

ADVANCED OTV ENGINE CONCEPTS

A. T. Zachary
Rockwell International/Rocketdyne Division

Orbital transfer vehicles (OTVs) of the 1990 to 2000 period will deliver payloads for the more energetic of the NASA missions currently defined: large structure deployment, satellite servicing, and manned sorties to geosynchronous orbit. Along with advances in vehicle design, advances in engine technologies are required to improve overall engine capabilities, and thus vehicle performance, reliability, cycle fatigue life, maintainability, and cost. This paper briefly presents the results and status of NASA-LeRC-funded engine technology effort to date and related company-funded activities.

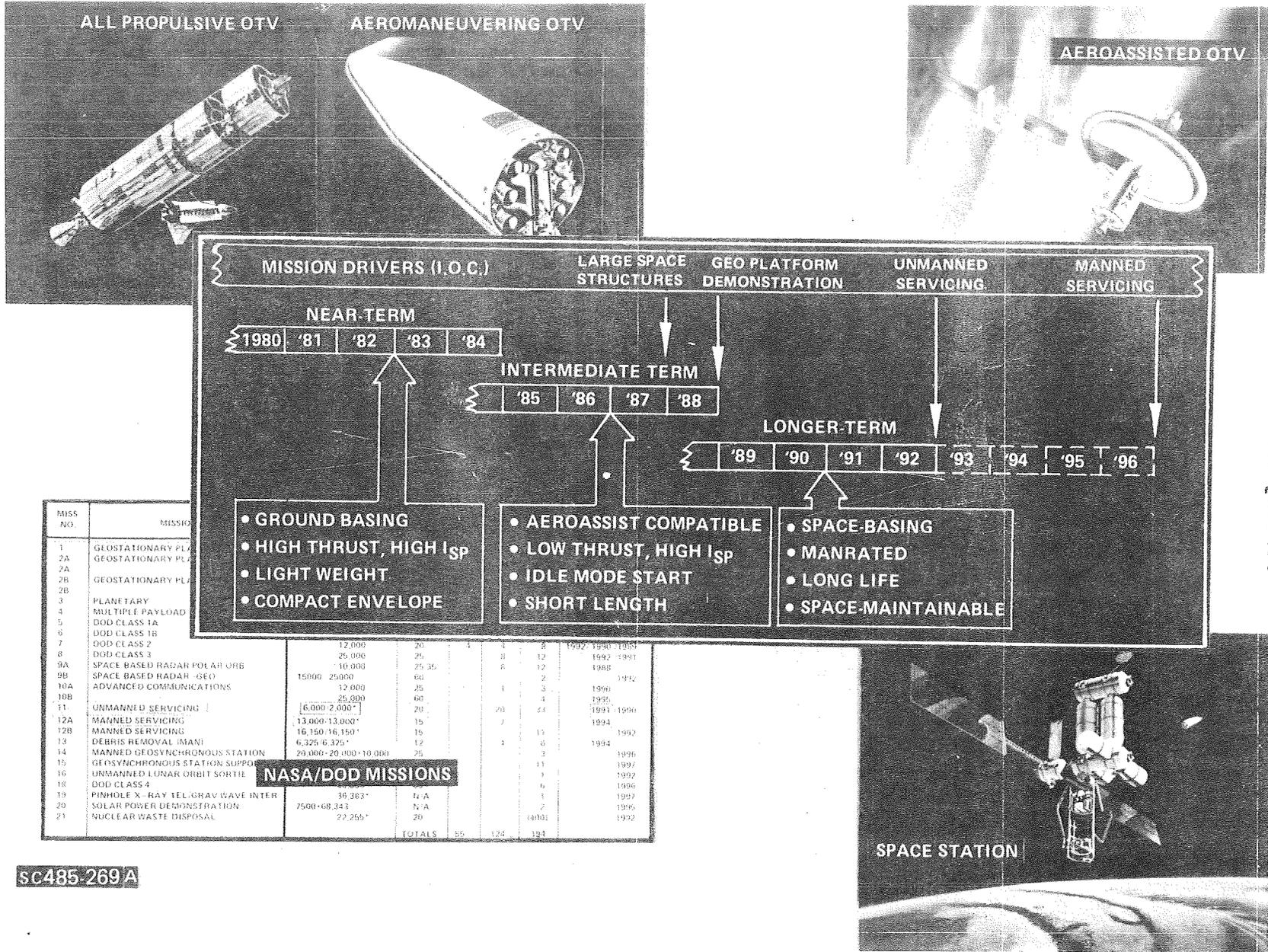
Advanced concepts in combustors and injectors, high-speed turbomachinery, controls, and high-area-ratio nozzles that package within a short length result in engines with specific impulse values 35 to 46 seconds higher than those now realized by operational systems. Equally, if not more important, will be the improvement in life, reliability, and maintainability.

INTRODUCTION

Studies conducted under NASA contracts have identified near-term, intermediate-term, and longer term technologies to meet the needs of a broad-based program of space utilization. As shown in figure 1, the evolution of the development process for the OTV leads to manned service near the end of the century. The technology drivers in meeting the goals of a viable, space-based system are space basing, aeroassist, manned operation, and low-g transfers. As presented in figure 2, approaches have been identified; however, with specific challenges that must be met. These challenges of on-orbit servicing, increased life, reliability, maintainability, reduced length, and increased performance will be achieved through an evolutionary process as indicated in figure 3.

The NASA plan for technology acquisition for the orbit transfer rocket engines of the period 1990 to 2000 is a three-phase approach encompassing conceptual definition, preliminary experimental evaluation, and critical component technology verification stages. This approach is as follows, with the principal goals of the studies identified.

- PHASE I Conceptual Designs and Technology Definition
- Identify, screen, evaluate, and select advanced technology concepts
 - Provide engine conceptual designs and technology acquisition plans



136

ORIGINAL PAGE IS OF POOR QUALITY

SC485-269A

Figure 1. OTV Engine Technology Depth and Timing Drivers Background

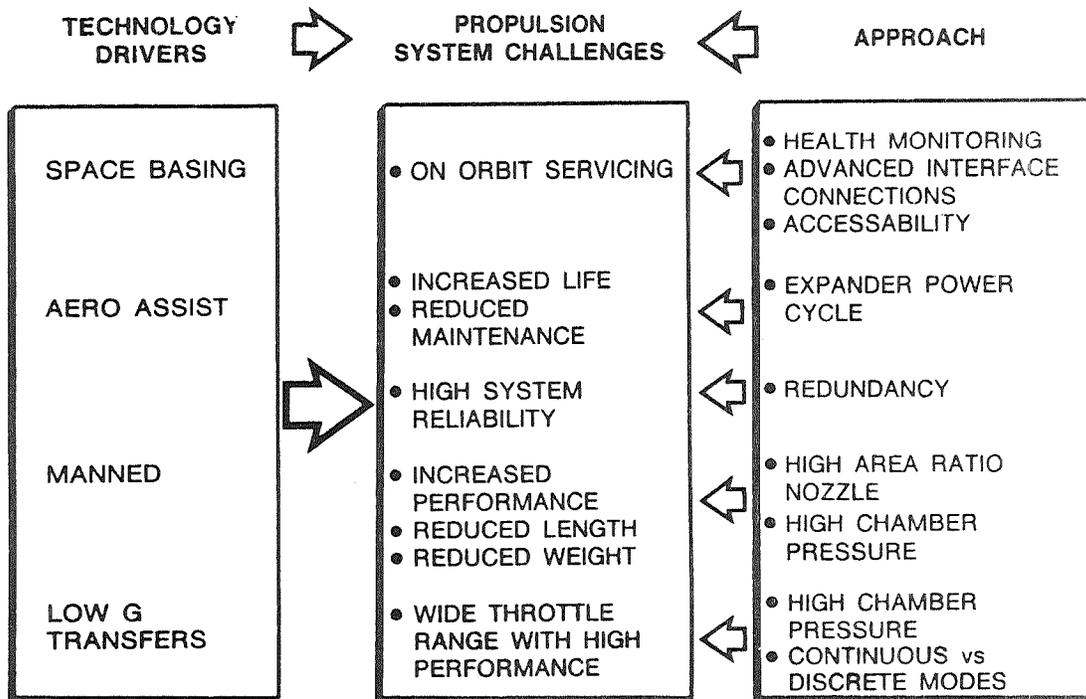


Figure 2. Engine Design Rationale

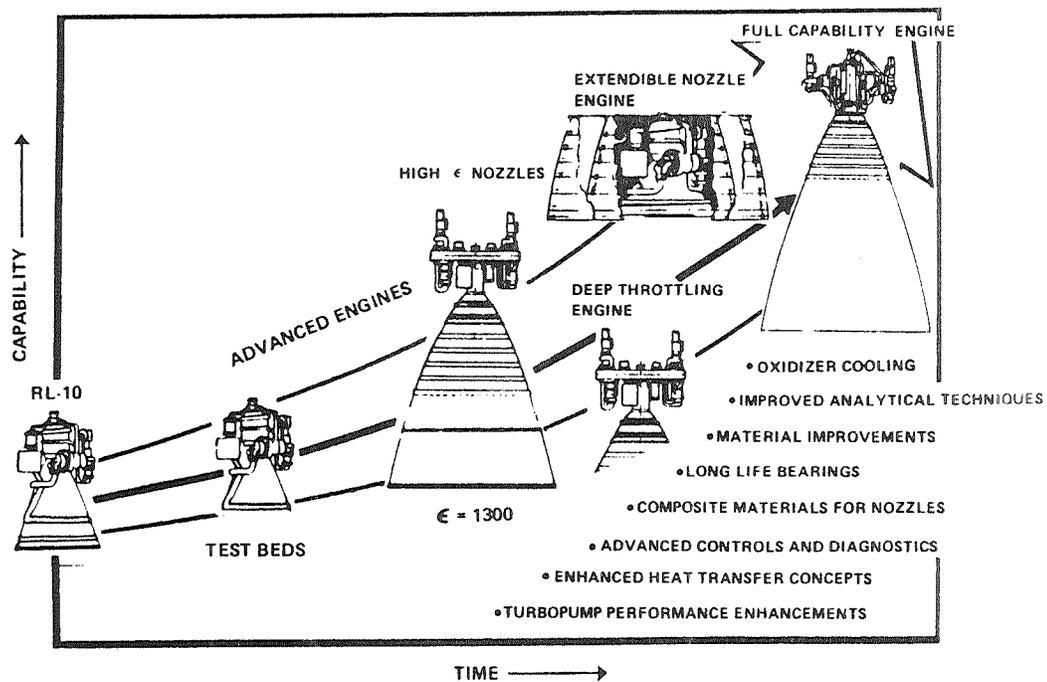


Figure 3. Cryogenic OTV Propulsion

- PHASE II Exploratory Research and Technology
- Unique and generic advanced technology concepts
 - Simulation testing in test rigs
- PHASE III Critical Component Design and Fabrication
- Critical component design and fabrication readiness

An important first step in these plans has been taken with the completion of the conceptual design and technology definition studies entitled, "Orbit Transfer Rocket Engine Technology," with the primary objective of identification, and selection of advanced technology concepts and technology acquisition plans that will benefit the OTV engines of the 1990s.

ULTIMATE OTV ENGINE EVOLUTION

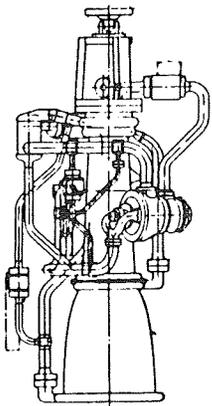
A phased approach has been selected for experimental development and verification of the technologies that will be featured in the ultimate OTV engine (fig. 4). The technologies will be evaluated in an integrated components evaluator upon which thrust chamber, turbomachinery, control system, and auxiliary system technologies will be verified in an engine system environment. The integrated components evaluator will facilitate the verification of advanced component concepts in three technology groupings: near-term, intermediate-term, and long-range categories, and their successive integration into advanced engine cores. At the completion of each technology period, an engine candidate and its technologies will have been defined that can be developed according to NASA needs. Each of these engines would provide large performance and operational benefits over the reference engine used in the studies (RL10A-3-3) and, because of the technology approach taken, could be developed as a growth version of the Advanced Core Engine. The near-term engine schematic and mockup are shown in figures 5 and 6, respectively.

The development of the ultimate engine would occur in the mid-1990s. The engine is planned as an expander cycle engine with a chamber pressure of 2000 psia, A nozzle expansion area ratio near 1300:1, and a specific impulse greater than 480 seconds. Operationally, the engine will be capable of 20 hours of service-free life, deep 30:1 throttling, and, with its health-monitoring and control system, capable of full space based maintenance and operation. For vehicles based in the Space Transportation System (STS) and for medium lift-to-drag aeromaneuvering OTVs, the engine will be fitted with a retractable nozzle to reduce stowed length to 40 inches.

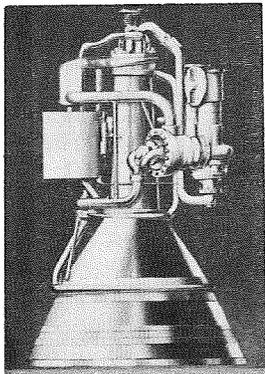
The engine thrust level and number of engines will undergo final selection when the vehicle crew safety and reliability approach are definitized. Since a large degree of technology commality exists in the range of thrusts of 3000 to 15,000 pounds, Rocketdyne's interim selection of 15,000 pounds engine thrust is appropriate for technology development.

KEY ENGINE DESIGN ISSUES

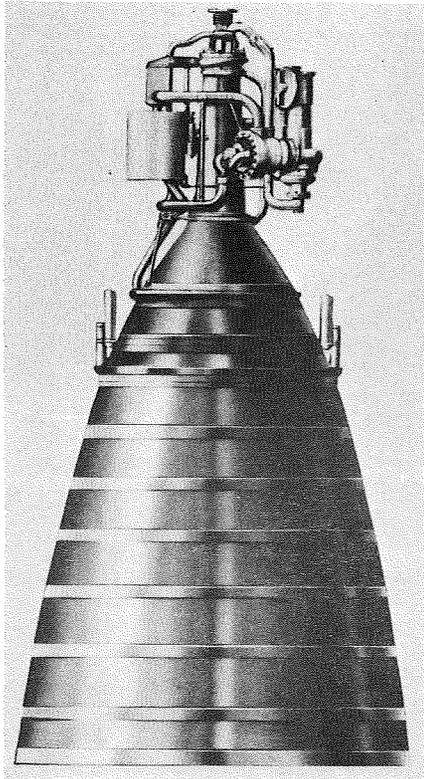
Key issues of the engine system and component design reside in the combustor/injector, nozzle, turbomachinery, control system, and the auxiliary heat exchangers as outlined in figure 7. High heat extraction in the combustor, injector, and nozzle, with simultaneous efficient combustion and gas expansion, are required to provide high chamber pressure and high specific impulse. A combustor and injector with extended



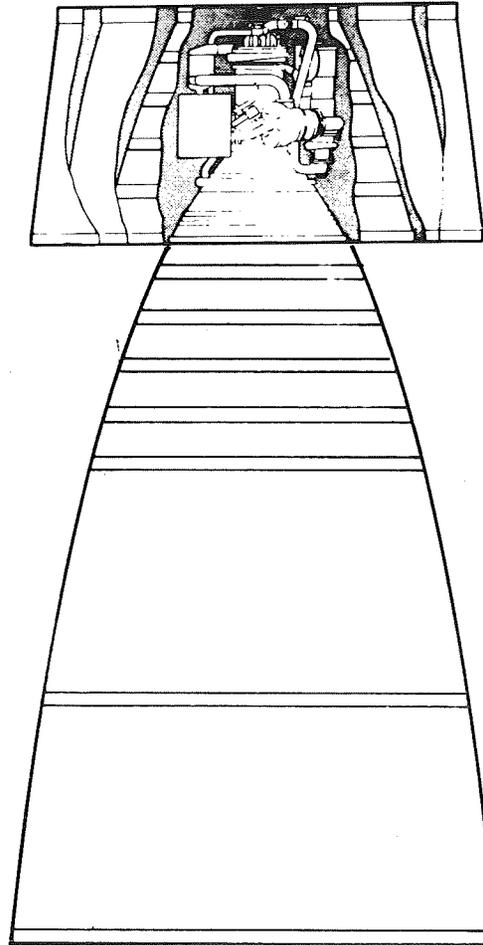
● INTEGRATED COMPONENTS EVALUATOR



● ADVANCED ENGINE CORE



● NEAR-TERM ADVANCED OTV ENGINE



● ADVANCED OTV ENGINE (GROUND AND SPACE-BASED)

Figure 4. Ultimate OTV Engine Evolution

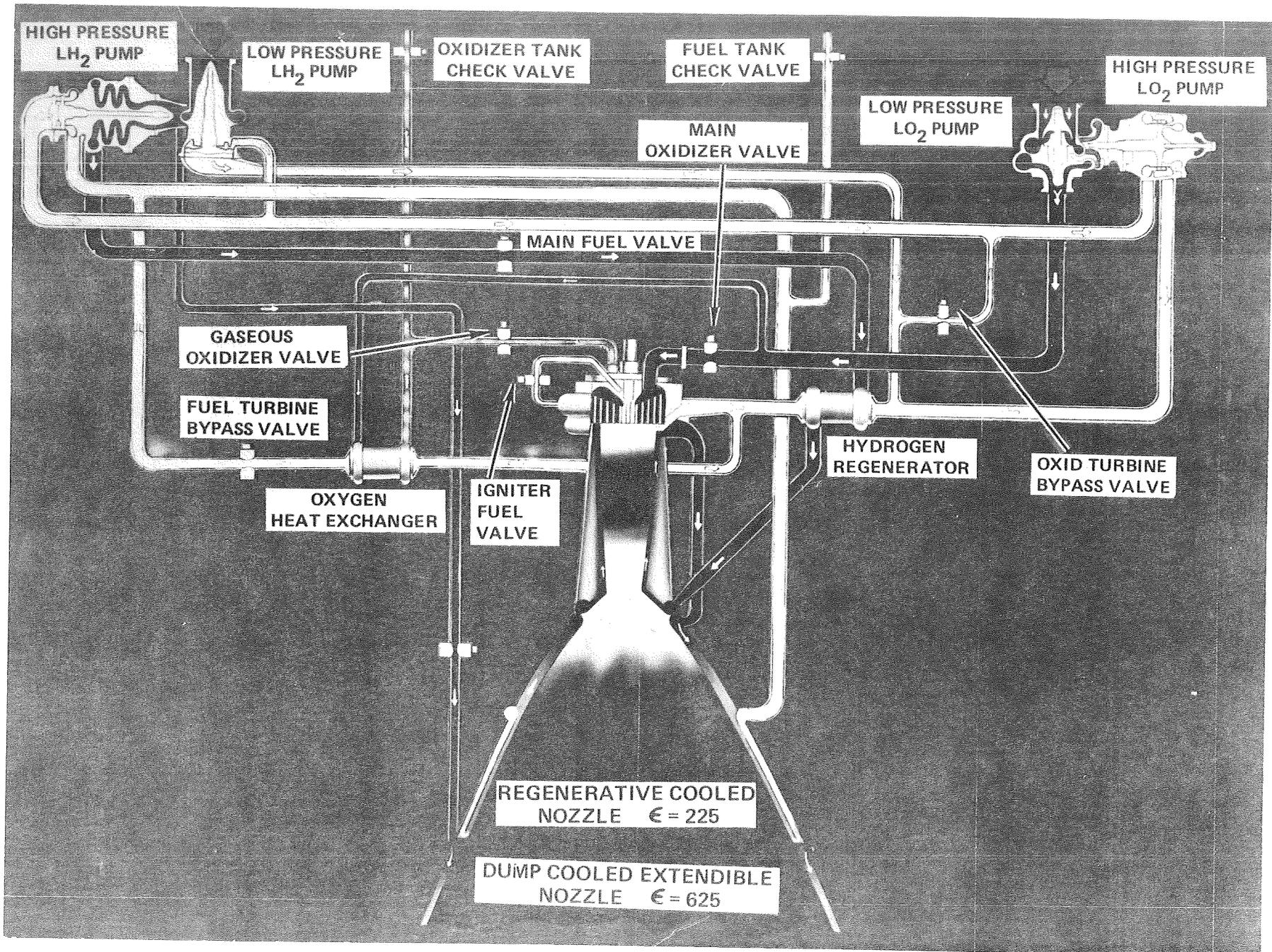


Figure 5. RS-44 Engine Schematic

ORIGINAL PAGE IS
OF POOR QUALITY

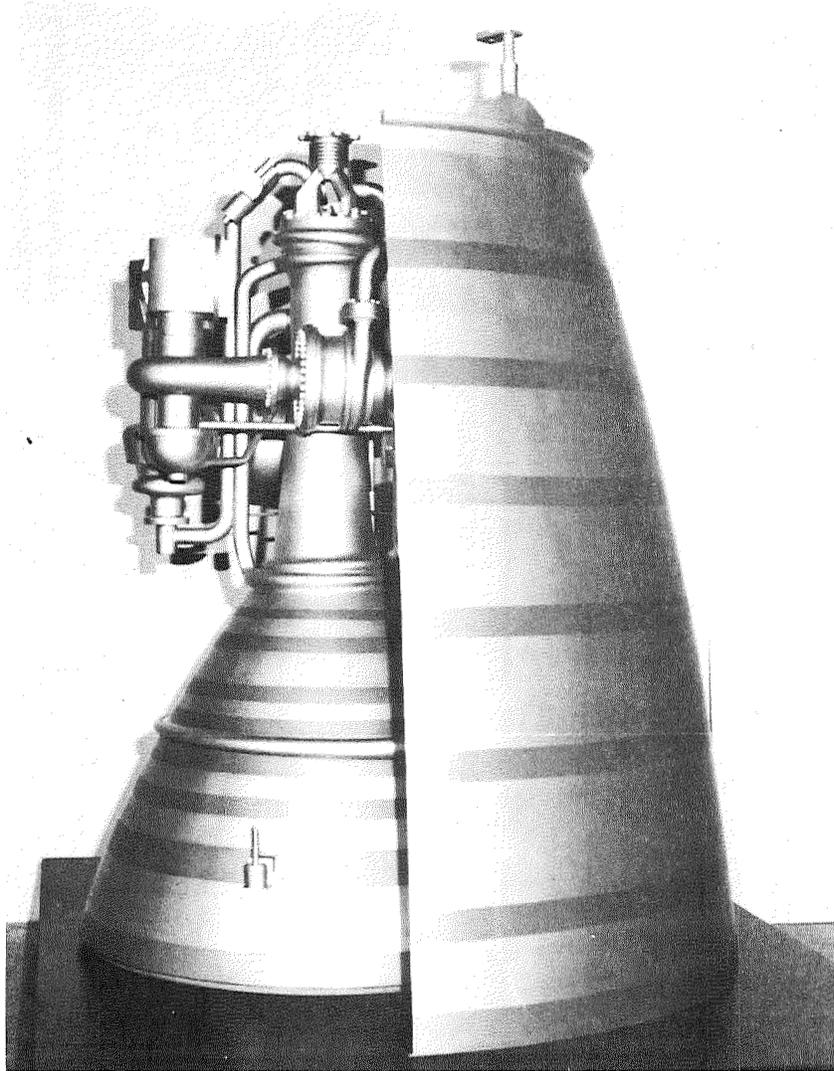
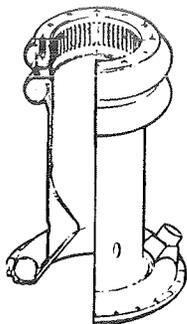


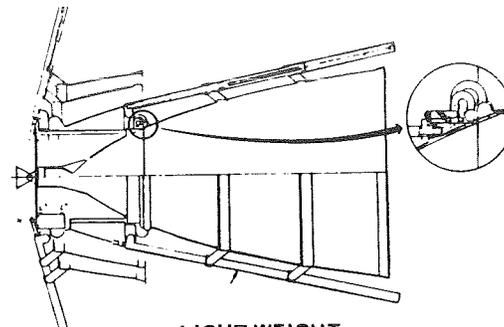
Figure 6. RS-44 Mockup

• HIGH HEAT-LOAD
COMBUSTOR/INJECTOR



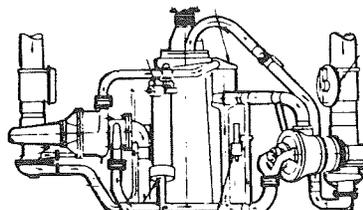
- HIGH Q EXTRACTION
- LONG LIFE
- HIGH COMB. EFF.

• HIGH AREA RATIO NOZZLE

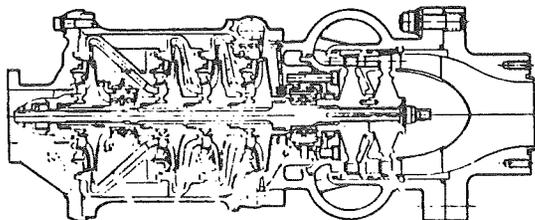


- LIGHT WEIGHT
- LONG LIFE
- SIMPLICITY/RELIABILITY

STS/SPACE-BASED OTV

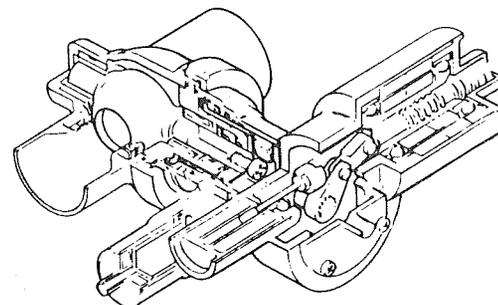


• HIGH-SPEED, MULTI-STAGE
TURBOMACHINERY



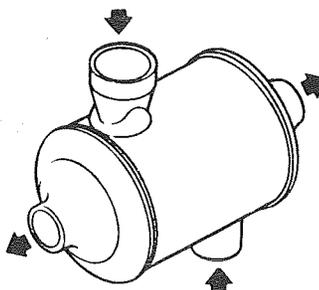
- LIGHT WEIGHT
- ROTORDYNAMICS
- LONG LIFE
- HIGH STRENGTH MATL'S

• ADVANCED CONTROL AND DIAGNOSTICS



- RELIABILITY/SIMPLICITY
- COMPACTNESS
- LIGHT WEIGHT
- LONG LIFE
- COST

• TURBINE-GAS
REGENERATOR



- HEAT TRANSFER EFF.
- COMPACTNESS
- LIGHT WEIGHT

Figure 7. Ultimate Engine Design - Key Issues

heat transfer surfaces, providing high heat extraction, efficient wall cooling, and wall strain management to maintain desired component life, are the technology challenges in the combustor and injector. A large nozzle expansion area ratio with a retractable nozzle is necessary for high specific impulse and envelope compactness. Advanced material technologies and retraction mechanisms that reduce weight and yet provide adequate reliability are key technology issues of the nozzle assembly.

High speed, multiple staging, small size, and high turbine and pump efficiency are requirements of the OTV engine turbomachinery. The technologies and technology issues to be addressed in achieving the high levels of performance required in each of these areas are: bearing life; rotordynamic characteristics of multiple-staged impellers; materials for increased turbine and impeller strength, life, and reduced weight; and reduction of parasitic performance losses of small turbomachinery through use of soft seals and efficient diffuser design of impeller-to-impeller crossover networks.

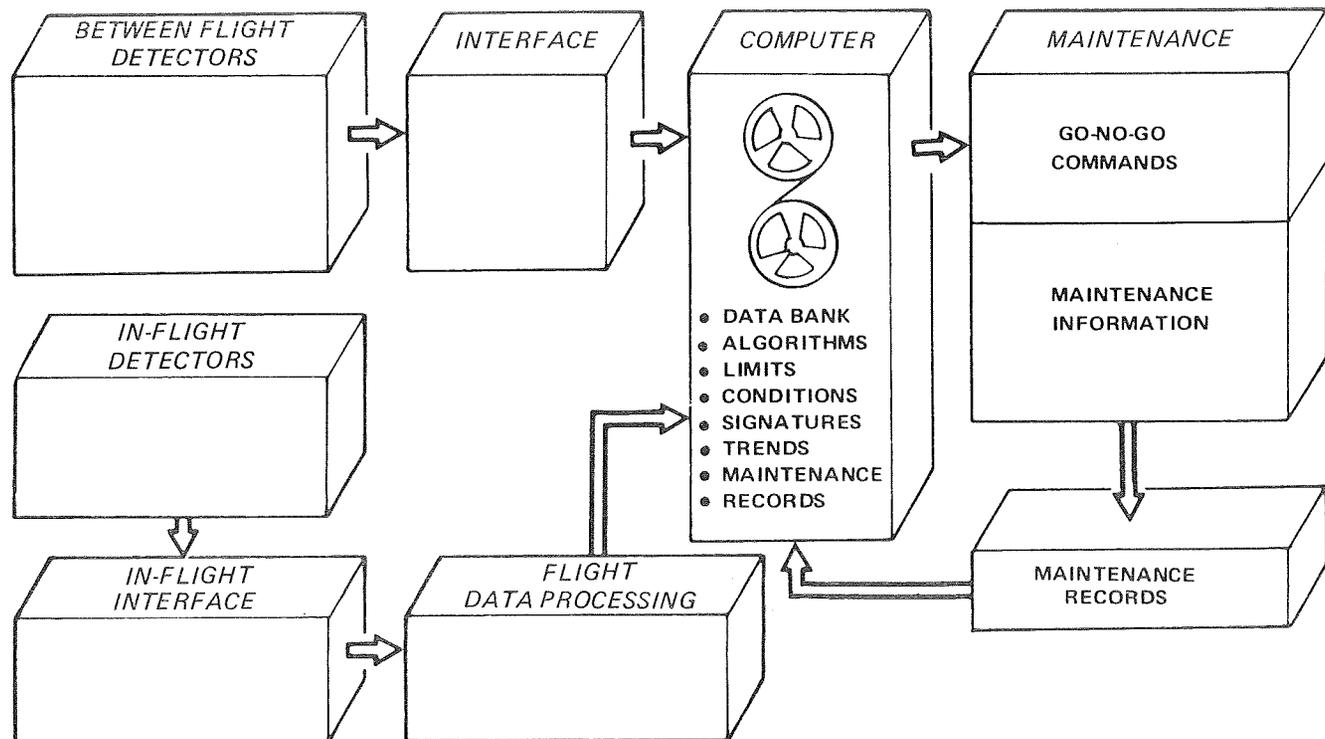
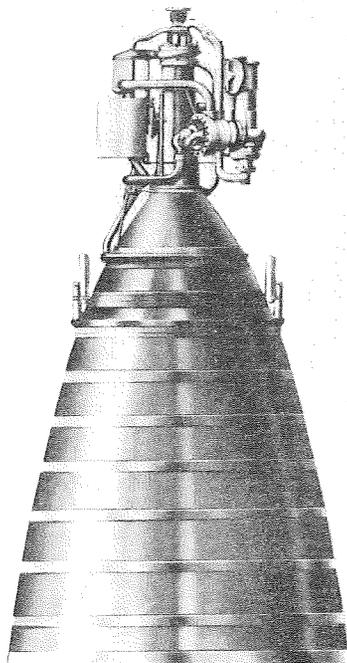
Low-torque, light-weight, electrically driven valves, and driver motors are technology issues to be developed for the advanced control system, as well as advanced sensor technology and advanced multivariable controller systems.

A turbine gas regenerator will provide increased power cycle performance through heat recuperation. For maximum benefits, the recuperator and the idle-mode heat exchanger will require high heat transfer efficiency in a compact envelope.

CONTROL SYSTEM TECHNOLOGY EVOLUTION

The near-term OTV engine shown in figure 4 uses a control and diagnostic system based on the current state of the art (SSME program) with one notable exemption: control valves are low-torque devices with an electric motor providing the primary means of actuation. Electrical power is desirable for upper-stage engines; however, low power requirements are necessary to keep the power supply small. The near-term OTV engine control system provides functions similar to the SSME system: control of engine operating modes, checkout and status monitoring, input/output data processing, and protection of engine and manrated capability. The controller is a full-range system providing closed-loop control of thrust and mixture ratio during mainstage, start, and shutdown transients. Control during transients is required to maintain component operating limits at levels compatible with the long life required in the near term (300 cycles, 10 hours). Redundancy in the controller, valves, and valve actuators is used to enhance the manrating capability of the system.

The longer range technology development of this system aims to improve control accuracy during transients, improve control system weight and simplicity, and improve control and diagnostic system reliability through improvements of the weakest link in the system: the sensors. Control accuracy improvement procedures will address modern multivariable control methodology and take advantage of modern miniaturization techniques for controller components. Emphasis of the long-range technology will be to provide a highly reliable control and diagnostics system specially suited for space-based OTV engine maintainability. The system will do continuous wear monitoring and fault prediction, and ideally be capable of fault compensation or avoidance. The diagnostic system is summarized in figure 8.



ACHIEVED BY USING A BETWEEN-FLIGHT AND/OR IN-FLIGHT CONDITION-MONITORING SYSTEM CONSISTING OF STATE-OF-THE-ART AND/OR NOVEL AUTOMATED DETECTION TECHNOLOGIES AND TAILORED DATA PROCESSING AND COMPUTERS.

Figure 8. Diagnostics for Maintainability Approach

ENGINE PACKAGING FOR SPACE-BASED MAINTAINABILITY

Several engine packaging concepts are shown in figure 9. Components in the near-term OTV engine are packaged to conserve space in a volume-limited shuttle orbiter. Power package components arranged around the combustor allow retraction of the extendible nozzle for stowage in the shuttle, and still provides required maintenance volumes for ground-based maintenance operations. The component interfaces of the near-term engine are designed with ground-based, line-replaceable unit philosophy.

For space-based operations, the overall maintenance, system and/or subsystem changeout philosophy will determine the engine component packaging arrangement and component interface design. Space-based maintenance costs and component changeout ease will determine the final maintenance philosophy. If, after economic analysis, engine changeout is the smallest maintenance module operation defined, then the near-term conventional engine packaging design with advanced engine/vehicle interface connections will be capable of space-based operation and maintenance.

The open-pack engine design will allow changeout of key engine components in a space environment. Increased maintenance volume will be defined for those components and a packaging design selected to facilitate component maintenance and changeout. An advanced control and diagnostics system will facilitate component changeout for cause rather than mandatory scheduled replacement.

In a space-based maintenance scenario where any or all components are subject to in-place maintenance and changeout, an advanced engine packaging configuration for efficient and speedy checkout removal and replacement will be desired. The components will be placed to facilitate access and their interface joints designed for minimum checkout and uncoupling time. A diagnostics system to facilitate judgement of components due for replacement and checkout of new components would then be required.

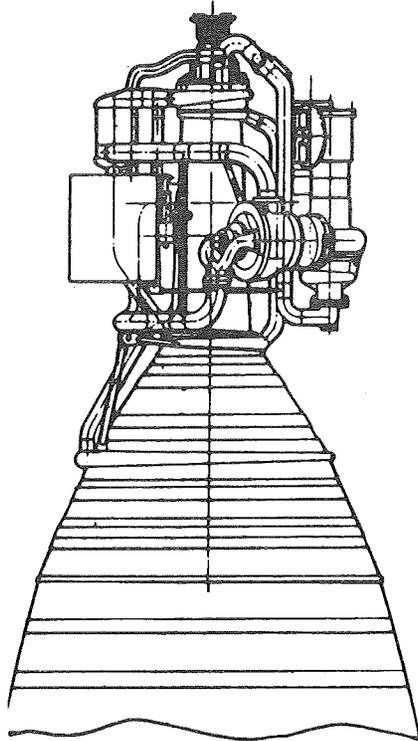
CONTRACT AND COMPANY-FUNDED ACTIVITIES

The current status of the NASA LeRC contract activities and Rocketdyne-funded parallel effort is outlined in Table I. With the completion of the system study to identify specific technology tasks to be studied, several of the tasks are now being funded or are in the process of approval and will be initiated shortly. The specific tasks in process are listed in Table II and encompass a number of critical technology areas in support of providing the technology base for a full capability engine in the 1990s.

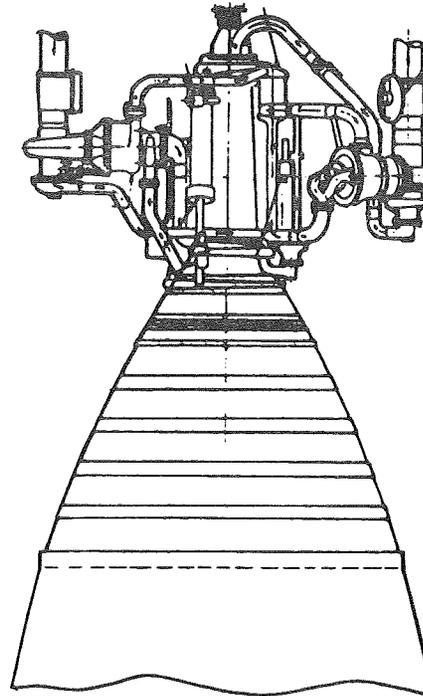
In conjunction with the NASA funded effort, key technologies have been under study at Rocketdyne and are now entering the hardware stage for demonstration. The key elements are shown in figure 10, and represent an important learning process in design and fabrication of high performance engine components. It is planned to continue the evaluation of these components and thus develop a realistic perspective in the problems of developing a high performance, reliable, maintainable engine system.

ADVANCED PACKAGING CONCEPTS

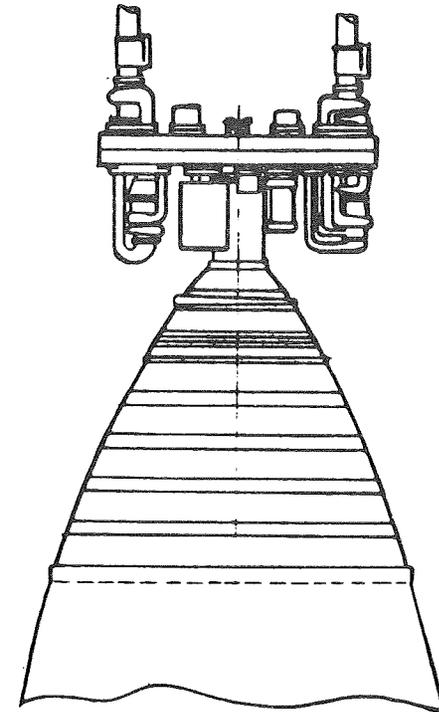
CONVENTIONAL PACKAGING



OPEN PACKAGING FOR
EASE OF MAINTENANCE



MODULAR PACKAGING
PULL OUT/PLUG IN MAINTENANCE



ADVANCED ENGINE PACKAGING AND DIAGNOSTICS FACILITATE ENGINE
AND COMPONENT SERVICE AND MAINTENANCE

Figure 9. Engine Packaging for Space-Based Maintainability

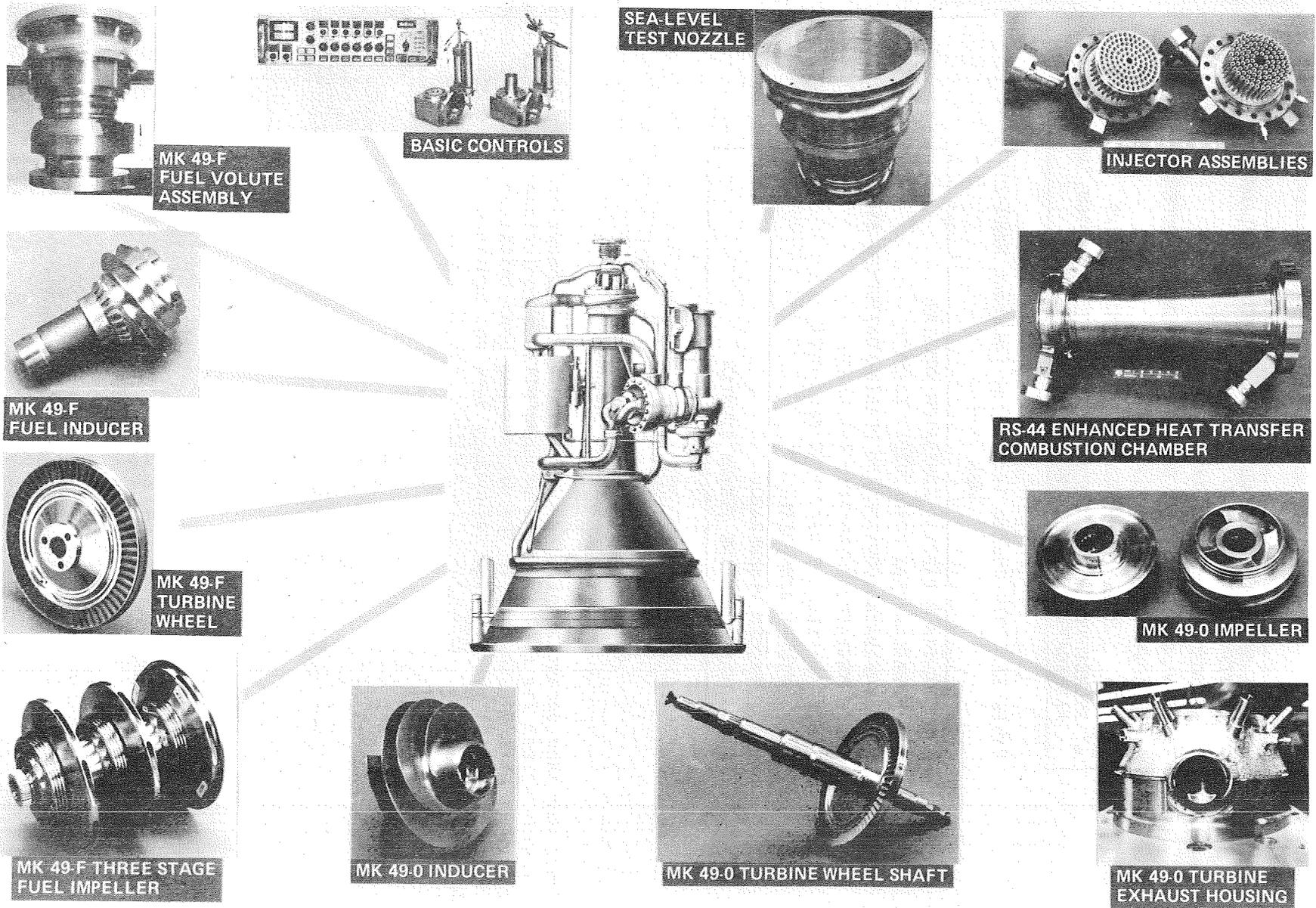


Figure 10. RS-44 Engine Test Bed Hardware

ORIGINAL PAGE IS
OF POOR QUALITY

Table I. Contract and In-House OTV Engine Activities

- NASA OTV ROCKET ENGINE TECHNOLOGY PROGRAM PLANNED TO CONTINUE THROUGH 1990
 - CONTRACT NAS3-23172 COMPLETED
 - SYSTEM STUDY - DEFINITION OF NEEDED TECHNOLOGY
 - CONTRACT NAS3-23733 STARTED
 - COMPONENT TECHNOLOGY AND SYSTEM STUDIES
- ROCKETDYNE IN-HOUSE COMPONENT ANALYSIS, DESIGN, AND FABRICATION PROCEEDING ON SCHEDULE

Table II. OTV Engine Technology Contract NAS3-23773
Task Status

- TWO-STAGE PARTIAL ADMISSION TURBINE
- ENHANCED HEAT LOAD THRUST CHAMBER
- INTEGRATED CONTROL AND HEALTH-MONITORING SYSTEM
- INTEGRATED COMPONENTS EVALUATOR
- HIGH VELOCITY DIFFUSING CROSSOVER
- SOFTWARE RING SEALS
- HYDROGEN REGENERATOR
- ADVANCED ENGINE SYSTEM STUDIES

CONCLUDING REMARKS

There are many potential problems in producing a high-performance, space-viable rocket engine system for the OTV. The process will be evolutionary and will require the support of NASA and Industry. The process has been initiated with a well-ordered plan for establishing the required technology base and continued future effort should be strongly supported.