ORBITAL TRANSFER VEHICLE PROPULSION ISSUES

VEHICLE/ENGINE INTEGRATION

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The development of a reusable and space-basable orbital transfer vehicle (OTV) necessitates an integral approach toward structural and propulsion subsystems design. Key drivers include gimbal/actuator location, feed line gimbal provisions, and accessability for orbital maintenance. Recent studies have considered the use of toroidal tank configurations with the engine(s) located within the central cavity of the toroid. The primary objective of that approach is to achieve minimum stage length. Dependent upon engine size and number, that concept introduces unique vehicle/engine integration requirements that necessitate special design considerations. Of particular concern is vehicle center-of-gravity (CG) location when the propellant tanks are more than 75% expended. A single engine installation will necessitate moving the engine further aft and/or relocation of the engine gimbal point to accommodate vehicle control requirements. Penalties associated with gimbal point relocation without increasing stage length or modifying typical advanced engine concepts, as well as a method for minimizing such penalties, are presented for a single engine toroidal tank OTV configuration. Alternative integrated vehicle structure/engine concepts are also presented for multi-engine configurations. Features of these potential concepts are presented which indicate the need for substantial additional study of feedline gimbal alternatives before firmly establishing advanced engine design.

INTRODUCTION

The issue of vehicle/engine integration is addressed in three areas; interfaces (physical and functional), installation requirements, and reliability apportionment (i.e., number of engines required to assure mission completion). Typical elements of each area are presented below.

- INTERFACES
  - -THRUST STRUCTURE GIMBAL ATTACH
  - -PRESSURANTS
  - -ACTUATOR(S)
  - -PUMP INLET(S)
  - -PURGE REQUIREMENTS
  - -ELECTRICAL/AVIONICS

- INSTALLATION
  - -ACCESSABILITY
  - -STIFFNESS
  - -INLET CONTOUR CONTROL (UPSTREAM)
  - -GIMBAL/ACTUATOR LOCATION
  - -FEED LINE(S) GIMBAL PROVISIONS

- EXTENDABLE NOZZLE COMPATIBILITY
- AERO-ASSIST KIT COMPATIBILITY

- RELIABILITY APPORTIONMENT
  - FAILURE MODES(S)
  - ENGINE-OUT CAPABILITY

The necessary vehicle/engine interfaces are defined by overall mission, system, and performance requirements. Although some interface requirements are subject to trade study analyses (i.e., autogenous vs helium pressurization, thrust vector control (TVC) vs Reaction Control System (RCS), once the interfaces are defined, their characteristics are established and it remains for the designer to provide an installation that will satisfy other program objectives (i.e., simplicity, accessability, cost, etc.). An efficient overall configuration can be achieved if only an integrated approach toward vehicle structure/engine design is implemented. The objective of this paper is to provide an example of the significant need for such an integrated design approach. To accomplish this, typical OTV concepts, which have been suggested in prior studies, are used to illustrate the potential problem areas that must be addressed prior to advanced engine definition.

DISCUSSION

A typical OTV concept which has received considerable attention in recent years utilizes a conventional propellant storage tank for LH_2, but an advanced toroidal tank design for LO_2 storage. A single engine is installed in the cavity of the toroidal tank in order to minimize stage length and Space Transportation System (STS) launch costs and/or maximize payload length. When operating in an expendable mode, with payload attached forward, this concept is viable. However, when operating in a reusable mode with stage return after payload deployment, the vehicle C. G. moves aft of the engine gimbal point (assuming a conventional engine design with front end gimbal). A potential solution is to move the engine further aft, but this defeats the original objective of shortest stage length. An alternate method, Figure 1 (using a Rocketdyne early RS-44 engine version as an example), is to add a throat gimbal kit which provides a "pseudo" gimbal axis about the engine throat. In this configuration the thrust loads are still transmitted through the power head and thrust structure into a bearing plate on the vehicle. Some redesign of the engine to attach the throat gimbal links is of course required. Another alternative is to redesign the engine for integral throat gimbal and thrust load transfer (i.e., similar to the Apollo Service Module Engine). This change would also necessitate relocation of the feed line interface to the throat gimbal ring. A comparison of the suggested engine modifications are presented below.

REDESIGN FOR THROAT GIMBAL & THRUST LOAD TRANSFER	REDESIGN FOR THROAT GIMBAL WITHOUT THRUST LOAD TRANSFER
• CONVENTIONAL GIMBAL STRUCTURE • MAJOR ENGINE REDESIGN • MINOR WEIGHT IMPACT • FEED LINE SYSTEM-MINOR INCREASE IN WEIGHT & COMPLEXITY • LIMITED POWER HEAD ACCESSABILITY • EXTENDABLE NOZZLE IMPACT	• COMPLEX GIMBAL STRUCTURE • MODERATE ENGINE REDESIGN • MAJOR WEIGHT IMPACT • FEED LINE SYSTEM-COMPLEX & HEAVY WITH INCREASED HEAT LEAK • LIMITED POWER HEAD ACCESSABILITY • EXTENDABLE NOZZLE IMPACT

To resolve such issues, further study of gimbal/feed line alternatives are recommended prior to establishing advanced engine configuration requirements.

The reusable and space-basable OTV is planned to evolve into a man-rated system. In order to achieve this objective, the issue of engine reliability and redundancy requirements must be addressed. The single engine reliability will dictate the number of engines required to satisfy overall mission probability of success, Figure 2. In order to meet manned mission requirements, the reliability apportionment for the propulsion system is in the order of 0.999. As indicated in Figure 2, a two engine configuration (with on engine capable of accomplishing the mission) is equivalent to a three engine configuration (with one engine capable of accomplishing the mission) and superior to a three engine configuration (with two engines required to accomplish the mission). A two engine OTV concept was therefore selected to evaluate vehicle/engine integration issues.

When using multiple engines of RS-44 size, the engines can no longer be installed within the toroidal tank cavity, Figure 3. In this configuration a key integration issue is propellant feed line gimbal requirements. In order to integrate the currently suggested RS-44 engine into a vehicle, feed line gimbal must be accomplished upstream of the pump inlets located on the power head. This would result in complex line routings within the toroidal cavity thus providing limited access for assembly and/or on-orbit maintenance. In addition, the greater articulation of relatively long line lengths (especially in an engine-out condition) would probably limit to two the number of engines that could be installed without significant increase in stage length. A preferred concept may be that which has been employed on the STS orbiter for the SSME; feed line gimbal downstream of the pump inlet. This installation could be lighter and simpler, and provide better access for assembly and on-orbit check out and maintenance. Using this approach, the feed line gimbal system would be included in the advanced engine design. This concept could also be beneficial in that changes in propellant flow characteristics with feed line contour changes during gimbal can be evaluated during engine analyses, design and testing. Propellant feed line gimbal for conventional tank design concepts, Figure 4, have also been evaluated and similar results obtained. Again, this is mainly due to the longer line lengths required and greater feed line articulation needed to satisfy the engine-out condition.

CONCLUDING REMARKS

The objective of this paper is not to recommend the potential changes in advanced engine design discussed above, but rather to emphasize the need for an integrated approach toward vehicle/engine design. This integrated approach becomes even more necessary when aero-assist concepts are considered, especially for those concepts that rely on engine firing during aero-assist maneuver.

An on-orbit checkout and maintenance philosophy must also be established to provide effective guidelines for engine design and self-monitor requirements. With the exception of oils and greases, the aviation industry trend is toward no scheduled maintenance between major overhauls. A similar objective might be considered for the reusable, space-basable OTV.

Engine redundancy, thrust level, throttling, etc. requirements remain as open issues. If properly executed by the selected contractors, the currently planned NASA MSFC OTV Concepts Definition and Systems Analysis Study should provide answers to these and most other vehicle/engine integration issues. In the interim, it appears prudent to maintain as much flexibility as possible in defining an advanced cryogenic engine configuration.

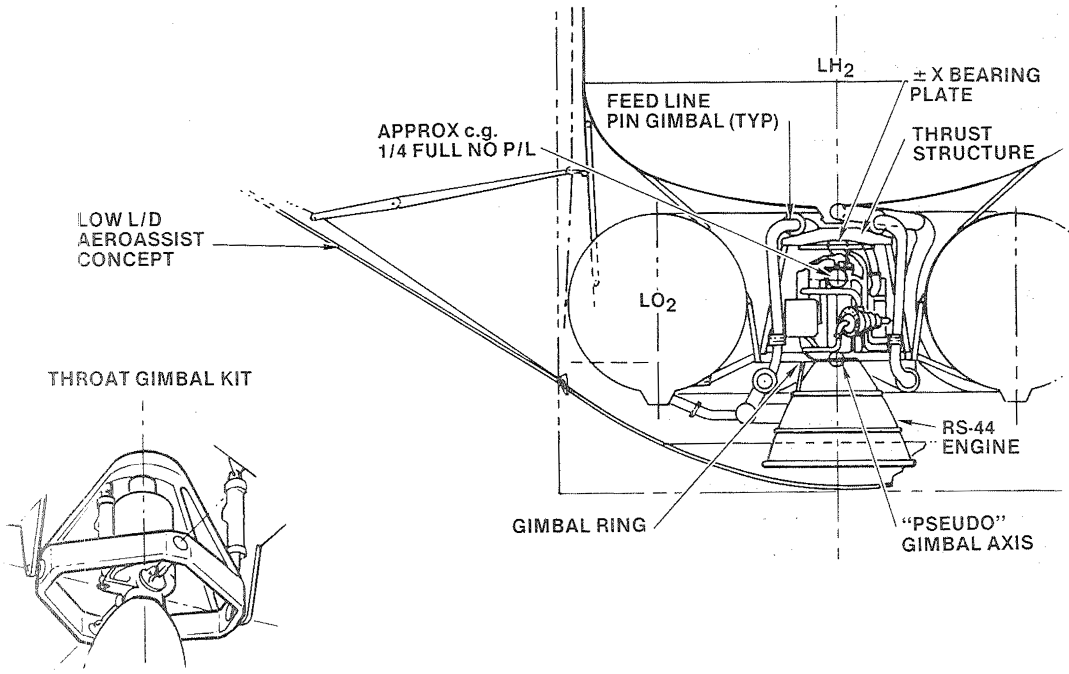

Figure 1. Single Engine Installation for Toroidal Tank Configuration

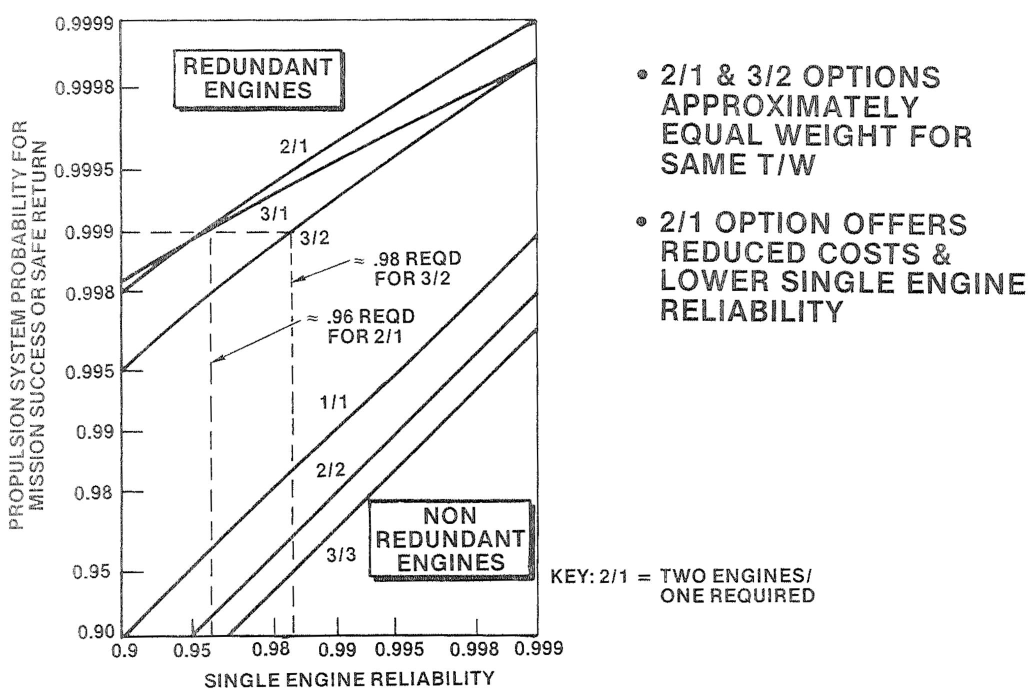

Figure 2. Engine Redundancy Requirements

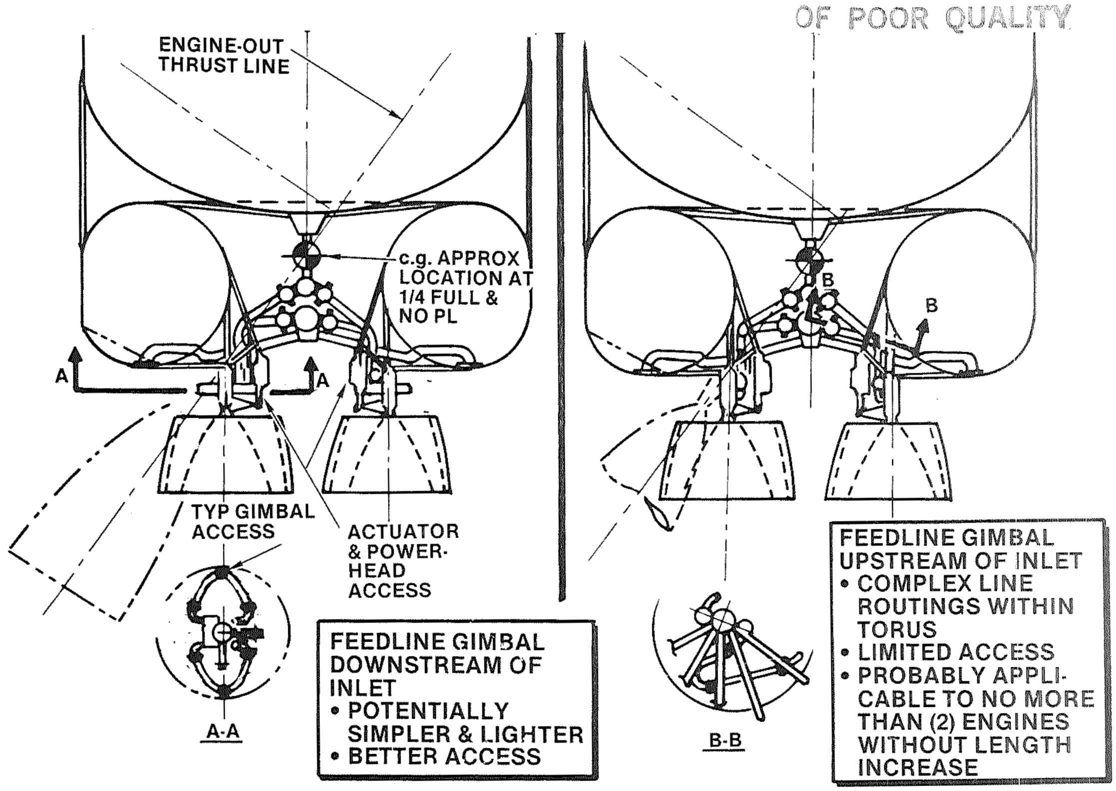

Figure 3. Multiple Engine Installation Options for Toroidal Tank Stage Concept

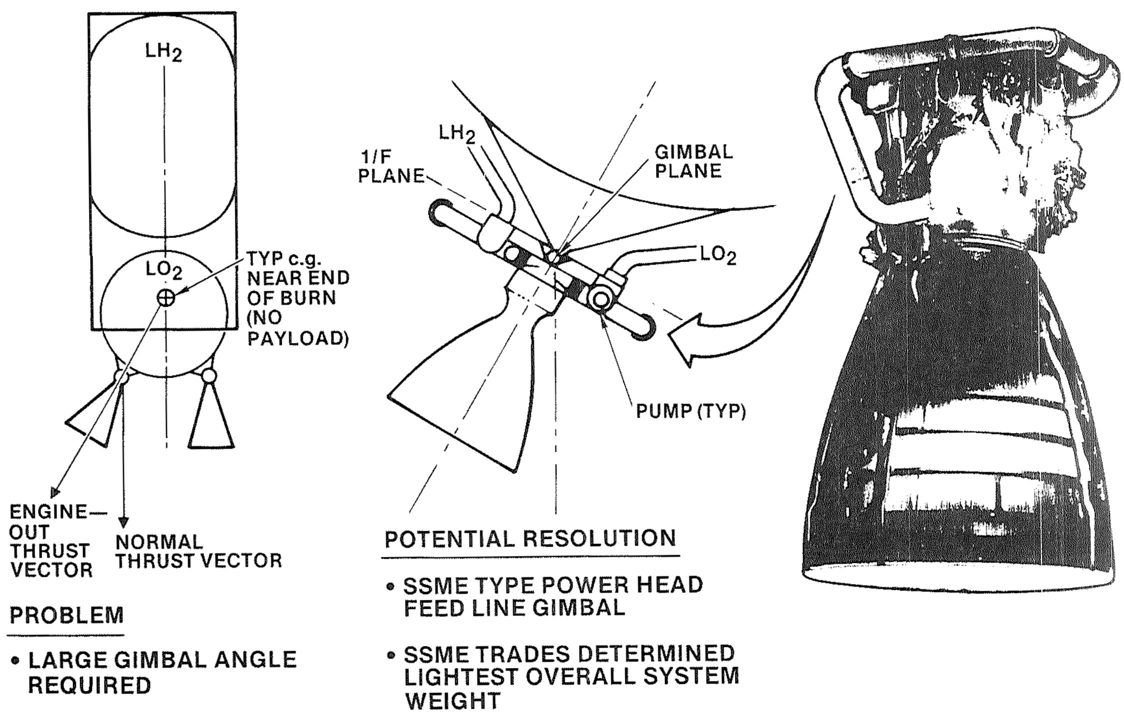

Figure 4. Multiple Engine Installation for Conventional Tank Configuration