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VEHICLE/ENGINE INTEGRATION

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As a systems integrator, Boeing recognizes that the main propulsion system has a profound affect on vehicle development cost and schedule. Significant engine weight growth or unplanned changes in performance capability have important implications in vehicle design and mission capture.

Agreement is needed on man-rating requirements as these will greatly affect vehicle/engine integration. As a minimum, elimination of all single point failures requires re-examination of aeroassist concepts which require large, retractable engine nozzles. Placing the nozzles behind the heat shield moves large deployed payloads in front of the shield-making P/L return impossible. The manned transfer cab is small enough to either fit behind the unmanned aeroassist device or have a kittable heat shield, depending on aeroassist concept. Preliminary reliability analyses indicate that a single engine is unable to meet manned mission reliability goals. An increase in the number of engines corresponds to a decrease in performance and an increase in maintenance requirements. Performance analyses currently show a 5000 to 7000 lb engine thrust range as optimum; however, the cost analysis is expected to move the optimum to a level above 7000 lbs. The high cost of space based maintenance may have the dual effect of increasing the thrust level, and derating the engine components to reduce the amount of engine maintenance required.

VEHICLE/ENGINE INTEGRATION ISSUES

Q. FROM A PRIME CONTRACTOR STANDPOINT WHAT ARE KEY VEHICLE/ENGINE INTEGRATION ISSUES?

- IMPACT OF ENGINE INTEGRATION ON CONFIGURATION DEVELOPMENT (DEVELOPMENT TIME, DDT&E, AND PERFORMANCE).
- IMPACT ON MAN RATING AND MISSION RELIABILITY (OPERATING COST).

Q. HOW DOES SPACE BASING IMPACT VEHICLE/ENGINE INTEGRATION?

- MODULARIZE ENGINE INSTALLATION AND/OR CRITICAL COMPONENTS TO ALLOW EFFECTIVE ON ORBIT SERVICING.
- HIGH SERVICING COSTS (~ $20,000/HR) MAKES DERATING ENGINE FOR LONG SERVICE - FREE LIFE ATTRACTIVE.

Q. HOW DOES AEROASSIST IMPACT VEHICLE/ENGINE INTEGRATION?

- ENGINE NOZZLE RETRACTION REQUIREMENT INTRODUCES SINGLE-POINT FAILURE MODES.
- LARGE, HIGH EXPANSION RATIO ENGINES DIFFICULT TO SHIELD FROM FREE STREAM FLOW.

Figure 1

EFFECT OF ENGINE RELIABILITY ON SYSTEM RELIABILITY

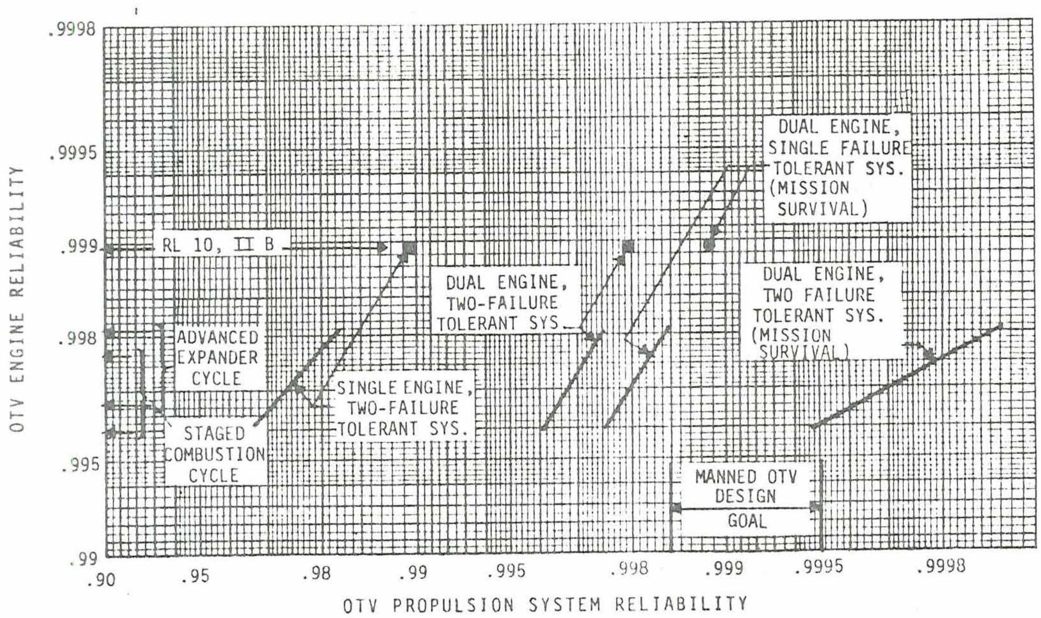

Figure 2

Fresh Look Lifting Brake Designed for Space Assembly

- COMBINE BEST FEATURES OF LIFTING BRAKE & AMOTV TO INCREASE L/D AND REDUCE SCAR WEIGHT
- SPACE ASSEMBLED PREFABRICATED COMPOSITE PANELS
- RIGID OR FABRIC REUSABLE TPS
- LARGE PLANFORM AREA REDUCES TEMPERATURES
- NO IMPINGEMENT PROBLEM

- STS COMPATIBLE OTV MOUNTED USING SHUTTLE FIXTURES
- OTV CAN BE EITHER GROUND BASED OR SPACE BASED
- NO NOZZLE RETRACTION REQUIRED
- GROSS TRIM ACCOMPLISHED BY SLIDING OTV ON RAILS
- CONTROL WITH AERODYNAMIC SURFACES & RCS

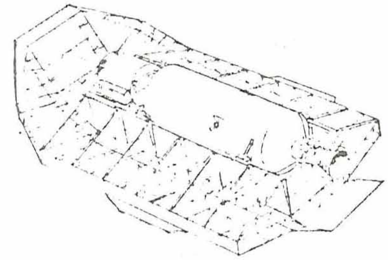

Figure 3

PRELIMINARY RESULTS OF VEHICLE/ENGINE INTEGRATION STUDY

- DUAL ENGINE INSTALLATIONS FAVORED
  - RELIABILITY VS. OPERATING COSTS

- ENGINES IN 7000 LB + TO 15000 LB + SIZE RANGE CURRENTLY FAVORED
  - FUNCTION OF HIGH EXPANSION RATIO NOZZLE EFFECTIVENESS
  - ENGINE DERATING WILL INFLUENCE SIZING TRADE
  - AVERAGE MISSION COST WILL BE SELECTION CRITERIA

- NON RETRACTABLE NOZZLES FAVORED FOR MAN RATING & MISSION RELIABILITY
  - PUTS PAYLOAD IN FRONT OF HEAT SHIELD
  - TREAT MANNED MISSIONS AS UNIQUE AND INTEGRATE HEAT SHIELD WITH MANNED MODULE

Figure 4

D. Florence
General Electric

Numerous propulsion subsystem related parameters impact the AOTV configuration development and ultimate performance. However, the major first order parameters appearing to have the greatest impact are engine specific impulse, Isp, propellant mixture ratio, MR, and packaging volume and length required for the engines and associated plumbing, Figure 1. It was demonstrated in Reference 1 that 1) improved specific impulse (443 to 480 sec) provides the largest benefit for both single stage and two stage AOTV's, 2) for the single stage AOTV, the combined effects of a smaller hydrogen tank due to increased mixture ratio and the shorter vehicle due to use of multiple small engines, provides a benefit nearly as large as the increased Isp.

For ground based AOTV's, the payload weight delivery or round trip capability, is highly dependent on the AOTV dry weight. Other major parameters effecting the payload magnitude include the engine Isp, low earth orbit payload capability of the launch vehicle, and AOTV L/D. For the GEO delivery mission, the vehicle L/D has a minor impact on payload delivery, for the round trip GEO mission, L/D is more important and for polar delivery, even more important, Reference 1. A single stage 38ft GEO delivery vehicle with propellant tanks sized for a mixture ratio of 7 and a single engine was described in Reference 1. Except for the advanced engine (Isp = 477 sec, MR = 7), this vehicle utilized state-of-the-art technology. Significant subsystem weight reductions are possible by incorporating advances projected due to state-of-the-art advances, Reference 1. The improved payload delivery of these lighter vehicles is illustrated in Figure 2, and compared to previous AMOOS results, Reference 2.

Configuration variations of the 38 ft GEO delivery vehicle identified in Reference 1, were explored for a Six Hour Polar Mission to determine effect on payload weight/length, Figure 3. Here, it is noted that incorporating an aft conical frustum angle of 1^{o} results in increased payload length. Lessor frustum angles are expected to produce even longer payloads, however, the axial center of gravity requirements become less attractive and more body flap (heavier) must be added to trim the vehicle at the desired angle of attack. The longer payload lengths are produced by the larger propellant mixture ratios. Additional payload length is obtained by blunting the nose, however, the loss of L/D reduces the payload weight delivery capability. In this evaluation, the AOTV structure and thermal protection subsystem weights were scaled as the vehicle length and surface are changed. Hence, we conclude that for increased allowable payload lengths in a ground based system, lower L/D is as important as higher MR in this range of mid L/D AOTV's.

References

1. Florence, D. & G. Fischer, "Moderate Lift to Drag Aero Assist", presented at the NASA Lewis Research Center Conference on Orbit Transfer Vehicle Propulsion Issues, April 3 & 4, 1984.

2. Program Development, NASA Marshall Space Flight Center, "Orbit Transfer Systems with Emphasis on Shuttle Applications - 1986-1991", NASA TMX-73394, 1977.

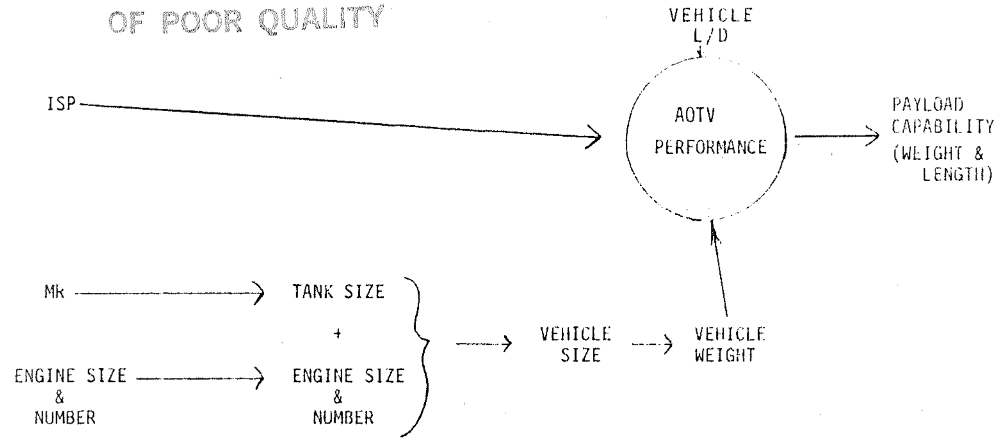

Figure 1. - Propulsion subsystem parameters with first-order impact on AOTV performance.

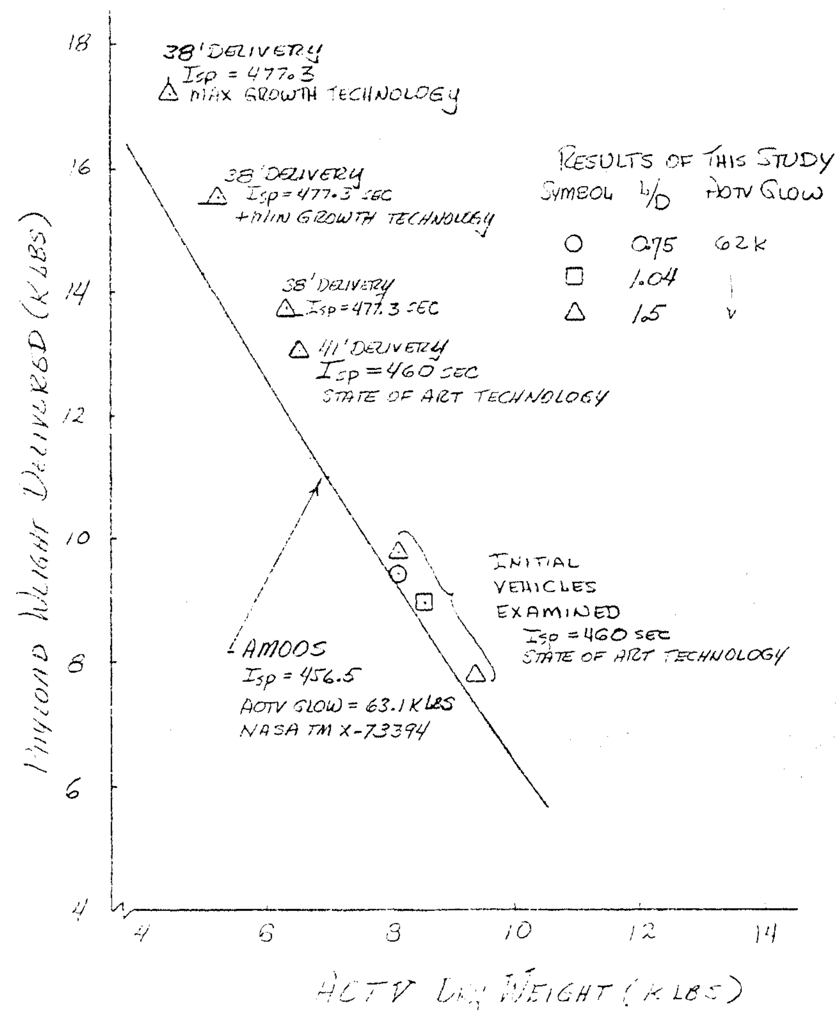

Figure 2. - Mid L/D AOTV GEO delivery capability for single-stage vehicles.

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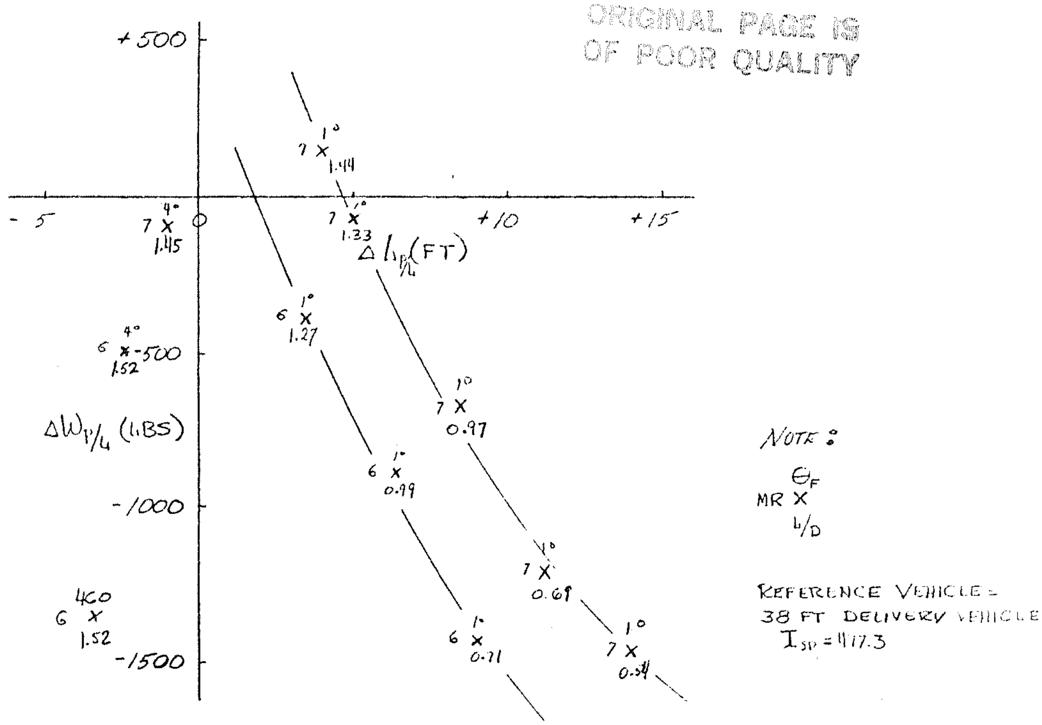


Figure 3. - Performance variations of a single-stage AOTV for polar delivery.

Roy W. Michel
Aerojet TechSystems Company

The Aerojet position is that the right approach to advanced OTV propulsion is with small multiple engines. In contrast to the other engine contractors, Aerojet has selected a nominal design thrust of 3000 lbF.

The small, multiple engine approach has several advantages, notably that crew safety and mission success are assured because of engine-out capability and that highest performance in a given length is obtained with small engines. Length is important both for earth-based OTVs and aeromaneuvering OTVs, and higher performance means greater payload capability.

Of several options for manned OTV reliability, only one provides the necessary reliability and is practical: redundant engines. Other options are far more costly or depend on back-up modes that simply do not exist.

The 3000 lbF thrust engine develops about 4 lbF sec/lbM higher performance than the 15,000 lbF engines within a given length, by virtue of higher area ratio. For the larger engine to achieve the same performance requires an additional three to four feet of length and two or three extendable nozzle segments. In an aeromaneuvering vehicle these extendable segments must also retract during passage through the atmosphere and thus constitute single point failure modes.

With multiple 3000 lbF thrust engines the whole mission model can be performed, efficiently, by a single propulsion system. Large space structures (LSS) are acceleration-limited and have a thrust requirement of 500 to 2500 lbF, which is met by one or two engines throttled. Many payloads are in the 3000 lbM class, which also requires one or two engines. High energy payloads and manned aeromaneuvering vehicles require 10,000 to 12,000 lbF thrust, obtained by a four engine configuration.

Aerojet's approach to space-based maintenance is to design the engine to be a space-replaceable unit, which is most plausible for small engines. If an engine component needs repair, the whole engine would be removed and returned to earth; repairs would be made by skilled technicians and the engine retested to assure its operation and performance.

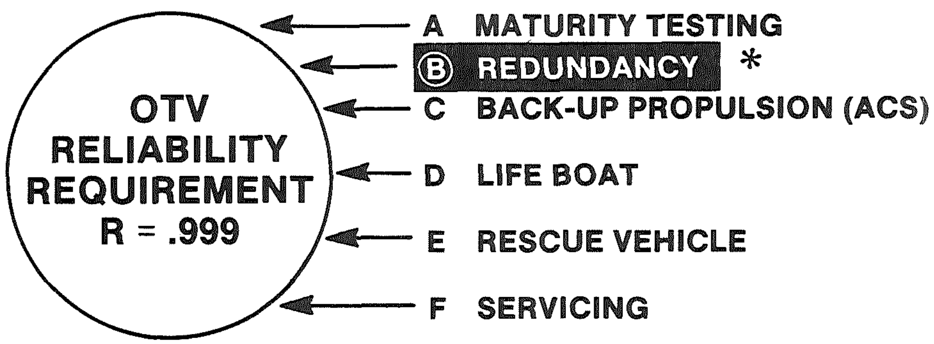
The several advantages of the small, multiple engine approach to OTV propulsion have a life cycle cost benefit on the order of $1 Billion. Altogether, the advantages and potential cost savings prove that the right approach to advanced OTV propulsion is with small, multiple engines.

ADVANTAGES OF SMALL, MULTIPLE ENGINES

- CREW SAFETY AND MISSION SUCCESS ASSURED
- HIGHEST PERFORMANCE FOR GIVEN LENGTH
- MORE PAYLOAD CAPABILITY
- GREATER MISSION FLEXIBILITY
- REAL SPACE-BASED MAINTENANCE
- SAVES $1 BILLION

Figure 1

OPTIONS FOR OTV RELIABILITY



* ASSURES MISSION SUCCESS

Figure 2

HIGHEST PERFORMANCE FOR GIVEN LENGTH

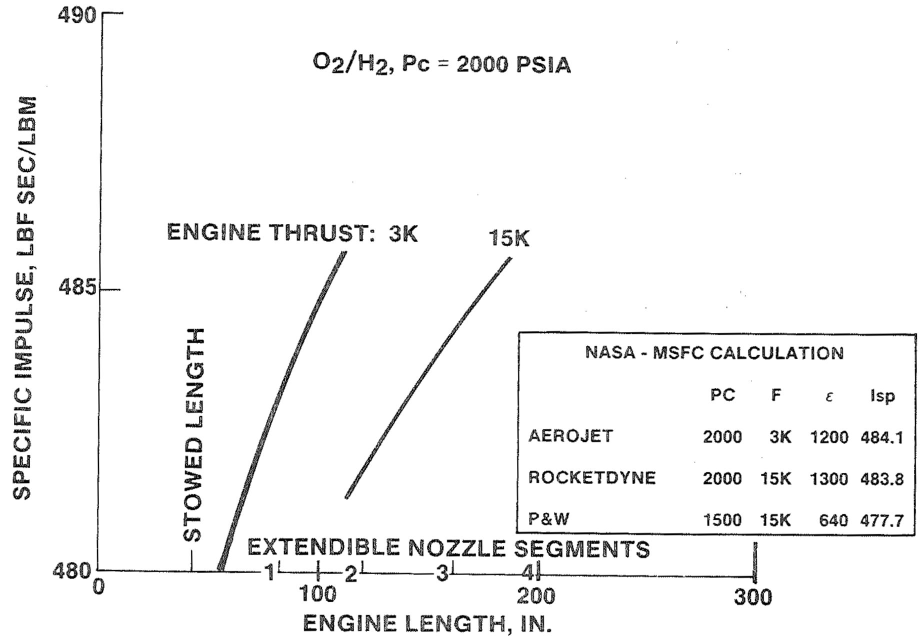


Figure 3

GREATER MISSION FLEXIBILITY

PAYLOAD	THRUST, lbF	# ENGINES
LSS	500-2500	1 OR 2 (THROTTLED)
3000 lbM	3000	1 OR 2
12,000 lbM	11,000	4
MANNED	9,500 (AEROMANEUVERING)	4

Figure 4

SMALL ENGINE MEANS REAL SPACE-BASED MAINTENANCE

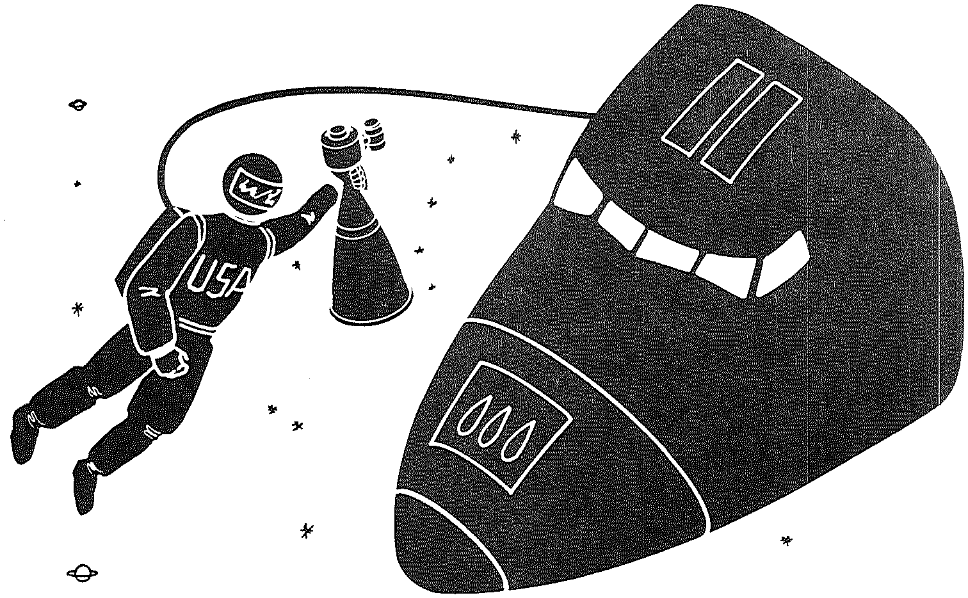


Figure 5

SMALL ENGINE APPROACH SAVES $1 BILLION

	VALUE
• RELIABILITY	$100 M
• WEIGHT	-40 M
• ENVELOPE/PACKAGING	70 M
• PERFORMANCE	400 M
• MISSION FLEXIBILITY	500 M
	$1000 M

Figure 6

J. R. Brown
Pratt & Whitney Aircraft

Pratt & Whitney Aircraft believes that several significant issues exist in the engine/vehicle integration area. These issues fall into the general categories of:

- o scenario validity
- o geometry constraints
- o throttle levels
- o reliability
- o servicing

We believe that one engine cannot be optimized to cover all possible perturbations of these issues. Rather, the issues must be resolved in a coordinated effort between the engine and systems contractor and only then can the engine configuration be selected.

IS CURRENT SCENARIO VALID?

- Space based OTV
- Propellant depot
- Manned GEO missions
- Substantial LEO-GEO traffic
- Low thrust deployment missions
- Only one type OTV
- New driver mission (e.g., lunar lander)

Figure 1

WHAT ARE ENGINE GEOMETRY CONSTRAINTS?

- Available length
- Available diameter
- Vehicle total thrust required
- Number of engines

Figure 2

WHAT THROTTLE LEVELS ARE REQUIRED?

- Steps (1%, 10%, 100%)
- Continuous (1%, 3% to 100%)
- Mixed (1%, 3% to 10%, 100%)

What response rate(s) are required?

Figure 3

WHAT ARE ENGINE REQUIREMENTS DURING AEROASSIST MANEUVER?

- Nonfiring
- Firing
  - Thrust level(s), response
  - Extendable nozzle position
- Engine environment
  - Thermal
  - Flow field

Figure 4

HOW DOES ENGINE INFLUENCE VEHICLE RELIABILTY?

- Number of engines
- Mission logic (number of failures to abort)
- Back-up dependency
  - Main engine
  - ACS
  - "Life boat"
  - Rescue mission

Figure 5

WHAT ARE VEHICLE SERVICING REQUIREMENTS/CAPABILITIES?

- Routine maintenance (after every mission)
- Periodic maintenance (after every 10 missions)
- Unscheduled maintenance
- Back-up mission logic
  - One spare vehicle
  - One spare + components
  - Two spare vehicles
  - Etc.
- Dependency on diagnostic systems

Figure 6

ENGINE/VEHICLE INTEGRATION SUMMARY

The engine contractors need to know:

1. How does vehicle limit engine geometry?
2. What is engine required to do?
   - Primary mode
   - Aeroassist mode
3. What propulsion system reliability is needed?
4. What engine servicing capability is available?

Figure 7