N93-22095

VEHICLE SYSTEMS

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TOM MODLIN

RAPPORTEURS
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TOM WHEELER

VEHICLE SYSTEMS PANEL

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL REPORT

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SUBPANEL CHAIRMAN

VEHICLE SYSTEMS PANEL

VEHICLE SYSTEMS PANEL CO-CHAIRMAN

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T. MODLIN - JSC

EXPENDABLE LAUNCH VEHICLES & CRYOTANKS

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W. B. LISAGOR	LaRC
D. BOLSTAD	MMC
H. CROOP	WL
J. DYER	GD
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R. DROPEK	HERCULES
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REUSABLE VEHICLES

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H. BABEL	MDSS
D. HERBENER	MMC
E. NIELSEN (WJSA)	RAPPORTEUR

VEHICLE SYSTEMS - EXPENDABLE

INTRODUCTION

PERSPECTIVES OF THE SUBPANEL ON EXPENDABLE LAUNCH VEHICLE STRUCTURES AND CRYOTANKS

- **NEW MATERIALS PROVIDE THE PRIMARY WEIGHT SAVINGS EFFECT ON VEHICLE MASS/SIZE**
  - PROVIDE ROBUSTNESS IN DESIGN
  - YIELD SYSTEMS COST SAVINGS
- **TODAY'S INVESTMENT**
  - DISPROPORTIONATELY SMALL
  - SIGNIFICANT BENEFITS APPARENT
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
- **TYPICALLY 10-20 YEARS TO MATURE AND FULLY CHARACTERIZE NEW MATERIALS**
  - MANUFACTURING PROCESSES MUST BE DEVELOPED CONCURRENTLY
  - USER NEEDS CAN ACCELERATE MATERIALS DEVELOPMENT
    - SELECTED EXAMPLES (8090, 2219, 7XXX)

VEHICLE SYSTEMS

TECHNOLOGY NEEDS ADDRESSED BY THE EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

- **MATERIALS DEVELOPMENT**
  - ADVANCED METALLICS
  - COMPOSITES
  - TPS/INSULATION
- **MANUFACTURING TECHNOLOGY**
  - NEAR NET-SHAPE METALS TECHNOLOGY
  - COMPOSITES
  - WELDING
- **NDE**

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

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DESCRIPTION:

- ADVANCED STRUCTURAL MATERIALS

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MILESTONES & RESOURCE REQUIREMENTS:

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BACKGROUND & RELATED FACTORS:

- IN THE LAST 10 YEARS, MANY NOVEL MATERIALS HAVE BEEN DISCOVERED THAT HAVE APPLICABILITY TO SPACE PROGRAMS
- THESE INCLUDE BUT ARE NOT LIMITED TO:
- ULTRA LIGHTWEIGHT AL ALLOYS
- METAL MATRIX COMPOSITES
- POLYMER BASED COMPOSITES
- DEVELOPMENT OF THESE MATERIALS TO MATURITY, AND APPLICATION IN NASA PROGRAMS, WILL HAVE A PROFOUND INFLUENCE ON WEIGHT AND COST SAVINGS AS WELL AS TECHNOLOGICAL IMPACT

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RECOMMENDED ACTIONS:

- EVALUATE THE APPLICATION AREAS AND STATE OF MATURITY OF THESE NEW MATERIALS
- DESIGN AND ANALYTICAL TOOL TO REALISTICALLY CALCULATE COST AND WEIGHT BENEFITS ARISING FROM INCORPORATION OF SUCH MATERIALS
- PRIORITIZE AND SELECT FOR FUNDING THE SEVERAL MATERIALS THAT OFFER THE MOST SIGNIFICANT PAY-OFF IN THE 3-10 YEAR TIME FRAME
- INSIST ON A TEAMING APPROACH THAT INCLUDES NASA, PRODUCERS AND USERS AND INVOLVES SELECTION, DESIGN, MANUFACTURING, AND ENGINEERING CRITERIA

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DESCRIPTION:

- NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES

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MILESTONES & RESOURCE REQUIREMENTS:

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BACKGROUND & RELATED FACTORS:

- CURRENT VEHICLE SYSTEM STRUCTURES EMPLOY CONVENTIONAL MATERIALS AND FABRICATION TECHNOLOGY
- RESULTANT STRUCTURES ARE TYPICALLY HIGH COST AND WEIGHT PENALTIES ARE BUILT INTO THE DESIGN
- NUMEROUS NEAR NET SHAPE FABRICATION OPPORTUNITIES EXIST, EMPLOYING FORMING AND JOINING TECHNOLOGIES WHICH ARE RECOGNIZED, BUT REQUIRE DEVELOPMENT
- PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION AND TOTAL PROGRAM COSTS

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RECOMMENDED ACTIONS:

- INITIATE AGGRESSIVE TECHNOLOGY DEVELOPMENT PROGRAM TO DEMONSTRATE FORMING AND JOINING PROCESSES SUITABLE FOR ALL APPROPRIATE VEHICLE SYSTEM STRUCTURES
- IDENTIFY VEHICLE STRUCTURES DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO NEAR NET SHAPE PROCESSING
- SELECT NEAR NET SHAPE PROCESSES AMENABLE TO VEHICLE HARDWARE
- DEVELOP CANDIDATE HARDWARE PROGRAM TO DEMONSTRATE/VALIDATE FABRICATION TECHNOLOGY

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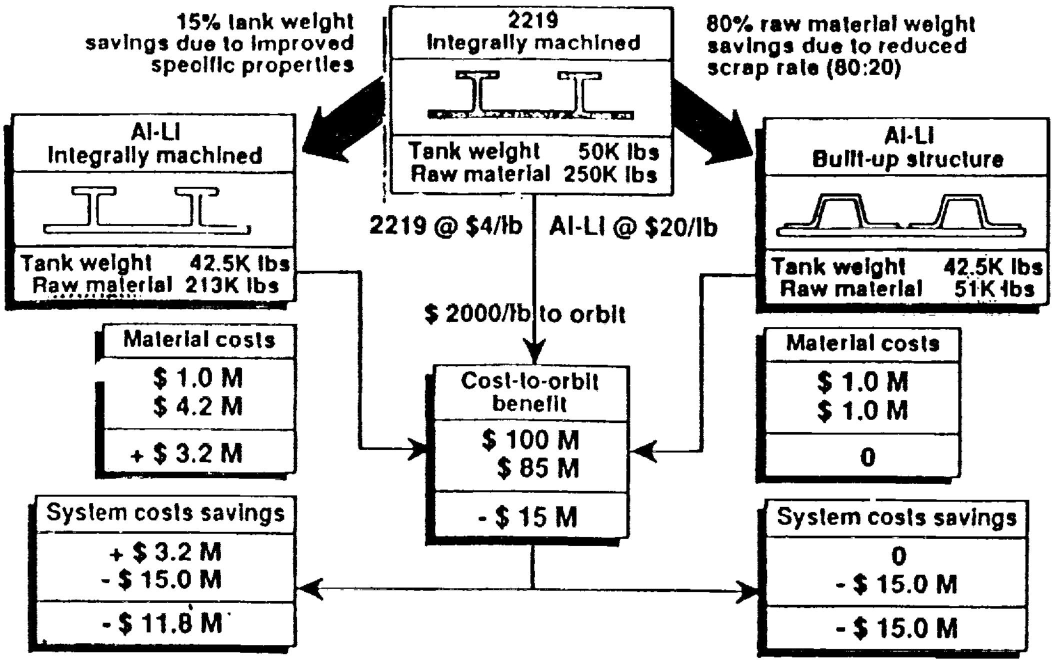
EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• NDE OF ADVANCED STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• NEED AUTOMATED REAL-TIME TECHNIQUES TO REDUCE COST • HIGHER-STRENGTH MATERIALS NEED MORE RELIABLE NDE • FRACTURE TOUGHNESS DRIVEN DESIGNS REQUIRE PRECISE FLAW IDENTIFICATION/DETECTION	• NDE PROCESSES TO EVALUATE INCLUDE: - REAL-TIME X-RAY - REAL-TIME ULTRASONICS - ACOUSTIC EMISSION - EDDY CURRENT • INCORPORATE AUTOMATION FEATURES • EVALUATE BUILT-IN SENSORS FOR COMPOSITES

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• Al-Li: TECHNOLOGY	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• SPACE PROGRAMS REQUIRE UNIQUE LIGHT WEIGHT MATERIALS • ALLOYS DEVELOPED FOR COMMERCIAL AND MILITARY AIRCRAFT NOT DIRECTLY APPLICABLE • MATERIAL PRODUCERS ARE NOT CURRENTLY PLANNING TO INDEPENDENTLY DEVELOP THE REQUIRED LAUNCH VEHICLES ALLOYS. DEVELOPMENT WILL BE MARKET/USER DRIVEN • NEAR-TERM Al-Li ALLOYS CAN PROVIDE UP TO 15 PERCENT WEIGHT SAVINGS. LONGER-TERM ALLOYS HAVE POTENTIAL WEIGHT SAVINGS UP TO 30 PERCENT • Al-Li ALLOYS PROVIDE UNIQUE PROCESSING OPTIONS, I.E. SUPERPLASTIC FORMING • LACK OF CODE R FUNDING LIMITS EFFECTIVENESS OF BRIDGING PROGRAM	• FUND GOVERNMENT, INDUSTRY, AND PRODUCER PROGRAM TO ACCELERATE NEAR-TERM AND FAR-TERM Al-Li DEVELOPMENT • TAILOR MATERIALS DEVELOPMENT WITH SELECTED MANUFACTURING PROCESSES

BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS



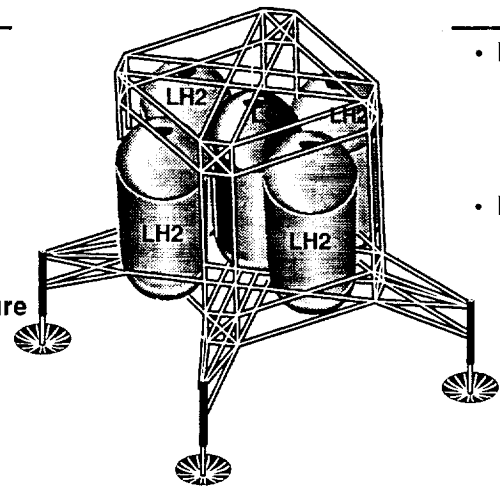
EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION: • COMPOSITE TECHNOLOGY FOR CRYOTANKS AND DRY BAY STRUCTURES (WITH EMPHASIS ON FIBER REINFORCED PLASTIC SYSTEMS)	**MILESTONES & RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • PROCESSES MUST BE DEFINED TO ACCOUNT FOR FRP MANUFACTURING CAPABILITIES • A TOTALLY INTEGRATED MATERIALS, DESIGN, MANUFACTURING, INSPECTION, AND TESTING PROCESS MUST BE IDENTIFIED WHICH WILL ACCOUNT FOR THE UNIQUE PROCESS NEEDS AND CAPABILITIES OF COMPOSITES • WEIGHT REDUCTION POTENTIAL IS 20-30 PERCENT	**RECOMMENDED ACTIONS:** • ESTABLISH COMPOSITE CRYOTANK SYSTEM/DESIGN REQUIREMENTS. IDENTIFY LINER REQUIREMENTS • DETERMINE STATE-OF-THE-ART CAPABILITIES IN FRP COMPOSITES FOR MATERIALS, DESIGN, MANUFACTURING, INSPECTION AND TESTING. SPECIFICALLY CONSIDER THE FOLLOWING: - IN-LINE INSPECTION - IN-SITU CURE METHODOLOGY - TOOLING APPROACH - JOINING TECHNOLOGY - COMPOSITE DAMAGE TOLERANCE AND REPAIR • DESIGN A BASELINE CRYOTANK • CONDUCT MANUFACTURING PROCESS TRADES • ESTABLISH A BASELINE MANUFACTURING PROCESS • DEFINE FACILITY SIZE REQUIRED TO SUPPORT FRP

MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

Cryotank

- Materials
  - Al-Li
  - SiCp/Al MMC
  - Ti
  - RMC
- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound RMC tanks
  - Explosively formed components



Core primary structure

- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E
- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened materials
  - Protective coatings/platings

Benefits

- Advanced materials: 20-30% weight savings; Increased payload; Greater range
- Low cost fabrication: 30% cost savings; Reduced assembly time
- NDE/durable materials: Increased reliability and vehicle life

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- WELDING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE
- REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING
- HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS
- LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES
- AUTOMATION POTENTIALLY CAN REDUCE NDE

RECOMMENDED ACTIONS:

- IDENTIFY PROCESS VARIABLES RELATIONSHIPS
- DEVELOP PROCESS MODELS
- IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK
- IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE
- VERIFY AND VALIDATE PROCESSES AND CONTROLS

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• NEAR NET-SHAPE METALS TECHNOLOGY - BUILT-UP STRUCTURES FOR CRYOGENIC TANKS AND DRY-BAY APPLICATIONS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• INTEGRALLY STIFFENED STRUCTURES FABRICATED BY MACHINING FROM A THICK PLATE RESULTS IN HIGH SCRAP RATES (85%+) • LOW BUY-TO-FLY RATIO REQUIRED FOR ECONOMIC UTILIZATION OF NEW HIGH PERFORMANCE METALS • BUILT-UP STRUCTURE APPROACH IS APPLICABLE TO BROAD RANGE OF STRUCTURAL COMPONENTS ENCOMPASSING TANKS AND DRY-BAY STRUCTURES • PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION COST	• IDENTIFY VEHICLE STRUCTURES, DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO BUILT-UP STRUCTURE APPROACH • DEVELOP FORMING AND JOINING PROCESS TO FABRICATE APPROPRIATE STRUCTURAL PREFORMS • DESIGN, FABRICATE AND TEST STRUCTURAL SUBELEMENTS • DEMONSTRATE STRUCTURAL INTEGRITY UNDER REALISTIC SERVICE CONDITIONS • VALIDATE TECHNOLOGY THROUGH DESIGN, FABRICATION AND TESTS OF FULL-SCALE TANKS AND DRY-BAY STRUCTURAL ARTICLES

SUMMARY OF THE DELIBERATIONS OF THE EXPENDABLE LAUNCH AND CRYOTANKS SUBPANEL

- **THE MAJOR NEAR TERM ISSUE FOR Al-Li IS WHETHER FUNDING WILL BE PROVIDED TO ASSURE INCORPORATION IN THE NLS**
  - PRODUCTION CAPABILITY IS IN PLACE FOR 8090, WELDALITE, AND 2090
  - NEAR NET SHAPE PROCESSES HAVE BEEN DEFINED AND SCALE UP ACTIVITIES ARE UNDERWAY
  - PROGRAM MANAGEMENT DECISIONS ARE REQUIRED TO EXPLOIT POTENTIAL
- **MATERIALS TECHNOLOGY PROGRAMS WITHIN NASA ARE TOO LIMITED/RESTRICTIVE**
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
  - CLEAR NEED FOR SUSTAINED/CONTINUING PROGRAMS TO SUPPORT USER NEEDS/LONG TERM NASA MISSIONS
- **SIGNIFICANT NEEDS EXIST FOR STRUCTURAL ANALYSIS AND OPTIMIZATION PROGRAMS**
- **NDE TECHNIQUES AND METHODS MUST BE EXPLOITED TO ASSURE INTEGRITY, RELIABILITY AND COST REDUCTIONS**
- **JOINING AND BONDING TECHNIQUES AND CONCEPTS MUST BE DEVELOPED AND CHARACTERIZED FOR FUTURE LARGE LAUNCH VEHICLE APPLICATIONS**

REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

PERSPECTIVES

- FUTURE VEHICLES REQUIRE LOW COST, HIGH RELIABILITY, ROBUSTNESS, LOW MAINTENANCE, ON-TIME LAUNCH CAPABILITY
- CURRENT TECHNOLOGY GAPS EXIST RELATIVE TO ACCOMPLISHING THE ABOVE GOAL
- MAJOR TECHNOLOGY CATEGORIES
  - MATERIALS
  - STRUCTURAL CONCEPTS
  - FABRICATION/MANUFACTURING
  - DESIGN/ANALYSIS/CERTIFICATION
  - NON-DESTRUCTIVE EVALUATION (NDE)

MAJOR PAYOFF ITEMS

MATERIALS	STRUCTURAL CONCEPTS	FABRICATION/ MANUFACTURING	DESIGN/ANALYSIS /CERTIFICATION	NDE
• COMPOSITES • Al-Li • TPS	• NEAR NET SHAPES • INTEGRALLY-MACHINED	• BOND • WELD • EXTRUDE • FORGING • POWDER • LIQUID ATOMIZATION	• CRITERIA • SYSTEMS OPTIMIZATION	• DESIGN FOR INSPECTABILITY • HEALTH MONITORING

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• IN SPACE JOINING - WELDING - BONDING	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REPAIR TECHNIQUES FOR IN SPACE HARDWARE REQUIRED • IN SPACE ASSEMBLY TECHNIQUES FOR LARGE STRUCTURES • WELDING AND BONDING PROVIDE HIGH WEIGHT, LEAK PROOF STRUCTURES • SOVIETS HAVE MADE EMERGENCY WELDING REPAIR ON MIR • ELECTRON BEAM PROCESS ONLY PROCESS PRESENTLY USED IN VACUUM	• IDENTIFY AND DEVELOP WELDING AND BONDING PROCESSES FOR IN SPACE USE • IDENTIFY LIMITING FEATURES OF ARC WELDING PROCESSES FOR USE IN SPACE • DEVELOP WELDING HARDWARE/SOFTWARE FOR SPACE USE • IDENTIFY SAFETY ISSUES ASSOCIATED WITH WELDING IN SPACE • DEVELOP REMOTE CONTROL AND MANIPULATORS FOR OPERATIONS • PLAN AND CONDUCT PROOF OF EXPERIMENT FOR SHUTTLE FLIGHT

REUSABLE VEHICLES SUBPANEL

ISSUE/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• DAMAGE TOLERANT DESIGN FOR COMPOSITE STRUCTURES	• PUBLISH DAMAGE TOLERANT DESIGN DATA BOOK FOR COMPOSITE STRUCTURE
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• SPACE TRANSPORTATION MISSIONS ARE WEIGHT DRIVEN • COMPOSITES REDUCE WEIGHT, REDUCE PART COUNT AND ARE ADAPTABLE TO COMPLICATED SHAPES • UNLESS PROPERLY DESIGNED, EASILY DAMAGED • GOAL: VISUALLY INSPECT ONLY WITH MINIMAL IMPACT ON WEIGHT	• DEVELOP DAMAGE TOLERANT PHILOSOPHY/CRITERIA • ASSEMBLE INDUSTRY AVAILABLE TEST DATA • IDENTIFY CANDIDATE FIBERS, RESINS, LAY-UPS, AND MANUFACTURING PROCESSES FOR DAMAGE TOLERANT SKIN DESIGNS • DEVELOP DESIGNED EXPERIMENT UTILIZING DAMAGE TOLERANT TESTING TO IDENTIFY DRIVERS (TEMPERATURE RANGE R.T. TO 600°F) • UTILIZE BEST SKIN DESIGNS FOR HONEYCOMB PANELS AND PERFORM DESIGNED EXPERIMENT TO AGAIN IDENTIFY DRIVERS (TEMPERATURE RANGE R.T. - 600°F)

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• OPTIMIZED SYSTEM ENGINEERING APPROACH TO ENSURE ROBUSTNESS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• LOW MARGINS IN THE ASCENT OPERATIONAL ENVELOPE INCREASES OPERATIONAL COST • MAINTENANCE AND REFURBISHMENT OF LOW-LIFE PARTS IS COSTLY IN INSPECTION, ANALYSIS AND CHANGE-OUT • ROBUSTNESS PROVIDES LOWER TOTAL COST, LESS REWORK, LAUNCH TIME, HIGHER PERFORMANCE AND LESS COMPLEX OPERATION	• DEVELOP CONCURRENT ENGINEERING TOOLS FOR FLIGHT MECHANICS, CONTROL, PERFORMANCE, LEADS, AEROELASTICITY, MANUFACTURING, OPERATIONS, etc... • DEVELOP INTER-DISCIPLINARY, TOTAL COST OPTIMIZATION AND TRADES ANALYSIS TOOLS • DEVELOP ACCURATE STATISTICAL QUANTIFICATION TOOLS FOR ALL SENSITIVE PARAMETERS • DEVELOP ATMOSPHERIC (WINDS) CHARACTERISTICS FOR DESIGN AND OPERATION • ANALYTICAL TOOLS TO MORE ACCURATELY PREDICT AERODYNAMICS, PLUMES, ACOUSTICAL, etc.. INDUCED ENVIRONMENT DATA CFD • DEVELOP MODEL SYNTHESIS TOOLS TO REDUCE MODEL DEVELOPMENT • DEVELOP SYSTEM PROBABILISTIC TOOLS TO GUIDE OPTIMIZATION CRITERIA

REUSABLE LAUNCH VEHICLES AND CRYOTANKS

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• MAINTENANCE AND REFURBISHMENT PHILOSOPHY	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CURRENT REUSABLE SPACE VEHICLES ARE ESSENTIALLY DE-CERTIFIED AS FLIGHT VEHICLES AT THE MOMENT OF TOUCHDOWN • RE-CERTIFICATION REQUIRES LARGE SCALE DISASSEMBLY, INSPECTION, AND TEST PRIOR TO NEXT FLIGHT • THESE ACTIVITIES ARE LABOR INTENSIVE AND ACCOUNT FOR A LARGE PART OF THE OPERATIONS COST OF THE VEHICLE.	• EXAMINE MAINTENANCE AND REFURBISHMENT PHILOSOPHIES OF NON-SPACE VEHICLE OPERATORS TO IDENTIFY "LESSONS LEARNED" FOR SPACE SYSTEMS • DEFINE EXPERIENCE DATA BASE FROM PAST REUSABLE VEHICLE FLIGHTS TO ALLOW STATISTICAL CORRELATION OF SYSTEM FAILURE MODES, EFFECTS, AND FREQUENCIES WITH MAINTENANCE AND REFURBISHMENT APPROACHES • DEVELOP CRITERIA TO DESIGN FOR MAINTENANCE AND ASSEMBLY • IDENTIFY MAINTENANCE AND REFURBISHMENT REQUIREMENTS FOR PROPOSED VEHICLE TECHNOLOGIES • COORDINATE TEST PHILOSOPHY AND STRUCTURAL/DESIGN CRITERIA EFFORTS (I.E. DESIGN FOR ASSEMBLY/ REPAIR APPROACHES)

TECHNOLOGIES

- ADVANCED STRUCTURAL MATERIALS
- AL-LI: TECHNOLOGY
- NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES
- NEAR NET SHAPE METALS TECHNOLOGY
- NEAR NET SHAPE EXTRUSIONS FOR STRUCTURAL HARDWARE
- NEAR NET SHAPE: FORGINGS
- NEAR NET SHAPE: SPIN FORGINGS
- WELDING
- IN-SPACE WELDING/JOINING
- COMPOSITES TECHNOLOGY FOR CRYOTANKS AND DRYBAY STRUCTURES
- JOINING TECHNOLOGY FOR COMPOSITE CRYOTANKS
- TOOLING APPROACH FOR MANUFACTURING LARGE DIAMETER CRYOTANKS
- DEVELOP A CURE METHODOLOGY FOR LARGE COMPOSITE CRYOTANKS
- STATE-OF-THE-ART BUCKLING STRUCTURE OPTIMIZER PROGRAM
- STATE-OF-THE-ART "SHELL OF REVOLUTION" ANALYSIS PROGRAM
- NDE FOR ADVANCED STRUCTURES
- IN-LINE INSPECTION OF COMPOSITES
- SCALE-UP OF LAUNCH VEHICLES
- LAUNCH VEHICLE TPS/INSULATION BEYOND 27.5 FT. DIAMETER
- DESIGN & FABRICATION OF THIN WALL CRYOTANKS FOR SPACE EXPLORATION (5-20 FT. DIA.)

7.1.2 Supporting Charts

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• CRYOGENIC TANKAGE - QUALIFY AL-LI TANKAGE	• SUFFICIENT DATA BASE FOR PROGRAM MANAGERS TO ACCEPT THE MATERIAL IN NEW LAUNCH VEHICLE PROGRAMS
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• LIGHTWEIGHT CRYOGENIC TANKS WILL INCREASE THE PAYLOAD TO ORBIT OF VARIOUS LAUNCH SYSTEMS • AL-LI HAS NOT REACHED THE MATURITY TO INCORPORATE INTO THE DESIGN WITHOUT CONSIDERABLE ADDITIONAL EFFORT BEYOND THAT CURRENTLY FUNDED.	• CONDUCT A PROGRAM COORDINATED WITH EXISTING PROGRAMS TO ENSURE THAT THE NECESSARY TECHNOLOGY HAS BEEN DEMONSTRATED AND THAT ENGINEERING PROPERTIES INCLUDING MIL-HDBK-5 STATISTICALLY DERIVED PARENT MATERIAL AND WELD PROPERTIES, FRACTURE TOUGHNESS, STRESS CORROSION, RESISTANCE, ETC. HAVE BEEN ESTABLISHED

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• CRYOGENIC TANKAGE - QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID HYDROGEN	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LIQUID HYDROGEN • RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (LN_2) DEMONSTRATED THAT THE COMPOSITE WAS NOT PERMEABLE AT LN_2 TEMPERATURES. EARLIER SMALL SCALE TESTS WITH GASEOUS HELIUM AT -420F DEMONSTRATED TECHNICALLY ACCEPTABLE PERMEABILITY AND RESISTANCE TO MICROCRACKING WHEN THERMALLY CYCLED. NASP 1/3 SCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED.	• ESTABLISH THE ENABLING TECHNOLOGY TO BUILD, INSULATE AND TEST A SUB-SCALE TANK. TANK TEST SUCCESSFUL • IDENTIFY WHERE THE TECHNOLOGY IS ADEQUATE AND WHERE DEVELOPMENT IS REQUIRED - DEMONSTRATE ADEQUATE TECHNOLOGY - DEVELOP TECHNOLOGY (SUBSCALE) • DECIDE ON MANUFACTURING APPROACH • DESIGN SUBSCALE TANK WITH ALL THE FEATURES OF A FULL SCALE TANK • FABRICATE, INSULATE, INSPECT AND TEST TANK WITH LH_2

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• CRYOGENIC TANKAGE - QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID OXYGEN	• DEMONSTRATE THE ABILITY TO MEET SAFETY REQUIREMENTS - FEASIBILITY PROGRAM $500K
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LOX • RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (LN_2) DEMONSTRATED THAT THE TANK WAS NOT PERMEABLE (IN AN ENGINEERING SENSE) AT LN_2 TEMPERATURES. NASP 1/3 SUBSCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED.	• ESTABLISH FEASIBILITY PROGRAM WITH THE FOLLOWING AS A MINIMUM: - ESTABLISH SET OF DESIGN GROUND-RULES - DEVELOP LINERS WITH DAMAGE THAT WILL PREVENT A CONFLAGRATION - TESTS TO DEMONSTRATE NO CONFLAGRATION – 1000 CYCLES OF RAPID O_2 PRESSURIZATION – CONDUCT RAPID FILL WITH PARTICLE IMPINGEMENT – BURST TEST

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LAUNCH VEHICLE TPS/INSULATION	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CLEAN AIR ACTS MANDATE ELIMINATIONS OF FREON BLOWING AGENTS • ROBUST DESIGN PHILOSOPHY DICTATES DURABLE TPS SYSTEMS • LONG DURATION SPACE MISSIONS REQUIRE SPACE QUALIFIED TPS MATERIALS TO SURVIVE ENVIRONMENT AND NOT CREATE DEBRIS FOR OTHER CRITICAL OPERATIONS	• CONTINUE ALS ADP TO DEVELOP ALTERNATE BLOWING AGENTS • LOOK BEYOND NEAR-TERM FIXES TO FUND LONG-TERM REPLACEMENT MATERIALS • DEVELOP ROBUST/REUSABLE OR EASILY REPLACEABLE TPS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DURABLE PASSIVE THERMAL CONTROL DEVICES AND/OR COATINGS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REUSABLE CTV PROGRAM REQUIRES LIGHTWEIGHT DURABLE INSULATION FOR MINIMUM COST AND QUICK TURN AROUND	• DEVELOP ROBUST HIGH PERFORMANCE, LOW COST AND REUSABLE THERMAL CONTROL DEVICES AND/OR COATINGS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOPMENT AND CHARACTERIZATION OF PROCESSING METHODS TO REDUCE ANISOTROPY OF MATERIAL PROPERTIES IN Al-Li	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• THE ANISOTROPY OF Al-Li, ESPECIALLY THE REDUCED STRENGTH IN THE SHORT TRANSVERSE DIRECTION, SIGNIFICANTLY IMPACTS THE UTILITY OF Al-Li APPLICATIONS • DESIGN ALLOWABLES ARE FREQUENTLY DICTATED BY THE S-T STRENGTH (PREVENTING THE ACHIEVEMENT OF MAXIMUM BENEFIT FROM Al-Li USE) AND COMMERCIAL AIRCRAFT BUILDERS HAVE HESITATED TO USE Al-Li BECAUSE OF CONCERN OVER THE LONG TERM EFFECTS OF ANISTROPY	• REFINE EXISTING LABORATORY SCALE PROCESS TO PRODUCE ISOTROPIC Al-Li • SUPPORT SCALE-UP OF LAB PROCESS TO PROTOTYPE COMMERCIAL PRODUCTION VOLUMES • CHARACTERIZE MATERIAL PROTOTYPES OF Al-Li PRODUCED BY THESE METHODS

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- DURABLE THERMAL PROTECTION SYSTEM (TPS)

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- FUTURE REUSABLE VEHICLE PROGRAMS REQUIRE LIGHTWEIGHT/DURABLE TPS FOR MINIMUM COST AND QUICK TURNAROUND
- DURABILITY FOR WIND/RAIN AND SERVICING OPERATIONS IS REQUIRED
- MECHANICALLY ATTACHABLE TPS CAN PROVIDE ACCESS FOR INSPECTION AND REPLACEMENT
- TPS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE DOES NOT EXIST

RECOMMENDED ACTIONS:

- CONTINUE DEVELOPMENT OF DURABLE BOND-ON CERAMIC TILES
- CONTINUE DEVELOPMENT OF DURABLE MECHANICALLY ATTACHABLE METALLIC AND CERAMIC DESIGNS
- DEVELOP HIGH TEMPERATURE ADHESIVES FOR BOND-ON DESIGNS
- DEVELOP SPECIFIC TPS DESIGNS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE INCLUDING HIGH STRENGTH & TEMPERATURE FOAM INSULATION- MAY INVOLVE GROUND PURGE SYSTEM
- DEMONSTRATE SUITABILITY OF DESIGNS BY FABRICATION AND TESTING TO APPROPRIATE WIND/RAIN, ACOUSTIC, AEROPRESSURE, THERMAL REQUIREMENTS

DESCRIPTION:

- UNPRESSURIZED Al-Li STRUCTURES (INTERSTAGES, THRUST STRUCTURES)
  - QUALIFY Al-Li FOR USE WITH UNPRESSURED VEHICLE AND STABILITY LIMITED STRUCTURES

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- MAJOR PORTIONS OF VEHICLE STRUCTURES ARE STABILITY LIMITED. THESE INCLUDE COMPRESSION AND BENDING LOADED STRUCTURES. Al-Li ALLOYS OFFER INCREASED IN SPECIFIC STIFFNESS OF 20-40% OVER CURRENT ALUMINUM ALLOYS, WITH THE POTENTIAL FOR CORRESPONDING WEIGHT SAVINGS IN THESE STRUCTURES

RECOMMENDED ACTIONS:

- FUND DEVELOPMENT AND TESTING OF DEMONSTRATION OF STABILITY LIMITED STRUCTURES (THRUST STRUCTURES, INTERTANK CONNECTORS, WING BOXES)
- COORDINATE WITH LOW COST MANUFACTURING AND NEAR NET SHAPE ACTIVITIES

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• NEAR NET SHAPE SECTIONS - EXTRUSIONS - FORGINGS	
BACKGROUND & RELATED FACTORS: • COST OF SCRAP METAL ON INTEGRALLY MACHINED HARDWARE IS NOT COST EFFECTIVE FOR NEWER METAL ALLOYS • RECENT ADVANCES IN ROLL FORGING AND INCREMENTAL FORGING OFFERS SIGNIFICANT MATERIAL COST AND PART COUNT REDUCTIONS FOR LAUNCH VEHICLES • PROCESS PARAMETERS NEED TO BE DEVELOPED FOR EACH NEW ALLOY	**RECOMMENDED ACTIONS:** • IDENTIFY CANDIDATE HARDWARE FOR LARGE EXTRUSIONS, ROLL AND INCREMENTAL FORGING PROCESSES • DEVELOP CANDIDATE HARDWARE TO DEMONSTRATE/VALIDATE FABRICATION TECHNOLOGY • GENERATE DESIGN ALLOWABLES

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• PRESSURIZED STRUCTURES	
BACKGROUND & RELATED FACTORS: • PRESSURIZED STRUCTURES COMMONLY USED AS CREW COMPARTMENTS ON SHUTTLE AND SPACE STATION ARE CURRENTLY FABRICATED FROM CONVENTIONAL MATERIALS. • NEW APPLICATIONS SUCH AS NASP, SSTO, AND MTVs WILL HAVE GREATER DEMANDS TO REDUCE WEIGHT WHILE BEING SUBJECTED TO HARSHER ENVIRONMENTS • ADVANCED MATERIALS SUCH AS Al-Li AND/OR COMPOSITES HAVE PROPERTIES CONDUCIVE TO THE ABOVE REQUIREMENTS. INTEGRAL SKIN AND STRINGER, SANDWICH PANELS, etc., ARE ALL DESIGNS WHERE THESE MATERIALS WOULD PROVE ADVANTAGEOUS	**RECOMMENDED ACTIONS:** • CONTINUE DEVELOPMENT OF DESIGN CRITERIA FOR THESE STRUCTURES • CONDUCT DEVELOPMENT TESTS TO DETERMINE THE APPLICABILITY OF THESE MATERIALS TO MEET THE REQUIREMENTS • DESIGN AND FABRICATE TEST ARTICLES TO VERIFY THE APPROACH

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- WELDING AND JOINING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING
- HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS
- LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES
- WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE
- AUTOMATION POTENTIALLY CAN REDUCE NDE

RECOMMENDED ACTIONS:

- IDENTIFY PROCESS VARIABLES RELATIONSHIPS
- DEVELOP PROCESS MODELS
- IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK
- IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE
- VERIFY AND VALIDATE PROCESSES AND CONTROLS
- DEVEOPMENT OF TELEROBOTIC CAPABILITY FOR ON-ORBIT REPAIR/MAINTENANCE/INSPECTION

DESCRIPTION:

- MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- THE THREAT TO SPACE VEHICLES FROM ORBITAL DEBRIS HAS BEEN RAPIDLY INCREASING
- CURRENT ALUMINUM DOUBLE-BUMPER SHIELDING IS VERY HEAVY AND NEWER SYSTEMS SUCH AS NEXTEL HAVE NOT BEEN QUALIFIED

RECOMMENDED ACTIONS:

- DEVELOP AND QUALIFY LIGHTWEIGHT SHIELDS AND ATTACHMENT TECHNIQUES
- CONDUCT A PROGRAM TO EVALUATE LIGHTWEIGHT SHIELDING DESIGNS TO MEET THE THREAT REQUIREMENTS.
- ESTABLISH AND VERIFY ANALYTICAL MODELS. GOAL IS TO MINIMIZE SECONDARY EJECT AS WELL AS DEVELOP AND QUALIFY AN ULTRA-LIGHTWEIGHT SHIELDING DESIGN

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• STATE-OF-THE-ART SHELL BUCKLING STRUCTURE OPTIMIZER PROGRAM TO SERVE AS A RAPID DESIGN TOOL	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CURRENT EMPHASIS ON DEVELOPMENT OF LARGE COMPLICATED FINITE ELEMENT PROGRAMS SUITED TO DETAILED ANALYSIS, NOT DESIGN OPTIMIZATION • AVAILABLE CODES ARE OUT OF DATE, NOT COMPREHENSIVE AND USER UNFRIENDLY • WILL IMPROVE THE QUALITY AND SPEED OF BOTH PRELIMINARY DESIGN AND DETAILED DESIGN	• PROVIDE FOLLOWING FEATURES - MACINTOSH OR WINDOWS USER INTERFACE WITH GRAPHIC DISPLAYS AND PULL-DOWN MENUS - SIMPLE USER FORMAT DESIGNED FOR USE BY BOTH DESIGN AND ANALYSIS DISCIPLINES - COMPLETE LIBRARY OF STIFFENED SHELL CONFIGURATIONS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• TEST PHILOSOPHY - RESTRICT STRUCTURAL TEST TO A LOAD FACTOR THAT ALLOWS ALTERNATE USAGES OF EXPENSIVE HARDWARE - NO TEST FACTOR	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• HARDWARE HAS BEEN TESTED TO DESTRUCTION OR YIELD TO THE POINT WHERE IT IS UNUSABLE FOR OTHER APPLICATIONS • STRUCTURES OF ADVANCED MATERIALS PRESENT SIGNIFICANT COST TO PROGRAMS • "NO TEST FACTOR" MAY BE USED AS AN ALTERNATE WHERE WEIGHT MAY NOT BE CRITICAL	• DEVELOP A TEST CODE THAT RESTRICTS TEST TO LOADS WHICH MAXIMIZE THE STRUCTURES "REUSABILITY." INDEPENDENT TESTS SHOULD BE CONDUCTED THAT ALLOW FOR DATA EXTRAPOLATION FROM THE LOWER LEADS TO QUALIFY HARDWARE

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• REDUCED LOAD CYCLE TIME	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• LONG TURNAROUND TIME LOAD CYCLES GREATLY INCREASES COST AND RESTRICTS IMPLEMENTATION OF NEEDED CHANGES • LOAD CYCLE COSTS ARE EXCESSIVE	• PROVIDE AN INTERDISCIPLINARY LOADS ANALYSIS TOOL THAT OUTPUTS LOADS AND STRESS INSTEAD OF SEQUENTIAL LOADS AND STRESS ANALYSIS • DEVELOP MODEL SYNTHESIS TECHNIQUES TO REDUCE MODEL DEVELOPMENT • DEVELOP AN OPTIMIZED CODE TO REDUCE COMPUTER COST

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• STRUCTURAL ANALYSIS METHODS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CURRENT ANALYSIS METHODS INVOLVE ANALYSIS BEING CONDUCTED BY ISOLATED GROUPS AND DISTRIBUTING RESULTS TO NEXT GROUP IN A SERIAL FASHION • ITERATIONS ARE LONG AND LABORIOUS • ANALYTICAL METHODS, PARTICULARLY IN THE AREA OF STABILITY KNOCK-DOWN FACTORS, SHOULD BE REVIEWED, UPDATED AS NECESSARY AND FORMALIZED	• DEVELOP ELECTRONICALLY-INTERFACED,SELF-CHECKING, AERODYNAMIC, THERMODYNAMIC, DYNAMIC & STRESS ANALYSIS TOOLS THAT ALLOW RAPID ITERATION AND APPLY THE BENEFITS OF CONCURRENT ENGINEERING • REVIEW AVAILABLE DOCUMENTATION ON STABILITY ANALYSIS DERIVING CONCURRENCE ON KNOCK DOWN FACTORS TO BE USED IN ABOVE ANALYSIS • TEST AS REQUIRED

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- OPTIMIZATION OF STRUCTURAL CRITERIA

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- CURRENT STRUCTURAL CRITERIA DOES NOT ALLOW ASSESSMENT OF VEHICLE RISK AS RELATED TO LOAD VARIABILITY, SUBSYSTEM REDUNDANCY AND FACTOR OF SAFETY
- LACK OF SIMPLE PROBABILISTIC APPROACH TO RISK ASSESSMENT STIFLES EXAMINATION OF REQUIRED FACTOR OF SAFETY TO MEET PROGRAM OBJECTIVES
- CURRENT APPROACH IS TO USE F.S. $\geq$ 1.25 FOR UNMANNED AND F.S. $\geq$ 1.4 FOR MANNED SYSTEMS

RECOMMENDED ACTIONS:

- DEVELOP SIMPLE PROBABILISTIC APPROACH WITH NECESSARY DATA TO DERIVE AND JUSTIFY STRUCTURAL CRITERIA
- DEVELOP ANALYSIS TOOLS TO IMPLEMENT STRUCTURAL RELIABILITY APPROACH AND SELECTION OF FACTORS OF SAFETY

DESCRIPTION:

- DEVELOP AN ENGINEERING APPROACH TO PROPERLY TRADE MATERIAL AND STRUCTURAL CONCEPTS SELECTION, FABRICATION, FACILITIES, AND COST (TOTAL COST)

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- STRUCTURAL SIMPLICITY REDUCES ASSEMBLY COST AND OPERATIONAL COST
- PROCESSING CAN INCREASE COST, MR HARDWARE, AND LOWER MARGINS (SENSITIVITIES)
- TOTAL COST IS THE DRIVER, NOT JUST WEIGHT
- SEQUENTIAL ENGINEERING IS COSTLY
- SEQUENTIAL ENGINEERING TENDS TO HIDE SENSITIVITIES AND PROPER TRADES

RECOMMENDED ACTIONS:

- DEVELOP CONCURRENT ENGINEERING TOOLS (ALL DISCIPLINES) THAT PROPERLY TRADE BETWEEN MATERIAL, STRUCTURAL CONCEPT, FABRICATING FACILITIES, PERFORMANCE, AND OPERATION
- DEVELOP OPTIMIZATION CRITERIA FOR TOTAL COST

7.2 PROPULSION SYSTEMS PANEL

7.2.1 Final Presentation