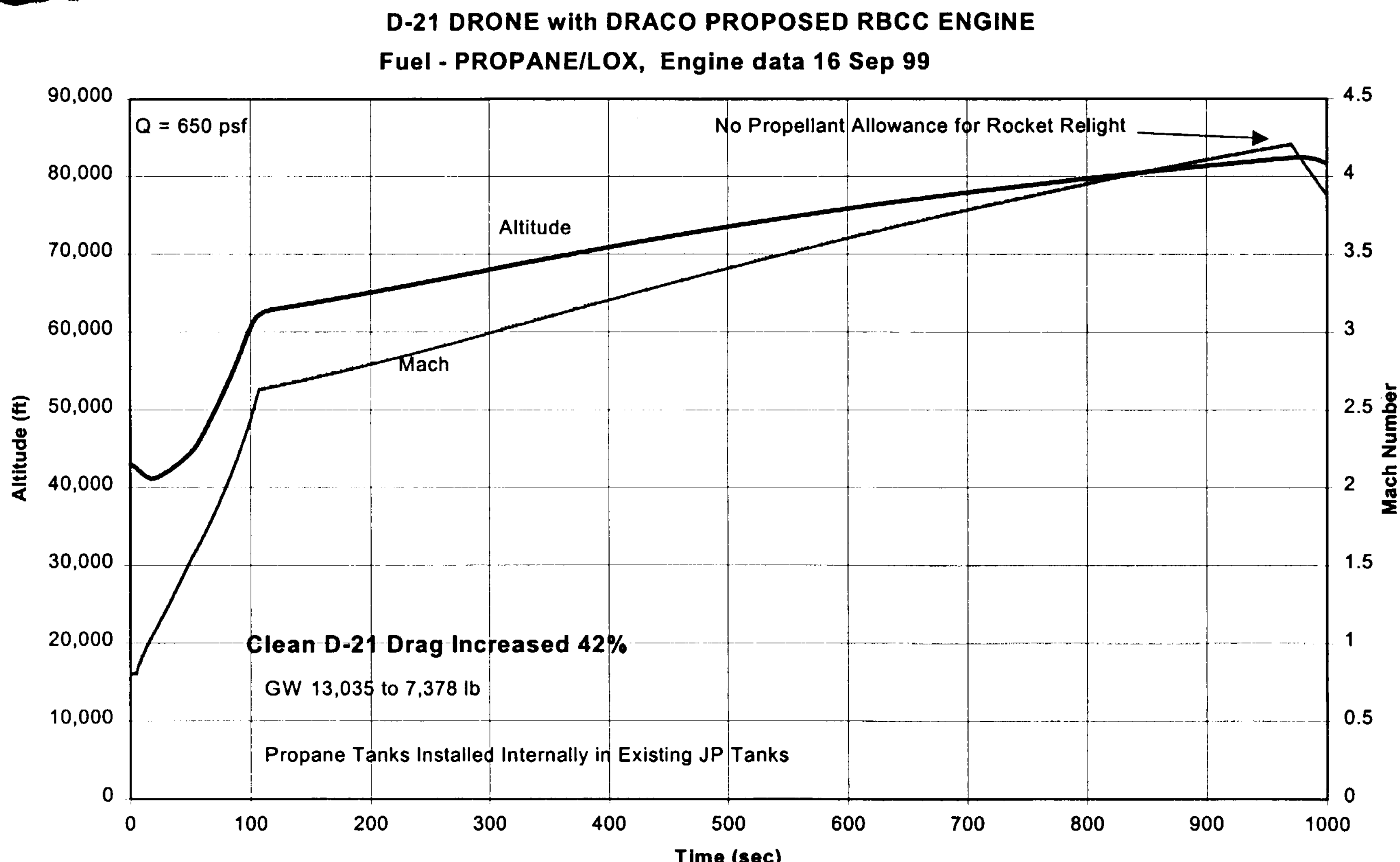
JP-5/H_2O_2, 1300 psf



JP-5/H2O2, 1300 psf, Gross Weight

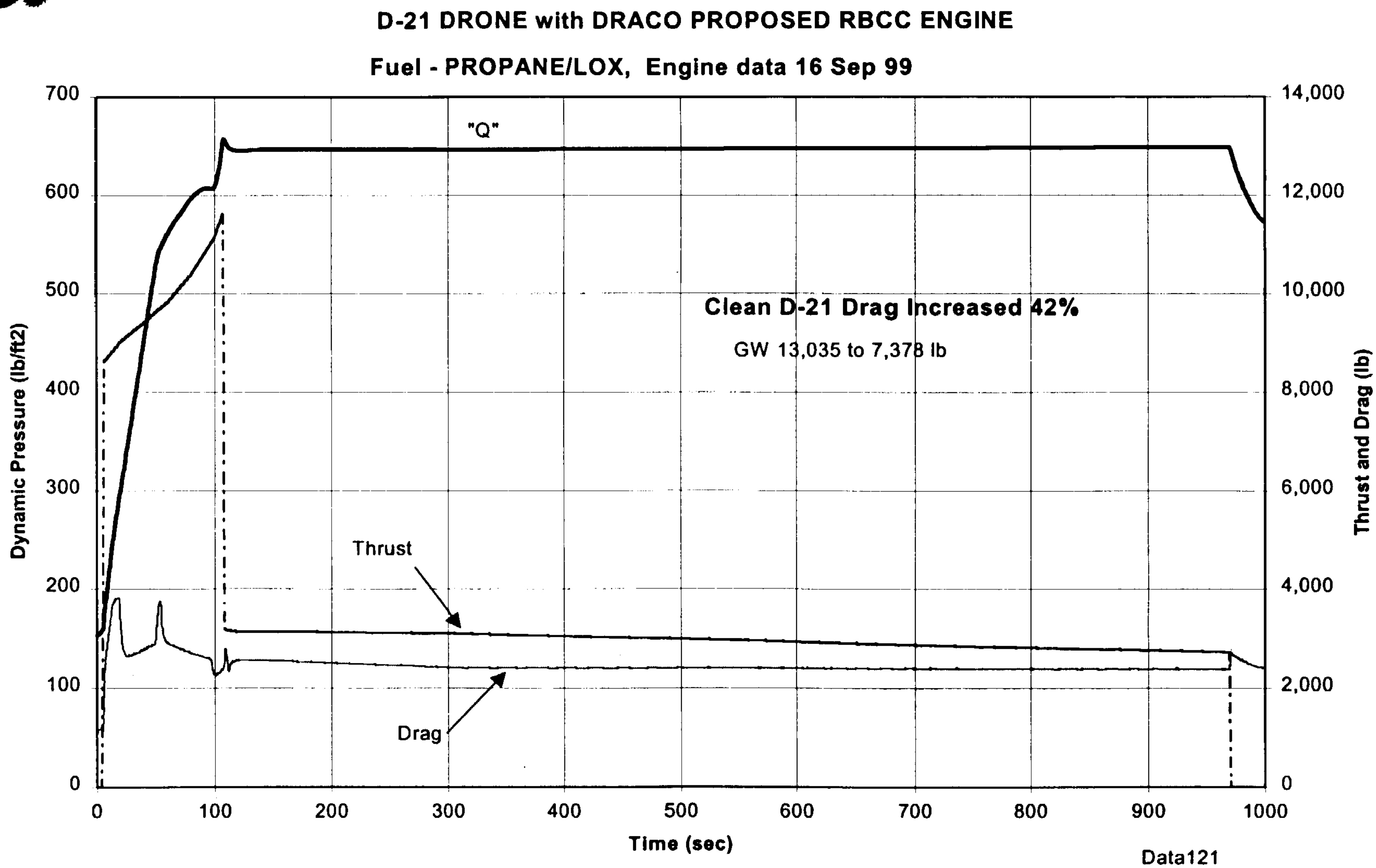
ORBITAL SCIENCES - DRACO - 30 September 1999 - Data120			sheet15
Weights for JP-5/H2O2, engine data 16 Sep			
D-21B Drone with DRACO Ejector Ramjet Installed	Weight (lb)	Weight (lb)	Weight (lb)
Drone as weighed @ Mojave			4145
Items Deleted			
Ramjet	-510		
Hydraulic Systems/Actuators/Pumps	-100		
APU/Generator/etc.	-250		
Vertical Tail	-326		
Miscellaneous (Avionics)	-50	-1236	2909
Baseline Structure Added			
Forward fuselage (incl avionics bay)	82		
Mid fuselage (incl conformal tanks)	511		
Aft fuselage (incl engine bay)	125		
Vertical tail	374		
Landing gear	350		
Movable Air Inlet Spike	100	1542	4451
Propulsion			
DRACO Ejector Ramjet- includes pumps, fuellines, etc.	900		
Fuel System - 200 lb		900	5351
Systems & Equipment			
Avionics Mass Properties, APU Power Option, 9/18,99	471		
Equipment Cooling, including nitrogen tank	39		
Nitrogen	45		
Drouge Chute	50		
Engine Residual Fluid	10		
Unusable Propellant,	71	686	
Payload - none			
Zero Propellant Weight			6037
Fuel			
JP-5 for ejector	560		
H2O2 - O/F 7.0 for JP-5/H2O2	3920		
JP-5 for ramjet	2130	6610	
Gross Weight at Engine Start			12647
664 lb Propellant set aside for rocket relight			

PROPANE/LOX, 650 psf

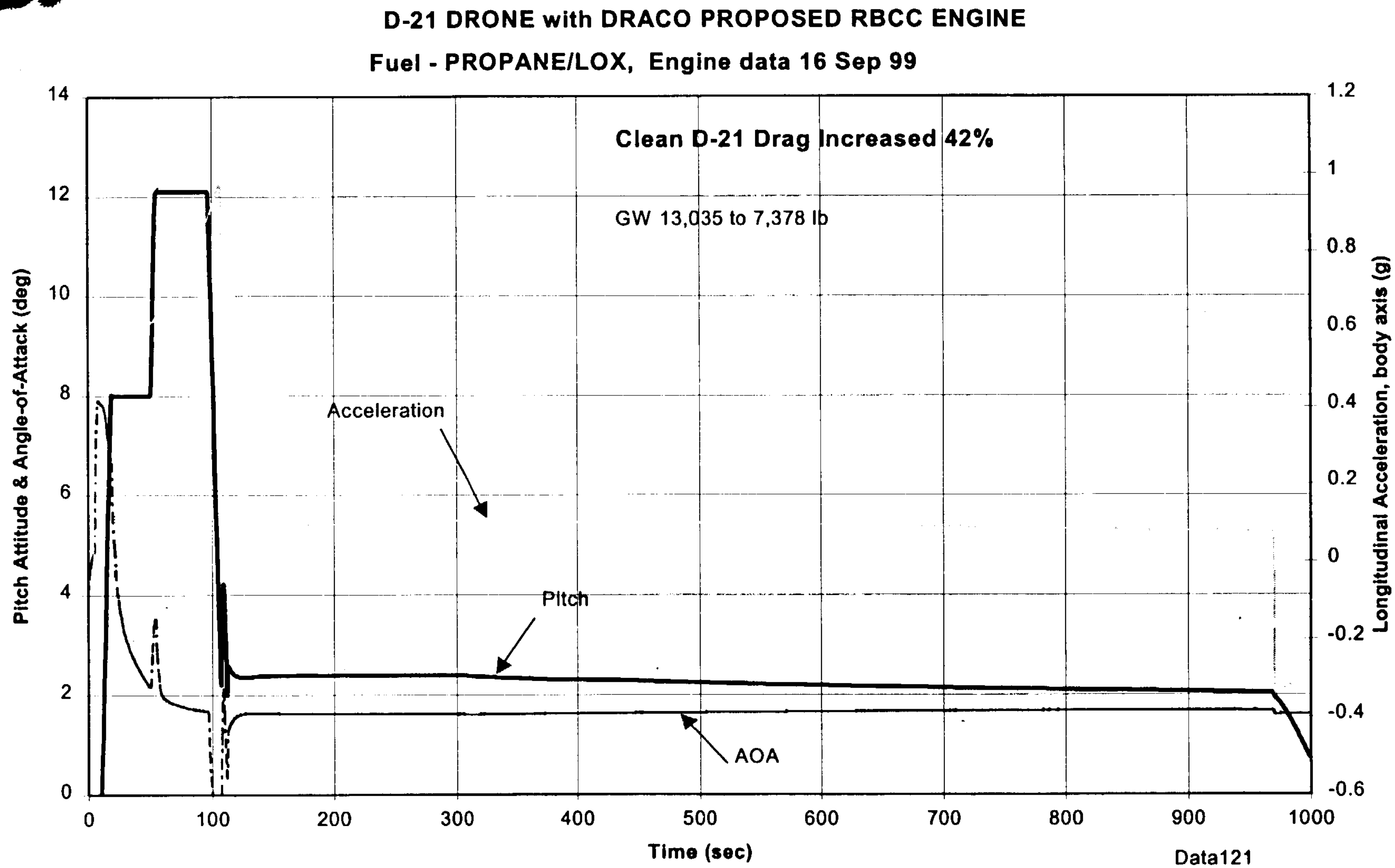


Data121

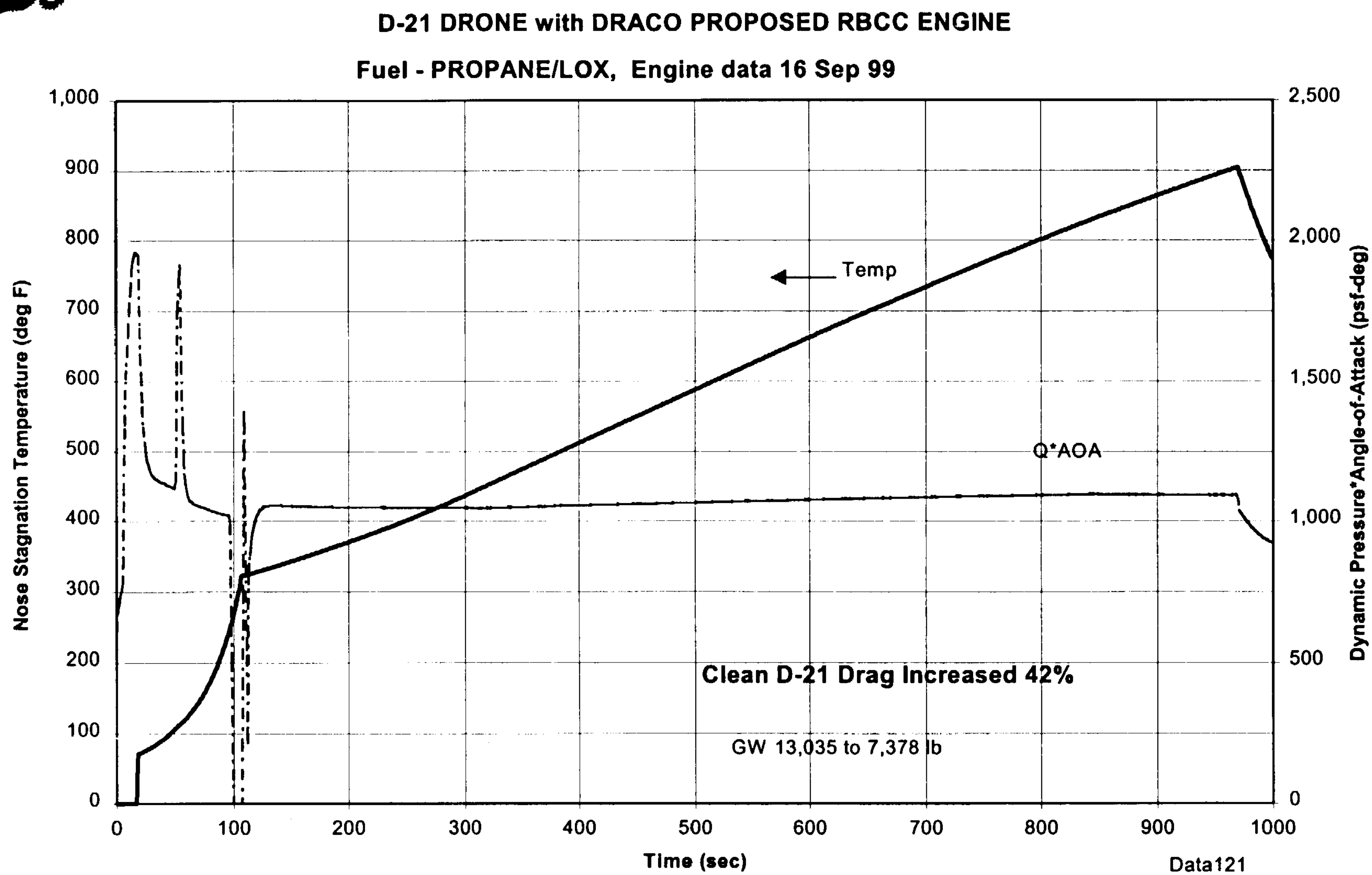
PROPANE/LOX, 650 psf



PROPANE/LOX, 650 psf



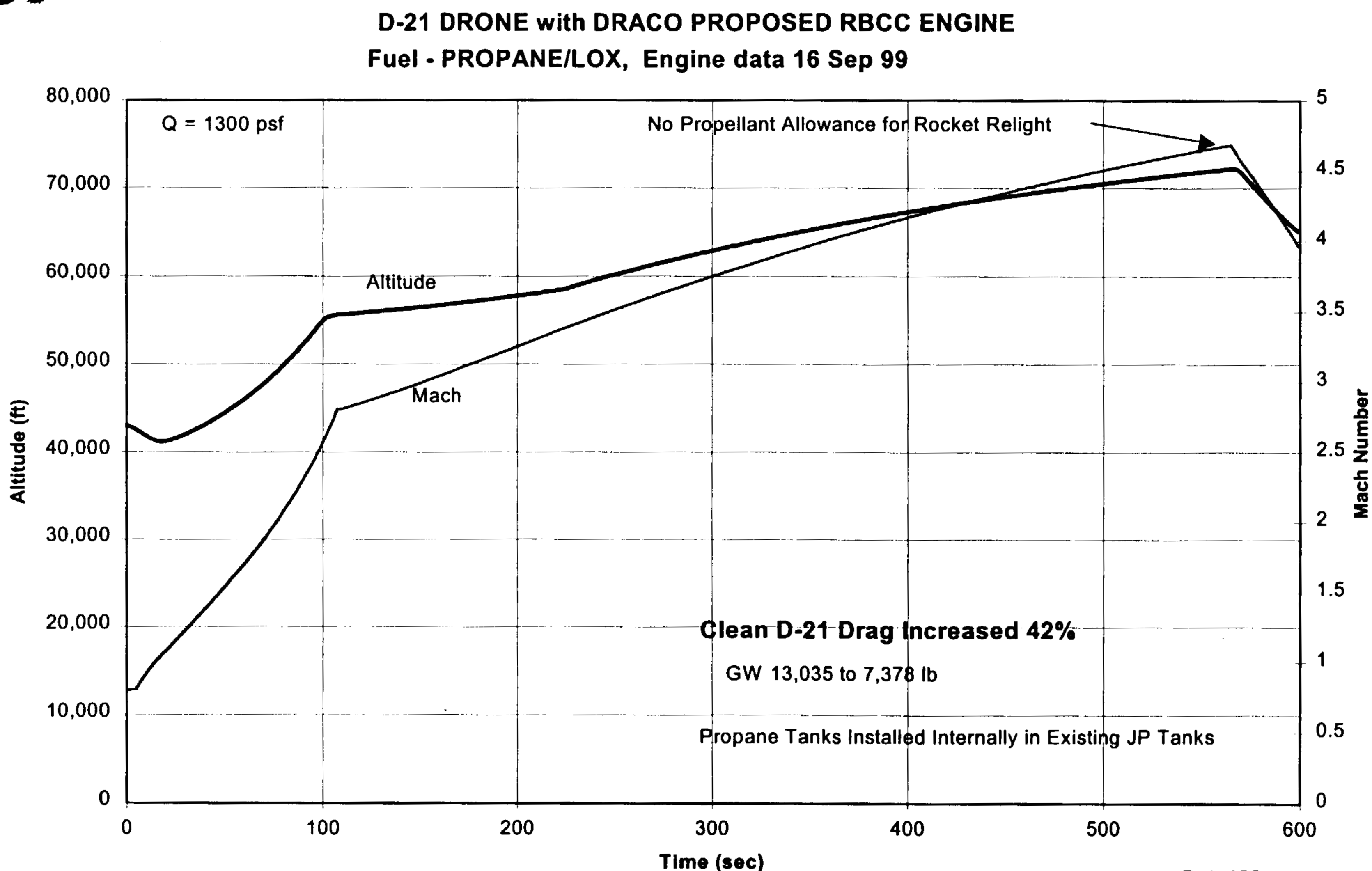
PROPANE/LOX, 650 psf



PROPANE/LOX, 650 psf, Gross Weight

ORBITAL SCIENCES - DRACO - 30 September 1999 - Data121			sheet16
Weights for PROPANE/LOX, engine data 16 Sep			
D-21B Drone with DRACO Ejector Ramjet Installed	Weight (lb)	Weight (lb)	Weight (lb)
Drone as weighed @ Mojave			4145
Items Deleted			
Ramjet	-510		
Hydraulic Systems/Actuators/Pumps	-100		
APU/Generator/etc. 250 lb	-250		
Vertical Tail	-326		
Miscellaneous (Avionics)	-50	-1236	2909
Baseline Structure Added			
Forward fuselage (incl avionics bay)	82		
Mid fuselage (incl conformal tanks)	466		
Aft fuselage (incl engine bay)	125		
Vertical tail	374		
Landing gear	350		
Movable Air Inlet Spike	100		
Internal Propane tanks installed in JP tanks area	1400	2897	5806
Propulsion			
DRACO Ejector Ramjet- includes pumps, fuellines, etc.	900		
Fuel System - 200 lb		900	6706
Systems & Equipment			
Avionics Mass Properties, APU Power Option, 9/18,99	471		
Equipment Cooling, including nitrogen tank	39		
Nitrogen	45		
Drouge Chute	50		
Engine Residual Fluid	10		
Unusable Propellant, 1% of 5657 lb	57	672	
Payload - none			
Zero Propellant Weight			7378
Fuel			
PROPANE for ejector	823		
LOX - O/F 3.4 for Propane/Lox	2798		
PROPANE for ramjet	2036	5657	
Gross Weight at Engine Start			13035

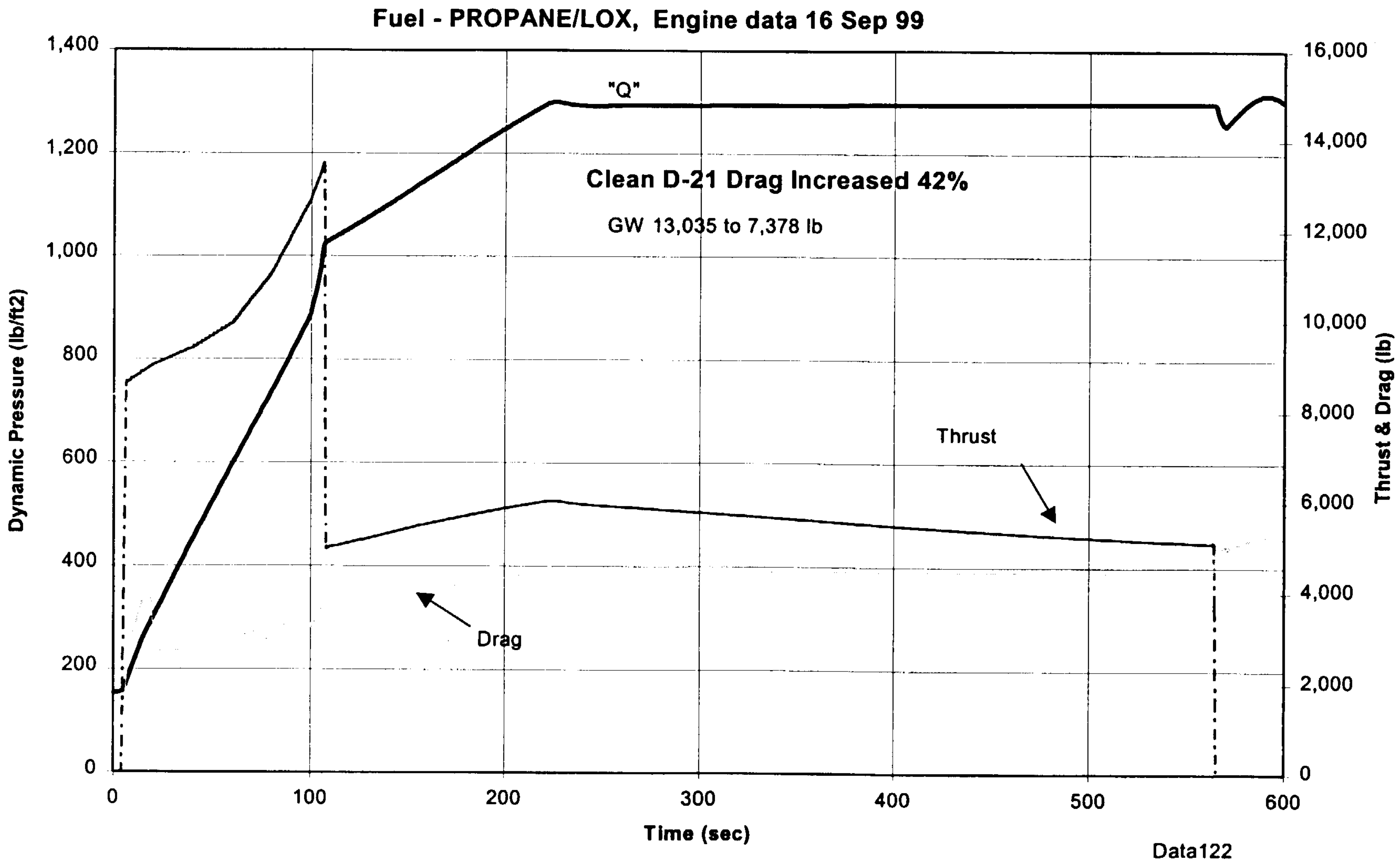
PROPANE/LOX, 1300 psf



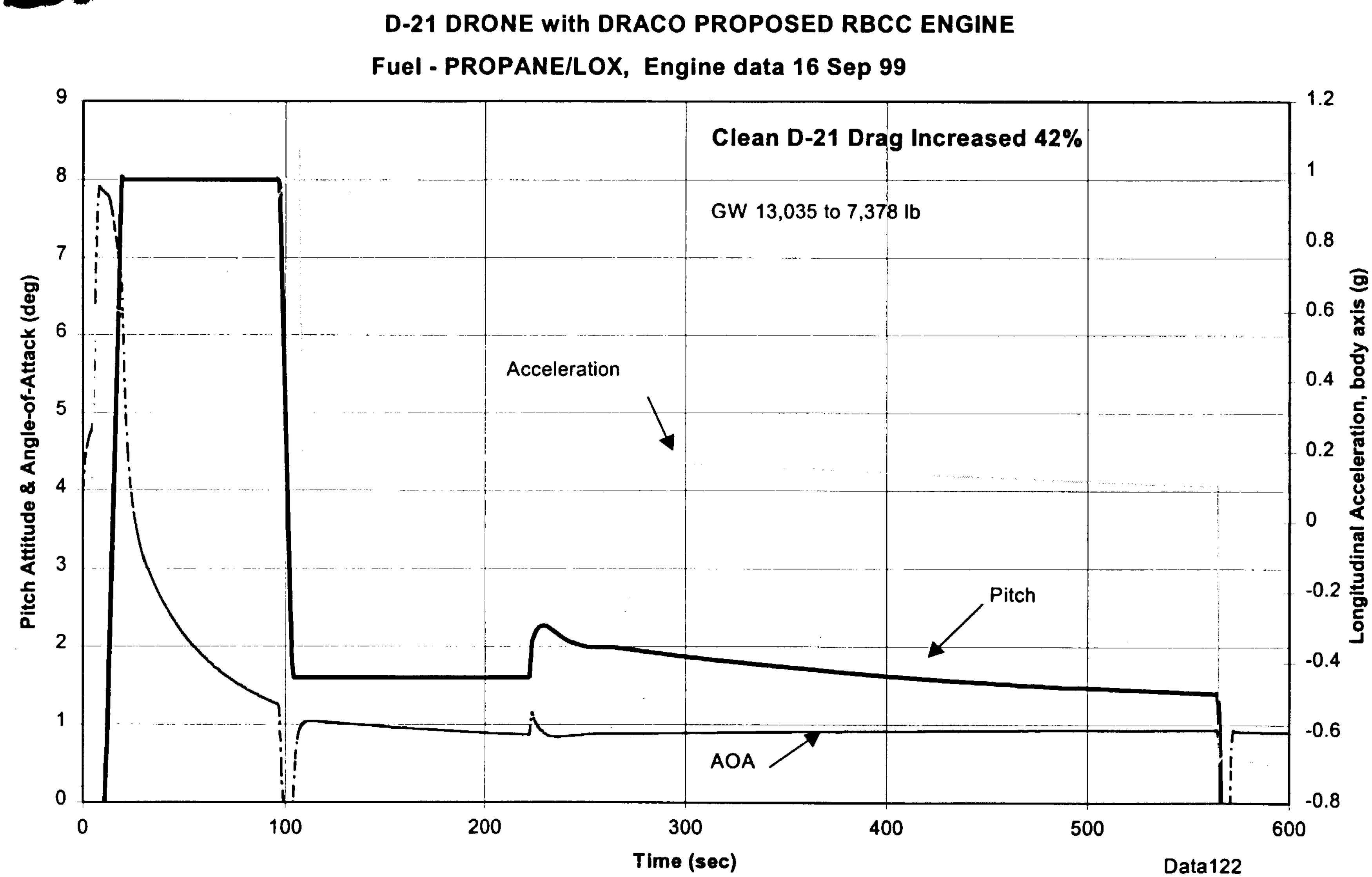
Data122

PROPANE/LOX, 1300 psf

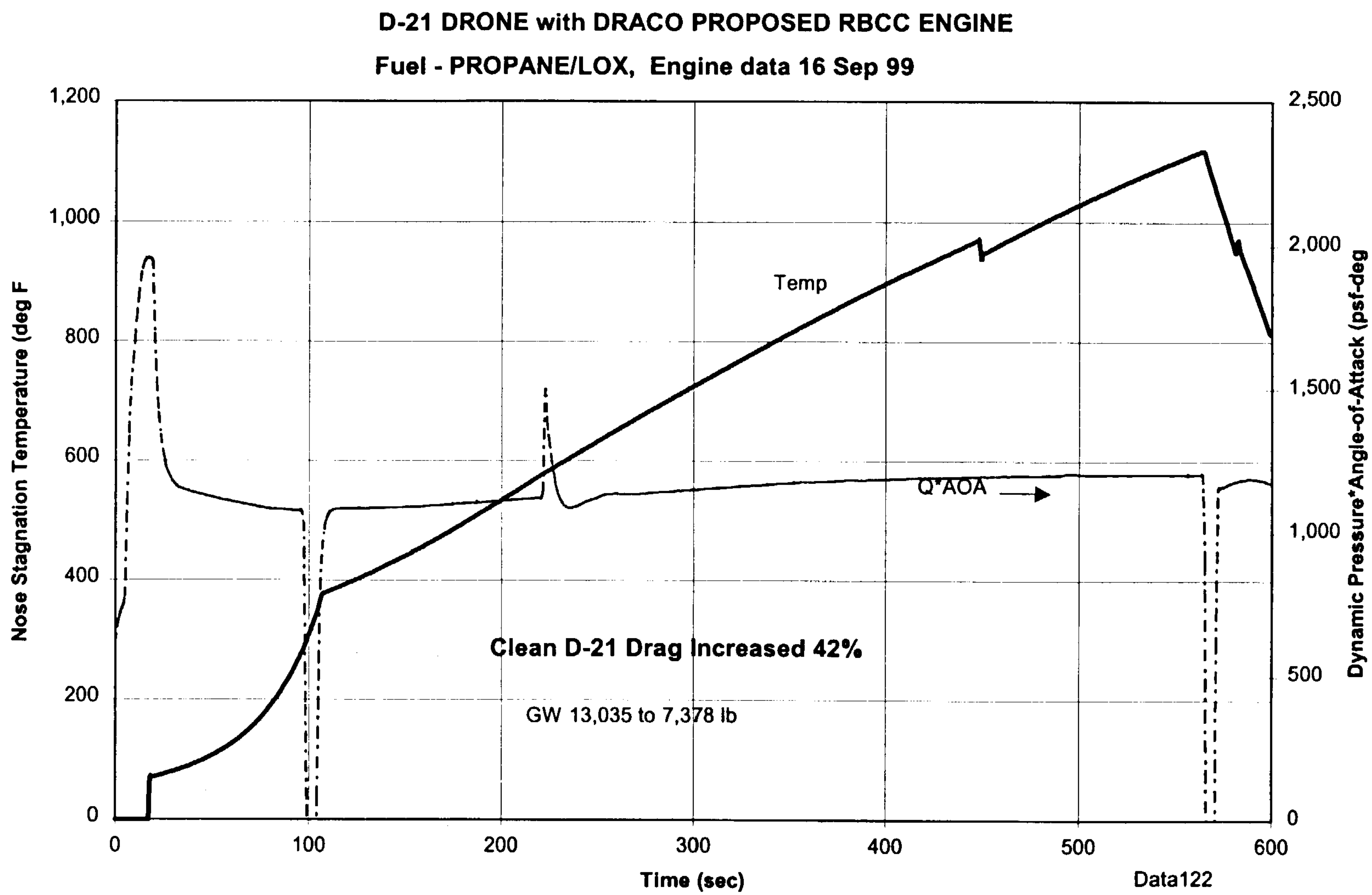
D-21 DRONE with DRACO PROPOSED RBCC ENGINE



PROPANE/LOX, 1300 psf



PROPANE/LOX, 1300 psf



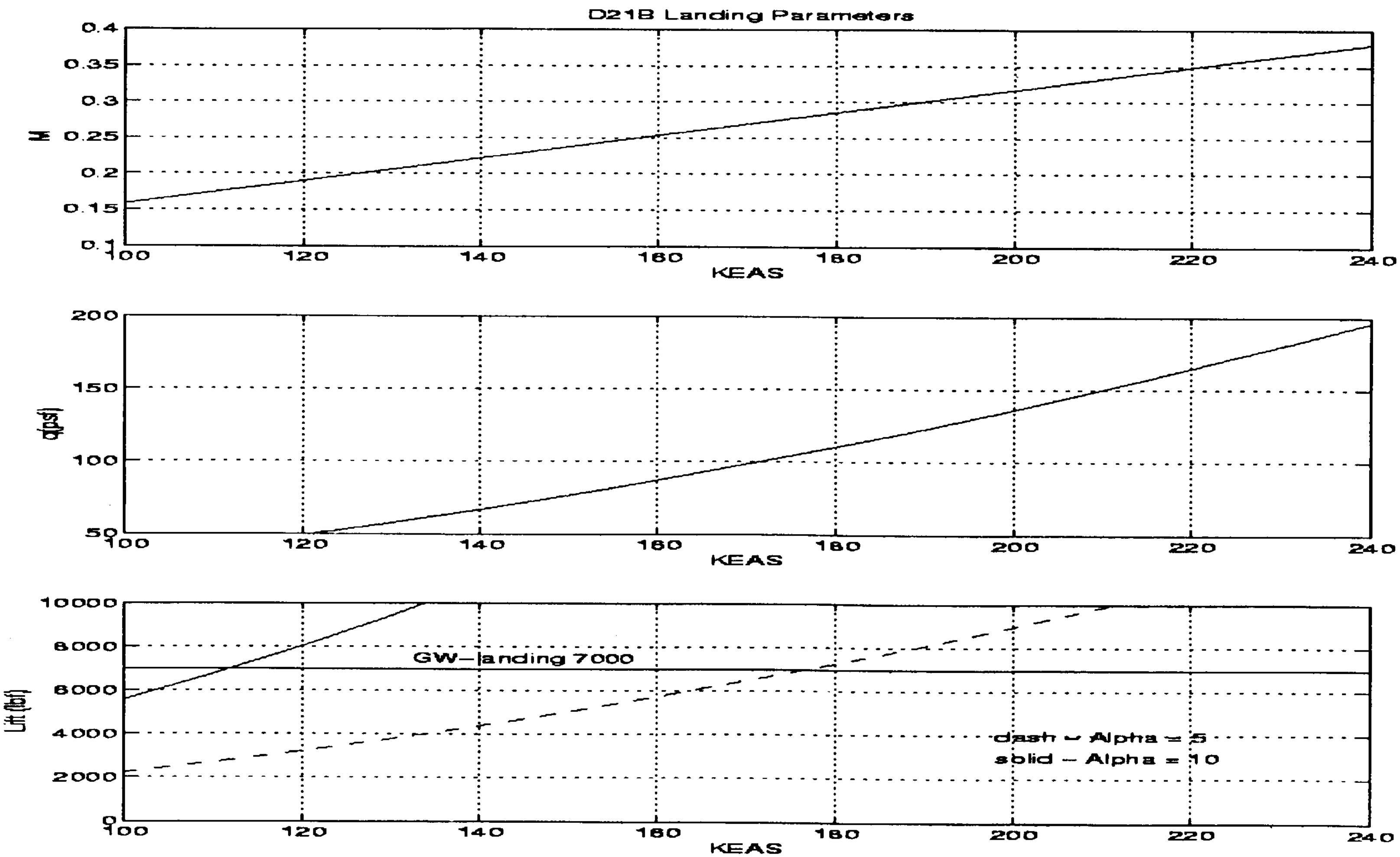
PROPANE/LOX, 1300 psf, Gross Weight

ORBITAL SCIENCES - DRACO - 30 September 1999 - Data121 & 122			sheet16
Weights for PROPANE/LOX, engine data 16 Sep			
D-21B Drone with DRACO Ejector Ramjet Installed	Weight (lb)	Weight (lb)	Weight (lb)
Drone as weighed @ Mojave			4145
Items Deleted			
Ramjet	-510		
Hydraulic Systems/Actuators/Pumps	-100		
APU/Generator/etc. 250 lb	-250		
Vertical Tail	-326		
Miscellaneous (Avionics)	-50	-1236	2909
Baseline Structure Added			
Forward fuselage (incl avionics bay)	82		
Mid fuselage (incl conformal tanks)	466		
Aft fuselage (incl engine bay)	125		
Vertical tail	374		
Landing gear	350		
Movable Air Inlet Spike	100		
Internal Propane tanks installed in JP tanks area	1400	2897	5806
Propulsion			
DRACO Ejector Ramjet- includes pumps, fuellines, etc.	900		
Fuel System - 200 lb		900	6706
Systems & Equipment			
Avionics Mass Properties, APU Power Option, 9/18,99	471		
Equipment Cooling, including nitrogen tank	39		
Nitrogen	45		
Drouge Chute	50		
Engine Residual Fluid	10		
Unusable Propellant, 1% of 5657 lb	57	672	
Payload - none			
Zero Propellant Weight			7378
Fuel			
PROPANE for ejector	823		
LOX - O/F 3.4 for Propane/Lox	2798		
PROPANE for ramjet	2036	5657	
Gross Weight at Engine Start			13035

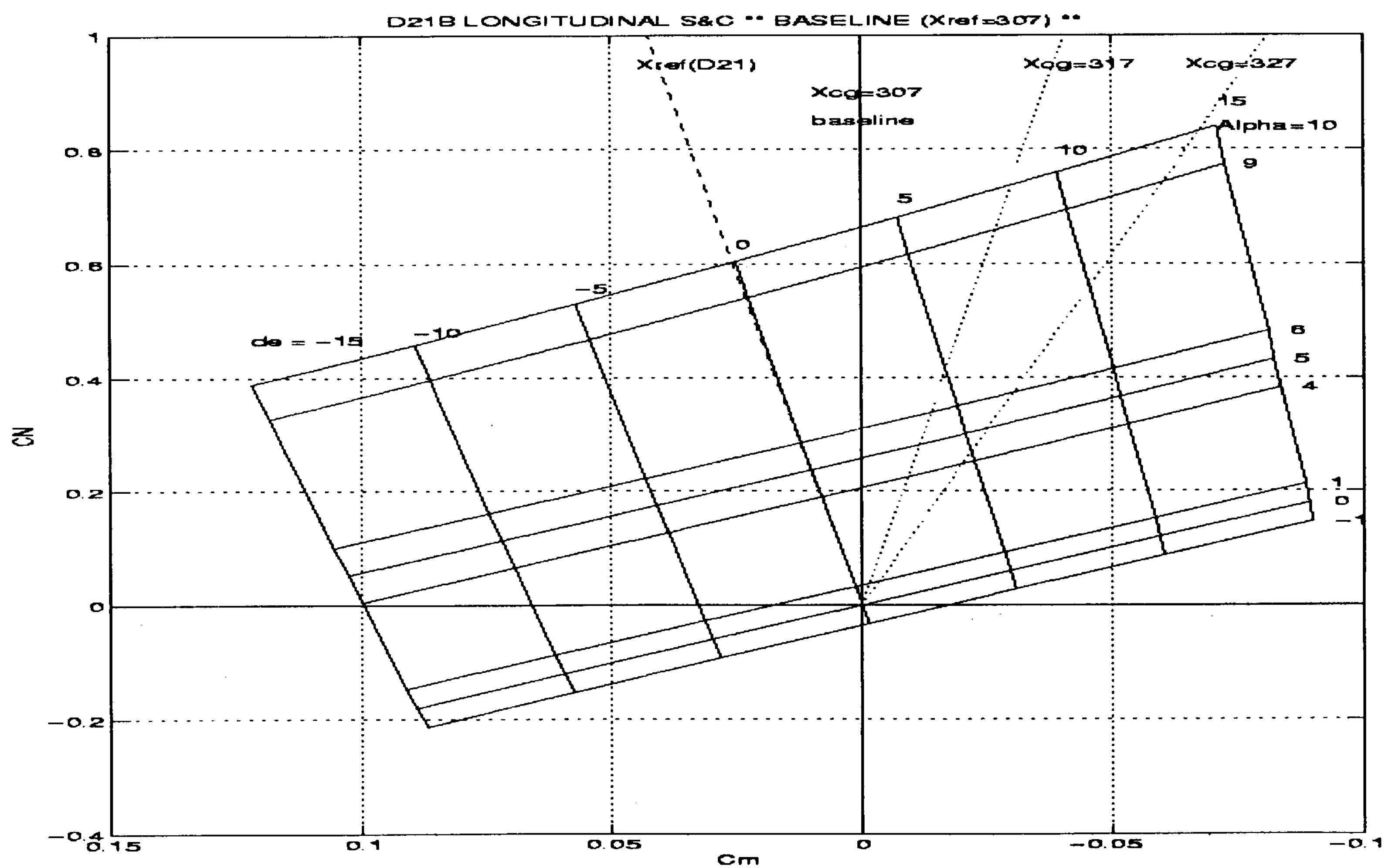
D21B Approach And Landing Assessment

- Approach and Landing Velocities Are Reasonable for a Safe Landing.
- Baseline Pitch Stability Indicates Slightly Unstable (C.G. @307), but Adequate Control Authority to Enable Safe Auto-pilot Control
- Baseline Lateral/directional Stability Indicates Statically Stable Between 1 and 10 Degrees Alpha, and Adequate Control Through 10 Degrees Alpha
- The Potential Vehicle Modifications Will Reduce Longitudinal Stability, But Will Little Effect on Lateral/directional Stability (Some Longitudinal Stability Regained With Gear Extended)
- Wind Tunnel Testing Would Be Required to Insure Reliable Auto-pilot Design

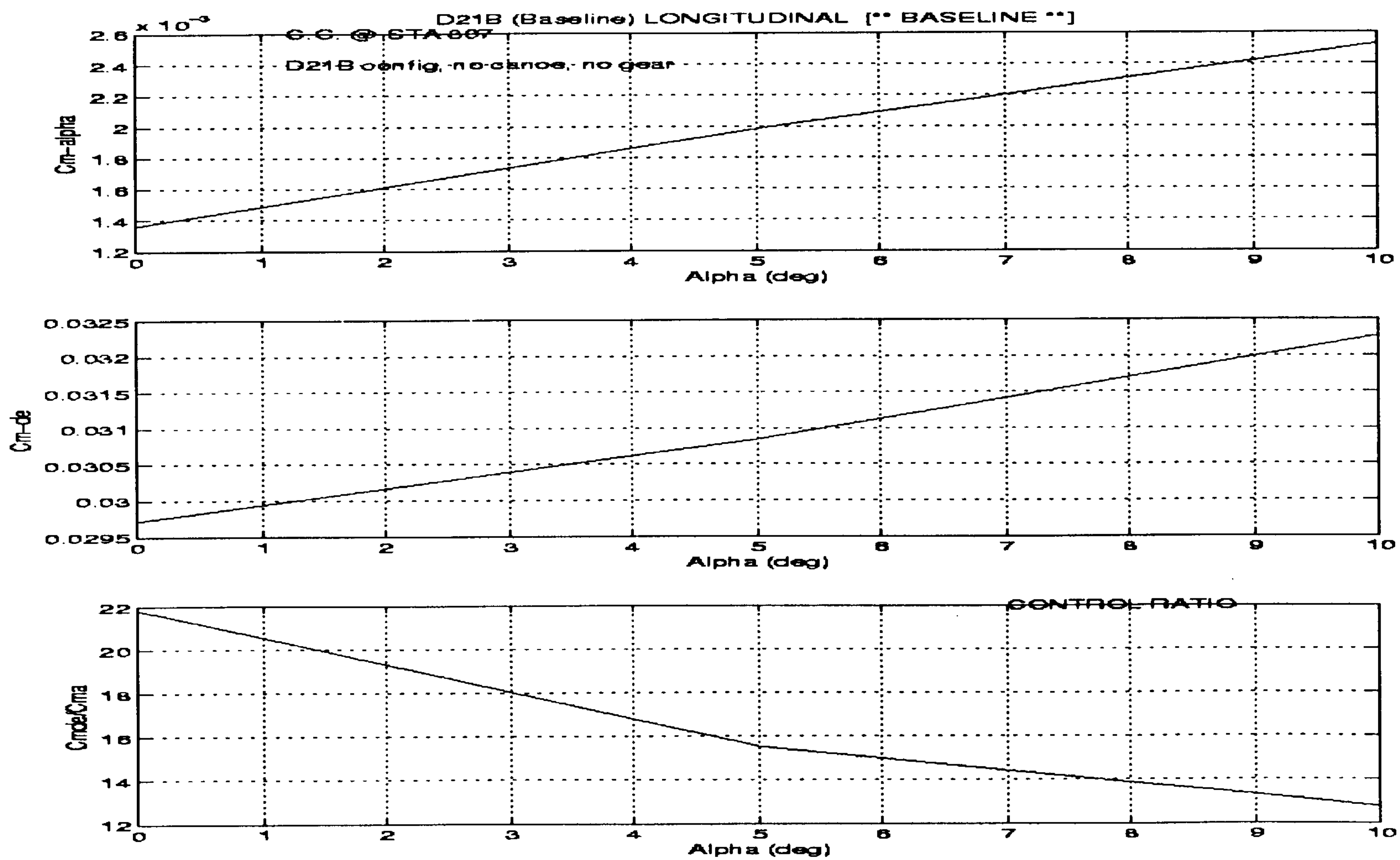
Landing Parameters



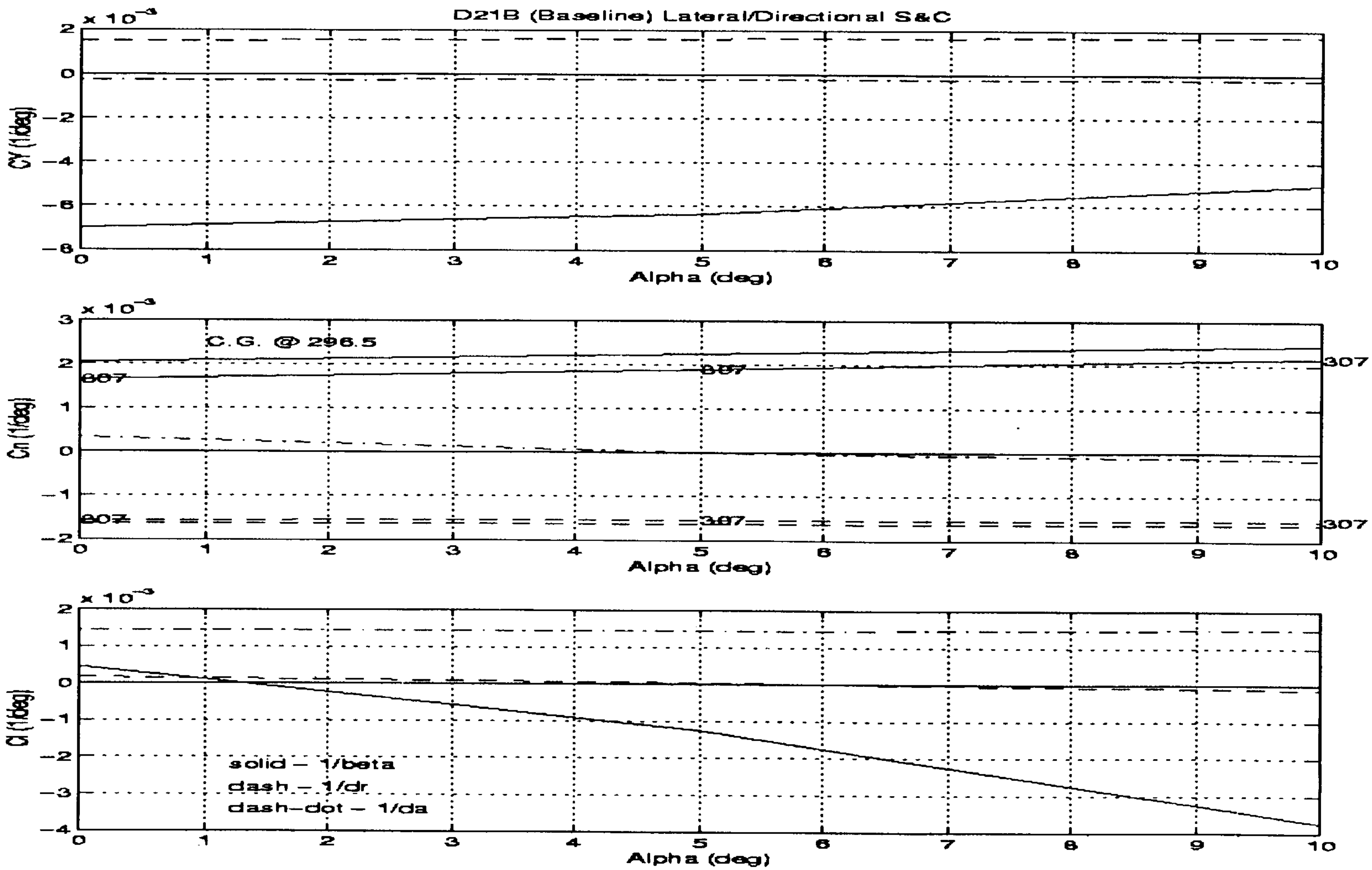
Longitudinal Stability and Control



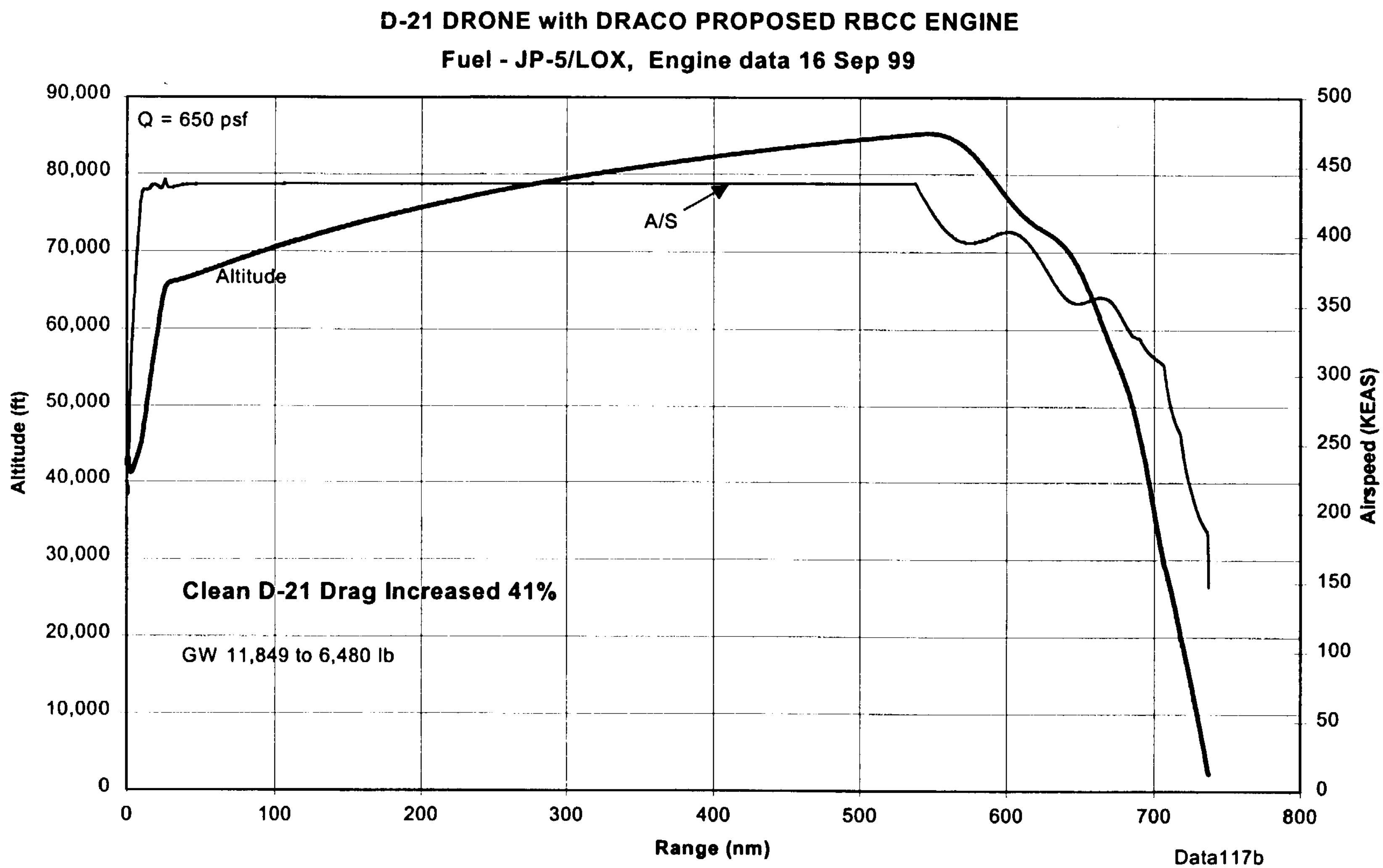
Longitudinal Control Ratio



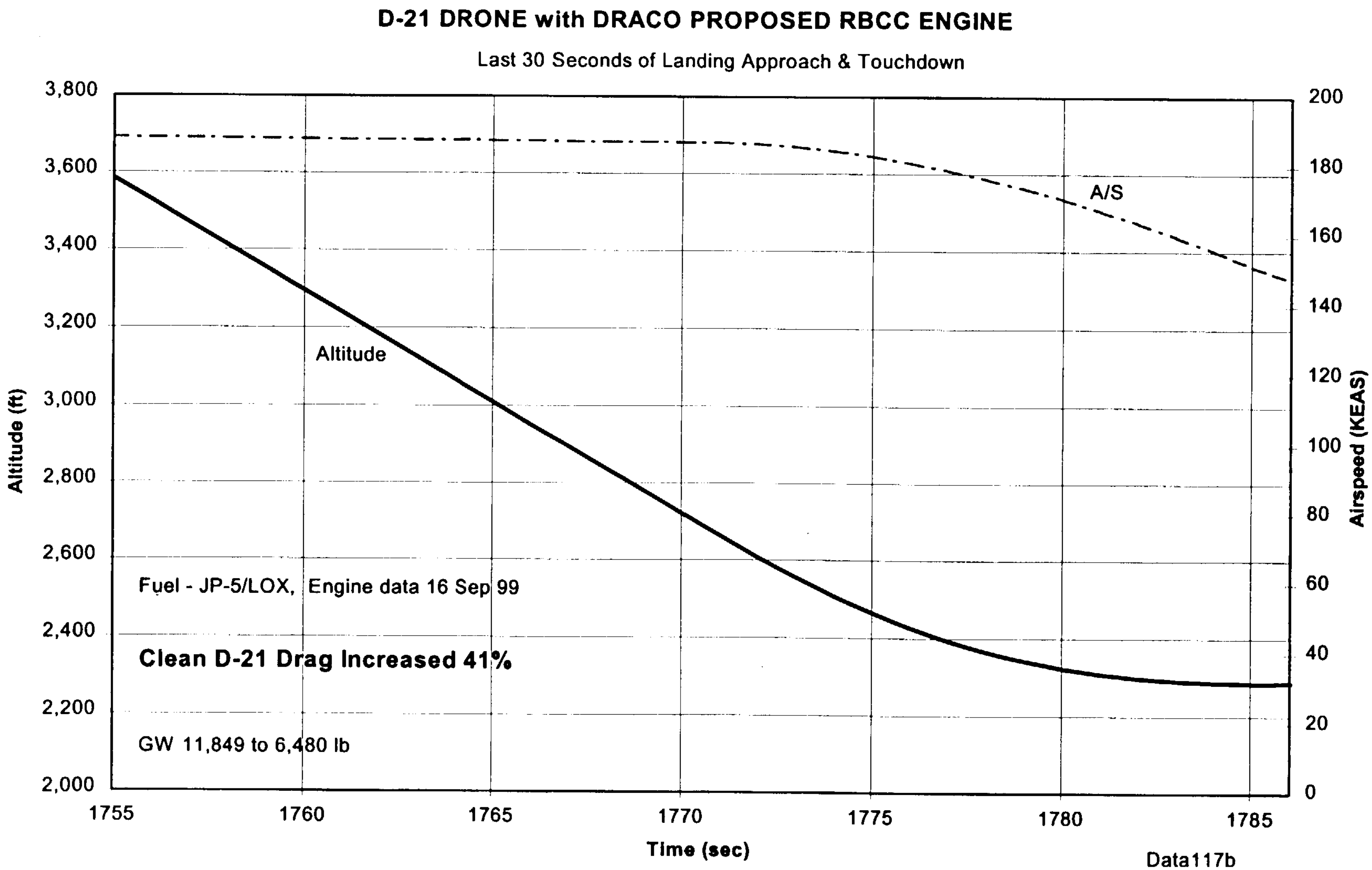
Lateral/Directional Stability and Control



Approach & Landing, Typical

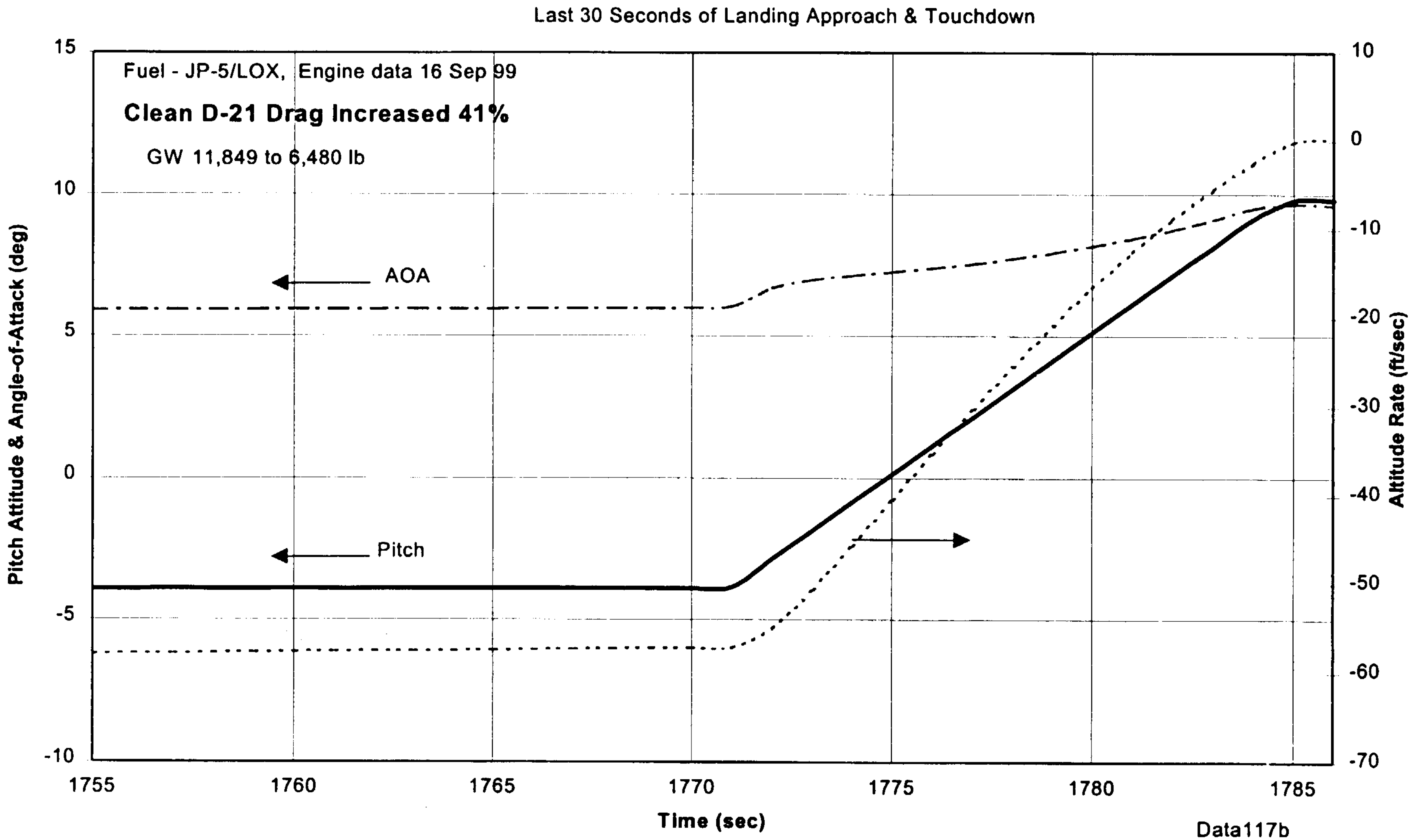


Approach & Landing, Typical



Approach & Landing, Typical

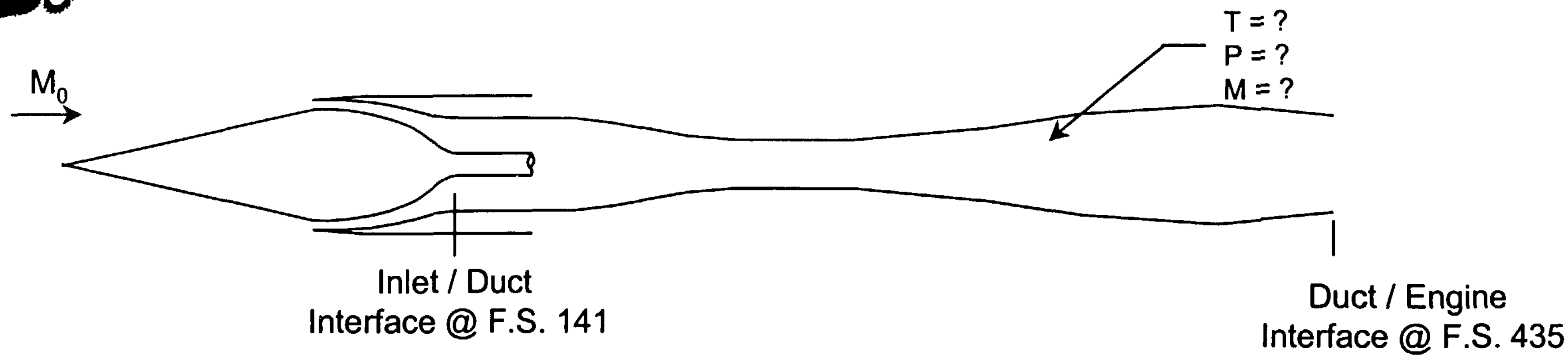
D-21 DRONE with DRACO PROPOSED RBCC ENGINE

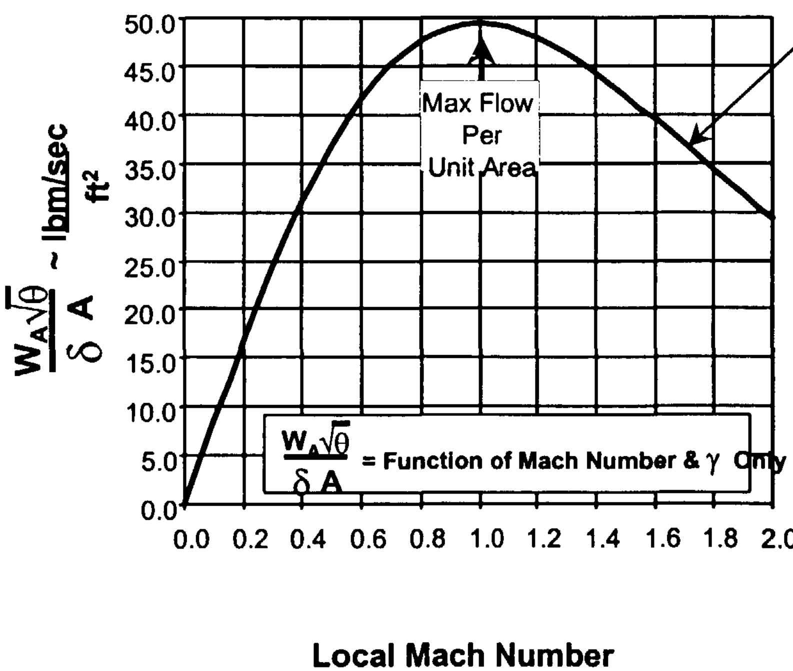


Status

- Flow-path Geometry Obtained from NASA D-21 Compendium
- Representative Engine Entrance Conditions Obtained From NASA-MSFC
  - Data is One Iteration Behind Thrust / Fuel Flow Data
- Distribution of Duct Flow Properties Examined for Predicted Flight Trajectory
  - Trajectory Consistent With 16-Sept-99 Engine Data
- Primary Attention Given to Duct Issues from F.S. 141 to F.S. 435
  - F.S. 141 Corresponds to TechLand Inlet / Duct Interface
  - F.S. 435 Corresponds to Duct / Engine Interface
- TechLand Inlet Geometry Briefly Examined

Analysis Approach



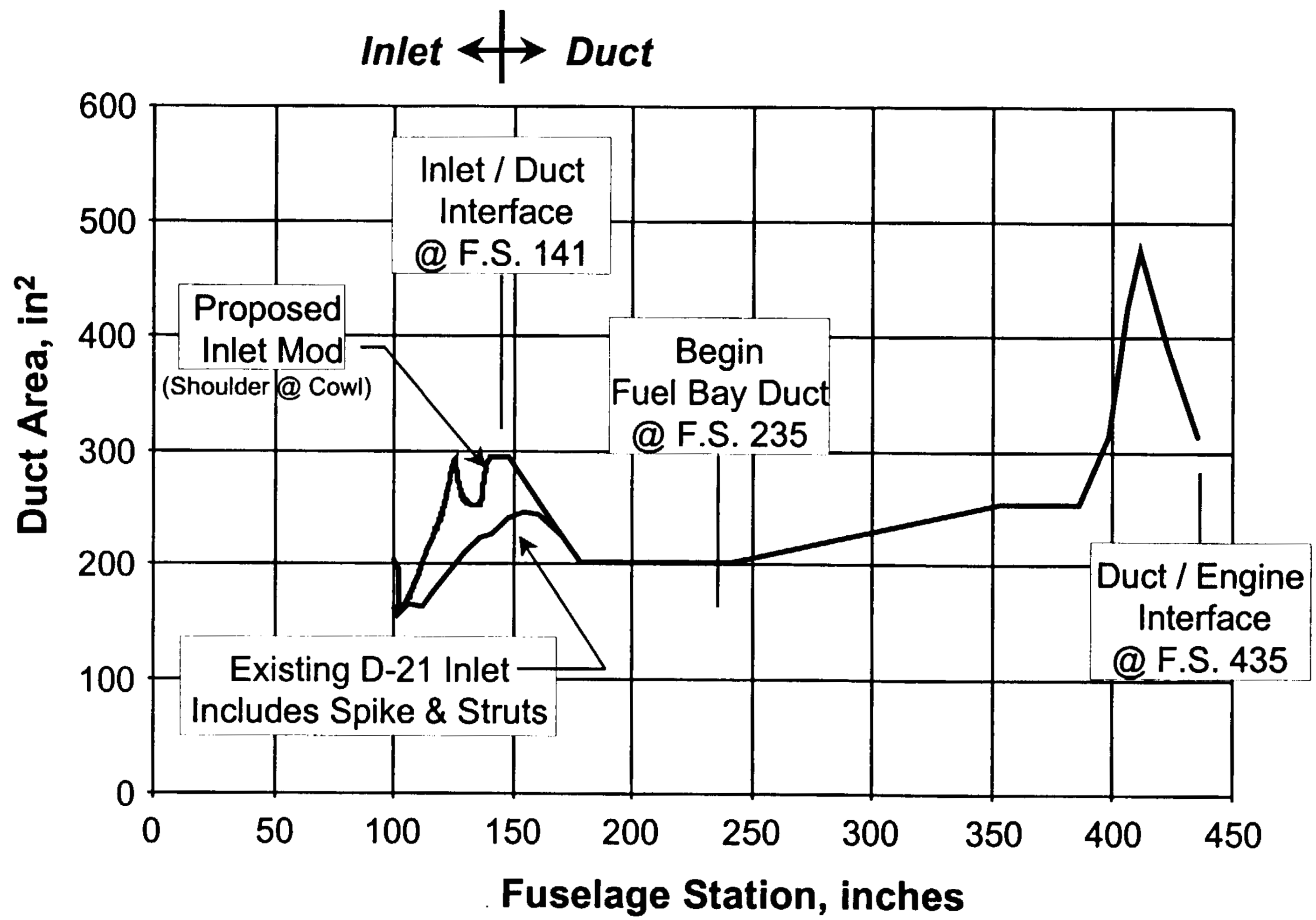


$$\frac{W_A\sqrt{\theta}}{\delta A} = M\sqrt{\gamma g / R}\,\frac{P_{SL}}{\sqrt{T_{SL}}}\left(1+\frac{(\gamma-1)}{2}M^2\right)^{\frac{(\gamma+1)}{2(1-\gamma)}}$$

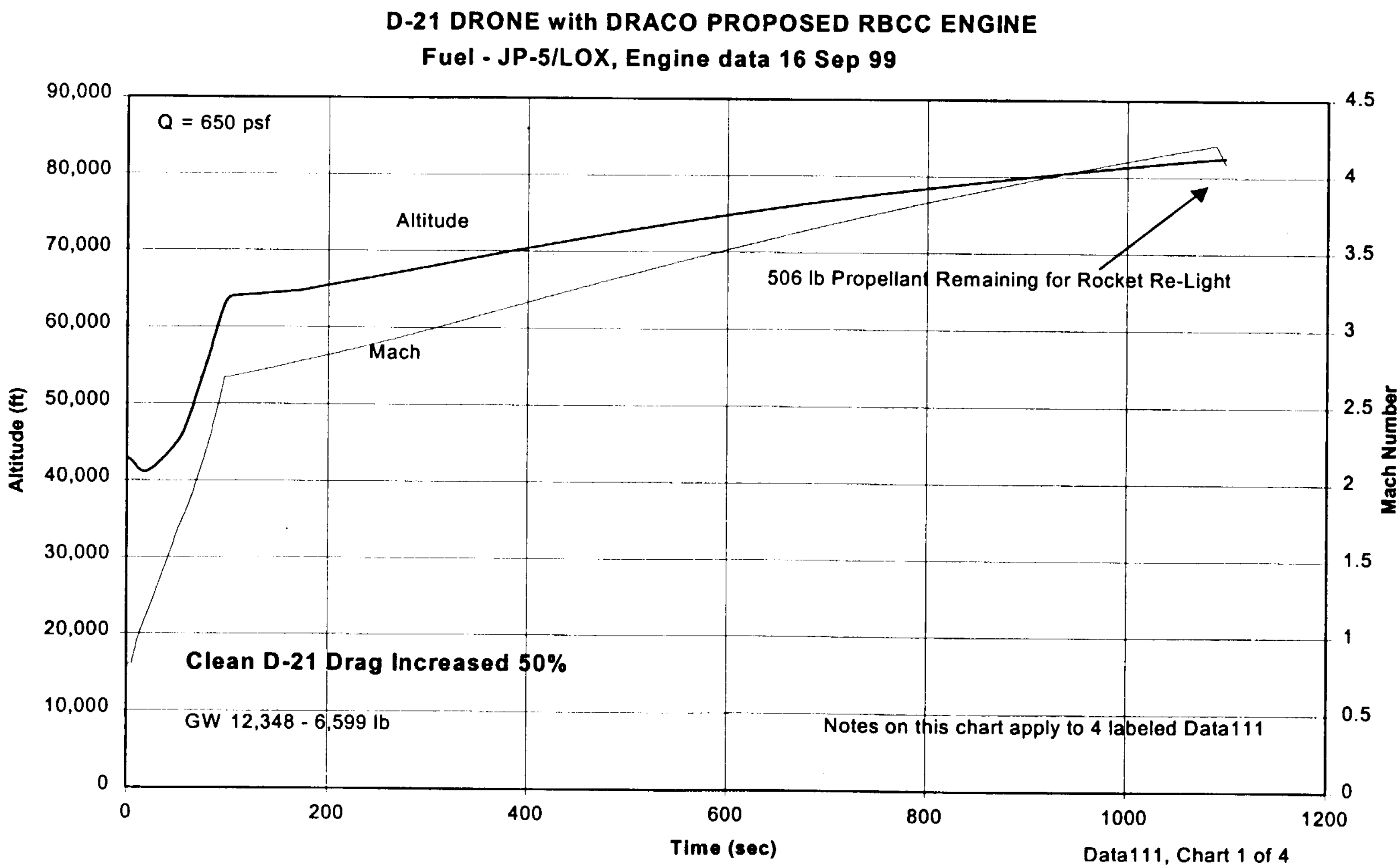
$$\frac{W_A\sqrt{\theta}}{\delta} = \text{Corrected Airflow} = \frac{W_A\sqrt{T_T/T_{SL}}}{P_T/P_{SL}}$$

- Corrected Airflow at Engine Face Available
- Area Distribution of Duct Reasonably Known
- Therefore, Mach Number Can Be Computed at Any Station
- Temperatures and Pressures Follow
- Max Flow Can Be Estimated Using Min Areas

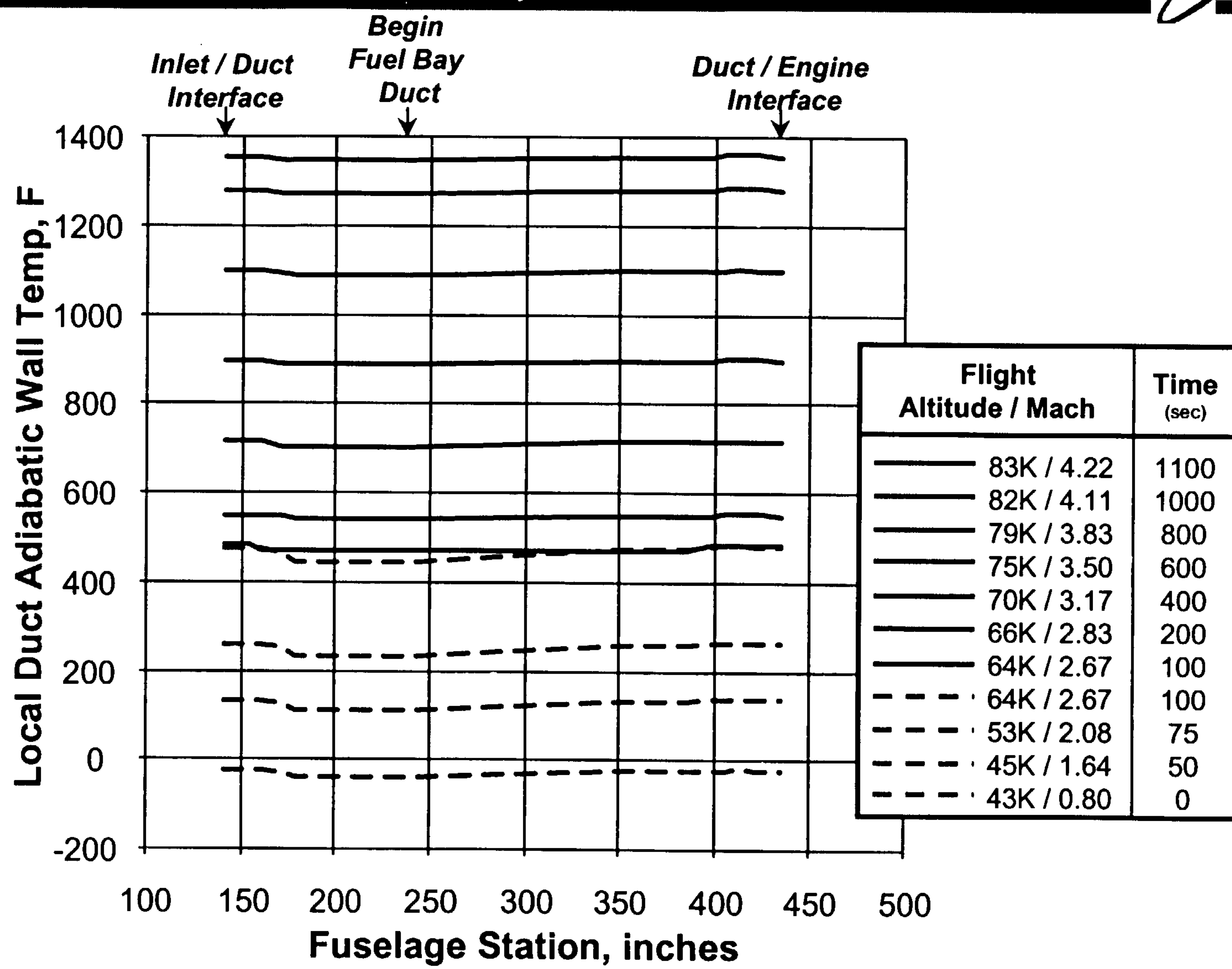
Inlet & Duct Geometry Comparison



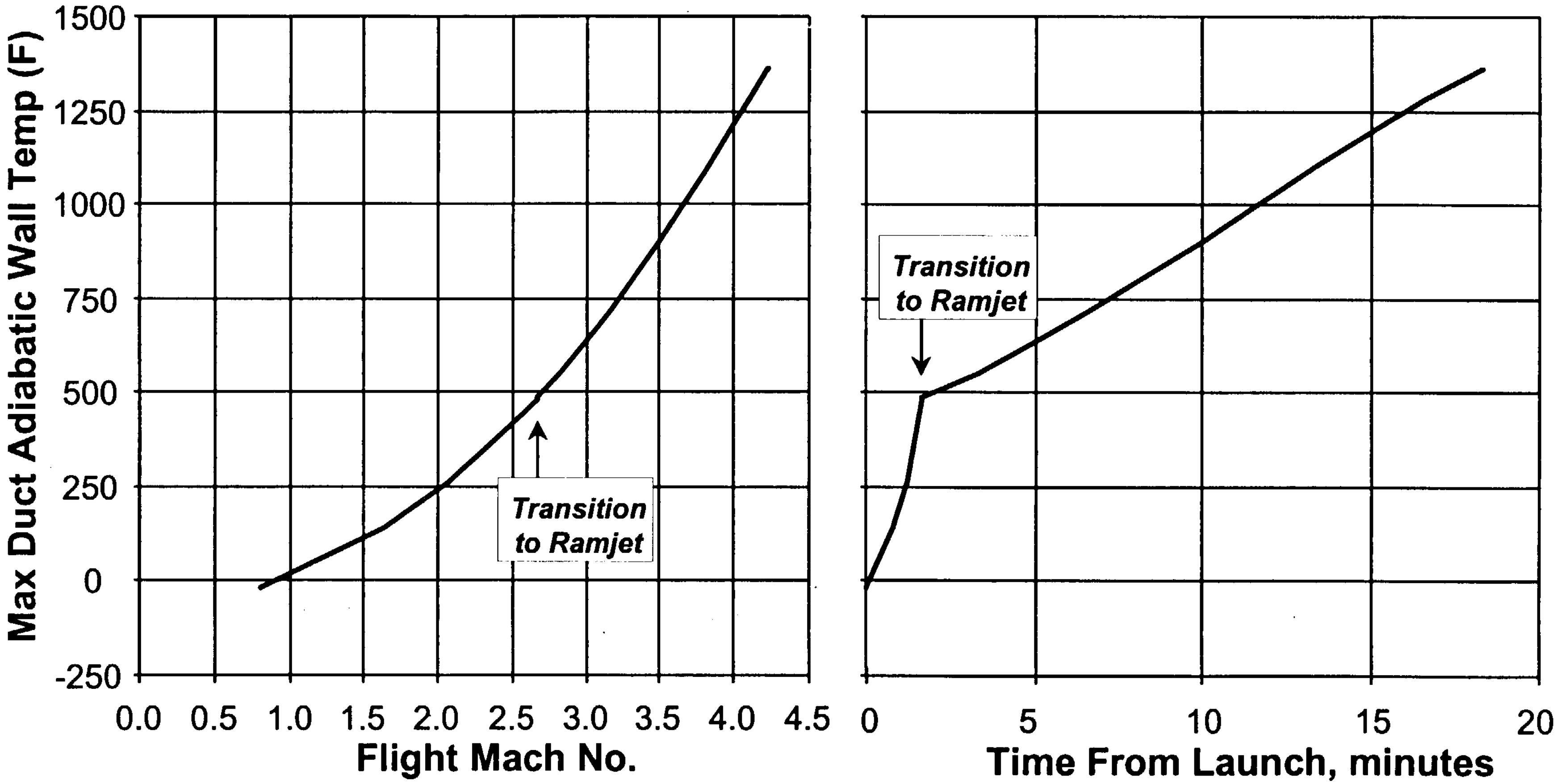
Trajectory Assumed For Analysis



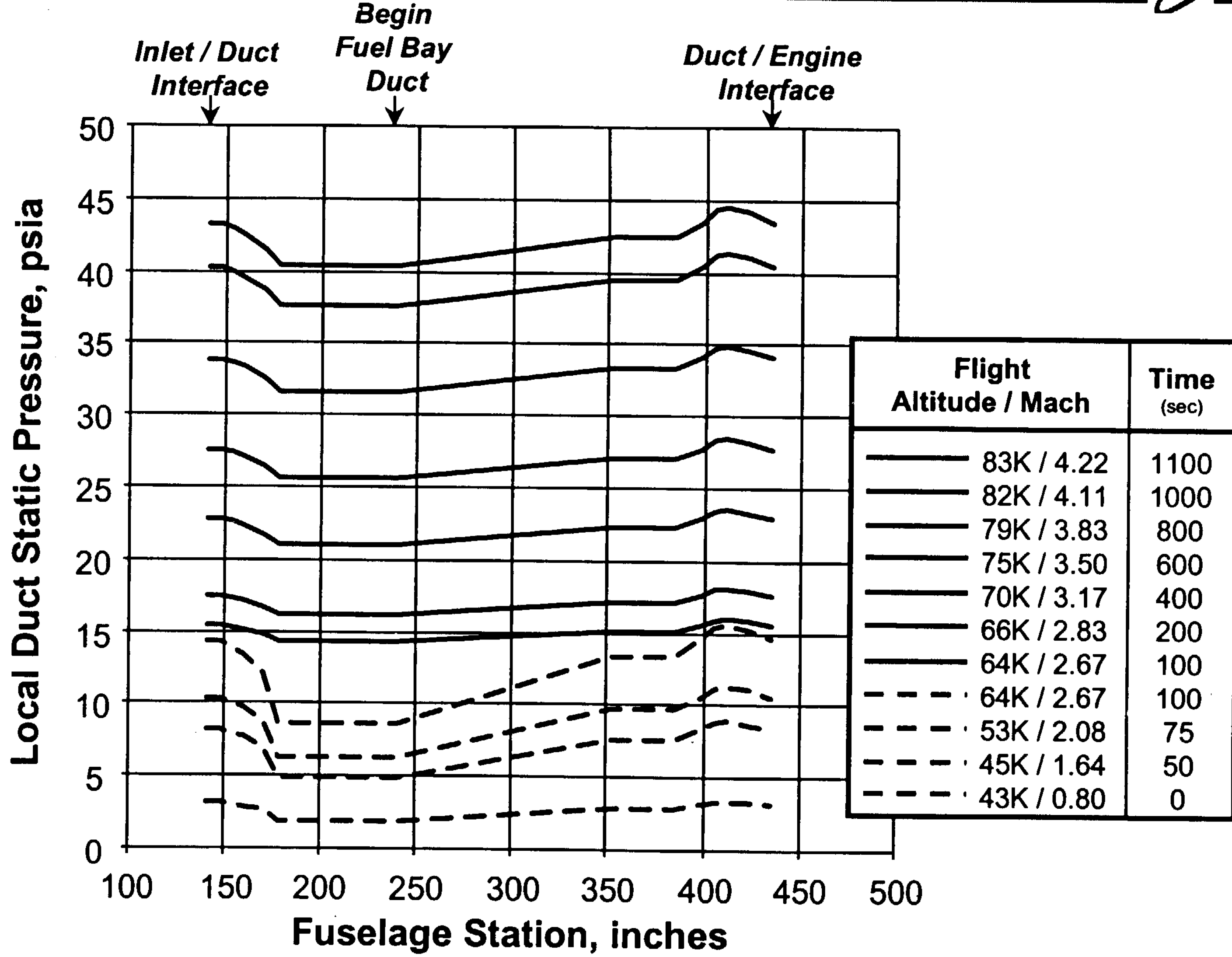
Duct Temperature Distribution



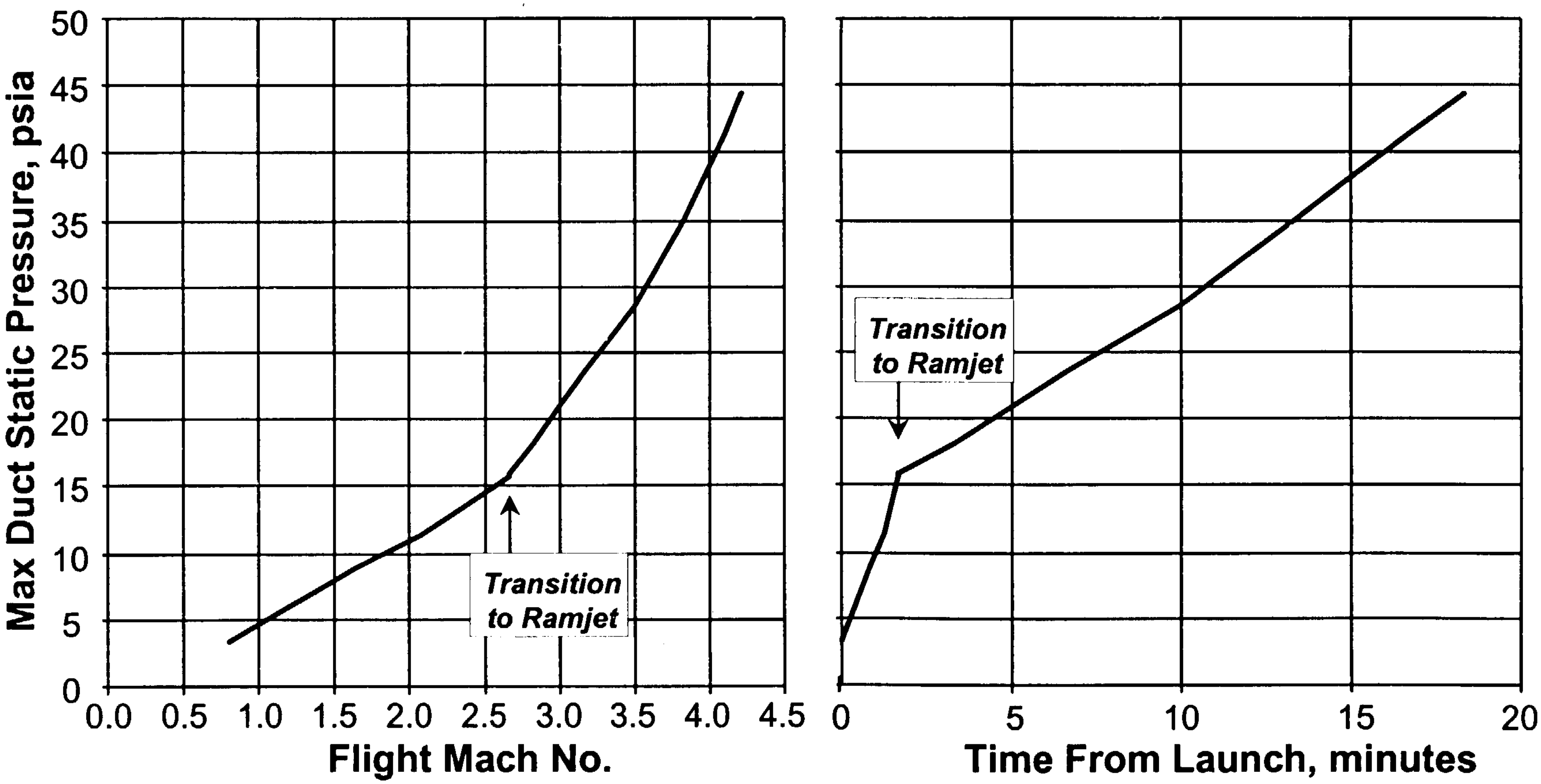
Duct Temperature Variation During Flight



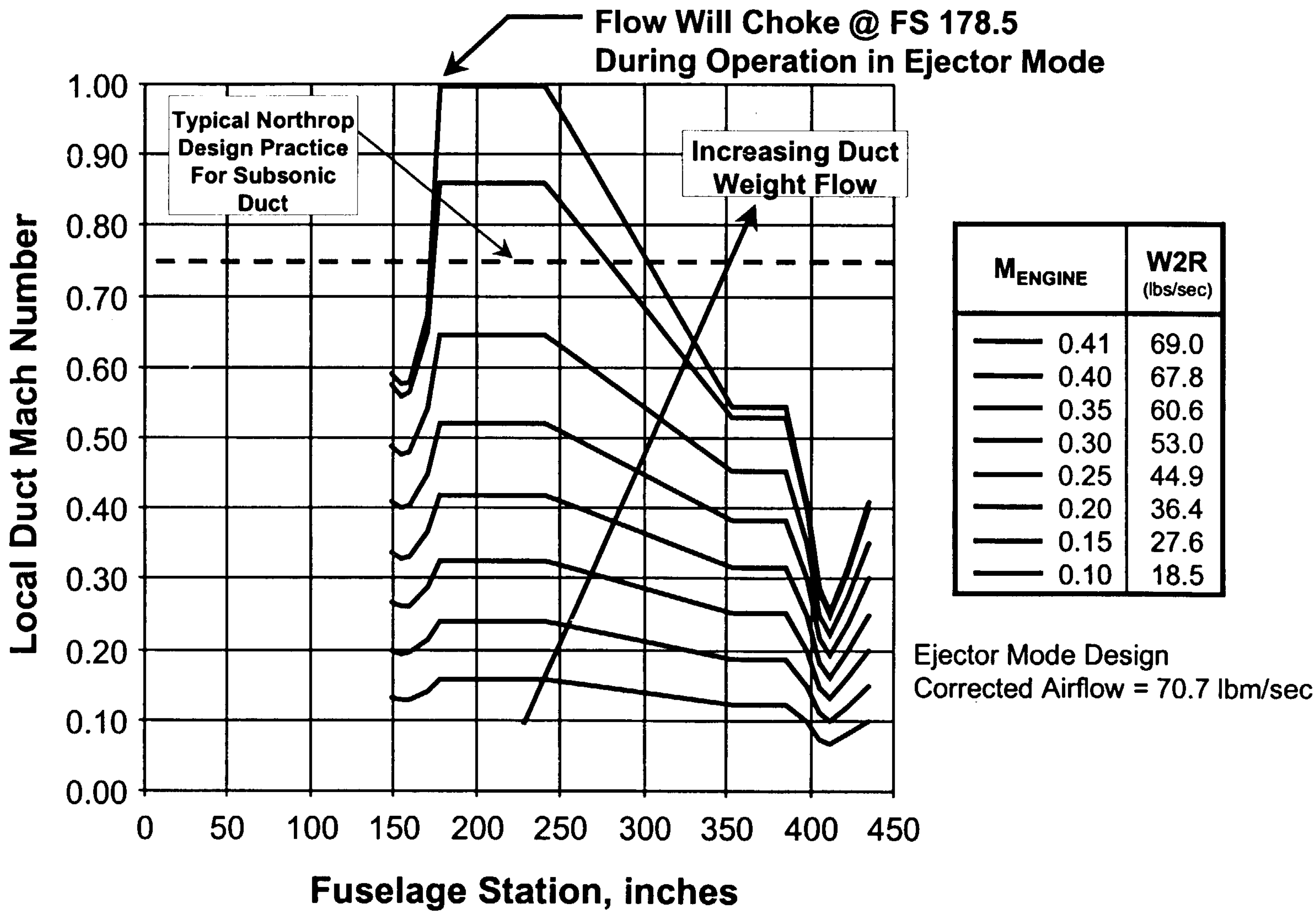
Duct Pressure Distribution



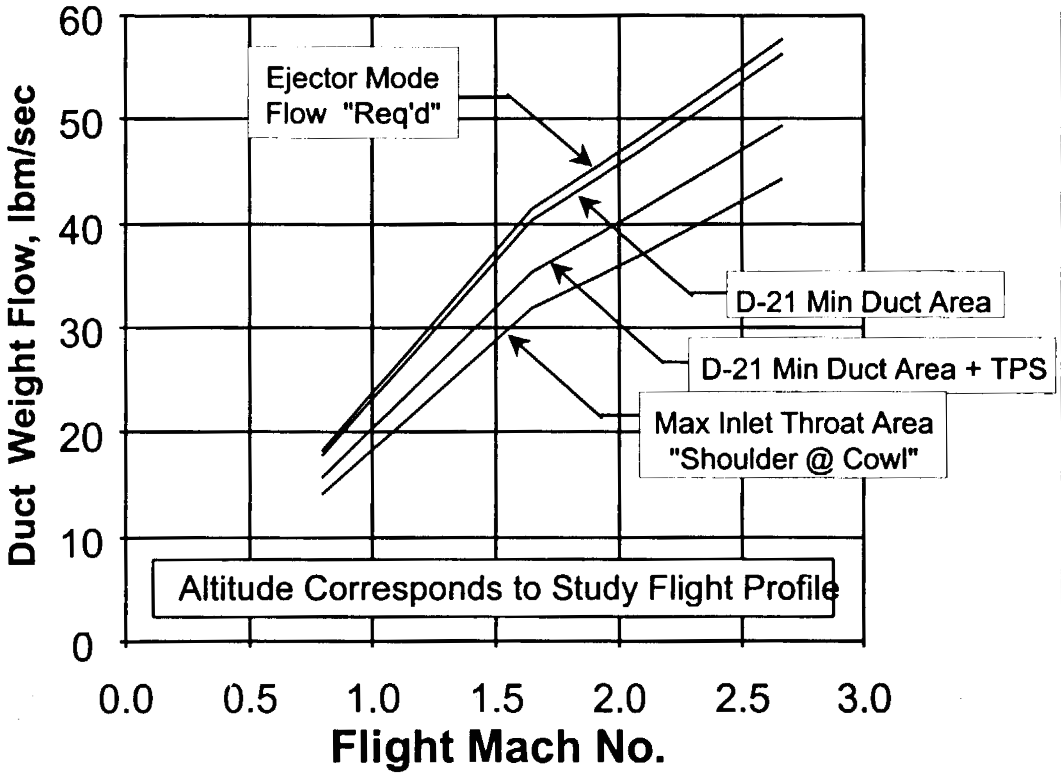
Duct Pressure Variation During Flight



Duct Mach Number Distribution



Maximum Duct Airflow Capability



Limiting Feature	Limiting Area (sq. in)	% Shortfall wrt "Req'd"
Min Duct @ FS 178.5-235	201.1	-2.4%
Min Duct @ FS 178.5-235 + 1/2" TPS	176.7	-14.2%
Max Inlet Throat Shoulder @ Cowl	158.5	-23.1%

If Real, the Sensitivity of Ejector Mode Thrust to Reduced Inlet Airflow Should Be Quantified

Summary

- Existing Duct Appears Adequate for Required Ramjet Mode Air Flows

- However, The Duct Appears to Be Slightly Undersized for Required Ejector Mode Air Flows--The Performance Impact Is Minimal (<5%).

- Existing Titanium Inlet Duct Not Compatible with Flight Mach Numbers Greater Than 3.5 Due to Thermal Issues

- Duct Replacement Although Possible, Would Substantially Increase The Cost And Complexity Of The Vehicle Modification.

- Practical Solutions to Duct Temperature Issues for Flight Beyond Mach 3.5 Will Further Reduce Duct Airflow Capability (e.g.., TPS Coatings)

Structural Loads Assessment: Airframe

Background:

- Original D-21 Loads Analysis Generally Involved a Free-flight Condition (5g Pull-up at M=3.3 and 450 keas), and Several Captive Carry Loads Cases
- Assumption: SR-71 Captive Carry Loads are More Severe Than For B-52; Therefore, Feasibility Study Focused on Free-flight Conditions

Findings:

- From the Lockheed Aerodynamics Database, the D-21 Had a Trim α of Approximately 2.3 Degrees at M=3.3, 450 keas (71 kft)
  - Results in αq = 1559 psf-degrees
- D-21 Free-flight Load Case (5g Pull-up) Would Imply That the Airframe Can Withstand an αq=7795 psf-degrees

Conclusions:

- Trajectory Simulations Conducted for Reuse Feasibility Indicate a Maximum αq=2000 psf-degrees. Therefore, the Airframe Can Handle Significantly More Load Than a M=4.0 Trajectory Should Produce.
  - Max αq for M=6.0 Trajectory Will Approach 7000 psf-degrees

Structural Loads Assessment: Engine Mounts

Background:

- Engine Mounts are at F.S. 435 (One Connection) and F.S. 468 (Three Connections); Ref. Lockheed SP-717, pg. 23
- Only the Fwd Mount (@ F.S. 435 Thrust Loads, All Connections Take Lateral Loads and Moments
- RJ-43 Engine Thrust Load = 2700 (ult.)

Findings:

- RBCC Engine in Ejector Mode Produces Approximately 12,000 lbf Thrust
- D-21 Mounts Were Analyzed Originally for -6570/+9960 lbf Thrust Loads
- Structural Margins for D-21 Mounts Tended to be Fairly High (M.S.>0.24), And Were Evaluated at 800-900 deg F (for RBCC, Max Loads are Early in Flight)

Conclusions:

- D-21 Airframe and Engine Mounts can Probably Accommodate an 11,000 lbf Thrust Engine With No Modifications
- Better Alignment of RBCC Attachment Points to D-21 Mounts Will Increase Margins

Structural Loads Assessment Summary

- D-21 Free Flight Loads Were Based on a 5.0 g Pull-up Condition
  - RBCC Mission Loads Will Be Encompassed by D-21 Loads up Through M = 5.0
  - Structural Loads on D-21 Airframe Shouldn't Limit the RBCC Operational Envelope
- RBCC Engine Thrust Loads Are ~25% Higher Than D-21 Engine Mount Design Loads (For AAR Mode Only)
  - Original D-21 Engine Mount Structural Margins Were Relatively High (>0.24)
  - Low RBCC Engine Mount Temperatures During Period of High Thrust Will Increase Material Strengths by 15-20% Relative to D-21
    - Result Is That Engine Mounts Should Be Structurally Adequate

Thermal Loads Assessment: Airframe Structure

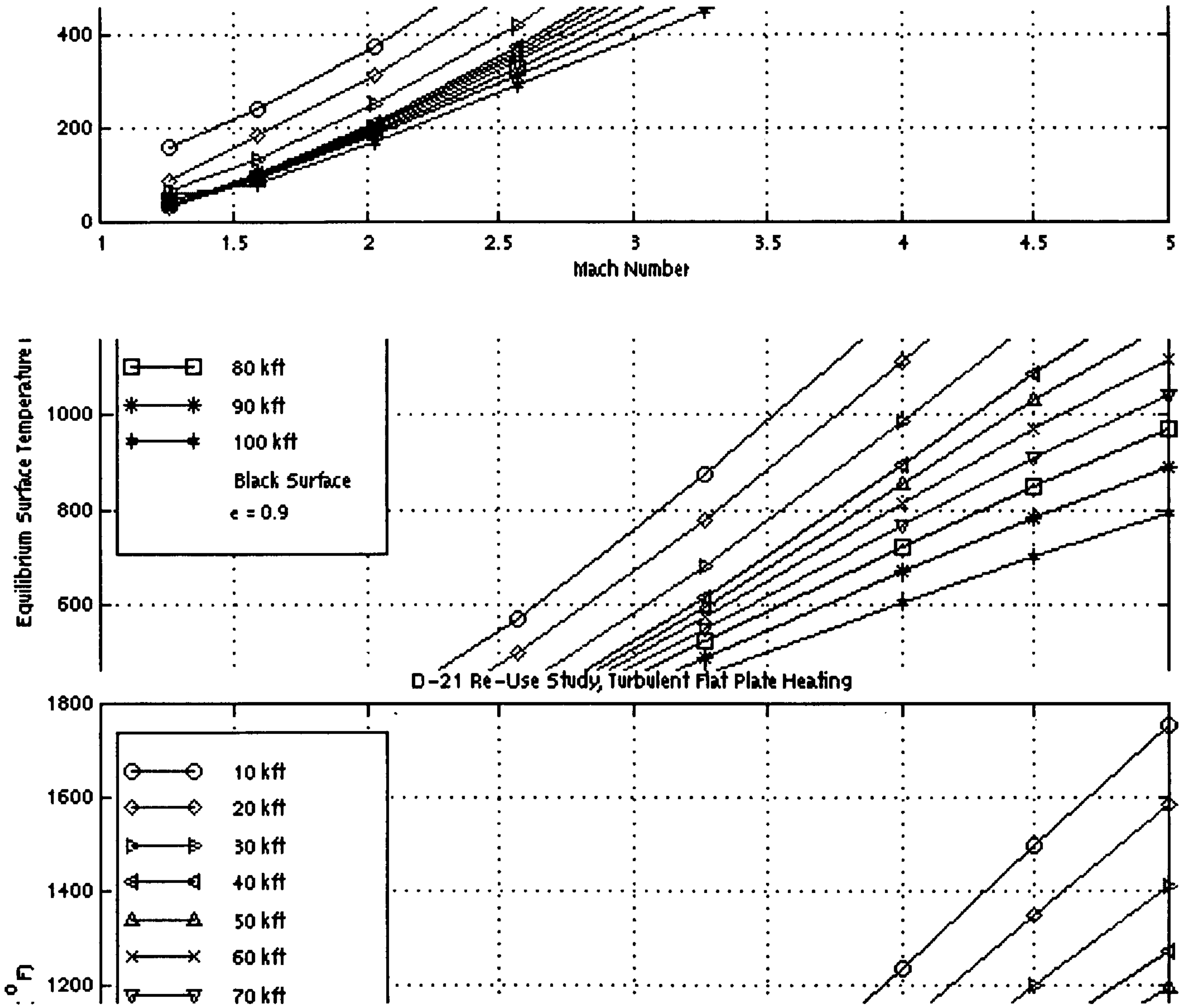
Background:

- D-21 Designed for M=3.3 @ 450 keas (71 kft)
  - T_{stag}=790 F
  - T_{equil}=570 F
- Design Temperature of 600 F Was Used For Most Structures; Inlet and Inner Duct Used 700 F
- Due to Engine Radiation Load, Structures in Engine Region Used 800-1000 F

Findings:

- Titanium Mechanical Properties Do Not Change Significantly (<10%) From 600-800 F, so M=4.0 Trajectories Should be Very Feasible From an Airframe Aeroheating Perspective
- For M>4.0, New or Additional TPS Will Be Required

Thermal Loads Assessment: Airframe Structure (cont'd)

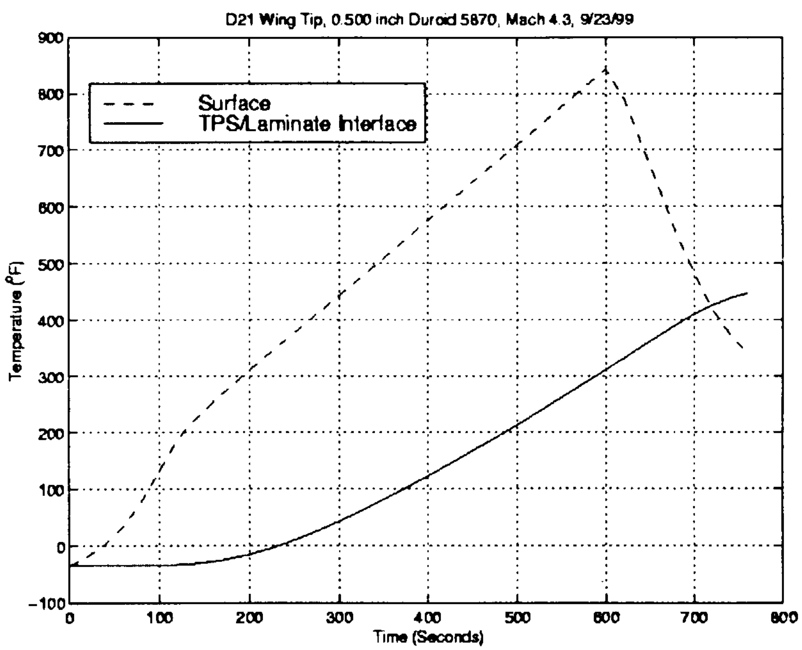


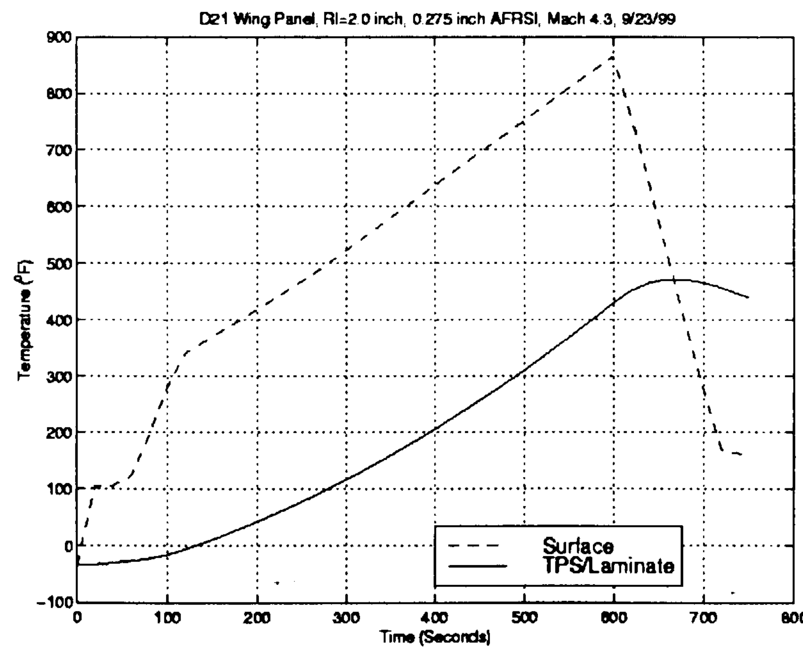
Thermal Loads Assessment: TPS

- Current TPS (Asbestos-impregnated Silicone) Is Adequate for RBCC Mission Durations and for M< 3.3
  - Reusability Is Unknown, but Expected to Be Limited (Especially For Control Surfaces and Leading Edges)
- Adequacy of Current TPS at M > 3.3 Is Unknown
- Recommend Coupon Testing of Existing TPS to Characterize Performance
  - Determine Suitability for RBCC Missions, Or...
  - Allow for Reverse-engineering With Updated TPS to Provide Same Substrate Temperatures As D-21
- Suitability of Various TPS Material for M > 3.3 Was Explored
  - Analyses Conducted up to M = 5.0 Indicate Reasonable TPS Weight/Thickness

Thermal Loads Assessment: TPS (cont'd)

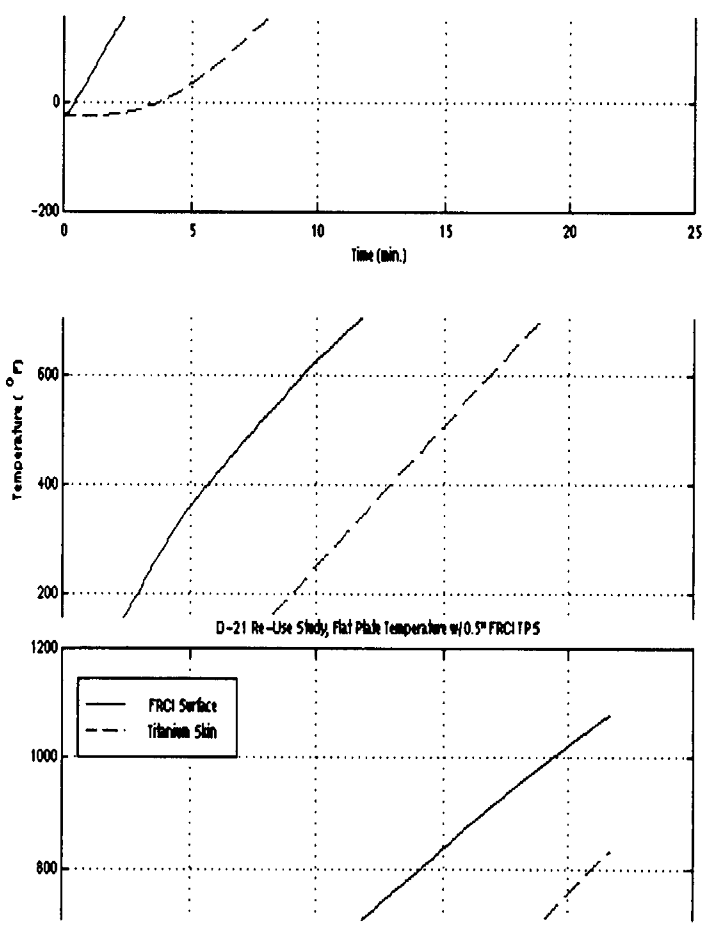
Mach 4.3 Mission with LOX/Propane; 1300 psf; 9/16/99 Engine Data

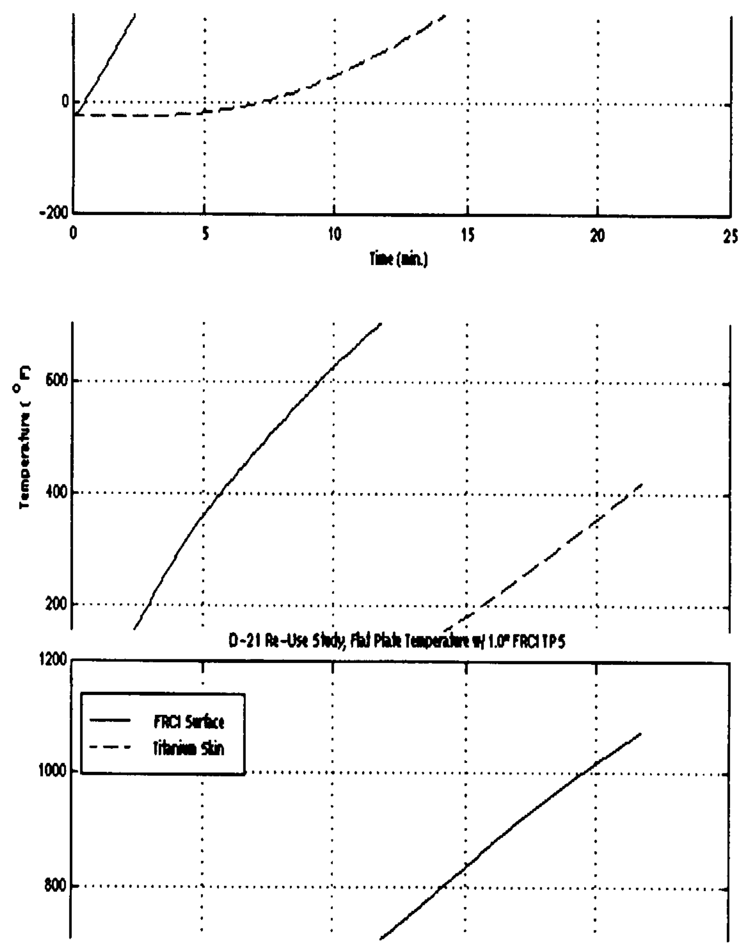




Thermal Loads Assessment: TPS (cont'd)

Mach 5.0 Mission with JP/LOX Propellants



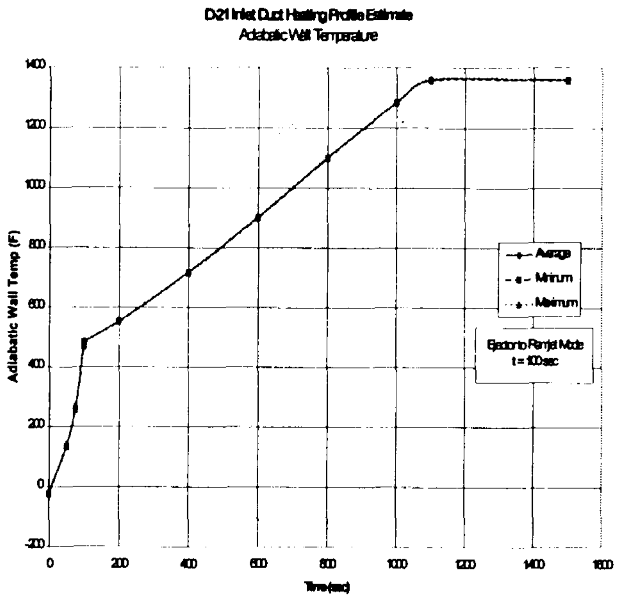


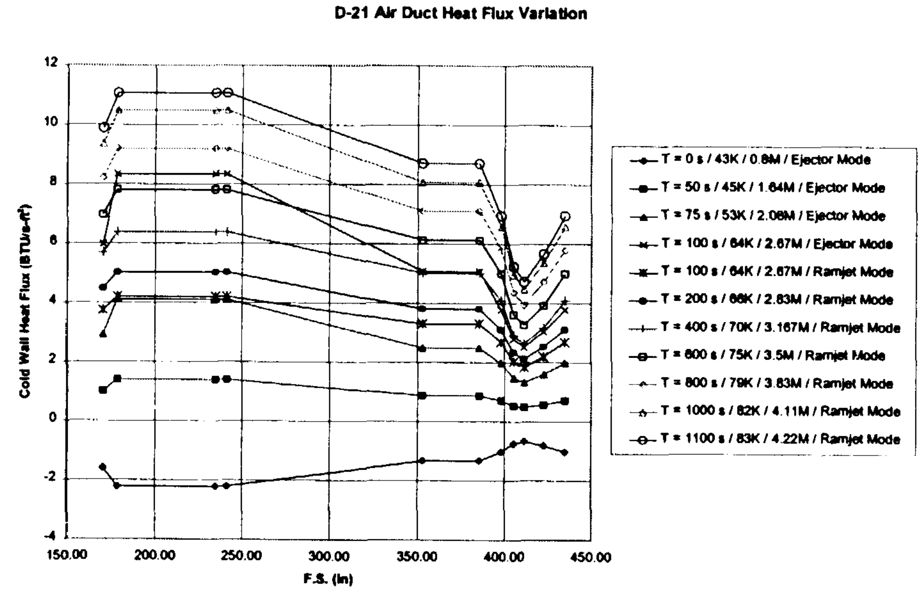
Thermal Loads Assessment: Engine Duct

- Most Critical Element of D-21 for Use at M>3.3 Is the Duct
  - Currently Serves As Fuel Tank Inner Diameter
  - Not Very Removable
  - Not Very Accessible
  - Not Easily Modified (Varying Diameter, Bellows, Stiffeners, Etc...)

- Implementation of Various TPS Materials Was Explored
  - Combination of Long Mission Duration and Lack of Means to Radiate Energy Away From Surface Result in Fairly Thick TPS Requirements
    - TPS Thickness Will Reduce Duct Flow Area (at Least 10%)
    - Application of TPS Would Be a Manufacturing Challenge

Thermal Loads Assessment: Engine Duct (cont'd)





TPS Material	Density (lb/ft^3)	Conductivity (BTU/ft-hr-R)	Specific Heat (BTU/lb-R)	Required Thickness Ave Q (in)	Required Thickness Max Q (in)	Comments
Black Glass	152.9	0.728	0.230	1.01	1.08	
Zirconium Oxide	317.1	0.447	0.11	0.835	0.885	Not realistic thickness
FRCI-12 Tiles	12.0	0.025	0.15	0.610	0.615	
AFRSI Blanket	15.0	0.016	0.177	0.400	0.400	Multiple Use Temp: 1200°F
ACUSIL II	16.0	0.030	0.23	0.575	0.580	Property degradation at T > 900°F

Thermal Loads Assessment Summary

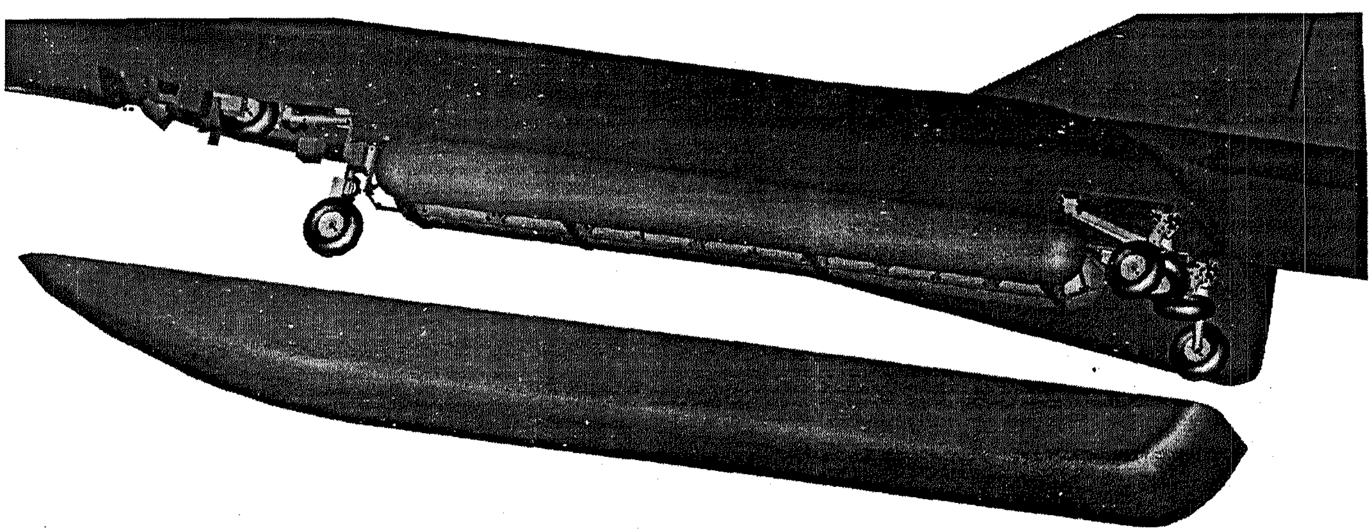
- New or Additional Thermal Protection System (TPS) Will Be Required for RBCC Missions in Excess of M = 3.5
  - May Need New TPS for Reusability Anyway
- Orbital Recommends Coupon Testing of Existing D-21 TPS
  - Characterize Performance and Reuse Capability
- TPS Alternatives for Use up to M = 5.0 Have Been Identified
  - Weight and Thickness Are Very Reasonable (<1000 lb & <1 Inch)
  - 650 q vs 1300 q Missions Had Negligible Impact on TPS Requirements
- Engine Duct Was Identified As Thermally Critical Item
  - Duct TPS Thickness for M>4.0 Will Be Significant (Will Reduce Engine Airflow)
  - Additional Detailed Analysis May Allow for Unmodified Operation to M > 3.3
  - Unmodified Duct Can Still Attain RBCC AAR to R/J Transition Point ("Sweet-Spot")

Vehicle Modification Assessment: External Tanks

- External Tanks Were Sized Using Thin Walls for Peroxide Tanks and Insulated (1" Thick) Walls for LOX Tanks. Tanks Sized at 15 Foot Length to Enable Support From The D-21 Ventral Attachment Points
  - Frontal Area Calculations Used Additional 5" Width and 3" Height to Account for Tank Support Structure and Aerodynamic Fairing

- Aerodynamic Fairing Could Feasibly Be Steel or Titanium Material

- Inclusion of External LOX Tanks and Fairing Seems Very Feasible



Vehicle Modification Assessment: Internal Tanks

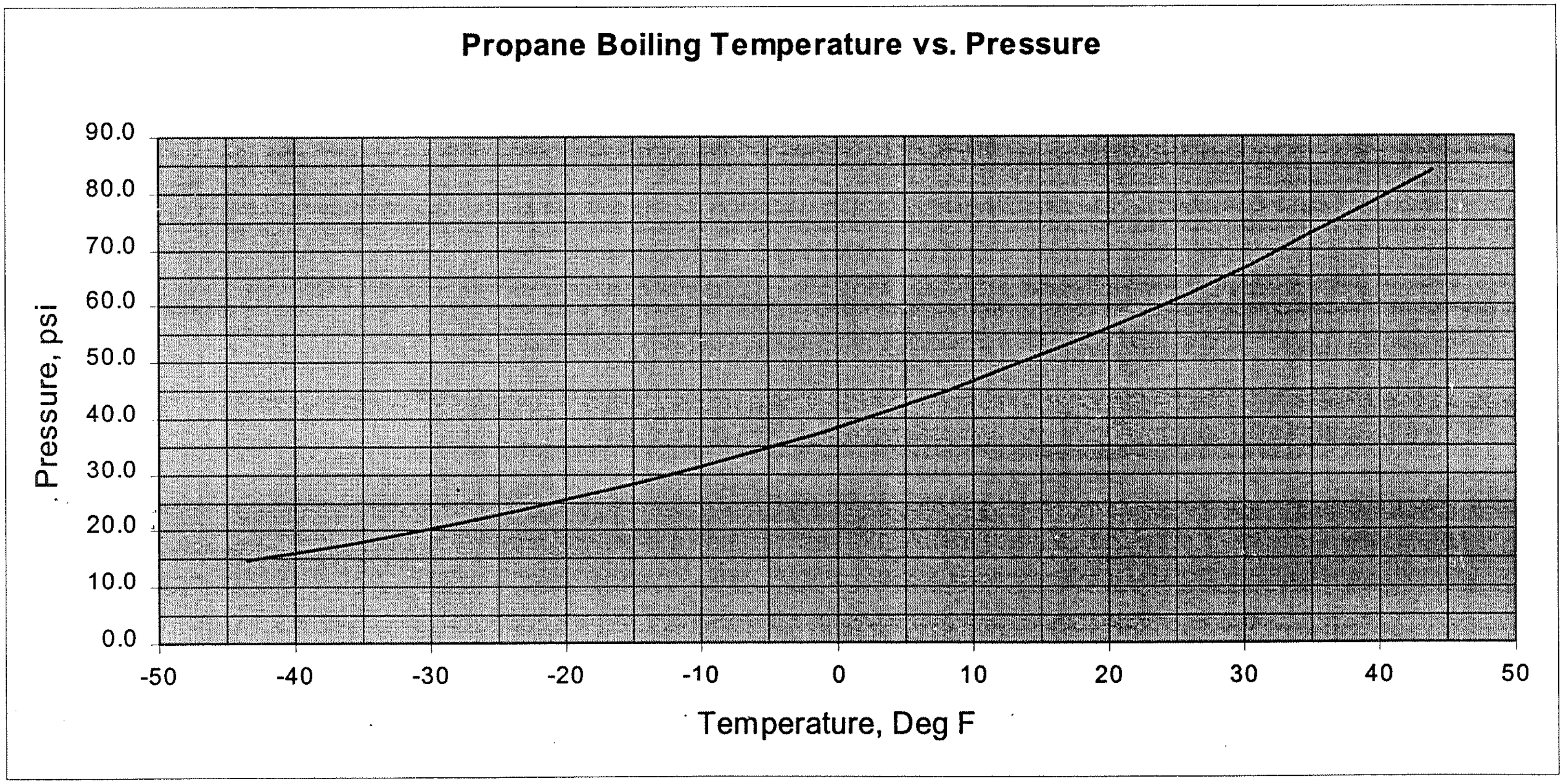
- Compatibility of Existing D-21 Tanks With RBCC Propellants Has Been Evaluated

- Current Tank Material Not Compatible With Hydrogen Peroxide
  - Inclusion of Inert Liner is Possible, But Would Require Vehicle Disassembly
  - Spray-on Material Would Be Most Likely Option Due To Presence of Numerous Stiffeners and Bulkheads
  - May Be Difficult To Ensure 100% Coverage
  - Storing Peroxide in Internal Tanks Doesn't Provide Much Advantage

- Storing LOX in Internal Tanks Would Drive Significant Insulation Requirements
  - Boil-off Losses Would Probably Be Significant
  - Storing LOX in Internal Tanks Doesn't Provide Much Advantage

- Current Tank Material is Compatible With Propane
  - Propane Will Need To Be Kept at Sub-zero Temperatures To Keep Tank Pressures and Boil-off Rates at Acceptable Levels

Vehicle Modification Assessment: Internal Tanks (cont'd)



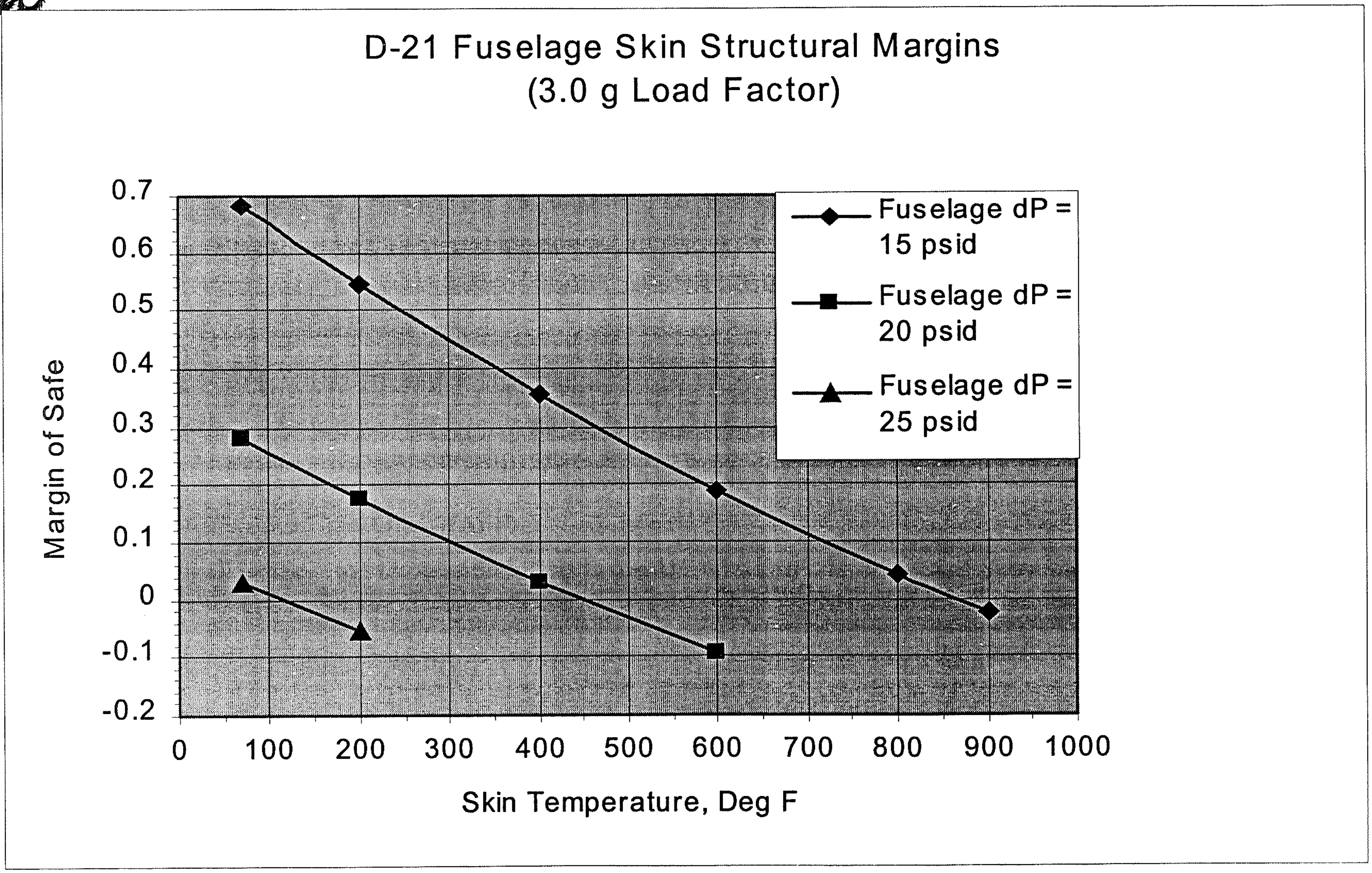
Vehicle Modification Assessment: Internal Tanks (cont'd)

- 30 psi Fuel Tank Pressure Requirement Drives the Tank (i.e. Fuselage Skin and Duct) Design

- Lockheed Stress Report Indicates Maximum Duct Pressure Capability (Crushing) ~ 9 psid
  - Orbital FEA of Outer Duct With Stiffeners Agrees With Lockheed Test Data
    - Non-linear Buckling Analysis Showed Failure @ 8 psid; 560°F
  - Results in Max Tank Pressure ~ 15 psia
    - 3 psi (Inner Duct Pressure @40kft) + 8 psi (N_2 Purge Pressure) + 9 psid - 5 psi (fuel loading)

- Fuselage Skin Limited to 30 psid Per Lockheed Stress Report (With No External Load)
  - Circular Interaction Equation Used to Combine Wing Loads and Tank Pressure Loads to Produce Fuselage Skin Margin of Safety
  - D-21 Tank Pressure ~ 3-5 psia, Which Allowed for Significant Wing Loads

Vehicle Modification Assessment: Internal Tanks (cont'd)



Vehicle Modification Assessment: Internal Tanks (cont'd)

- Conclusion:
  - Current Fuselage Skin and Duct Designs Both Conflict With 30psi Fuel Tank Pressure Requirement
  - Modification of Both of These Structures Would Be Extremely Costly

- Solutions:
  - Reduce Tank Pressure Requirement (May Necessitate a Boost Pump)
  - Build Internal Conformal Tanks

Vehicle Modification Assessment: Internal Tanks (cont'd)

- Internal Conformal Tanks May Be Feasible (Although Inefficient and Costly)

- Requirements:
  - Must Withstand at Least 30 psid
  - Must Hold Enough Fuel to Accomplish the Mission (Need 85% Volumetric Efficiency for Propane; Not an Issue for JP Fuel)

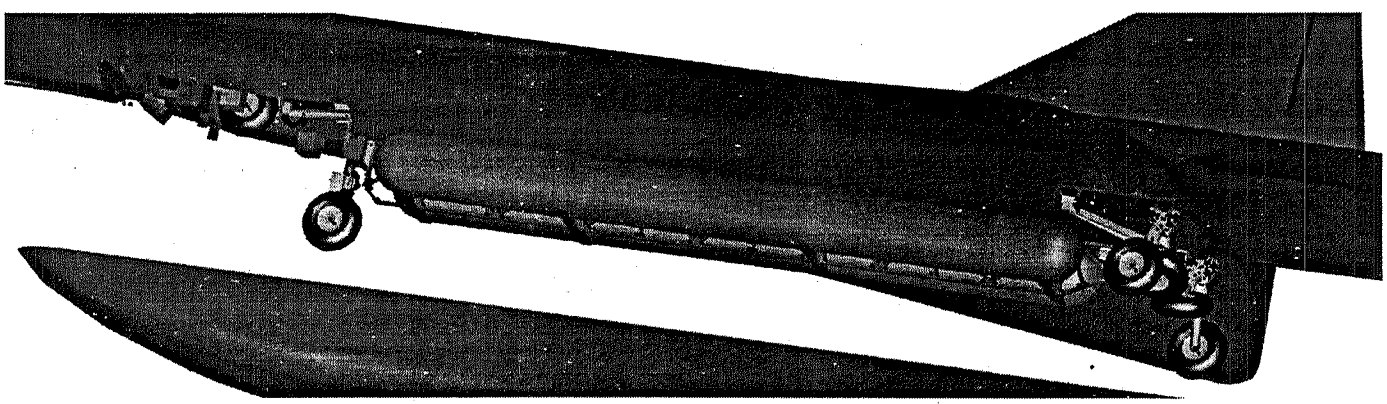
- Constraints Include:
  - Bulkheads Every 12.5 Inches (17 Bulkheads)
  - Non-uniform Duct Diameter and Placement
    - Means Conformal Tank Segments Need to Be Unique to Some Extent
  - Need to Remove and Replace Skins, Verify Sealing, Etc...
  - Will Require Significant Plumbing and Test Verification

Vehicle Modification Assessment: Internal Tanks (cont'd)

- Conclusions
  - Implementation of Internal Conformal Tanks Is Feasible
  - Tank System Weight (Not Optimized) ~ 1400 lbm (0.1" Thick Aluminum; 60 Individual Segments)
    - Propane/LOX Mission Simulations Included Additional 1400 lbm
    - 1400 lbm Weight Impact on Current JP/LOX Simulations Would Be Severe

Vehicle Modification Assessment: Landing Gear

- Cursory Landing Gear Sizing and Attachment Feasibility Were Evaluated
  - Landing Gear Sized Between General Aviation Aircraft (Vehicle Weight ~ 3000 lb.) And X-34, F-5, T-38
  - Landing Gear Assumed to Have Extend Only Capability for Simplicity
  - Landing Gear Attachment Points Were Located at D-21 Fortified Bulkheads
    - Nose Gear at Forward SR-71 Attachment Bulkhead
    - Trailing Gear at D-21 Fwd/Aft Engine Mount Bulkheads
  - Review of Lockheed Stress Analysis Indicates D-21 Fortified Bulkhead Design Loads (~ 4000 lbf in Radial Direction) Are of Similar Magnitude to Expected RBCC Vehicle Landing Loads



Vehicle Modification Assessment Summary

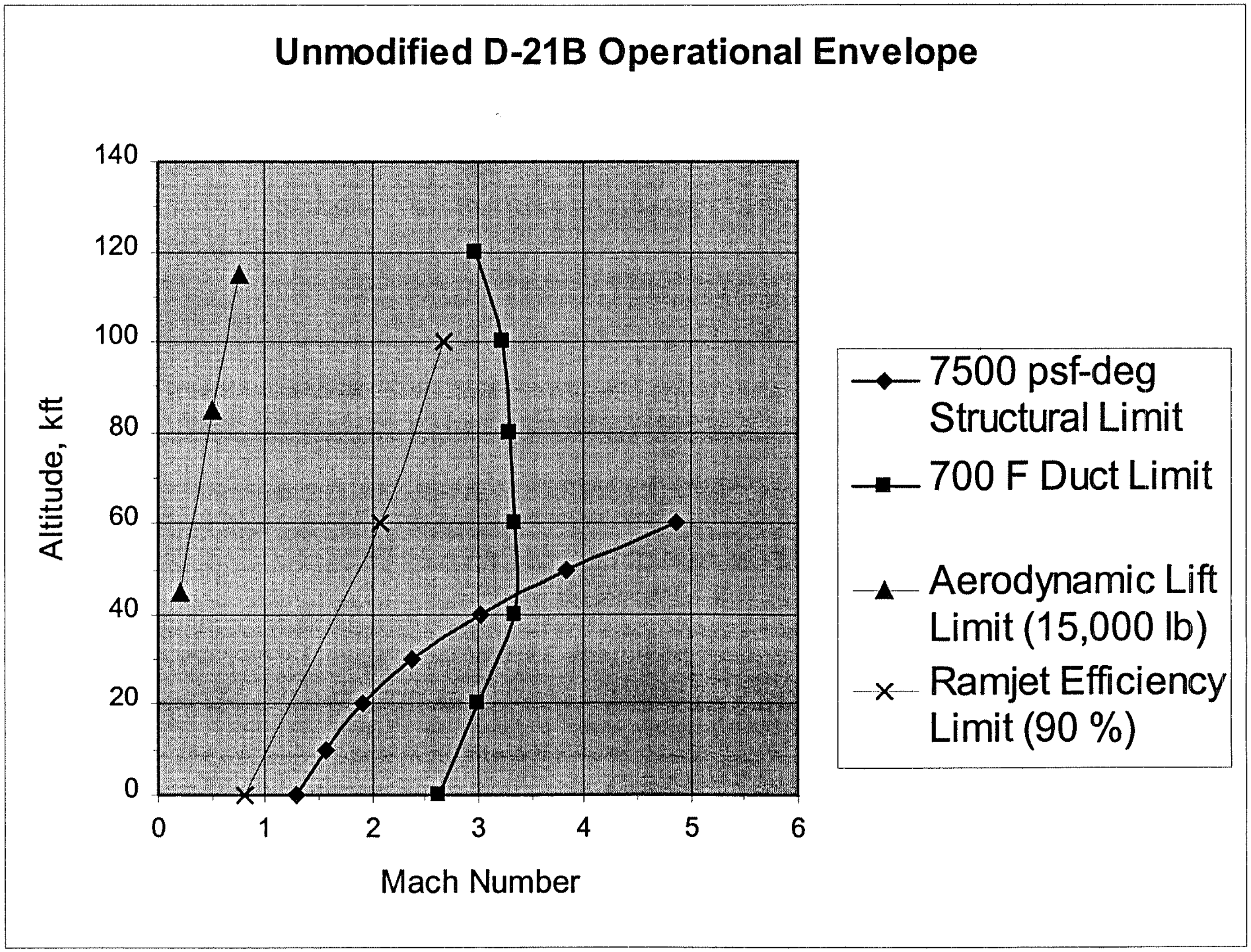
- Feasibility and Sizing of Externally Mounted Tanks (LOX, H_2O_2, Propane) Have Been Evaluated
  - Easily Within Current State-of-the-art for Manufacturing/Integration

- Feasibility and Cost/Weight Ramifications of Adding Internal Conformal Tanks Have Been Evaluated
  - Storing Propane and JP Fuels in Internal Conformal Tanks Is Feasible
  - Will Be Expensive and Will Reduce Overall Vehicle Performance (Added Weight)

- RBCC Propellant Tank Pressure Requirement (30 psi) Is a Significant Design Driver
  - Essentially Eliminates Usability of Existing D-21 Tankage
  - Implementation of Boost Pumps Should Be Considered as an Alternative to Adding Internal Conformal Tanks

- Cursory Landing Gear Sizing Was Conducted
  - No Obvious Off-the-shelf Solution Exists, but Development of Landing Gear Is Not a Significant Technical Hurdle; Vendors Have Indicated ROM Cost ~$200K
  - Landing Gear Loads are Similar to D-21 Fortified Bulkhead Design Loads

Limits On Unmodified D-21B Airframe With RBCC Engine Installed



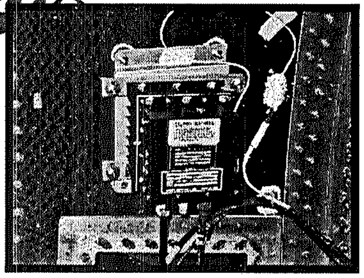
Avionics Requirements

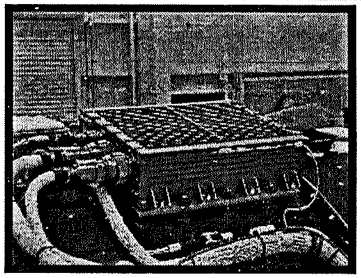
- Maximize use of Orbital Flight Proven Avionics (Pegasus and X-34)
- Autonomous Landing and Guidance Software Derived from X-34
- Redundant Flight Termination System Designed to NASA Dryden Safety Requirements (X-34 Baseline)
- System Redundancy Requirements will Duplicate X-34.
- Flight Control Actuators (Refurbished) from Original D21 Base-lined
- Hydraulic System Pressurized by Electrically Actuated Pumps. Hydraulic System Has Redundant Pumps, Motors, and Batteries.
- System Power Requirements Driven by RBCC Power Requirements (Translating Inlet Cone, Engine Subsystems, etc.)

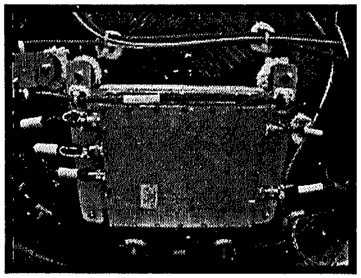
Heritage Flight Proven Avionics From Pegasus And X-34 Programs

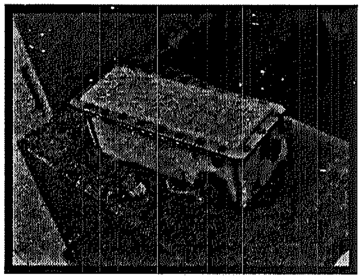
Flight Computer	Pegasus, X-43, X-34
Inertial Navigation System	Pegasus, OSP, X-43, X-34
Differential GPS	X-34
Air Data System	X-34
Flight Termination Receivers	Pegasus, X-43, X-34
Flight Termination Logic Units	Pegasus, OSP, Taurus, X-43, X-34
PCM Transmitter, Antennas & RF Components	Pegasus, OSP, Taurus, X-43, X-34
Telemetry Multiplexer	OSP, Taurus, X-43, X-34
Batteries (Essential, Transient, Hydraulic Pump, Flight Termination, Telemetry)	Pegasus, OSP, Taurus, X-43, X-34
Electrically Actuated Hydraulic Pump	X-34
Valve Actuators	Pegasus

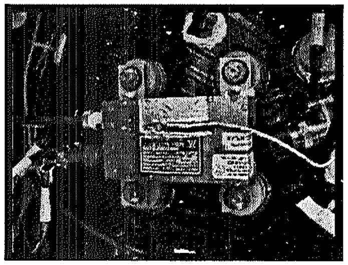
Flight Proven Avionics From Pegasus Program

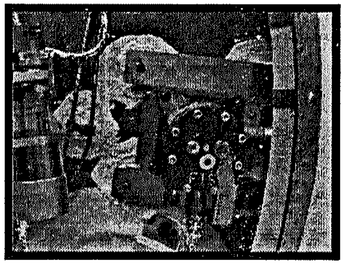

C Band Transponder

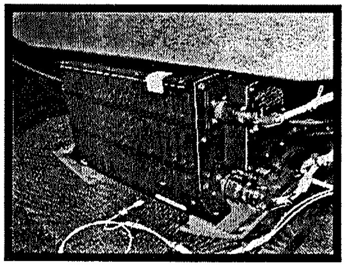

Flight Computer

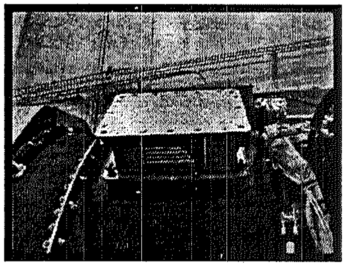

Flight Termination Logic Unit

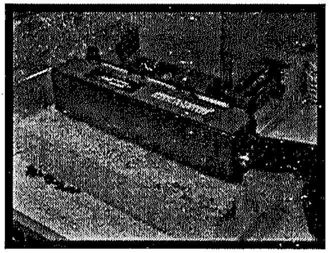

Flight Termination Battery

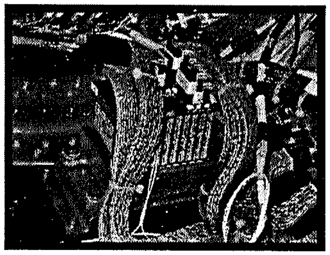

Flight Termination Receiver


Flight Termination Safe & Arm


LN100 INS Unit


Transient Battery


Avionics Battery


Loral Encoder

Avionics Mass, Volume, And Location Estimates

Avionics Mass, Volume, and Location Estimates

Description	Weight (Pounds)	Quantity	Total Weight	Dimensions h - w - L	Heritage	Installation Locatio
Flight Computer (SBS-or)	10.2	1	10.2	10 x 12 x 4	Pegasus	Camera Bay
INS (LN-100)	22	1	22.0	14 x 7 x 8	Pegasus	Camera Bay
Radar Altimeter	4.2	1	4.2	8 x 4 x 4	X-34	Canoe
DGPS Receiver	3.8	2	7.6	6 x 7 x 4	X-34	Camera Bay
Air Data System	5	1	5.0	6 x 8 x 4	NASA	Camera Bay
Transponder	3	1	3.0	5 x 5 x 3	Pegasus	Camera Bay
Flight Termination Logic Unit	4.5	2	9.0	9 x 8 x 3	Pegasus	Camera Bay
Flight Termination Receivers	0.5	2	1.0	3 x 4 x 1	Pegasus	Camera Bay
Safe & Arms	4.6	4	18.4	6 x 6 x 5	Pegasus	Two in Camera Bay, two in Can
FTS Bus Battery	5	2	10.0	6 x 8 x 3	Pegasus	Camera Bay
PCM Transmitter	2	2	4.0	2 x 3 x 1	X-34	Camera Bay
Multiplexers	3	2	6.0	6 x 4 x 3	X-34	At engine & in the Camera bay
Mux Transducers	0.05	250	12.5	1 x 1 x 1	X-34	Distributed throughout the vehicl
Camera Controller	5	1	5.0	6 x 8 x 3	Pegasus	Camera Bay
Camera	1	2	2.0	2 x 2 x 8	Pegasus	In canoe: one fwd & one side vi
Antennae, couplers, dividers	0.1	10	1.0	1 x 2 x 2	Pegasus	Camera Bay
Mechanical Hydraulic Pump	20	2	40.0	8 x 8 x 6	X-34	Installed in the canoe
Hydraulic Pump Controller	20	2	40.0	8 x 12 x 14	X-34	Installed in the canoe
HTDU (Valve Driver)	3.5	2	7.0	5 x 5 x 3	Pegasus	Camera Bay
PDU	2.7	2	5.4	7 x 5 x 3	Pegasus	Camera Bay
Engine Control Unit	10	1	10.0	5 x 5 x 3	DRACO	Camera Bay
Heaters / Thermostats	0.1	10	1.0	na	DRACO	Various locations
Valves /Solenoids	1	8	8.0	na	DRACO	Installed on the engine
Switches / Relays	1	8	8.0	na	DRACO	Installed on the engine
Drogue Controller	0.5	1	0.5	2 x 2 x1	DRACO	Canoe
Cover Controller	0.5	1	0.5	2 x 2 x 1	DRACO	Canoe
Connector	0.2	130	26.0	1 x 1 x 1	Pegasus	Througout vehicle
Harnesses	20	1	20.0	na	Pegasus	Througout vehicle
Essential Bus Battery	11	1	11.0	4 x 18 x 4	Pegasus	Camera Bay
Pump Bus Battery	29	10	290.0	7 x 9 x 7	X-34	Canoe
Battery Interface Unit	8	1	8.0	4 x 8 x 9	X-34	Canoe
Telemetry Bus Battery	11	1	11.0	4 x 18 x 4	Pegasus	Camera Bay
Transient Bus Battery	5	1	5.0	8 x 5 x 3	Pegasus	Camera Bay
Power Transfer Switch	2.8	1	2.8	5 x 5 x 3	Pegasus	Camera Bay
Total Avionics Weight:			615.1	pounds		

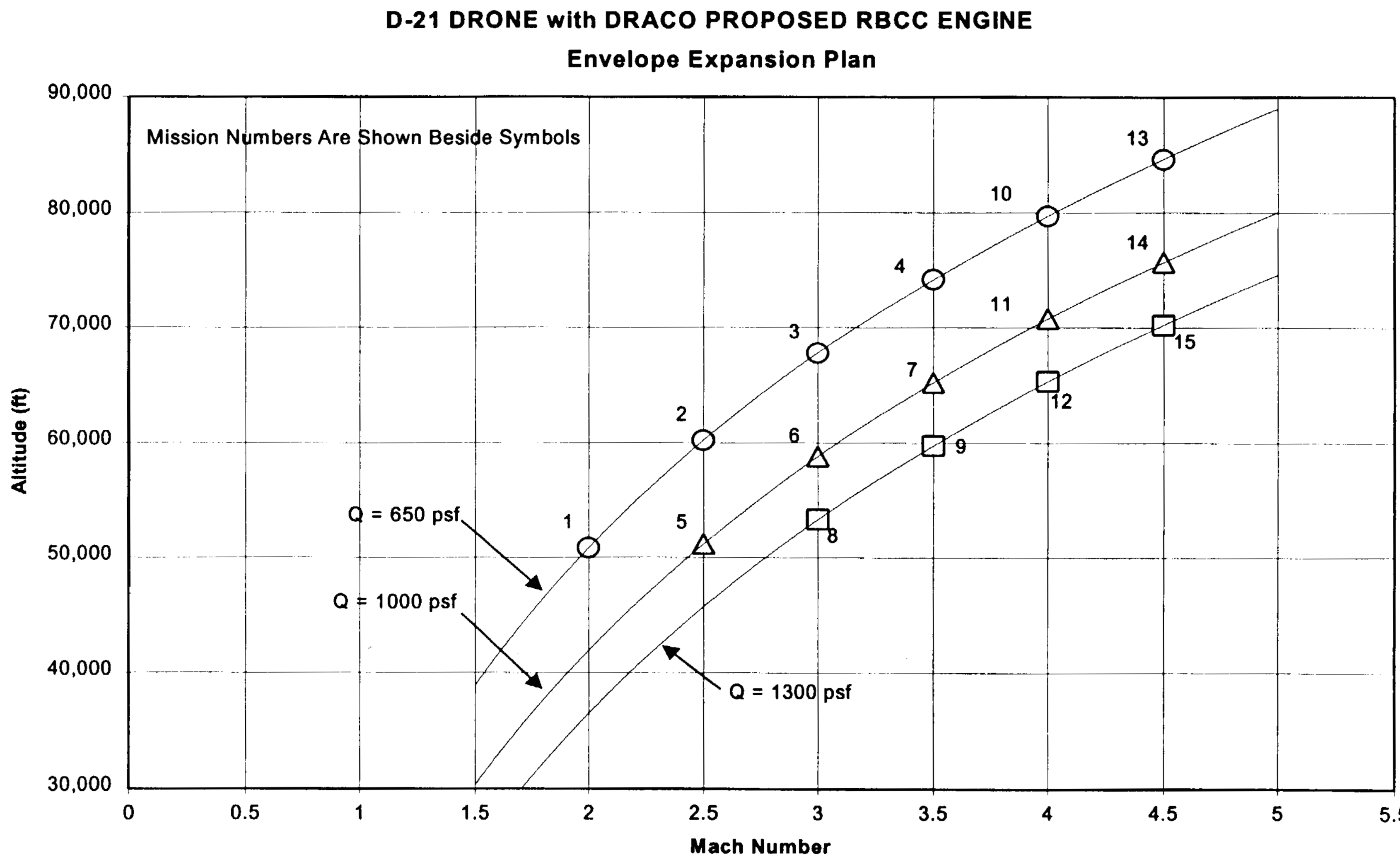
Power System Requirements

- Design Reference Missions for Power System Sizing: 40 Minutes
  - 5 Minutes of Systems Test (Ground Testing)
  - 5 Minutes of Internal Power Prior to Drop
  - 15 Minutes of Powered Flight
  - 10 Minutes Coast and Landing
  - 5 Minutes Post Landing
- Power Requirements for RBCC Engine Provided by NASA
  - 15 KW Peak, 5 KW Average
  - Primary Driver of Power System Sizing
- Power System Options Evaluated
  - Battery Powered Avionics, Telemetry, Hydraulic Pumps and Flight Termination Systems
  - Use Existing D21 APU for Power And Batteries For FTS
  - Use Allied Signal Hydrazine Power APU to Provide Power Independent of Batteries or Air Driven Systems

DRACO Test Program Summary

Test Description	Duration	# of Flts	Vehicle Performance / Comments
Low Speed W/T	3 Mo		Validate Approach & Touchdown Speeds, AOAs, And B-52 Separation Aerodynamics
Leading Edge Thermal	3 Mo		Evaluate Capability Of Existing Edges Or New Edges
Fuel Tank Press	1 Mo		Evaluate Pressure Capability Vs Boost Pump Requirement
DFRC Simulator	9 Mo		Evaluate Autoland System & Fly Trajectories
Ground Vibration (GVT)	1 Mo		
Control Surface Proof	1 Mo		Test For Higher Dynamic Pressure Requirement
Integrated Systems C/O	2 Mo		
High Speed Tow	1 Mo		Incorporate Lessons Learned From X-34 Tow Tests
"Box Drop"	1 Mo		Ground Functional Test Of Separation Mechanisms
Captive Carry Flights	3 Mo	5	Drag Verification For Separation Analysis; Propellant Dump; Range /TM Checks; LOX Top-off; Mated Handling Qualities
Unpowered ALT	3 Mo	5	Drop At: 15, 20, 30, 35, 40 Kft
RBCC Envelope Exp: Q=650	6Mo	6	M= 2.0, 2.5, 3.0, 3.5, 4.0, 4.5
Q=1,000	3 Mo	5	M= 2.5, 3.0, 3.5, 4.0, 4.5
Q=1,300	3Mo	4	M= 3.0, 3.5, 4.0, 4.5
Total	48Mo	25	Plan On 50% To 100% Increase In Flight Number Count For Systems Problems, Range Aborts, Etc

DRACO D-21 / RBCC Flight Test Envelope Expansion Plan



Phase 3: Pre RBCC Install Tests

- Vehicle Configuration / Location: Ready For Flight Minus RBCC Engine / NASA DFRC

- Tasks:

1) Ground Vibration Tests On D-21 And Mated With B-52
2) Control Surface Proof Loads Testing
3) Hardware-In-The-Loop Tests With DFRC Simulator
4) High Speed Tow Test Simulations Of Landing Rollout And Braking System
5) Integrated Systems Check-out On Wing Of B-52
6) "Box-Drop" Ground Separation Testing
7) B-52 Captive Carry Flight Tests Including LOX Top-off And Propellant Dump (5 Flts)
8) Unpowered Approach And Landing Tests (5 Flts)
10) Engineering Analysis Support At Chandler & Dulles
11) 10 B-52 & F-18 flts X $60,000 Per 2 Hr Flt = $600,000 X1.5 Reserve
12) Other Materials & Misc Support Equipment Requirements

•Phase Duration: 12 Months

Phase 4: RBCC Powered Flight Tests

- Vehicle Configuration / Location: Full-up RBCC Configuration At NASA DFRC

- Tasks:

0) RBCC Installed Ground Engine Runs - Ejectror Mode Only (3 Months)

1) 6 Envelope Expansion Flights At Q=650 psf ; M = 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

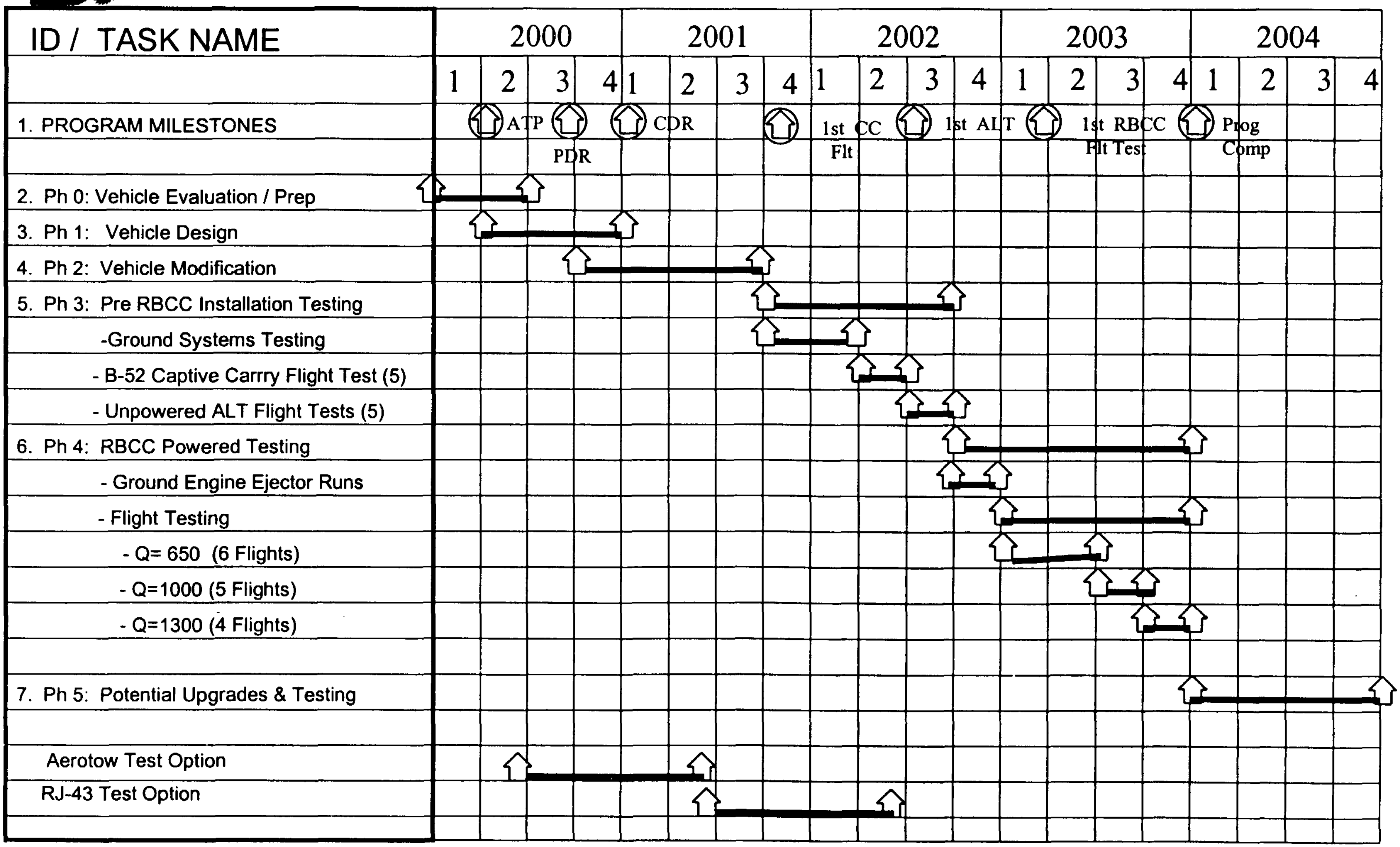
2) 5 Envelope Expansion Flights At Q=1000 psf; M = 2.5, 3.0, 3.5, 4.0, 4.5

3) 4 Envelope Expansion Flights At Q=1300 psf; M = 3.0, 3.5, 4.0, 4.5

4) 15 B-52 & F-18 flts X $60K Per 2 Hr Flt = $900,000 X 1.5 Reserve = $1.35M

•Duration: 15 Months

D-21B RBCC Modification And Flight Test Schedule



Phase 0: Vehicle Evaluation / Preparation

- Vehicle Configuration / Location: As Is / OSC Chandler Or NASA DFRC

- Tasks:

1) Asbestos Removal - OSC Subcontractor
2) Vehicle Disassembly / Inventory & Component Refurb Analysis
3) JP Tank Pressure Tests
4) Mock-up: Landing Gear, Canoe, LOX Tank, Variable Inlet Installations
5) Leading Edge TPS Evaluation In Thermal Test Chambers (Ames Assist)
6) Low Speed Wind Tunnel Tests - Landing (Langley Assist)
7) Weight& Balance -(Dryden Assist)
8) Vehicle Measurements For CAD And Aero Models - Theodolite
9) Lockheed Martin Drawing And Tech Database Evaluation
10) Formalize DFRC Interest In Unmanned Aerotow & Unpowered Approach And Landing Test Program, As Well As USAF Interest For Future Strike A/C Weapons Separation Demo

- Phase Duration: 6 Months

Phase 1: Vehicle Design

- Vehicle Configuration / Location: Cleaned & Prepped For Mod / OSC Chandler Or NASA DFRC
- Tasks:

1) B-52 Interface: Pylon/Adaptor, LOX Top-off, Launch Ops Station Design - DFRC Assist
1a) Evaluate Aerotow Approach For ALT Testing With DFRC Assistance
2) Systems Installation Design Using Components From D-21, X-34, Pegasus, And Others
3) Landing Gear and Fairing / Door Designs
4) LOX , H202, And / Or Propane Tank and Support Structure Design
5) " Canoe" Fairing And Support Structure Design
6) Propulsion Integration Design For DRACO RBCC Engine, Variable Inlet, And Support Systems - MSFC Assist
7) Thermal Protection System Design Utilizing Existing Sys From X-34 Etc- Ames Assist
8) Flight Control & Guidance Software & Simulations - DFRC Assist
9) Begin Flight Test and Vehicle Operations / Facilities Planning
10) Wind Tunnel Test Final Vehicle Configuration

- Phase Duration: 9 Months (Overlaps With First 3 Months Of Mod Period)

Phase 2: Vehicle Modification

- Vehicle Configuration / Location: OSC Chandler Or NASA DFRC

- Tasks:

1) Fabricate And Assemble Vehicle Assembly Tool
2) Fabricate "Canoe" Fairing And Support Structure
3) Fab And/Or Assemble Landing Gear Components
4) Purchase Or Fab LOX Tanks
5) Refurbish Existing D-21 Systems To Be Re-used (If Any): FCS Actuators, APU, etc
6) Purchase Systems From X-34, Pegasus, And Others: Avx, FCS, Batteries, Fab Wire Harnesses etc
7) Purchase And Install Thermal Protection System Blankets
8) Fab And Assemble B-52 Pylon And/Or Adaptor: Utilize Pegasus Or X-38 If Possible
9) Install And Check-out Systems
10) Fab And Install RBCC Engine Mock-up For Ballast, Base Drag Simulation, & Interface Checks

- Phase Duration: 12 months

Phase 3: Pre RBCC Install Tests

- Vehicle Configuration / Location: Ready For Flight Minus RBCC Engine / NASA DFRC

- Tasks:

1) Ground Vibration Tests On D-21 And Mated With B-52
2) Control Surface Proof Loads Testing
3) Hardware-In-The-Loop Tests With DFRC Simulator
4) High Speed Tow Test Simulations Of Landing Rollout And Braking System
5) Integrated Systems Check-out On Wing Of B-52
6) "Box-Drop" Ground Separation Testing
7) B-52 Captive Carry Flight Tests Including LOX Top-off And Propellant Dump (5 Flts)
8) Unpowered Approach And Landing Tests (5 Flts)
10) Engineering Analysis Support At Chandler & Dulles
11) 10 B-52 & F-18 flts X $60,000 Per 2 Hr Flt = $600,000 X1.5 Reserve
12) Other Materials & Misc Support Equipment Requirements

•Phase Duration: 12 Months

Phase 4: RBCC Powered Flight Tests

- Vehicle Configuration / Location: Full-up RBCC Configuration At NASA DFRC

- Tasks:

0) RBCC Installed Ground Engine Runs - Ejector Mode Only (3 Months)

1) 6 Envelope Expansion Flights At Q=650 psf ; M = 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

2) 5 Envelope Expansion Flights At Q=1000 psf; M = 2.5, 3.0, 3.5, 4.0, 4.5

3) 4 Envelope Expansion Flights At Q=1300 psf; M = 3.0, 3.5, 4.0, 4.5

4) 15 B-52 & F-18 flts X $60K Per 2 Hr Flt = $900,000 X 1.5 Reserve = $1.35M

- Duration: 15 Months

Phase 5: Potential Upgrades To Test-bed

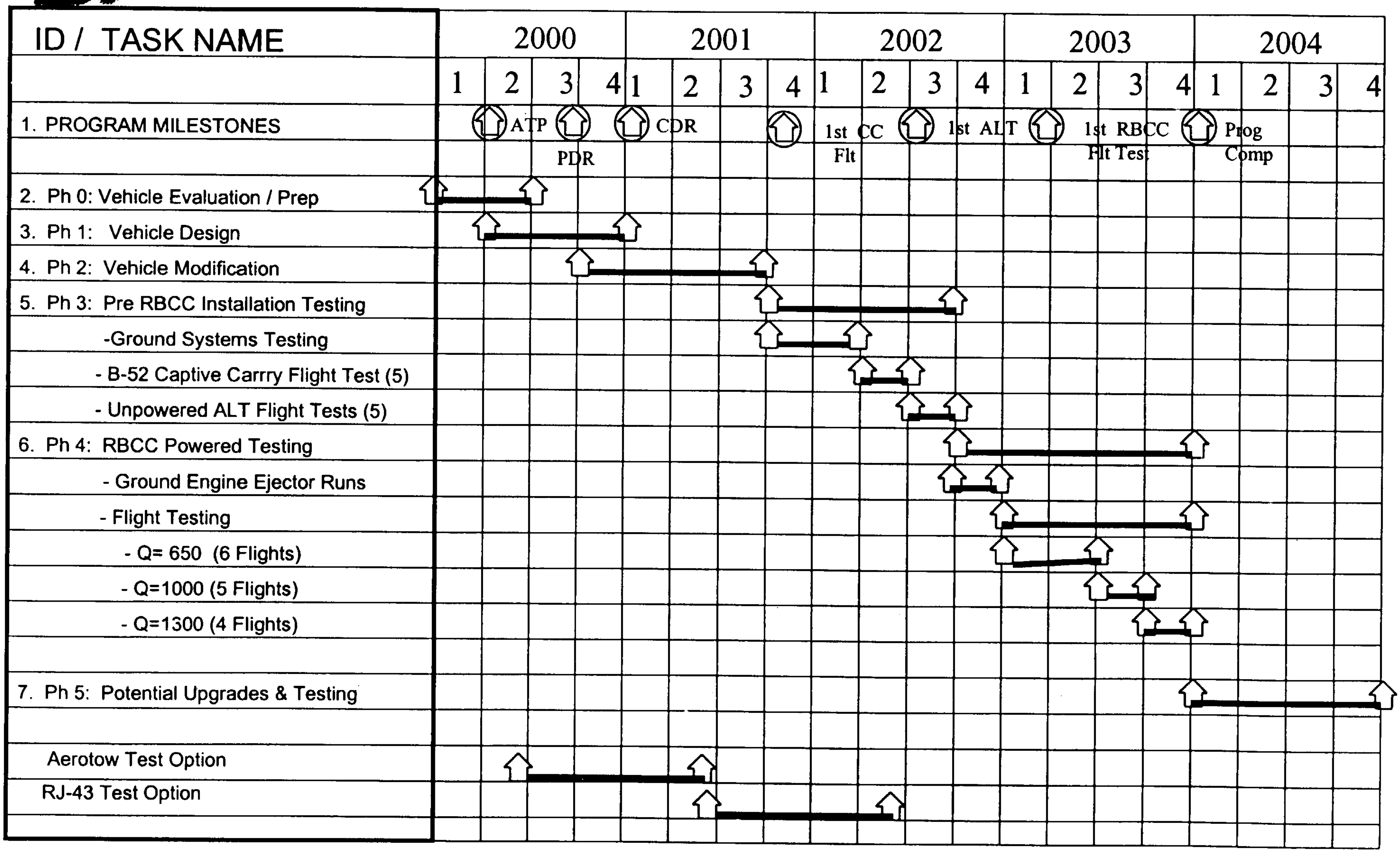
- Vehicle Configuration / Location: Full-up RBCC Configuration At NASA DFRC

- Tasks:

1) Alternate Propellant Conversions
2) RBCC Engine Modifications And Performance Enhancements
3) Solid Rocket Boost Upgrade For Testing RBCC At Higher Mach Numbers
4) Landing Gear Upgrade For Runway Take-off Demonstration
5) TPS Upgrades For Higher Sustained Q And Skin Temperatures
6) Inlet Duct Upgrade For Longer Test Times At Higher Dynamic Pressures
7) Mach 3+ Weapons Separation Demo For USAF FSA Customer
8) Bantam Class Upper Stage Demo Separation

- Issues / Comments: Allows Other Interested Potential Customers To Contribute To Program Funding And Development If NASA Desires

D-21B RBCC Modification And Flight Test Schedule



DRACO D-21 Modification Program
Phased ROM Cost Estimate

Phase	Description	Duration * (Months)	Location	ROM
0	Vehicle Evaluation/Preparation	6	Chandler/DFRC	$1.7M
1	Vehicle Design	9	Chandler/Dulles	$4.3M
2	Vehicle Modification	12	Chandler/DFRC	$6.0M
3	Pre RBCC Testing	12	DFRC	$7.9M
4	RBCC Flight Tests	15	DFRC	$7M
	Total Program	48		$26.8M

* Note: Some Durations Overlap

ROM Pricing Methodology

- The Individual Tasks in each Phase Were Priced by Developing Basis of Estimates including Orbital Manpower, Material, Subcontracts and Travel
- Man Hours at an Average Rate were then Factored for Program Management and Business Operations Support.
- Material and Subcontracts were Factored by an Approximate G&A Rate and a ROM Factor
- Total Cost is the Sum of Labor and Material, Travel, and Subcontracts
- Phase 2, 3, and 4 are Escalated at 5% Per Year to Achieve "Then Year" Dollars

Pricing Reasonableness Tests

- The Pricing of Individual Tasks were Compared with Similar Tasks on Pegasus and Taurus Missions

- The Overall D21B Modification Program was then Compared with the Hyper-X Booster Program
  - Man Hours Are very Similar For Comparable Tasks And Phases
  - Certain Materials and Subcontracts Compared Closely in Pricing Estimates

- Hyper-X Booster and D21B have many Technical Similarities
  - Both Vehicles are NOT Clean Sheet Vehicles but are a Substantial Modification to Existing Vehicles
  - Both Vehicles have Similar Flight Envelopes and are Air Dropped from a B-52
  - Both Vehicles have Similar Levels of System Redundancy

Conclusions

- Orbital Believes That The D21B Airframe Represents A Feasible Low Cost Airframe That Is Applicable To A Large Portion Of The DRACO RBCC Engine Test Requirement
- As Expected, The Amount Of Modification Is Directly Related To The Maximum Mach Number Required (Inlet Duct And Airframe Skin Temperature Issues).
- Breakpoints In Modification Costs Correlate To Specific Limitations In The D-21:
  - Assuming The Inlet Is Modified With A Translating Cone, The Basic Airframe Does Not Have Limits Below M=3.5
  - Between M=3.5 And Approximately M=4.0, The Vehicle Is Limited by Duct Aero-heating. The Duct Heating Issue May Be Resolvable With Upgrades Such As Liners, Coatings, Or Duct Wall Material Changes
  - The Airframe Is Limited To Approximately M=6 By Aerodynamic Loads

Conclusions (Continued)

- Orbital Believes The Best Performance-Cost Trade Limits The Vehicle To Less Than M=4
- A Phased Approach Is The Lowest Risk And Most Cost Effective Approach To Obtaining An RBCC Test-bed For NASA. This Approach Reduces Schedule, Cost, And Technical Risk By Completing Smaller And Less Expensive Phases Before Proceeding To The Next Phase.
- More Detailed Design And Cost Estimation Can Not Be Determined Without Further Disassembly Of The D21B Airframe And / Or Access To The Lockheed Martin Drawings And Technical Database, Plus Additional Time And Funding

Conclusions (Continued)

- LOX/Propane Is Only A Feasible Propellant Combination For Use On The D-21B If The Propane Tanks Can Be "Submerged" Within The Mold Line Of The Old JP Tanks
  (This Mod Would Require Substantially More Cost And Technical Risk)

- JP/H202 Is Not Only A Feasible Propellant Combination For The D-21B With An RBCC Engine But Has Several Distinct Advantages Including:
  - Elimination Of The Cryo Tank Requirement And Associated Operational Issues
  - Elimination Of The 25% Boil-off Penalty Used With LOX
  - Allows The Use Of Efficient Conformal Tank Designs

  * Note: Availability Of High Concentration H2O2 May Be An Issue

- NASA B-52 (008) Air-Launch Is The Preferred Launch Approach For The Modified D-21B For The Following Reasons:
  - Known D-21B/B-52 Separation Characteristics From Prior USAF Operations
  - Extensive Similar B-52 (008) Air-Launch Experience With X-15, Lifting Bodies, Pegasus, Hyper-X, And X-38
  - Maximizes The Envelope Expansion Opportunities With The RBCC Engine
  - Reduces Risk To Test Program By Allowing A Phased Approach To Envelope Expansion: Unpowered Approach And Landing First Etc. . .
  - In Flight LOX Top-Off Precedent Set With X-15

Conclusions (Continued)

- Runway Landing On Wheeled Landing Gear Is The Preferred Recovery Technique For The Following Reasons:
  - Approach And Landing Speeds Are Reasonable (140 Kts; Lower Than X-34)
  - AOA Will Be Less Than 10 Degrees With A 1.3 Factor Of Safety
  - The Vehicle Is Unstable In Pitch At Subsonic Air Speeds; There Are Several Methods Available To Address This Design Issue When Funding Permits
  - Turn-around Time Between Flights Will Be Reduced And Maximizes The Demonstration Potential Of RBCC Engine Operation For NASA

- Existing Inlet Duct Configuration Presents Minor Reductions Of Air Augmentation In Ejector Mode

- D-21B / RBCC Modification Can Maximize The Use Of Existing Systems And Expertise From Other Orbital Sciences Hypersonic Vehicles Including X-34, Pegasus, And Hyper-X. This Saves NASA A Substantial Amount Of Research Dollars And Also Reduces Risk To The Program Through The Use Of Flight Proven Hardware And Software.

Opportunities For NASA Participation And Cost Reduction

- ROM Cost Estimates Were Developed Conservatively Without Regard To Possible Scope That Could Be Accomplished By NASA Personnel And Facilities

- Phase 0: Vehicle Evaluation And Preparation
  - NASA Ames: Perform Testing Of Existing D-21 TPS
  - NASA Langley: Perform Low Speed Wind Tunnel Testing Necessary To Establish Runway Landing Performance
- Phase1: Vehicle Design
  - NASA Marshall: Assist In Engine And Variable Inlet Integration Design
  - NASA Dryden:
    - Design B-52 Mechanical And Electrical Interfaces Including LOX Transfer System
    - Develop "Hardware-In-The-Loop" Simulation
    - Develop Aerotow Launch Option For ALT Tests
  - NASA Ames: Assist In TPS Selection And Installation Design
  - NASA Langley: Perform Wind Tunnel Tests On Final Design Configuration
- Phase 2: Vehicle Modification
  - NASA Dryden: Fab & Install B-52 Interface Hardware
- Phases 3 & 4: Ground And Flight Tests
  - NASA Dryden: Provide B-52 Air Launch Service And Flight Ops Support

Applicable Orbital Experience

- Hypersonic Aerodynamics, Instrumentation, Flight Controls, and Airframe Design and Analysis
- Air Launch Operations from the NASA B-52-008.
- Thermal Protection System Design, Development, and Integration.
- Availability of Flight Proven Subsystem Designs From Pegasus, X-34, and Hyper-X Booster. These Design and Pedigree of these Systems have been Reviewed by NASA KSC Flight Assurance as Part of the SELVS Program.
- Familiarity with Ground and Flight Operations at NASA Dryden. At least Two Other Orbital Programs will be in Flight Test at Dryden in 2000 and 2001 (X-34 and Hyper-X Booster).
- Orbital's Extensive Experience with reuse of Existing Government Assets on our Sub-orbital Launch Vehicle Programs Provides a Unique Capability to Assess Poorly Documented and Sometimes Poorly Maintained Assets. Examples Include Reuse of Minuteman I and II, Sergeant, Talos, Terrier, etc.

Orbital Is NASA's Best Choice To Perform the D21B Modification

- Orbital has the Advantage of Four years worth of Northrop Grumman Studies on D21 Test-bed Modifications. Orbital and Northrop Have Invested Significant Internal Funding on This Concept.

- Orbital's D21 Test-bed Can Take Advantage of X-34 Systems already developed with MSFC Funding. Air Launch, Common Hardware and Software, Runway Landing, and Thermal Protection Systems are Examples of the Synergy Between D21, X-34, and Pegasus. This Provides the Lowest Cost and Risk Approach To NASA.

- Orbital Will Perform the D21 Modification Within the Launch Systems Group, Ensuring that X-34 Manpower and Schedules are Not Impacted by The D21 Modification.

- Orbital's Hyper-X Booster is a Useful "Pathfinder" for D21 Air Launch Operations.

- Orbital's Performance And Cost Effectiveness On X-34 And Hyper-X Are Convincing Proof That NASA Will Get Value For Its Dollars Spent On DRACO Test-bed Development

- Orbital is Developing Alternative Uses and Funding Sources for the D21 Test-bed

- This Product Fits with Orbital's Strategic Plan for Future Products.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	25 Oct 1999	Final

4. TITLE AND SUBTITLE
D-21 RBCC Modification Feasibility Study Final Report

5. FUNDING NUMBERS
C
MSFC PO# H-31404D

6. AUTHORS
Orbital Sciences Corporation
Launch Systems Group

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Orbital Sciences Corporation
Launch Systems Group
21700 Atlantic Blvd.
Dulles Va. 20166

8. PERFORMING ORGANIZATION REPORT NUMBER
TM-15296

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Study on the Modifications Required to Reengine the Lockheed D-21 Drone for NASA RBCC Engine.

14. SUBJECT TERMS
D-21 Modifications

15. NUMBER OF PAGES
127

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	