N93-22095

VEHICLE SYSTEMS

CO-CHAIRMAN

TOM BALES

TOM MODLIN

RAPPORTEURS

JACK SUDDRETH

TOM WHEELER

VEHICLE SYSTEMS PANEL

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

SUBPANEL REPORT

THOMAS BALES
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. VAN SICLIN	LTV
R. DROPEK	HERCULES
J. WADSWORTH	LOCKHEED
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D. SCHMIDT	ALCOA
J. SUDDRETH (SRS)	RAPPORTEUR

REUSABLE VEHICLES

T. MODLIN - JSC

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R. RYAN	MSFC
R. EHERT	ROCKWELL
R. JEWELL	MSFC
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J. SHULTZ	BOEING
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D. JOHNSON	LTV
R. STEWART	MDSS
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

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• ADVANCED STRUCTURAL MATERIALS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• 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	• 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

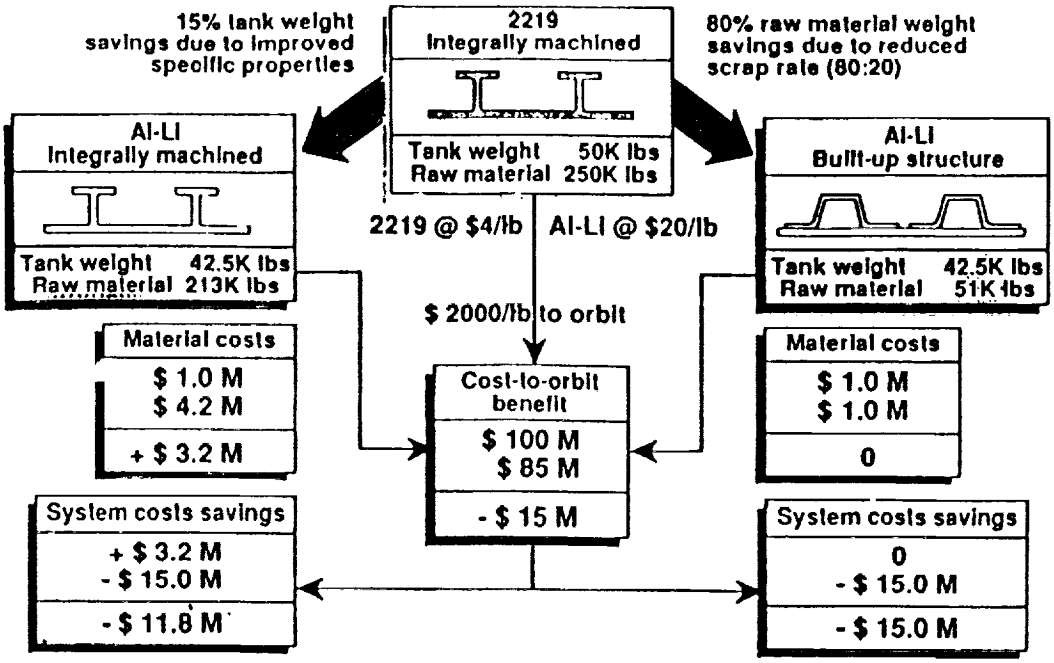
DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CURRENT VEHICLE SYSTEM STRUCTURES EMPLOY CONVENTIONAL MATERIALS AND FABRICATION TECHNOLOGY • RESULTANT STRUCTURES ARE TYPICALLY HIGH 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	• 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

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

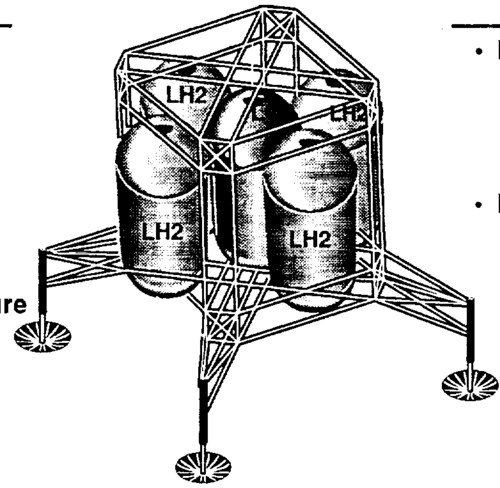
RECOMMENDED ACTIONS:

- 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: • DAMAGE TOLERANT DESIGN FOR COMPOSITE STRUCTURES	**MILESTONES & RESOURCE REQUIREMENTS:** • PUBLISH DAMAGE TOLERANT DESIGN DATA BOOK FOR COMPOSITE STRUCTURE
BACKGROUND & RELATED FACTORS: • 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	**RECOMMENDED ACTIONS:** • 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: • OPTIMIZED SYSTEM ENGINEERING APPROACH TO ENSURE ROBUSTNESS	**MILESTONES & RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • 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	**RECOMMENDED ACTIONS:** • 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: • 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.	**RECOMMENDED ACTIONS:** • 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

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

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- CRYOGENIC TANKAGE
  - QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID OXYGEN

MILESTONES AND RESOURCE REQUIREMENTS:

- DEMONSTRATE THE ABILITY TO MEET SAFETY REQUIREMENTS
  - FEASIBILITY PROGRAM $500K

BACKGROUND & RELATED FACTORS:

- 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.

RECOMMENDED ACTIONS:

- 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:

- LAUNCH VEHICLE TPS/INSULATION

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- 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

RECOMMENDED ACTIONS:

- 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

REUSABLE VEHICLES SUBPANEL

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:	MILESTONES AND RESOURCE REQUIREMENTS:
• WELDING AND JOINING - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• 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	• 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:	MILESTONES AND RESOURCE REQUIREMENTS:
• MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• 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	• 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

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

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

VEHICLE SYSTEMS PANEL

DESCRIPTION: • REDUCED LOAD CYCLE TIME	**MILESTONES AND RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • LONG TURNAROUND TIME LOAD CYCLES GREATLY INCREASES COST AND RESTRICTS IMPLEMENTATION OF NEEDED CHANGES • LOAD CYCLE COSTS ARE EXCESSIVE	**RECOMMENDED ACTIONS:** • 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: • STRUCTURAL ANALYSIS METHODS	**MILESTONES AND RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • 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	**RECOMMENDED ACTIONS:** • 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

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• OPTIMIZATION OF STRUCTURAL CRITERIA	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• 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	• 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:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOP AN ENGINEERING APPROACH TO PROPERLY TRADE MATERIAL AND STRUCTURAL CONCEPTS SELECTION, FABRICATION, FACILITIES, AND COST (TOTAL COST)	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• 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	• 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