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5.0 ADVANCED PROPULSION

5.1 CSTI Earth-to-Orbit Propulsion R&T Program Overview – Steven J. Gentz, Marshall Space Flight Center

NASA supports a vigorous Earth-to-orbit (ETO) research and technology program as part of its Civil Space Technology Initiative. The purpose of this program is to provide an up-to-date technology base to support future space transportation needs for a new generation of lower cost, operationally-efficient, long-lived and highly reliable ETO propulsion systems by enhancing the knowledge, understanding and design methodology applicable to advanced oxygen/hydrogen and oxygen/hydrocarbon ETO propulsion systems. Program areas of interest include analytical models, advanced component technology, instrumentation, and validation/verification testing. Organizationally, the program is divided between technology acquisition and technology verification as follows:

- Technology Acquisition
  - Bearings
  - Structural Dynamics
  - Turbomachinery
  - Fatigue, Fracture and Life
  - Ignition and Combustion
  - Fluid and Gas Dynamics
  - Instrumentation
  - Controls
  - Manufacturing, Producibility and Inspection
  - Materials
- Technology Verification
  - Large Scale Combustors
  - Large Scale Turbomachinery
  - Controls and Health Monitoring

The ETO Propulsion Technology Program is tightly linked to the user community, and it supports all advanced engine programs. Many of these program elements are directly related to advanced materials and structures, as are recent program highlights such as the demonstration of extended life silicon nitride bearings.

NASA's ETO Program is well-coordinated with research and development activities by industry and other government agencies to avoid duplication of effort. NASA's efforts in the area of aerospike engines are limited to a small study effort because SDIO is sponsoring significant research as part of its SSTO program. Similarly, the ETO program is monitoring the airbreathing propulsion work in progress by NASP rather than fund a separate effort.

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NASA CSTI Earth-To-Orbit Propulsion R&T Program Overview

James L. Moses
MSFC

Presented
by
Steve J. Gentz, MSFC

NASA Earth-To-Orbit Propulsion R&T Program

Purpose

- Provide an up-to-date technology base to support future space transportation needs

Objective

- Continuing enhancement of knowledge, understanding, and design methodology applicable to the development of advanced oxygen/hydrogen and oxygen/hydrocarbon ETO propulsion systems

Justification

- Space transportation systems can benefit from advancements in propulsion system performance, service life and automated operations and diagnostics

Contents

- Analytical models for defining engine environments and for predicting hardware life (flow codes, loads definition, material behavior, structural response, fracture mechanics, combustion performance and stability, heat transfer)
- Advanced component technology (bearings, seals, turbine blades, active dampers, materials, processes, coatings, advanced manufacturing)
- Instrumentation for empirically defining engine environments, for performance analysis, and for health monitoring (flow meters, pressure transducers, bearing wear detectors, optical temperature sensors)
- Engineering testing at subcomponent level to validate analytical models, verify advanced materials, and to verify advanced sensor life and performance
- Component/test bed engine for validation/verification testing in true operating environments

NASA Earth-to-Orbit Propulsion R&T Program

Work Breakdown

- Technology acquisition phase
  - Seeks improved understanding of the basic chemical and physical processes of propulsion
  - Develops analyses, design models and codes using analytical techniques supported by empirical laboratory data as required
  - Results are obtained through ten discipline working groups
    - Bearings
    - Structural dynamics
    - Turbomachinery
    - Fatigue/fracture/life
    - Ignition/combustion
    - Fluid & gas dynamics
    - Instrumentation
    - Controls
    - Manufacturing/producibility/inspection
    - Materials

Work Breakdown (Continued)

- Technology verification phase
  - Validates technology arising from the acquisition phase at the large scale component, subsystem or engine system (TTB) level
  - Three categories of effort
    - Large scale combustors
    - Large scale turbomachinery
    - Controls and health monitoring

Earth-to-Orbit Propulsion

OBJECTIVES

- **Programmatic**

  Develop and validate technology, design tools and methodologies needed for the development of a new generation of lower cost, operationally-efficient, long-life, highly reliable ETO propulsion systems

- **Technical**

Manufacturing	- High quality, low cost, inspectable
Safety	- Safe shutdown to fault tolerant ops
Maintainability	- Condition monitoring diagnostics
Ground Ops	- Automated servicing and checkout
Performance	- Max commensurate with life
Advanced Cycles	- Full flow, combined cycle, etc.

SCHEDULE

- 1992 Electronic engine simulation capability operational
- 1993 3D CFD codes for turbomachinery flows validated and documented
- 1995 Low cost manufacturing processes applicable to shuttle and NLS/HLLV propulsion verified and documented
- 1996 System monitoring capability for safe shutdown and for enhanced preflight servicing and checkout demonstrated
- 1999 Probabilistic codes, fatigue methodology and life prediction/damage models validated and documented
- 2005 Advanced manufacturing processes and design methodologies applicable to fully reusable, long-life AMLS propulsion verified and documented; propulsion system monitoring and control for automated operations demonstrated

RESOURCES*

	CURRENT
• 1991	$21.8 M
• 1992	$28.7 M
• 1993	$33.9 M
• 1994	$25.1 M
• 1995	$26.4 M
• 1996	$27.6 M
• 1997	$28.8 M

* Note: This element is closely coordinated with development efforts in NASA/OSF and other related government programs; resources shown are NASA/OAET only

PARTICIPANTS

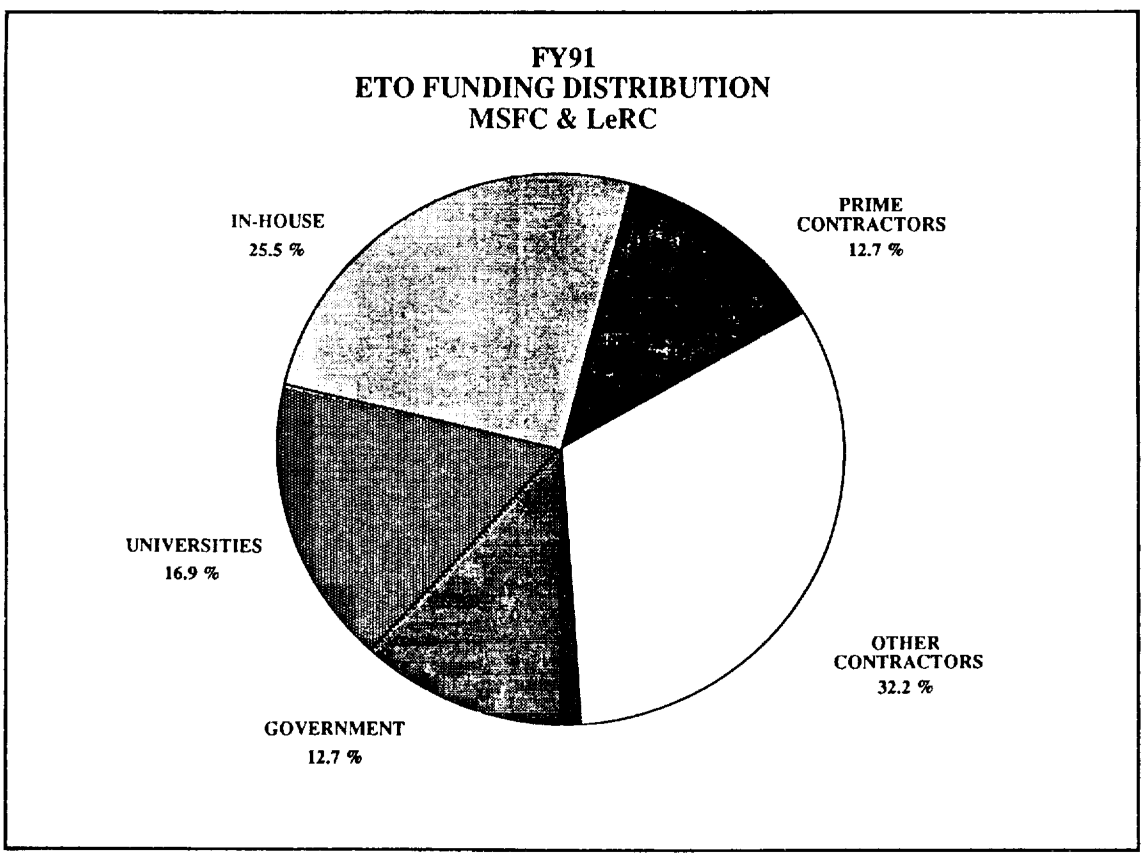
- **Marshall Space Flight Center**
  Lead Center-technology acquisition, test rig validation, large scale validation, technology test bed
- **Lewis Research Center**
  Participating Center-technology acquisition, test rig validation
- **Langley Research Center**
  Supporting Center-vehicle systems analysis
- **Stennis Space Center**
  Supporting Center-facility turbomachinery

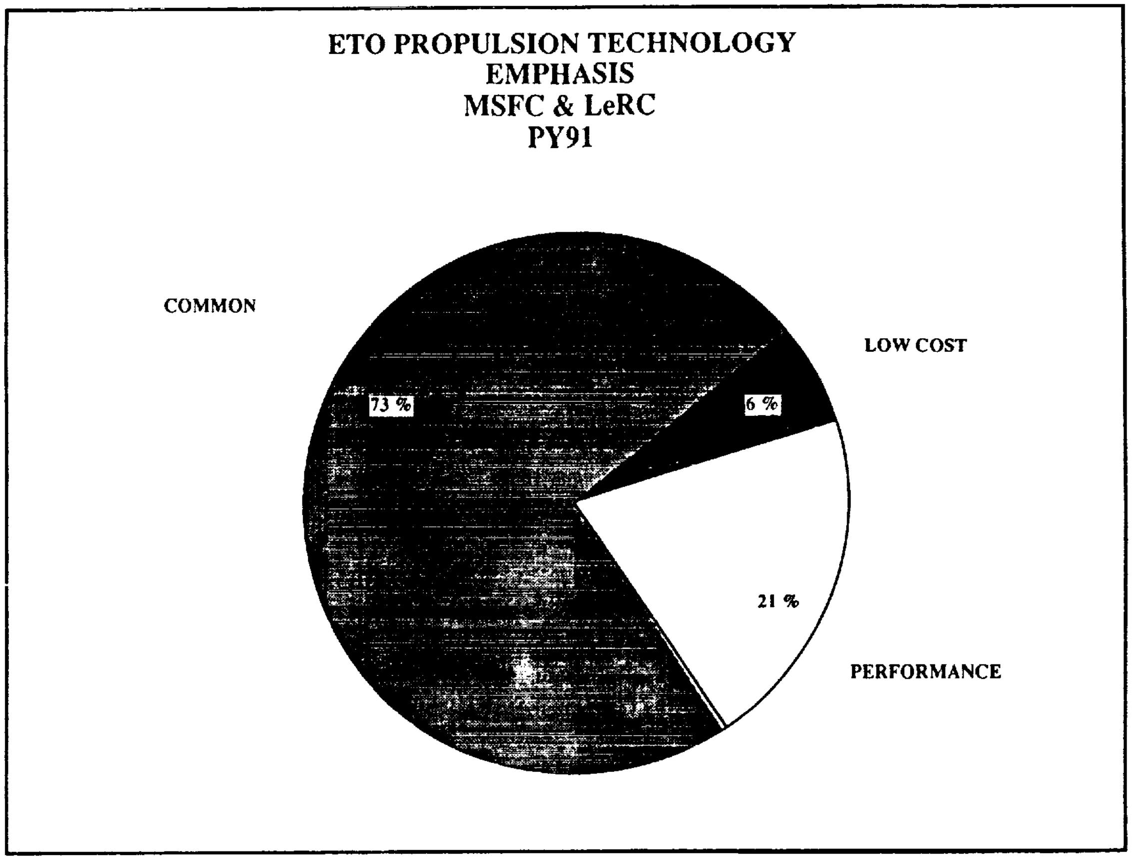
ETO Propulsion Technology Approach

- Civil Space Technology Initiative (CSTI) program emphasizes validated technology delivered on schedule.
- Concepts, codes, techniques obtained in the Technology Acquisition Phase.
- Validated at the appropriate level by means of component subsystem or system level testing (TTB).
- OAET provides technology to TTB. OSF provides integration funds to incorporate technology items into TTB.
- Technology is transferred to industry via papers & conferences such as Biannual Propulsion Conference at MSFC and Biannual Structural Dynamics Conference at LeRC.
  - Technologists also are working flight programs
- Technology must be generic, but should be applicable to on-going or anticipated programs.
  - Goal is to provide a broad technology base that will support a wide variety of propulsion options

ETO PROPULSION FUNDING SUMMARY - $K

	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96
TECHNOLOGY ACQUISITION								
BEARINGS	2093	1561	1562	1200	1200	800	1000	1200
STRUC. DYNAMICS	1371	1162	1350	1400	1800	1500	1700	1700
TURBOMACHINERY	1229	1137	1764	1600	1600	1100	1050	1200
FATIGUE/FRACTURE	1285	837	1115	1200	1410	1200	1200	1200
COMBUSTION	3123	2875	1126	1700	1960	1200	1000	1200
FLUID & GAS DYN.	1600	989	1697	1300	1200	900	1000	1200
INSTRUMENTATION	1420	836	920	1100	1400	1000	1000	1200
CONTROLS	1753	1182	1455	1800	1600	1000	1050	1200
MANUFACTURING	763	835	1088	1100	1650	1300	1300	1400
MATERIALS	1580	1020	1270	1000	1400	800	1000	1200
TOTAL TECH. ACQ.	16217	12434	13347	13400	15220	10800	11300	12700
VALIDATION								
COMBUSTION VALID.	2160	622	750	1100	1780	1100	1200	2000
TURBO. VALID.	5285	2412	4619	3000	4700	3600	3600	3600
SYS. MONITOR. VALID.	4578	4459	2606	8000	8800	6000	6500	5300
TOTAL VALIDATION	12023	7493	7975	12100	15280	10700	11300	10900
TOTAL PROGRAM	28240	19927	21322	25500	30500	21500	22600	23600
PMS	3375	3484	2616	3200	3400	3600	3800	4000
CENTER TOTALS	31615	23411	23938	28700	33900	25100	26400	27600

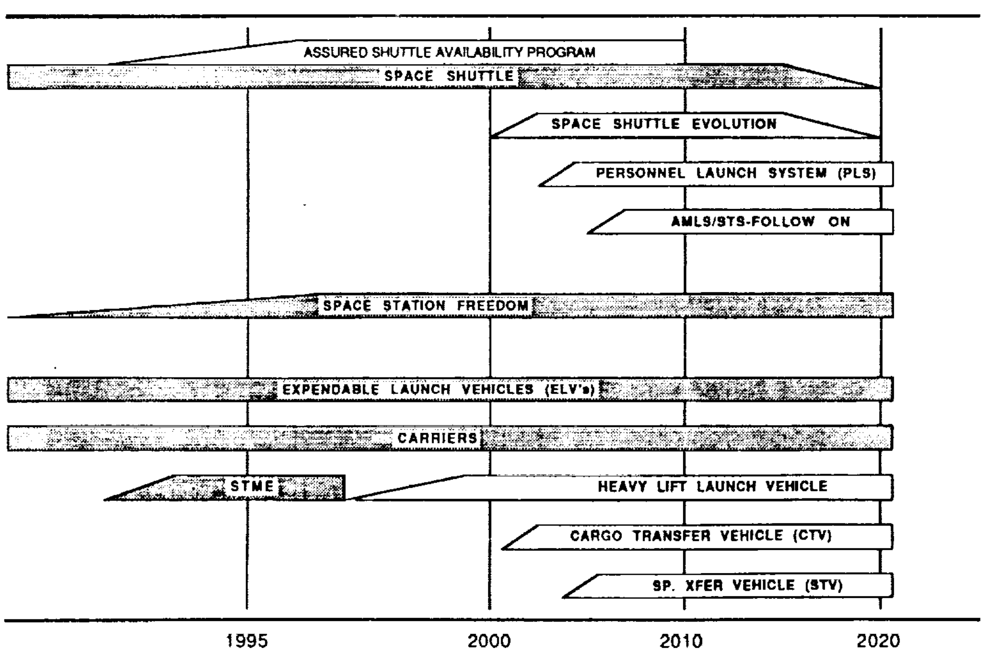




INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

FLIGHT PROGRAMS VISION

OFFICE OF SPACE FLIGHT



NASA Earth-To-Orbit Propulsion R&T Program

Recent Program Highlights

- Silicon nitride bearings have shown greatly extended life over SSME flight bearings in MSFC bearing tester.
- Completed assembly of a cryogenic rolling element bearing tester at LeRC.
- Turbopump test stand design complete. Stand is in MSFC FY93 C of F budget.
  - Reviewed with Headquarters August 1990
- First ever measurement of heat flux on a flight type rocket engine turbine blade with a plug type heat flux sensor.
- Management approval obtained for proceeding with advanced main combustion chamber technology (full scale program).
  - Reviewed with Headquarters April 1990
  - Concept adopted by STME and evolutionary SSME
- CFD Consortium turbine team is interactive with ALS Design Process

Earth-To-Orbit Propulsion R&T Program Activities

- Conducted biannual ETO Technology Conference May 15-17, 1990. 123 papers presented. 400 attendees.
- Conducted Propulsion Program Review for OAET, September 16-18,1991.
- Conducted Detailed ALS assessment of ETO Propulsion Project, March 1991, MSFC.
- Conducted 3rd screening of technology items for TTB March 8, 1991.
- Conducted biannual Structural Durability Conference at LeRC, May 1991.
- Presented program to Space Systems and Technology Advisory Committee, June 1991.
- Presented program to Space Technology Interdependency Group (STIG) July 12, 1991, JSC.

Focused Technology: ETO Propulsion

Summary

IMPACT: The ETO Propulsion Technology Program supports all advanced engine programs. Half of the 200 tasks in the Program were judged by an ALS consortium contractor team to be directly applicable to ALS propulsion technology needs. ETO addresses the top 3 priority technology issues of the Office of Manned Space Flight.

USER COORDINATION: Closely tied to SSME/ALS. SSME review held at Tyson's Corner, Va., Oct.1989. ALS/SSME review held at MSFC February 1990. A special ALS review was held for ALS at MSFC in March 1991. Interagency coordination provided by Space Technology Interdependency Group (STIG).

TECHNICAL REVIEWS: Annual RTOP review held in Nov/Dec each year, Government only. Covers each task, technical and budget, in the program. Other reviews as required.

OVERALL TECHNICAL and PROGRAMMATIC STATUS: Activities are maturing. Technology items for validation are being developed, such as bearings, sensors, and health monitoring algorithms.

RATIONALE for AUGMENTATION: Several areas require additional funding, Advanced Manufacturing, Propulsion System Studies and Additional Testing Capability. In addition the combination of budget constraints and the CSTI emphasis on validated technology starves the program of new technologies.

MAJOR TECHNICAL/PROGRAMMATIC ISSUES: Several propulsion options are available to the U.S. for the next generation of vehicles. The ETO program must maintain a broad base of technology to address a range of options. In addition, the absence of Program Advanced Development programs makes the ETO program the Nation's propulsion Advanced Development Program by default.

What Earth-To-Orbit Does Not Address

TOPIC	COMMENTS
• Aerospike nozzle	• Small study efforts • SDIO is spending significant funds on Aerospike SSTO
• Airbreathing/Combined Cycle	• NASP Program • OEAT Workshop is plannned
• Storable propellants	• No identified requirement
• Hybrid propulsion	• Commercial program; augmented for '95
• Pressure fed	• Residual activity at MSFC, no further work planned after current contracts expire

MSFC Structural Dynamics Summary

		Prior	FY90	FY91	FY92	FY93	FY94	FY95	Product
B9	Blade Tip Rubbing Stress Prediction								Verified Method for Predicting Blade Tip Rubbing Stress
B14	Structural Damping Prediction Methods								Summary of SSME Measured Damping Characteristics
B18	Detection of Degradation in Turbomachinery Bearings								Test Verified Method of Identifying Bearing Signatures
B19	Acoustic Characteristics of Turbomachinery cavities								Prediction Method for Acoustic Response of Turbomachinery Cavities
B20	High Frequency Flow/Structure Interaction								Method for Predicting Flow/Structure Interaction
B22	Turbine Blade-Damper Analysis								Analysis Capability for Large Blade-Damper Systems
B23	Dynamics of Bearings Components								Method for Predicting the Dynamic Motion of Bearing Balls & Cage
B24	Dynamics Analysis Program								Implement a Universally Acceptable General Purpose Analysis Code

LeRC Structural Dynamics Working Group Summary

		Prior	FY90	FY91	FY92	FY93	FY94	FY95	Product
B15(A)	Probabilistic Structural Analysis Methods		Select component codes delivered		Component risk	System risk		System certification	Methods/Codes for Reliability & Risk
B14(C)	Analysis/Tailoring		Risk concept demonstrated	Random processes synthesized		Certification concept demonstrated			Contract/Grants Code Validation & Concept Demonstration
B15(F)	Coupled Fluid/Structure Interaction				Code delivered				Methods/Codes Hot Fluid/Structure Interaction
B15(G)	Probabilistic Fracture Finite Elements		Elements formulated		Code delivered				Methods/Codes for Probabilistic Fracture
B16	Composite Load Spectra			Acoustic loads code delivered		Coupled loads/ structure code delivered			Methods/Codes for Probabilistic Loads Simulation

MSFC Materials Development/Evaluation Working Group Summary

		Prior	FY89	FY90	FY91	FY92	FY93	FY94	FY95	Product
M1	Hydrogen Alloy Development Determination of Ignition									Weldable, High Strength, Corrosion Resistant Structural Alloy With Immunity to Hydrogen Effects
M2a	Temperatures and Burning Rates in High Pressure Oxygen			∇ Characterization Complete						Develop Theoretical Understanding of Fundamental Oxidation Process in High Pressure Oxygen
M2b	Oxidation of Materials in High Pressure Oxygen									Develop Methodology for Evaluating Materials Undergoing Oxidation in High Pressure/Temperature Environments
M2c	Coefficient of Friction Investigations									Develop a Test System to Evaluate the Coefficient of Friction of Materials in High Pressure Oxygen
M4a	Fracture Characteristics of Single Crystal Blade Materials				∇ Methodology Developed					Develop Methodology and Correlations for Fracture Surfaces of Hydrogen Environment as a Function of Temperature, Pressure, and Material
M4b	Evaluation and Characterization of Single Crystal Materials			∇ Converted to In-House Characterization						Characterization of Orientation Effects of PWA 480 as a Function of Temperature and Environment
M18	Development of a New Cage Material/ Composite for Cryogenic Bearings			∇ Initiate Component Validation						Develop a 3,000 psi LOX Compatible Bearing Cage Material
M19a	Development of New Materials for Cryogenic Turbopump Bearings		∇ Initiate Component Validation							Complete Bearing Materials Comparisons According to Developed Materials Evaluation Criteria
M19b	Development of Fracture Tough and Corrosion Resistant Bearing Material									Formulate Fundamental Methodology for Development of Fracture Tough and Corrosion Resistant Cryogenic Bearings
M20	Crack Growth in Turbopump Bearing Materials			∇ Bearing Model Developed						Validate Crack Growth Model of Defects in Bearing Raceways
M22	Ductile Coatings for Hydrogen Embrittlement Protection									Develop Ductile Coatings for Hydrogen Protection of Advanced Propulsion Components (Over Existing Guidelines)
M23	Hydrogen Test Standardization									Publish NASA Specification Outlining Guidelines for Materials Testing in High Pressure Hydrogen
M27	Superplastic and Solid-State Joining Process Development									Identify Materials and Process Refinements for Incorporation into Advanced Propulsion Components

LeRC Materials Development/Evaluation Working Group Summary

		Prior	FY90	FY91	FY92	FY93	FY94	Product
M12	ADVANCED SINGLE CRYSTAL TURBINE BLADE MATERIALS							Advanced single crystal processing techniques to increase life and reliability of turbopump turbine blades
M13b	FABRICATION PROCESS DEVELOPMENT FOR W-Re-Hf-C WIRE							A demonstrated process for production of .014 mil W-Re-Hf-C wire for use in W-Wire reinforced superalloy turbine blades
M13c	FRS ENGINEERING DESIGN PROPERTY STUDY							A characterized fiber reinforced superalloy system ready for scale-up for turbopump turbine blades
M21	HYDROCARBON FUELS/MATERIALS COMPATIBILITY							Validated approach to protect MCC cooling channels from sulfur corrosion and a method for cooling passage refurbishment
M24	TUNGSTEN/COPPER COMBUSTION LINER MATERIAL PROPERTY STUDY							A validated computer code to assist in the design of fiber reinforced combustion chamber liners and characterization of the effect of composite wire distribution on mechanical and thermal properties
M25	FIBER REINFORCEMENT COMBUSTION LINER FABRICATION STUDY							A full scale contoured combustion chamber with a liner of refractory metal wire reinforced copper alloy capable of being test fired.
M26	ADVANCED COPPER ALLOYS							Improved copper-base alloys for high heat flux applications