*NASA Conference Publication 3112, Vol. 1*

# Space Transportation Propulsion Technology Symposium

## *Volume 1—Executive Summary*

P_36

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## *Volume 1—Executive Summary*

*NASA Office of Space Flight*
*Washington, D.C.*

Proceedings of a symposium held at
the Pennsylvania State University
State College, Pennsylvania
June 25–29, 1990

NASA
National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Program
**1991**

## PREFACE

The Space Transportation Propulsion Technology Symposium in June was the culmination of disussions and a process begun in early 1990. The Symposium was a success because of the contributions by the invited speakers, the panel leaders, and all of the panel participants. Their contributions are greatly appreciated.

There were also a number of people who participated in the planning and direct support of the Symposium that should be recognized for their significant efforts and contributions:

The NASA Inter-Center Planning Group members:

Chester Vaughan (JSC)
Paul Herr (HQS/MD)
David Stone (HQS/RS)
Warren Wiley (KSC)
William Escher (HQS/RP)
Robert Schwinghamer (MSFC)

The Panel Rapporteurs and Facillitators:

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Rodney Johnson (SRS)
Brenda Wilson (W.J.Schafer)
Mel Bryant (MSFC)
Carl Aukerman (Sverdrup)
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Support Contractors:

Alan Angleman (W.J.Schafer)
Brenda Wilson (W.J.Schafer)
Jack Suddreth (SRS)
Frank Stephenson (TBC)
Author

The Symposium was held to provide a forum for communication within the Propulsion Technology Developer and User Communities. Because of the support and the enthusiastic participation by the Symposium participants, it was a success and should provide dividends and a reference source within NASA, and within the propulsion discipline for years to come.

R. J. Schwinghamer

**Robert Schwinghamer**
**General Chairman**
**Space Transportation Propulsion**
**Technology Symposium**

Chet Vaughan

**Chester Vaughan**
**Co-Chairman**
**Space Transportation Propulsion**
**Technoogy Symposium**

Warren Wiley

**Warren Wiley**
**Co-Chairman**
**Space Transportation Propulsion**
**Technology Symposium**

## EXECUTIVE SUMMARY

# SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

**THE PENNSYLVANIA STATE UNIVERSITY**
**STATE COLLEGE PENNSYLVANIA**

**JUNE 25-29, 1990**

## I INTRODUCTION

The Space Transportation Propulsion Technology Symposium (STPTS) was held at the Pennsylvania State University in State College, Pennsylvania, June 25-29, 1990. The Symposium was held in recognition by the NASA technology developer and user organizations that there was a growing need to provide a forum where propulsion developers and users could exchange technical information, viewpoints and ideas relative to the future direction of space transportation propulsion systems. Emphasis was placed on prospective propulsion requirements and initiatives, planned and underway, that are focused on supporting current, next generation, and future space transportation systems, with the primary objectives of discerning whether proposed designs truly meet future transportation needs and identifying technology gaps and overlaps, if any, and other programmatic deficiencies.

A program committee consisting of representatives from HQS, MSFC, JSC, KSC, and the Pennsylvania State University (Figure 1), was formed to plan and organize the Symposium and to invite participation of key propulsion people from the NASA technology, development and operations centers, the propulsion and prime contractor industrial sector and associated subcontractors, the academic community, and relevant DOD laboratories. The objectives of the Symposium were defined and an overall approach structured to meet those objectives. Mr. Robert J. Schwinghamer of the Marshall Space Flight Center agreed to serve as the General Chairman, along with two Co-Chairmen, Mr. Chester A. Vaughan of the Johnson Space Center and Mr. Warren I. Wiley of the Kennedy Space Center. Dr. Robert Jacobs and Dr. Charles Merkle of the Pennsylvania State University agreed to serve as Academic Chairman and Co-Chairman respectively. The success of the Symposium was due in large measure to the efforts of the chairmen and their co-chairmen.

The Symposium focused on examining existing and planned propulsion design, development, manufacturing, certification, and operations processes, with the objective of recommending needed changes to those processes that will greatly strengthen the agency's capabilities and competitive posture in space transportation. Identifying key propulsion technologies needed to effectively enable implementation of those changes was also a prime consideration. Some of the goals of these changes include improving hardware quality, producibility and cost, increasing safety and reliability, reducing development and certification testing and time, reducing the risk of schedule and cost impacts, and streamlining ground and flight operations. Special attention was given to the unique

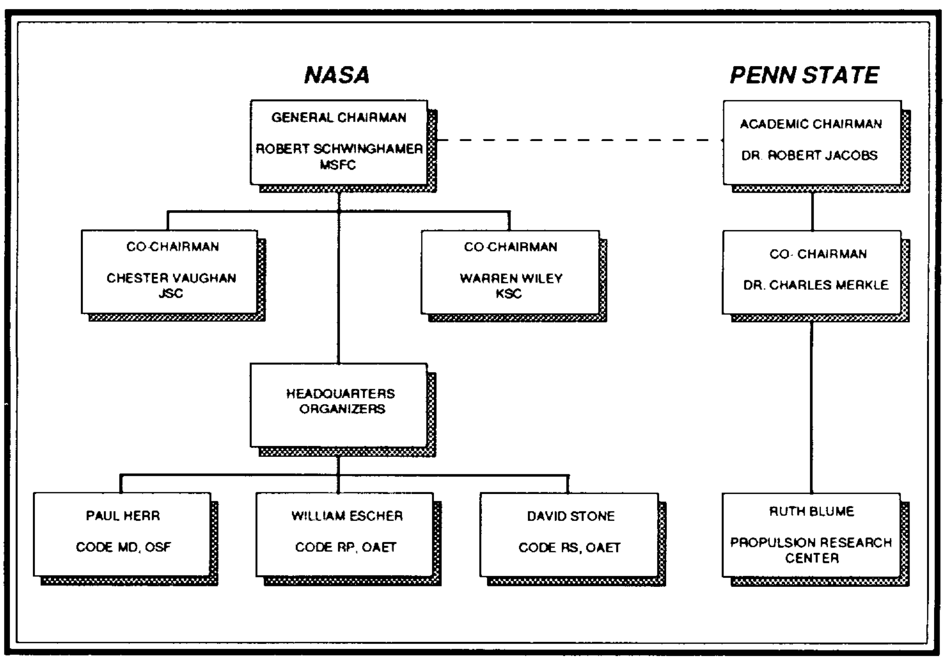


**Figure 1. Symposium Planning Group**

- o BOTH VEHICLE LEVEL AND PROPULSION SYSTEM LEVEL NATIONAL LONG RANGE STRATEGIC PLANS ARE SORELY NEEDED
- o "LESSONS LEARNED" FROM PRIOR EXPERIENCE INDICATE THAT FUTURE PROPULSION SYSTEMS SHOULD BE DEVELOPED AT THE "SYSTEM" LEVEL USING THE CONSORTIUM APPROACH, ALONG WITH TQM AND CONCURRENT ENGINEERING, AND MUST BE DESIGNED FOR IN-SERVICE "OPERATIONAL EFFICIENCY" (SIMPLE, NON-MANPOWER INTENSIVE OPERATIONS)
- o DESIGN CHARACTERISTICS ENABLING OPERATIONALLY EFFICIENT SYSTEMS MUST BE INCORPORATED AT THE BEGINNING OF DESIGN AND DEVELOPMENT (e.g., DIAGNOSTIC SENSORS, HIGH DESIGN MARGINS, ADV MANUFACTURING TECHNIQUES, ETC.)
- o SYSTEM MONITORING FOR FLIGHT PERFORMANCE, SAFETY, DATA RECORDING, MAINTENANCE SCHEDULING, AND AUTONOMOUS PREFLIGHT CHECKOUT ESSENTIAL FOR FUTURE SYSTEMS
- o USERS NEED TO BE DIRECTLY INVOLVED IN TECHNOLOGY PROGRAMS: CO-CHAIR TECHNOLOGY WORKING GROUPS AT START OF PHASE A TO PROVIDE DESIGN CRITERIA PRIOR TO PHASE B
- o USERS MUST CONDUCT FOCUSED TECHNOLOGY/ADVANCED DEVELOPMENT PROGRAMS IN PHASE B TO DEMONSTRATE TECHNOLOGY & VALIDATE DESIGN REQUIREMENTS PRIOR TO PHASE C
- o TECHNOLOGIES NEED TO BE DEVELOPED FOR UPGRADING THE ELV FLEET (LOW COST BOOSTERS, CLEAN SOLIDS, 30K-50K THRUST LOX/LH2 UPPER STAGE); FOR PURSUING ATTRACTIVE PROPULSION ALTERNATIVES (LRB'S, HYBRIDS, PLUG CLUSTERS, METALLIZED PROPELLANTS); AND FOR SPACE-BASED SYSTEMS (ENGINES AND CRYOGENIC FLUID STORAGE AND TRANSFER)
- o GOLD PLATED PROGRAMS MUST BE AVOIDED
- o ENVIRONMENTAL ISSUES MUST ADDRESSED
- o FOREIGN COMPETITION IS GROWING AND MUST BE CHALLENGED
- o EDUCATION ON THE SPACE PROGRAM IS A MUST AT ALL LEVELS

**Figure 2. Major Symposium Findings**

operational issues of complex, multi-use, space-based propulsion systems. In order to address these subjects in depth, four panels were formed to review and assess "user" needs and to consider and recommend changes to long-standing agency practices. Panel topics included: 1) Systems Engineering & Integration, 2) Development, Manufacturing & Certification, 3) Operational Efficiency and 4) Program Development & Cultural Issues. In addition, Propulsion Systems Options speakers (total of 25) provided input data to the panels by describing current, next generation, foreign, and potential futuristic propulsion systems. Essentially all of the output of the Symposium was accomplished in the four concurrent panel sessions. Although many conclusions and recommendations emanated from the panel deliberations, the most predominant and recurring are listed in Figure 2.

## APPROACH

The purpose and objectives of the Symposium are listed in Figure 3. In order to meet these objectives, the Symposium was structured as shown in the attached

### PURPOSE OF SYMPOSIUM

- o Provide An Open Forum Where Space Propulsion Technology Developers And Users Could Freely Interchange Information , Ideas, And Viewpoints Relative To What The Nation's Propulsion Needs Are Today And Will Be In The Future, And The Technology Advances Required To Fill Those Needs
- o Provide An Opportunity For The User Community To Assess And Critique The Design, Development, And Operations Of Current Propulsion Systems, Proposed Next Generation System Options, And Futuristic Systems That Offer Superior Alternative Choices, But Which Are Early In Technology Development

### SYMPOSIUM OBJECTIVES

- o Attempt To Project Propulsion Advancements Which Are Needed And Can Feasibly Be Achieved In The Opening Decades Of The Twenty-first Century And To Consider Such Key Issues As Environmental Considerations, Resource Utilization, And International Developments
- o Through Four Topical Panels Involving Government, Industry, And Academia Membership, To Solidly Address Key Issues Which Are Expected To Shape The Future Of Space Transportation Propulsion:
  - System Engineering And Integration
  - Development, Manufacturing, And Certification
  - Operational Efficiency
  - Program Development And Cultural Issues
- o Recommend Appropriate Actions For The Agency And The Propulsion Community, Toward Ensuring The Development And Demonstration Of Propulsion Technologies From Which Tomorrow's Space Propulsion Systems Can Be Effectively And Economically Developed Into Hardware Systems Which Will Make Access To Space Both Routine And Affordable

**Figure 3. Symposium Purpose and Objectives**

| | |
|---|---|
| o SPACE EXPLORATION INITIATIVE | C.C. PRIEST, NASA HQ |
| o NATIONAL SPACE TRANSPORTATION STRATEGY | D. BRANSCOME, NASA HQ |
| o MAINTAINING TECHNICAL EXCELLENCE | T. DAVIDSON, AIA |
| o OPERATIONAL EFFICIENCY - NEW APPROACHES TO FUTURE PROPULSION SYSTEMS | R. RHODES, NASA KSC |

**Figure 4. Symposium Themes**

agenda (Appendix I-1). The General Chairman called the meeting to order and described the expected output of the Symposium. Supporting remarks were given by each of the co-chairmen and a Headquarters perspective was presented by Darrell Branscome, Director of the Advanced Program Development Office in the NASA Office of Space Flight. The keynote address was given by J. R. Thompson, Jr., the NASA Deputy Administrator, in which he stressed the importance of space transportation to the nation's future space activities and the need to build on existing capabilities for future propulsion systems and flight programs. Symposium themes were then offered by several speakers as shown in Figure 4.

The remainder of the first day (Tuesday) and half of the second day (Wednesday) were devoted to providing input data to the panels through a series of presentations by the Propulsion System Options speakers describing current (including foreign), next generation, and futuristic systems as currently perceived. Environmental issues and concerns were also presented to the panels by Joyce Jatko, NASA HQ, for consideration in their deliberations. The speakers and the topics they discussed are listed in Figure 5. White papers developed by each speaker were available throughout the Symposium, as were hard copies of each presentation, as reference material for each of the panels.

| TOPIC | SPEAKER | ORGANIZATION |
|---|---|---|
| CURRENT SYSTEMS: | | |
| EXPENDABLE LAUNCH VEHICLES: | PAUL FULLER | COMSTAC |
| SHUTTLE PROPULSION: | RUSS BARDOS | NASA HQ/ME |
| UPPER STAGES: | | |
| - UPPER STAGE PROJECTS (SOLIDS) | CHARLIE GUNN | NASA HQ/ML |
| - CRYO. STAGE PROP. (RL-10 & DER.) | JIM BROWN | PRATT&WHITNEY |
| SATELLITE/SPACE PROBE PROPULSION | MACK DOWDY | JPL |
| NEXT GENERATION: | | |
| SHUTTLE DERIVATIVES | | |
| - MANNED SDV'S | WAYNE ORDWAY | NASA JSC |
| - UNMANNED SDV'S (SHUTTLE C) | UWE HUETER | NASA MSFC |
| - LIQUID, HYBRID BOOSTERS | UWE HUETER | NASA MSFC |
| - SOLIDS | CORKY CLINTON | NASA MSFC |
| | BOB LUND | THIOKOL |
| HEAVY LIFT LAUNCH VEHICLES (ALS STME): | JAN MONK | NASA MSFC |
| AIR FORCE SPACE SYSTEMS PROPULSION | DALE HITE | AFAL |
| UNMANNED LAUNCH VEHICLES/UPPER STAGES | CHARLIE GUNN | NASA HQ/ML |
| SPACE TRANSFER VEHICLES : | | |
| - VEHICLE CONCEPTS AND REQUIREMENTS | FRED HUFFAKER | NASA MSFC |
| - ADVANCED CRYO. PROPULSION SYSTEMS | BILL TABATA | NASA LERC |
| ADVANCED MANNED LAUNCH SYSTEMS | DEL FREEMAN | NASA LARC |
| - SHUTTLE II, SSTO VEHICLES | | |
| - ADVANCED ROCKETS | | |
| - COMBINED CYCLE PROPULSION | | |
| NASP | MING TANG | NASA HQ/R |
| ENVIRONMENTAL CONSIDERATIONS: | JOYCE JATKO | NASA HQ/NXF |
| FOREIGN TECHNOLOGY: | | |
| JAPANESE | CHUCK MERKLE | PENN STATE |
| RUSSIAN | BOB JONES | ROCKETDYNE |
| EUROPEAN, OTHER | ERIC RICE | ORBITEC |
| FUTURISTIC SYSTEMS: | | |
| NUCLEAR THERMAL PROPULSION | | |
| - FISSION | GARY BENNETT | NASA HQ/RP |
| - FUSION | NORM SCHULZE | NASA HQ/Q |
| SOLAR & NUCLEAR ELECTRIC PROPULSION | DAVE BYERS | NASA LERC |
| ADVANCED PROPULSION CONCEPTS | BOB FRISBEE | JPL |

**Figure 5. Propulsion Options Speakers**

The panels then met separately to discuss the topics they were to consider. The breakout session deliberations took place over Wednesday afternoon and most of Thursday. Each panel's structure, its leaders, and the topics discussed are shown in Appendix I-2. The appendix also shows how the Propulsion System Options subjects that were presented in the first plenary session were to flow into the four panels as input data. White papers were presented by selected panel members on each of the topics listed. The results of each panel's deliberations were presented in summary form during the final plenary session Friday morning.

Other highlights of the Symposium included an after dinner speech (Wednesday evening banquet) by former astronaut James McDivitt, now a Senior Vice President of Rockwell International, and an address Friday morning by Representative Robert S. Walker, Congressman from Pennsylvania. Mr. McDivitt discussed broad science and engineering education challenges and the proactive role which the nation's aerospace community can play in promoting new initiatives in education in cooperation with primary and secondary schools and the university establishments. Congressman Walker, a strong supporter of the space program, focused his remarks on the difficulties associated with providing adequate funding for space activities because of competition for federal funding from other programs. He also suggested that NASA's sometimes shaky relationship with the Congress could be improved, pointing out that conflicting information is sometimes submitted to the Congress from different parts of the NASA organization.

NASA (85)

| | |
|---|---|
| HQ | 21 |
| MSFC | 27 |
| JSC | 8 |
| LeRC | 15 |
| KSC | 8 |
| LaRC | 1 |
| SSC | 5 |

CONSULTANTS (2)

UNIVERSITIES (30)

| | |
|---|---|
| PENN STATE UNIVERSITY | 25 |
| UNIVERSITY OF ILLINOIS | 1 |
| UNIVERSITY OF CINCINNATI | 2 |
| UNIVERSITY OF ALABAMA | 1 |
| UNIVERSITY OF ARIZONA | 1 |

OTHER GOV'T (5)

INDUSTRY (108)

| | |
|---|---|
| ADVANCED RESEARCH | 1 |
| AEROJET | 9 |
| ATLANTIC RESEARCH | 1 |
| ANSER | 1 |
| BALL | 1 |
| BOEING | 3 |
| CENTER FOR ADV. PROPULSION | 1 |
| FORD AEROSPACE | 2 |
| GENERAL DYNAMICS | 8 |
| HERCULES | 1 |
| HONEYWELL | 1 |
| IBM | 1 |
| INTERN'L TECH. UNDERWRITERS | 1 |
| JET PROPULSION LAB | 2 |
| LOCKHEED | 7 |
| MARTIN MARIETTA | 9 |
| MARQUARDT | 1 |
| McDONNELL DOUGLAS | 4 |
| ORBITAL TECHNOLOGIES | 1 |
| PRATT & WHITNEY | 8 |
| ROCKETDYNE | 2 |
| ROCKET RESEARCH | 1 |
| ROCKWELL | 18 |
| SRS TECHNOLOGIES | 6 |
| SVERDRUP TECHNOLOGIES | 5 |
| THIOKOL | 3 |
| THE BIONETICS CORP. | 1 |
| TRW | 2 |
| UNITED TECHNOLOGIES | 1 |
| VITRO | 2 |
| W. J. SCHAFER | 4 |

TOTAL (230)

**Figure 6. Symposium Attendees by Organization**

Another highlight of the Symposium was a review Thursday afternoon of the work being conducted by Penn State as a NASA Propulsion Engineering Research Center, which included a tour of the facilities being used in support of their research efforts. The Symposium was well attended by a total of 230 participants, representing a broad and diverse cross-section of the propulsion technical community. The distribution of attendees by organization is shown in Figure 6.

## DISCUSSION

- o A NATIONAL STRATEGIC PLAN FOR ROCKET PROPULSION IS SORELY NEEDED (R&T THROUGH VALIDATION, EDUCATIONAL OBJECTIVES AND FOCUS, NATIONAL PARTICIPATION, REVITALIZED WORKFORCE/FACILITIES/ TECHNOLOGY BASE)
- o FOR OPERATIONAL EFFICIENCY, FUTURE VEHICLES & PROPULSION SYSTEMS SHOULD BE SIMPLE & ROBUST. USE COMMONALITY AND INTEGRATED FUNCTIONS, APPLY TQM, AND USE ENVIRONMENTALLY CLEAN SYSTEMS
- o TIE TECHNOLOGY DEVELOPERS AND USERS CLOSER TOGETHER AND DEFINE TECHNOLOGY "HANDOFF" POINT
- o EDUCATION ON THE SPACE PROGRAM IS A MUST AT ALL LEVELS
- o PAY CLOSE ATTENTION TO ENVIRONMENTAL ISSUES AND EXPECT IMPACTS TO COSTS, SCHEDULES & TEST LOCATIONS
- o UTILIZE EMERGING TECHNOLOGIES FOR EXTENDING SHUTTLE PROPULSION COMPONENT/SUBSYSTEM LIFE
- o IDENTIFY ELV ENHANCING TECHNOLOGIES AND USE TO UPGRADE ELV FLEET: CONSIDER LOW COST LIQUID BOOSTERS, 30-50K THRUST LOX/HYDROGEN UPPER STAGE, CLEAN, LOW COST, RELIABLE SOLIDS
- o DEVELOP A LONG RANGE INDUSTRY/GOVERNMENT PLAN FOR NEXT GENERATION ELV DEVELOPMENT
- o ESTABLISH NATIONAL CONSORTIUM FOR NEXT GENERATION UNMANNED STS; BUILD ON EXISTING CAPABILITIES, WHERE PRACTICAL, SUCH AS SHUTTLE DERIVED ELEMENTS, BUT CONSIDER LRB'S AND HYBRIDS FOR INCREASED CAPABILITY, RELIABILITY, AND LOWER COST
- o ASSESS PROGRAM MANAGEMENT APPROACH FOR NEXT ENGINE DEVELOPMENT (FRESH PERSPECTIVE)
- o FOCUS SOLID PROPULSION TECHNOLOGY ON COST, RELIABILITY, CLEAN PROPELLANTS, THRUST TERMINATION/RESTART
- o TECHNOLOGY DEVELOPMENT NEEDED FOR SPACE-BASED SYSTEMS REQUIRING MINIMUM MAINTENANCE, REUSE, AND ROBOTIC SERVICING AND REPAIR
- o FOREIGN COMPETITION FOR COMMERCIAL LAUNCHES IS STEADILY INCREASING AND NEEDS TO BE SERIOUSLY ADDRESSED

**Figure 7. Major Findings of Propulsion Options Speakers**

As indicated above, the Propulsion Options Speakers presented descriptions of the propulsion systems used in current space transportation systems (including foreign) and those projected for use on next generation and future systems. While doing so, they also provided insight into perceived problems and deficiencies (both technical and managerial) and cited technologies that could help solve many of those problems now and in the future. They also recommended changes in the ways we do business that could contribute to avoiding similar problems in the future. The major findings of the speakers are listed in Figure 7.

Following the Propulsion Options Speakers' presentations, the four panels convened separately to review, discuss, and debate the specific topics assigned to their panel and to attempt to reach a consensus as to what recommendations should be made with regard to needed cultural changes, improved space transportation development approaches, propulsion technology needs for existing and future systems, etc. The major output of the Symposium resulted from the panel deliberations. The results were remarkably complete and showed considerable depth, reflecting the amount of effort expended by the panel members during their deliberations and pre-Symposium homework done by the panel leaders.

It was apparent that the Symposium attendees were acutely aware of agency (and national) problems in the space transportation area and many have been seeking solutions to these problems for a number of years. The Symposium provided a forum for participants to express their views and offer solutions for others to evaluate, debate, and agree with or suggest alternatives. The panel leaders and members are to be commended for an outstanding effort over a very short period of time. Copies of presentations given throughout the conference and "white" papers written on specific topics are included in the companion conference proceedings (Volume 2). This executive summary is focused primarily on capturing the essence and results of the panel deliberations. Panel reports are provided in Appendix II through VI. Major findings, conclusions, and recommendations of the panels are also discussed and summarized below:

**PANEL A - SYSTEMS INTEGRATION AND ENGINEERING**

The Systems Integration and Engineering Panel covered three major phases of flight system design and development: 1) Preliminary Design Activities; 2) Phase C/D Activities; and 3) Flight System Evolution. Subpanels were formed to review how these activities have been performed in the past and to consider changes that could be made that would not only lead to a better product in terms of cost, producibility, quality, safety, reliability, maintainability, and operability, but would also allow an orderly evolution to other higher capability systems as the need materializes. Specific subjects considered by each of the subpanels are listed in Figure 8. Figure 9 describes the needs and issues identified by each of the subpanels. Underlying key issues ad-

SYSTEMS ENGINEERING & INTEGRATION PANEL

SUBPANELS

PRELIMINARY DESIGN ACTIVITIES

- o CONCEPTUAL DESIGN/PHASE A STUDIES
- o PRE-DEVELOPMENT/PHASE B STUDIES
- o SYSTEMS ARCHITECTURE
- o VEHICLE END-TO-END SUBSYSTEM INTERDEPENDENCIES
- o TRAJECTORY/PERFORMANCE PLANNING OPTIONS

PHASE C/D ACTIVITIES

- o PRE-DEVELOPMENT TECHNOLOGY MATURITY
- o PDR PENETRATION
- o MODULAR VS LRU'S
- o FMEA/CIL
- o DESIGN MARGIN

FLIGHT SYSTEM EVOLUTION

- o UPRATING (PERFORMANCE/LIFE)
- o COST REDUCTION
- o ASSURED ACCESS

**Figure 8. SE&I Subpanel Topics**

SYSTEMS ENGINEERING & INTEGRATION PANEL

PRELIMINARY DESIGN ACTIVITIES

- o SELECTIONS BASED ON OPTIMISTIC TECHNOLOGY PREDICTIONS RISK DELAYS & COST ESCALATION
- o INCLUDE INTERCENTER PARTICIPATION IN PRELIMINARY DESIGN STUDIES
- o INITIATE TECHNOLOGY EFFORTS TO PROVIDE DESIGN CRITERIA PRIOR TO PHASE B
- o ADDRESS USER REQUIREMENTS BY USER CO-CHAIRING TECHNOLOGY WORKING GROUPS AT START OF PHASE A
- o HAVE USER CONDUCT FOCUSED TECHNOLOGY PROGRAM & VALIDATE DESIGN REQUIREMENTS IN PHASE B
- o HOW TO APPROACH TECHNOLOGY DEVELOPMENT FOR A 30 YEAR PROGRAM
- o INDENTIFY DESIGN REQUIREMENTS FOR SYSTEMS THAT CANNOT BE ACCEPTANCE TESTED
- o OPTIONS SHOULD BE NARROWED IN A TIMELY MANNER
- o DEVELOP A GOOD AND ACCESSIBLE TECHNOLOGY BASE FOR LESSONS LEARNED
- o IMPROVE MISSION AND COST MODEL FIDELITY

PHASE C/D ACTIVITIES

- o WHERE NEED OUTWEIGHS RISK, CARRY PRODUCT IMPROVEMENTS ALONG DURING DEVELOPMENT
- o CONSIDER CONSORTIUMS TO MINIMIZE INNOVATION TRANSFER CONCERNS BETWEEN CONTRACTORS
- o USE PROBABILISTIC DESIGN APPROACHS
- o VALIDATE REQUIRED RELIABILITY BEFORE DELIVERY
- o THE PDR SHOULD BE A CONTINUOUS PROCESS
- o CONSIDER MODULAR APPROACH VS. LRU'S & EVOLUTION TOWARD ROBOTIC ASSEMBLY & SERVICING
- o CONDUCT FMEA ASSESSMENT EARLIER THAN THE PDR
- o INCORPORATE HIGH DESIGN MARGINS TO PROVIDE ROBUST DESIGNS AND ALLEVIATE COST OVERRUNS

FLIGHT SYSTEM EVOLUTION

- o FOCUS ON HIGH RELIABILITY INCLUDING FAULT TOLERANCE & ENGINE OUT CAPABILITY
- o CONDUCT DESIGN TRADES TO FACILITATE SYSTEMS ANALYSIS SUCH AS:
  - ENGINE RECOVERY VS. EXPENDABILITY
  - DESIGN REQUIREMENTS FOR REUSABILITY
  - ENGINE SCALING RELATIONS WITH THRUST LEVEL
  - THROTTLING
  - ENGINE GIMBALLING VS. DIFFERENTIAL THRUST FOR CONTROL
  - ENGINE UPRATE CAPABILITY VS. NEW PROPULSION DESIGN FOR GROWTH
- o PERFORM MORE QUANTITATIVE ANALYSIS, USE DIAGNOSTIC TOOLS, AVOID CATASTROPHIC FAILURE MODES, ENHANCE SYSTEM DESIGN, AND PURSUE ALTERNATIVE BOOSTER SYSTEMS

**Figure 9. SE&I Subpanel Needs/Issues**

dressed during the panel deliberations included safety and reliability, performance/design options, cost, and the technology maturation process. A summary of the panel's findings in each of these areas is provided in the following paragraphs.

SAFETY AND RELIABILITY:

Safety and reliability issues considered were:

o Improved propulsion system reliability
o Assured access to space
o Design margin
o Acceptance test requirements

Recommended Approaches:

- Institute development at the overall propulsion system level (not just the constituent engine level).
- Improve risk assessment methods/management.
- Design for benign failure modes (i.e., avoidance of catastrophic failures).
- Design-in integrated health monitoring/control systems.
- Fully implement FMEA/CIL
- Develop probabilistic risk assessment - quantitative methods & data bases for criteria selection in the areas of reliability requirements, safety factors, process control, verification/acceptance testing, and health monitoring/control capability.
- Pursue alternative booster systems (liquids and hybrids) for Shuttle, ALS, and PLS.
- Develop capability to quantify reliability without system acceptance tests.
- Develop empirical/analytical approaches to propulsion system certification.

PERFORMANCE/DESIGN OPTIONS:

Issues considered under performance/design options were:

o Growth evolution
o The PDR process
o Planetary derived propellants.

Recommended approaches:

- Plan future evolution by using the integrated modular design approach, carrying high payoff technologies in parallel, conducting full scale testing to support evolution, and setting goals for program benefits and product improvements.
- Involve a full concurrent engineering team and reviewers to define requirements, to delineate lessons learned, and to conduct conceptual reviews and a phased PDR.
- Develop the technology for indigenous planetary derived propellants, including studies to determine potential propellants, technology for propellant pro ductions and for propulsion systems utilizing in-situ propellants.

COST:

Issues addressed under cost were:

o Reusability
o Operability
o Mission & cost models
o Maintenance (modular vs LRU's)
o Low cost systems.

Recommended solutions:

- Address reusability in technology and advanced development programs
- Develop interactive government/industry cost models in Phase A and Phase B
- Validate operations cost models
- Use concurrent engineering for better cost data
- Drive early studies to greater detail
- Include risk control in program plan and cost estimates
- Conduct cost and mission sensitivity analysis
- Select a modularity approach compatible with optimum program plans for development, assembly/removability, maintenance, product improve ment, fault detection, and fault tolerance
- Identify and implement technology alternatives that can reduce recurring cost
- Perform requirements analysis to ensure requirements are real.

TECHNOLOGY MATURATION PROCESS:

Technology maturation issues considered were:

o Technology transfer
o Technology approach for 30-year program
o Intercenter participation
o Demonstrated system technology
o Technology that addresses user requirements
o Developing an experience data base
o Narrowing options in Phase A.

Recommended solutions:

- Improve technology transfer to Phase C participants by distributing technology projects and mitigating risks, improving communications to propulsion community, conducting redundant/ parallel contracts, forming consortia, and requiring private industry investment.

- Develop approach to 30 year technology program, including focusing technology on next generation systems, providing for block changes instead of continuous update, providing parallel test bed program to test evolutionary changes, and designing interfaces to accept subsystem evolution.
- Promote intercenter participation by including support centers in early studies, assuring support center requirements in Pre-Phase A and Phase A, and conducting QFD to define requirements.
- Demonstrate system technology to at least Level 5 for space-based engines and cryogenic storage systems including maintainability, cryogenic fluid transfer, alternative propulsion system concepts (e.g., plug cluster, metallized propellants, etc.)
- Pursue alternative booster systems including hot-gas pressurization systems, hybrids, pressure-fed liquids, and clean propellant solids.
- Address user requirements by user co-chairing technology working groups at start of Phase A, by user conducting focused technology program during Phase B, using concurrent engineering team to define technology needs with early trade studies, using system conceptual design update to direct technology development, and using system design update as management tool for assessing technology development program.
- Develop an experience data base including dedicated effort to gather "lessons learned"
- Narrow options at the end of Phase A to a few most attractive concepts whose technologies still need maturing.

## PANEL B - DEVELOPMENT, MANUFACTURING, AND CERTIFICATION

The topics presented and discussed by the Development, Manufacturing, and Certification panel are listed in Figure 10.

Summary sheets on each topic were prepared prior to the Symposium. Each summary sheet contained the issues to be discussed, proposed actions/programs to address those issues, and the major objectives and milestones of those programs. The topics were presented to the panel by one or more persons and then discussed by the panel participants. Following the discussion, the summary sheets were revised as necessary and collectively used as the panel report to the full symposium. There were 42 issues raised as part of the 12 topics presented to the panel resulting in 36 proposed actions/programs to support 31 defined major objectives. A summary of the major points on each topic is presented below:

1. Probabilistic Structural Analysis Methods

The certification of space transportation propulsion systems using current methods is costly and time-consuming because current designs are based on deterministic structural analysis supported by test. Probabilistic analysis is used to evaluate load, structural, and material behavior uncertainties. The probabilistic structural response and reliability risk are then determined which leads to certification. Statistical scatter can be used to compare stress to strength response.

*Recommend* continuation/augmentation of ongoing programs at LeRC and JPL.

2. Technology Transfer Methodology

Desirable features of future propulsion systems are dependent on the availability of technology. Technology implementation is need driven, not technology driven (failure, new requirements, etc). Bridging is needed between technology developers and users. Overruns have been smaller when predevelopment coordination has been greater.

*Propose* co-sponsorship (technologist and user) of technology programs and scope changes to focus the

DEVELOPMENT, MANUFACTURING, & CERTIFICATIONPANEL

SUBPANELS

SYSTEM DEVELOPMENT

- o PROBABILISTIC STRUCTURAL ANALYSIS METHODS
- o TECHNOLOGY TRANSFER METHODOLOGY
- o NATIONAL TEST BED CONCEPT
- o HISTORICAL PROBLEM AREAS

MATERIALS AND MANUFACTURING

- o MANUFACTURING PROCESSES AND APPLICATION S
- o NATIONAL MATERIALS DATA BASE
- o NONDESTRUCTIVE EVALUATION
- o CONCURRENT ENGINEERING

FLIGHT CERTIFICATION

- o INTEGRATION OF DIAGNOSTICS INTO TEST PROCEDURES
- o LIFE CYCLE COST BASED TEST PROGRAM DECISIONS
- o CERTIFICATION TEST REQUIREMENTS - MANRATING
- o TEST VS. SIMULATION

**Fig 10. DM&C Subpanel Topics**

emphasis and revise the reporting system.

3. Propulsion Testing

There is a lack of a national plan for propulsion testing. Test facilities are becoming obsolete or non-existent resulting in a loss of skilled test personnel. A universal system level NASA propulsion test bed is required.

*Propose* establishment of a task team to define requirements/capabilities (lead by HQS) for advocacy/ implementation of a plan, and a sustaining working group to support advocacy.

4. Historical Problem Areas

Reliability is the driver on existing programs. Major failure mode for Shuttle propulsion systems is fluid leakage. Primary deficiencies are materials, simple designs, mature hardware, and firm definition of requirements. Lessons learned include: avoid "single string" systems; designs must be inspectable; need all-welded feed system; dynamic envelope; provide needed instrumentation; system integration needed; must meet safety requirements; should not let politics drive the system.

*Propose* initiation of development programs with sufficient funding to address Shuttle and other long-life system issues.

5. Manufacturing Processes

Process development lags material development — an integrated plan is needed. Manufacturing technology often lacks focus. Increased fabrication costs result from complex designs. Current technology is inadequate to support on-orbit assembly.

*Recommend* establishment of broad based peer groups to review technology development programs, implementation of a review/reporting system similar to that used for IR&D programs, incorporation of technology transfer into the development plan for new equipment.

6. Materials

Space Propulsion materials research is fragmented and needs a long range master plan. Data on existing materials is not well organized or widely accepted. Materials development and manufacturing technology programs need to be integrated. Materials development, materials characterization, dissemination of properties, advanced facilities, and characterization of fire hazards/propellants are needed.

*Propose* the establishment of a space propulsion materials development and test plan, a national materials data base, and standard test methods to facilitate data base utility.

7. Nondestructive Evaluation

Current NDE technology is inadequate for precise materials characterization/process control. The data base for developing standards and certification does not cover critical propulsion components. NDE and design need to be integrated to enhance component inspectability. Main issues are materials characterization, reduction of manufacturing defects, standards and certification, advanced NDE techniques, and designing for inspectability. Probabilistic NDE can be used to characterize defect populations.

*Propose* initiating a program to correlate NDE parameters to destructively measured materials properties, development of in-situ monitoring for process correction, establishment of a standards/calibration methodology data base, development of a prototype engine test monitoring system, and the identification of high risk/high payoff components/structures.

8. Concurrent Engineering

The development cycle from establishment of mission requirements to system-in-service is inadequate for simultaneous interaction among disciplines, inflexible for adapting technology advancements, based on ad-hoc revisions, time-consuming, costly, and reliant on extensive component testing for verification and simulated proof testing for system verification. The goal of concurrent engineering is to reduce time and cost while improving quality. To implement concurrent engineering, we must change the existing culture and implement the basic principles of TQM.

*Propose* program to develop computational simulation of concurrent engineering.

9. Life Cycle Cost Based Test Program Decisions (Combined with Item 11)

10. Integration of Diagnostics into Test Procedures

This topic deals with the transfer of instrumentation technology to advanced development to operational activities. Test technology development should lead the design phase by a minimum of two to three years. Technology infusion can improve flight certification operations. Ownership of technology by operations personnel, such as plume analysis for engine health monitoring is needed.

DEVELOPMENT, MANUFAC TURING, & CERTIFICATIONPANEL

- o Technologists Tend To Overlook Mundane Unglamorous Problem Areas And This Is Why We Still Struggle With Problems Like Leaking Valves And Couplings, Iron Nitrate Contaminants, And Extensive Checkout Operations.
- o There Often Exists A Gap Between Technology Products And Program Needs. Advanced Development Programs Should Be Supported (Funded) To Bridge This Gap, Or The Technologist Should Make His Products Readily Useable By The System Developer.
- o Cultural And Programmatic Barriers Exist To Efficient Technology Transfer. Responsible And Dedicated NASA-wide Working Groups Are Recommended For Various Disciplines To Plan Specific Programs -- An Indication That There Is A Lot Of Important Information That Is Not Shared Routinely, And That A Strong NIH Syndrome Exists And Must Be Overcome.
- o Our Propulsion Test Facilities Are Aging And Need To Be Upgraded. SEI Cannot Succeed Without Efficient And Cost Effective Test Facilities.
- o Certification For Space-based/Long Duration Flight Propulsion Systems Will Be A Major Issue And We Will Need To Augment Our Current Methodology To Accommodate It -- Some New Materials, Test/NDE Methods, And Analytical Approaches.

**Figure 11. DM&C Panel Conclusions**

*Propose* the establishment of a propulsion instrumentation working group, the conducting of joint workshops, increased technology funding, establishment of " teamwork" and "ownership" recognition with emphasis on integrating the processes, development of a technology transfer program to transfer commercial technology to NASA, and establishment of a user recognized validation/proof of utility method.

11. Certification Test Requirements

There is currently no industry/government recognized methodology for improving certification test requirements. The present approach is heavily dependent on expensive, time consuming test programs. There is no quantification of engine reliability, little certification at the component level, and no space-based engine system criteria. Existing engines vary widely in design and mission requirements and thus certification requirements. Current requirements lead to low demonstrated reliabilities and low confidence levels.

*Propose* the establishment of a NASA/Industry working group to develop new and more uniform certification requirements and to verify methodologies and tools for future ETO and space-based systems.

12. Test Versus Simulation

Exclusive reliance on analysis instead of testing increases program risk. Space flight environmental effects cannot be accurately simulated. The complexity of interactive characteristics of various subsystems defies accurate simulation. Advanced vehicles may require special/unusual test facilities for propulsion system testing. Propulsion system testing minimized catastrophes and mission loss in the past and will continue to be necessary in the future.

*Propose* performance of ground and flight experiments to characterize low-g fluid behavior and heat transfer and the development and verification by test of comprehensive component and system models that address fluid dynamics, thermodynamics, and mechanical performance in all flight regimes.

Summary conclusions reached by the panel are presented in Figure 11.

**PANEL C - OPERATIONAL EFFICIENCY**

Prior to the Symposium, the panel leader distributed a discussion outline and a questionnaire for use during the panel deliberations. Respondents to the questionnaire were asked to consider all areas of operations relative to a specific list of future vehicles which included Shuttle derivatives, expendable launch vehicles, upper stages, next generation manned deep space vehicles, near-Earth satellites, deep space probes, and futuristic systems. One observation that was predominant throughout the survey as well as during the Symposium was: If NASA is to make significant improvement in the operational efficiency of propulsion systems, it must have a visible, integrated, long range development plan for the total space transportation system (STS).

Once at the Symposium, the Operational Efficiency Panel created two subpanels to consider ways to improve the operational efficiency of future space vehicle design, development, and launch and flight operations. One subpanel examined upper stages, deep space probes, and near-Earth satellites, while the other considered expendable launch vehicles and Shuttle derivatives. The results of the survey cited above were used as a starting point for subpanel deliberations. The principal observations and issues generated by the

OPERATIONAL EFFICIENCY PANEL

- o As TQM Has Proven To Many, Continuous Interaction Between "Users" And Suppliers Is Necessary To Provide A Better Product. Numerous Weaknesses Have Been Noted With The Existing Technology Planning Process. Recommend Setting Up Points Of Contact In The NASA Centers/HQS And Industry To Ensure Continous Dialogue.
- o Technology Needs To Be Directed Not Only To Reusable Space-Based Propulsion Systems, But Also To Improving The Capability Of Expendable Systems.
- o The STS Should Include Consideration For Both Direct Launch And Earth Orbit Assemble Missions.
- o Emphasis At This Session Was On Chemical Propulsion; Need To Have More Consideration For Nuclear/Electric Engines And Systems.
- o Information Available At This Conference Did Not Include Engineering Data On The Total System. NASA Needs To Be Careful And Not Sub-optimize.
- o The Spacecraft Propulsion System Is The Final "Stage" And The Highest Leverage Link In The SpaceTransportation System (Up To 80% Of Injeected Mass Is Propulsion. Unique Low Thrust Propulsion Technology Needs Should Be Included.
- o Commercial Operations Needs Should Be Considerd In Any New Engine Developed For Exploration.
- o Reliablility And Safety Are Obtained By The Proper Blend Of Simplicity, Design Margin, Redundancy, And Maintainability.
- o Design To Minimize The Requirement For Maintenance.
- o Design To Accommodate Orbital And Ground Maintenance Of Selected Items With Appropriate Accessibility And Ease Of Fault Isolation And Detection.
- o Long Duration Mars/Planetary Mission Propulsion System Needs 12-18+ Months Space Environment Test/Demonstration And Hot Fire Checkout Prior To Critical Use Commitment.

**Figure 12. Ops Efficiency Panel Observations/Issues**

panel and presented to the Symposium are listed in Figure 12.

Principal findings by the panel for each vehicle type considered as reflected in the survey results, are discussed in the following paragraphs.

Shuttle Derivatives: (2010 to 2030 Time Frame)

Integrated $LO_2/LH_2$ propulsion systems are favored as the most efficient system for the next generation shuttle. These would also have application to upper stages and manned deep space vehicles. Pressure-fed liquid and hybrid boosters may hold some promise for simplicity and robustness. Solid booster concerns were expressed in the areas of stacking and environmental impact if used in large numbers. Consideration should be given to sacrificing some performance for accessible module subsystems and pre-launch and flight health monitoring systems. Other suggestions included elimination of hydraulic and hypergol systems, the use of on-board mission planning flight computers, redundant verniers, and control computers removed from engine vibrations.

Expendable Launch Vehicles: (2000 to 2025)

For assured access to space, a mixed fleet/family, possibly modular, will always have advantages, although concerns were expressed about the use of one propulsion system for all vehicles.

Improved operational efficiency would require:

Complete plan of ground support systems and logistic interfaces, modular accessible systems with minimum ground assembly and checkout, electromechanical actuators, built-in leak detectors, health monitoring and diagnostics, no toxic fluids, no hydraulics, minimum manpower involvement at all levels, pad engine out performance, system to complete equivalent of 5 missions of ground tests with no failures before acceptance. ELV propulsion system should be designed to a level of reliability so as to be accepted as man-rated.

Upper Stages: (2000 to 2025)

The role for upper stages is generally perceived to be orbital insertion, high orbit and synchronous positioning, and interplanetary transfer and surface excursions. To fill these roles, it is believed that a family of upper stages is required.

In general, they can be made more efficient by:

Common engines and subsystems, and engine stage clustering, solids/liquids near term and solar/nuclear electric long term, developing as a building block for Lunar/Mars propellant system, protection from meteorites and orbital debris, propellant transfer and space storable propellants, modular space-based subsystems, multiple engine starts.

Next Generation Manned Deep Space Vehicles:

Nuclear propulsion systems are believed to offer the best efficiency; however, near term development will require that chemical systems be given higher priority. Surface excursion systems will require a basic oxygen/hydrogen system.

Considerations for operational efficiency are:

Flexibility of design for change-out, adaptation, and growth in a space-based environment (modular subsystems), zero leakage quick disconnects, long-life components with minimum maintenance, onboard repair capability, reliable propellant quantity gauging and on-orbit refueling, minimum number of fluids/gases, allowances for performance degradation, onboard system health monitoring, and space-based diagnostic ability.

Near Earth Satellites:

Different mission roles for satellites will require a family of different type propulsion systems.

Areas to be considered for improvement are:

Lighter weight tankage and reliable feed systems, methods for disposal after lifetime (space debris problem), increased engine efficiency at low thrust levels and pulse widths, high efficiency electrothermal and arcjet systems, long-life ion thruster systems, unlimited duty cycles, accurate propellant mass statusing, capability for space-based refueling, adequate electrical power for engines, and reduced ground monitoring.

Deep Space Probes: (2000 to 2025)

Both high performance space storable chemical and nuclear electric propulsion engines have potential for significant reductions in mission duration. Because of performance limitations, deep space missions are being considered that have durations of 14 years. Space probe missions usually cannot afford a propulsion system development program and must rely on systems developed for other projects.

Areas to be considered for improvements are:

Design for isolated checkout, operation, and self repair, shorter mission time to reduce mission control teams/facilities requirements, develop upper stage that can use modular units to convert to deep space missions, develop new booster such as ALS, avoid designs that have obstructions in front of nozzles, and increased thermal range for components such as thruster valves.

Futuristic Systems:

The responding propulsion system managers would budget 42% (average) of their futuristic funding for nuclear thermal/electrical propulsion systems. Solar electric was next with 25%. Indigenous planetary propellant material would receive 18% and fusion, laser, antimatter, etc. would receive 15%. Based on current technology, it appears the next generation spacecraft will use a type of advanced LO2/LH2 propulsion system. Unfortunately, chemical LO2/LH2 propulsion systems have a specific impulse barrier of approximately 490 seconds. To break this barrier NASA must fund development of futuristic propulsions systems.

Other Observations and Recommendations:

- NASA must develop a plan that coordinates all aspects of the STS that have propulsion system interfaces.

- Propulsion system designers and managers must understand the impact their system would have on ground operations, flight control operations, facilities, the environment, and other operating propulsion systems.

- NASA should support the AIA Propulsion Strategic Plan. Although this plan does present an in-depth study approach, it does not consider how these propusion studies can be integrated into the development of a high flight rate STS.

- Until NASA develops a long range goal for the STS, it risks funding studies that may have no applications for the next generation of space propulsion systems.

- A concept worksheet has been devised as a procedure for identifying and evaluating propulsion interface problems with STS's.

Conclusions:

A system is only as efficient as its least efficient subsystem. In order for a system to be efficient, all subsystems must be designed to support the entire system. This is especially true for a space transportation system (STS). If we are to design an STS that will routinely transport personnel and payloads to deep space, we must ensure that each subsystem will not interfere with the operations of any other system.

In the current STS, the operational efficiency of the propulsion systems is lacking. To avoid this debilitating problem for the next generation of propulsion systems:

Propulsion research studies, engine development, and support facilities must be evaluated on contributions they can offer to the total STS; operational efficiency must have the same management priority level as safety; and NASA must have a visible long-term strategic plan with well defined goals for the total STS.

PROGRAM DEVELOPMENT & CULTURAL ISSUES PANEL

- o DO A GOOD JOB OF PROGRAM PLANNING
  - NEED TO SPEND THE TIME TO DO IT RIGHT, NOT DO IT OVER
  - NEED TO MAKE INVESTMENT IN TECHNOLOGY AND ADVANCED DEVELOPMENT
  - NEED TO UNDERSTAND "SHOULD COST"
  - MAKE CONTINGENCY PLANS (BUDGET, TECHNOLOGY, SCHEDULE)
- o PAY ATTENTION TO THE CUSTOMER
  - MAINTAIN PROGRAM CREDIBILITY -- BE TRUTHFUL, DON'T OVERSELL
  - EDUCATION
  - STOP "NASA BASHING"
  - REACH OUT EMPHASIS
- o OVERCOME MICROMANAGEMENT
  - NEED TO GIVE PEOPLE THE RESPONSIBILITY TO DO THE JOB AND THEN LET THEM DO IT
  - IT IS THE SENSE OF CONGRESS THAT R139 SHOULD BE 150K
  - OMB, GAO, OTA, SPACE COUNCIL, STAFFERS, CONGRESS, PRESS....
  - LETS STUDY IT --- AGAIN
  - LETS FORM A COMMITTEE
- o PAY ATTENTION TO REAL PROGRAM REQUIREMENTS
  - DESIGN-IN MARGINS, LOW-COST, OPERABILITY
  - JUST SAY "NO": MAINTAIN COST/SCHEDULE CREDIBILITY, AVOID "CAN DO", AVOID "GET BY"
  - PROCESS CHANGES: STREAMLINE ACQUISITION, ZERO-BASE CONTRACT SPECIFICATIONS, ELIMINATE OPPORTUNITY/ABILITY TO INSPECT/TEST; STABILIZE FUNDING (MULTI-YEAR), HOW MANY PEOPLE ARE REALLY REQUIRED
  - UTILIZE TECHNOLOGY: ELIMINATE PROBLEM SUBSYSTEMS/PROCESSES, IMPROVE MANUFACTURING, AUTOMATE INFORMATION PROCESSING (PAPERLESS SYSTEM)
- o MAKE NASA A TQM ORGANIZATION
  - TOP MANAGEMENT COMMITTMENT
  - LISTEN TO STAFF
  - COOPERATIVE CONTRACTOR ENVIRONMENT

**Figure 13. PD&CI Panel Major Findings**

- o CONCERN RAISED OVER LACK OF COMMUNICATIONS BETWEEN CENTERS.
- o CONSENSUS IS THAT WE MUST MAINTAIN PUBLIC INTEREST - WITH LOSS IN PUBLIC SUPPORT AND ENTHUSIASM, PROGRAM BUDGETS ARE CUT.
- o MOST FEEL WE WILL NEVER ATTAIN PUBLIC INTEREST IN LUNAR/MARS MISSION - WE NEED TO PROVIDE THEM WITH A PROGRAM "WITH-IN REACH" - SHORT TERM GOALS
- o MUST EMPHASIZE THAT SPACE OPERATIONS IS NOT ROUTINE - LESSONS LEARNED FROM CHALLENGER.
- o SINCE THE CHALLENGER ACCIDENT, IS THERE A PLAN TO IMPLEMENT IN CASE OF ANOTHER ACCIDENT?
- o NASA NEEDS TO LEARN HOW TO LOBBY FOR FUNDING, AS WELL AS GAIN PUBLIC SUPPORT.
- o PROMOTE NASA - ATTRACT YOUNG (OF ALL AGES) INTO FIELD - PROMOTE INTEREST IN SPACE.
- o THERE SEEMS TO BE MUCH CONCERN ABOUT TECHNOLOGY TRANSFER AND WHO'S GOING TO TAKE OVER IN A FEW YEARS WHEN MANY RETIRE.
- o ENVIRONMENTAL CONCERNS WERE ADDRESSED - NEED TO DEVELOP A TECHNOLOGY BASE (SOLID PROPELLANTS MAY NOT BE ACCEPTABLE IN 5 YEARS).
- o AVOIDANCE OF GOLD-PLATING (PERFECTING PROGRAMS BEFORE A PRODUCT IS DELIVERED) IS STRESSED (I.E., RUSSIA'S SPACE STATION MAY NOT BE GLAMOROUS BUT AT LEAST IT IS OPERATIONAL).
- o NASA NEEDS TO MAKE MORE EFFICIENT USE OF IT'S PEOPLE (GOVT./CONTRACTORS).
- o NASA NEEDS TO MAKE MORE EFFICIENT USE OF IT'S MONEY - TOO MANY OVERLAPPING JOBS.

**Figure 14. PD&CI Panel "Lessons Learned" Issues/Concerns**

## PANEL D - PROGRAM DEVELOPMENT AND CULTURAL ISSUES

The Program Development and Cultural Issues Panel was structured to compare the Shuttle program approach to that being proposed by the ALS program in the areas of requirements, technology/performance/operations, reliability/safety, and procurement/contracting. The major findings of the panel are listed in Figure 13. Prior to considering these topics individually, a session on "lessons learned" was conducted. Comments and observations made during that session are summarized in Figure 14. Individual sessions were then held to discuss the above topics. Presentations were given by a number of speakers covering either the Shuttle or the ALS under each topic. The major points made by the speakers, some of the key issues and concerns raised, and resulting comments and suggestions are offered below under each of the topics discussed:

Requirements:

*Shuttle*

The Shuttle evolved from a fully reusable booster/orbiter to an unmanned booster, an expendable propellant tank, and a manned orbiter prior to initiation of Phase C/D activities because of tradeoffs made between development and operations costs. Only two of the nine original top level requirements have been met by the present configuration. Original specification called for 100 flight capability and a two week turnaround time.

*ALS*

Reduced defense spending, international competition, and information and data explosion have prompted the need for a cultural change. This change can be implemented by computer access to everyone, multidiscipline teams, consortium teams, younger management, listening to customer needs, and TQM. The ALS philosophy embraces a simple, robust system that can provide routine, reliable, and affordable operations. The teaming approach involves a joint effort by NASA/USAF and teaming of contractors to produce best design at lowest cost (three engine contractors, e.g.). Operations capability includes broad spacecraft requirements envelopes, standard interfaces, all ground support provided through launch pad, fly through failure, clean pad, operational economies (modularity, commonality, etc.). Vehicle hold-down and one engine out capability is to be included. The launch site operational requirements goal is to reduce on site manpower from 1000's to four.

*Issues/Concerns/Suggestions*

1. Culture must change! Culture can be made to change through the threat of world-wide competition, use of TQM - common sense management, realization of lost ELV business after Challenger disaster, emphasizing threat of program cancellation without increased effort and support of NASA.

2. For programs like ALS and NASP, can the blending of the Air Force (an operations' driven military organization) with NASA (a research and development organization) be accomplished?

3. Is it better to improve existing systems rather than starting with a clean sheet design? (consensus was "no").

4. NASA must apply lessons learned with engines, operations, design (Shuttle, Atlas, etc.).

5. The credibility of on-site manpower goal for ALS of four was questioned.

6. A concern was raised that the ALS has returned to the same problems as the Shuttle had in 1971.

Technology/Performance/Operations:

*Shuttle*

Drivers in SSME design included NASA/Shuttle program schedule and budget, high performance and reusability requirements, cost effective Shuttle operations (more flights - less cost), manned Shuttle, minimal cost-per-flight and minimized crew/vehicle stress loads, and maximal payload accommodation. SSME was still a giant step in rocket technology - first staged combustion cycle engine, first recoverable, reusable engine, first large throttleable, digital controlled engine, highest chamber pressure/performance engine (prior to Russian RD-170).

*ALS*

High reliability and low cost are achieved through simplified design, low cost materials and manufacturing, continuous process improvement, and improved operations. A consortium approach should be used along with TQM. The government role is key — limit specifications, maintain funding/scheduling, fix requirements, and avoid gold-plating.

*Issues/Concerns/Suggestions*

1. Lessons learned from SSME include: Engines could have been heavier, there was insufficient hardware to adequately support the development program, the heat exchanger was a constant issue but decisions driven by cost prevented redesign, funding for pumps (testing, development) was cut with each budget reduction and the pumps proved to be a major problem.

2. The SSME was designed to operate at 100% power level, but pushed to 104% (with goal of 109%) due to Shuttle weight growth and associated payload degradation. NASA would have been much better off if it had stayed with original design margins. NASA must retain fixed requirements in the future.

3. Should we try to maintain a strict schedule or a realistic one?

4. Need to change safety investigations/checks back to simple procedures.

5. Two-thirds of total life cycle costs are determined by the end of concept design - NASA must stop accepting budget cuts early on and under-engineering the front end of program development.

6. NASA needs to understand TQM and tailor it to its needs.
7. Launch site manpower requirements need to be assessed and reduced. During the Redstone/Mercury/Gemini era there were 27 launches per year with 350 government personnel plus support contractors; during the Apollo era there were 30 launches per year with 3000 government plus 18,000 contractors; with the Shuttle we are at 15 launches per year with 2500 government and 15,000 contractors. Operations are a major cost driver.

<u>Reliability/Safety</u>:

*ALS*

The STME approach includes vehicle engine-out capability, the use of TQM, simple robust design with known characteristics. Concurrent engineering considers all factors up front and can shorten product development time and lead to a much more acceptable product. Reduced process variability equals improved reliability and safety. Quality engineering equals improved reliability.

<u>Results</u>: Reduced inspection, decreased lead time, less rework and scrap, improved operability, less variability, increased customer satisfaction, fewer maintenance problems, fewer delays and engineering changes.

<u>Procurement/Contracting</u>:

*Shuttle*
(Competitive Approach to System Acquisition)

Acquiring major space transportation systems is a critical, expensive activity which impacts technology, the nation's fiscal policies, and accomplishment of agency's missions.

<u>A-109</u> (systematic, integrated management approach) objectives include: Ensure system fulfills mission needs and operates effectively, establish integrated approach for budgeting, contracting, and managing, ensure procedures employed provide appropriate tradeoffs, and maintain competition throughout acquisition process wherever feasible.

<u>Mission Need Statement</u> (Prior to Phase B): Defines mission purpose, cost, roles and responsibilities of organizations, schedule.

<u>Procurement Process</u>: Preliminary design done in Phase B. Phase B and Phase C/D conducted under full, open competition unless justified.
<u>Streamlining Techniques</u>: No initial scoring with a few proposals, page limitations - limit contractor to specified proposal lengths.

*ALS*

Competitiveness of three liquid engine contractors has eroded since the 1960's - NASA does not have the resources to allow for a competitive A-109 process. ALS propulsion company consortium approach allows for engine that minimizes flight system development cost and schedule; ideas from participating contractors "completely integrated" for best and unique design (precludes single contractor from winner take all). Maintains vigorous industry for liquid rocket engines in U.S and enhances competition for the future. With budget constraints, teaming has potential for best product at reduced development costs.

*Issues/Concerns/Suggestions*

1. How can we generate multi-year funding with half year money?

2. The government does not think life cycle — it makes no commitment to long term funding.

3. NASA must streamline the procurement process (a two year process is costly, time consuming).

4. Cultural change is occurring in ALS program with the teaming of three competitor propulsion contractors.

5. Having only one liquid rocket engine (SSME) limits viability.

6. The U.S. is losing its lead in international propulsion industry - nothing new since SSME.

7. The U.S. will not accept buying foreign space technology or hardware, as a matter of national pride.

8. Disclosure of proprietary information needs much consideration.

9. Can STME be made useful for the Shuttle as well as the ALS or other applications.

## SUMMARY

The Space Transportation Propulsion Technology Symposium provided a long-needed forum where technology developers and users could meet to discuss the future direction of space transportation propulsion systems. The technology users were given the opportunity to express their concerns as to design, development, manufacturing, and operational deficiencies of current, next generation, and future systems. They were also encouraged to offer suggested changes and alternatives that could overcome these deficiencies and ultimately enhance the nation's ability to transport men and equipment into space safely, routinely, and economically. Key technologies critical to the successful implementation of these suggested alternative approaches were also identified.

A broad range of propulsion specialists from government, industry, and academia participated very actively in the Symposium in both the plenary and panel breakout sessions. This active participation by the attendees, along with early coordinated planning and strong leadership from the Symposium and panel chairmen and co-chairmen, contributed immeasurably to the Symposium's success. Innumerable issues and concerns were raised during the week and discussed individually at length. Consensus opinions were formed, from which conclusions and recommendations were generated and presented to the Symposium as a whole. All of the major issues and concerns were considered of equal importance and each was given due consideration during panel deliberations. However, there were several predominant, recurring concerns that were deemed most pressing by the participants and these have been cited as the major Symposium findings (Figure 2.).

## FOLLOW-UP ACTIVITIES

Although it was considered a resounding success by those who attended, the participants made it clear that the Symposium should not be considered an end unto itself but should precipitate a series of ongoing activities designed to foster implementation of the Symposium recommendations. Though successful in itself, without aggressive follow-up activities the Symposium could fall short of its potential for improving the way we conduct our space propulsion business ("...better and smarter").

The first order of business will be briefings to NASA management on the outcome of the Symposium itself. The present document should serve to support this objective. Secondly, an active working group will be chartered and staffed by key NASA personnel, including those from both technology developer and technology user centers. Other appropriate government agencies, as well as industry and academia will also be asked to participate. The purpose of the working group will be to promote that continued open communications between technology developers and users which was established at the symposium. It will provide strategic planning support to the agency in order to ensure the development of a sound technology base and the implementation of greatly improved design, development, manufacturing, and operations strategies that will help meet the nation's space transportation goals of the future. Ad hoc panels will be formed to address specific critical issues as requested and provide inputs to the planning process. It is envisioned that the working group and its panels would meet as frequently as necessary to carry out their functions individually.

If the goals, suggestions, and recommendations put forth by the participants are successfully implemented as a result of subsequent working group activities, the major objectives of the Space Transportation Propulsion Technology Symposium will have been achieved.

# APPENDICES

# AGENDA

## SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

The Pennsylvania State University, University Park, PA 25-29 June 1990

### Monday, 25 June

| | | |
|---|---|---|
| 4:00-8:00 | Registration: Badge, Agenda (final), Preprints, Banquet ticket, Visitor info, etc. (Coffee available)-Lobby, Nittany Lion Inn | PSU Staff |
| 5:00-6:30 | *Social Mixer* - Ticketed Participants & Guests-Colonial Room, Nittany Lion Inn | PSU Staff |
| 6:30-8:00 | *Dinner -Open Evening* | All |

### Tuesday, 26 June

| | | |
|---|---|---|
| 7:00-8:00 | *Breakfast: Waring Commons* (Registration Continues- Lobby, Kern Graduate Center) | PSU Staff |

***PLENARY SESSION***- 112 Kern Graduate Center

| | | |
|---|---|---|
| 8:00-8:15 | Welcome and Announcements | R. Jacobs, PSU |
| 8:15-9:00 | Symposium Overview | |
| | -Call to Order, General Chairman's Remarks | R. Schwinghamer |
| | -Co-Chairmen's Comments | C. Vaughan, W. Wiley |
| | -Headquarter's Perspectives | D. Branscome |
| 9:00-9:45 | Keynote Address- James R. Thompson, Jr. NASA Deputy Administrator | All |
| 9:45-10:00 | *Break (Beverages available)*- Lobby, Kern Graduate Center | PSU Staff |
| 10:00-12:30 | Development of Symposium Themes | |
| | -Space Exploration Initiative | C.C. Priest, NASA HQ |
| | -National Space Transportation Strategy | D. Branscome, NASA HQ |
| | -Maintaining Technical Excellence | T. Davidson, AIA |
| | -Operational Efficiency - New Approaches | R. Rhodes, KSC |
| | to Future Propulsion Systems | G. Wong, Rocketdyne |
| 12:30-1:30 | *Luncheon: Waring Commons* | PSU Staff |

***PROPULSION SYSTEM OPTIONS***: ***Systems/Requirements Input to Panels***

| | | |
|---|---|---|
| | **CURRENT SYSTEMS** - Input to Panels | |
| 1:30-1:50 | Expendable Launch Vehicle Propulsion | P. Fuller, Rocketdyne |
| 1:50-2:10 | Shuttle Propulsion Systems | R. Bardos, NASA HQ |
| 2:10-2:50 | Upper Stages/Propulsion | C. Gunn, NASA HQ<br>J. Brown, P&W |
| 2:50-3:10 | Satellite/Spacecraft Propulsion | M. Dowdy, JPL |
| 3:10-3:30 | *Break (Beverages available)*- Lobby, Kern Graduate Center | |
| | **NEXT GENERATION** - Input to Panels | |
| 3:30-4:10 | Shuttle Derivatives - Manned | W. Ordway, JSC |
| | Unmanned | U. Heuter, MSFC |

**Appendix I-1.1 STPTS Agenda**



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| | | |
|---|---|---|
| 4:10-5:10 | Booster Propulsion - Liquids/Hybrids<br>Solids | U. Heuter, MSFC<br>C. Clinton, MSFC<br>R. Lund, Thiokol |
| 5:10-5:30 | ALS | J. Monk, MSFC |
| 5:30-5:50 | **ENVIRONMENTAL CONSIDERATIONS** | J. Jatko, NASA HQI |
| 6:00-7:30 | NASA Propulsion Engineering Research Center at Penn State- Facilities tour followed by: *Social Mixer: Wine & Cheese (Shuttle Buses will operate between Kern and Center facilities)*<br>*Dinner on your own* | PSU Staff |

## Wednesday, 27 June

| | | |
|---|---|---|
| 7:00-7:50 | *Breakfast: Waring Commons* (Registration Continues- Lobby, Kern Graduate Center) | PSU Staff |

***PLENARY SESSION***- 112 Kern Graduate Center

| | | |
|---|---|---|
| 7:50-8:00 | Announcements | |
| | **NEXT GENERATION** - Input to Panels (Cont'd) | |
| 8:00-8:20 | AF Space Systems Propulsion | D. Hite, AFAL |
| 8:20-8:40 | Unmanned Launch Vehicles/Upper Stages | C. Gunn, NASA HQ |
| 8:40-9:20 | Space Transfer Vehicles | F. Huffaker, MSFC<br>B. Tabata, LeRC |
| 9:20-9:40 | Advanced Manned Launch Systems (AMLS) | D. Freeman, LaRC |
| 9:40-10:00 | National Aerospace Plane (NASP) | M. Tang, NASA HQ |
| 10:00-10:20 | *Break (Beverages available)*- Lobby, Kern Graduate Center | |
| 10:20-11:20 | **FOREIGN TECHNOLOGY** - Input to Panels | |
| | - Japanese Technology | C. Merkle, Penn State |
| | - Russian Technology | R. Jones, Rocketdyne |
| | - European, Other Technology | E. Rice, Orbitec |
| 11:20-12:40 | **FUTURISTIC SYSTEMS** - Input to Panels | |
| | - Nuclear and Solar Electric Propulsion | D. Byers, LeRC |
| | - Nuclear Thermal Propulsion | G. Bennett, NASA HQ |
| | - Fusion Propulsion | N. Schulze, NASA HQ |
| | - Advanced Propulsion Concepts | R. Frisbee, JPL |
| 12:40-1:40 | *Luncheon: Waring Commons* | PSU Staff |

***BREAKOUT SESSIONS***

| | | |
|---|---|---|
| 1:40-5:30 | **PANELS CONVENE**- Various rooms, Willard Building (See enclosed map)<br>Note: Computer chart making support available - 101A, Kern Graduate Center | Panel Leaders and Members |

**Appendix I-1.2 STPTS Agenda (Cont'd)**

| | | |
|---|---|---|
| 3:15-3:30 | *Break (Beverages available)-* Lobby, Kern Graduate Center & 2nd floor, Willard Building | |
| 5:30-6:00 | Resolution of Issues (If Required) | Panel Leaders & Staff |
| 6:00-7:00 | *Social Mixer-* Lobby, Days Inn | PSU Staff |
| 7:00-8:30 | *Banquet-* Banquet Room, Days Inn<br>Speaker: Mr. James McDivitt<br>Senior Vice President<br>Rockwell International | All |

**Thursday, 28 June**

| | | |
|---|---|---|
| 7:00-8:00 | *Breakfast: Waring Commons* (Registration Continues- Lobby, Kern Graduate Center) | PSU Staff |

***BREAKOUT SESSIONS***

| | | |
|---|---|---|
| 8:00-2:00 | **PANELS RECONVENE**- Various rooms in Willard Building Focus: Document Findings, Summarize, Prepare Briefings.<br>Note: Computer Chart Making Support Available in 101A, Kern Graduate Center | Panel Leaders and Members |
| 10:00-10:15 | *Break (Beverages available)-* Lobby, Kern Graduate Center & 2nd floor, Willard Building | |
| 12:00-1:00 | *Luncheon:Waring Commons* | PSU Staff |

***PLENARY SESSION***

| | | |
|---|---|---|
| 2:00-5:30 | NASA Propulsion Engineering Research Center at Penn State, Second Annual Symposium- Concurrent sessions in rooms 101 and 112, Kern Graduate Center (See enclosed agenda) | PSU Staff |
| (As Avail/Req'd) | Rapporteur's Perceptions and Critique of Panel Deliberations and Results | Council of Rapporteuers (Off Line to Staff) |
| 3:30-3:45 | *Break (Beverages available)-* Lobby, Kern | |
| 6:00-7:30 | *Picnic-* Lawn of Hetzel Union Building (Inside HUB if inclement weather) | PSU Staff |

**Friday, 29 June**

| | | |
|---|---|---|
| 7:00-8:00 | *Breakfast: Waring Commons* | PSU Staff |
| 8:15-9:00 | *Speaker:* The Honorable Robert S. Walker,<br>U.S. House of Representatives | All |
| 9:00-9:30 | Panel A Reports (to Plenary Session) | Panel A |
| 9:30-10:00 | Panel B Reports (to Plenary Session) | Panel B |
| 10:00-10:15 | *Break (Beverages available)-* Lobby, Kern Graduate Center | |
| 10:15-10:45 | Panel C Reports (to Plenary Session) | Panel C |
| 10:45-11:15 | Panel D Reports (to Plenary Session) | Panel D |
| 11:00-12:00 | Open Discussion, Summary of Conclusions and Closing Remarks (Revew of Findings, etc.) | R. Schwinghamer, C. Vaughan, W. Wiley |
| 12:00-1:00 | *Luncheon: Waring Commons/Symposium Adjournment* | |

**Appendix I-1.3 STPTS Agenda (Cont'd)**

# SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

## Panel Topics

**GENERAL CHAIRMAN**
**ROBERT SCHWINGHAMER**
**COCHAIRMEN**
**CHESTER VAUGHAN - JSC, WARREN WILEY - KSC**

### *PROPULSION SYSTEM OPTIONS*

**CURRENT SYSTEMS**
- o ELVs - Small, Med, Lrge
- o Shuttle - SSME, OMS, RCS, RSRM, ASRM
- o Upper Stages
- o Satellite/Space Probe Prop

**NEXT GENERATION (Candidates)**
- o Shuttle Derivatives
- o Booster Propulsion (Liquid, Hybrid, Solid
- o Advanced Launch Systems
- o Unmanned Launch Vehicles and Upper Stages
- o Space Transfer Vehicles/Adv. Cryo. Propulsion
- o Adv. Manned Launch Sys. (Shuttle II, SSTO, Comb. Cycle Prop., Adv. Rockets)
- o NASP

**ENVIRONMENTAL ISSUES**

**FOREIGN TECH.**
- o Japanese
- o Russian
- o European
- o Other

**FUTURISTIC SYSTEMS (Candidates)**
- o Nuclear Thermal Propulsion (Fission, Fusion)
- o Nuclear &Solar Electric
- o Adv. Propulsion Concepts

* Panel Rapporteur/Facillitator

### SYSTEMS ENGINEERING & INTEGRATION

+ Len Worlund - MSFC
Phil Deans - JSC
Frank Berkopec - LeRC

(+ Panel Leader)

**o Prelim Design Activities**
- ° Conceptual Design (Phase A Studies)
- ° Pre Development/ Phase B Studies
- ° System Architecture
- ° Vehicle End-to-End Subsystem Interdependencies
- ° Trajectory/Performance Planning Options

**o Phase C/D Activities**
- ° Pre Development Technology Maturity
- ° PDR Penetration
- ° Modular vs LRU's
- ° FMEA/CIL
- ° Design Margin

**o Flight System Evolution**
- ° Uprating (Perf/Life)
- ° Cost Reduction
- ° Assured Access

* Irving Davids
* Carl Aukerman

### DEVELOPMENT, MANUFACTURING & CERTIFICATION

+ Walt Karakulko - JSC
Paul Shuerer - MSFC
Steve Dick - SSC

**o System Development**
- ° Probabilistic Structural Analysis Methods
- ° Tech Trfr Methodology
- ° National Test Bed Concept
- ° Historical Problem Areas - Solutions Needed

**o Mat'ls & Manufacturing**
- ° Manu. Processes & Applications
- ° National Mat'ls Data Base
- ° NDE
- ° Concurrent Engineering

**o Flight Certification**
- ° Integration of Diagnostics into Test Process
- ° Life Cycle Cost Based Test Program Decisions
- ° Certification Test Requirements - Manrating
- ° Testing vs. Simulation

* Mel Bryant
* Bill Hope

### OPERATIONAL EFFICIENCY

+ Don Nelson - JSC
Russ Rhodes - KSC
Marv Carpenter - SSC
Fred Huffaker - MSFC

**o Pre-Launch Activities**
- ° Operationally Efficient Propulsion Systems
- ° Facilities Requirements

**o Flight Operations**
- ° Data Acquisition
- ° Flight Control
- ° Weather Limitations/ All Weather Capability

**o Mission Success Assurance**
- ° Safety & Diagnostics
- ° Configuration Control

**o Space Basing**
- ° System Concepts
- ° Propellant Storage/Trfr

**o Review Survey**

**o Subpanel Discussions on Ops Efficiency for:**
- ° Shuttle Derivatives
- ° ELV's
- ° Upper Stages/Manned
- ° Satellites/Deep Space Probes

* Bill Dickinson
* Brenda Wilson

### PROGRAM DEVELOPMENT & CULTURAL ISSUES

+ Ed Gabris - HQS
Chuck Eldred - LaRC
Harry Erwin - JSC
Gene Austin - MSFC

**o Lessons Learned (Shortcomings)**

**o Requirements**
- ° Shuttle Level II
- ° Fixed Capability
- ° ALS
- ° Environmental Consid/TQM
- ° Assured Access to Space

**o Technology/Perf/Ops**
- ° Tech Limited
- ° Perf Driven
- ° Labor Intensive
- ° Perf Margin
- ° Cost Driven
- ° Skeleton Crews

**o Reliability/Safety**
- ° By Test
- ° Redundancy
- ° Engine On/Off/Out
- ° Constraints (Redlines)
- ° Margin/Design
- ° Fault Tolerant Safety
- ° Hlth Monitoring

**o Procurement/Contracting**
- ° Competitive
- ° Mission Need Statement/A109
- ° Yr-to-Yr Funding
- ° IR&D
- ° Consortium
- ° Multi-Yr Funding
- ° Joint Funding
- ° IR&D

* Rodney Johnson
* Diane Gentry

**Appendix I-2 Panel Topics**

# THE PROPULSION SYSTEMS OPTIONS PANEL

The panel chairmen for the Propulsion Systems Option Panel were Bob Zurawski (HQ), Eric Hyde (MSFC), and Sol Gorland (LeRC). The purpose of this panel was to provide input to the 4 panels on accomplishments and areas of technical needs from existing propulsion sytems and outward to those future propulsion systems being considered for space transportation systems. It also addressed key topics impacting the propulsion discipline (i.e., foreign technology and environmental issues). Twenty four speakers from various organizations (NASA, industry, and academia membership) addressed 5 categories of interest . The general findings of the panel are outlined as follows:

## GENERAL FINDINGS

- Need to develop and implement a national strategic plan for rocket propulsion technology
- Use NASA's Aeronautics program as a model for future planning
- Use building block approach for space transportation/operations infrastructure
- Implement user focused technology programs
- Develop & implement education programs

## CURRENT SYSTEMS

- Shuttle life cycle extension offers significant savings
- ELV upgrades are required to remain competitive
- Shuttle propulsion issues currently being worked (RSRM,SSME, RCS,SRB)

## NEXT GENERATION SYSTEMS

- Develop/Implement a plan for next generation ELV development
- Establish a national consortium for next generation space transportation
- Heavy lift launch capabilities needed
- Space based systems require technology commitment
  - Design for minimal maintenance, reuse, robotic servicing
- High priority technology needs
  - Liquids(low cost LOX/LH2 and LOX/RP)
  - Upper stage propulsion
  - Solids (clean propellants)

## FUTURISTIC SYSTEMS

- Advanced propulsion systems provide major reductions in mass & trip time (e.g., nuclear thermal, solar, fusion, solar sails, tethers, etc.)
- Electric propulsion extends orbit life of satellite (permits use of smaller, cheaper launch vehicles)
- Future systems technology requires technology commitment now

## ENVIRONMENTAL ISSUES

- Environmental requirements are changing rapidly

- Environmental issues will impact cost/schedule/testing

- Need greater NASA/industry cooperation
  -Plan for compliance(cost,schedule)
  - Test in less sensitive areas
  - Establish environmental committees

## FOREIGN TECHNOLOGY

- Significant advancements by foreign nations in development of space programs threaten U.S. position

- Need to develop a foreign technology data base
  - "Understand" our competition
  - Use in future program planning

- Successful foreign approaches utilize modularity, commonality, and multiple engine stages

## THE SYSTEM ENGINEERING & INTEGRATION PANEL

The Systems Engineering & Integration Panel was chaired by Len Worlund (MSFC) with Phil Deans (JSC) and Frank Berkopec (LeRC) serving as co-chairmen. The facilitator and rapporteur were Carl Aukerman and Irving Davids, respectively.

Panel members participated in three subpanels formed by the chairman during pre-symposium activities.

1.) Preliminary Design Activities (Worlund)
2.) Phase C/D Activities (Berkopec)
3.) Flight System Evolution (Deans)

These subpanels addressed four categories of concern: ***Safety and Reliability, Performance/Design Options, Cost, & Technology Maturation Process.*** The panel identified key issues, their impacts, and proposed resolutions for each of these topics. During the session, 20 key issues/needs were discussed and a summary of the panel's specific needs/capabilities to address these issues follows:

SPECIFIC NEEDS/CAPABILITIES

- Health monitoring and control
- Design of benign failure modes
- Implementation of probabilistic design techniques
    - FMEA/CIL, risk analysis, & data bases
- Technology development in areas of planetary resource utilization and propulsion system recovery/reuse
- Design methodology to quantify reliability without system acceptance tests
- EMA's, IHM, built-in-test offer improved systems
- System test beds for critical technologies
    - Space engines/systems, boosters

PROGRAMMATIC NEEDS:

- User co-chaired working groups at Phase A start; user focused technology
- Long-term program development approach to include:
    - Interfaces designed for adaptability
    - Test beds provided in parallel with program
    - Block changes

- Thorough technology maturation processes
    - Drive early studies to greater detail
    - Assure mature technology levels prior to Phase C
- Implementation of a "phased" PDR process
- Establishment of "real"system requirements
- Interactive government/industry cost models

## DEVELOPMENT, MANUFACTURING AND CERTIFICATION PANEL

The chairman of the Development, Manufacturing and Certification Panel was Walt Karakulko (JSC) and the co-chairmen were P.Shuerer (MSFC) and J.S. Dick (SSC). Bill Hope (SRS Technologies) was the rapporteur and Mel Bryant served as the facilitator for the panel.

The panel reviewed 12 topics and examined such areas as issues, proposed actions/programs, major objectives and major milestones which are documented in the conference proceedings. The focus of the panel was in 3 major areas:

*SYSTEM DEVELOPMENT*

1.) Probabilistic Structural Analysis Methods
2.) Technology Transfer Methodology
3.) Propulsion Testing/National Test Bed Concept (See Appendix I-2)
4,) Historical Problem Areas

*MATERIALS AND MANUFACTURING*

5.) Manufacturing Processes & Applications
6.) Materials/National Materials Data Base
7.) Nondestructive Evaluation
8.) Concurrent Engineering

*FLIGHT CERTIFICATION*

9.) Infusion of Instrumentation Technology Into Operational Tests/Integration of Diagnostics into Test Processes
10.) Certification Test Requirements
11.) Life Cycle Costs Based Test Program Decisions
12.) Test Vs Simulation

The panel discussed a number of specific needs to develop improved propulsion systems. It also identified programmatic deficiencies and changes needed to assure the development of an adequate propulsion technology base.

SPECIFIC NEEDS/CAPABILITIES:

- *A national propulsion system "test bed"*
  - A national test plan
  - A task team & HQ advocate
- *Databases of information*
  - "Lessons learned"
  - Standards/Calibration Methodologies
  - Materials Properties
- *Space-based technologies*
  - Low-g fluid behavior
  - Simulation for space environmental effects
  - Models for thermal/fluid dynamic analysis of all flight regimes
  - Identify/define requirements for space-basing
- *Programs to address historical problem areas:*, e.g. Shuttle and long term system issues

The panel outlined its major objectives and milestones for implementation of the proposed actions. A "quick look" at these goals follows:

MAJOR OBJECTIVES/MAJOR MILESTONES

- Automated software packages for certification of propulsion systems

- Ensure technology development matches user needs
  - Target new FY 92 RTOPS for co-ownership with validation a part of technology scope

- Ensure availability of adequate propulsion test facilities, technical skills and expertise
  - HQ advocate (1990)
  - Working group (1992)
  - Complete National Propulsion Test Plan (1993)

- Initiate programs to address historical problem areas
  - Shuttle Support (1991)
  - SSF Support (1992)
  - Mars Support (1995)

- Establish, update a space manufacturing development plan
  - Initial plan (1991);Update annually
  - Initiate technology demos (1991)

- Establish, update a national space propulsion materials development and test plan and maintain a national materials database

- Integrate NDE, materials and processing and analysis/design activities

- Computational simulation of concurrent engineering processes

- Establish and implement a long range plan for continued improvements in technology/operations transfer process
  - Working group 9/90
  - Long range plan development 3/91
  - Implement plan 10/91-

- Establish justifiable requirements and testing for certification of space-based and ETO systems

- Develop comprehensive data base for identification of space environment and effects on propulsion system fluids

# THE OPERATIONAL EFFICIENCY PANEL

The chairman of the operational efficiency panel was Don Nelson (JSC). However, in Don's absence, Chester Vaughan (JSC) substituted as the panel chairman. The co-chairmen were Russ Rhodes (KSC), Marv Carpenter (SSC), Fred Huffaker (MSFC) and Charles Holliman (HQ). Brenda Wilson (W.J.Schafer, Associates) and Bill Dickenson (KSC) served as the panel rapporteurs.

The Operational Efficiency Panel was set up as two concurrent subpanels;

1.) *Upper Stages*
2.) *Expendable Launch Vehicles (ELV's) & Shuttle Derived Vehicles*

As part of the panel deliberations, participants developed a comprehensive list of technology needs for Upper Stages, Existing Class ELV Upgrades, and Future Class ELV's. A complete list of these technology needs can be found in the conference proceedings.

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The Upper Stages subpanel, moderated by Fred Huffaker outlined goals for rocket engine and propulsion system development:

- *U.S. preeminence in rocket engine development, production, testing for national, international and commercial use.*
- *Alternate space transportation engine technologies for man-rated, extended duration space missions*
- *Development of propulsion systems technology in parallel with engines*
- *Low thrust propulsion systems to maximize mission success*

The ELV and Shuttle Derived Vehicles subpanel led by Russ Rhodes (KSC) was comprised essentially of liquid propulsion specialists who strongly favored funding of liquid rocket propulsion technology.

A brief discussion of the panel's findings and it's recommended actions to ensure a sound propulsion system technology base follows:

- Provide for continuous interactions between user/developer
  - Set up point of contact at HQ and industry
- Technology scope should include:
  - Reusability, space-basing and improvements to expendable systems
- Emphasis needed on unique low thrust technologies
  - Nuclear/electric engines/subsystems
- Must consider needs for commercial operations in new engine development
- Design for minimal maintenance, including both orbital and ground maintenance

- Long duration (Mars/planetary) propulsion systems need 12-18 months space environment test and hot-fire prior to commitment

In addition, recommendations were made for improving operational management

*OPERATIONAL MANAGEMENT NEEDS*

- Develop an accepted technique for operability measurement
- An organized approach for each technology item--i.e., a sponsor, a funding manager, etc.
- Establish a senior operations level position at HQ
- Funding managed by operating center rather than design center
- Propose an annual propulsion system operational efficiency working group

Prior to the symposium a survey was distributed by the panel to key NASA and space industry propulsion systems managers. This survey addressed the propulsion aspects of space vehicles and a complete summary of results can be obtained from the panel chairman, Don Nelson (JSC).

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PRE-SYMPOSIUM SURVEY RESULTS SUMMARY:

Consideration of the following areas (as indicated by key NASA and space industry propulsion systems managers) offers improvements in operational efficiency for the next generation of spacecraft:

- Minimum manpower at all levels of operation
- Modular, accessible systems with minimal ground assembly and checkout
- Onboard realtime mission planning flight computers
- Modular subsystems
- Health monitoring systems for pre-launch and flight
- Space-based diagnostic ability
- Minimal fluids/gases
- Elimination of hydraulic and toxic propellants
- Integrated consumables system (propulsion, life support, fuel cells)

The following are *glimpses* of the comprehensive lists of technical needs developed by members of the Operational Efficiency Panel ( A complete guide of these references is published in the conference proceedings)

## UPPER STAGE TECHNOLOGY NEEDS

- Engine propulsion needs --upgrade of LO2/LH2 RL-10, an alternate space based engine
- Engine technologies --EMA's, elimination of He
- Propulsion support systems --Health monitor & control, zero-leak quick disconnects at interfaces, engine & vehicle sensors
- Cryo fluid management technologies
- Space based operations --space tug, power,robotics, data management,EVA
- Integrated propulsion systems
  -Large O2/H2 reaction control system
- Universal data information system
- Advanced spacecraft propulsion--space-basing, reusable, low thrust chemical, min. contaminants

## ELV TECHNOLOGY UPGRADES/NEEDS

- EMA's
- Improved hydrogen detection techniques
- Laser initiated ordnance
- Integrated propulsion module designs
- Improved heat shields
- Contamination tolerant hardware/processes

## NEXT GENERATION/FUTURE ELV NEEDS

- Automated launch operations--minimal hands-on functions
- Low cost liquid propellants
- Totally integrated logistics support system
- EMA's
- Modular propulsion modules
- Low cost, expendable disconnects

## ENDORSEMENTS FOR FURTHER STUDY

- Single Stage To Orbit (SSTO)
- Integrated propulsion modules
- All H2/O2 propellants
- An "operations testbed"
- An integrated logistics support system
- Composite tanks/components
- Elimination of all toxic/environmentally damaging propellants
- Universally integrated launch facility

## PROGRAM DEVELOPMENT AND CULTURAL ISSUES

The chairman of the Program Development and Cultural Issues Panel was Ed Gabris (HQ) and the co-chairmen for the panel were Harry Erwin (JSC), Gene Austin (MSFC), and Chuck Eldred (LaRC). Serving as the facilitator and rapporteur were Rod Johnson and Diane Gentry (SRS Technologies).

The five key areas of focus for this panel session were as follows:

- *LESSON LEARNED (THEIR SHORTCOMINGS)*
- *RELIABILITY/SAFETY*
- *TECHNOLOGY/PERFORMANCE OPERATIONS*
- *PROCUREMENT/CONTRACTING*
- *REQUIREMENTS*

As a result of much discussion, two key ideas comprise the overall opinions of the panel participants:

- Culture Change is Essential
- Better Overall Planning is Necessary

This panel strongly supports and recommends the implementation of a cultural change within NASA to ensure the success and survival of future space programs.

Overall the panel did not determine *how* to implement the changes needed rather they addressed the key concerns and issues that need consideration and made recommendations for improvements. An overview of these recommendations follows:

PANEL RECOMMENDATIONS:

- Provide increased emphasis on program planning
  - Invest in technology, make contingency plans
- Increase emphasis on program requirements
  - Design in and maintain operability, low cost and margins
- Implement TQM throughout NASA--starting with top level commitment
- Institute process changes--i.e, streamline acquisition process, multi-year funding, zero base contract specs, eliminate redundant inspections, implement improved staffing plan
- Maintain program credibility--do not oversell
- Develop and implement education programs--at all levels

# Report Documentation Page

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16. Abstract


The Space Transportation Propulsion Technology Symposium was held at the Pennsylvania State University in State College, PA, June 25-29, 1990. The Symposium was held to provide a forum for communication within the propulsion technology developer and user communities. Emphasis was placed on propulsion requirements and initiatives to support current, next generation and future space transportation systems, with the primary objectives of discerning whether proposed designs truly meet future transportation needs and identifying possible technology gaps, overlaps and other programmatic deficiencies. Key space transportation propulsion issues were addressed through four panels with government, industry and academia membership. The panels focused on systems engineering and integration; development, manufacturing and certification; operational efficiency; and program development and cultural issues.


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