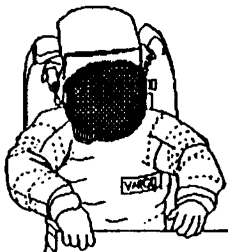
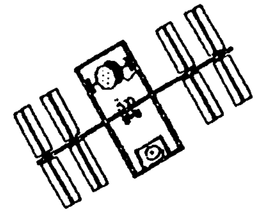
ON-ORBIT ASSEMBLY TASK DEFINITION STUDY





SPACE STATION EVOLUTION SYMPOSIUM

MCDONNELL DOUGLAS SPACE SYSTEMS COMPANY
KENNEDY SPACE CENTER

ADVANCED PRODUCT DEVELOPMENT

8 FEBRUARY 1990

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McDonnell Douglas Space Systems Company at Kennedy Space Center (MDSSC-KSC) has been tasked since November 1987 to provide support to the Space Station Evolution Working Group (EWG) based at NASA's Langley Research Center (LaRC). Work in the first year of this study included extensive data gathering and the development of study methodologies. The OEXP case studies as summarized in NASA Technical Memorandum 4075, Exploration Studies Technical Report FY 1988 Status, and NASA Document Z-2.1-002, Study Requirements Document FY 1989 Studies (SRD), define the mission scenarios and technical requirements which MSFC engineers and their contractors (Martin Marietta and Boeing) utilized in their design of exploration vehicles. LaRC selected case studies and vehicle designs upon which the study team performed processing analyses. An on-orbit SSF refurbishment crew of four dedicated to OEXP vehicle processing was baselined for all studies. In some instances, LaRC modified the vehicle designs, launch manifests, or mission scenarios provided by MSFC to obtain specific data from the processing analyses. The results from the following case studies analyzed during 1989 are provided in this report: Phobos Gateway On-Orbit Assembly and Launch, Lunar Evolution Vehicle On-Orbit Refurbishment, and Mars Mission Vehicle On-Orbit Assembly and Launch. In addition, a concept for facility accommodations at Space Station Freedom (SSF) was developed and support equipment to be provided at the facility was defined.

In support of the MSFC Launch/On-Orbit Processing (LOOP) study, LaRC asked us to assess ground and on-orbit processing impacts resulting from launching the OEXP vehicles on several different ETO launch vehicles.

Results developed by this study, including processing tasks and times, and personnel and equipment requirements, will be entered into the VPOD data base. VPOD will be used by LaRC to analyze future OEXP vehicles configurations, SSF facility and resource impacts, and life cycle cost predictions.

OBJECTIVES

- THE OBJECTIVES OF THE ON-ORBIT ASSEMBLY/SERVICING TASK DEFINITION STUDY ARE TO:
  - APPLY THE SPACE VEHICLE PROCESSING EXPERIENCE AND KNOWLEDGE RESIDENT AT KSC TO SSF ON-ORBIT PROCESSING (ASSEMBLY, TESTING, REFURBISHMENT, AND REFLIGHT),
  - DEVELOP GROUND AND ON-ORBIT PROCESSING TASK FLOWS BASED ON QUANTIFIABLE GROUND ANALOGIES,
  - IDENTIFY REQUIRED FACILITIES AND EQUIPMENT AND THE RESULTING SSF IMPACTS,
  - DETERMINE IMPACTS ON KSC FACILITIES TO ACCOMMODATE VEHICLE GROUND PROCESSING,
  - MAKE RECOMMENDATIONS CONCERNING VEHICLE AND FACILITY DESIGNS TO ENHANCE VEHICLE PROCESSING EFFICIENCY AND REDUCE OPERATIONAL COSTS,
  - INCORPORATE DATA GENERATED BY THIS STUDY INTO LaRC's VEHICLE PROCESSING OPERATIONS DATA BASE (VPOD).

A KSC data base of procedures and processing flows from Shuttle, Spacelab, Delta, Centaur, and Apollo/Saturn programs was used to determine the tasks, timelines, manpower, resources, and facilities necessary to process OEXP vehicles both on the ground at KSC and on orbit at Space Station Freedom. These ground assembly, refurbishment, test, checkout, and launch procedures contain schedules, manpower, and support equipment requirements. The most appropriate analogy was selected for each OEXP vehicle element and task from this KSC data base. Additionally, the study team conducted detailed technical interviews with the NASA and contractor systems engineers and technicians who are currently processing space vehicle flight hardware at KSC. Frequent telecons with the OEXP vehicle design engineers help determine system design details and processing requirements. Only those tasks which by necessity must be performed on-orbit due to the payload mass and volume restrictions of the ETO launch vehicle were incorporated. All other tasks were baselined for accomplishment on the ground prior to ETO launch. Once the tasks necessary to accomplish the mission were determined, they were organized into logical processing flows. Transition tables, the "building blocks" used to construct processing flows, were generated as accounting tools used to derive on-orbit times and manhours from the analogous ground tasks. Ground serial times are limited by personnel access to the hardware, whereas on-orbit serial times are determined by manpower and resource limitations. Labor intensive hands-on assembly task times have been adjusted to accommodate the limitation of using only two EVA crew members at a time. The Lunar/Mars flight crews were used to assist in stowing equipment during vehicle closeout. Transition tables also reference the KSC procedures used for analogy, which is either an Operations/Maintenance Instruction (OMI) for Shuttle/Spacelab, or a Launch Preparation Document (LPD) for the Delta Launch Vehicle.

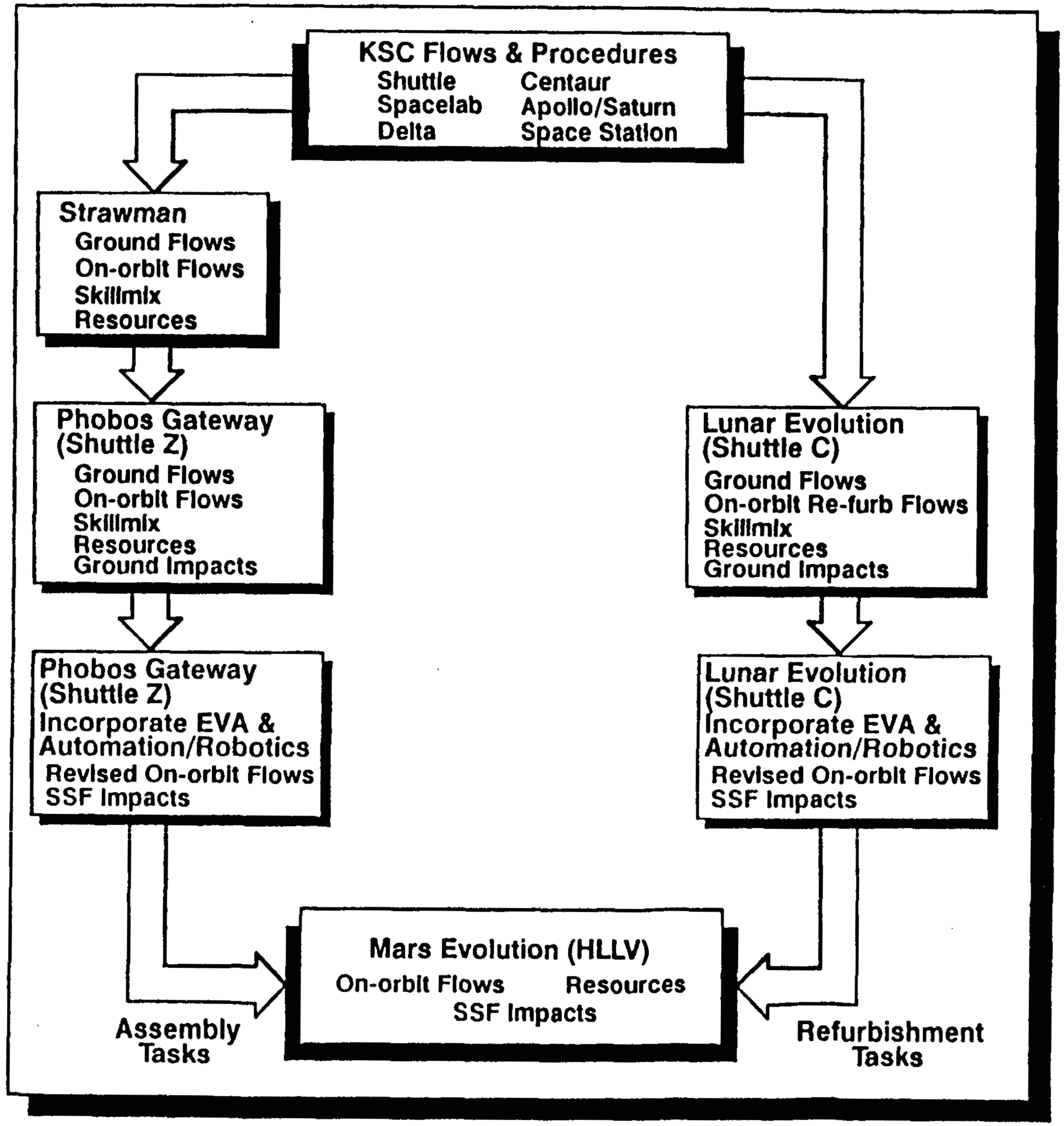
The study team developed a "Strawman" vehicle as a conceptual tool to assist in the transfer of KSC space vehicle processing experience to the performance of equivalent tasks on-orbit at SSF. This "Strawman" vehicle consisted of a crew module (similar to a Spacelab or Space Station pressurized module), a manned lander module, a four segment aerobrake, and two cryogenic propulsion stages (similar to the Centaur upper stage). A processing concept and flow to assemble, checkout, service, and launch this "Strawman" vehicle from KSC was developed from our data base. This imaginary vehicle was then transitioned to SSF for analogous on-orbit processing.

The Phobos Gateway vehicle was the first one selected by LaRC for analysis. This vehicle was compared to the "Strawman" vehicle for similarities, and the appropriate "Strawman" transition tables and assembly flows were transferred to the Phobos Gateway analysis. Where differences existed, the KSC data base was revisited for new analogies.

For the Lunar Evolution case study, LaRC directed that a *refurbishment/turnaround analysis* of the *Lunar Piloted Vehicle* (LPV) and Lunar Cargo Vehicles (LCV) at SSF be performed. The LPV and LCV designs were compared to the Shuttle and Spacelab, as they are the only space vehicles for which refurbishment data exist.

The Mars Mission Vehicle had a high degree of commonality with elements of the Phobos Gateway and Lunar Piloted Vehicles, and processing operations were derived from them. This Mars vehicle assembly flow was submitted to MDSSC-JSC for review and incorporation of accurate EVA/RMS operations times. Additional iterations to these flows to incorporate realistic EVA/RMS times and automation/robotics technology enhancements are planned.

Approach


KSC Flows & Procedures
Shuttle
Spacelab
Delta
Centaur
Apollo/Saturn
Space Station
Strawman
Ground Flows
On-orbit Flows
Skillmix
Resources
Phobos Gateway (Shuttle Z)
Ground Flows
On-orbit Flows
Skillmix
Resources
Ground Impacts
Phobos Gateway (Shuttle Z)
Incorporate EVA & Automation/Robotics
Revised On-orbit Flows
SSF Impacts
Lunar Evolution (Shuttle C)
Ground Flows
On-orbit Re-furb Flows
Skillmix
Resources
Ground Impacts
Lunar Evolution (Shuttle C)
Incorporate EVA & Automation/Robotics
Revised On-orbit Flows
SSF Impacts
Mars Evolution (HLLV)
On-orbit Flows
Resources
SSF Impacts
Assembly Tasks
Refurbishment Tasks

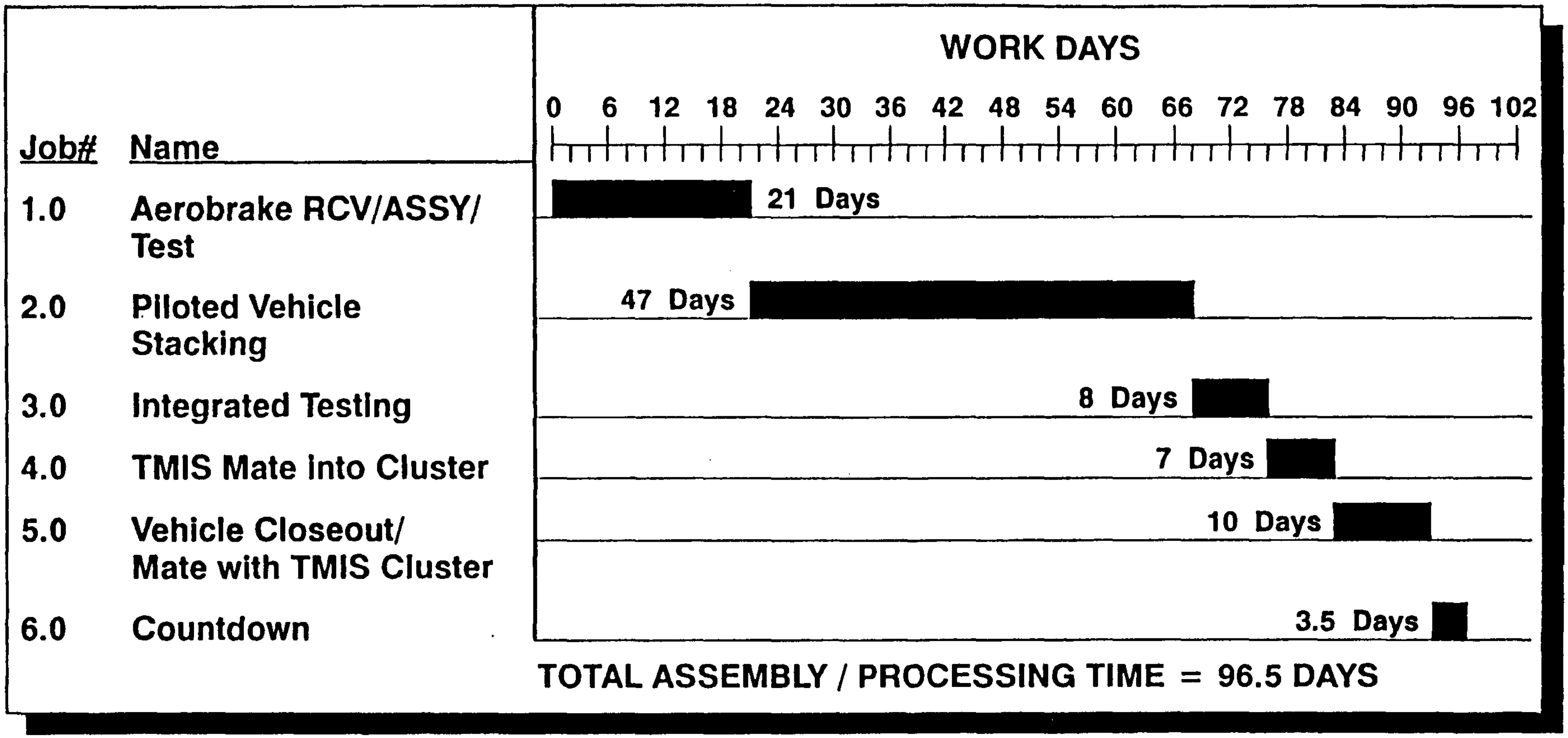
The Phobos Gateway vehicle analyzed was designed by Martin Marietta Aerospace. Three Shuttle-Z ETO vehicles launch the piloted vehicle components, which are assembled on a lower keel platform of SSF. All vehicle elements are delivered to SSF in time to support continuous assembly of the vehicle. All hypergolic propellant loading and ordnance installation occurs on the ground. The Trans-Mars Injection System (TMIS) stages and propellant are placed in LEO by three additional Shuttle-Z launches, and are clustered remotely at the co-orbiting Cryogenic Propellant Depot (CPD). An advanced Orbital Maneuvering Vehicle (OMV) brings the assembled piloted vehicle to the CPD for mating with the TMIS cluster, and for Trans-Earth Injection System (TEIS) cryogenic propellant loading. The fully integrated and fueled vehicle is then deployed for the trans-Mars injection burn. This launch manifesting was determined by LaRC.

The overall Phobos Gateway vehicle on-orbit processing flow is shown. Total assembly/processing time is 96.5 days (8 hours work shifts). Times shown are "KSC ground equivalent" times and do not incorporate EVA/RMS and automation or robotics enhancements.

KSC analogies used for Phobos Gateway processing, with rationale, include:

o Aerobrake assembly = Spacelab Instrument Pointing System installation (extensive crane, positioning, and bolting operations)
o Aerobrake Thermal Protection System (TPS) = Shuttle TPS (closeout panels with pre-installed thermal tiles)
o Mars Descent Vehicle (MDV) = Delta 2nd stage (hypergolic propellant propulsion stage) with aerobrake and Apollo rover
o Phobos Excursion Vehicle (PHEV) = Apollo Lunar Module, Spacelab pressurized module, and Delta 2nd stage (manned cabin with hypergolic propulsion)
o Trans Earth Injections System (TEIS) = Centaur and Delta 1st stage (cryogenic propulsion stage)
o Mars Orbit Operations System (MOOS) = Shuttle Orbital Maneuvering System (hypergolic propulsion pod including engines and tanks)
o Habitat module = Spacelab pressurized module (similar configuration, function, and life support systems)
o Reaction Control System (RCS) = Shuttle Orbital Maneuvering System (same as MOOS)
o Earth Capture Crew Vehicle (ECCV) = Apollo Command Module and PHEV (manned re-entry vehicle with hypergols and life support)
o Trans Mars Injection System (TMIS) = Centaur and Delta 1st stage (cryogenic propulsion stage).

Phobos Gateway
Overall On-orbit Processing Flow



The Lunar Piloted Vehicle and the Lunar Cargo Vehicle were designed by Martin Marietta. These vehicles are identical, except that the eight-man crew module is replaced on the LCV by an unmanned cargo element. The fully assembled and fueled vehicles are placed in LEO by a Shuttle-C ETO Launch Vehicle. The Space Shuttle orbiter is an ideal analogy since its flight crew systems, consumables, crew size, and mission duration are similar to the LPV. Some Shuttle tasks, such as hydraulic and auxiliary power unit servicing, have been deleted as the planned LPV does not utilize such systems and components.

Postflight deservicing begins when the LPV returns to the SSF from a Lunar mission. A self-diagnostic health check will be performed on all vehicle systems, and a visual inspection will be performed before the vehicle enters the SSF hangar. An advanced OMV will bring the vehicle within grappling range of one of the hangar's manipulator arms. After berthing in the hangar, the vehicle will be connected and switched to SSF facility power, life support, communications, and data system. The flight crew will egress, and residual propellants will be drained. Perishables, scientific results, and waste will be removed from the crew module. Inspections will be performed to document post-flight damage and vehicle condition.

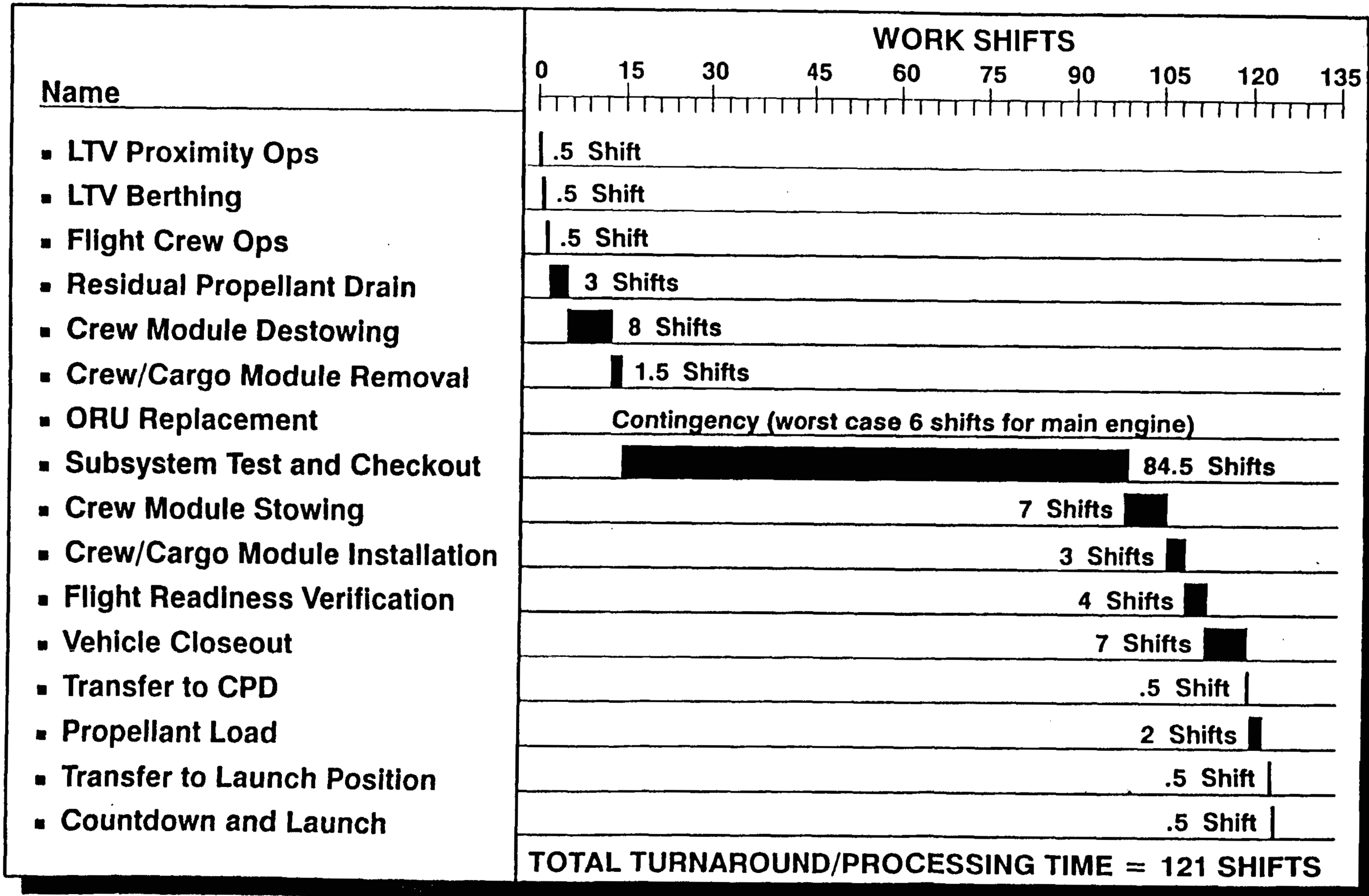
Refurbishment, retest, and closeout operations are then accomplished. Orbital Replacement Unit (ORU) tasks were based on similar Shuttle line replaceable unit (LRU) requirements. The aerobrake is replaced after every five missions. Thermal protection system (TPS) repair is performed "as needed" between aerobrake replacements. Shuttle TPS damage for a typical mission (less launch and landing damage) was used to estimate the number of tile and fabric repairs for each aerobrake use. Tile cavity damage is repaired using the fill-in/spray-on ablative repair kit developed by Martin Marietta for Shuttle in-space use. Refurbishment of the LPV/LCV propulsion system will consist of extensive post-flight inspections, followed by electrical checkout, engine servicing, and leak and functional checkout. The shuttle propulsion analogies used were the Space Shuttle Main Engine (SSME), External Tank (ET), Power Reactant Storage and Distribution (PRSD) tanks, and the Reaction Control System (RCS). Crew module refurbishment required 54.5 shifts. The crew module waste management system is serviceable (drain and flush) in place. LPV windows were chosen to be similar to the electrically heated Apollo/Skylab type windows, eliminating the extensive dissicant replacement operations on the Shuttle windows. Replacement of the crew consumables is done by changeout of lockers and prepacks. EVA suits will be exchanged on an "as-used" basis. Spacelab pressurized module installation and mate with the Shuttle orbiter (including associated electrical and fluid connections) was used as the analogy for mating either a cargo module or a crew module with the Lunar transfer vehicle.

Following ORU replacement and subsystem test and checkout, integrated testing will be performed on the entire Lunar transfer vehicle. Included in this verification phase is flight software load, a countdown demonstration test, and a flight simulation test in which critical portions of the mission sequence are simulated to verify functional integrity of vehicle systems. During vehicle closeout, fluids and gases will be topped off, final crew equipment will be stowed, SSF umbilicals will be disconnected from the vehicle, and final inspection and closeout photography will be performed. Flight crew ingress will occur, and the vehicle will be powered up and switched to on- board system.

Cryogenic propellant depot (CPD) and launch operations begin with the docking of an advanced OMV to the vehicle, followed by transfer to the CPD. Shuttle External Tank propellant load and countdown was used as the analogy for this section of the ops concept.

The overall generic timeline for Lunar vehicle tunaround of 121 shifts incorporates parallel operations where feasible. (Non-parallel, serial operations resulted in a total turnaround time of 173.5 shifts). All Lunar vehicle processing times are "KSC ground equivalent" times and do not have EVA and automation enhancements yet incorporated.

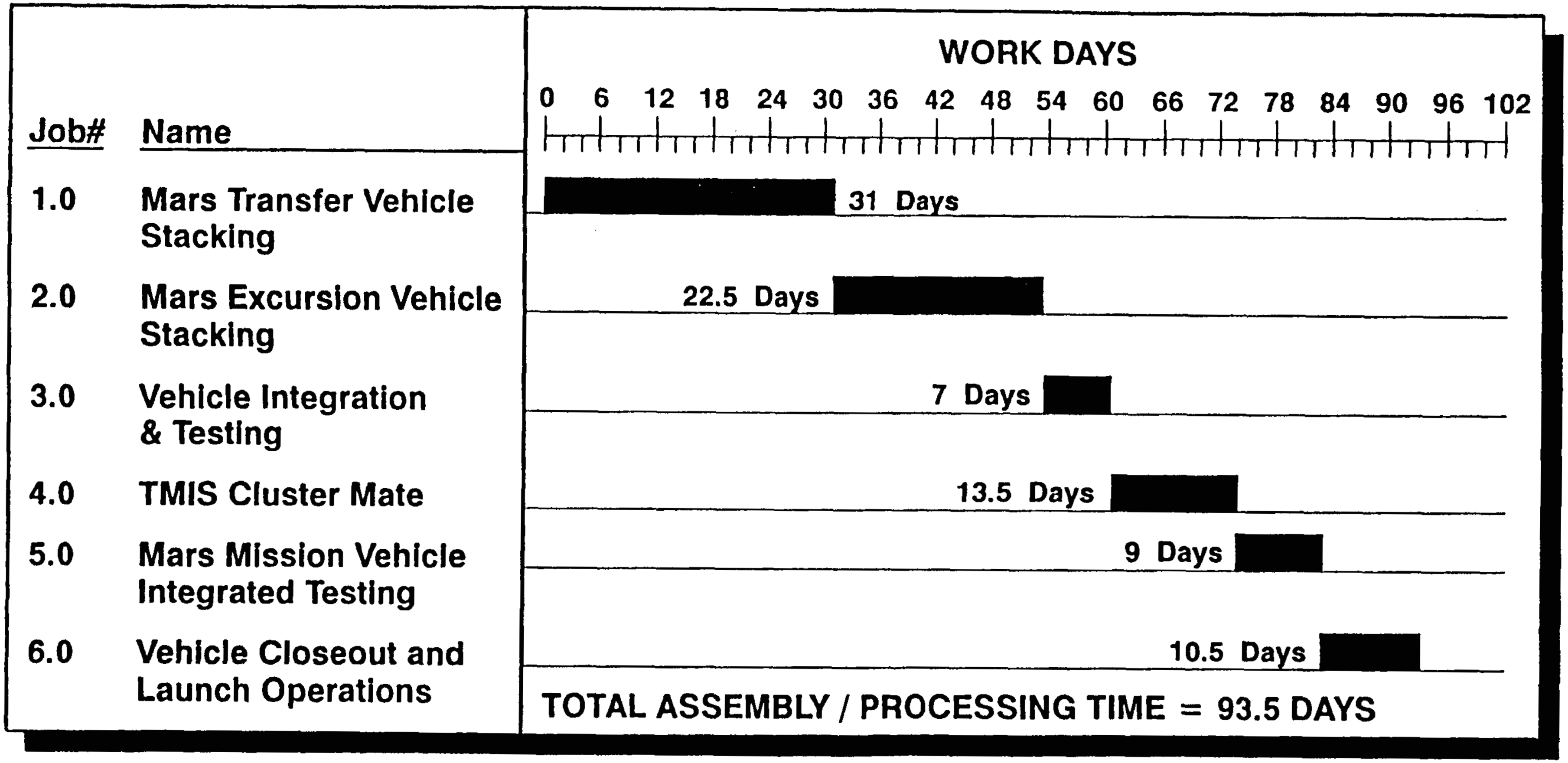
LPV/LCV Overall On-orbit Turnaround Flow



The Mars Mission vehicle on which an assembly analysis was performed was designed by Boeing Aerospace. The piloted vehicle consists of the Mars Transfer Vehicle (MTV), which houses the crew in a zero gravity mode during transit, attached by four manipulator arms to the Mars Excursion Vehicle (MEV), which lands on the Martian surface. The TEIS and MEV descent/ascent hydrogen and oxygen tanks are launched wet from Earth, but require top-off before trans-Mars injection. The TMIS core stage (with five integrated engines) and three strap-on tank sets arrive on orbit fueled, and do not require top-off due to the short dwell time prior to use.

The overall Mars mission on-orbit assembly flow shown was derived from previously generated Phobos Gateway assembly and Lunar Evolution refurbishment results. Aerobrake assembly, included in both the MTV and MEV stackings, was shortened due to a two segment aerobrake being used instead of the four segment Phobos Gateway aerobrake. TMIS clustering times were adjusted to reflect the core stage with three strap-on tank set configuration. The Mars mission assembly timelines are the first study results to incorporate realistic EVA and RMS operations enhancements. These timelines also incorporate Boeing-accepted, MDSSC-KSC study team design recommendations. The overall on-orbit processing time of 93.5 days reflects a time savings of 46% over the initial processing timeline.

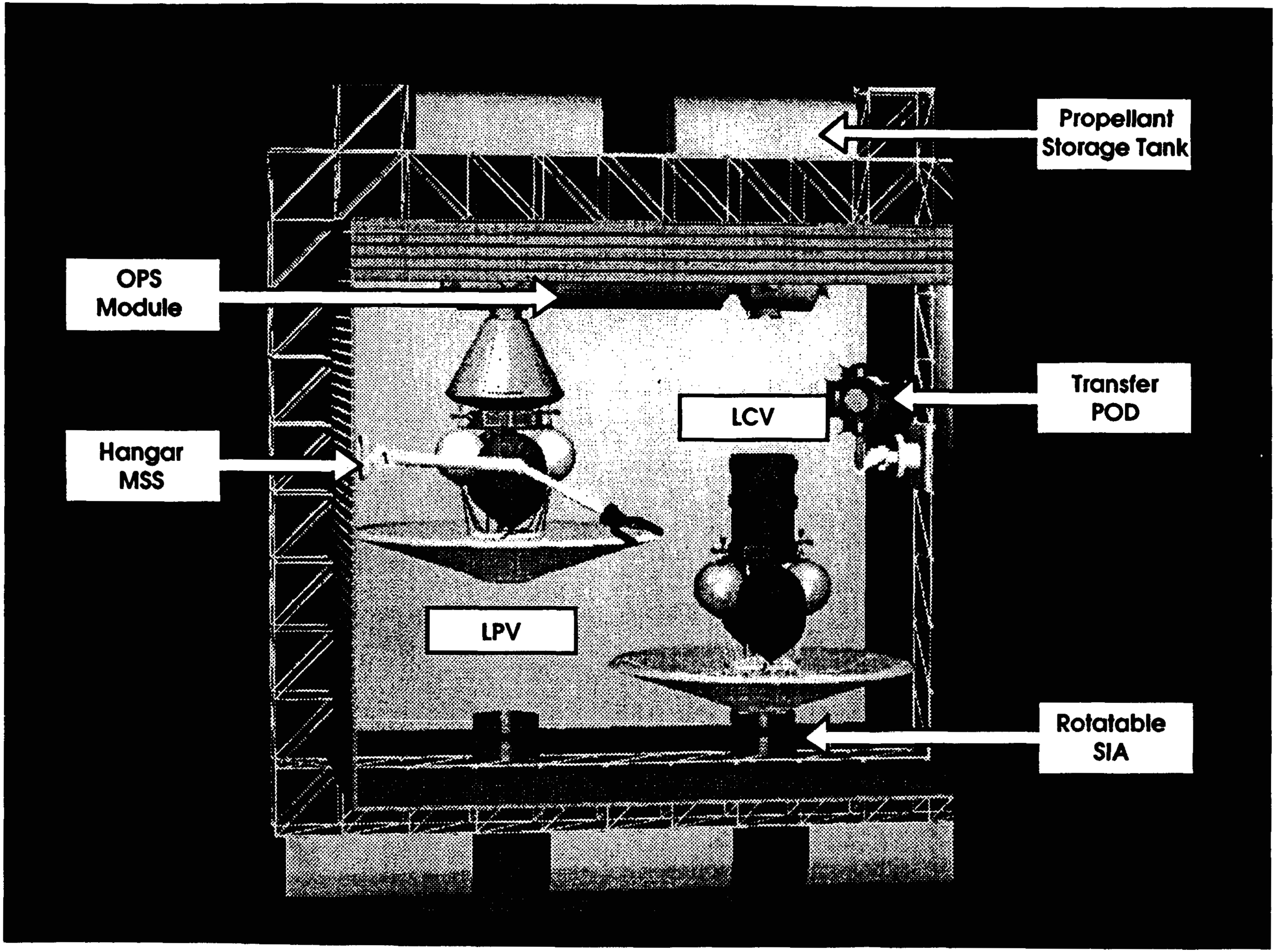
Mars Mission
Overall On-orbit Assembly Flow



In order to support LaRC in their providing input to Section 3.10 (Evolution) of the Space Station Program Requirements Document, the study team was tasked with generating a list of "hooks and scars" to the assembly complete station which would enable it to evolve into an OEXP transportation node. For the purpose of determining "worst case" impacts to SSF, all vehicle processing operations, including cryogenic propellant loading, were baselined as taking place at SSF. An additional requirement was that the "hooks and scars" must encompass either Mars vehicle processing or parallel processing of two Lunar vehicles. The SRD also stated that meteroid/debris protection was required for the Lunar vehicles while at SSF.

This dual mission processing facility, configured for Lunar vehicle refurbishment is shown. The lower keel location was determined by previous LaRC studies to be the site with least impact to the SSF stability, control, and microgravity requirements. Cryogenic propellant storage tanks are shown around the perimeter of the hangar.

SSF Processing Hangar



The procesing hangar will provide vehicle storage, power, cooling, and fluids servicing. Two Mobile Service Stations (MSS) are provided for simultaneous telerobotic processing of two vehicles. Vehicles can be berthed to rotatable Station Interface Adapters (SIA), which simplify MSS access for vehicle inspection and servicing. An airlock and crew transfer pod are used to transfer crew members and equipment between the ops module and the OEXP vehicles without having to perform EVA.

SSF Processing
Hangar Requirements

- Hangar bay (120 ft x 120 ft x 90 ft) – dual bays (Lunar Evolution) or single bay (Mars Evolution) configuration to support on-orbit assembly, testing and servicing
- Hangar utility tray pop-up interfaces at port-starboard locations
- Two mobile service systems (MSSs) which can translate up/down or across Hangar area
- Meteoroid/debris shield to protect OEXP vehicles and EVA crew
- Hazard monitoring system in hangar bay (hypergols, hydrogen, ammonia, & radiation)
- Storage provisions for equipment, tools, and ORUs
- Fixed area lighting and video cameras
- Fire detection and suppression
- Propellant storage and transfer (113 tons of cryogens and 12.4 tons of hypergols based on Cycle 2 OEXP vehicle specs, April '89)

Extensive effort was expended to define OEXP vehicle interface requirements at the processing hangar, truss interfaces, station modules, and OEXP vehicle umbilicals. Resource requirements were identified from known OEXP vehicle specifications and SSF system designs. Projected vehicle interfaces were compared to Space Station Program Office Architectural Control Documents, baseline configuration documents, and functions, power, and weight data books. Associated "hooks and scars" which reflect SSF evolutionary requirements that should be incorporated into the assembly complete station, are provided.

SSF "Hooks & Scars" to Accommodate Hangar

SYSTEM	SCARS	QUANTIFICATION	REFERENCE
GN&C, Structure & Propulsion	CMG truss strength/stiffness & attach points for hangar, MSC's, and propellant storage add thrusters/propellant	As required to maintain SSF stability/reboost with 999-ton vehicle and 170-ton facility attached	OXEP vehicle specs April '89 Mars Evolution Mission 2
Fluids/Gasses	Gaseous nitrogen stub (1 port, 1 starboard bay), water stub (1 port, 1 starboard bay), gaseous Helium system (1 port, 1 starboard bay)	78,270 cubic feet, 116 gallons, 36,063 cubic feet	STS ET scaled down STS closeout equivalent STS ET scaled down
Environmental Control Life Support System	2 fire detection/supression stubs (1 port, 1 starboard bay)		
Electrical Power (EPS)	2 120V dc stubs (1 for port, 1 for starboard bay)	33.8 KW nominal max to each bay (46,5 KW total peak for both bays–integrated testing not performed in parallel)	22 KW vehicle power based on Apollo, Spacelab, and Viking analogies + 6.5 KW hangar support power + 85% conversion efficiency (Phobos Gateway integrated testing)
Thermal Control System (TCS)	2 ammonia LOOP scars (1 for port, 1 for starboard bay)	35.5 kw heat rejection for each bay (48.8 KW peak for both bays)	105% of electrical load

The basic dual bay hangar facility includes a pressurized operations module, which functions as the monitor and control center for all vehicle processing and testing. It includes a node with cupola and RMS control station, and is located within the processing hangar to allow close proximity access and unobstructed visual line of sight to the OEXP vehicles. A pressurized "pocket lab" is recommended to permit shirt sleeve maintenance on items requiring frequent service. Nodes are used for vehicle berthing and logistic resupply of the vehicles.

SSF Processing Operations
Module Requirements

OPERATIONS MODULE WITH ATTACHED NODE, CUPOLA, AIRLOCK, AND CREW TRANSFER POD

Provide structural and utility interfaces on the Phase 1 station as a provision for a pressurized operations module to include a node, cupola, and airlock remote from all other pressurized modules and integrated to an assembly hangar to be located on the growth station.

JUSTIFICATION

- Operations module will provide a crew support station dedicated to support unique mission operations and equipment necessary to assemble, test, and refurbish OEXP vehicles and serves as an operations control center. This station includes an IVA workstation, MPAC, ATE/BITE, and Maintenance Support station.
- Cupola is in direct view of assembly area and includes an EVA/RMS Control workstation to facilitate EVA and RMS operations.
- Airlock will store EVA equipment and provide Egress/Ingress for a 4-man EVA crew.
- Crew transfer pod is a modified airlock to provide pressurized crew transfer between SSF modules, operations module, and OEXP crew cabins via RMS.

Operations module " hooks and scars" which reflect SSF evolutionary requirements that should be incorporated into the assembly complete station are provided. Additionally, living accommodations for the assembly/refurbishment work crews will be required.

SSF "Hooks & Scars" to Accommodate Ops Module

SYSTEM	SCARS	QUANTIFICATION	REFERENCE
Electrical Power (EPS)	1 DC 120V stub	8.5 KW nominal	W.P. 1
Thermal Control System (TCS)	1 ammonia LOOP stub	9.0 KW heat rejection	105% of electrical load
Data Management System (DMS)	1 DMS optical stub, 1 timing stub	39.04 MBPS	Mars piloted vehicle specs, June '89 MMC
Communications and Tracking	1 audio stub, 1 video stub, 1 control & monitoring stub, 1 caution & warning stub, 1 state vector stub	13.4 MBPS, 4.75 MBPS	Mars piloted vehicle specs, June '89 MMC
Structure	Attachment for OPS module with node, cupola, & airlock		
Environmental Control Life Support System	Oxygen stub, Nitrogen stub, water stub, water recover stub, fire detection/ suppression stubs	As required to support OPS module with node, cupola, & airlock	W.P.1

In support of a "Skunk Works" request, the study generated a list of proposed orbital support equipment (OSE), and estimated the total mass. Lunar vehicle refurbishment was selected for the OSE analysis since refurbishment requires more tasks to be performed on more systems than vehicle assembly. Shuttle ground support equipment (GSE) was used for the analogy. Shuttle GSE, however, fills warehouses and tool cribs, and had to be reduced to a realistic level for orbital operations. GSE for systems not found on the LPV (such as hydraulics and auxiliary power units) was deleted.

Upgrading GSE into OSE will require optimization for space usage such as weight and volume reduction, and use of advanced technology to function in vacuum, microgravity, and thermal extremes. Additional expense will be incurred certifying OSE as flight hardware. This OSE list was given to SSF Work Package 2 mass engineers at MDSSC-SSD at Huntington Beach for mass estimation. Total mass for this entire set of OSE is estimated at 3420 pounds. SSF logistics engineers will need to plan for ETO manifesting and packaging, and SSF storage of this OSE.

Orbital Support Equipment

Fluid System Test Devices
Aerometric Leak Detector
Air Measuring Unit
Atmospheric Pneumatic Flow Tester
Coolant Containers
Coolant Deaeration Unit (Fuel Cells)
Coolant Loop Service Unit
Coupler Assemblies
Dissolved Oxygen Analyzer
Drain & Purge Adapter Set (Water)
ECLSS Pressure Distribution Unit
ECLSS Radiator Flow C/O Unit
Entrained Gas Detection Unit - (FC-Coolant Loop)
Expanders/Reducers
Flow Rate Calibration Kit
Flow Meter and Test Set
Flow Meter Bypass Valve Assembly
Fluid Port Adapters
Fluid Sample Collector
Fluid System Test Device
Funnel with Cover and Tube
GO2 Pressure Regulator Unit
GO2 Service Set
High Pressure Flow tester
Iodine Injector Set
Lapping Kit
Leak Check Equipment (Hand Held Spectrometer or Infrared Sensor)
Leak Detectors - (Helium, Hydrogen, Nitrogen)
Leak TEC Solutions
LH2 Storage and Transfer Equip
Mop and Sop Spill Kit
Plugs/Caps
Pneumatic Analyzer Test Set
Portable Purge Unit
Portable Propellant Tank
Pressure Calibration Kit
Pressure Distribution Unit with Gages
PRSD Electrical Control and Monitor Unit
QD Filters
Rigid and Flex Hoses
Rigid and Flex Tubing Assemblies
Sample Probes (Hydroscope, etc.)
Tee's/Elbows
Temperature Calibration Kit
Thermometer
Tool Set/Value Adapters
Unions
Volumetric Leak Detector
Vacuum Cleaner
Valves

Electrical Support Equipment
7-Track Magnetic Tape Recorder Equivalent
Adapter Cables
Adapter Cables (Universal)
Airlock Electrical Control and Monitoring Unit
Antenna and Transmission Line C/O Set
Antenna Hats
Battery Charger
Breakout Boxes
Bridges (Multi-milliohms Range)
Brush Mark - Channel Recorder
Bus Monitor Unit
C&T Modular Index Measuring Unit
Clamp-on Ammeter with Probes
Digital Data Monitoring Unit
Digital Multimeter
Digital Theodolites
Digital Volt Meter and Fluke Meter
Electrical Patch Distribution Assembly
Electrical Testers (Rate Gyro's, Accelerometers)
Frequency Counter
Gimbal Actuator Test Set
GPC Monitoring Unit
Impedance Matching and Power Distribution Unit
Instrumentation Test Set
Interface Simulators
Mobile DMS Interface and Cable
Oscilloscope with Test Lead Pack and Probes
Patch Board (Universal)
Payload/Simulator Cargo
PCM Simulator
Phase Sequence Indicator
Portable Power Source (dc)
Resistor Pack (Load Pack)
RF Transmission Cables
RF Uplink Converter Unit
Shorting/Wrap-around Plugs
Signal/Frequency Generator
Soldering Equipment
Stray Voltage C/O Unit
TLM Test/CAL Set
Unbilical Port Breakout
Video/Audio Recorder

Mechanical Support Equipment
Alignment Equipment
Antenna Stow/Deployment Simulator
Astro Arc Welder
Brushes
Grounding Straps
Hose Clamp Pliers
Induction Blazing Equipment
Main Engine Alignment Set
Manual Valve Actuation Tool
O-Ring Removal Tool
ORU Guide Bars (Installation and Removal)
OSE Access Ladder
OSE Tool Kit
OSE Workstand
Protective Covers
RMS Checkout Test Controller
RMS Display and Control Panel C/O Unit
RMS End Effector Checkout Unit
RMS Grapple Fixture and Target
RMS Hand Controller C/O Unit
RMS Hand Controller Simulator
RMS Test C/O Equipment
RMS Wrist EXT Kit
Scrapper
Supply/Tool Tote Tray
Tank Sling
Torque Wrench/Remote Torque Wrench
TPS Tile Repair Kit

Maintenance Crew Items
Gloves ((Solvent Resistant)
Portable Vacuum Cleaner
Masks (Air Filtration)
Tape (Nylon, Masking, Teflon, Velcro)
Plastic Ties
Sealed Plastic Containers (for Fluid Collection)
Plastic Tubing
Flashlight (Handheld, Gooseneck)
Freon 12 (14-oz. Can w/Spray Nozzle)
Mirrors (Handheld)
Inspection Magnifying Glass
Zip Lock Bags (Various Sizes)

Propulsion System
Pneumatic Storage and Regulated Supply System
LOX Storage and Transfer System
LH2 Storage and Transfer System
Borescope Equipment
Engine Handling Fixture
Tank Handling Fixture
Entrapped Fluids Removal Unit
Filter/QD Assembly
Gas Analyzer
Sampling Equipment
Liquefaction System
Leak Check Equipment
ORU Mounts
Turbo Pump Lubrication Unit
Ultrasonic Extensometer
Waste Oil Collection Tank
Cover Plate Set -
- Umbilical Disconnects
- Overboard Vents
- Engine Throat Plugs
- Engine/PCA Interface
- Tank/PCA Interface

Waste Management System
Urinal Assembly Cleaning Kit
Transport Tube Cleaning Kit
WCS Checkout Unit

KSC ground processing experience has clearly demonstrated that on-orbit processing of space flight vehicles is very labor intensive. Consequently, it is absolutely essential that *the design of these vehicles, facilities, and support equipment be optimized to eliminate or reduce on-orbit operations.* EVA/telerobotic accessibility is of vital concern. Hardware desgin recommendations are provided.

These examples clearly demonstrate the importance of incorporating KSC processing experience early in the hardware design phase. In view of this, a collection of over 300 KSC "lessons learned" with applicability to on-orbit processing at SSF is included as a supplement to the GFY 89 study summary report. Also, it is strongly recommended that all future OEXP vehicle designs and mission manifests intending to utilize on-orbit assembly, refurbishment, or servicing be reviewed by KSC personnel with space vehicle flight hardware ground processing and launch operations experience.

Major study goals for GFY 90 include the incorporation of EVA and automation/robotic enhancements to the on-orbit processing flows, generation of revised "hooks and scars" for SSF evolution in time to support the rephased SSF PDR, entry of all processing flows and requirements into the VPOD data base, and support to the JSC and MSFC "Skunk Works" currently defining NASA's response to President Bush's Human Exploration Initiative.

Hardware Design Recommendations

- Design serviceable hardware for ease of EVA and/or telerobotic access
- All manipulated elements should contain integrated grapple fixtures
- Snap-in mounting of ORUs
- Built-in test equipment should be capable of automated fault detection and isolation (at least to ORU level)
- Automated umbilical mate/demate with auto-verification of mated interface
- Use quick-disconnect fluid (liquid and gas) connections for all EVA/RMS installed umbilicals, cables and lines
- Key connections and interfaces to preclude incorrect installation
- Propellant tanks, engines, and manifolds integrated on ground whenever possible
- On-board leak detection and isolation capability
- Minimize handling and bolting operations for Aerobrake assembly and replacement
- Standardize fasteners
- Launch crew modules outfitted with equipment and consumables
- Components should be certified for multi-mission operating life between refurbishments tasks
- Periodic maintenance and servicing requirements should be staggered in order to equalize workload from mission to mission
- Vertical integration of cargo shroud (as opposed to a payload bay configuration) will simplify cargo processing and allow larger and heavier payloads