N93-22096

PROPULSION SYSTEMS PANEL

PANEL Co-Chairman
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R. Miner / LeRC

LIQUID PROPULSION
L. Johnston / MSFC

- R. Bruce / SSC
- D. Dennies / Aerojet
- W. Dickenson / KSC
- R. Dreshfield / LeRC
- W. Karakulko / Lockheed
- M. McGaw / LeRC
- P. Munafo / MSFC
- C. Rhemer / P&W
- R. Sackheim /TRW
- J. Wooten / Rocketdyne
- G. Woodcock / Boeing

SOLID PROPULSION
R. Clinton / MSFC

- G. Baaklini / LeRC
- J. Crose / PDA
- F. Davidson / ARC
- W. Figge / ARC
- D. Guillot / Thiokol
- A. Holzman / UT-CSD
- W. Kearney / Aerojet
- J. Koenig / SRI
- B. Loomis / SAIC
- B. Marsh / MICOM
- C. Olsen / Thiokol
- R. Sullivan / MSFC
- G. Wendel / Hercules
- K. Woodis / MSFC

NUCLEAR PROPULSION
J. Stone / LeRC

- S. Bhatacharyya / Argonne
- R. Carruth / MSFC
- M. Cooper / Westinghouse
- R. Cooper / ORNL
- G. Halford / LeRC
- T. Herbell / LeRC
- B. Matthews / DOE
- W. Long / B&W
- J. Wooten / Rocketdyne

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

CASES:

- HIGH RELIABILITY CASE JOINTS AND ATTACHMENTS COMPATIBLE WITH OPTIMIZED COMPOSITE DESIGNS (1)
- COMPOSITE CASE DESIGN AND ANALYSIS METHODOLOGY (5)
- CASE MATERIALS AND MATERIAL FORMS SUITABLE FOR ENVIRONMENTALLY SAFE, LOW COST, RELIABLE, HIGH RATE PRODUCTION (1)
- CASE EQUIPMENT AND PROCESSES SUITABLE FOR LOW COST/HIGH RATE PRODUCTION (1)
- COMPOSITE CASE CODE DEVELOPMENT (1)
- SELF-INSULATING CASE (1)
- LOW COST/RAPID TURNAROUND CASE TOOLING (1)

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

NOZZLES:

- CHARACTERIZATION OF MATERIAL RESPONSE AND CONSTITUTIVE MODELING OF ABLATIVE MATERIALS (4)
- PROCESS UNDERSTANDING AND LIMIT DETERMINATION FOR OPTIMIZATION AND CONTROL OF NOZZLE COMPONENTS (4)
- NOZZLE FAILURE CRITERIA, DAMAGE, MATERIAL VARIABILITY AND EFFECTS OF DEFECTS (3)
- ROBUST ABLATIVE NOZZLE MATERIALS AND PROCESS DEVELOPMENT (4)
- NOZZLE THERMOSTRUCTURAL CODE DEVELOPMENT (2)
- NOZZLE DESIGN METHODOLOGY (3)
- LIGHTWEIGHT, LOW TORQUE FLEX BEARING DESIGN MATERIALS, AND PROCESS DEVELOPMENT (1)
- ENVIRONMENTALLY SOUND CLEANING PROCESSES FOR CASE AND

SOLID PROPULSION

NOZZLES(CONT):

- CORRELATION OF CHEMICAL PROPERTIES TO MECHANICAL PROPERTIES FOR CRITICAL NOZZLE MATERIALS, STRUCTURAL ADHESIVES, ABLATIVE COMPOSITES, FLEX SEAL ELASTOMERS (1)
- LOW COST ABLATIVE NOZZLE MATERIALS AND PROCESS DEVELOPMENT (1)
- DESIGN GUIDE FOR NOZZLE STRUCTURAL ADHESIVE SELECTION (2)
- CARBON-CARBON CHARACTERIZATION AND MICROMECHANICAL MODELING (1)
- CONSTITUTIVE MODELING AND FAILURE CRITERIA FOR NONINSULATORS (2)
- EROSION MODELING OF NOZZLE MATERIALS (1)
- LARGE NOZZLE 3D CARBON-CARBON ITE AND BACKUP INSULATOR DEVELOPMENT AND CHARACTERIZATION (2)

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

BONDLINES/PROPELLANT:

• MATERIAL AND PROCESS VARIABILITY REDUCTION	(3)
• ANALYTICALLY DRIVEN TEST TECHNOLOGY FOR PROPELLANT AND BONDLINE CONSTITUTIVE MODEL DEVELOPMENT	(11)
• BONDLINE DESIGN FOR INSPECTABILITY	(4)
• BONDLINE STRUCTURAL AND HEALTH MONITORING METHODOLOGIES	(5)
• BONDLINE CONTAMINATION STUDIES	(1)
• PROPELLANT AND BONDLINE FAILURE CRITERIA	(7)
• EFFECTS OF DEFECTS FOR BONDLINES	(5)
• CLEAN SOLID PROPELLANT DEVELOPMENT AND VERIFICATION	(1)
• BONDLINE PROCESSING PROTOCOL (REPAIR/REWORK)	(1)
• NDF FOR PROPELLANT	(1)

SOLID PROPULSION

INSULATION:

• THERMOPLASTIC ELASTOMER (TPE) INSULATOR FABRICATION TECHNOLOGY AND BONDLINE CHARACTERIZATION FOR LARGE MOTORS	(2)
• ADVANCED BONDING CONCEPTS FOR LINERLESS INSULATION DEVELOPMENT	(2)
• LOW COST INSULATION PERFORMANCE TEST METHODOLOGY DEVELOPMENT AND CORRELATION WITH MOTOR PERFORMANCE	(1)
• FIBER/POLYMER INTERACTION TAILORING FOR DEVELOPING IMPROVED FIBER FOR INTERNAL INSULATORS	(1)
• SPRAYABLE SOLVENT-FREE, HIGH TEMPERATURE TPE THERMAL PROTECTION (EXTERNAL) SYSTEM	(1)

HYBRID ROCKET PROPULSION:

• HYBRID ROCKET PROPULSION FEASIBILITY DEMONSTRATION	(2)

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

LIQUID PROPULSION

• IMPROVED FABRICATION PROCESSES	(11)
• IMPROVED ANALYSIS AND TEST METHODS	(4)
• PROPELLANT COMPATIBLE MATERIALS (E)	(6)
• IMPROVED BEARING AND SEAL MATERIAL AND FABRICATION PROCESSES (E)	(7)
• IMPROVED COMBUSTION CHAMBER MATERIALS DEVELOPMENT (E)	(7)
• IMPROVED TURBOPUMP MATERIALS	(4)
• IMPROVED NOZZLE MATERIALS	(4)
• DEVELOP GLOBAL MATERIALS AND PROCESSES DATA BASE	(3)
• LIGHTWEIGHT STRUCTURAL MATERIALS DEVELOPMENT	(2)
• LIGHTWEIGHT INSULATION MATERIALS DEVELOPMENT (E)	(1)
• IMPROVED ENGINE HARDWARE	(4)

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • IMPROVED FABRICATION PROCESSES	**MILESTONES AND RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • OPTIMIZATION OF FABRICATION PROCESSES IS REQUIRED TO INCREASE YIELD AND QUALITY AND REDUCE COST - CURRENT SSME MCC PROCESS TIME COULD BE REDUCED BY 70% • DEMONSTRATION OF FABRICATION PROCESSES ON FULL SCALE HARDWARE IS REQUIRED TO DEFINE PROCESS LIMITATIONS AND ASSURE TRANSITION TO PRODUCTION	**RECOMMENDED ACTIONS:** • FULL-SCALE COMPONENT TRIALS FOR COMBUSTION CHAMBER FABRICATION TECHNOLOGY - PLASMA SPRAY FORMING - PLATELET TECHNOLOGY - LIQUID INTERFACE DIFFUSION BONDED (LIDB) - TUBULAR CONSTRUCTION • CHARACTERIZATION OF IMPROVED FABRICATION PROCESSES - NEAR NET SHAPE FABRICATION - FINE-GRAINED CASTINGS - SUPERPLASTIC FORMING ENGINE COMPONENTS - MACHINING OF HIGH ASPECT RATIO COOLANT CHANNELS - ELECTROFORMING - INFLATION FORMED LASER-WELDED COOLANT TUBES • JOINING PROCESS DEVELOPMENT FOR FULL-SCALE ENGINE

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• IMPROVED ANALYSIS AND TEST METHODS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• INADEQUATE ANALYSIS AND CERTIFICATION TEST PROGRAMS FOR LONG LIFE ENGINE COMPONENTS AND SYSTEMS	• DEVELOP DURABILITY MODELING PROCEDURES IN ONE COMPUTER CODE THAT ACCOUNT FOR: - CYCLIC INELASTIC CONDITIONS - CRACK INITIATION AND GROWTH • DEVELOP TESTING METHODS TO EVALUATE THE AGING CHARACTERISTICS OF MATERIALS AND COMPONENTS IN A TIME PERIOD SIGNIFICANTLY SHORTER THAN THE ACTUAL INTENDED SERVICE LIFE

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• PROPELLANT-COMPATIBLE MATERIALS	• EPA-DRIVEN REQUIREMENTS (ENABLING)
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• FUELS FOR SPACE SYSTEMS MAY DEGRADE MATERIALS BEHAVIOR - HYDROGEN - SULFUR IN HYDROCARBONS - NITROGEN TETROXIDE - HYDRAZINE • MATERIALS WHICH RUB IN AN OXIDIZING ENVIRONMENT MAY IGNITE AND BURN • ENVIRONMENTAL CONCERNS DICTATE ELIMINATION OF HAZARDOUS MATERIALS	• HYDROGEN RESISTANT MATERIALS • IMPROVED MATERIALS FOR RUBBING IN OXYGEN ENVIRONMENT (IMPELLERS, TURBINES, BEARINGS, ETC) • ENVIRONMENTALLY COMPATIBLE MATERIALS FOR PRE-CLEANING AND FINE-CLEANING • METHOD TO NEUTRALIZE EFFECTS OF NITROGEN TETROXIDE IN RCS VALVES AND PLUMBING • EFFECTS OF IMPURITY ADDITIONS IN HYDROGEN • FUNDAMENTAL STUDY OF MATERIAL BEHAVIOR IN OXYGEN

LIQUID PROPULSION SYSTEMS SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- IMPROVED BEARING AND SEAL MATERIAL AND FABRICATION PROCESSES

MILESTONES AND RESOURCE REQUIREMENTS:

- CRYOGENIC SLIDING WEAR TESTER
  - LOX CAPABILITY
- SSME HYDROSTATIC BEARING (1996) (ENABLING)

BACKGROUND & RELATED FACTORS:

- TURBOPUMP BEARINGS ARE LIFE-LIMITING IN SSME
- CONTINUED IMPROVEMENT OF BEARINGS AND SEALS IS REQUIRED TO INCREASE RELIABILITY OF REUSABLE ENGINE SYSTEMS
- DEVELOPMENT OF HYDROSTATIC BEARINGS WILL PROVIDE SIMPLER DESIGNS, EASE OF MANUFACTURE AND HIGHER STIFFNESS AND DAMPING WITHOUT STEADY-STATE WEAR

RECOMMENDED ACTIONS:

- CONTINUE DEVELOPMENT OF ROLLING ELEMENT BEARING MATERIALS FOR CRYOGENIC APPLICATIONS
- CONTINUE DEVELOPMENT OF BEARING CAGE MATERIALS WHICH PROVIDE SOLID LUBRICATION TO THE ROLLING ELEMENTS
- DEVELOP IMPROVED SEAL MATERIALS
- INVESTIGATE MATERIALS FOR APPLICATION TO CRYOGENIC HYDROSTATIC BEARINGS
- DEVELOP FOIL BEARINGS
- CONTINUE INVESTIGATION OF DUAL PROPERTY BEARING RACE PROCESSING
- INVESTIGATE THE APPLICATION OF CERAMIC MATERIALS IN CRYOGENIC BEARINGS
- INVESTIGATE THE APPLICATION OF NANOCRYSTALLINE MATERIALS TO BEARINGS

PROPULSION SYSTEMS PANEL

LIQUID PROPULSION SYSTEMS SUBPANEL

BASE R&T PROGRAM

FINDINGS:

- TECHNOLOGIES HAVE BEEN PRIORITIZED WITH A VIEW TOWARD RELATIVELY NEAR TERM REQUIREMENTS
- A SUBSTANTIAL BASE R&T PROGRAM IS ALSO REQUIRED TO ADDRESS HIGH-PAYOFF TECHNOLOGIES
- SIGNIFICANT POTENTIAL EXISTS FOR SHARING ADVANCED TECHNOLOGY RESEARCH BURDEN WITH OTHER GOVERNMENT AGENCIES AND INDUSTRY

RECOMMENDATIONS:

- A LONG-RANGE TECHNOLOGY PLAN TO DEFINE LONG-TERM PRIORITIES
- AN AGGRESSIVE INITIATIVE TO ESTABLISH TECHNOLOGY-SHARING AGREEMENTS WITH OTHER INSTITUTIONS SUCH AS:
  - CERAMIC TURBINES WITH AIR FORCE
  - ELECTRIC PROPULSION WITH AF AND SDI

PROPULSION SYSTEMS PANEL

LIQUID PROPULSION SYSTEMS SUBPANEL

PERIPHERAL TECHNOLOGIES

FINDINGS:

- MAJOR PERFORMANCE-ENHANCING TECHNOLOGIES HAVE BEEN IDENTIFIED WHICH ARE NOT CLEARLY WITHIN THE PURVIEW OF MATERIALS AND STRUCTURES:
  - CFC-FREE INSULATIONS
  - GELLED PROPELLANTS
- QUAD CHARTS OF THESE TECHNOLOGIES ARE INCLUDED IN THE PANEL REPORTS

RECOMMENDATIONS:

- THESE TECHNOLOGIES TO BE CONSIDERED FOR INCORPORATION INTO THE CODE R RESEARCH PLAN

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • HIGH RELIABILITY CASE JOINTS/ATTACHMENTS COMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN	**MILESTONES AND RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - JOINT DESIGNS HEAVY/STRUCTURALLY INEFFICIENT - LOW RELIABILITY - INCOMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN • SYSTEMS APPLICATIONS: - CRITICAL NEED FOR ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - IMPROVED RELIABILITY - REDUCED WEIGHT - REDUCED COST	**RECOMMENDED ACTIONS:** • DEVELOP CASE DESIGNS WHICH MINIMIZE OR ELIMINATE JOINTS • OPTIMIZE JOINT DESIGNS COMPATIBLE WITH COMPOSITES-ELIMINATE HOLES, MINIMIZE LOCAL REINFORCEMENTS • FABRICATE/TEST JOINT DESIGNS

LIQUID PROPULSION SYSTEMS SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- CHARACTERIZATION OF MATERIAL RESPONSE AND CONSTITUTIVE MODELING OF ABLATIVE MATERIALS
  - CHEMICAL DECOMPOSITION PHYSICS
  - PYROLYSIS GAS FLOW
  - MATERIAL PROPERTY CHARACTERIZATION
  - DEVELOP VERIFIED MODELS

MILESTONES AND RESOURCE REQUIREMENTS:

- (EPA DRIVEN REQUIREMENTS) (ENABLING)

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - THERMOSTRUCTURAL RESPONSE OF ABLATIVES NOT SUFFICIENTLY UNDERSTOOD FOR RELIABLE DESIGN
  - PORE PRESSURE GENERATION IS THE UNDERLYING CAUSE OF POCKETING, PLY LIFT, WEDGE OUT, DELAMINATION, etc...
  - CURRENT STATE-OF-THE-ART IN NOZZLE DESIGN ANALYSIS LACKS EXPLICIT TREATMENT OF PORE PRESSURE
- IMPROVED CONSTITUTIVE RELATIONS ARE REQUIRED FOR ACCURATE ANALYTICAL PREDICTIONS AND SAFE DESIGNS
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS USING ABLATIVE TPS INCLUDING RSRM, ASRM, NLS, AND ALL OTHER SOLID ROCKET MOTORS (POTENTIAL APPLICATION IN ENTRY SYSTEMS)
- BENEFITS/PAYOFFS:
  - THIS EFFORT IS THE KEY TO OPTIMIZED DESIGN, IMPROVED RELIABILITY, CORRECT MATERIAL SELECTION AND LOWER SYSTEMS DEVELOPMENT AND OPERATIONAL COSTS

RECOMMENDED ACTIONS:

- DESIGN AND CONDUCT EXPLORATORY LABORATORY EXPERIMENTS TO CHARACTERIZE KEY PROPERTIES
- PERFORM ANALYSIS TO SUPPORT EXPERIMENT DESIGN, DATA INTERPRETATION AND MODEL CORRELATION
- DEVELOP CONSTITUTIVE RELATIONS FOR THERMAL, GAS FLOW AND STRUCTURAL MODELING
- DETERMINE THE NECESSITY FOR COUPLED/PROGRESSIVE ANALYSIS
- CONSTRUCT AND CONDUCT ANALOG EXPERIMENTS TO VALIDATE MODELS
- EXPLORE THE USE OF MICROMECHANICAL MODELS TO IMPROVE ANALYSIS TRACTABILITY
- INVESTIGATE THE EFFECTS OF PROPERTY VARIATION BY CHARACTERIZING ALTERNATE MATERIALS

DESCRIPTION:

- PROCESS UNDERSTANDING AND LIMIT DETERMINATION FOR OPTIMIZATION AND CONTROL OF NOZZLE COMPONENTS
  - TAPEWRAPPED/CURED ABLATIVES
  - FLEXSEAL FABRICATING
  - ADHESIVE BONDING

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - MATERIAL AND PROCESS VARIABLE INFLUENCE ON CRITICAL PROPERTIES IS NOT SUFFICIENTLY UNDERSTOOD FOR DESIRED RELIABILITY
  - LACK OF UNDERSTANDING OF PROCESS REDUCES MANUFACTURING YIELD
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS INCLUDING RSRM, ASRM, TITAN, SRMU, AND NLV
- BENEFITS/PAYOFFS:
  - THIS EFFORT CONTRIBUTES INCREASED RELIABILITY, REPRODUCIBILITY, AND MANUFACTURING YIELD

RECOMMENDED ACTIONS:

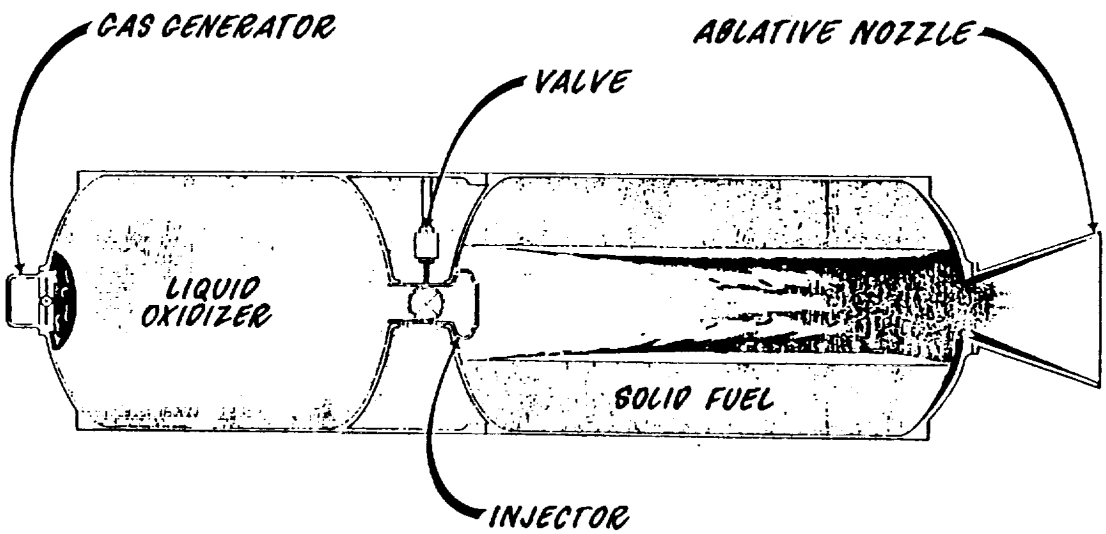
- PERFORM DESIGNED EXPERIMENTS TO IDENTIFY CRITICAL PROPERTIES
- EVALUATE MATERIAL AND PROCESS VARIABLE INFLUENCES ON CRITICAL PROPERTIES
  - ABLATIVES
    - PERMEABILITY
    - INTERLAMINAR PROPERTIES
    - MICROSTRUCTURE
    - VOLATILES/MOISTURE
  - FLEXSEAL
    - SHIM/ELASTOMER INTERFACIAL BONDING
  - ADHESIVES
    - BOND STRENGTH
- ESTABLISH RAW MATERIAL AND PROCESS LIMITS AND CONTROLS
- VERIFY AND VALIDATE PROCESSES AND CONTROLS

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• PROPELLANT AND BONDLINE MATERIAL AND PROCESS VARIABILITY REDUCTION - INSULATION, LINER, ADHESIVE, AND PROPELLANT VARIABILITY DETERMINATION - PROCESS CONTROL AND MONITORING - TQM PHILOSOPHY: INTERACTION WITH MATERIAL SUPPLIERS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - IMPACT OF RAW MATERIAL VARIABILITY AND NON-CONFORMING MATERIALS ON BOND STRENGTH AND PROCESSES IS NOT FULLY KNOWN - LACK OF QUANTIFICATION OF PROCESS VARIABLES ON CRITICAL PROPERTIES • SYSTEM APPLICATION: - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS • BENEFITS/PAYOFFS: - REDUCED MATERIAL AND PROCESS VARIABILITY WILL LEAD TO IMPROVED RELIABILITY AND REDUCED FABRICATION COST	• IDENTIFY CRITICAL MATERIALS AND ACCEPTANCE TESTS WITH SUPPLIER INTERACTION • CONDUCT STATISTICAL TESTS TO DEFINE DEGREE OF VARIABILITY OF COMPONENTS PROPERTIES AND EFFECT ON BONDLINE STRENGTH AND PROCESSES • DEVELOP A CRADLE-TO-GRAVE ANALYTICAL PROCESSING MODEL TO CONTROL AND MONITOR TO A STATE (I.E. DEGREE OF CURE) NOT TIME, TEMPERATURE, PRESSURE, ETC. • ESTABLISHED GO/NO-GO CRITERIA

HYBRID ENGINE OPERATION



LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• HYBRID ROCKET BOOSTER DEMONSTRATION - DEVELOP CODES AND EXPERIMENTAL DATA BASE FOR THE DESIGN OF LARGE HYBRID ROCKET MOTORS - DEMONSTRATE HYBRID ROCKET MOTORS AT BOOSTER THRUST LEVELS (150K-1.5M lb THRUST)	• TEST FACILITY CAPABLE OF: - 1.5M-lb THRUST - 3,500 lb/sec LOX FLOW @ 1200 psia
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• HYBRID ROCKETS OFFER: - INERT HANDLING - CLEAN EXHAUST - ELIMINATION OF EXPLOSIVE HAZARDS AND EFFECTS OF DEFECTS IN CRACKS AND DEBONDS • HYBRID ROCKETS CAN BE: - THROTTLED - SHUT DOWN • THE COST OF HYBRID BOOSTERS IS ESTIMATED AT 80% TO 100% OF SRMs AND MUCH LOWER THE LRBs • HYBRIDS USE EXISTING TECHNOLOGY FOR CASE, NOZZLE, AND LIQUID FEED SYSTEMS • HIGHER Isp THAN SOLIDS AND EQUAL TO THAT OF LOX/HYDROCARBON	• CODE DEVELOPMENT AND DATA BASE AT 500-lb, 15K-lb, AND 150K-lb THRUST LEVEL (JOINT NASA/CORPORATE IR&D PROGRAMS) • 750K-lb THRUST DEMONSTRATION • 1.5M-lb THRUST DEMONSTRATION

FINDINGS:

- INTERFACE ACROSS GOVERNMENT AGENCIES IS CRITICAL FOR TECHNOLOGY TRANSFER TO AVOID DUPLICATION OF EFFORT
- CONCURRENT ENGINEERING IS ESSENTIAL FOR THE SUCCESSFUL DEVELOPMENT OF A SOLID ROCKET MOTOR SYSTEM
- KEY TECHNOLOGY REQUIREMENTS OFFERING THE POTENTIAL TO SIGNIFICANTLY REDUCE COST, IMPROVE RELIABILITY AND PERFORMANCE OF SOLID ROCKET MOTORS ARE COMMON ACROSS ALL SUBSYSTEMS
  - UNDERSTANDING AND CONTROL OF MATERIAL AND PROCESS VARIABILITY
  - ANALYTICALLY DRIVEN TEST METHODOLOGY DEVELOPMENT AND IMPROVED CONSTITUTIVE MODELS
  - ESTABLISHMENT OF FAILURE CRITERIA
  - UNDERSTANDING EFFECTS OF DEFECTS
  - DESIGN FOR INSPECTABILTY
  - ENVIRONMENTALLY DRIVEN PROCESS AND TECHNOLOGY DEVELOPMENT
- SOLID PROPULSION INTEGRITY PROGRAM (SPIP) AND ALS LOW COST CASE INSULATION AND NOZZLE (LOCCIN) PROGRAMS ARE CORNERSTONES FOR TECHNOLOGY DEVELOPMENT AND TRANSFER (COMMUNICATION WITHIN INDUSTRY)

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

RECOMMENDATIONS:

- FORM A TECHNICAL STEERING GROUP WHICH CONTAINS REPRESENTATIVES FROM THE MAJOR PROPULSION HOUSES, MEMBERS FROM THE JANNAF STRUCTURES AND MECHANICAL BEHAVIOR SUBCOMMITTEE, THE COMPOSITE CASE SUBCOMMITTEE, AND THE ROCKET NOZZLE TECHNOLOGY SUBCOMMITTEE STEERING GROUPS UNDER A CHARTER TO PROMOTE AND ENHANCE SOLID ROCKET MOTOR TECHNOLOGY
- UTILIZE A MULTIDISCIPLINARY APPROACH IN PREPARATION OF RESEARCH AND DEVELOPMENT PROPOSALS TO ADDRESS TECHNOLOGY REQUIREMENTS AND AS A CRITERIA FOR FUNDING
- IMPLEMENT THERMAL ANALYSIS IN FLEXSEAL AND PHENOLIC MANDREL TOOL DESIGN
- TRANSFER DEVELOPED NOZZLE DESIGN, ANALYSIS, AND TESTING TECHNOLOGIES THROUGH ESTABLISHMENT OF REGULARLY SCHEDULED SEMINARS, HANDBOOK DEVELOPMENT, AND ACCESSIBLE COMPUTERIZED DATA BASES

PROPULSION SYSTEMS PANEL

"BRIDGING THE GAP"

- FORMALIZE THE PROCESS FOR TECHNOLOGY TRANSFER
  - PROVIDE GUIDANCE TO TECHNOLOGY DEVELOPERS IN THE RTOP CALL
    - MAJOR PROGRAM DIRECTORS/CHIEF ENGINEERS "TOP TEN" LIST OF TECHNOLOGY NEEDS
  - KEEP MAJOR PROGRAM DIRECTORS/CHIEF ENGINEERS INVOLVED IN THE TECHNOLOGY REVIEW PROCESS
    - REVIEW AND COMMENT ON DEVELOPERS PROPOSED RESPONSE TO TECHNOLOGY NEEDS LIST
    - PROMOTE TECHNOLOGY TRANSFER BETWEEN DEVELOPER AND PRIME CONTRACTORS (ESTABLISH EARLY COMMUNICATION LINKS BETWEEN TECHNOLOGY DEVELOPERS AND TECHNOLOGY USERS - PRIME AND SUBCONTRACTORS)
  - USE TECHNOLOGISTS AS AN INTERNAL CONSULTING RESOURCE
- BUILD ON THE INFORMAL PERSONAL RELATIONSHIPS BETWEEN TECHNOLOGY DEVELOPERS AND TECHNOLOGY USERS ESTABLISHED IN THE STRUCTURES AND MATERIALS WORKSHOP

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

NUCLEAR PROPULSION

- NTP FUELS/COATINGS (E)
- NEP REFRACTORY ALLOYS (E)
- NEP FUELS (E)
- NEP RADIATOR MATERIALS (E)
- NTP NOZZLES (SPI)
- TURBOPUMP MATERIALS (SPI)
- LIGHT-WEIGHT TANKAGE / INSULATION (SPI)
- HI TEMPERATURE THERMAL & ELECTRICAL INSULATION (SPI)
- PRESSURE VESSELS (SPI)
- NON-FUEL COATINGS (SPI)
- HI TEMPERATURE SEALS
- NEUTRONIC CONTROL MATERIALS
- LIGHT RADIATION SHIELDING
- RADIATION HARD, HI TEMPERATURE ELECTRONICS

NUCLEAR PROPULSION SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

NTP FUELS AND COATINGS:

- ~100% FISSION PRODUCT RETENTION
- THERMAL STABILITY (LOW MASS LOSS AT T≥3000K IN H2 IN 5 HR)
- HIGH MELTING POINT (> 3400K)
- HIGH FUEL DENSITY ([U] >10%)
- THERMAL SHOCK RESISTANCE
- SLOW DEGRADATION MECHANISMS
- CHEMICAL COMPATIBILITY WITH COATING AND MATRIX MATERIALS
- HIGH SURFACE AREA TO VOLUME RATIO
- FABRICABILITY

MILESTONES AND RESOURCE REQUIREMENTS:

- DEVELOPMENT, CHARACTERIZATION, AND EXPILE TESTING TO SELECT HIGH TEMPERATURE NTP FUEL - 19[illegible]
- MODIFY TESTING FACILITIES AND PERFORM PROTOTYPICAL TESTS - 19[illegible]
- CONSTRUCT NUCLEAR FURNACE AND TEST ASSEMBLIES - 19[illegible]
- R&D ON ADVANCED CONCEPTS - CONTINUING

- BUDGETS DEPEND ON NUMBER OF CONCEPTS, HONEST EVALUATIONS SHOULD BE COMPLETED BEFORE CONCEPT SPECIFIC TESTING

BACKGROUND & RELATED FACTORS:

- PRISMATIC CARBIDE FUELS (MOST EXPERIENCE, TRL=6)
  - PROVEN OPERATING EXPERIENCE TO 2750K FOR 2H IN H2
  - SUBJECT TO THERMAL SHOCK, CRACKING, & H2 CORROSION
  - PLAUSIBLE DESIGNS UP TO 3000K EXIT TEMP AND T/W≥8
- CERMET REFRACTORY FUELS (SAFEST, MOST RELIABLE)
  - ROBUST FUEL DESIGN, COMPATIBLE WITH H2
  - HIGH FISSION PRODUCT RETENTION
  - LOW ISP AND THRUST/WEIGHT
- PARTICLE BED CARBIDE FUELS (BEST PERFORMANCE)
  - HIGH THRUST/WEIGHT, HIGH OPERATING TEMPERATURE
  - HIGH FUEL LOSS AND FISSION PRODUCER RELEASE
  - NO EXPERIENCE FOR LONG LIFE, HIGH TECHNOLOGY RISK
- GASEOUS FUELS (MOST "SPOTTY")
  - CONTAINMENT AND COMPATIBILITY OF GAS PHASE FUEL

RECOMMENDED ACTIONS:

- REDUCE CONCEPTS BY DEFINING CRITERIA, ELIMINATING NON-PERFORMERS, DOWN SELECTING, AND COMBINING DESIGNS
- START R&D ON COMMON FUELS & COATING TECHNOLOGY ISSUES
- CONSTRUCT TESTING FACILITIES
- START R&D TO DEMONSTRATE EVOLUTIONARY IMPROVEMENT IN SAFETY AND PERFORMANCE (INCREASE TIME & TEMPERATURE)
- START FABRICATION AND CHARACTERIZATION DEVELOPMENT
- START PROTOTYPICAL FUEL ELEMENT TESTING
- GENERATE DATA TO:
  - SUPPORT ENGINEERING DESIGNS
  - QUALIFY OPERATING MARGINS
  - PREDICT RELIABILITY
  - COMPLETE SAFETY ANALYSES

NUCLEAR PROPULSION SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- NEP REFRACTORY ALLOY TECHNOLOGY FOR ALL MAJOR SUBSYSTEMS
  - LIFETIMES > 2 YEARS AT TEMPERATURES > 1500K
  - COMPATIBILITY WITH CANDIDATE FUELS
  - COMPATIBILITY WITH WORKING FLUIDS AND COOLANTS
  - HIGH STRENGTH AT OPERATING TEMPERATURES
  - RESISTANCE TO RADIATION DAMAGE
  - READILY FABRICATED INTO COMPLEX COMPONENTS

MILESTONES AND RESOURCE REQUIREMENTS:

- RECEIVE PRODUCT FORMS OF CANDIDATE MATERIALS BY 1994
- ACQUIRE PRELIMINARY DATA BASES -1996
  - MECHANICAL PROPERTIES TESTS AND DESIGN VALIDATION
  - IRRADIATION DAMAGING EFFECT
  - WORKING FLUID AND COOLANT COMPATIBILITY
- DOWNSELECT OPTIMUM ALLOY FOR REFERENCE SYSTEM DESIGN - 1997
- ACQUIRE ENGINEERING DATA BASE SUITABLE FOR APPROVAL FOR GROUND OPERATION OF REACTOR-2006

BACKGROUND & RELATED FACTORS:

- MOST CANDIDATE ALLOYS ARE NOT IN PRODUCTION NOW
- A SIGNIFICANT TECHNICAL DATA BASE EXISTS FROM THE SPACE POWER PROGRAMS (1960'S) AND THE SP-100 (1980'S)
  - Nb AND Ta-BASED ALLOYS HAVE A HIGH LEVEL OF DEVELOPMENT
    - COMPLEX COMPONENTS SUCCESSFULLY FABRICATED
    - LARGE DATA BASE
  - Mo AND W-BASED ALLOYS HAVE A LOWER LEVEL OF MATURITY
    - DIFFICULT TO FABRICATE
    - LIMITED TO MODEST DATA BASE

RECOMMENDED ACTIONS:

- REDUCE CANDIDATE CONCEPTS AND SELECT CANDIDATE MATERIALS
- DEVELOP MATERIALS SPECIFICATIONS
- OPTIMIZE FABRICATION METHODS
- IDENTIFY SUPPLY INFRASTRUCTURE
- GENERATE PRELIMINARY DATA BASE FOR:
  - RADIATION DAMAGE EFFECTS
  - COMPATIBILITY WITH COOLANT & WORKING FLUIDS
  - HIGH TEMPERATURE MECHANICAL PROPERTIES
- REFURBISH FACILITIES TO SUPPORT THE ABOVE

DESCRIPTION:

- NEP FUELS AND CLADDING:
  - HIGH BURNUP; 10-25 AT. % FOR LIQUID METAL COOLED AND 3-5 AT. % FOR GAS COOLED REACTORS
  - LOW FISSION GAS RELEASE AND SWELLING
  - FUEL/CLADDING/FISSION PRODUCT COMPATIBILITY
  - FUEL CLADDING INTEGRITY
  - HIGH CREEP STRENGTH CLADDING MATERIALS
  - THERMIONIC FUEL ELEMENT INTEGRITY
  - BENIGN OFF-NORMAL PERFORMANCE

MILESTONES AND RESOURCE REQUIREMENTS:

- DEVELOPMENT OF STABLE FUELS - 1996
- LAB SCALE COMPATIBILITY TESTING - 1998
- PROTOTYPICAL FUEL ELEMENT TESTING
  - SINGLE PIN IRRADIATION TESTING - 1998
  - FUEL ASSEMBLY TESTING - 2000
  - SYSTEM SELECTION - 2000
- INTEGRATED GROUND ENGINEERING SYSTEM TEST FACILITY - 2000

- BUDGETS DEPEND ON NUMBER OF CONCEPTS. HONEST EVALUATIONS SHOULD BE COMPLETED BEFORE CONCEPT SPECIFIC TESTING.

BACKGROUND & RELATED FACTORS:

- LIQUID METAL COOLED REACTOR FUELS
  - DEMONSTRATE UN OPERATION AT 6 AT. % BURNUP AT 1400K
  - OPERATION TO 10 AT. % AT 1500K PLAUSIBLE
  - DEMONSTRATED UO_2 TFE OPERATION AT 1800K FOR 2 YEARS
  - OPERATION FOR 10 YEARS AT 2400K PROBLEMATICAL
- GAS COOLED REACTOR FUELS
  - OPERATES WELL BELOW FUELS & MATERIALS CAPABILITIES
  - OPERATES WAY BEYOND BURNUP EXPERIENCE BASE

THE MAJOR ISSUES WITH NEP REACTORS ARE THE HIGH BURNUP REQUIRED TO COMPLETE MISSION TIMES AND RELATIVELY HIGH TEMPERATURES REQUIRED TO DECREASE MASS-TO-POWER RATIO

RECOMMENDED ACTIONS:

- REDUCE CONCEPTS BY DEFINING CRITERIA, ELIMINATING NON-PERFORMERS, DOWN SELECTING, AND COMBINING DESIGNS
- DEVELOP AND TEST STABLE, COMPARABLE, HIGH TEMPERATURE FUELS
- START PROTOTYPICAL, HIGH BURNUP IRRADIATION TESTING PROGRAM
- CONSTRUCT GROUND TESTING FACILITIES
- GENERATE DATA TO:
  - SUPPORT ENGINEERING DESIGNS
  - QUALIFY OPERATING MARGINS
  - PREDICT RELIABILITY
  - COMPLETE SAFETY ANALYSIS

NUCLEAR PROPULSION SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LIGHT, HIGH TEMPERATURE, HIGH PERFORMANCE RADIATOR MATERIALS - T>1000K - HIGH SPECIFIC CONDUCTIVITY - PROTECTION FROM ALKALI METALS - HIGH STRENGTH/STIFFNESS - HIGH EMISSIVITY/COATING	• SELECT MATERIAL SYSTEM 1995 • RADIATOR PROTOTYPE DEMONSTRATION 1998
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REFRACTORY METALS WELL DEVELOPED BUT HEAVY • CARBON/CARBON COMPOSITES USING HIGH STRENGTH FIBERS DEVELOPED, BUT LOW STRAIN TO FAILURE OF HIGH CONDUCTIVITY FIBERS LIMIT FABRICATION OF COMPOSITES. LIGHTWEIGHT PROTECTION FROM ALKALI METALS ALSO A PROBLEM • GRAPHITE/COPPER UNDER DEVELOPMENT. INTERFACIAL STRENGTH/WETTING IS PROBLEM. HEAVIER THAN CARBON/CARBON. NEED PROTECTION FROM ALKALI METALS	• CARBON/CARBON - SELECT MOST ROBUST HIGH CONDUCTIVITY FIBER - DEVELOP COMPOSITE ARCHITECTURE TO REDUCE WEIGHT AND INCREASE THROUGH-THICKNESS CONDUCTIVITY - DEVELOP LIGHT PROTECTIVE LINER - OPTIMIZE SURFACE EMISSIVITY • GRAPHITE/COPPER - OPTIMIZE INTERFACIAL BONDING - DEVELOP JOINING PROCESS - OPTIMIZE SURFACE EMISSIVITY • FABRICATE SUBSCALE RADIATOR SEGMENT

PROPULSION SYSTEMS PANEL

NUCLEAR PROPULSION SYSTEMS SUBPANEL

FINDING:

- OPERATING CONDITIONS LIKELY TO BE SIGNIFICANTLY OUTSIDE CURRENT EXPERIENCE BASE
- MULTIPLICITY OF UNCERTAINTIES EFFECTING DURABILITY
- LARGE NUMBER OF MATERIALS WHICH MIGHT BE CONSIDERED FOR VARIOUS COMPONENTS
- CRITICAL MATERIALS ARE NOT AVAILABLE
  - NO LONGER PRODUCED
  - IN LABORATORY DEVELOPMENT
  - IN CONCEPTUAL STAGE ONLY
- FUNDING PRECLUDES CONCURRENT DEVELOPMENT OF MANY CANDIDATES

RECOMMENDATIONS:

- ENSURE CONCURRENT ENGINEERING BETWEEN SYSTEM DESIGN AND MATERIALS DEVELOPMENT
- ENSURE MINIMAL DUPLICATION IN QUALIFICATION OF MATERIALS BETWEEN DIFFERENT PROGRAMS AND CONTRACTORS
- ENSURE ADVANCED DESIGN METHODOLOGY/VALIDATION IS INCLUDED EARLY TO ASSURE A HIGH PERFORMANCE, DURABLE, AND SAFE DESIGN

7.2.2 Supporting Charts

SPACE TRANSPORTATION STRUCTURES AND MATERIALS WORKSHOP

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

- IMPLEMENTATION OF THERMAL ANALYSIS IN FLEX SEAL AND PHENOLIC MANDREL TOOL DESIGN (1)
- NOZZLE DESIGN/ANALYSIS TECHNOLOGY TRANSFER BY SEMINARS, HANDBOOK DEVELOPMENT, AND COMPUTERIZED DATA BASES (1)

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

FINDINGS:

- INTERFACE ACROSS GOVERNMENT AGENCIES IS CRITICAL FOR TECHNOLOGY TRANSFER TO AVOID DUPLICATION OF EFFORT
- CONCURRENT ENGINEERING IS ESSENTIAL FOR THE SUCCESSFUL DEVELOPMENT OF A SOLID ROCKET MOTOR SYSTEM
- KEY TECHNOLOGY REQUIREMENTS OFFERING THE POTENTIAL TO SIGNIFICANTLY REDUCE COST, IMPROVE RELIABILITY AND PERFORMANCE OF SOLID ROCKET MOTORS ARE COMMON ACROSS ALL SUBSYSTEMS
  - UNDERSTANDING AND CONTROL OF MATERIAL AND PROCESS VARIABILITY
  - ANALYTICALLY DRIVEN TEST METHODOLOGY DEVELOPMENT AND IMPROVED CONSTITUTIVE MODELS
  - ESTABLISHMENT OF FAILURE CRITERIA
  - UNDERSTANDING EFFECTS OF DEFECTS
  - DESIGN FOR INSPECTABILTY
  - ENVIRONMENTALLY DRIVEN PROCESS AND TECHNOLOGY DEVELOPMENT
- SOLID PROPULSION INTEGRITY PROGRAM (SPIP) AND ALS LOW COST CASE INSULATION AND NOZZLE (LOCCIN) PROGRAMS ARE CORNERSTONES FOR TECHNOLOGY DEVELOPMENT AND TRANSFER (COMMUNICATION WITHIN INDUSTRY)

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

RECOMMENDATIONS:

- FORM A TECHNICAL STEERING GROUP WHICH CONTAINS REPRESENTATIVES FROM THE MAJOR PROPULSION HOUSES, MEMBERS FROM THE JANNAF STRUCTURES AND MECHANICAL BEHAVIOR SUBCOMMITTEE, THE COMPOSITE CASE SUBCOMMITTEE, AND THE ROCKET NOZZLE TECHNOLOGY SUBCOMMITTEE STEERING GROUPS UNDER A CHARTER TO PROMOTE AND ENHANCE SOLID ROCKET MOTOR TECHNOLOGY
- UTILIZE A MULTIDISCIPLINARY APPROACH IN PREPARATION OF RESEARCH AND DEVELOPMENT PROPOSALS TO ADDRESS TECHNOLOGY REQUIREMENTS AND AS A CRITERIA FOR FUNDING
- IMPLEMENT THERMAL ANALYSIS IN FLEXSEAL AND PHENOLIC MANDREL TOOL DESIGN
- TRANSFER DEVELOPED NOZZLE DESIGN, ANALYSIS, AND TESTING TECHNOLOGIES THROUGH ESTABLISHMENT OF REGULARLY SCHEDULED SEMINARS, HANDBOOK DEVELOPMENT, AND ACCESSIBLE COMPUTERIZED DATA BASES

DESCRIPTION: • HIGH RELIABILITY CASE JOINTS/ATTACHMENTS COMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN	**MILESTONES AND RESOURCES REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - JOINT DESIGNS HEAVY/STRUCTURALLY INEFFICIENT - LOW RELIABILITY - INCOMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN • SYSTEMS APPLICATIONS: - CRITICAL NEED FOR ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - IMPROVED RELIABILITY - REDUCED WEIGHT - REDUCED COST	**RECOMMENDED ACTIONS:** • DEVELOP CASE DESIGNS WHICH MINIMIZE OR ELIMINATE JOINTS • OPTIMIZE JOINT DESIGNS COMPATIBLE WITH COMPOSITES-ELIMINATE HOLES, MINIMIZE LOCAL REINFORCEMENTS • FABRICATE/TEST JOINT DESIGNS

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- COMPOSITE CASE DESIGN AND ANALYSIS METHODOLOGY
  - DEVELOPMENT OF MATERIAL TEST METHODS
  - FAILURE CRITERIA AND EFFECTS OF DEFECTS
  - COMPOSITE CASE PROCESS MODELING
  - DESIGN GUIDE FOR COMPOSITE ROCKET MOTOR CASES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - LACK OF STANDARDS FOR CASE DESIGN/ANALYSIS
  - CURRENT MODELING PROCEDURES ARE INADEQUATE
  - HIGH COST OF FULL SCALE TESTING
  - MATERIAL PROPERTY DEFINITION IS INADEQUATE
  - CURRENT FAILURE CRITERIA ARE INADEQUATE
  - SCALING PHENOMENA MUST BE UNDERSTOOD
  - ANALYSIS AND TEST DATA ARE NOT AVAILABLE FOR DETERMINING EFFECT OF DEFECT
  - NEED TO CONSIDER ALTERNATIVE MANUFACTURING METHODS (E.G., INFLATABLE MANDREL)
  - NEED TO ADDRESS RESIDUAL STRESSES FROM MANUFACTURING
- SYSTEM APPLICATIONS:
  - ALL SRM UTILIZING FILAMENT WOUND CASES
- BENEFITS AND PAYOFF:
  - STANDARDIZATION TO STREAMLINE THE DESIGN AND VERIFICATION PROCESS,
  - MORE OPTIMUM DESIGNS AND LOWER COST OF DEVELOPMENT

RECOMMENDED ACTIONS:

- ASSEMBLE INTERDISCIPLINARY TEAM OF EXPERTS IN CASE DESIGN/ANALYSIS/TEST
- DEVELOP CONSENSUS AND DOCUMENT RELEVANT THEORIES OF BEHAVIOR AS FUNDAMENTAL BASIS FOR DESIGN/ANALYSIS/TEST
- DEFINE COMPREHENSIVE TEST REQUIREMENTS
- DESIGN/ANALYZE/TEST ANALOG EXPERIMENTS FOR CASE DESIGN VERIFICATION
- DEVELOP A COMPREHENSIVE MATERIAL PROPERTY DATABASE
- CONDUCT ANALYTICAL CORRELATION TO UNIFY ANALOG, SUB-SCALE AND FULL-SCALE CASE RESPONSE WITH MATERIAL PROPERTY DATABASE
- DEVELOP VERIFIED FAILURE CRITERIA
- EXPLORE THE EFFECTS OF DEFECTS
- DOCUMENT TECHNOLOGY IN THE FORM OF A DESIGN GUIDE

DESCRIPTION:

- CASE MATERIALS/MATERIAL FORMS SUITABLE FOR ENVIRONMENTALLY SAFE, LOW COST, RELIABLE AND HIGH RATE PRODUCTION

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - MATERIALS/MATERIAL FORMS POTENTIALLY UNSAFE, NOT SUITABLE FOR HIGH-RATE PRODUCTION, PROCESS SENSITIVE
- SYSTEMS APPLICATIONS:
  - CRITICAL FOR ALL COMPOSITE STRUCTURES INCLUDING CASES
- BENEFITS/PAYOFFS:
  - REDUCED PRODUCTION COST
  - ENVIRONMENTALLY SAFE MATERIALS
  - IMPROVED PERFORMANCE AND RELIABILITY

RECOMMENDED ACTIONS:

- DEVELOP LOW COST/HIGH PERFORMANCE ENVIRONMENTALLY-SAFE FIBER/RESIN SYSTEMS
- DEVELOP PROCESS INSENSITIVE MATERIALS FORMS SUITABLE FOR HIGH-RATE PRODUCTION
- DEMONSTRATE HIGH-RATE CASE PRODUCTION CAPABILITIES USING ANALOG CASES

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- CASE EQUIPMENT/PROCESS SUITABLE FOR LOW COST/HIGH RATE PRODUCTION

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - SLOW/COSTLY, LIMITED IN-PROCESS CONTROL
- SYSTEMS APPLICATIONS:
  - APPLICABLE TO FABRICATION FOR ALL COMPOSITE STRUCTURES, INCLUDING CASES
- BENEFITS/PAYOFFS:
  - IMPROVED RELIABILITY
  - REDUCED COSTS
  - HIGH-RATE PRODUCTION

RECOMMENDED ACTIONS:

- EVALUATE S.O.A. IN COMMERCIAL COMPOSITE PRODUCTION SECTOR
- SELECT/DEVELOP OPTIMUM EQUIPMENT/PROCESS FOR LOW-COST, HIGH-RELIABILITY CASE PRODUCTION INCLUDING IN-LINE PROCESS CONTROL/INSPECTION
- DEMONSTRATE TECHNOLOGY FOR SUB- AND FULL-SCALE ANALOG CASES

DESCRIPTION:

- COMPOSITE CASE ANALYSIS CODE DEVELOPMENT
  - A CODE WHICH APPLIES THE RESULTS OF TECHNOLOGY ADVANCEMENT IN THE AREA OF PREDICTING STRUCTURAL RESPONSE OF ROCKET MOTOR CASES
  - CODE TO EMPHASIZE THE "CASE" BUT TO CONTAIN ACCURATE SUB-MODELS OF GRAIN, INSULATOR, BOND-LINE AND ATTACHMENT STRUCTURES
  - THE GOAL IS A STANDARDIZED CODE THAT PREDICTS CASE RESPONSE VERY ACCURATELY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - NON-STANDARD METHODOLOGY
  - DIFFICULTY IN USING DESIGN DATA TO CREATE ADEQUATE MODELS
  - INADEQUATE MATERIAL PROPERTY SYNTHESIS AND NONLINEAR THEORIES
  - INADEQUATE ACCOUNTING FOR LARGE DEFLECTION AND ROTATION EFFECTS
  - UNSUBSTANTIATED FAILURE CRITERIA
  - UNKNOWN IN SITU MATERIAL PROPERTIES
  - BUILDUP GEOMETRY NOT PREDICTABLE
  - POOR SHEAR PLY MODELS FOR Y-JOINT AND BOSS REGIONS
  - 3D VS 2D, HOLES, ATTACHMENTS
  - POOR MODELING OF JOINTS
  - INTERFACE TO COMMERCIAL SOFTWARE (CAE) NEEDED
- INITIAL CONDITIONS FOR ANALYSIS NEEDS TO REFLECT PROCESSING HISTORY (E.G., RESIDUAL STRESS, MANDREL DEFORMATION, ETC.).
- SYSTEM APPLICATIONS:
  - APPLIES TO ALL SOLID ROCKET MOTOR CASE REQUIREMENTS AND COMPOSITE FUEL TANKS
- BENEFITS AND PAYOFFS:
  - MORE ACCURATE ANALYSIS IMPROVES DESIGN EFFICIENCY
  - PROMOTES PERFORMANCE UPGRADES AND CONTRIBUTES TO ENHANCED RELIABILITY.

RECOMMENDED ACTIONS:

- PHASE 1 PROGRAM TO ADDRESS STANDARDIZATION, USER FEATURES AND INTEGRATION WITH MULTIPLE COMMERCIAL SOFTWARE PACKAGES IN THE CAD AND CAE AREAS. USER FEATURES TO INCLUDE RAPID GEOMETRY DEFINITION LINKED TO DESIGN FEATURE, AUTOMATED MESH GENERATION, MATERIAL PROPERTY GENERATION USING MICRO-MECHANICS AND COMPUTERIZED DATA BASES, INTERFACE TO BUCKLING CODES, POST-PROCESSING FOR PLY STRESSES, FIBER STRESSES AND STRAINS
- PHASE 2 PROGRAM TO ADDRESS NONLINEAR MATERIAL BEHAVIOR (ANISOTROPY, SHEAR PLY, AND BONDLINE INTERFACES, SLIDING AND GAPPING OF JOINTS, LARGE DEFLECTIONS, NEAR INCOMPRESSIBILITY FOR GRAIN AND LOW SHEAR MODULUS MATERIALS, CRAZING, ETC.). PHASE 2 SHOULD BE COORDINATED WITH AN EXPLORATORY TEST DRIVEN TECHNOLOGY DEVELOPMENT PROGRAM. IT SHOULD ALSO BE DEVELOPED IN CONCERT WITH SUB-SCALE TEST DATA.
- PHASE 3 PROGRAM TO ADDRESS FAILURE CRITERIA, FRACTURE MECHANICS PROBABILISTIC PHENOMENA, IN SITU MATERIAL PROPERTIES, MODELING MANUFACTURING EFFECTS (E.G., RESIDUAL STRESS), OPTIMIZATION. PHASE 3 SHOULD DEMONSTRATE ACCURATE PREDICTION OF FULL-SCALE CASE RESPONSE AND CONNECT TO COUPON AND SUB-SCALE DATA.

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION: • SELF INSULATING CASE	**MILESTONES AND RESOURCES REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - COSTLY MULTI-STEP INSULATION AND CASE FABRICATION - POTENTIAL BONDLINE FAILURE • SYSTEMS APPLICATIONS: - ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - ELIMINATES BONDLINE FAILURE THEREBY IMPROVING RELIABILITY - REDUCED COST	**RECOMMENDED ACTIONS:** • DEVELOP SELF-INSULATING CASE MATERIALS/PROCESS • FABRICATE/DEMONSTRATE SUB- AND FULL-SCALE CASES

DESCRIPTION: • LOW COST/RAPID TURN-AROUND CASE TOOLING	**MILESTONES AND RESOURCES REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - TOOLING COST EXCESSIVE - REQUIRE LONG LEAD TIME - INCAPABLE OF ASSISTING PROCESS CONTROL • SYSTEMS APPLICATIONS: - ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - REDUCED COST - IMPROVED RELIABILITY - RAPID TURN-AROUND	**RECOMMENDED ACTIONS:** • DEVELOP LOW COST/HIGH RATE TOOLING CONCEPTS • FABRICATE/DEMONSTRATE SUB- AND FULL-SCALE TOOLING CONCEPTS

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- CHARACTERIZATION OF MATERIAL RESPONSE AND CONSTITUTIVE MODELING OF ABLATIVE MATERIALS
  - CHEMICAL DECOMPOSITION PHYSICS
  - PYROLYSIS GAS FLOW
  - MATERIAL PROPERTY CHARACTERIZATION
  - DEVELOP VERIFIED MODELS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - THERMOSTRUCTURAL RESPONSE OF ABLATIVES NOT SUFFICIENTLY UNDERSTOOD FOR RELIABLE DESIGN
  - PORE PRESSURE GENERATION IS THE UNDERLYING CAUSE OF POCKETING, PLY LIFT, WEDGE OUT, DELAMINATION, etc...
  - CURRENT STATE-OF-THE-ART IN NOZZLE DESIGN ANALYSIS LACKS EXPLICIT TREATMENT OF PORE PRESSURE
- IMPROVED CONSTITUTIVE RELATIONS ARE REQUIRED FOR ACCURATE ANALYTICAL PREDICTIONS AND SAFE DESIGNS
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS USING ABLATIVE TPS INCLUDING RSRM, ASRM, NLS, AND ALL OTHER SOLID ROCKET MOTORS (POTENTIAL APPLICATION IN ENTRY SYSTEMS)
- BENEFITS/PAYOFFS:
  - THIS EFFORT IS THE KEY TO OPTIMIZED DESIGN, IMPROVED RELIABILITY, CORRECT MATERIAL SELECTION AND LOWER SYSTEMS DEVELOPMENT AND OPERATIONAL COSTS

RECOMMENDED ACTIONS:

- DESIGN AND CONDUCT EXPLORATORY LABORATORY EXPERIMENTS TO CHARACTERIZE KEY PROPERTIES
- PERFORM ANALYSIS TO SUPPORT EXPERIMENT DESIGN, DATA INTERPRETATION AND MODEL CORRELATION
- DEVELOP CONSTITUTIVE RELATIONS FOR THERMAL, GAS FLOW AND STRUCTURAL MODELING
- EXPLORE THE USE OF MICROCHEMICAL MODELS TO IMPROVE ANALYSIS TRACTABILITY
- DETERMINE THE NECESSITY FOR COUPLED/PROGRESSIVE ANALYSIS
- INVESTIGATE THE EFFECTS OF PROPERTY VARIATION BY CHARACTERIZING ALTERNATE MATERIALS
- CONSTRUCT AND CONDUCT ANALOG EXPERIMENTS TO VALIDATE MODELS

DESCRIPTION:

- PROCESS UNDERSTANDING AND LIMIT DETERMINATION FOR OPTIMIZATION AND CONTROL OF NOZZLE COMPONENTS
  - TAPE WRAPPED/CURED ABLATIVES
  - FLEXSEAL FABRICATION
  - ADHESIVE BONDING

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - MATERIAL AND PROCESS VARIABLE INFLUENCE ON CRITICAL PROPERTIES IS NOT SUFFICIENTLY UNDERSTOOD FOR DESIRED RELIABILITY
  - LACK OF UNDERSTANDING OF PROCESS REDUCES MANUFACTURING YIELD
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS INCLUDING RSRM, ASRM, TITAN, SRMU, AND NLV
- BENEFITS/PAYOFFS:
  - THIS EFFORT CONTRIBUTES INCREASED RELIABILITY, REPRODUCIBILITY, AND MANUFACTURING YIELD

RECOMMENDED ACTIONS:

- PERFORM DESIGNED EXPERIMENTS TO IDENTIFY CRITICAL PROPERTIES
- EVALUATE MATERIAL AND PROCESS VARIABLE INFLUENCES ON CRITICAL PROPERTIES
  - ABLATIVES
    - PERMEABILITY
    - INTERLAMINAR PROPERTIES
    - MICROSTRUCTURE
    - VOLATILES/MOISTURE
  - FLEXSEAL
    - SHIM/ELASTOMER INTERFACIAL BONDING
  - ADHESIVES
    - BOND STRENGTH
- ESTABLISH RAW MATERIAL AND PROCESS LIMITS AND CONTROLS
- VERIFY AND VALIDATE PROCESSES AND CONTROLS

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- NOZZLE FAILURE CRITERIA
  - CRITERIA TO ASSESS PERFORMANCE
  - ASSESS VARIABILITY AS RELATED TO MATERIAL ISSUES
  - DEFINE INHERENT DEFECTS
  - RELATE DEFECTS TO PERFORMANCE
  - DETERMINE BEST NDE FOR DETECTION OF THESE DEFECTS
  - EVALUATE RELIABILITY OF NDE DETECTION
  - DEVELOP SYSTEM PERFORMANCE RELATED ACCEPTANCE CRITERIA
  - DEVELOP NDC/MATERIALS/PROCESS HISTORY TRACEABILITY
  - UTILIZE ABOVE TO SORT AGING EFFECTS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - THERE ARE NO COMMONLY ACCEPTED FORMULATIONS FOR FAILURE CRITERIA OF CARBON PHENOLICS
  - CURRENT NDE IS NOT RELATED TO KNOWN DEFECTS
  - MULTI AXIAL, OFF AXIS, AND FRACTURE MECHANICS DATA ARE REALLY LACKING
  - INFLUENCE WITH MANUFACTURING VARIABLES ON MATERIAL PROPERTY VARIATION IS UNKNOWN
  - CURRENT ACCEPTANCE CRITERIA FOR NOZZLE STRUCTURES ARE BASED ON SUBJECTIVE RULES RATHER THAN UNDERSTANDING OF PHYSICAL AND CHEMICAL ASPECTS OF FAILURE
  - MATERIALS AND PROCESS VARIATIONS ARE DIFFICULT TO TRACE DURING DISCREPANCY REVIEW
- SYSTEMS APPLICATION:
  - ALL SRM SYSTEMS WHICH USE ABLATIVE THERMAL PROTECTION SYSTEMS
- BENEFITS/PAYOFFS
  - INCLUDES IMPROVED RELIABILITY, IMPROVED DESIGN/ANALYSES, HIGHER CONFIDENCE MARGINS, AND IMPROVED INSPECTION CAPABILITY

RECOMMENDED ACTIONS:

- DETERMINE MULTI-AXIAL, OFF AXIS, FRACTURE MECHANICS AND OTHER DATA TO FORMULATE THE FAILURE CRITERIA FOR NOZZLE MATERIALS
- DEVELOP CORRESPONDENCE BETWEEN LOW CRITICAL VALUES AND APPROPRIATE NONDESTRUCTIVE TECHNIQUES
- EXPAND AND OPTIMIZE CAPABILITY SELECTED NDC TECHNIQUES FOR FULL SIZE COMPONENTS
- CONFIRM CORRELATION BY APPLICATION OF SELECTED NDCs TO REAL COMPONENTS AND TESTS COMPARED FROM THOSE PARTS AT THE INDICATED LOCATIONS
- DEVELOP AND EVALUATE THE EFFECTS OF DEFECTS AND AGING ON CRITICAL PROPERTIES
- DEVELOP ROBUST TESTS FOR CRITICAL PROPERTIES FOR USE AS ACCEPTANCE TESTS
- DEVELOP SYSTEM FOR MATERIAL HISTORY TRACEABILITY

DESCRIPTION:

- ROBUST ABLATIVE NOZZLE MATERIAL AND PROCESS DEVELOPMENT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - CURRENT MATERIALS ARE DEFECT AND PROCESS SENSITIVE
  - PROMISING CANDIDATES EXIST BUT WARRANT MATURATION OF MATERIAL AND PROCESS CONTROL
- SYSTEM APPLICATION
  - CURRENT AND PROJECTED LAUNCH VEHICLE SRB's (RSRM, ASRM, TITAN, SRMV AND DELTA) INCORPORATE ABLATIVE NOZZLE COMPONENT
- BENEFIT OR PAYOFF
  - CONTRIBUTE INCREASED RELIABILITY, REPRODUCIBILITY, AND MANUFACTURING YIELD

RECOMMENDED ACTIONS:

- DEFINE MATERIAL REQUIREMENTS
- ENGINEER MATERIALS WHICH ARE INSENSITIVE TO RAW MATERIAL AND PROCESS VARIATIONS (TARGET THROAT AND EXIT CONE)
- EVALUATE CANDIDATE MATERIAL SYSTEMS
  - PAN FIBER/LOW K PAN
  - ALTERNATIVE ARCHITECTURES
  - NONCONDENSATE RESINS/HIGH CHAR YIELD
  - LOW DENSITY EXIT CONES
- HARDWARE DEMONSTRATION/VALIDATION

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- NOZZLE THERMOSTRUCTURAL CODE DEVELOPMENT
- CODE REQUIREMENTS DEFINITION
- CODE DEVELOPMENT - 2D/3D COUPLED NONLINEAR HEAT TRANSFER, PYROLYSIS GAS GENERATION AND FLOW, AND STRUCTURAL ANALYSIS CAPABILITY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - SOLID ROCKET MOTOR ANALYSIS COMMUNITY BELIEVES THAT THE ONLY VALID SOLUTION METHODOLOGY FOR ANALYZING SRM NOZZLES IS A COUPLED HEAT TRANSFER, PYROLYSIS GAS GENERATION-FLOW, AND SOLID STRUCTURAL ANALYSIS SOLUTION
  - A STRONG NEED EXISTS TO DEVELOP NUMERICAL TECHNIQUES THAT EMPLOY NEW MATERIAL CONSTITUTIVE RELATIONS, MATERIAL DECOMPOSITION MODELS, PYROLYSIS GAS FLOW MODELS AND WHICH EXPLICITLY ACCOUNT FOR PYROLYSIS GAS PORE PRESSURE
  - CURRENT SOFTWARE TOOLS CANNOT PERFORM THE JOB
- SYSTEMS APPLICATIONS:
  - ALL SOLID ROCKET MOTORS WHICH USE ABLATIVE TPS
- BENEFIT OR PAYOFF:
  - THIS EFFORT WILL DEVELOP THE NECESSARY SOFTWARE TOOLS FOR ACCURATELY PREDICTING THE THERMOSTRUCTURAL RESPONSE OF NOZZLE LINER MATERIALS. IT WILL REDUCE OPERATIONAL AND DEVELOPMENT COSTS AND IMPROVE RELIABILITY

RECOMMENDED ACTIONS:

- IDENTIFY THE EXTENT OF NECESSARY COUPLING BETWEEN THE VARIOUS DISCIPLINES:
  - EFFECT OF STRESS STATE ON PERMEABILITY
  - EFFECT OF MECHANICAL STRAIN ON PORE PRESSURE
  - EFFECT OF STRESS STATE ON THERMAL CONDUCTIVITY
- DEFINE THE NUMERICAL TECHNIQUES AND SOLUTION ALGORITHMS NEEDED
- JUDGE WHETHER PATH DEPENDENCIES ARE REQUIRED
- THE CODE SHOULD BE BUILT IN STAGES, MODELING THE SIMPLEST PHENOMENA FIRST, FOLLOWED BY THE INCORPORATION OF MORE COMPLEX, COUPLED PHENOMENA ONCE THE CODE HAS REACHED A SUFFICIENT LEVEL OF MATURITY
- THE EFFORT WILL BE ACCOMPLISHED BY A MULTI-COMPANY TEAM COMPOSED OF EXPERTS IN THE VARIOUS DISCIPLINES ALONG WITH CONSULTANTS FROM GOVERNMENT AND UNIVERSITIES

DESCRIPTION:

- NOZZLE DESIGN METHODOLOGY
  - DEVELOP A TESTING AND CORRELATIVE ANALYSIS PHILOSOPHY WHICH CAN BE USED TO VERIFY AN IMPROVED DESIGN/ANALYSIS METHOD
  - EVALUATE NEW MATERIALS (E.G., PAN, BRAID, LFP,PAA) AND NOVEL DESIGNS
  - INCORPORATE PORE PRESSURE DRIVEN ANALYSIS METHODOLOGY AND DEVELOP REQUIRED MATERIAL PROPERTIES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT SDA THERMOSTRUCTURAL ANALYSES ARE DESIGNED JUST TO MEET MINIMUM CONTRACT REQUIREMENTS AND DON'T REALLY IMPACT DESIGN DECISIONS
  - NEEDS EXIST TO VERIFY ANALYSIS RESULTS
  - SENSITIVITY TO MATERIAL AND PROCESS PARAMETERS IS POORLY UNDERSTOOD. SELECTING NEW MATERIALS FOR FUTURE NOZZLES IS RISKY.
  - THE POTENTIAL OF NEW MATERIALS IS COSTLY TO DETERMINE. SCREENING METHODS ARE INADEQUATE.
  - AFFECTS RELIABILITY, FABRICATION COST, MATERIAL SELECTION, PRODUCTION EFFICIENCY, COST.
- SYSTEM APPLICATIONS:
  - ALL SRM ABLATIVE NOZZLES (RSRM, ASRM, ALS, NLS, ETC.)
- BENEFITS AND PAYOFF:
  - THIS IS KEY TO IMPROVED RELIABILITY, OPTIMIZED DESIGNS, PROPER MATERIAL SELECTION. ENABLES IMPROVED PRODUCIBILITY, WEIGHT MINIMIZATION, LOWER FABRICATION COST.

RECOMMENDED ACTIONS:

- DEVELOP A SERIES OF ANALOG TESTS WHERE EACH TEST ISOLATES A PARTICULAR PHYSICAL EVENT UNDER KNOWN BOUNDARY CONDITIONS SO THAT ANALYSIS CAN BE VERIFIED INCREMENTALLY
- ANALYSIS OF ANALOGS SHOULD BE ITERATIVE WITH UPDATES OF THE ASSUMPTIONS AND APPROACH UNTIL GOOD CORRELATION IS OBTAINED
- DEVELOP SENSITIVITY DATA THROUGH EXTENSIVE PARAMETRIC STUDIES. IDENTIFY USEFUL THEORETICAL DESCRIPTIONS OF TRENDS.
- UTILIZE BEST POSSIBLE CODE COMPATIBILITIES
- EXTEND MODELING METHODS TO NEW NOZZLE CONCEPTS
- CONDUCT INTERACTIVE PROGRAMS BETWEEN MATERIALS/TEST/ANALYSIS FOR DESIGN EVOLUTION
- DOCUMENT MATERIAL PROPERTY AND CODE INPUT DATA BASE
- CHARACTERIZE PORE PRESSURE DRIVEN PROPERTIES FOR "NEW" MATERIALS
- VERIFY ANALYSIS WITH HIGHLY INSTRUMENTED SUB-SCALE MOTOR FIRINGS.

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• LIGHTWEIGHT, LOW TORQUE FLEX BEARING DESIGN, MATERIALS AND PROCESS DEVELOPMENT	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - CURRENT FLEXSEALS ARE PROCESS SENSITIVE - NOT OPTIMIZED FOR PERFORMANCE (WEIGHT, TORQUE) - NEW ELASTOMER AND SHIM MATERIALS AND FLEXSEAL DESIGN CONCEPTS ARE AVAILABLE TO OPTIMIZE PERFORMANCE AND REDUCE VARIABILITY • SYSTEM APPLICATION: - ALL LARGE SOLID ROCKET MOTORS AND ETO BOOSTERS • BENEFIT OR PAYOFF: - IMPROVED RELIABILITY - REDUCED SYSTEM WEIGHT YIELDS INCREASED PAYLOAD CAPABILITY AND LOWER COST TO ORBIT	**RECOMMENDED ACTIONS:** • DEFINE REQUIREMENTS • ENGINEER MATERIALS AND PROCESSES TO OPTIMIZE PERFORMANCE • EVALUATE CANDIDATES - HIGH STRENGTH/HIGH-STRAIN ELASTOMERS - HIGH STRENGTH SHIMS - IMPROVED AND AUTOMATED PROCESSING (INJECTION) • HARDWARE DEMONSTRATION AND VALIDATION

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• ENVIRONMENTALLY SOUND CLEANING PROCESSES FOR CASE AND NOZZLE BONDING - CHEMISTRY REQUIREMENTS - FACILITY REQUIREMENTS	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - ENVIRONMENTAL REGULATION LIMIT USE OF VAPOR DE-GREASERS - OTHER SOLVENT SYSTEMS HAVE SAFETY AND EFFICIENCY ISSUES - PUBLIC PERCEPTION OF NASA CRITICAL TO CONTINUED SUPPORT • SYSTEM APPLICATION - ALL SRM CLEANING APPLICATIONS • BENEFIT OR PAYOFF - IMPROVED RELIABILITY - ENABLING TECHNOLOGY	**RECOMMENDED ACTIONS:** • INVOLVE CONTRACTORS AND NASA TECHNOLOGY CENTERS • INVESTIGATE TECHNOLOGY TRANSFER FROM AUTOMOTIVE APPLICATIONS • INCLUDE CORROSION RESISTANCE, BOND STRENGTH AND MANUFACTURABILITY IN STUDY

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- CORRELATION OF CHEMICAL PROPERTIES TO MECHANICAL PROPERTIES FOR CRITICAL MATERIALS
  - STRUCTURAL ADHESIVES
  - FLEXSEAL ELASTOMERS ABLATIVE COMPOSITES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - RELATIONSHIP BETWEEN RECEIVING INSPECTION AND MATERIAL PERFORMANCE IS UN-QUANTIFIED
  - MATERIAL VARIATIONS HAVE DETRIMENTAL, UNDOCUMENTED EFFECTS ON COMPONENT PERFORMANCE
  - FAILURE INVESTIGATIONS UNABLE TO GATHER NEEDED DATA FROM AFTER THE FACT EFFORTS
- SYSTEM APPLICATION:
  - ALL SRM SYSTEMS
- BENEFIT OR PAYOFF
  - IMPROVED RELIABILITY
  - REDUCED FABRICATION COSTS

RECOMMENDED ACTIONS:

- CHARACTERIZE CRITICAL MATERIALS, ADHESIVES, ABLATIVES, NOZZLE ELASTOMERS
- DETERMINE OPTIMUM METHOD OF INSTRUMENTAL ANALYSIS
- PERFORM DESIGNED EXPERIMENT TO CORRELATE ANALYSIS TO MATERIAL PERFORMANCE CHARACTERISTICS
- ESTABLISH STATISTICAL DATA BASE FOR EACH CRITICAL MATERIAL

DESCRIPTION:

- LOW COST ABLATIVE NOZZLE MATERIALS AND PROCESS DEVELOPMENT
  - INNOVATIVE DESIGNS AND MATERIAL/STRUCTURES ARCHITECTURES
  - RAW MATERIALS
  - PROCESS
  - LIFE CYCLE COST DEFINITION/ASSESSMENT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT SYSTEMS EMPLOY EXPENSIVE RAW MATERIALS WHICH REQUIRE COMPLEX PROCESSES
  - COST AND RELIABILITY ARE DRIVERS FOR NEW LAUNCH SYSTEMS
  - NEW MATERIALS AND PROCESSES ARE REQUIRED TO MEET REDUCED COST GOALS
- SYSTEM APPLICATION:
  - FUTURE SYSTEMS UPGRADES INCLUDING RSRM, ASRM, TITAN AND NLS
- BENEFIT OR PAYOFF:
  - REDUCED COST
  - INCREASED RELIABILITY

RECOMMENDED ACTIONS:

- DEFINE MATERIAL REQUIREMENTS
- ENGINEER MATERIALS WHICH CONTRIBUTE TO REDUCED COST
- EVALUATE CANDIDATE MATERIAL SYSTEMS
  - LOW COST FIBERS
  - NET SHAPE FABRICATION
  - INJECTION MOLDING
- HARDWARE DEMONSTRATION/VALIDATION

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- DESIGN GUIDE FOR NOZZLE STRUCTURAL ADHESIVE SELECTION
  - RECOMMENDED SELECTION TEAM STRUCTURE
  - RECOMMENDED SELECTION PARAMETERS
  - SCREENING TEST METHODS
  - OPTIMIZATION

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - "EXPERT" OPINION USED IN THE PAST TO SELECT ADHESIVES, NO OPTIMIZATION PROCESS
  - REQUIREMENT FOR SIMILARITY TO PREVIOUS APPLICATIONS LIMIT CHOICE OF MATERIALS
  - IMPORTANT SELECTION CRITERIA ARE NEGLECTED IN DECISION PROCESS
- SYSTEM APPLICATION:
  - ALL NEW SRM NOZZLES
  - ADHESIVE REPLACEMENTS
- BENEFIT OR PAYOFF
  - IMPROVED RELIABILITY FROM ROBUST DESIGN
  - IMPROVED PRODUCTION TIME

RECOMMENDED ACTIONS:

- APPLY CONCURRENT TEAMS TO SELECTION PROCESS
- USE ANALYSIS CODES IN PRELIMINARY SELECTION PHASE TO ESTABLISH PROPERTY REQUIREMENTS
- DOCUMENT ACTUAL SELECTION PROCESS IN A DESIGN GUIDE

DESCRIPTION:

- CARBON-CARBON CHARACTERIZATION AND MICROCHEMICAL MODELING
  - DATA FOR ADVANCED MODELING (2D/3D)
  - EFFECTS OF DEFECTS/ACCEPTANCE CRITERIA
  - MATERIALS DATA BASE

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - ASRM ITE REJECTED IN PART DUE TO NEGATIVE MARGINS
  - TECHNOLOGY DOES NOT EXIST TO UTILIZE AND DESIGN 3D CC ITE AND OTHER CARBON-CARBON STRUCTURES
  - ANALYSIS INCONSISTENT WITH EXPERIENCE
  - DATA BASE DOES NOT EXIST FOR DESIGN (PARTIAL 2D/POOR 3D)
  - ENABLING TECHNOLOGY, IMPROVED RELIABILITY
- SYSTEM APPLICATION:
  - SRM SYSTEMS WHICH USE CARBON-CARBON COMPONENTS
  - NASP AND OTV
- BENEFIT OR PAYOFF
  - IMPROVED RELIABILITY

RECOMMENDED ACTIONS:

- ITERATIVE ANALYSIS/TEST PROGRAM FOR IMPROVED PREDICTION CAPABILITY
- PROGRAM FOR CHARACTERIZATION OF EFFECTS OF DEFECTS, AND RELATIONSHIP TO NDE
- DEVELOPMENT OF A PHYSICAL, MECHANICAL AND THERMAL PROPERTIES DATA BASE

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- EROSION MODELING OF NOZZLE MATERIALS
  - PARTICLE EROSION: MECHANICAL AND CHEMICAL MECHANISMS
  - PARTICLE RADIATION: DATA AND MODELS ARE LACKING
  - CHEMICAL REACTIONS AT SURFACE: EQUILIBRIUM OR KINETICALLY CONTROLLED
  - SURFACE CONVECTIVE BOUNDARY CONDITION: TURBULENT, ROUGHWALL REGIME

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - SURFACE CANNOT BE PREDICTED WITH ACCURACY WITHOUT RESORT TO EMPIRICALLY DETERMINED ADJUSTMENT FACTORS: DEMONSTRATED IN FIRING AND FLIGHT
- SYSTEM APPLICATION:
  - ALL SRM SYSTEMS, PARTICULARLY NLS BOOSTERS
- BENEFIT OR PAYOFF
  - MORE ACCURATE PREDICTION OF PERFORMANCE AND INSIGHT INTO MATERIAL IMPROVEMENTS, RESULTING IN IMPROVED RELIABILITY

RECOMMENDED ACTIONS:

- CONSTRUCT AND CONDUCT EXPERIMENTS TO EXPLORE:
  - PARTICLE IMPACT ON CHARRING ABLATIVES
  - RADIATION HEAT LOAD AT SURFACE
  - CHAR-GAS CHEMISTRY
  - CONVECTIVE HEAT TRANSFER
- LABORATORY, ARC-JET AND/OR GROUND TEST
- ANALYZE DATA AND CONSTRUCT MODELS
- VALIDATE MODELS THROUGH ANALOG AND/OR PREDICTIONS OF GROUND FIRINGS
- DISSEMINATE COMPUTER CODE MODULES

DESCRIPTION:

- CONSTITUTIVE MODELING AND FAILURE CRITERIA FOR NONINSULATORS
  - MEASURE FLEX BEARING ELASTOMERIC MATERIAL RESPONSE
  - DEVELOP CONSTITUTIVE RELATIONS FOR FLEX BEARING ELASTOMERS
  - OBTAIN STRENGTH PROPERTIES FOR ADHESIVES
  - DEVELOP FAILURE CRITERIA FOR ADHESIVES USED IN NOZZLE BONDLINES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - THERE IS CURRENTLY NO UNIVERSALLY ACCEPTED APPROACH FOR MODELING THE STRUCTURAL RESPONSE OF NOZZLE BONDLINES. SOME ANALYSIS MODEL THE BONDLINES AS A CONTINUUM WHERE AS OTHERS MODEL THE BONDLINES WITH SPRING ELEMENTS
  - THERE IS CURRENTLY NO UNIVERSALLY ACCEPTED FAILURE CRITERIA FOR NOZZLE BONDLINES
  - THERE IS A LACK OF MATERIAL PROPERTIES TO SUPPORT PROPOSED CONSTITUTIVE MODELS AND FAILURE CRITERIA FOR ADHESIVES USED IN NOZZLE BONDLINES
  - THERE IS NO UNIVERSALLY ACCEPTED APPROACH FOR MODELING NOZZLE FLEX BEARINGS. SOME NOZZLE MANUFACTURERS MODEL THE ELASTOMERIC MATERIAL USED IN FLEX BEARINGS AS A LINEAR ELASTIC MATERIAL WHEN, IN FACT, THESE MATERIALS ARE NOT LINEARLY ELASTIC
  - THERE IS A LACK OF AVAILABLE MATERIAL RESPONSE PROPERTIES TO SUPPORT PROPOSED CONSTITUTIVE MODELS FOR ELASTOMERS USED IN FLEX BEARINGS
  - THE STIFFNESSES OF NOZZLE FLEX BEARINGS ARE GENERALLY NOT WELL PREDICTED. THE TRUE STIFFNESS OF A FLEX BEARING IS NOT KNOWN UNTIL THE FLEX BEARING IS BUILT AND TESTED
- SYSTEM APPLICATION:
  - ALL SOLID ROCKET MOTORS
- BENEFIT OR PAYOFF
  - IMPROVED RELIABILITY
  - REDUCED DEVELOPMENT COST

RECOMMENDED ACTIONS:

- THE APPROPRIATE FORM OF THE CONSTITUTIVE RELATIONS FOR ADHESIVES USED AS NOZZLE BONDLINES SHOULD BE DETERMINED THROUGH EXPERIMENTAL METHODS
- CONSTITUTIVE COEFFICIENTS FOR ADHESIVE BONDLINES SHOULD BE DETERMINED
- A NUMBER OF DIFFERENT FORMS OF A FAILURE CRITERIA FOR NOZZLE BONDLINES SHOULD BE INVESTIGATED
- TESTING SHOULD BE CONDUCTED IN ORDER TO SELECT THE APPROPRIATE FORM OF THE FAILURE CRITERIA AND TO DETERMINE THE STRENGTH PARAMETERS FOR ADHESIVES USED AS NOZZLE BONDLINES
- CONSTITUTIVE RELATIONS FOR ELASTOMERIC MATERIALS SHOULD BE INVESTIGATED
- TESTS SHOULD BE CONDUCTED TO DETERMINE THE APPROPRIATE FORM OF THE CONSTITUTIVE RELATIONS AND TO DETERMINE THE CONSTITUTIVE COEFFICIENTS FOR BONDLINES AND ELASTOMERIC MATERIALS

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- LARGE NOZZLE CARBON-CARBON ITE AND BACKUP INSULATOR DEVELOPMENT AND CHARACTERIZATION
- DEVELOP THE TECHNOLOGY REQUIRED TO DESIGN, ANALYZE, CHARACTERIZE AND PROCESS LARGE CARBON-CARBON 3D ITE WITH OPTIMUM PROPERTIES
  - MATERIALS CHARACTERIZATION, DESIGN AND ANALYSIS
  - PROCESS UNDERSTANDING AND OPTIMIZATION
  - PRODUCT VERIFICATION

MILESTONES AND RESOURCES REQUIREMENTS:

- NON-DEGRADING THERMAL STRUCTURAL INSULATOR DEVELOPMENT

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - INABILITY TO ACCURATELY ANALYZE 3D C-C MATERIALS
  - INABILITY TO EXPERIMENTALLY OBTAIN NONORTHOGONAL PROPERTIES
  - PROCESSING SCALE-UP ISSUES ARE UNKNOWN
  - INSPECTION TECHNIQUES LIMITED; EFFECTS OF DEFECTS NOT UNDERSTOOD
  - MATERIALS DATA BASE IS LIMITED; NO DATA EXISTS ON NEW FIBER SYSTEMS
  - FAILURE CRITERIA ARE INSUFFICIENT
- SYSTEM APPLICATION
  - FUTURE SRM SYSTEMS AND UPGRADES TO ORBITAL TRANSFER VEHICLES WITH SOLID, LIQUID OR NUCLEAR PROPULSION
- BENEFIT OR PAYOFF
  - IMPROVED ANALYTICAL AND MATERIAL TESTING CAPABILITIES FOR ALL CARBON-CARBON ITE
  - ADVANCED INSPECTION TECHNIQUES AND RELIABILITY ASSESSMENT CONFIDENCE
  - PROVIDE NEW MATERIALS WITH INHERENTLY HIGHER SAFETY MARGINS
  - ADVANCED CARBON-CARBON TECHNOLOGY ENABLING APPLICATION TO NEW SYSTEMS

RECOMMENDED ACTIONS:

THREE CURRENT TASKS COMPRISE THE RECOMMENDED PROGRAM

- TASK 1 - MATERIAL CHARACTERIZATION, DESIGN AND ANALYSIS
  - EXPLORATORY TESTING
  - STRESS-STRAIN MODEL
  - FAILURE CRITERIA DEVELOPMENT
  - CHARACTERIZATION, TEST METHODOLOGY AND DATA GENERATION
- TASK 2 - PROCESS UNDERSTANDING AND OPTIMIZATION
  - CONSTITUENT MATERIAL AND PROCESS DEVELOPMENT
  - PROCESS MODEL DEVELOPMENT AND VERIFICATION
  - PROCESS/PROPERTY SENSITIVITY ANALYSIS
- TASK 3 - PRODUCT VERIFICATION
  - ACCEPTANCE TEST DEVELOPMENT
  - NDE TECHNIQUE AND ADVANCEMENT
  - EFFECTS OF DEFECTS CHARACTERIZATION

DESCRIPTION:

- PROPELLANT AND BONDLINE MATERIAL AND PROCESS VARIABILITY REDUCTION
  - INSULATION, LINER, ADHESIVE, AND PROPELLANT VARIABILITY DETERMINATION
  - PROCESS CONTROL AND MONITORING
  - TQM PHILOSOPHY: INTERACTION WITH MATERIAL SUPPLIERS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - IMPACT OF RAW MATERIAL VARIABILITY AND NON-CONFORMING MATERIALS ON BOND STRENGTH AND PROCESSES IS NOT FULLY KNOWN
  - LACK OF QUANTIFICATION OF PROCESS VARIABLES ON CRITICAL PROPERTIES
- SYSTEM APPLICATIONS:
  - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - REDUCED MATERIAL AND PROCESS VARIABILITY WILL LEAD TO IMPROVED RELIABILITY AND REDUCED FABRICATION COST

RECOMMENDED ACTIONS:

- IDENTIFY CRITICAL MATERIALS AND ACCEPTANCE TESTS WITH SUPPLIER INTERACTION
- CONDUCT STATISTICAL TESTS TO DEFINE DEGREE OF VARIABILITY OF COMPONENTS PROPERTIES AND EFFECT ON BONDLINE STRENGTH AND PROCESSES
- DEVELOP A CRADLE-TO-GRAVE ANALYTICAL PROCESSING MODEL TO CONTROL AND MONITOR TO A STATE (I.E. DEGREE OF CURE) NOT TIME, TEMPERATURE, PRESSURE, ETC.
- ESTABLISHED GO/NO-GO CRITERIA

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- ANALYTICALLY DRIVEN TEST TECHNOLOGY FOR PROPELLANT AND BONDLINE CONSTITUTIVE MODEL DEVELOPMENT
  - DEVELOP STANDARDIZED TEST TECHNIQUES
  - EVALUATE PROPELLANT/BONDLINE RESPONSE
  - DEVELOP MODELS AND INCORPORATE INTO STRUCTURAL CODES TO DETERMINE EFFECT ON DESIGN MARGINS OF SAFETY/STRUCTURAL INTEGRITY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT TEST DATA TYPICALLY USED IN ANALYSES INADEQUATE TO DESCRIBE PROPELLANT AND BONDLINE BEHAVIOR UNDER ACTUAL LOADING CONDITIONS
  - MODELS AND CONSTITUTIVE THEORY DEVELOPMENT LIMITED BY INABILITY TO MEASURE PROPELLANT/BONDLINE BEHAVIOR UNDER REAL LOADING CONDITIONS
  - MULTI-AXIAL AND MICROSTRUCTURAL TEST TECHNOLOGY CURRENTLY AVAILABLE TOO COSTLY TO BE PRACTICAL
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - HIGHER RELIABILITY

RECOMMENDED ACTIONS:

- SURVEY LITERATURE FOR CURRENT MULTI-AXIAL AND MICROSTRUCTURAL TEST TECHNIQUES
- DEVELOP LOW COST TEST TECHNIQUES FOR MULTI-AXIAL PROPELLANT/BONDLINE CHARACTERIZATION
- DEVELOP TEST TECHNIQUES TO EXAMINE MICRO- AND MACROSTRUCTURAL BEHAVIOR UNDER ACTUAL MOTOR STRESS/THERMAL CONDITIONS
- DEVELOP MODELS/CONSTITUTIVE THEORY TO DESCRIBE MULTI-AXIAL AND MICROSTRUCTURAL PROPELLANT BEHAVIOR
- COMPARE PREDICTED THEORETICAL BEHAVIOR WITH DATA COVERING A BROAD RANGE OF MEASURED BEHAVIOR
- INCORPORATE MODELS/CONSTITUTIVE THEORY INTO STRUCTURAL ANALYSIS CODES/METHODOLOGIES

DESCRIPTION:

- ANALYTICALLY DRIVEN TEST TECHNOLOGY
  - INSULATION, LINER, ADHESIVE, AND PROPELLANT VARIABILITY DETERMINATION
  - PROCESS CONTROL AND MONITORING
  - TQM PHILOSOPHY: INTERACTION WITH MATERIAL SUPPLIERS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - IMPACT OF RAW MATERIAL VARIABILITY AND NON-CONFORMING MATERIALS ON BOND STRENGTH AND PROCESSES IS NOT FULLY KNOWN
  - LACK OF QUANTIFICATION OF PROCESS VARIABLES ON CRITICAL PROPERTIES
- SYSTEM APPLICATIONS:
  - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - REDUCED MATERIAL AND PROCESS VARIABILITY WILL LEAD TO IMPROVED RELIABILITY AND REDUCED FABRICATION COST

RECOMMENDED ACTIONS:

- IDENTIFY CRITICAL MATERIALS AND ACCEPTANCE TESTS WITH SUPPLIER INTERACTION
- CONDUCT STATISTICAL TESTS TO DEFINE DEGREE OF VARIABILITY OF COMPONENTS PROPERTIES AND EFFECT ON BONDLINE STRENGTH AND PROCESSES
- DEVELOP A CRADLE-TO-GRAVE ANALYTICAL PROCESSING MODEL TO CONTROL AND MONITOR TO A STATE (I.E. DEGREE OF CURE) NOT TIME, TEMPERATURE, PRESSURE, ETC.
- ESTABLISHED GO/NO-GO CRITERIA

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- BONDLINE DESIGN FOR INSPECTABILITY
  - ASSURE ACCESSIBILITY FOR NDI BY
  - MODIFYING EXISTING DESIGNS
  - ADAPTING EXISTING NDE METHODOLOGIES
  - USING EMBEDDED SMART SENSORS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT BONDLINE DESIGN IS BASED ON PERFORMANCE vs COST AND SAFETY vs DESIGN MARGINS WITH MINIMAL CONSIDERATION GIVEN TO THE ABILITY TO VERIFY BONDLINE INTEGRITY PRIOR TO LAUNCH
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - IMPROVED RELIABILITY OF BONDLINE SYSTEMS
  - REDUCED MAINTENANCE COST
  - COST SAVINGS THROUGH THE REDUCTION OF MATERIAL REVIEW BOARD
  - INFORMATION GENERATED WILL HELP MAKING FUTURE SRMs MORE REPRODUCIBLE

RECOMMENDED ACTIONS:

- IDENTIFY UNINSPECTABLE, UNINSPECTED AND UNDER INSPECTED AREAS
- ASSESS STATE-OF-THE-ART NDE AND MODIFY AS NEEDED TO EVALUATE CRITICAL AND DIFFICULT-TO-INSPECT REGIONS
- DEVELOP/INTEGRATE NEW NDE/NDC MODALITIES INCLUDING SMART MATERIAL SENSORS
- MODIFY EXISTING DESIGNS FOR INCORPORATION OF NDI INSTRUMENTATION
- DEMONSTRATE INSPECTABILITY IMPROVEMENTS WITH DESIGN CHANGES

DESCRIPTION:

- BONDLINE STRUCTURAL AND HEALTH MONITORING METHODOLOGIES
  - IN-SITU EVALUATION OF BONDLINE STRENGTH
  - BONDLINE DESIGN METHODOLOGIES
  - TRANSDUCER DEVELOPMENT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - ACTIVE HEALTH MONITORING TECHNIQUES FOR SRMs ARE CURRENTLY NONEXISTENT
  - CONTINUED MONITORING OF AN SRM WILL ALLOW A MORE ACCURATE MARGIN OF SAFETY DETERMINATION DUE TO BETTER UNDERSTANDING OF TEMPERATURE, HUMIDITY, STRESS AND STRENGTH
  - DETECTION METHODS CAN INCLUDE CONTACT, NON-CONTACT, EMBEDDED TECHNIQUES, OR BE INCORPORATED INTO THE MATERIAL USED
  - STEEP STRESS GRADIENTS IN LARGE SRMs REQUIRE SMALLER STRESS GAGES THAN CURRENTLY AVAILABLE
  - STRESS TRANSDUCERS ARE NEEDED TO MEASURE BOTH NORMAL AND SHEAR STRESS
  - TECHNIQUES FOR DETERMINING BONDLINE STRENGTH CAN EXPLOIT CHEMICAL AND/OR MECHANICAL DESIGN APPROACHES
- SYSTEM APPLICATIONS:
  - ALL SRMs
- BENEFITS/PAYOFFS:
  - THIS TECHNOLOGY WILL PRODUCE IMPROVED UNDERSTANDING OF BONDLINE AGING, THEREBY IMPROVING SRM RELIABILITY

RECOMMENDED ACTIONS:

- IDENTIFY CANDIDATE TECHNIQUES, DETECTION METHODS AND TRANSDUCERS (1)
- DEVELOP VIABLE MINIATURIZED TRANSDUCERS (1)
- VALIDATE TRANSDUCERS ON ANALOG MOTORS (1)
- DEMONSTRATE ON A SELECTED SRM (2)

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• BONDLINE CONTAMINATION STUDIES - IDENTIFY SOURCES OF CONTAMINATION AND THEIR AFFECT ON BOND STRENGTH - DETECTION OF CONTAMINATION DURING THE MANUFACTURING OPERATION	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: • CONTAMINATION IDENTIFIED AS THE NUMBER ONE CRITICAL PROCESS PARAMETER TO CONTROL AND IMPROVE RELIABILITY • SYSTEM APPLICATIONS: - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS • BENEFITS/PAYOFFS: - IMPROVED PROCESS CONTROL WILL LEAD TO IMPROVED RELIABILITY	• IDENTIFY TECHNIQUES TO DETECT CONTAMINANTS ON METAL AND NON-METALS • ESTABLISH PROTOCOL FOR CONTROLLED LABORATORY CONTAMINATION STUDIES • DETERMINE SENSITIVITY OF CONTAMINATION ON BOND STRENGTH AND CORRELATE WITH DETECTOR TECHNIQUES • DEVELOP METHODOLOGY TO IMPLEMENT DETECTOR TECHNIQUE IN PRODUCTION WITH GO/NO-GO CRITERIA

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• PROPELLANT AND BONDLINE FAILURE CRITERIA - BOTH FLAWED AND UNFLAWED MATERIALS - BROAD RANGE OF ENVIRONMENTAL AND MECHANICAL LOADINGS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - CURRENT FAILURE CRITERIA DO NOT ACCURATELY PREDICT FAILURES IN PROPELLANTS AND BONDLINES; THIS CAUSES LOW RELIABILITY AND LACK OF CONFIDENCE IN STRUCTURAL MARGINS - A SATISFACTORY FRACTURE MECHANICS THEORY DOES NOT EXIST FOR BONDLINES WITH MANUFACTURING DEFECTS - ANALYSIS AND TEST TECHNIQUES MUST BE DEVELOPED TO DETERMINE THE STRENGTH OF UNFLAWED MATERIALS AND THE FRACTURE MECHANICS BEHAVIOR FOR FLAWED MATERIALS • SYSTEM APPLICATIONS: - ALL SRMs • BENEFITS/PAYOFFS: - IMPROVED CONFIDENCE IN PREDICTION, ACCURACY, BETTER DEFECT ACCEPTANCE PROCEDURES, HIGHER RELIABILITY	• IDENTIFY VIABLE FAILURE CRITERIA AND FRACTURE MECHANICS APPROACHES (1) • DEVELOP THEORIES FOR FAILURE AND FRACTURE, AND MODEL FITTING TECHNIQUES (1) • PLAN AN EXPERIMENTAL PROGRAM TO TEST FAILURE THEORIES (2) • MANUFACTURE MATERIAL SAMPLES AND CONDUCT TESTS (2) • REFINE/MODIFY THEORY BASED ON TEST RESULTS (1) • VALIDATE THEORY USING ANALOG MOTOR DESIGNED FOR PROPELLANT AND BONDLINE FAILURE (1)

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:
- EFFECTS OF DEFECTS FOR BONDLINES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- DEFICIENCIES:
  - IN CURRENT BONDLINE DESIGN, KNOWLEDGE OF SHEAR AND TENSILE STRENGTH, SHEAR AND TENSILE STIFFNESS, AND CHEMICAL MIGRATION IS NOT PROPERLY UNDERSTOOD
  - FAILURE CRITERIA ARE NOT WELL UNDERSTOOD FOR SYSTEMS WITH DEBONDS/FLAWS
  - BONDLINES IN CURRENT SYSTEMS HAVE REGIONS THAT ARE UNINSPECTABLE, OR WHERE THE SIZE OF A CRITICAL DEFECT IS SMALLER THAN THE RESOLUTION OF NDE METHODS
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTOR SYSTEMS
- BENEFITS/PAYOFFS
  - IMPROVED RELIABILITY OF MOTOR SYSTEMS AND IMPROVED UNDERSTANDING OF THE CRITICAL PERFORMANCE PARAMETERS NECESSARY TO DEFINE SYSTEM SPECIFIC ACCEPTANCE CRITERIA

RECOMMENDED ACTIONS:
- IDENTIFY CAUSES OF REAL BONDLINE DEFECTS (1)
- DEVELOP MATHEMATICAL MODELS WHICH SIMULATE REAL BOND BEHAVIOR (2)
- DEVELOPMENT OF MANUFACTURING PROTOCOL AND FABRICATION OF SPECIMENS (2)*
- ACQUISITION AND CORRELATION OF NON-DESTRUCTIVE CHARACTERIZATION (NDC) AND MATERIAL PROPERTIES ON DEFECT SAMPLES (3)
- ANALYZE BALLISTIC AND THERMAL EFFECTS OF DEFECTS (3)
- ESTABLISH APPLICABILITY OF FRACTURE MECHANICS (3)
- DEFINE METHODOLOGY TO CONSIDER DEFECTS DURING DESIGN PROCESS (4)
- VERIFY UTILIZING ANALOG MOTORS (5)

DESCRIPTION:
- CLEAN SOLID PROPELLANT DEVELOPMENT AND VERIFICATION
  - ENVIRONMENTAL IMPACTS
  - SAFETY
  - PROCESSABILITY
  - BALLISTIC PERFORMANCE

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- DEFICIENCIES:
  - CURRENT SOLID PROPELLANTS PRESENT ENVIRONMENTAL RISKS AND LIABILITIES
  - LOW HCL FORMULATIONS AVAILABLE DO NOT MEET PERFORMANCE OR SAFETY REQUIREMENTS OF SYSTEM NEEDS
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
  - PRIMARY APPLICATION FOR LARGE ETO BOOSTERS
- BENEFITS/PAYOFFS:
  - MITIGATES ENVIRONMENTAL RISKS AND LIABILITIES PRESENTED BY EXISTING PROPELLANTS

RECOMMENDED ACTIONS:
- SURVEY EXISTING TECHNOLOGY AND CONDUCT FURTHER RESEARCH TO ADDRESS DEFICIENCIES
- SELECT MOST PROMISING FORMULATIONS
- DEMONSTRATE PERFORMANCE
- CONDUCT PROCESSING AND INTERFACE TRADE STUDIES
- MATERIAL PROPERTY CHARACTERIZATION AND CONSTITUENT FINGERPRINTING
- PROCESS DEVELOPMENT AND VERIFICATION
- PATHFINDER AND FULL-SCALE DEMONSTRATION

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• BONDLINE PROCESSING PROTOCOL - ESTABLISH PROCEDURES/METHODOLOGIES FOR CONDUCTING BONDLINE REPAIR/REWORK PROCEDURES	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - BONDLINES WILL REQUIRE REPAIRS AND REWORK. THESE ARE UNPLANNED AND HAVE COST/RELIABILITY IMPACTS • SYSTEM APPLICATIONS: - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS • BENEFITS/PAYOFFS - IMPROVED BONDING PROCEDURES WILL IMPROVE RELIABILITY AND REDUCE COST	**RECOMMENDED ACTIONS:** • DEFINE CURRENT REPAIR/REWORK PROCEDURES AND CRITICAL PROCESS PARAMETERS • CONDUCT BOND EXPERIMENTS AND DEFINE: - DEFINE VARIABILITY - PROCESS WINDOWS - ACCEPT/REJECT CRITERIA

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• NDE FOR PROPELLANT - VARIATIONS IN MECHANICAL PROPERTIES OF PROPELLANT NEED TO BE EVALUATED - DAMAGE, e.g., INTERNAL CRACK GROWTH AND MICROVOIDS FORMATION NEED TO BE CHARACTERIZED	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - CHANGES IN PROPERTIES DUE TO AGING CONDITIONS ARE NOT FULLY KNOWN - PROPELLANT DENSITY VARIATIONS MASK NDC OF BONDLINES • SYSTEM APPLICATIONS: - ALL SOLID ROCKET MOTORS • BENEFITS/PAYOFFS: - ACCURATE PERFORMANCE PREDICTION - IMPROVED RELIABILITY	**RECOMMENDED ACTIONS:** • ESTABLISH CORRELATIONS BETWEEN NDE PARAMETERS AND MATERIALS PROPERTIES • ESTABLISH EFFECTS OF DEFECTS • POD STATISTICS FOR QUANTITATIVE NDC • PREDICT STRUCTURAL INTEGRITY FOR QNDE

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- BONDLINE AND PROPELLANT AGING
  - ESTABLISH METHODS TO MEASURE AND CORRELATE AGE-RELATED CHANGES TO PROPERTIES
  - DETERMINE AFFECTS OF AGING ON FLIGHT PERFORMANCE AND SAFETY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - LIMITED CORRELATION AND UNDERSTANDING OF AGING EFFECTS ON STRUCTURAL INTEGRITY OF PROPELLANTS AND BONDLINES IN EARTH ENVIRONMENTS
  - NO DATA EXISTS SHOWING AGING EFFECTS ON PROPELLANTS AND BONDLINES IN THE NEAR-EARTH SPACE ENVIRONMENT
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - EXTENDED LIFE
  - IMPROVED RELIABILITY

RECOMMENDED ACTIONS:

- IDENTIFY ALL SIGNIFICANT AGE-RELATED SOURCES OF CHANGE TO CRITICAL PROPERTIES
- IDENTIFY COMPONENT INTERACTION AGING MECHANISMS
- CONDUCT EXPERIMENTS TO MEASURE CHANGES TO CRITICAL PROPERTIES IN THE STORAGE/DEPLOYMENT ENVIRONMENTS
- DEVELOP AGING MODEL THAT ACCOUNTS FOR AGE-RELATED CHANGES
- INCORPORATE MODELS INTO APPROPRIATE CODES

DESCRIPTION:

- THERMOPLASTIC ELASTOMER (TPE) INSULATOR FABRICATION TECHNOLOGY AND BONDLINE CHARACTERIZATION FOR LARGE MOTORS
  - DEVELOP NEW INSULATOR TECHNOLOGY FOR IMPROVED RELIABILITY AND REDUCED COST

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - AT PRESENT, THERE IS NO TECHNOLOGY DEVELOPED OR UNDER DEVELOPMENT TO FABRICATE LARGE TPE INSULATORS (>3000 LBS) REQUIRED BY THE LARGEST SOLID MOTORS. ALSO BETTER UNDERSTANDING OF LINERLESS, ADHESIVE FREE BONDING IS NEEDED
- SYSTEM APPLICATIONS:
  - ALL LARGE SRM SYSTEMS AND LARGE ETO BOOSTERS
- BENEFITS/PAYOFFS:
  - ENABLING TECHNOLOGY FOR THE USE OF LOW COST, ASBESTOS FREE TPE INSULATIONS IN LARGE SOLID ROCKET MOTORS
  - IMPROVED RELIABILITY
  - SIGNIFICANTLY REDUCED COST
  - REDUCES OR ELIMINATES ENVIRONMENTAL RISKS
  - EXTENDED LIFE OF THE MOTOR

RECOMMENDED ACTIONS:

THIS PROGRAM WOULD DEVELOP APPLICATION TECHNOLOGY FOR APPLYING TPE INSULATIONS AT HIGH RATES TO 500 LBS/HR IN A CONTROLLED MANNER. IN PRACTICE THIS TECHNOLOGY COULD BE USED IN CONJUNCTION WITH THE SPRAY TECHNOLOGY (LOCCIN DEV) WHICH COULD PROVIDE PRECISION THICKNESS CONTROL AND POSSIBLE ADHESION ADVANTAGES

- THE R&D EFFORT CONSISTS OF 5 MAJOR TASKS:
  - INVESTIGATION OF CURRENT TECHNOLOGY FOR FORMING LARGE THERMOPLASTIC STRUCTURES
  - DESIGN OR MODIFY EQUIPMENT INCLUDING A ROBOTICS CONTROLLED DELIVERY HEAD TO DELIVER THE TPE INSULATION TO THE CASE OF MANDREL
  - FABRICATE AND TEST LARGE MOTOR INSULATORS DEMONSTRATING THE EQUIPMENT AND PROCESS TO OBTAIN RELIABILITY AND COST DATA
  - DEMONSTRATE PERFORMANCE IN A NASA MATERIAL EVALUATION MOTOR
  - TPE INSULATION BONDLINE CHARACTERIZATION AND ANALYSIS

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• ADVANCED BONDING CONCEPTS FOR LINERLESS INSULATION DEVELOPMENT	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - CURRENT PROPELLANTS/INSULATION BONDING GENERALLY RESULTS IN DECREASED STRENGTH DUE TO COMPLEXITY OF THE SYSTEM, POOR BONDING, AGE-OUT, DIFFICULTIES IN MANUFACTURING, HIGHER COST, etc... • SYSTEM APPLICATIONS: - ALL SRM SYSTEMS • BENEFITS/PAYOFFS: - IMPROVED RELIABILITY - EXTENDED LIFE - REDUCED FABRICATION COSTS AND TIME - TECHNOLOGY ELIMINATES THE USE OF SOLVENTS AND REDUCES ENVIRONMENTAL RISK	**RECOMMENDED ACTIONS:** • ADVANCED BONDING CONCEPTS FOR CLASS 1.3 PROPELLANTS USED FOR SPACE LAUNCH APPLICATIONS WOULD BE DEMONSTRATED - DEVELOP A BOND SYSTEM WHERE STABLE BONDING ADDITIVES ARE INCORPORATED INTO THE INSULATION AND NO ADDITIONAL ADHESIVES ARE NEEDED - EVALUATE ADVANCED BONDING CONCEPTS FOR PROPELLANT/INSULATION TO INCLUDE LINERLESS, INSULINER AND BARRIER CONCEPTS AS A MINIMUM - EVALUATE INNOVATIVE MANUFACTURING CONCEPTS FOR BONDING

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• LOW COST INSULATION PERFORMANCE METHODOLOGY AND CORRELATION WITH MOTOR PERFORMANCE - LOW COST INSULATION PERFORMANCE TESTS FOR IMPROVED QC AND RELIABILITY	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - PERFORMANCE OF THE INSULATOR IS CRITICAL YET NO DIRECT METHOD OF ASSESSING THE ABLATIVE PERFORMANCE OF EACH LOT IS AVAILABLE - THE METHODOLOGY WOULD ALSO BE USEFUL IN OPTIMIZING NEW INSULATION MATERIALS • SYSTEM APPLICATIONS: - ALL SRM SYSTEMS, LARGE ETO BOOSTERS • BENEFITS/PAYOFFS: - IMPROVED QUALITY CONTROL OF INSULATION MATERIAL - IMPROVED RELIABILITY - REDUCED DEVELOPMENT COSTS	**RECOMMENDED ACTIONS:** • THIS PROGRAM WOULD DEVELOP THE THEORY, TEST AND CORRELATION NECESSARY TO PREDICT PERFORMANCE OF INSULATION MATERIALS IN FULL SCALE MOTORS FORM DATA FROM A SET OF INEXPENSIVE LABORATORY TESTS • A FOUR TASK PROGRAM IS RECOMMENDED: - LITERATURE SEARCH AND DEVELOPMENT OF THEORY - DEVELOPMENT OF THE SPECIFIC TEST(S) REQUIRED FOR EVALUATION - CORRELATION OF TEST RESULTS WITH MOTOR TEST RESULTS AND REFINEMENT OF THEORY - DEVELOPMENT OF STATISTICAL CORRELATION OF THEORY AND FULL SCALE MOTOR PERFORMANCE

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• FIBER/POLYMER INTERACTION TAILORING FOR DEVELOPING IMPROVED FIBERS FOR INTERNAL INSULATIONS - DEVELOP TECHNOLOGY FOR IMPROVED NON-ASBESTOS INSULATION FOR IMPROVED RELIABILITY AND REDUCED COSTS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - CURRENTLY FIBERS ARE REQUIRED FOR ABLATIVE PERFORMANCE IN HIGH PERFORMANCE INSULATIONS BUT THE NON- ASBESTOS FIBERS IN STATE-OF-THE-ART INSULATIONS TODAY LIMIT THE STRAIN CAPABILITY OF THE MATERIALS MUCH MORE THAN ASBESTOS FIBERS - REDUCED STRAIN CAPABILITY OF NON-ASBESTOS INSULATION REDUCES RELIABILITY OF THE INSULATION • SYSTEMS APPLICATIONS: - ALL SRM SYSTEMS. PRIMARY APPLICATION FOR LARGE ETO BOOSTERS • BENEFITS/PAYOFFS: - REDUCED COST - REDUCED ENVIRONMENTAL RISK - EASY, RELIABLE REPAIRABILITY - INCREASE RELIABILITY BECAUSE OF INCREASED MECHANICAL PROPERTIES AND HIGHER TEMPERATURE CAPABILITIES	• THIS PROGRAM WOULD DEVELOP ALTERNATIVES TO THE CURRENTLY USED ORGANIC FIBERS PROVIDING TECHNOLOGY TO SIGNIFICANTLY IMPROVE STRAIN CAPABILITY AND REDUCE COST OF ADVANCED INSULATION MATERIALS • THE PROGRAM WOULD CONSIST OF 4 TASKS: - LITERATURE AND INDUSTRY SEARCH TO FIND NEW/OR PROMISING FIBERS AND TECHNOLOGY - FORMULATION OF NEW INSULATIONS INCORPORATING THE NEW FIBERS AND/OR TECHNOLOGY - SUBSCALE EVALUATION OF THE ABLATIVE PERFORMANCE OF THE NEW INSULATIONS - LARGE SCALE EVALUATION (NASA TEST MOTOR) OF THE NEW INSULATIONS

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• SPRAYABLE SOLVENT-FREE, HIGH TEMPERATURE TPE THERMAL PROTECTION (EXTERNAL) SYSTEM - DEVELOP IMPROVED EXTERNAL TPS FOR ENVIRONMENTAL RISKS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - CURRENT SPRAYABLE TPS TECHNOLOGY REQUIRES USE OF SOLVENTS WHICH ADD SIGNIFICANT COST AND/OR ENVIRONMENTAL RISKS - FUTURE APPLICATIONS WILL REQUIRE HIGHER TEMPERATURE CAPABILITY, REDUCED COST AND SOLVENT FREE PROCESSING TO REDUCE ENVIRONMENTAL RISKS • SYSTEMS APPLICATIONS: - ALL SRM SYSTEMS. PRIMARY APPLICATION FOR LARGE ETO BOOSTERS • BENEFITS/PAYOFFS: - REDUCED COST - REDUCED ENVIRONMENTAL RISK - EASY, RELIABLE REPAIRABILITY - INCREASE RELIABILITY BECAUSE OF INCREASED MECHANICAL PROPERTIES AND HIGHER TEMPERATURE CAPABILITY	• DEVELOPMENT OF SPRAYABLE TPS MATERIALS USING THERMOPLASTIC OR THE BINDER FOR LOW DENSITY FILLERS WILL MEET THE REQUIREMENTS OF REDUCED COST AND REDUCED ENVIRONMENTAL RISK • THE PROGRAM WOULD CONSIST OF 4 TASKS: - LABORATORY DEVELOPMENT OF MATERIALS WITH REQUIRED PROPERTIES - SPRAY PROCESS SELECTION, MODIFICATION AND DEVELOPMENT - OPTIMIZATION OF MATERIALS, LARGE SCALE MANUFACTURING AND SPRAY PROCESS - CHARACTERIZATION OF SPRAYED TPS MATERIALS, BONDING, AND AGING

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:
• HYBRID ROCKET BOOSTER DEMONSTRATION
  - DEVELOP CODES AND EXPERIMENTAL DATA BASE FOR THE DESIGN OF LARGE HYBRID ROCKET MOTORS
  - DEMONSTRATE HYBRID ROCKET MOTORS AT BOOSTER THRUST LEVELS (150K-1.5M lb THRUST)
	MILESTONES AND RESOURCES REQUIREMENTS:
	• TEST FACILITY CAPABLE OF:
	  - 1.5M-lb THRUST
	  - 3,500 lb/sec LOX FLOW @ 1200 psia

BACKGROUND & RELATED FACTORS:
• HYBRID ROCKETS OFFER:
  - INERT HANDLING
  - CLEAN EXHAUST
  - ELIMINATION OF EXPLOSIVE HAZARDS AND EFFECTS OF DEFECTS IN CRACKS AND DEBONDS
• HYBRID ROCKETS CAN BE:
  - THROTTLED
  - SHUT DOWN
• THE COST OF HYBRID BOOSTERS IS ESTIMATED AT 80% TO 100% OF SRMs AND MUCH LOWER THE LRBs
• HYBRIDS USE EXISTING TECHNOLOGY FOR CASE, NOZZLE, AND LIQUID FEED SYSTEMS
• HIGHER Isp THAN SOLIDS AND EQUAL TO THAT OF LOX/HYDROCARBON
	RECOMMENDED ACTIONS:
	• CODE DEVELOPMENT AND DATA BASE AT 600-lb, 15K-lb, AND 150K-lb THRUST LEVEL (JOINT NASA/CORPORATE IR&D PROGRAMS)
	• 750K-lb THRUST DEMONSTRATION
	• 1.5M-lb THRUST DEMONSTRATION

WHY AREN'T HYBRIDS OPERATIONAL?

- EARLY BOOSTER EMPHASIS WAS PLACED ON HIGH DENSITY IMPULSE SYSTEMS. COST, SAFETY, ENVIRONMENTAL AND RELIABILITY ISSUES WERE OF LOW PRIORITY IN THE HEYDAY OF THE AMERICAN SPACE PROGRAM
- PRESENT AND FUTURE EMPHASIS IS ON COST, ENVIRONMENTAL EFFECTS, SAFETY AND OPERATIONAL FLEXIBILITY
- OPERATIONAL SUCCESSES OF LARGE LIQUID ENGINES AND SRM BOOSTERS FOR THE SHUTTLE AND TITAN III CAUSED INTEREST/NEED IN HYBRIDS TO WANE
- ALL THE 1960s AND 70s WORK IN HYBRIDS WAS DONE BY PRIMARILY LIQUID OR SOLID PROPULSION COMPANIES WITHOUT A HIGH DEGREE OF SERIOUS INTEREST
- "POLITICAL FACTORS APPEAR TO INTERFERE WITH TECHNICAL FACTORS." - CULTURAL ISSUE

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- TECHNOLOGY TRANSFER

  THERMAL ANALYSIS APPLIED TO FLEXSEAL AND PHENOLIC MANDREL TOOL DESIGN
  - COMMON DESIGN TOOL
  - UNIFORM PART CURES
- HIGH PAYBACK IMMEDIATE IMPLEMENTATION ON ARMS CONTRACT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES::
  - CURRENT TOOLING DESIGN CRITERIA ARE ONLY STRESS-BASED
  - NON-UNIFORM HEAT TRANSFER CAN RESULT
  - MATERIAL VARIATION DETRIMENTAL TO PERFORMANCE
- SYSTEMS APPLICATIONS:
  - ALL SRM CURE TOOLING
- BENEFITS/PAYOFFS:
  - REDUCED FABRICATION COST
  - IMPROVED PRODUCTION TIME

RECOMMENDED ACTIONS:

- IDENTIFY CRITICAL TOOLING AND IMPOSE THERMAL ANALYSIS AS A CONTRACT REQUIREMENT
- IMPLEMENT COMMON DESIGN TOOLS FOR BOTH COMPONENT DESIGN AND TOOL DESIGN (CAD SYSTEM)

DESCRIPTION:

- TECHNOLOGY TRANSFER
- ANALYSIS AND TESTING KNOW-HOW AND TOOLS MUST BE DISTRIBUTED TO GOVERNMENT AND INDUSTRY TO OBTAIN PROPER BENEFIT OF R&D EXPENSES
- CURRENT PROBLEMS ARE VERY MULTI-DISCIPLINARY WHICH COMPLICATES TECHNOLOGY TRANSFER

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- A RECENT NASA STUDY RECOMMENDED AN INDUSTRY WIDE MILITARY HANDBOOK PROJECT TO DEVELOP DESIGN/ANALYSIS DATA FOR CARBON-CARBON AND CARBON-PHENOLIC
- THERE IS A NEED FOR STANDARDIZED TESTING METHODS TO IMPROVE THE RELIABILITY AND CREDIBILITY OF DATA
- NEW MATERIALS HAVE TEST REQUIREMENTS
- NEW ANALYSIS PROCEDURES REQUIRE PEER REVIEW
  - PERIODIC SEMINARS HAVE BEEN SHOWN TO BE AN EXCELLENT VEHICLE FOR TECHNOLOGY TRANSFER
  - COMPUTERIZED AND CENTRALIZED DATA BASES ARE NEEDED TO GET THE MOST BENEFIT FROM DATA ACQUISITION PROGRAMS
- SYSTEMS APPLICATIONS:
  - ALL SRMs
- BENEFIT/PAYOFF:
  - IMPROVED COMMUNITY/CULTURE, IMPROVED RELIABILITY, MORE EFFICIENT DESIGN/ANALYSIS AND COST SAVING

RECOMMENDED ACTIONS:

- CONDUCT A MILITARY HANDBOOK PROJECT FOR HIGH TEMPERATURE COMPOSITES
- PATTERN AFTER MILITARY HANDBOOK 17 FOR COMPOSITES
- SELECT A MILITARY SPONSOR
- APPOINT AND FIND AN EXECUTIVE COMMITTEE TO PLAN SEMINARS, OVERSEE DOCUMENTATION OF HANDBOOKS AND MEET QUARTERLY
- APPOINT AND FUND A HANDBOOK EDITOR
- SPONSOR ROUND-ROBIN TEST ACTIVITIES
- HOLD SEMINARS TWICE A YEAR
- INVITE ANALYSIS, TEST AND DESIGN PEOPLE FROM ALL COMPANIES AND GOVERNMENT AGENCIES INVOLVED IN SOLID ROCKET NOZZLE RELATED R&D
- SELECT, DESIGN AND IMPLEMENT A CENTRALIZED COMPUTER DATA BASE FOR MATERIAL PROPERTY DATA
- PUBLISH AN INITIAL VERSION OF BOTH HARDWARE AND SOFTWARE FORMS
- UPDATE THE HANDBOOK ANNUALLY
- PROVIDE TESTING GUIDELINES TO GOVERNMENT PROJECTS
- SPONSOR TEST METHOD DOCUMENTATION FOR PEER REVIEW

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- IMPROVED COMBUSTION CHAMBER MATERIALS
  - REGENERATIVELY COOLED
  - RADIATION COOLED

MILESTONES AND RESOURCE REQUIREMENTS:

- STME COMBUSTION CHAMBER, (1995) (ENABLING)

BACKGROUND & RELATED FACTORS:

- THERMAL ENVIRONMENTS, E.G. HIGH TEMPERATURES, HIGH STRAINS, LIMIT LIFE IN CURRENT (SSME) COMBUSTION CHAMBER
  - IMPROVED CONDUCTIVITY, HIGHER STRENGTH WOULD EXTEND LIFE, LOWER LIFE CYCLE COSTS
- MATERIAL DEVELOPMENT REQUIRED TO SUPPORT SMALLER THRUSTERS FOR LUNAR/MARS MISSIONS

RECOMMENDED ACTIONS:

- MATERIAL DEVELOPMENT ACTIVITIES HIGH CONDUCTIVITY MATERIALS
  - HIGH TEMPERATURE (>3000F) MATERIAL SYSTEMS
  - THERMAL BARRIER COATINGS
  - METAL MATRIX COMPOSITES
  - METAL/COMPOSITES JACKET
  - CERAMIC MATRIX COMPOSITES
  - METAL-COATED COPPER LINER (BLANCH RESISTANCE)

DESCRIPTION:

- IMPROVED TURBOPUMP MATERIALS

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- HISTORICALLY, MATERIALS HAVE BEEN A LIMITING FACTOR IN TURBOPUMP DEVELOPMENT
  - LIFE LIMITING IN SSME
  - MATERIALS AND PROCESSES LIMITING DESIGN IN STME TURBOPUMPS
- PROMISING MATERIALS EXIST, BUT DEVELOPMENT TO ENGINEERED MATERIAL STATUS USUALLY LAGS DESIGN REQUIREMENTS. AS A RESULT, PERFORMANCE IS LIMITED BY MATERIAL CAPABILITY
- COMPLACENCY PROBLEM- DESIGNERS BELIEVE MATERIALS AND PROCESSES WILL BE THERE WHEN NEEDED

RECOMMENDED ACTIONS:

- HYDROGEN-RESISTANT MATERIAL
- IMPROVED TURBINE BLADE MATERIALS
- COMPOSITES
  - METAL
  - CERAMIC
  - INTERMETALLIC
  - POLYMERIC
- TITANIUM/TITANIUM ALUMINIDES
- OXYGEN AND CRYOGEN COMPATIBLE ELASTOMERS
- POWDER METAL ALLOYS

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• IMPROVED NOZZLE MATERIALS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• IMPROVED, MORE EFFICIENT NOZZLE FABRICATION CONCEPTS REQUIRE MATERIALS WITH SUPERIOR STRENGTH/ WORKABILITY CHARACTERISTICS • PROJECTED DEEP SPACE MISSIONS REQUIRE LONGER LIFE/LIGHTER WEIGHT NOZZLE DESIGNS	• CERAMIC/ REFRACTORY COMPOSITE NOZZLES • HIGH STRENGTH, HIGH ELONGATION SHEET MATERIALS • METAL MATRIX COMPOSITES • HIGH TEMPERATURE ELASTOMERIC SEALANTS AND ADHESIVES

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOP GLOBAL MATERIALS AND PROCESSES DATA BASE	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DESIGN EFFORTS LIMITED BY LACK OF INFORMATION ON MATERIALS AND PROCESSES - INADEQUATE COLLECTION AND DISSEMINATION OF MATERIALS AND PROCESSES DATA - INAPPROPRIATE FORM OF DATA-NOT RESPONSIVE TO CONTEMPORARY ANALYSIS METHODS • COMPANIES BECOME LOCKED INTO FAMILIAR MATERIALS	• NASA-WIDE MATERIALS DATA BASE WORKING GROUP - STME WORKING GROUP AS STARTING POINT - CONSORTIUM FOR MATERIALS TESTING TO FEED DATA BASE - STANDARDIZE TEST METHODS - EXPAND/UPDATE DATA REPORTING FORMAT – FRACTURE MECHANICS – LOW/HIGH CYCLE FATIGUE – ENVIRONMENTAL EFFECTS – PROCESSING HISTORY, etc. • COMPUTERIZE DATA BASE AND IMPROVE ACCESSIBILITY • DEVELOP ARTIFICIAL INTELLIGENCE FOR MATERIALS AND PROCESS SELECTION

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LIGHTWEIGHT MATERIALS DEVELOPMENT (STRUCTURAL)	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REDUCED WEIGHT IS A MAJOR DESIGN GOAL	• ALUMINUM-LITHIUM • NON-METALLIC ENGINE COMPONENTS TANKS - PLUMBING - VALVES - NOZZLES - TURBOPUMP COMPONENTS - etc...

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LIGHTWEIGHT INSULATION MATERIALS DEVELOPMENT	• (EPA DRIVEN REQUIREMENTS) (ENABLING)
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• EPA RESTRICTIONS DICTATE MAJOR CHANGES IN CURRENT MATERIAL FORMULATIONS	• CFC-FREE MATERIALS DEVELOPMENT

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOPMENT HARDWARE FOR STME AND IMPROVED SSME AMCC CONFIGURATIONS	• HARDWARE • HOT FIRE TEST
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CANDIDATE ADVANCED MAIN COMBUSTION CHAMBER (AMCC) CONFIGURATIONS FOR STME AND IMPROVED SSME ARE LACKING DEVELOPMENT HARDWARE FOR: - LIBD (LIQUID INTERFACE DIFFUSION BONDING) - VPS (VACUUM PLASMA SPRAY)	• PROVIDE TWO DEVELOPMENTAL AMCC's FOR EACH: - LIDB - VPS • VERIFY BY: - TESTING - MATERIAL AND BOND JOINT EVALUATIONS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOP A TRULY ONE SHOT CHAMBER AND NOZZLE SUCH AS USED ON SOLID ENGINES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• ONE OF THE MOST EXPENSIVE PARTS OF THE ROCKET ENGINE IS THE THRUST CHAMBER AND NOZZLE, USUALLY BECAUSE IT IS DESIGNED FOR 10-20 USES NEEDED TO QUALIFY AN ENGINE SYSTEM. A TRULY EXPENDABLE SYSTEM DESIGNED FOR ONE FIRING COULD SIGNIFICANTLY REDUCE COST OF AN ENGINE	• BEGIN TESTING AND DESIGN COMPOSITE CERAMIC TYPE NOZZLE

LIQUID PROPULSION SYSTEMS SUB-PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DIAGNOSTIC/PROGNOSTIC HEALTH MONITORING SYSTEMS SUPPORT (COMPONENT DURABILITY MODELS)	• $250K/YR FOR DESIGN /TEST TIME FRAME OF ENGINE
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• ENGINE SYSTEM DURABILITY AND RELIABILITY • ENABLING TECHNOLOGY • IMPROVED RELIABILITY • REDUCED MAINTENANCE	• DEVELOP COMPONENT DURABILITY MODELS RELATING DAMAGE TO MISSION HISTORY/ENGINE PERFORMANCE /USAGE FOR RELEVANT COMPONENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• REDUCE FRICTION, GALLING, AND BINDING PROBLEMS IN PROPULSION SYSTEM COMPONENTS WHICH HAVE METAL TO METAL SLIDING SURFACES (POPPETS, PISTONS, GUIDES)	• MATERIALS CHARACTERIZATION PROGRAM - 1-2 YEARS, 500/YEAR • DEMONSTRATION PROGRAM - 1-2 YEARS, 1000/YEAR
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• SLIDING METAL SURFACES IN FLOW CONTROL DEVICES SUCH AS VALVES AND REGULATORS TEND TO GALL AND STICK	• INITIATE DEVELOPMENT PROGRAM TO INVESTIGATE THE POSSIBILITY OF USING CERAMIC MATERIALS FOR COMPONENT PARTS TO ALLEVIATE THE METAL-TO-METAL SLIDING SURFACE PROBLEMS • DEMONSTRATE BY TEST CERAMIC COMPONENT PARTS IN RELEVANT ENVIRONMENTS

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- DEVELOP LIGHTWEIGHT PROJECTILE SHIELDING FOR SPACE PROPULSION SYSTEMS

MILESTONES AND RESOURCE REQUIREMENTS:

- SURVEY EXISTING TECHNOLOGY
- BUILD PROTOTYPE SHIELD
  - 1 YEAR, 500
- TEST SHIELDS AT WSTF
  - 1 YEAR, 600

BACKGROUND & RELATED FACTORS:

- THE METEORITE/SPACE DEBRIS SHIELDING FOR THE SSF PROPULSION MODULE WEIGHS 1300 LBS. (MODULE STRUCTURE WEIGHS 1000 LBS.)

RECOMMENDED ACTIONS:

- DEVELOP LIGHTWEIGHT MATERIALS FOR USE AS SHIELDING AGAINST PROJECTILES MOVING AT ORBITAL VELOCITIES. BUILD THE SHIELDS AND TEST THEM AT NASA's HAZARDOUS HYPERVELOCITY IMPACT FACILITY AT WHITE SANDS

DESCRIPTION:

- GELLED PROPELLANTS FOR OTV's, EARTH-TO-ORBIT BOOSTERS, AND SPACE TRANSFER/SEI VEHICLES

MILESTONES AND RESOURCE REQUIREMENTS:

- DEMONSTRATE GEL PROPELLANT CAPABILITIES AND PROPERTIES
- ESTABLISH SYSTEM & COMBUSTION DESIGN CRITERIA
- ESTABLISH SYSTEM BENEFITS & TECHNOLOGY IMPACTS
- CONDUCT DEMONSTRATION AND VALIDATION TESTS
- COMPLETE FULL SCALE DEVELOPMENT
- ESTABLISH RESOURCE REQUIREMENTS TO ACCOMPLISH THE ABOVE

BACKGROUND & RELATED FACTORS:

- GELLED PROPELLANTS ARE LIQUID FUELS AND OXIDIZERS THAT HAVE SPECIAL GELLING AGENTS AND METALS ADDED TO FORM THIXOTROPIC COMPOUNDS WITH INCREASED SAFETY AND PERFORMANCE.
- BOTH EARTH STORABLES AND CRYOGENIC (LO_2/LH_2) PROPELLANTS CAN BE GELLED TO INCREASE DENSITY, PERFORMANCE, AND TO SUPPRESS THE BOILING POINT
- GELLED LH2 SLUSH AND GELLED LH_2/SOLID CH_4
- SPECIFIC BENEFITS INCLUDE:
  - HIGH PROPULSIVE PERFORMANCE
  - HIGH DENSITY & BOILING POINT SUPPRESSION
  - PACKAGING FLEXIBILITY AND EFFICIENCY
  - GREATLY IMPROVED SAFETY OVER LIQUIDS & SOLIDS
  - ENERGY MANAGEMENT (THROTTLING, PULSING, ETC.)
  - HIGH MASS FRACTION

RECOMMENDED ACTIONS:

- CONDUCT MISSION/SYSTEM ANALYSES TO IDENTIFY TECHNOLOGY IMPACTS AND REQUIREMENTS
- CONDUCT TECHNOLOGY PROGRAMS TO DEVELOP ADVANCED HIGH PERFORMANCE GELS
- CHARACTERIZE GELS IN THE LABORATORY
- DESIGN & DEVELOP GEL PROPULSION SYSTEM
- ESTABLISH GEL PROPULSION TEST BED
- CONDUCT FULL SCALE DEVELOPMENT

LIQUID PROPULSION SYSTEMS SUB-PANEL

TECHNOLOGY TRANSFER

FINDINGS:

- THE PREVAILING APPROACH TO TECHNOLOGY TRANSFER CAN BE STATED AS FOLLOWS:
  - "ESTABLISH CO-OWNERSHIP OF TECHNOLOGY PROGRAMS"
  - "PROMOTE CONSTANT DIALOGUE BETWEEN TECHNOLOGISTS AND SYSTEM DEVELOPERS"
  - "REQUIRE VALIDATION OF TECHNOLOGY IN APPROPRIATE ENVIRONMENT AND CONFIGURATION - DON'T PLACE BURDEN OF PROOF ON SYSTEM DEVELOPERS
- A MECHANISM IS REQUIRED TO FORCE THAT PROCESS

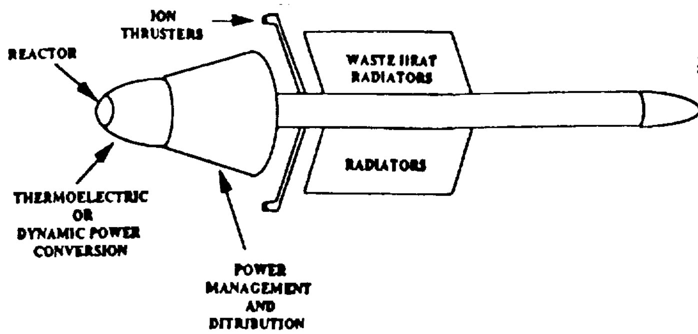
RECOMMENDATIONS:

- A NASA BUDGET LINE ITEM FOR A NATIONAL COMPONENT/SUB-SYSTEM TEST BED PROGRAM, DEDICATED TO TECHNOLOGY VALIDATION

COMMENTS

- COMPLACENCY PROBLEM: PROJECTS BELIEVE MATERIALS AND PROCESSES WILL BE THERE WHEN NEEDED
- ORGANIZATIONS TEND TO BECOME "LOCKED IN" TO FAMILIAR MATERIALS
  - THE SITUATION IS EXACERBATED BY NEAR-SIGHTED MATERIAL DEVELOPMENT EFFORTS
- TECHNOLOGIES/PRIORITIES EMERGING FROM THIS WORKSHOP REPRESENT A CURRENT SNAPSHOT. A MECHANISM SHOULD BE PROVIDED FOR PERIODIC UPDATE
  - STEERING COMMITTEES?
- NASP: TOO FAR ALONG TO BE DRIVER TO THIS MEETING, BUT SHOULD BENEFIT FROM LONG-RANGE INITIATIVES
- PARALLEL/COMPLEMENTARY DEVELOPMENT PROGRAMS NEED TO BE COORDINATED WITHIN THE GOVERNMENT

NUCLEAR ELECTRIC PROPULSION



SYSTEM NEEDED FOR:

- CARGO TO MARS
- CARGO TO MOON
- + LUNAR SURFACE POWER
- + MARS SURFACE POWER

KEY COMPONENTS

- REACTOR
- POWER CONVERSION SYSTEM
- RADIATORS
- PMAD
- ION THRUSTER

KEY REQUIREMENTS

- 1700K + 7-10YRS-4 CYCLES
- 1700K + 7-10YRS-10^9 CYCLES
- 1200K+ 7-10 YRS- e>0.9
- HI RAD FLUX
- Cs Erosion Resistance, High alpha

SOA

- SP-100 - COMPONENTS UNDER DEVELOPMENT-NO SYSTEMS TEST

ONGOING PROGRAMS

- PWC-11 CREEP
- W/Nb COMPOSITE FUEL CLAD MATERIAL
- G/Cu RADIATOR MATERIAL

GAPS

- REFRACTORY METAL DESIGN/VALIDATION

NEEDS & OPPORTUNITIES

- STRUCTURAL ALLOY WITH DENSITY - 6-8

PRIORITIES	RATIONAL
•	•
•	•
•	•

NUCLEAR ELECTRIC PROPULSION

SUMMARY OF KEY MATERIAL REQUIREMENTS

SUBSYSTEM		1		2
REACTOR	CHOICE	MAJOR NEEDS	CHOICE	MAJOR NEEDS
• FUEL	(U/ZR) C	•STOICHIOMETRY CONTROL •STABILITY TO 3000K IN H_2	(W/UO2)	• FISSION PRODUCT CONTAINMENT COATING
• FUEL CLAD	PWC-11	•PRODUCTION OPTIMIZATION	Re	• WELDING OPTIMIZATION
• POWER CONVERSION SYSTEM				
• BRAYTON –TURBINE	FRS	•FAB TECH FOR RADIAL •DATA BASE	MO	• DATA BASE
• STIRLING –TUBING –SEALS	?	•DEVELOP COMPOSITE •DATA BASE		

NUCLEAR/ELECTRIC PROPULSION SUB-PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
BACKGROUND & RELATED FACTORS • SOA - PAST EFFORT - ONGOING PROGRAMS - LEVEL OF EVOLUTION • TECHNOLOGY GAPS • BENEFITS IF FILL GAPS	RECOMMENDED ACTIONS:

7.3 ENTRY SYSTEMS PANEL