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ADVANCED EARTH-TO-ORBIT PROPULSION TECHNOLOGY PROGRAM OVERVIEW

IMPACT OF CIVIL SPACE TECHNOLOGY INITIATIVE

Frank W. Stephenson Jr., NASA HQS

ABSTRACT

The NASA Earth-to-Orbit (ETO) Propulsion Technology Program is dedicated to advancing rocket engine technologies essential for the development of fully reusable engine systems that will enable future space transportation systems to achieve truly low cost, routine access to space. The program addresses technology advancements in the areas of engine life extension/prediction, performance enhancements, reduced ground operations costs, and in-flight fault tolerant engine operations. This focused program was initiated in FY 1981 with the primary objective of acquiring increased knowledge and understanding of rocket engine chemical and physical processes in order to evolve more realistic analytical simulations of engine internal environments, to derive more accurate predictions of steady and unsteady loads, and using improved structural analyses, to more accurately predict component life and performance, and finally to identify and verify more durable advanced design concepts. In addition, efforts were focused on engine diagnostic needs and advances that would allow integrated health monitoring systems to be developed for enhanced maintainability, automated servicing, inspection, and checkout, and ultimately, in-flight fault tolerant engine operations In FY 1988, the NASA/OAST Civil Space Technology Initiative (CSTI) was approved by the Congress and is currently being implemented. Included in that initiative is increased emphasis on ETO propulsion technology. It provides the means for validating acquired technologies on large-scale component and subsystem technology testbed hardware in real rather than simulated operating environments. This paper addresses the program goals and objectives, and the impact of CSTI on the ETO Propulsion Technology Program.

CIVIL SPACE TECHNOLOGY INITIATIVE

The Civil Space Technology Initiative (CSTI) was developed to restore and revitalize the U.S. civil space technology base that has been in a steady decline for many years. An assessment of the current state of technology in this country as a result of this decline is presented in Figure 1, along with some sobering potential consequences. One principal concern is the fact that U.S. world leadership in space is being seriously challenged and could be overtaken by foreign interests in the not too distant future.

STATE OF TECHNOLOGY

OAST

☒ TECHNOLOGY BASE IS DEFICIENT
  - LIVING OFF PAST
  - TECHNOLOGY NO LONGER LEADS WITH SOLUTIONS.... IT CHASES PROBLEMS

☒ EXPECTATIONS EXCEED WHAT TECHNOLOGY CAN DELIVER

☒ U.S. LEADERSHIP CHALLENGED

☒ DECLINE OF NASA EXPERTISE

Figure 1.

The concept of CSTI evolved from a recognized need to revitalize the nations's civil space technology base. As the first step in this process, CSTI has been focused on transportation to and operations in low-Earth-orbit and in supporting science, as shown in Figure 2.

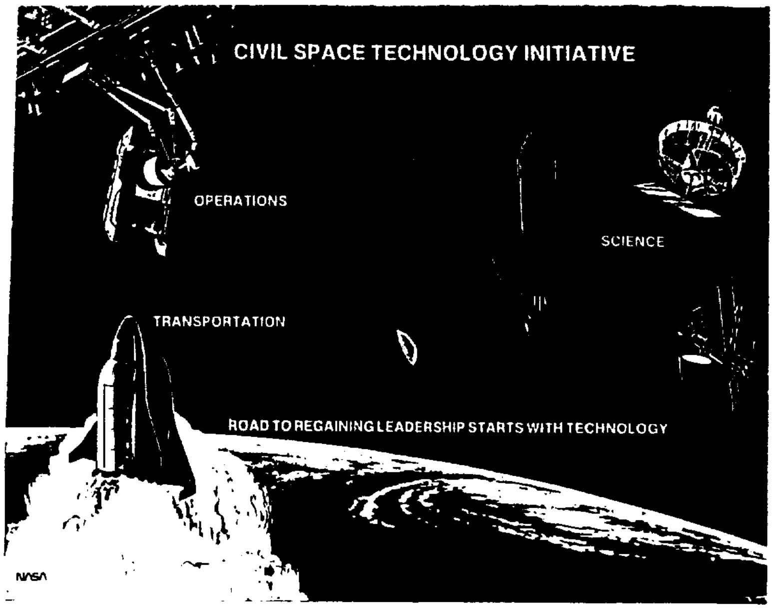


Figure 2.

In order to address the most critical technology issues, focused technology efforts have been planned, each with multiple technology program elements. All of technology elements are coordinated with and in some cases partially co-managed with user offices. The focused efforts and their program elements are listed in Figure 3, and Figure 4 shows how multiple elements are grouped to provide the technology base for either enabling low cost access to space or to enable specific NASA missions.

CSTI FOCUS

☒ AUTOMATION AND ROBOTICS
  - ROBOTICS
  - AUTONOMOUS SYSTEMS

☒ PROPULSION
  - EARTH-TO-ORBIT
  - BOOSTER TECHNOLOGY

☒ VEHICLE
  - AEROASSIST FLIGHT EXPERIMENT

☒ INFORMATION SYSTEMS
  - SCIENCE SENSOR TECHNOLOGY
  - DATA: HIGH RATE/CAPACITY

☒ LARGE STRUCTURES AND CONTROL
  - CONTROL OF FLEXIBLE STRUCTURES
  - PRECISION SEGMENTED REFLECTORS

☒ POWER
  - HIGH CAPACITY

Figure 3.

CSTI FOCUSED THRUSTS

ENABLE LOW-COST ACCESS TO SPACE

- LAUNCH VEHICLE PROPULSION
- BOOSTER TECHNOLOGY
- LAUNCH SYSTEM AUTOMONY
- AEROBRAKING TECHNOLOGY

ENABLE NASA MISSIONS

- HIGH CAPACITY POWER
- AUTOMATION & ROBOTICS
- LARGE STRUCTURES & CONTROL
- SENSOR DEVICE TECHNOLOGY
- HIGH DATA RATE SYSTEMS

Figure 4.

Figure 5 is a summary of the NASA/OAST budget as it was submitted to the Congress for FY 1989. It shows the approved funding for FY 1988 for both the R&T Base and CSTI Programs, as well as the requested funding for FY 1989. It also shows shows FY 1987 funding, including the Office of Space Flight (Code M) ETO propulsion related supporting technology funding. It should be noted that a part of the OAST Propulsion R&T program along with the Chemical Propulsion Systems Technology Program were incorporated into CSTI in FY 1989. The proposed FY 1989 Pathfinder Initiative is included. Pathfinder represents the second step in the space technology revitalization process. It is geared towards providing the technology base for missions beyond low-Earth-orbit, in particular human missions to the Moon and to Mars, as well as associated precursor missions. Funding dedicated specifically to propulsion technologies in the R&T Base, CSTI, and Pathfinder programs is outlined on the figure.

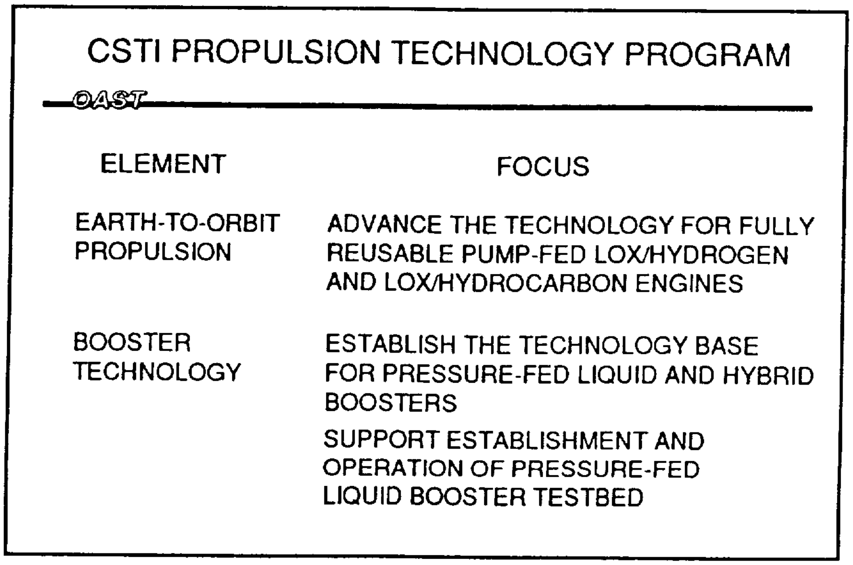
OAST FY 1989 SPACE R&T BUDGET SUBMISSION TO CONGRESS

	FY87	FY88	FY89	FY90	FY91	FY92	FY93
SPACE R&T	206.0	223.6	390.9	459.7	486.8	472.7	477.8
R&T BASE	130.6	108.4	134.1	140.2	144.7	148.5	154.1
Propulsion R&T	*18.8*	*13.3*	*19.7*	*20.7*	*21.3*	*21.9*	*22.7*
(Code M: Durablilty)	*(3.0)*						
SYSTEMS TECHNOLOGY	75.4						
Chem Prop Systems Tech	*9.9*						
(Code M: SSME Testbed)	*(10.0)*						
Space Flight Syst Tech	11.3						
Automation & Robotics	18.0						
CSTI PROGRAM		115.2	156.8	179.5	162.1	124.2	103.7
Automation & Robotics		25.1	25.9	26.6	27.6	28.1	29.3
Propulsion		*23.8*	*46.7*	*51.4*	*48.1*	*26.7*	*22.6*
Vehicle		15.0	28.0	46.0	40.0	30.0	13.0
Information Technology		16.5	17.1	17.5	12.6	12.9	13.3
Large Structures & Ctrl		22.0	25.1	23.9	24.5	20.1	20.9
Power		12.8	14.0	14.1	9.3	6.4	4.6
PATHFINDER			100.0	140.0	180.0	200.0	220.0
Exploration Technology			17.0	25.0	47.0	50.0	61.0
Operations Technology			41.0	46.0	52.0	45.0	38.0
Humans-in-Space Tech			13.0	26.0	40.0	49.0	52.0
Transfer Vehicle Tech			14.0	18.0	41.0	56.0	69.0
(Chem/Electric Propul sion)			*(8.0)*	*(8.0)*	*(19.0)*	*(23.0)*	*(26.0)*
Mission Studies			15.0	25.0	-	-	-

Figure 5.

IMPACT OF CSTI ON THE NASA ADV ETO PROPULSION TECHNOLOGY PROGRAM

The CSTI Propulsion Technology Program has two major elements, which are Earth-to-Orbit Propulsion and Booster Technology. As shown in Figure 6, the focus of the ETO Propulsion Program is to advance the technology for fully reusable pump-fed liquid oxygen (LOX)/hydrogen and LOX/hydrocarbon engines. The Booster Program is focused on safe-abort options to the current Space Shuttle Solid Rocket Boosters (SRB's). Technologies for both Pressure-Fed Liquid (PFL) Boosters and Hybrid Boosters are planned.



CSTI PROPULSION TECHNOLOGY PROGRAM

ELEMENT	FOCUS
EARTH-TO-ORBIT PROPULSION	ADVANCE THE TECHNOLOGY FOR FULLY REUSABLE PUMP-FED LOX/HYDROGEN AND LOX/HYDROCARBON ENGINES
BOOSTER TECHNOLOGY	ESTABLISH THE TECHNOLOGY BASE FOR PRESSURE-FED LIQUID AND HYBRID BOOSTERS SUPPORT ESTABLISHMENT AND OPERATION OF PRESSURE-FED LIQUID BOOSTER TESTBED

Figure 6.

Figure 7 illustrates the size difference between the current SRB's and Hybrid replacements as configured from preliminary studies. Since this conference is concerned with technology issues related to pump-fed reusable engines, no further discussion of the pressure-fed and hybrid technology programs will be included.

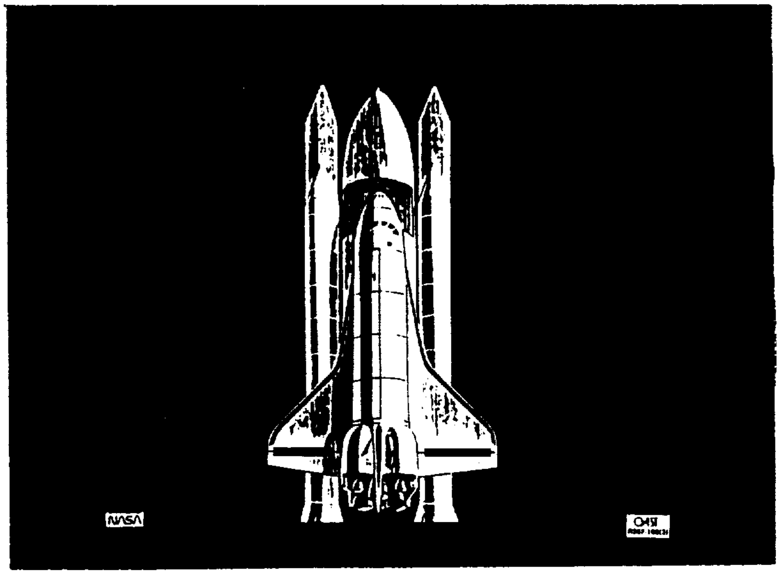


Figure 7

Figure 8 depicts several classes of potential future ETO launch vehicles ranging from expendables, on the left side of the chart, through partially reusables to fully reusable flyback systems on the right, including the National Aerospace Plane (NASP). The vertical takeoff configurations on the right represent possible Shuttle II configurations (piloted vehicles), whereas those on the left are configured primarily as higher payload cargo delivery systems.

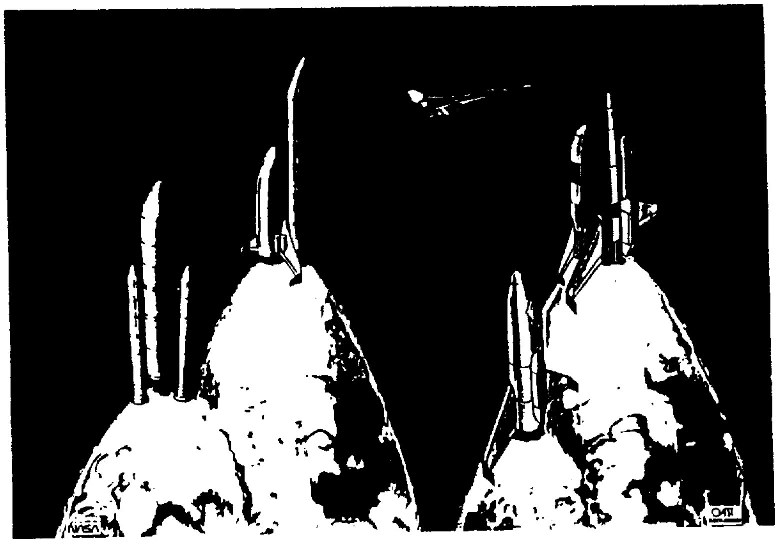


Figure 8

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OF POOR QUALITY

The focus of the ETO Propulsion Technology Program is primarily in support of fully reusable flyback vehicles, as stated in Figure 9.

CSTI ETO PROPULSION TECHNOLOGY PROGRAM

PROGRAM OBJECTIVE:

TO PROVIDE A VALIDATED TECHNOLOGY BASE THAT WILL ENABLE THE FUTURE DESIGN, DEVELOPMENT, AND OPERATION OF REUSABLE EARTH-TO-ORBIT PROPULSION SYSTEMS WITH KNOWN DESIGN MARGINS ASSURING 100 MISSION LIFE WITH HIGH ENGINE PERFORMANCE, RELIABILITY, AND QUALITY ASSURANCE, AND WITH FULLY AUTOMATED GROUND AND FLIGHT OPERATIONS.

Figure 9.

However, the technology base that is established will provide the understanding needed to trade engine service life against both cost and performance in order to optimize engine life cycle costs that will result in the least expensive ETO launch system, whether it is expendable, partially reusable, or fully reusable. This concept is graphically illustrated in Figure 10.

ENGINE PERFORMANCE/LIFE RELATIONSHIPS

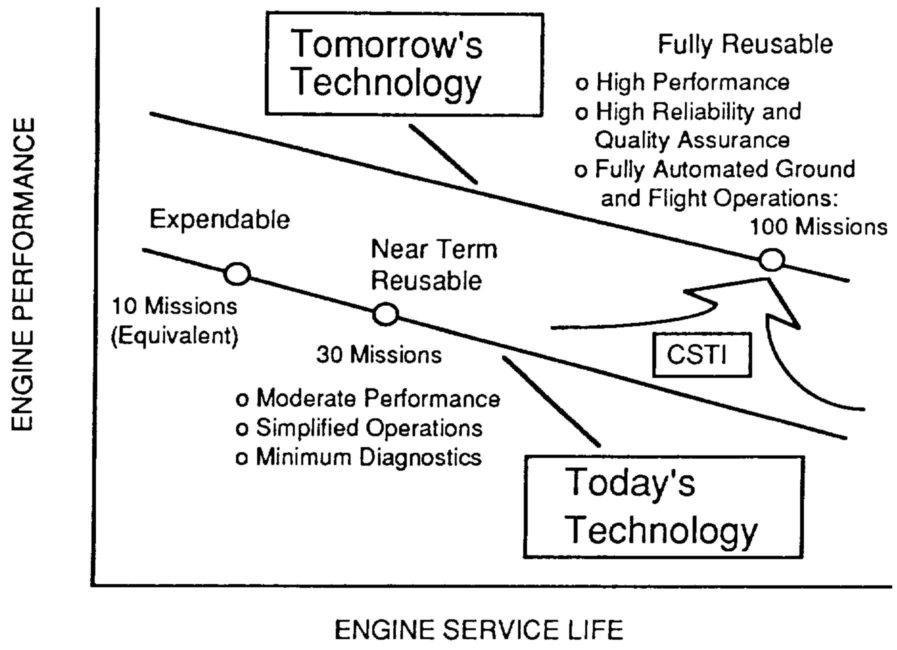


Figure 10.

Although a somewhat simplistic representation, it clearly indicates the goal of this program, which is to raise the technology level of ETO propulsion systems through a comprehensive in-depth focused technology program that will provide the capability to perform the trades cited above. Although a 100 mission service life capability has been established as a goal, the actual number of missions that will optimize vehicle costs will be determined from the type of vehicle selected, the kinds of missions that it is required to perform, and the launch rate that will ultimately be reached.

The program was originally structured along discipline lines in FY 1981. A working group made up of experts was created in a number of disciplines, but each discipline program was constructed to focus on critical problems across a number of specific engine components and subsystems as identified in the Space Shuttle Main Engine (SSME) development program. This structure which is still in effect is shown in figure 11.

TECHNOLOGY PROGRAM STRUCTURE

Hardware Focus Working Groups	Turbomachinery	Combustion Devices	Instrumentation	Controls	Ancillary Components	Engine System
A. Bearings	X		X			X
B. Structural Dynamics	X	X	X		X	X
E. Turbomachinery/ Fluid Dynamics	X		X			X
F. Fatigue/Fracture/Life	X	X	X		X	X
G. Combustion/Ignition		X	X			X
H. Fluid & Gas Dynamics	X	X				X
J. Instrumentation	X	X	X	X	X	
K. Controls			X	X	X	X
L. Manufacturing/Producibility/Inspection	X	X	X		X	
M. Materials	X	X	X		X	

Figure 11.

The turbomachinery area is a typical example of how discipline technologies are collectively focused on understanding and ultimately developing the design and analysis tools for longer-life, more efficient machines. Figure 12 shows a cross section of the SSME high pressure liquid oxygen pump.

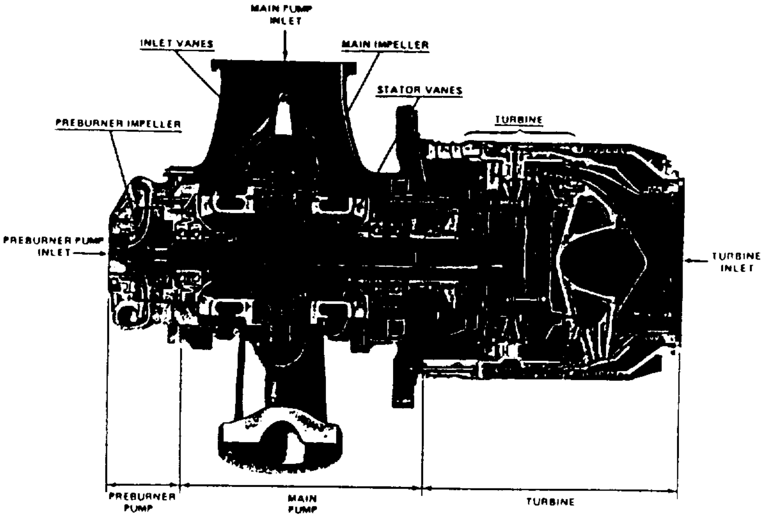
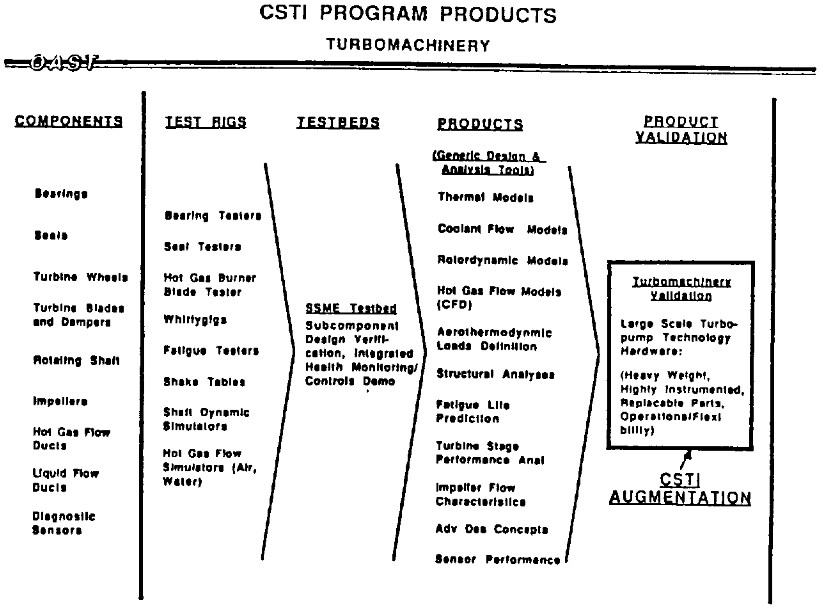


Figure 12.

The many internal parts that make up a turbopump can be seen in the drawing. These are also listed on the left side of Figure 13 along with typical test rigs that are used to either generate empirical data with which to construct analytical models and associated computer codes or to evaluate advanced designs in a simulated engine environment.



CSTI PROGRAM PRODUCTS

TURBOMACHINERY

COMPONENTS

Bearings

Seals

Turbine Wheels

Turbine Blades and Dampers

Rotating Shaft

Impellers

Hot Gas Flow Ducts

Liquid Flow Ducts

Diagnostic Sensors

TEST RIGS

Bearing Testers

Seal Testers

Hot Gas Burner Blade Tester

Whirlygigs

Fatigue Testers

Shake Tables

Shaft Dynamic Simulators

Hot Gas Flow Simulators (Air, Water)

TESTBEDS

SSME Testbed

Subcomponent Design Verification, Integrated Health Monitoring/Controls Demo

PRODUCTS

(Generic Design & Analysis Tools)

Thermal Models

Coolant Flow Models

Rotordynamic Models

Hot Gas Flow Models (CFD)

Aerothermodynmic Loads Definition

Structural Analyses

Fatigue Life Prediction

Turbine Stage Performance Anal

Impeller Flow Characteristics

Adv Des Concepts

Sensor Performance

PRODUCT VALIDATION

Turbomachinery Validation

Large Scale Turbopump Technology Hardware:

(Heavy Weight, Highly Instrumented, Replacable Parts, Operational/Flexibility)

CSTI AUGMENTATION

Figure 13.

The kinds of analytical models that are currently being developed in this manner are shown in the column labeled products. An example of a typical test rig is shown in Figure 14. This is a cryogenic bearing tester and represents an example of what it takes to try and simulate internal environments with such a device.

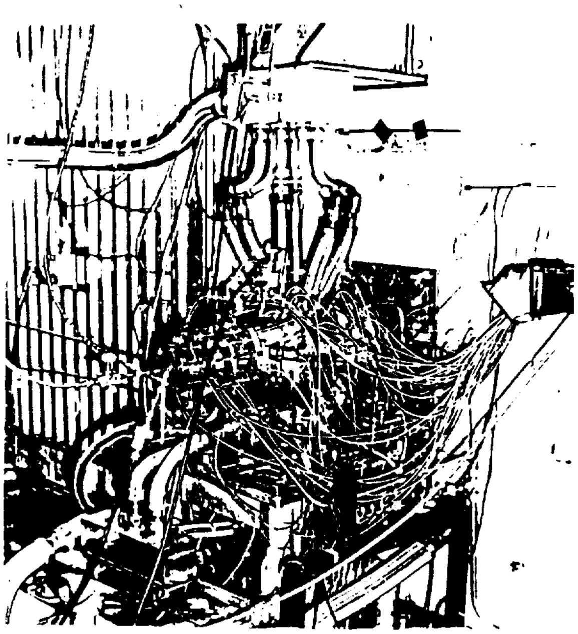


Figure 14.

A number of components, including advanced turbine blades, bearings and seals, as well as advanced instrumentation and diagnostic sensors will be further evaluated in the Code M SSME Technology Test Bed, which will allow testing in a real engine environment. A highly instrumented testbed engine is also scheduled for test which will provide initial limited validation of analytical models that have been previously developed utilizing the empirical data generated with test rigs and laboratory equipment. The flow of activity from rig testing for code develoment and component technology development into the testbed is illustrated in Figure 15.

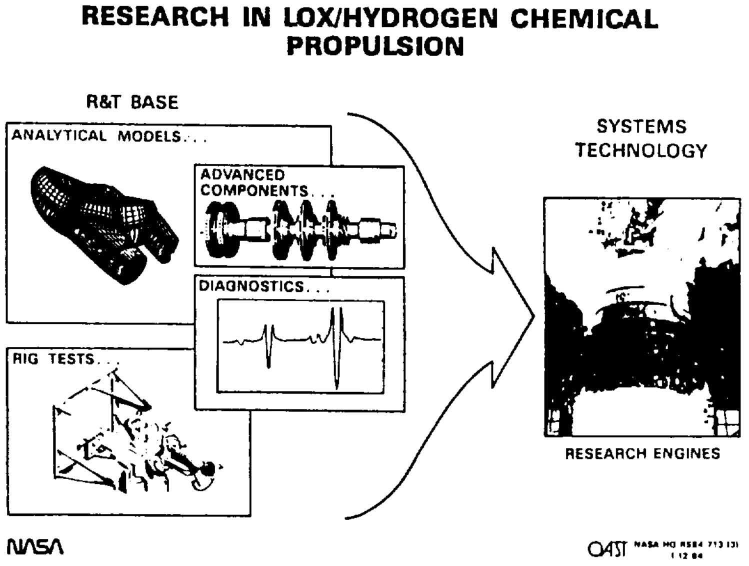


Figure 15.

As illustrated in Figure 13, the CSTI augmentation for ETO propulsion technology will provide the opportunity to validate the developing analytical models and advanced component designs in the real operating enviroments of large-scale subsystem testbed hardware. This technology hardware will be be well be equipped with research quality intrumentation, will be capable of operating over a wide range of conditions in order to develop an extended empirical data base, and will also be designed for part interchangeability so that alternate designs can be evaluated in the same piece of hardware. This will be the first time in many years that as a nation we will again be able to test large-scale turbomachinery by itself, rather than as part of an engine, such as in the SSME. Figure 16 illustrates such a bolt together large-scale turbopump.

GENERIC HIGH PRESSURE PUMP

- DEVELOP GENERIC HIGH PRESSURE PUMP
  - BREAKAWAY ROTATING ASSEMBLY, BOILER PLATE HOUSING . . .
- PROVIDE SUBSYSTEM LEVEL VERIFICATION
  - EXTEND RANGE OF OPERATING PARAMETERS, STRESS ANALYTICAL METHODS . . .

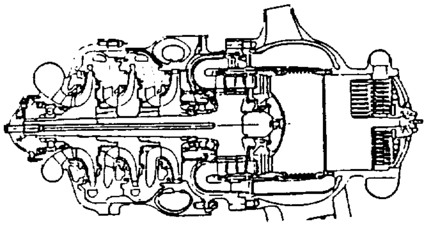


Figure 16.

A similar flow of activity will occur in the combustion devices area. Figure 17 lists the major components the are found in either Main Combustion Chambers (MCC's) or Gas Generators (GG's) along with typical test rigs used to evaluated advanced component designs or to generate empirical data for extending analytical models to a new range of operating conditions, in particular, much higher combustion pressures (up to 4000 psia in MCC's and 5000 to 6000 psia in GG's).

CSTI PROGRAM PRODUCTS

COMBUSTION DEVICES

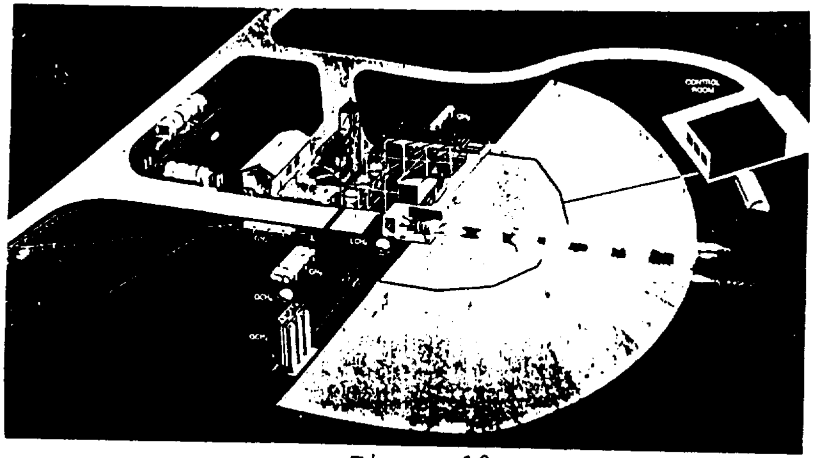
COMPONENTS	TEST RIGS	PRODUCTS	PRODUCT VALIDATION
		(Generic Design & Analysis Tools)	
		Combustion Models	
Injectors	Subscale Combustors	Instability Models	
Ignitors	Subscale Gas Generators/ Turbine Simulators	Heat Transfer/Carbon Deposition Models	Combustion Devices Validation: Subscale, Large Scale MCC, GG Technology H'dware: (Heavy Weight, Highly Instrumented, Replaceble Parts, Operational Flexibility
Combustion Chambers	Fluid Injection/ Atomization/ Vaporization Lab Tests	Propellant Cooling Characteristics/Limits	
Stability Aids	Heated Tube Testers (Heat Transfer)	Structural Analyses	
Nozzles	Mat'ls Compatibility Lab Tests	Low Cycle Thermal Fatigue Life Prediction	
Manifolds		Nozzle Flow Models	CSTI AUGMENTATION
Diagnostic Sensors		Adv Fabrication	
		Adv Des Concepts	
		Sensor Performance	

Figure 17.

Again, the CSTI augmentation will provide us with the capability of testing at more representative thrust level's (from 50,000 to 750,000 pounds) and combustion pressures (up to 3500 psia) with which to validate analytical codes and to develop realistic scaling laws in the areas of combustion, stability, cooling, heat transfer and nozzle flow. Figure 18 is a picture of a small scale 40K thrust combustor undergoing testing at to generate heat transfer and combustion performance. This has provided data at much higher pressures (up to 2500 psia) than we have had before, but at relatively low thrust.

Figure 18.

It is planned to upgrade this test stand for the higher thrust and pressure operating conditions, as shown in the Figure 19 artist's sketch.



MSFC TEST CELL 116
PRESSURE FED TEST FACILITY

Figure 19.

Figure 20 shows the design of a large-scale injector that is planned for testing in the upgraded facility.

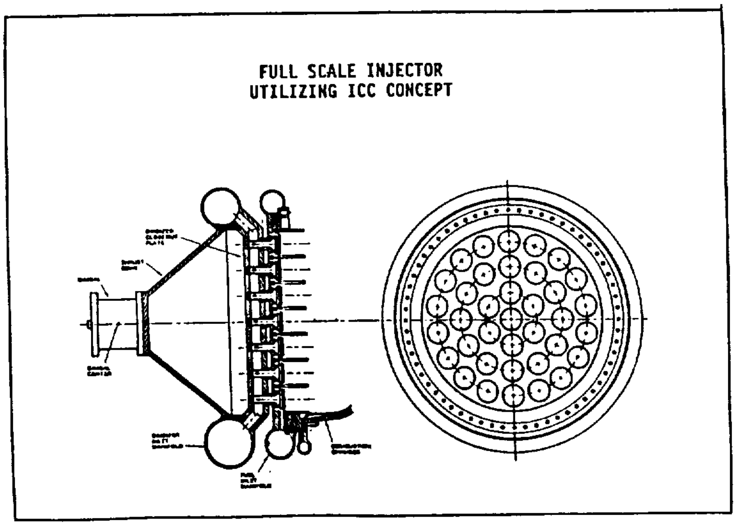


Figure 20.

Finally, the CSTI augmented program will allow an expanded and focused effort in the Health Monitoring and Controls area. To date, the principal effort has been in identifying and demonstrating potential diagnostic sensor and advanced instrumentation candidates in the laboratory and in test rigs such as bearing testers. This effort is being extended to include the installation of health monitoring system in one of the SSME turbopumps for testing on the technology testbed. However, the major focus of the new program will be on defining integrated health monitoring/control system architechure and logic, and identifying overall system components and their performance and operational requirements. A schematic of one potential system approach is shown in Figure 21.

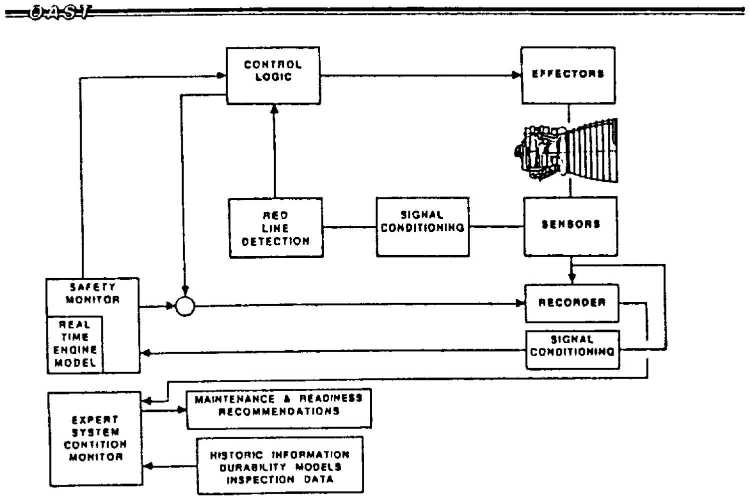

CSTI HEALTH MONITORING & CONTROLS

Figure 21

Such a system would provide both a component in-flight condition monitoring system for a later maintenance requirements check and a real time safety monitoring system for the incipient failure detection and correction capability needed for in-flight fault-tolerant engine operations. As individual components and subsystems are developed, an overall integrated system will be assembled and, to the degree possible, installed in an SSME technology testbed for verification and demonstration testing.

SUMMARY

In summary, the CSTI Focused Space Technology program is being implemented to revitalize the Civil Space Technology Base. However, even with the modest increase in funding for all of the OAST space technology activities between FY 1987 and FY 1988, the total still represents only about 2.5% of the overall NASA budget. Planned funding in future years, if approved, would raise that percentage to a level closer to that needed to accomplish the CSTI objectives. As a key part of CSTI, a healthier focused ETO propulsion technology program will provide NASA with the capability to validate analytical methods and advanced design concepts in large-scale component, subsystem, and system hardware for the first time in many years. It will put in place the technology base for future ETO engine systems that can be designed to minimize launch costs to low-Earth-orbit and to enable routine access to space. In turn, this will lay the ground work for restoring and maintaining world leadership in space for this nation.

LEWIS RESEARCH CENTER COMMENTS

Mr. Stanley J. Marsik
ETO Propulsion R & T Program Co-Manager
NASA/LEWIS Research Center

Good Morning. Let me wish cordial greetings to all of you from the Lewis Research Center. In the previous presentations you have been exposed to the Advanced ETO Program, the progress of which will be reported here in some 100 papers in the next 3 days. Frank Stephenson and previous speakers indicated that this program is a joint effort between the two Centers, Marshall and Lewis. I am confident that I am expressing the feeling of all of us involved in this effort from both Centers, that this has been and continues to be a very, very rewarding experience and that the close ties between the two Centers are reflected and are readily noticeable. The success of this program hinges on communication, how we communicate the results to one another, and obviously one means of communication are meetings like this. This is the third conference on Advanced ETO Propulsion Technology which is being held here at Marshall. There have been two Structural Durability Conferences at Lewis that are also part of this same program. Perhaps here is my chance to plug the next Structural Durability Conference at Lewis that is being planned for the latter part of May of next year. I hope you will consider this an invitation to attend this conference next year at Lewis.

I think that the real substance of these meetings is to bring people together, to get to know each other, to exchange ideas, and to discuss various possibilities and approaches, and that can sometimes be a real challange. I hope that you will do a lot of interacting during the next three days. With that, I wish all of you a very, very fruitful meeting and most wonderful time here in Huntsville. Thank you very much.