

## SPACE SHUTTLE AUXILIARY PROPULSION TECHNOLOGY PLANS

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### INTRODUCTION

Auxiliary propulsion for the Space Shuttle has been identified as a critical technology area. Requirements for long system life, reusability, minimal checkout and maintenance, and high performance are unique and critical to the Space Shuttle concept. The technology base for auxiliary propulsion systems utilizing gaseous hydrogen and gaseous oxygen, the selected propellants, is very limited, however, and a major extension to current state-of-the-art will be needed to meet such requirements. In addition, consideration of translational propulsion (e.g., orbital maneuvering) will impose an added complexity. To insure that decision milestones can be met in a timely manner, thus leading to an acceptable Space Shuttle development schedule, NASA has initiated an in-depth component and system technology program in this area.

## APS Technology Plan

Five general objectives have been outlined for the technology work in the auxiliary propulsion system (APS) area. A continuing effort is devoted to identification of technology needs, as related to the most current operational requirements, and to assessment of technology status relative to the needs. Screening of components and subsystems, to define the most attractive systems, is required in order to provide a reasonable limitation to the work in this area. For those items not previously evaluated, fundamental limits as well as operational limits must be established if overall feasibility is to be demonstrated. The largest efforts, however, will be devoted to generation of extensive engineering data. Such data will provide an in-depth understanding of system and component design and operation, and they will also be useful in establishing realistic performance and design characteristics. This technology level is required if shuttle vehicle study efforts, both current and future, are to be meaningful, and if risk is to be minimized in the development stage. Finally, during the development program itself, it is expected that technology efforts may be required to provide support or to explore attractive alternate approaches, possibly approaches offering improvements in system performance.

The approach to meeting these objectives is primarily as outlined. System concepts will be defined, and associated components and subsystems identified. Analytical screening will reduce the number to a workable level, and then experimental evaluation of the critical items will be conducted. This establishes performance characteristics necessary for final system design. Ultimately, complete system evaluation—both analytically and experimentally—will be required to obtain an understanding of component and subsystem interactions.

# AUXILIARY PROPULSION SYSTEM TECHNOLOGY PLAN

## OBJECTIVES

- IDENTIFY TECHNOLOGY STATUS & NEEDS
- DEFINE ATTRACTIVE SYSTEMS, SUBSYSTEMS, & COMPONENTS
- DEMONSTRATE FEASIBILITY
- GENERATE COMPREHENSIVE TECHNOLOGY BASE TO:  
    PROVIDE INPUT TO VEHICLE TRADEOFF STUDIES & DESIGNS  
    PROVIDE BASIS FOR INITIATION OF LOW TECHNICAL RISK  
    DEVELOPMENT
- SUPPORT DEVELOPMENT EFFORTS

## APPROACH

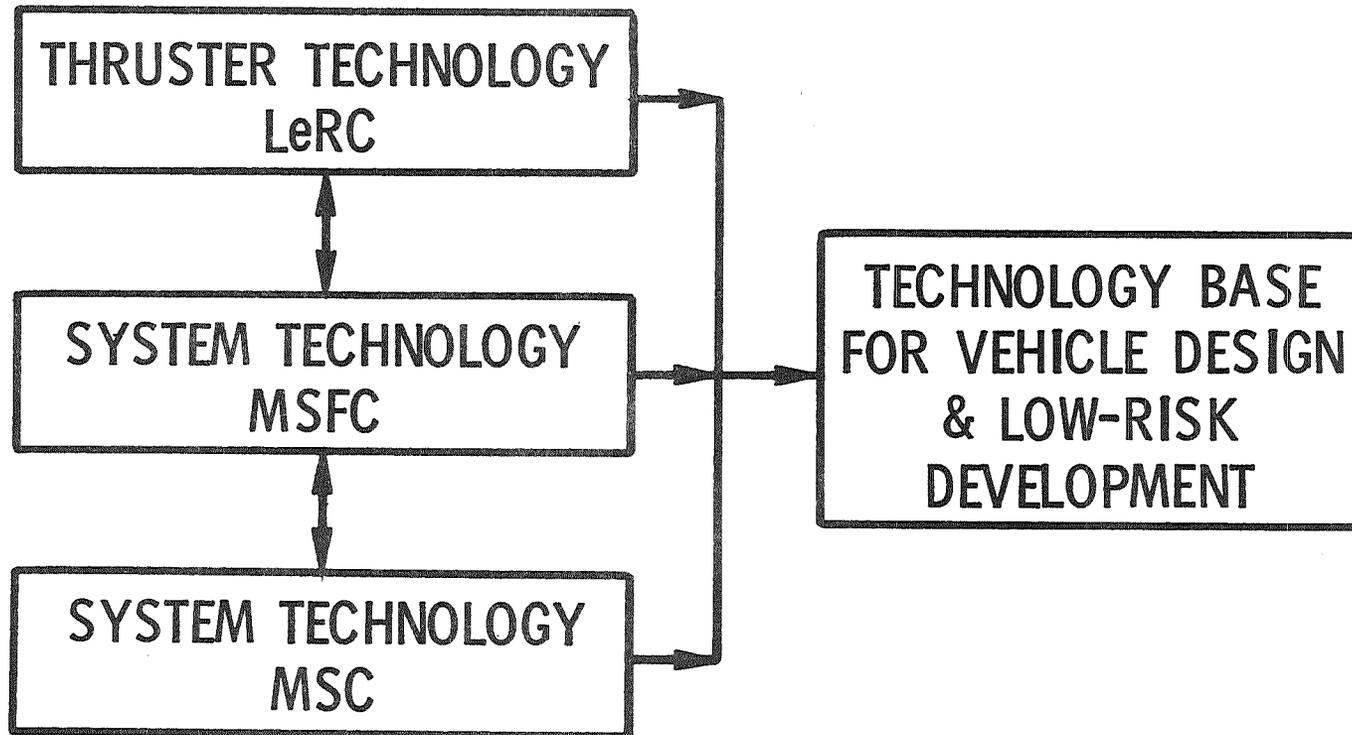
- CONCEPTUAL DEFINITION
- SCREENING
- INVESTIGATION OF CRITICAL COMPONENTS/SUBSYSTEMS
- SYSTEM EVALUATION

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Auxiliary Propulsion System  
Technology Plan - Responsibilities

To conduct this technology program on the APS, three centers - Lewis Research Center, Marshall Space Flight Center, and the Manned Spacecraft Center - have been assigned certain general responsibilities. Definition of system requirements will be a prime responsibility of MSFC and MSC due to their close relationships to the current vehicle studies. Associated feed system technology efforts, and in particular the feed system-vehicle integration, will also be primarily conducted by these centers. The thruster technology program, which includes efforts on thrust chamber cooling, combustion, ignition, and control valves, will be the responsibility of Lewis. Obviously, close coordination between all three centers and their associated contractors is required if duplication or unnecessary efforts are to be avoided, and its results are to be utilized in a timely manner.

# AUXILIARY PROPULSION SYSTEM TECHNOLOGY PLAN



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## APS Definition Study

Basic to all the effort in the auxiliary propulsion area are the APS Definition Study contracts recently awarded. These studies will generate information and data for use in the overall shuttle vehicle study efforts as well as for the technology programs. The studies are broad in scope in order to identify attractive concepts, to define ranges of application, to define any limitations on performance or design, to identify critical technology areas, and to establish development or technology priorities.

To be realistic, the studies are centered around two different vehicle designs representative of the ones currently under consideration. For these vehicles, trade-off studies will be conducted for a variety of system concepts, and following a screening and selection process, preliminary design studies and trades will be performed in detail. To be included in the study are guidance and control analysis; effects of vehicle configuration on thrust level, number of engines, and location of engines; determination of total impulse and impulse bit requirements; definition of vehicle interior environments; and, finally, design of the feed system based on these and various other inputs from the study.

A key factor in these studies is that the results must have sufficient scope and flexibility to be pertinent to other shuttle vehicle designs as they evolve. Another important consideration is that systems for attitude control, with varying requirements for translational maneuvers, are to be evaluated and optimized. This evaluation will be of importance in establishing preliminary requirements for the Orbiter Maneuvering System (OMS).

Follow-on activities in the definition area may be necessary to evaluate integration of the auxiliary propulsion feed system with other cryogenic storage and feed systems of the Space Shuttle. The desirability of such integration is presently being evaluated. More in-depth study is required, however, to fully establish the impact of such integration on the APS requirements.

# AUXILIARY PROPULSION SYSTEM DEFINITION STUDY

## OBJECTIVES

- GENERATE DATA FOR VEHICLE STUDY & DESIGN EFFORTS
- IDENTIFY ATTRACTIVE CONCEPTS
- DEFINE RANGES OF APPLICATION & LIMITATIONS
- IDENTIFY CRITICAL TECHNOLOGY AREAS & DEVELOPMENT PRIORITIES

## APPROACH

- SPECIFIC VEHICLES SELECTED
- TRADE-OFF STUDY OF ALTERNATE SYSTEM CONCEPTS
- PRELIMINARY DESIGN OF SELECTED SYSTEM(S)

## CONSIDERATIONS

- INFORMATION PERTINENT TO OTHER VEHICLES
- BOTH ATTITUDE CONTROL & TRANSLATION MANEUVERS

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## APS Definition Study - Responsibilities

This definition study is to be performed by two different contractors, reporting to MSFC and MSC as shown. The work is divided into low pressure studies and high pressure studies, reflecting the general types of feed systems to be separately evaluated. Low pressure feed systems utilize the main engine ascent tankage in some manner, and the APS thrusters operate in the range of 10-20 psia. High pressure APS thrusters have chamber pressures in the order of 100-500 psia, and the associated feed system may use turbo pumps, as one example.

## AUXILIARY PROPULSION SYSTEM DEFINITION STUDY

NASA CENTER	CONTRACTORS	
	LOW PRESSURE STUDY	HIGH PRESSURE STUDY
MSC	MCDONNELL DOUGLAS <sup>1</sup> (NAS 9-11012)	TRW SYSTEMS <sup>2</sup> (NAS 9-11013)
MSFC	TRW SYSTEMS <sup>2</sup> (NAS 8-26249)	MCDONNELL DOUGLAS <sup>2</sup> (NAS 8-26248)

<sup>1</sup>ASSISTED BY AEROJET LIQUID ROCKET CO.

<sup>2</sup>ASSISTED BY AIRESEARCH, & PRATT & WHITNEY AIRCRAFT.

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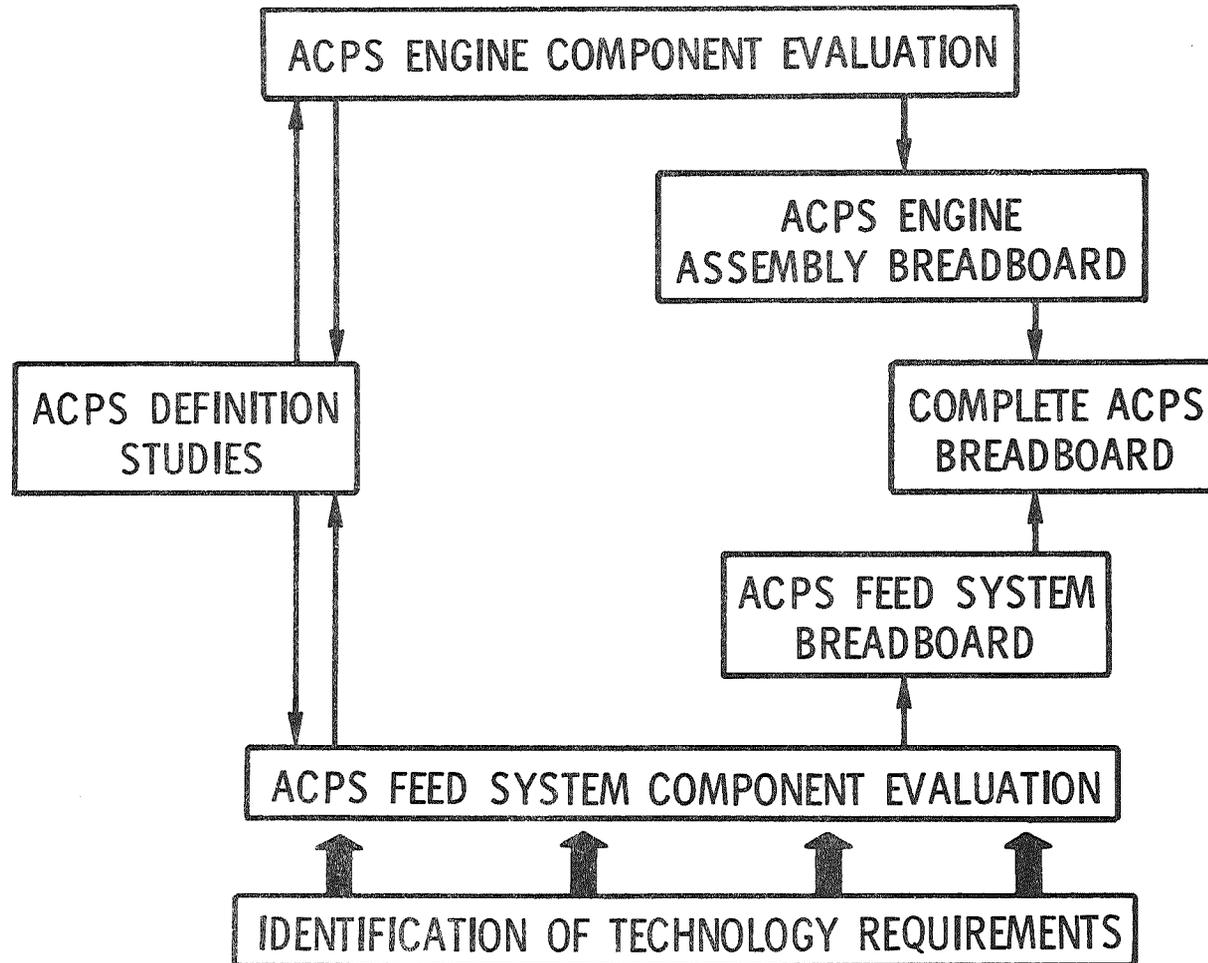
## Attitude Control Propulsion System

### Technology Plan

The Attitude Control Propulsion System (ACPS) is required to satisfy all the attitude control functions as well as some amount of translational maneuvering. The overall plan for technology efforts in this area begins with the APS Definition Studies. These studies will establish detailed requirements for both ACPS engine and feed system components. However, based on preliminary knowledge of these requirements, component evaluation will start prior to completion of the definition studies. Hopefully, component data will be available in time to factor into the definition studies. As rapidly as possible, work on breadboard systems will be initiated to gather information on component interactions. Marriage of the engine and feed system into a complete integrated package will be the final step in the technology program.

Identification of technology requirements will be a continuing process throughout the course of the technology efforts. Such identification can come from many different sources (such as the Phase B Vehicle Studies), and the technology efforts will be modified, as necessary, to reflect the latest requirement.

# ATTITUDE CONTROL PROPULSION SYSTEM TECHNOLOGY PLAN



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## ACS Engine Technology Program

In the engine technology area, the general objective is again to establish a comprehensive technology base. The general approach has been to break the effort down into four key items: (1) injection techniques for gaseous propellants, (2) chamber cooling designs for long life, (3) reliable ignition concepts for hydrogen-oxygen in a manner consistent with attitude control requirements, and (4) design of valves for fast operation and high cycle life. In all these areas, the operational limits, life expectancy, response, and performance must be established on the component level. Next, integration and evaluation of interactions must be accomplished. Forthcoming from this effort will be the design data necessary for initiation of low-risk development.

Considerations unique to the shuttle vehicle concept will guide the efforts in all of the technology areas. One hundred missions (as a goal) with multiple uses on each flight constitute severe requirements. To do this with a minimum of inspection and servicing is particularly demanding. Finally, since mission requirements are not well established, and, indeed, since they may never be, the auxiliary propulsion system must be capable of widely varying operating ranges. These considerations have a major impact on engine design, and the entire engine technology program is devoted to obtaining an understanding of how these requirements can best be met, and to what degree.

# ACS ENGINE TECHNOLOGY PROGRAM

## OBJECTIVE

- GENERATE A COMPREHENSIVE TECHNOLOGY BASE TO:  
DEFINE GUIDELINES FOR SYSTEM & VEHICLE TRADEOFF STUDIES  
PROVIDE BASIS FOR LOW-RISK ENGINE DEVELOPMENT

## APPROACH

- INVESTIGATE KEY COMPONENT TECHNOLOGY AREAS OF:  
GASEOUS PROPELLANT INJECTION  
LONG LIFE CHAMBER  
RELIABLE IGNITION  
HIGH CYCLE LIFE VALVE
- EVALUATE OPERATIONAL LIMITS, LIFE, RESPONSE, PERFORMANCE
- EVALUATE INTERACTIONS ON INTEGRATED ENGINE
- ESTABLISH DESIGN CRITERIA

## UNIQUE DESIGN CONSIDERATIONS

- LIFE (REUSABILITY), MINIMUM INSPECTION & SERVICING, FLEXIBILITY

## ACS Engine Technology Areas

Considerations to be investigated for each component area are listed. Work on injectors will be conducted jointly with the cooling analysis of the thrust chambers. Since performance of the attitude control thrusters is not as important a consideration as durability and life, injector efforts will primarily be devoted to achieving a cool, uniform boundary layer. Streaking must be minimized, and the wall temperatures must be kept to a very low value, if thermal fatigue problems are to be avoided. Establishment of operational limits - such as propellant temperature and pressure ranges - will also be an important part of this investigation. Their effects on mixture ratio and thrust level will be evaluated, and control techniques determined.

In the ignition area, three approaches are being pursued. Electrical ignition - which includes spark plugs and plasma devices - constitutes the main stream effort. Operating limits and design variables will be evaluated for these units. Investigation of the problems associated with high tension electrical leads, and the possible electromagnetic interference (EMI) from spark plugs, will be included. Catalytic ignition has been under investigation by LeRC for a number of years. Many design variables and operating limits are already known. For the Space Shuttle, design criteria will be extended, durability and life of the catalyst bed will be more firmly established, and improvements in the design - such as heating of the catalyst bed to promote more rapid ignition at low propellant temperatures - will be made. A third approach which is being investigated, although to a more limited amount than for electrical or catalytic devices, is the use of auto-ignition. This concept uses the so-called "resonance tube" ignition principle. Hydrogen gas flows from a nozzle and impinges on the open end of a tube (closed at the other end). Shock waves in the tube cause an increase in gas temperature. Oxygen gas, admitted from the closed end, will then ignite with the hot hydrogen gas. This concept has been the subject of research programs at several labs (e.g. LeRC and Ohio State University), but there are still many design variables, operating limits, and other unknowns which must be resolved.

The area of valves represents a major problem area, and one in which the Shuttle requirements - as presently known - are well beyond current state-of-the-art. To achieve low leakage values, for the large number of required cycles, will necessitate major advances in sealing closure design. Our program will screen valve concepts and experimentally evaluate design criteria for many different sealing closures (e.g. poppet, ball, butterfly, blade, etc.) Both metal-on-metal and metal-on-plastic seat combinations will be included. For the low pressure APS, weight and response of the valves will be a major problem to overcome. Line sizes, hence the valves, will be very large (6-9 inches diameter). New valving concepts may be required for this system.

Following the above component efforts, a complete engine package will be assembled and tested to determine interaction effects, pulsing performance, and life.

# ACS ENGINE TECHNOLOGY AREAS

## THRUST CHAMBER/INJECTOR

INJECTION DESIGN CRITERIA  
COOLING CONCEPT SCREENING  
DURABILITY & LIFE  
PERFORMANCE & RESPONSE  
PROPELLANT TEMP/PRESSURE SENSITIVITY  
FABRICATION

## IGNITION

ELECTRICAL, CATALYTIC, AUTOIGNITION  
DESIGN VARIABLE EFFECTS  
OPERATING LIMITS  
RESPONSE  
DURABILITY & LIFE  
VEHICLE INTERACTIONS

## VALVES

DESIGN CONCEPT SCREENING  
SEALING CLOSURE INV  
LEAKAGE  
CYCLIC LIFE  
ACTUATOR INV  
RESPONSE  
WEIGHT  
VEHICLE INTERACTIONS

## THRUST CHAMBER ASSEMBLY

INTEGRATION (INTERACTION EFFECTS)  
PULSED PERFORMANCE & RESPONSE  
DURABILITY & LIFE

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## ACPS Engine Program Schedule

The schedule for the engine program is shown on the attached figure. Parallel and multiple contracts on thrusters, ignition, and valves will extend from July, 1970 to July, 1971. New programs under consideration for this fiscal year (FY 1971) include efforts on pressure regulators and gas/gas combustion. Pressure regulation will be critical for engine mixture ratio control, and reliable components in this area are a necessity. Since our understanding of gas/gas combustion and combustion instability is limited, efforts in this area are also necessary. Following completion of the component work, complete engine breadboard systems will be assembled and tested, using optimum and flightweight (or at least flight type) components. NASA in-house activities will be maintained throughout the technology time period to support the contract efforts. These activities consist of evaluation of alternate component and system concepts, as well as integration of components from several different contractors. Close coordination will be maintained with the system definition studies and with the Phase B Vehicle Studies.

# ATTITUDE CONTROL PROPULSION SYSTEM

## ENGINE PROGRAM SCHEDULE

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PROGRAM	CY 1970	CY 1971	CY 1972
THRUSTERS			
IGNITION			
VALVES			
PRESSURE REGULATOR			
GAS/GAS COMBUSTION			
ENGINE BREADBOARD			
NASA IN-HOUSE ACTIVITIES			
<hr style="border-top: 1px dashed black;"/>			
SYSTEM DEFINITION - MSFC/MS			
PHASE B VEHICLE STUDIES			

CS-54906

## Attitude Control Propulsion System

### Feed System Program

This program will be based upon identification of attractive feed system approaches during the APS Definition Studies. Components of such systems will be investigated, and, ultimately, system breadboards will be evaluated. Some previously identified critical components and their design considerations are listed. Liquid acquisition devices are particularly critical, being basic to many different types of feed systems. Such devices probably constitute the area of greatest unknown and will require intensive investigation to establish feasibility and to determine design parameters.

# ATTITUDE CONTROL PROPULSION SYSTEM FEED SYSTEM PROGRAM

## OBJECTIVES

- GENERATE COMPONENT TECHNOLOGY
- DEFINE:
  - SYSTEM DYNAMICS & INTERACTIONS
  - OPERATIONAL LIMITS
  - EXTENT OF REUSE, REFURBISHMENT, & ONBOARD CHECKOUT

## CRITICAL ITEMS

- HEAT EXCHANGERS - THERMAL FATIGUE, CONTROL
- GAS GENERATORS - THERMAL FATIGUE, CONTROL, IGNITION
- VALVES - LOW LEAKAGE, HIGH CYCLIC LIFE
- PRESSURE REGULATION - LONG LIFE
- PUMPS OR TURBOCOMPRESSORS - TWO PHASE FLOW, MULTIPLE START,  
LOW FLOW
- STORAGE TANKS & ACCUMULATORS - THERMAL CONTROL, WEIGHT, CYCLIC  
LIFE
- LIQUID ACQUISITION OR PHASE SEPARATION DEVICES - RELIABLE,  
ACCELERATION INSENSITIVE
- SYSTEM CONTROL - INTERACTIONS

CS-54907

## Attitude Control Propulsion System

### Feed System Program Schedule

As previously indicated, efforts will start on critical components as rapidly as possible. As components become available, feed system breadboards will be fabricated and tested. Several component and system areas have previously been identified, and efforts are already underway as shown. Gaseous feed system flow dynamics will be an effort under the cognizance of MSC for FY 1971. Effects of vibration and cycling on bellows design is being evaluated under a LeRC contract with Bell Aerosystems, Inc. In support of the NASA program, the Air Force is conducting work on propellant orientation and gaging. Close coordination will be maintained with the system definition studies, engine component and breadboard evaluations, and the Phase B vehicle studies.



### Orbiter Maneuvering System (OMS) Engine

Large translational maneuvers will place a premium on high performance. The need for high specific impulse, along with thrust requirements of 8,000 to 15,000 lbs. may require another engine system in addition to the attitude control propulsion system. This engine will have requirements (actually goals at the present time) and implied design considerations as shown. The use of helium pressurization or autogeneous pressurization for multiple restarts will require careful evaluation. Use of autogeneous pressurization might provide a lighter weight system, but would require a pressure-fed idle mode for engine start, along with quick chilldown capability. Reusability (for 100 missions) implies an engine that is easily inspected and maintained. Reliability requirements will place a premium on conservative safety margins and design. Flexibility in the engine is desirable to provide propellant utilization control (by capability for operation over a broad mixture ratio range). Integration to the largest possible extent with the ACPS is also desirable to provide minimum weight and maximum reliability for the total auxiliary propulsion system.

## ORBITER MANEUVERING SYSTEM (OMS) ENGINE

- FUNCTION: PERFORM HIGH  $\Delta V$  TRANSLATIONS ( $\approx 1500$  FPS TOTAL)
- THRUST: 8 000-15 000 LB

### REQUIREMENTS (GOALS)

10 RESTARTS/MISSION

MAINTAINABLE & REUSABLE  
(100 MISSION LIFE)

RELIABLE

FLEXIBLE

### DESIGN CONSIDERATIONS

AUTOGENEOUS PRESSURIZATION;  
PRESSURE-FED IDLE MODE; QUICK  
CHILLDOWN

ACCESSIBLE & EASILY REPLACED  
COMPONENTS; SELF-CONTAINED  
CHECKOUT

CONSERVATIVE STRESS VALUES; HIGH  
MARGINS ON COOLING; CONTROLS  
REDUNDANCY, DYNAMICALLY STABLE

BROAD O/F OPERATING RANGE; HIGH  
MARGINS ON POWER; INTEGRATION  
WITH ACS; HIGH ISP; LOW WT

## OMS Engine Program

Several programs in this area are planned for FY 1971. MSC will conduct an OMS/Vehicle Trade-Off Study to establish system requirements, desirable degree of integration with the ACPS, and attractive feed system designs. LeRC will conduct an engine characterization program, concentrating on turbopump drive cycle screening and selection, followed by preliminary engine design. As indicated, this characterization would also include dynamic modeling and control system evaluation. This program would be similar to recent programs conducted by LeRC for characterization of a FLOX Methane Engine (NAS3-12010 and NAS3-12024). Further efforts on evaluation of fiberglass composite feed lines is also planned. Such lines may provide a quick chilldown capability, desirable for both the OMS engine and the main engines of the Space Shuttle.

# OMS ENGINE PROGRAM

FY 1971

## OMS/VEHICLE TRADE-OFF STUDY - MSC

- DEFINE SYSTEM REQUIREMENTS & VEHICLE INTEGRATION EXTENT
- ESTABLISH PRELIMINARY SYSTEM DESIGN
- IDENTIFY TECHNOLOGY NEEDS
- MAJOR CONSIDERATION - EVALUATE OMS ENGINE INTEGRATION WITH ACPS

## ENGINE CHARACTERIZATION - LeRC

- EVALUATE
  - COOLING TECHNIQUES
  - TURBOPUMP DRIVE CYCLES
  - CONTROL SYSTEMS
- PERFORM
  - COMPONENT DESIGN
  - ENGINE PRELIMINARY DESIGN
  - DYNAMIC MODELING
- INVESTIGATE
  - INTEGRATION WITH ACPS
  - CHILLDOWN & STARTUP
  - SELF-CONTAINED CHECKOUT INSTRUMENTATION

## THERMAL CONDITIONING - LeRC

- COMPOSITE FEED LINES