General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)
STUDY OBJECTIVE

"ANALYZE, IN A PRELIMINARY FASHION, THE IMPLICATIONS OF USING THE SHUTTLE WITH THE SOC, INCLUDING CONSTRAINTS THAT WILL PLACE UPON THE SOC DESIGN. IDENTIFY ALL THE CONSIDERATIONS INVOLVED IN THE USE OF THE SHUTTLE AS A PART OF THE SOC CONCEPT."

- IMPLICATIONS TO THE SOC
- IMPLICATIONS TO AN OTV/MOTV
- IMPLICATIONS TO AN OTV/MOTV
# STUDY TASKS

<table>
<thead>
<tr>
<th>TASK</th>
<th>ISSUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 ORBITAL ALTITUDE</td>
<td>• AT WHAT ALTITUDE SHOULD THE SOC OPERATE WHILE BEING COMPATIBLE WITH THE SHUTTLE CAPABILITIES?</td>
</tr>
<tr>
<td>2.0 BERTHING AND/OR DOCKING</td>
<td>• IS A STANDARD BERTHING/DOCKING INTERFACE FEASIBLE?</td>
</tr>
<tr>
<td></td>
<td>• CAN THE ORBITER DOCK TO THE SOC?</td>
</tr>
<tr>
<td></td>
<td>• CAN THE ORBITER BERTH TO THE SOC USING THE RMS?</td>
</tr>
<tr>
<td>3.0 SOC ASSEMBLY</td>
<td>• WHAT EQUIPMENT AND OPERATIONS ARE REQUIRED FOR THE SHUTTLE TO ASSEMBLE THE SOC?</td>
</tr>
<tr>
<td></td>
<td>• WHAT ARE THE IMPLICATIONS TO THE SOC ELEMENTS?</td>
</tr>
<tr>
<td>4.0 SOC RESUPPLY AND FUEL TRANSFER</td>
<td>• WHAT ARE THE IMPLICATIONS OF SOC RESUPPLY VIA THE LOGISTICS MODULE AND THE SHUTTLE?</td>
</tr>
<tr>
<td></td>
<td>• WHAT ARE THE IMPLICATIONS OF TRANSFERRING PROPELLANTS FROM THE SHUTTLE TO THE SOC?</td>
</tr>
<tr>
<td></td>
<td>• DEVELOP A SHUTTLE LOGISTICS MODEL</td>
</tr>
<tr>
<td>5.0 FLIGHT SUPPORT FACILITY</td>
<td>• WHAT ARE THE IMPLICATIONS TO THE SOC TO PROVIDE SPACECRAFT SERVICING?</td>
</tr>
<tr>
<td></td>
<td>• WHAT ARE THE IMPLICATIONS TO THE SHUTTLE TO PROVIDE SPACECRAFT SERVICING?</td>
</tr>
<tr>
<td></td>
<td>• WHAT ARE THE SPACE-BASED VEHICLE REQUIREMENTS?</td>
</tr>
</tbody>
</table>
ORBITAL ALTITUDE

USE VARIABLE ALTITUDE STRATEGY

• CAPITALIZES ON GREATER SHUTTLE P/L'S AT LOW ALTITUDES

• COMBINES ORBITAL SAFETY WITH EFFICIENCY

• SAVES UP TO 15% LOGISTICS OVER CONSTANT ALTITUDE STRATEGY

FLY HIGH DURING HIGH ATMOS DENSITY

FLY LOW WHEN ATMOS DENSITY IS LOW

ALTITUDE, NM

ALTITUDE EXCURSIONS DUE TO VARIATIONS IN DENSITY & TRAFFIC

OPTIMUM ALTITUDE FOR NOMINAL DENSITY THRU SOLAR CYCLE

YEAR

1990 1995 2000

SPACE OPERATIONS/INTEGRATION & SATellite Systems Division

Rockwell International

101SSD22106
BERTHING AND/OR DOCKING

DOCKING MODULE CONCEPT

COMMON INTERFACE DESIGN IS POSSIBLE

PROXIMITY OPERATIONS

- CLOSURE PATH EFFECTS
- RUNAWAY JET
- ABOARDS FROM RUNAWAY JET ARE POSSIBLE
- SOC DESIGN FOR THRUST WHILE DOCKED

RMS BERTHING IS FEASIBLE BUT REQUIRES SOFTWARE MODS

PLUME IMPINGEMENT

- DESIGN FOR "HI Z" ABORT MODE
- LONG TERM CONTAMINATION NEEDS STUDY

Space Operations/Integration & Satellite Systems Division

Rockwell International

101SSD22107
SOC ASSEMBLY

- ASYMMETRIC CONFIGURATION PROBLEMS

- RCS SUPPLEMENT REQUIRED FOR SOC BUILDUP

- SOC CAN BE ASSEMBLED WITH ORBITER PROVISIONS IN DEVELOPMENT OR PLANNED

- PLUS SUPPLEMENTAL LIGHTS & ALIGNMENT AIDS
SOC RESUPPLY AND FUEL TRANSFER

LOGISTICS OPERATION

- LOGISTIC MODULE EXCHANGE
- FLIGHT SUPPORT FACILITY LOGISTICS
- CONSTRUCTION LOGISTICS

PROPELLANT TRANSFER

- ZERO "G" TRANSFER IS FEASIBLE
- PROPELLANT STORAGE HIGHLY DESIRABLE

Original page of poor quality.
STUDY EXTENSION TASKS

TASK 1.0 SHUTTLE FLEET UTILIZATION & PROGRAMMATICS
OBJECTIVE: DETERMINE SHUTTLE FLEET UTILIZATION REQUIREMENTS & RELATED PROGRAMMATICS DATA FOR SOC/SHUTTLE OPERATIONS IN LEO.

TASK 2.0 SOC ASSEMBLY OPERATIONS
OBJECTIVE: TO CONFIRM THE CAPABILITY OF THE RMS TO ASSEMBLE THE SOC, & TO DETERMINE THE ASSEMBLY OPERATIONAL IMPLICATIONS & THE IMPLICATIONS TO THE SOC MODULES

TASK 3.0 SHUTTLE SYSTEM PROPELLANT SCAVENGING
OBJECTIVE: DETERMINE PRINCIPAL FUNCTIONAL IMPACTS ON THE SOC DUE TO PROPELLANT SCAVENGING

* TASK 4.0 FLIGHT SUPPORT FACILITY
OBJECTIVE: TO COMPARE THE SERVICING/CHECKOUT LOGIC & COSTS ASSOCIATED WITH PERFORMING FLIGHT SUPPORT SERVICES ON FREE-FLYING SATELLITES & OTV'S AT THE SOC, ON THE GROUND & FROM THE ORBITER
### TASKS SCHEDULE

<table>
<thead>
<tr>
<th>MILESTONES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SHUTTLE FLEET UTILIZATION &amp; PROGRAMMATIC</strong> (MYERS)*</td>
</tr>
<tr>
<td><strong>SOC ASSY OPERATIONS</strong> (TOTAL)*</td>
</tr>
<tr>
<td><strong>SHUTTLE SYST. PROPELLANT SCAVENGING</strong> (MYERS)*</td>
</tr>
<tr>
<td><strong>(ROCKWELL STUDY -- SHUTTLE IMPLICATIONS ANALYSIS)</strong></td>
</tr>
<tr>
<td><strong>FLIGHT SUPPORT FACILITY</strong> (TOTAL)*</td>
</tr>
<tr>
<td><strong>OPERATIONS ANALYSIS</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TASKS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MID-TERM REVIEW</strong></td>
</tr>
<tr>
<td><strong>FINAL DRAFT</strong></td>
</tr>
<tr>
<td><strong>FINAL REPORT</strong></td>
</tr>
<tr>
<td><strong>FINAL REVIEW</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1981</strong></td>
</tr>
<tr>
<td><strong>1982</strong></td>
</tr>
</tbody>
</table>

*() RESPONSIBLE ENGINEER
This task will determine the key interrelationships among the main STS utilization variables, with particular emphasis on the differences between SOC and "non-SOC" scenarios. We will be looking at the interacting effects of cargo density, OTV performance models, and Shuttle logistics performance for their effects on fleet utilization and fleet size requirements. In particular, we will examine the potential benefits within the SOC scenario of increasing Shuttle load factors by adding high-density propellants to low-density cargo manifests to always fly the orbiter near its 65K lb payload capacity.

The further fleet utilization benefits of scavenging ET residual propellants will also be investigated. This technique is particularly suited to the SOC scenario where propellant storage capability in space could easily be provided as part of the SOC flight support activity.

It is also planned to investigate the potential ground turnaround benefits which can be attained with an orbiter dedicated to SOC resupply missions.
SHUTTLE FLEET UTILIZATION AND PROGRAMMATICS

TASK SCOPE AND APPROACH DEFINED

- TRAFFIC ANALYSIS
- MANIFEST DEFINITIONS
- TRADES:
  - SOC VS NO SOC
  - DEDICATED ORBITER
  - SOC PROPELLANT STORAGE
  - P/L TOP-OFF TANK SIZES
  - ET PROPELLANT RECOVERY

*GROUND TURNAROUND FACILITIES AND TIME*

*FLEET SIZE*

*P/L VOLUME*

*FLT RATES*
SUMMARY

GOALS:

- DEVELOP AN UNDERSTANDING OF THE GROUND TURNAROUND PROCESS & POTENTIAL SOC RELATED INTERACTIONS
- DETERMINE THE SIGNIFICANCE &/OR NEED FOR DEDICATED ORBITER(S)
- SHOW FLEET IMPACTS FROM NON-SOC SCENARIO
- DETERMINE PROPELLANT TANK SIZES MATCHING TRAFFIC PREDICTIONS . . . . , AND UNDERSTAND THE INTERACTIONS WITH PAYLOAD DENSITY, ET SCAVENGING AND PAYLOAD TOP OFF
Our approach to the Assembly Operations task is to use a company-developed computer program RMSKAT (Remote Manipulator System Kinematic Analysis Tool). The program assesses the motion path the RMS is expected to follow in assembling each module, and indicates whether it is within the capability and desired operating range of the RMS. The assessment is based on a SOC assembly concept that was generated during our initial effort on the SOC/Shuttle Interaction Study. From that concept, grapple fixtures were located on each module and the initial and final end effector coordinates were determined for each assembly operation. The coordinates served as the inputs to the RMSKAT computer program.
TASK 2 - SOC ASSEMBLY OPERATIONS APPROACH

SOC ASSEMBLY CONCEPT

GRAPPLE FIXTURE COORDINATES

RMS PARAMETERS

RMSKAT

ASSESS RMS MOTION PATH

ADOPT AS BASELINE

WITHIN DESIRED OPERATING RANGE?

YES

Determine Implications

COMATIBLE WITH RMS Capabilities?

YES

SELECT ANOTHER LOCATION

NO
The RMSKAT program is used for the kinematic evaluation of the RMS operational envelopes. It features rigid body simulations only, i.e., without flexible body effects. Besides the typical computer printouts, the program presents a graphic feedback of the kinematic path of the RMS and its grappled payload. Both types of output are illustrated on the next two charts. Incorporation of the SOC graphics is partially complete at this time.

RMSKAT can be operated in any one of two modes, as indicated.
REMOTE MANIPULATOR SYSTEM KINEMATIC ANALYSIS TOOL (RMSKAT)*

- COMPUTER PROGRAM FOR KINEMATIC EVALUATION OF RMS OPERATIONAL ENVELOPES
- RIGID BODY SIMULATIONS ONLY
- GRAPHIC FEED BACK (SOC GRAPHICS MOD IN PROGRESS)
- TWO OPERATING MODES

**INPUT**
- START & FINAL END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM
- RMS JOINT ANGLE SPECIFICATIONS

**OUTPUT**
- RMS JOINT ANGLE READINGS AT SPECIFIED TIME INTERVALS
- END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM

*DEVELOPED WITH DISCRETIONARY FUNDS
SOC TUNNEL ASSEMBLY

This chart illustrates a typical graphic output of RMSKAT. In this particular example, the assembly operation of the SOC tunnel module is featured. It should be noted that the SOC interfaces with the orbiter on an assumed handling and positioning aid (HPA) which places the SOC interface outside the orbiter payload bay envelope. The use of the HPA was found necessary to bring the depicted tunnel assembly operation within the reach limits of the RMS.

Another point of interest for the RMS is the geometric relationship of its wrist segment to its lower-arm segment, as can be clearly seen in the upper sketch. The relationship is an acute angle, and this was one of two points that were found to exceed the wrist pitch joint limits, as indicated on the next chart.
SOC TUNNEL ASSEMBLY
Assessment of the first set of grapple fixture locations, as determined by the base-lined assembly sequence, resulted in the RMS joint angles indicated on this chart. Grapple fixture locations on two modules, Service Module No. 1 (SM-1) and the tunnel module (TM), were found to exceed the wrist pitch joint limits. The operational limits of each RMS joint are indicated in the heading of each column. Besides the operational limits, certain desired limits exist for the elbow pitch and the wrist yaw joints which state that the wrist pitch joint should be less than ±60° at the time of berthing and, similarly, the elbow joint should be greater than -40°. The circled results exceed these desirments and, consequently, grapple fixtures on the affected modules will be relocated and reassessed until compatible locations are found.
**RMS ANGLES -- SOC ASSEMBLY**

<table>
<thead>
<tr>
<th>MODULE</th>
<th>SY (-177.4 TO 177.4)</th>
<th>SP (0.6 TO 142.4)</th>
<th>EP (-0.4 TO -157.6)</th>
<th>WP (-116.4 TO 116.4)</th>
<th>WY (-116.6 TO 442)</th>
<th>WR (-442 TO 442)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM-1 STOWED</td>
<td>-31.54</td>
<td>50.71</td>
<td>-72.86</td>
<td>-11.92</td>
<td>-53.47</td>
<td>-28.52</td>
</tr>
<tr>
<td></td>
<td>-46.68</td>
<td>68.02</td>
<td>-82.50</td>
<td>51.77</td>
<td>-61.30</td>
<td>17.48</td>
</tr>
<tr>
<td></td>
<td>-61.82</td>
<td>85.34</td>
<td>-92.14</td>
<td>115.45</td>
<td>-69.13</td>
<td>63.48</td>
</tr>
<tr>
<td>SM-1 DEPLOYED</td>
<td>-76.97</td>
<td>102.65</td>
<td>-101.79</td>
<td>179.14</td>
<td>-76.97</td>
<td>109.48</td>
</tr>
<tr>
<td>SM-2 STOWED</td>
<td>-32.82</td>
<td>54.09</td>
<td>-78.37</td>
<td>-8.85</td>
<td>-52.40</td>
<td>152.65</td>
</tr>
<tr>
<td>SM-2 DEPLOYED</td>
<td>-32.59</td>
<td>76.54</td>
<td>-85.32</td>
<td>-92.01</td>
<td>16.32</td>
<td>-55.85</td>
</tr>
<tr>
<td>HM1 STOWED</td>
<td>-30.93</td>
<td>60.48</td>
<td>-82.34</td>
<td>-12.68</td>
<td>-53.97</td>
<td>-29.10</td>
</tr>
<tr>
<td>HM1 DEPLOYED</td>
<td>-21.64</td>
<td>78.56</td>
<td>-42.91</td>
<td>-79.48</td>
<td>-61.20</td>
<td>140.00</td>
</tr>
<tr>
<td>HM2 = HM1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM STOWED</td>
<td>-28.62</td>
<td>53.82</td>
<td>-72.01</td>
<td>-18.26</td>
<td>-55.85</td>
<td>148.57</td>
</tr>
<tr>
<td>LM DEPLOYED</td>
<td>-61.31</td>
<td>75.58</td>
<td>-68.93</td>
<td>-28.61</td>
<td>-26.91</td>
<td>169.66</td>
</tr>
<tr>
<td>TM STOWED</td>
<td>-28.99</td>
<td>71.21</td>
<td>-133.56</td>
<td>-37.38</td>
<td>-16.96</td>
<td>120.45</td>
</tr>
<tr>
<td></td>
<td>0.54</td>
<td>75.00</td>
<td>-97.30</td>
<td>15.80</td>
<td>30.20</td>
<td>56.70</td>
</tr>
<tr>
<td></td>
<td>27.91</td>
<td>78.80</td>
<td>-61.10</td>
<td>69.10</td>
<td>43.30</td>
<td>6.90</td>
</tr>
<tr>
<td>TM DEPLOYED</td>
<td>56.36</td>
<td>82.58</td>
<td>-24.99</td>
<td>122.41</td>
<td>56.36</td>
<td>-70.52</td>
</tr>
</tbody>
</table>
There is 9500 lb of propellant or more remaining in the ET at the end of boost. This includes flight performance reserves, trapped residuals, and other unused propellants. The 9500 lb is the expected average for cases where the Shuttle is delivering a maximum 65,000-lb payload to orbit. With smaller payloads, even more ET propellants will be available—almost pound for pound.

The benefits of recovering these propellants and delivering them to a storage facility on the SOC for later use on OTV missions are enormous. Significant savings in annual Shuttle flights through reduced OTV propellant deliveries are possible.

We have conducted preliminary investigations of the major feasibility issues related to the implementation of this technique. These include trajectory mods to the boost profile and the closely related effects on ET debris impact zones, the various factors affecting cryogenic fluid flow phenomena, some of the transient effects on fluid integrity at MECO, various ullage or propellant settling thrust options and hardware arrangements for the receiver tanks, and plumbing interfaces with the orbiter main propulsion system.

All of these investigations to date have given strong indications of the practical feasibility of performing suborbital recovery of ET propellant residuals or even larger amounts of unused propellants.
TRAJECTORY ANALYSIS

One of the important considerations affecting the feasibility of ET propellant scavenging is the nature and magnitude of the changes which must be made to the Shuttle boost trajectory in order to give sufficient time to perform the propellant transfer operations. The main factors in this analysis are the ullage thrust options (thrust levels employed), the post-MECO time-trajectory relationships and their effects on the ET debris impact zones. As part of these considerations, we were also concerned with how much propellant is needed for ullage thrusting and the combined affects of all factors on Shuttle payload.

It was determined that a relatively linear relationship exists between the Shuttle burnout velocity at MECO and the amount of ullage thrusting time which could be applied. In essence, ΔV’s from ullage thrusting can be used to approximately compensate for small changes in MECO velocity such that ET impacts occur in acceptable zones (primary or secondary) while providing sufficient time for the propellant transfer operations. Up to 20 minutes or more are available for propellant transfer with low thrust ullage options. MECO changes of less than ±1 second (<100 fps bias) in combination with appropriate ullage thrusting periods will meet the ET impact constraints.

It was further determined that the net effects of all factors on the Shuttle payload are negligible. These include the direct effects of changing MECO velocity (ΔPL/ΔV_{MECO} - 25.7 lb/fps), the change in OMS propellants for subsequent maneuvers flying the orbiter on up to orbit, and the extra RCS propellants required for ullage thrusting.

These analyses showed boost trajectory solutions to ET propellant recovery requirements are easily possible.
TRAJECTORY ANALYSIS

- ET IMPACT SATISFIED
- MECO CHANGES MINOR
- SHUTTLE BOOST TRAJ CONSTRAINTS ARE MET
- NEGLIGIBLE SHUTTLE P/L IMPACTS
ULLAGE THRUST PROPELLANT REQUIREMENTS

This chart shows the amount of RCS propellants which are required for ullage thrusting as a function of thrusting time. Three thrust options are shown: (1) dual RCS, (2) single RCS (alternate left-right firing), and (3) an "idealized" case with thrust equal to drag plus 50 lb. Aerodynamic drag at MECO ranges from 10 to 30 or 40 lb, and decays rapidly to less than 1 lb. Thus, the idealized case is essentially 50 lb of continuous thrust.

The dual RCS case is shown to require over 8000 lb of propellant for a thrust period of 20 minutes. Propellant consumption is 414 lb/minute and includes an 11% factor for attitude control. Single RCS consumption would be one-half this amount (207 lb/minute), while the idealized case would use only 11.5 lb/minute.

The amount of RCS propellant available after other maneuvers required for ascent/descent and mission operations is shown to be 1604 lb. Propellant needs beyond this amount can be met by utilizing the OMS cross-feed capability. Here, propellant from the OMS tanks can be transferred to the RCS system for use by the RCS thrusters. Ample OMS propellant exists to meet all of the ullage thrust options, but propellant amounts over the 1604 lb available in the RCS system would reduce the Shuttle payload. The low-thrust options for ullage thrusting fall well within the 1604-lb limit.

Thus, propellant availability for ullage thrusting is not a serious problem.
ULLAGE THRUST PROPELLANT REQUIREMENTS

**RCS PROPELLANT BUDGET, LB**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCENT/DESCENT</td>
<td>(3398)</td>
</tr>
<tr>
<td>INSERTION AND ORBIT ADJUST</td>
<td>1127</td>
</tr>
<tr>
<td>ENTRY</td>
<td>1164</td>
</tr>
<tr>
<td>RESIDUALS AND CONTINGENCIES</td>
<td>1107</td>
</tr>
<tr>
<td>MISSION OPERATIONS</td>
<td>(1450)</td>
</tr>
<tr>
<td>RENDEZVOUS</td>
<td>1450</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4848</strong></td>
</tr>
</tbody>
</table>

**TOTAL PROPELLANT LOADED**

- **7254 lb**

**AVAILABLE FOR ULLAGE THRUST**

- **7254 - 4848 = 2406 lb**

**2/3 IN AFT QUADS = 1604 lb**

---

**GRAPHIC**

- **ULLAGE PROPELLANT REQMT (1000 LB)**
- **TIME, MINUTES**
- **DUAL RCS**
- **2400 LB AT t = 10 MIN**
- **SINGLE RCS**
- **400 LB AT t = 10 MIN**
- **BASIC QUAD LIMIT (1604 LB)**
- **IDEALIZED, DRAG + 50 LB**
- **OMS CROSS FEED PROPPELLANT REQD (1000 LB)**
- **OMS PROPELLANT CROSSFEED REQUIRED**
PROPPELLANT TRANSFER PROCESS

The transfer process in moving the propellants from the ET to receiver tanks in the orbiter is affected by many factors. The focal point for all of these effects is the pressure differential between the ET and the receiver tank.

The LO₂ and LH₂ tanks in the ET are pressurized by "bleed gas" loops in their respective systems. These "hot" gases are fed back into the ET during boost to maintain sufficient system pressure to avoid cavitating the turbopumps feeding the main engines. The required tank pressures are approximately 20 and 32 psia for the LO₂ and LH₂ tanks respectively. At MECO the pressurization system is shut off and the vapor in the tanks is cooled by contact with the relatively cool tank walls and by residual liquid propellants in the tank. This cooling process causes the pressure in the ET tanks to decay; the rate of decay is affected by ullage thrust levels, high thrust produces faster ET pressure decay.

In contrast to the ET tanks above, the pressure environment in the receiver tanks rises with time. After the initial pressure surge for tank chilldown this pressure rise is due to the heat leaks into the system. In the LO₂ system significant heat inputs occur from the boost heated belly tiles of the orbiter along the LO₂ feedline and heat soakback from the main engines and plumbing. The LH₂ system is also heated by engine soakback, but also receives considerable heating from the aft bulkhead which can be exposed to direct solar heating at MECO. Thus, receiver tank pressures rises with time.

In the case of LH₂ transfer the starting pressure (32 psia) is sufficiently high that an adequate pressure differential exists to perform pressurized transfer within reasonable periods of time (up to 10 or 20 minutes).

The low starting pressure for LO₂, however, imposes the requirement for pumped transfer. Pressurized transfer of nominal amounts of LO₂ could probably be made to work, but for wider applications of the scavenging techniques and to gain higher technical confidence, a pumped LO₂ transfer approach is preferred.
PROPELLANT TRANSFER PROCESS

RECEIVER TANK

LO₂
ET TANK

ΔP DECAY;

ET ULLAGE PRESS

PRESSURE

TIME, MINUTES

0 10 20

PUMPED TRANSFER REQUIRED

RECEIVER TANK PRESSURE

ΔP

32

Adequate ΔP

ET ULLAGE PRESSURE

PRESSURE

TIME, MINUTES

0 10 .20

PRESSURIZED TRANSFER THE WAY TO GO

RECEIVER TANK

LH₂
ET TANK

ΔP

Space Operations/Integration & Satellite Systems Division
Rockwell International

10155D22144
PRACTICAL SCAVENGING CONCEPTS

This chart depicts some of the main hardware considerations pertinent to ET propellant scavenging. First, there are a number of possible ullage thrust options. Ullage thrusting is required to keep the residual propellants settled at the bottom of tanks. Analysis has shown that existing primary RCS thrusters can be used, although propellant consumption can be greatly reduced by adding vernier thrusters to fire in the X-direction (the current verniers do not thrust in this direction). Thus, practical solutions to ullage thrusting are possible.

Analysis has also shown that 4 inch transfer lines will be sufficient to perform the basic propellant flow process. With this line size a pump must be used in the LO2 transfer system. Modified centaur pumps can be used for this application, but smaller capacity pumps of new design would use less electrical power. Preliminary looks indicate ample space is available in the orbiter engine compartment to install these elements. Thus, practical pumping solutions are possible.

A number of receiver tank options were explored, both internal and external to the orbiter. Some of the external options could probably be made to work, but would have significant orbiter design impacts. Internal designs ranging from conventional, easy to install tanks to more advanced torus configuration were determined to have capabilities ranging from 10,000 to 30,000 pounds (sized for a 6:1 mixture ratio and to fit the OMS kit length of 9 feet). The enormous benefit potential of the propellant scavenging concept suggests an optimum tank concept leaning toward the advanced designs would be highly appropriate. Regardless of the final tanking concept selected, practical solutions are possible.
PRACTICAL SCAVENGING CONCEPTS

ULLAGE THRUST OPTIONS

- DUAL RCS THRUSTERS
  - 2 x 870 = 1740 lb
  - T/W = 0.028 g/s
  - \( \Delta V \) = 155 ft/sec
  - MINIMUM ORBITER IMPACT

- SINGLE RCS THRUSTER
  - 1 x 870 = 870 lb
  - T/W = 0.024 g/s
  - \( \Delta V \) = 125 ft/sec
  - ATTITUDE CONTROL SOFTWARE MOD

- ADDED VERNIER THRUSTERS
  - INITIAL = 2 x 870 = 1740 lb
  - APPROX. 46 - 60 sec
  - T/W = 0.012 g/s
  - \( \Delta V \) = 60 ft/sec
  - ATTITUDE CONTROL SOFTWARE MODS

HARDWARE CONCEPTS

- CONVENTIONAL
- TORUS
- WING INTERNAL
- TIP TANKS
- BELLY TANKS

Space Operations/Integration & Satellite Systems Division
Rockwell International
101SSD22140
CREW CONSIDERATIONS

It is envisioned that the orbiter crew would play an active role in the ET propellant scavenging operations. Given the ability to monitor temperatures, pressures, flow rates and fluid characteristics probably the simplest transfer concept would involve crew participation. Further studies are required to define the specific nature of the crew requirements and the degree of automation to be introduced into the flow process.

For our preliminary look, here, it has been determined that control panel space is available for appropriate flow monitor and control functions. Further, this panel area (panel R-11) is within the reach envelope of the mission specialist from his seated position at MECO. Thus, crew participation in the transfer process appears possible. Additional study is required to determine the transition effects on crew capabilities from the boost environment to zero-g. However, fighter pilots frequently perform in this type of environment so crew participation in the flow control process appears feasible.
CREW CONSIDERATIONS

AFT FLIGHT DECK - VIEW LOOKING AFT

MISSION OPERATIONS
DISPLAYS & CONTROLS
MISSION SPECIALIST
R-11 FUEL SCAVENGING
CONTROL PANELS
PAYLOAD OPERATIONS
DISPLAYS & CONTROLS

FLIGHT DECK

YO 38
NOM REACH
LOOKING AFT

YO 0.0
MISSION OPERATIONS
DISPLAYS & CONTROLS

PANEL R-11
Q SEAT YO 23.25
BASIC SEAT - FWD POS

• PANEL SPACE IS
  AVAILABLE
• C&D'S WITHIN
  REACH

Space Operations/Integration &
Satellite Systems Division
Flockwell
International
The amount of propellant remaining in the ET at the end of boost is dependent upon how much payload was carried to orbit. Aside from the flight performance reserves and residuals trapped in the system the ET will contain an additional 0.95 pounds of propellants for every pound of unused payload capacity that might exist on a given flight manifest.

The relationship between LO₂, LH₂ and total propellants remaining and the Shuttle unused payload capacity is shown in the accompanying chart. Values of propellant remaining can be up to 80,000 pounds or even higher depending upon future Shuttle improvements and/or growth options.

Superimposed on these propellant/payload relationships are three possible scavenging scenarios. These range from the "basic scavenging" situation in which only the nominal residuals remaining after a full payload launch are recovered. The second scenario reflects the density characteristics of most dry cargo manifests. Hard cargos approximately filling the orbiter bay tend to weigh about 30,000 pounds. This type of payload manifest could either be "topped off" on the ground with propellants to bring the total payload up to the orbiter capacity or the system could be "dry" launched and the 30,000 to 40,000 pounds of remaining propellants scavenged similar to the case above.

In the third scenario we carry the "dry" launch concept all the way to a dedicated tanker flight. Here, instead of launching the orbiter with a full cargo of propellant the tanker is launched empty and the full 71,000 pounds (theoretical maximum) of propellants would be recovered through scavenging operations.

Thus, a wide range of scavenging scenarios is possible.
NOMINAL PROPELLANT RESIDUALS AT MECO

- INCLUDES ET & MPS PLUMBING

ORBITER 103 NOMINAL RESIDUAL FOR ZERO CARGO (71K LB)

DEDICATED TANKER "DRY LAUNCH"

TOTAL

P/L TOPPING

BASIC SCAVENGING

ORBITER 103 (TARGET)

VOL XIV

LH₂

UNUSED PAYLOAD CAPACITY - 1000 LB

0 20 40 60 80

0 20 40 60 80

NOMINAL RESIDUAL AT MECO - 1000 LB

114% THRUST

STRAP-ONS
SCAVENGING ANALYSIS SUMMARY

All analysis to date have indicated that suborbital recovery of unused ET propellants is a viable concept with enormous benefits to the SOC operational scenario.

Trajectory analyses have shown ET debris impact constraints can be satisfied with minor ΔV biases at MECO for a wide range of ullage thrust options including the use of existing primary RCS thrusters. All of these solutions provide ample time for the propellant transfer operations and are within RCS propellant budget limits.

Practical hardware concepts for receiver tanks and plumbing are achievable within the space/volume constraints of the orbiter engine compartment. MECO transient effects and fluid flow phenomena can all be satisfied with practical control and design solutions.

The MECO changes and subsequent flight maneuvers have negligible effects on Shuttle payload capability.

The system can be designed and qualified to meet the safety standards currently applied to the Shuttle system. Scavenging is a post MECO operation which would not jeopardize earlier main engine operations.

A wide range of scavenging applications are possible. We can safely and efficiently recover propellant amounts ranging from the 9,500 pound expected for Shuttles launched with maximum payloads up to 70,000 pounds or more for the dedicated tanker "dry launch" concept where the orbiter is launched with an empty tank (no other payload) and all the ET propellants remaining are transferred via scavenging operations.

Thus, ET propellant scavenging is judged to be a viable and desirable concept.
SCAVENGING ANALYSIS SUMMARY

- ET PROPELLANT SCAVENGING IS FEASIBLE
- WIDE RANGE OF SCAVENGING SCENARIOS ARE POSSIBLE

- BASIC SCAVENGING
  \( w_p \approx 10-15K \text{ LB} \)

- P/L TOP-OFF
  \( w_p \approx 30-40K \text{ LB} \)

- DEDICATED TANKER
  \( w_p \approx 70 + \text{ KLB} \)
To accomplish this task, our approach is to select several representative spacecraft and analyze their servicing requirements if they are to be serviced by the SOC, by the orbiter, and on the ground. From the analysis, implications to the SOC, the orbiter, and the spacecraft will be determined. For the SOC, the implications will lead to a preliminary integrated configuration of the Flight Support Facility. Furthermore, the implications, along with those of ground servicing and orbiter servicing, will serve as the basis for generating end-to-end costing of the servicing functions and comparison of the costs of the various servicing methods.
TASK 4 -- FLIGHT SUPPORT FACILITY

SURVEY LIT. FOR CANDIDATE S/C

SELECT REF. S/C FOR SOC STUDY

GROUND SERV. SCENARIOS

GENERATE SERV. SCENARIOS AT SOC

ANAL. SERV. FUNCT. & DET. IMPL.

INTEG. SERV. FUNCT. INTO SOC CONFIG.

COMPARE COSTING

IDENTIFY IMPLICATIONS

ORBITER SERV. SCENARIOS

GENERATE END-TO-END COSTING
REPRESENTATIVE SPACECRAFT

To determine the implications and drive out the required servicing provisions of the SOC Flight Support Facility, three spacecraft were selected for detailed analysis. These spacecraft are characterized by many subsystems and features that are likely to be included on many of the spacecraft that are expected to be serviced by the SOC. Consequently, the diversity of these subsystems and features was the main contributor to their selection. The OTV is a cryogenic stage that also uses hydrazine for its RCS. In addition, it utilizes helium and gaseous nitrogen for various pneumatic valve actuation, pressurization, and purge systems. This spectrum of fluids must be supplied through the SOC Flight Support Facility and, consequently, will dictate the required provisions for fluid loading operations.

The communication satellite is a relatively large spacecraft that requires extensive deployment and checkout operations and final mating to the OTV for launch to GEO. The Space Processing Facility is smaller in size and its servicing requirements consist mainly of refueling and module exchange operations during frequent revisits to the SOC.

To scope the analysis of servicing these spacecraft, six scenarios were selected for estimating servicing man-hours and final cost comparisons. For the OTV, ground and SOC servicing scenarios were analyzed. The other two spacecraft were considered in terms of orbiter and SOC servicing. It is noted that servicing the communication satellite consists mainly of initial deployment, mating to the OTV, and launch to GEO. Once launched, it will not revisit SOC.
### REPRESENTATIVE SPACECRAFTS

<table>
<thead>
<tr>
<th></th>
<th>S/C</th>
<th>GROUND SERVICING</th>
<th>ORBITER SERVICING</th>
<th>SOC SERVICING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OTV</strong></td>
<td></td>
<td>✓</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td><strong>COMM SAT</strong></td>
<td>N/A</td>
<td></td>
<td>✓ INITIAL ASSY &amp; LAUNCH TO GEO</td>
<td>✓ INITIAL ASSY &amp; LAUNCH TO GEO</td>
</tr>
<tr>
<td><strong>SPACE PROCESSING FACILITY</strong></td>
<td>N/A</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

- FEATURES SIGNIFICANT TO SERVICING
  - LOADING OF FLUIDS
  - CRYOGENICS - LO₂, LH₂
  - NON-CRYOGENICS - He, GN₂, HYDRAZINE
  - MODULE & COMPONENT EXCHANGE OPS
  - EXTENSIVE DEPLOYMENT & C/O OPS
  - FREQUENT REVISITS
  - SMALL TO LARGE S/C
CHECKOUT/SERVICING MAN-HOURS

Detailed activities for the six selected servicing scenarios were individually generated and analyzed in terms of functions that are required to turn-around the spacecraft within assumed servicing boundaries. Subsequently, timelines were estimated to perform the servicing functions as illustrated on this chart. A summary of the results is presented on the next chart.
### CHECK-OUT SERVICING MANHOURS

#### SPACE PROCESSING - SOC

#### SPACE PROCESSING - ORBITER

#### COMM SAT - SOC

#### COMM SAT - ORBITER

#### OTV - SOC

### CHECK-OUT/SERVICING TIMELINE

**OTV-GROUND SERVICING**

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RETURN OTV TO ORBR</td>
<td>(1)</td>
</tr>
<tr>
<td>SAFE, RETRIEVE &amp; BERTH</td>
<td>(2,3,4)</td>
</tr>
<tr>
<td>SAFE &amp; STOW</td>
<td>(5%)</td>
</tr>
<tr>
<td>RETURN TO EARTH</td>
<td>(7)</td>
</tr>
<tr>
<td>SAFE &amp; TRANSP. TO ORB</td>
<td>(9,10)</td>
</tr>
<tr>
<td>UNSTOW OTV, TR. TO OTV P.E.</td>
<td>(11,12)</td>
</tr>
<tr>
<td>INSPECT, MATE C/O GSE</td>
<td>(13,14)</td>
</tr>
<tr>
<td>TEST OTV</td>
<td>(15)</td>
</tr>
<tr>
<td>SCHED REPAIR</td>
<td>(16)</td>
</tr>
<tr>
<td>UNSCHED REPAIR</td>
<td>(17)</td>
</tr>
<tr>
<td>C/O OTV</td>
<td>(18,19,20)</td>
</tr>
<tr>
<td>VERIFY ORBR INTEGR &amp; TRANSPORT TO PAD</td>
<td>(21,22)</td>
</tr>
<tr>
<td>RESUPPLY NON-CRYO CONSUM &amp; STOW IN ORBR</td>
<td>(23,24)</td>
</tr>
<tr>
<td>RESUPPLY CRYO</td>
<td>(25)</td>
</tr>
<tr>
<td>SHUTTLE LAUNCH OF OTV</td>
<td>(26)</td>
</tr>
</tbody>
</table>

**Elapsed Time (Hours):**

- 20
- 40
- 60
- 80
- 100
- 120
- 140

---

Space Operations/Integration & Satellite Systems Division

Rockwell International

101SSD22085
CHECKOUT/SERVICING MAN-HOURS SUMMARY

The results of the timeline estimates show that the difference between the elapsed time required to service the communication satellite from the SOC and that of servicing it from the orbiter is very small. Similar results are indicated for the Space Processing Facility. However, servicing the OTV on the ground requires considerably more time than servicing it on the SOC. The difference is attributed mainly to the design philosophy that was assumed for each of the OTV servicing scenarios. For the ground-designed OTV, a scenario without SOC or in-space fueling provisions was assumed which necessitated launching the OTV in the fueled state. To accommodate this mass-sensitive condition, a conventional aerospace structural design was assumed that could not afford the weight penalties associated with extensive servicing accessibility provisions or remote module exchange operations. In addition, ground servicing implies considerable transportation timelines where the OTV must be moved from one dedicated servicing facility to another. These constraints do not exist for the SOC servicing scenario where the space-designed OTV was assumed to be launched in the unfueled condition. As a non-weight-sensitive payload, weight penalties of accessibility provisions and remote/automatic component/module exchange operations are more tolerable.
# CHECK-OUT/SERVICING MANHOURS SUMMARY

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>ELAPSED TIME</th>
<th>MAN-HOURS</th>
<th>NO. CREW</th>
<th>RANGE</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTV - GROUND</td>
<td>134.0</td>
<td>576.0</td>
<td>3 - 6</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>OTV - SOC</td>
<td>26.3</td>
<td>99.7</td>
<td>3 - 5</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>COMM SAT - ORBITER</td>
<td>50.8</td>
<td>164.8</td>
<td>2 - 4</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>COMM SAT - SOC</td>
<td>61.0</td>
<td>199.6</td>
<td>2 - 5</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>SPACE PROCESSING - ORBITER</td>
<td>27.5</td>
<td>106.0</td>
<td>2 - 4</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>SPACE PROCESSING - SOC</td>
<td>29.6</td>
<td>103.4</td>
<td>3 - 4</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>
Analysis of the turnaround functions and activities for each of the selected servicing scenarios implied a general set of required provisions and equipment to perform the servicing operations. This chart presents a summary of the particular set concerned with OTV servicing on the SOC. Similar sets were identified for each of the remaining servicing scenarios.
## OTV-SOC Servicing Implications

<table>
<thead>
<tr>
<th>OTV</th>
<th>SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Remote Safing System</td>
<td>• OTV Control &amp; Monitor Station</td>
</tr>
<tr>
<td>• Communication &amp; Data Link to SOC &amp; Ground OCC</td>
<td>• Communication &amp; Data Links to OTV &amp; ITS Ground OCC</td>
</tr>
<tr>
<td>• Non-Propulsive Vent System</td>
<td>• Active Docking Port on FSF with Alignment Monitoring System</td>
</tr>
<tr>
<td>• Docking Port with Alignment Target</td>
<td>• Extendable Non-Propulsive Boom</td>
</tr>
<tr>
<td>• OTV-SOC System Interfaces (3-Fluid &amp; 1-Elect), with Dual Quick Disconnects</td>
<td>• Mobile Manipulators (2) with Std End Effector &amp; SPE</td>
</tr>
<tr>
<td>• OTV-SOC Structural Interfaces (2 PIDA Devices)</td>
<td>• CCTV Camera on Mobile Manipulators</td>
</tr>
<tr>
<td>• OTV-SOC Manipulator Interfaces (2 Grapple Fixtures)</td>
<td>• Open Cherry Picker &amp; MMU</td>
</tr>
<tr>
<td>• Accessible Component Design</td>
<td>• Retractable Umbilicals -- 3 Fluid &amp; 1 Elect</td>
</tr>
<tr>
<td></td>
<td>• LRU Storage &amp; Retrieval System</td>
</tr>
</tbody>
</table>
SCENARIOS WILL BE GAINED

KEY INSIGHTS INTO COST EFFECTIVENESS OF VARIOUS SERVICING
SERVICING TIMELINES AND COST DATA ARE BEING GENERATED
SERVICING IMPLICATIONS IDENTIFIED

Flight Support Facility Analyses Well Underway

WIDE RANGE OF APPLICATION SCENARIOS IS POSSIBLE
Acceptable Safety Standards Can Be Met
No Significant STS Payload Impact
ET Impact Satisfied
Ample Transfer Time

ET Propellant Scavenging Proven Feasible

High Confidence to Clearance Geometries
Computer Interreceptive Graphics Will Give

SOC Assembly Analyses Underway

Important Results Are Expected
Fleet Utilization Analyses Has Been Started

Conclusions And Plans
SHUTTLE TURNAROUND ANALYSIS

GROUND TURNAROUND 160 HOURS

PAD OPERATIONS
- MOVE TO PAD
- INTERFACE VERIFICATION
- VERTICAL PAYLOAD INSTL
  (XFER 6 HR FROM OPT)
- FLUID SERVICING
- PROPELLANT LOADING
- CREW INGRESS
- SYSTEMS CHECK

ORBITER LANDING FACILITY
- SAFETY INSPECTION
- CONNECT COOLING GSE
- CONNECT TOW EQUIPMENT
- CREW EXCHANGE

SHUTTLE VEHICLE ASSEMBLY & C/O
- ORBITER MATING
- INTERFACE VERIFICATION
- ORDNANCE INSTL/CONNECTION
- CLOSEOUT

2 HR LAUNCH CAPABILITY

24 HR OFF

34 HR SVAC

65 HR

52 HR

1 HR OFF

6 HR XFER AISLE

ORBITER PROCESSING FACILITY
- SAFE & DESERVICE
- REMOVE PAYLOAD
- MAINTENANCE/REFURBISHMENT
- PAYLOAD INSTALLATION
- FUNCTIONAL VERIFICATION

SRB STACK OPERATIONS
- PARALLEL WITH OPF ACTIVITY

EXTERNAL TANK C/O & STACKING OPS
- PARALLEL WITH OPF ACTIVITY

ORBITER PREMATE OPERATIONS
- RETRACT LANDING GEAR
- CONNECT CRANES
- ROTATE TO VERTICAL

- USE STAR 20 & AUXILIARY DOCUMENTS FOR BASELINE
- 2-SHIFT OPERATIONS
- DETERMINE FLEET, FACILITY TIME INTERACTIONS

Space Operations/Integration & Satellite Systems Division

Rockwell International

101SSD21925
DEDICATED ORBITER EFFECTS

NON-SOC TO SOC MISSION CONFIGURATION
- MAX CHANGEOUT OPERATION
- BEST AND WORST MISSION SCHEDULES
- RANGE OF TRAFFIC LEVELS
SOC VS NO SOC

SPACE PROGRAM REQMTS
MISSION MODEL

SOC

- SOC SUPPORT REQMTS
- MANIFEST RULES FOR SOC
  - P/L TOPPING
  - ET PROPELLANT SCAVENGING
  - SOC INTERFACE EQUIP
- MISSION SCHEDULING RULES
  - OTV AND PROPELLANT AVAILABILITY
  - SPLIT P/L DELIVERIES

VS

NO SOC

- MISSION SUPPORT REQMTS
  - UNIQUE EQUIPMENT SPECIAL OPERATIONS
- MANIFEST RULES FOR NON-SOC OPERATIONS
  - P/L CAPABILITY TO DESTINATION ORBITS
  - P/L SHARING CONSTRAINTS
- MISSION SCHEDULING RULES
  - MULTI-SHUTTLE MISSIONS
  - LAUNCH WINDOW CONSTRAINTS
  - MISSION DURATION
SOC PROPellant DELIVERY OPTIONS

TRAFFIC MODEL

<table>
<thead>
<tr>
<th>COMMERICAL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESEARCH AND APPLICATION</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>ISSUED</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ET SCAVENGING TANKS

P/L TOPPING TANKS

FIXED CARGO

ISSUES

- SIZE RANGE OF P/L TOPPING TANKS
- COMBINED P/L TOPPING & ET SCANVENGE TANKS
- POSSIBILITY OF LAUNCH "DRY" CONCEPT

MANIFEST VARIATIONS
<table>
<thead>
<tr>
<th>Year</th>
<th>Commercial</th>
<th>NASA</th>
<th>DOD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Space Traffic**

**Reference Traffic Model Construction**

- Ground Rules and Assumptions
- Space Program Levels
- Hi - Lo Mix
- Manifest Definition and Schedules
COMMUNICATION DEMAND PROJECTIONS AND TECHNOLOGY DEVELOPMENTS

ROCKWELL COMMUNICATIONS
TRAFFIC MODEL
U.S. COMMERCIAL

COMMUNICATIONS DEMAND
PREDICTIONS ~2000 AD

100,000
10,000
1,000
100
10

EQUIVALENT V. JACE CHANNELS PER SATellite

1945 50 55 60 65 70 75 80 85 90 95 2000

YARS

SYNCOl 10
INTELSAT I
INTELSAT III
INTELSAT IV
INTELSAT V
SBS
FUTURE COMSAT
"ROCKWELL STUDY RANGE"
"INTELSAT VII CONCEPT"
"MATURING COMMUNICATIONS"
"1ST COMMERCIAL COMMUNICATIONS"
"SPUTNIK"
"IDEA"

NOTE: 1000 VOICE CHANNELS EQUIVALENT TO ONE 36 MHz TRANSPONDER

GLOBAL
U.S. ONLY
1.1% YEAR GROWTH RATE

Space Operations/Integration & Satellite Systems Division

Rockwell International

101SSD22102
MISSION MANIFEST DEVELOPMENT

<table>
<thead>
<tr>
<th>PAYLOAD CATEGORY</th>
<th>MISS OTV</th>
<th>MASS (LBS)</th>
<th>LENGTH (FEET)</th>
<th>SHUTTLE FLIGHT NO.</th>
<th>CODE</th>
<th>CARGO MANIFEST</th>
<th>WEIGHT (K LBS)</th>
<th>LENGTH (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOC LOGISTICS</td>
<td>4</td>
<td>35,000</td>
<td>26</td>
<td>1-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTV</td>
<td>1</td>
<td>5,020</td>
<td>25</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTV DELIVERY NO. 2</td>
<td>0</td>
<td>11,000</td>
<td>20</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TELEOPERATOR</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMMUNICATIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US COMMERCIAL TYPE IV S/C</td>
<td>5</td>
<td>12,000</td>
<td>44</td>
<td>7-11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TYPE V S/C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOREIGN TYPE IV S/C</td>
<td>2</td>
<td>12,000</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TYPE V S/C</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 11 YEARS OPERATIONS
- ALL MISSIONS AREAS
- PAYLOAD PHYSICAL CHARACTERISTICS AND MANIFESTING GROUNDRULES USED TO ESTABLISH 3 TRAFFIC MODELS
- UNALLOCATED LOAD FACTOR (LF) AND PAYLOAD VOLUME USED IN PROPellant TRANSPORT ANALYSIS (A)
SUMMARY

GOALS:

- DEVELOP AN UNDERSTANDING OF THE GROUND TURNAROUND PROCESS & POTENTIAL SOC RELATED INTERACTIONS
- DETERMINE THE SIGNIFICANCE &/OR NEED FOR DEDICATED ORBITER(S)
- SHOW FLEET IMPACTS FROM NON-SOC SCENARIO
- DETERMINE PROPELLANT TANK SIZES MATCHING TRAFFIC PREDICTIONS . . . , AND UNDERSTAND THE INTERACTIONS WITH PAYLOAD DENSITY, ET SCAVENGING AND PAYLOAD TOP OFF
POSSIBLE SCAVENGING SCENARIOS

BASIC SCAVENGING

- LAUNCH WITH 65K P/L
- RECOVER STATISTICAL FPR
- SIZE SCAVENGE SYSTEM TO +3σ RESIDUALS
- OPTIONS CAN BE SIZED TO OTHER P/L WEIGHTS

P/L TOP-OFF

- LAUNCH WITH LESS THAN 65K HARD CARGO
- TOP-OFF TO 65K WITH PROPELLANT
- SIZE SCAVENGE SYSTEM TO +3σ RESIDUALS
- OPTION TO COMBINE SCAVENGE VOLUME INTO TOP-OFF TANKS
- OPTION TO LAUNCH "DRY"

DEDICATED TANKER

- LAUNCH WITH 65K PROPELLANT
- SIZE SCAVENGE SYSTEM TO +3σ RESIDUALS
- OPTION TO OVERSIZE TANKER TO INCLUDE SCAVENGE
- OPTION TO LAUNCH "DRY"
KEY ISSUES

- MECO TRANSIENTS
  - ULLAGE THRUST STEERING
  - PRACTICAL HARDWARE CONCEPTS
  - PROCEDURES AND CREW OPERATIONS
  - SAFETY IMPLICATIONS
ULLAGE THRUST OPTIONS

DUAL PRCS THRUSTERS

- 2 X 870 = 1740 lb_f
- T/W = 0.0047 g/s
- \( \dot{w}_p \approx 414 \text{ lb/min} \)
- MINIMUM ORBITER IMPACT

SINGLE PRCS THRUSTER

- 1 X 870 = 870 lb_f
- T/W = 0.0024 g/s
- \( \dot{w}_p \approx 207 \text{ lb/min} \)
- ATTITUDE CONTROL SOFTWARE MOD

ADDED VERNIER THRUSTERS

- \( T_{\text{INITIAL}} = 2 \times 870 = 1740 \text{ lb_f} \) (APPROX. 40 - 60 sec)
- \( T_{\text{FINAL}} = \text{DRAG + 50 lb_f} \)
- T/W = \( 10^{-4} \) g/s
- \( \dot{w}_p \approx 11.5 \text{ lb/min} \)
- HARDWARE & SOFTWARE MODS
ULLAGE THRUST PROPELLANT REQUIREMENTS

<table>
<thead>
<tr>
<th>RCS PROPELLANT BUDGET, LB.</th>
<th>ASCENT/DESCENT</th>
<th>(3398)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INSERTION AND ORBIT ADJUST ENTRY</td>
<td>1127</td>
</tr>
<tr>
<td></td>
<td>RESIDUALS AND CONTINGENCIES</td>
<td>1164</td>
</tr>
<tr>
<td>MISSION OPERATIONS</td>
<td>(1450)</td>
<td></td>
</tr>
<tr>
<td>RENDEZVOUS</td>
<td>1450</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>4848</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL PROPELLANT LOADED
7254 LB

AVAILABLE FOR ULLAGE THRUST
7254 - 4848 = 2406 LB

2/3 IN AFT QUADS = 1604 LB

---

![Diagram showing Ullage Thrust Requirements](image_url)
POST MECO TRAJECTORY PROFILE OPTIONS

CASE 3: 20 MINUTE ULLAGE (50 LB + DRAG)
CASE 4: 21 MINUTE ULLAGE (1 RCS)

MPS ULLAGE
21 MIN (1 RCS)

ET JETTISON
OMS BURN

OMS BURN

20 MIN (50 LB + DRAG)

ET DISPOSAL

TUMBLING

NON-TUMBLING

AFRICA

AUSTRALIA

DOWNRANGE FROM ETR (1000 NM)

ALTITUDE (1000 FT)

160 NM INSERTION
28.5 DEG INCLINATION

NON-TUMBLING

TUMBLING

ORIGINAL PAGE 18
OF POOR QUALITY

Space Operations/Integration & Satellite Systems Division
Rockwell International

10155D21978
DELTA MECO FOR ET IMPACT CONTROL

RCS BURN TIME (MIN)

"IDEALIZED" THRUSTING

MECO CONDITIONS
- h = 57 NMI
- \( \gamma \) = 0.65 DEG
- V = 25,680 FPS

ET CONDITIONS
- WT = 70,772 LB
- Tumbling Drag
- Minimum impact latitude, 0 deg for secondary zone

PRIMARY ZONE
- 1 RCS
- 2 RCS

SECONDARY ZONE
- 1 RCS
- 2 RCS

AFRICA IMPACT

AUSTRALIA IMPACT

MECO \( \Delta V \) BIAS (FT/SEC)

0 25 50 75 100 125

-50 -25 0
**ET IMPACT DISPERSIONS**

**SECONDARY ZONE DISPERSIONS ARE PROBABLY ACCEPTABLE**

<table>
<thead>
<tr>
<th>IMPACT ZONE</th>
<th>NUMBER OF RCS</th>
<th>RCS THRUST (LB)</th>
<th>THRUST TIME (MINUTESC)</th>
<th>$aR/aW$ (NM/%)</th>
<th>$aR/aC_A$ (NM/%)</th>
<th>$aR/aV$ (NM/FPS)</th>
<th>$aR/a_p$ (NM/%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SECONDARY</td>
<td>1</td>
<td>870</td>
<td>20.8</td>
<td>10</td>
<td>-9.8</td>
<td>109</td>
<td>-10.1</td>
</tr>
<tr>
<td>SECONDARY</td>
<td>2</td>
<td>1740</td>
<td>11.0</td>
<td>6.4</td>
<td>-5.9</td>
<td>63</td>
<td>-6.1</td>
</tr>
<tr>
<td>PRIMARY</td>
<td>1</td>
<td>870</td>
<td>5.0</td>
<td>2.8</td>
<td>-2.9</td>
<td>42</td>
<td>-3.0</td>
</tr>
<tr>
<td>PRIMARY</td>
<td>2</td>
<td>1740</td>
<td>5.0</td>
<td>2.8</td>
<td>-3.0</td>
<td>43</td>
<td>-3.1</td>
</tr>
</tbody>
</table>

$V_{MECO} = 25,680$ FPS (NOMINAL)

ET WEIGHT = 70,772 LB

$C_{AET} = 0.25$

STD AMOS (1962)
# Payload Impacts

<table>
<thead>
<tr>
<th>Option</th>
<th>ET Impact Zone</th>
<th>No. of RCS Thrusters</th>
<th>Thrust (LB)</th>
<th>Ullage Time (Minutes)</th>
<th>∆V MECO (FPS)</th>
<th>∆V P/L (1) Per ΔMECO (LB)</th>
<th>∆OMS Propellant (LB)</th>
<th>RCS Propellant for Ullage Thrust (LB)</th>
<th>∆P/L Net (LB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>2</td>
<td>1740</td>
<td>5</td>
<td>-50</td>
<td>+1284</td>
<td>+474</td>
<td>2070</td>
<td>+344</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>1</td>
<td>870</td>
<td>5</td>
<td>-25</td>
<td>+642</td>
<td>+469</td>
<td>1035</td>
<td>+742</td>
</tr>
<tr>
<td>3</td>
<td>I</td>
<td>0</td>
<td>50+DRAG</td>
<td>20</td>
<td>-5</td>
<td>+128</td>
<td>+260</td>
<td>224</td>
<td>+1248</td>
</tr>
<tr>
<td>4</td>
<td>II</td>
<td>1</td>
<td>870</td>
<td>20.3</td>
<td>0</td>
<td>-2597</td>
<td>4306</td>
<td>2702</td>
<td>-105</td>
</tr>
<tr>
<td>5</td>
<td>II</td>
<td>2</td>
<td>1740</td>
<td>11</td>
<td>0</td>
<td>-2564</td>
<td>4554</td>
<td>2950</td>
<td>-386</td>
</tr>
<tr>
<td>6</td>
<td>II</td>
<td>2</td>
<td>1740</td>
<td>8</td>
<td>+30</td>
<td>-771</td>
<td>-2589</td>
<td>3312</td>
<td>+110</td>
</tr>
</tbody>
</table>

(1) An early MECO cutoff provides an increase in payload at the rate of 25.7 lb per fps

(2) Negative number indicates less than full RCS propellant is required and offloaded propellant could be credited to additional payload.

Negligible payload impact
THRUSTR AND CG GEOMETRY

CG COORDINATES

<table>
<thead>
<tr>
<th>BRM NO. 6</th>
<th>MECO MASS, lb</th>
<th>X₀</th>
<th>Y₀</th>
<th>Z₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>65K ETR</td>
<td>366,500</td>
<td>964</td>
<td>2.1</td>
<td>324</td>
</tr>
<tr>
<td>30K ETR</td>
<td>352,400</td>
<td>922</td>
<td>2.0</td>
<td>266</td>
</tr>
</tbody>
</table>

AFT RCS THRUST APPLICATION

<table>
<thead>
<tr>
<th></th>
<th>X₀</th>
<th>Y₀</th>
<th>Z₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEFT</td>
<td>1516</td>
<td>-132</td>
<td>480.5</td>
</tr>
<tr>
<td>SIDE</td>
<td>1529</td>
<td>-132</td>
<td>480.5</td>
</tr>
<tr>
<td>UP</td>
<td>1542</td>
<td>-132</td>
<td>480.5</td>
</tr>
<tr>
<td>RIGHT</td>
<td>1516</td>
<td>132</td>
<td>480.5</td>
</tr>
<tr>
<td>SIDE</td>
<td>1529</td>
<td>132</td>
<td>480.5</td>
</tr>
<tr>
<td>DOWN</td>
<td>1542</td>
<td>132</td>
<td>480.5</td>
</tr>
<tr>
<td>LEFT</td>
<td>1516</td>
<td>-111.95</td>
<td>437.4</td>
</tr>
<tr>
<td>SIDE</td>
<td>1529</td>
<td>-111.0</td>
<td>440.0</td>
</tr>
<tr>
<td>DOWN</td>
<td>1542</td>
<td>-110.06</td>
<td>442.6</td>
</tr>
</tbody>
</table>

Space Operations/Integration & Satellite Systems Division

Rockwell International

10155D21913
ULLAGE THRUST STEERING

FWD RCS STEERING

\[ T_Z = 640 \text{ lb}_f \]
\[ \% T_Z = \frac{\Delta Z}{L_{\text{FWD}}} \times \frac{870}{640} \]
\[ \approx 2.7\% \text{ PER ft } \Delta Z \]
\[ \dot{w}_p = 428 \text{ lb/min MAX} \]

AFT RCS STEERING

\[ T_Z = 870 \text{ lb}_f \]
\[ \% T_Z = \frac{\Delta Z}{L_{\text{AFT}}} \]
\[ \approx 2\% \text{ PER ft } \Delta Z \]
\[ \dot{w}_p = 414 \text{ lb/min MAX} \]

ANGULAR ACCELERATION

\[ \Delta t_1 \approx 6.6 \text{ sec} \]
\[ \Delta t_2 \approx 0.8 \text{ sec} \]
MECO THRUST TRANSIENT EFFECTS

- **Bulkhead "Twang"**
  - BEFORE MECO
  - AFTER MECO
  - Strain energy

- **RCS Thrust Direction**
  - MAIN ENGINE THRUST ENVELOPE AT MECO (DUE TO CG VARIATIONS)
  - 11.5°
  - 5.5°

- **MECO Thrust Tailoff**
  - \( T = 1.5 \text{ sec} \)

- **Shuttle Hydro Elastic Modeling at MECO**
  - SHELL-FLUID \( f_c = 26 \text{ Hz} \)
  - \( T = 39 \phi / T \)
  - Structural response:
    - \( R = 1 + \cosh\left(\frac{\pi T}{T_i}\right) \approx 1.00016 \)
  - **No "Twang" Problem**

- **Pendulum Motion**
  - CENTERED ABOUT \( 10^0 \text{ RCS Thrust Direction} \)
  - \( T = 2\sqrt{\frac{T}{g}} = 64.8 \text{ sec} \)
  - AT \( T/W = 0.0047 \text{ g's} \)
  - **Amplitude**
    - \( R \theta_{\text{MAX}} \approx 16 \text{ inches} \)
  - **Very Mild Transient**

---

Original Page 13

Space Operations/Integration & Satellite Systems Division

Rockwell International

'101SSD21920
ET LO₂ TANK DRAINING

60 KLB LO₂

33.4 IN.

FEEDLINE (17 IN. DIA) HOLDS ~17KLB LO₂

EDGE OF SUMP BELL 17°

RCS VECTOR 10°

OUTLET G, 8°

- NO GEOMETRIC OR INERTIAL TRAPPING OF LOX DURING ET SCAVENGING (DUE TO LARGE OUTLET BELL)
- LO₂ TRAPPED IN ET BY SURFACE TENSION:
  ~ 2000 LB AT 10⁻⁴ G
  ~ 300 LB AT 10⁻³ G
- ADEQUATE TANK DRAINING IS POSSIBLE

CRUCIFORM ANTI-VORTEX BAFFLES (PROVIDE SLOSH DAMPING AT LOW LIQUID LEVELS)
LH₂ TANK DRAINING

EXTERNAL TANK 17 IN. LH₂ FEED DUCT

- ORBITER ET

- ANTI-VOlTEX BAFFLES (PASSIVE SLOSH DAMPING)

- EDGE OF SIPHON 17°

- RCS VECTOR 10°

- OUTLET Q. 8°

- NOMINAL RESIDUAL (3098 LB)

- LH₂ TRAPPED IN ET
  (FLOW INERTIA AND SURFACE TENSION)

  ~1000 LB AT 10⁻⁴ G & 650 LB/MIN
  ~200 LB AT 10⁻³ G & 650 LB/MIN
  ~400 LB AT 10⁻⁴ G & 100 LB/MIN

- ADEQUATE TANK DRAINING IS POSSIBLE

Space Operations/Integration & Satellite Systems Division

Rockwell International

101SSD21996
NOMINAL PROPELLANT RESIDUALS AT MECO

- INCLUDES ET & MPS PLUMBING

'ORBITER 103 NOMINAL'
RESIDUAL FOR ZERO
CARGO (71K LB)

DEDICATED
TANKER
"DRY LAUNCH"

TOTAL

P/L TOPPING

BASIC
SCAVENGING

ORBITER 103
(TARGET)

VOL XIV

STRAP-ONS

LH₂

LO₂

114% THRUST

UNUSED PAYLOAD CAPACITY - 1000 LB

NOMINAL RESIDUAL AT MECO - 1000 LB
PROPELLANT RESIDUALS AT MECO (+5 SECONDS)

**LOX**
- Max Possible Residual (Dry Launch) 65,000
- Tank Bottom 17,000
- +3 Sigma Residual 11,035
- Nominal Residual 6280
- ET Disconnect
- -3 Sigma Residual (Low Level C/O) 1525
- Main Oxidizer Valve

**LH₂**
- Max Possible Residual (Dry Launch) 13,000
- +3 Sigma Residual 13893
- Nominal Residual 3098
- FUEL BIAS
- -3 Sigma Residual 2303
- Low Level Cutoff 1203
- Tank Bottom 1563
- ET Disconnect 1403
- Main Fuel Valve

Space Operations/Integration & Satellite Systems Division
Rockwell International
101SSD21918
FLOW RATE REQUIREMENTS

**LH₂ FLOW RATE**

**LO₂ FLOW RATE**

PROPELLANT QUANTITY, LB

FLOW RATE, LB/MIN

TRANSFER TIME, MINUTES

550 TO 650 LB/MIN

10K

5K

3K

1K

PROPELLANT QUANTITY, LBS

FLOW RATE, LB/MIN

TRANSFER TIME, MINUTES

1500 TO 2000 LB/MIN

50K

40K

30K

20K

10K

5K
ET LO₂ TRANSFER PHENOMENA

- 65 KLB XFER
- NO PUMP
- 7.5 IN. DIA LINE

10 (PUMP ONLY)

2 IN. DIA

30 PSI

OVBD VENT

RECEIVER TANK

- AXIAL MIXING AND ULLAGE CONDENSATION

BOOST PUMP (OPTIONAL)

14 BTU/SEC MPS HEATING

CHILLDOWN SPRAY NOZZLES (TANGENTIAL)

BOOST PUMP (OPTIONAL)

15 BTU/SEC FEEDLINE HEATING (FROM ORBITER TILES)

ET LO₂ TANK

NEGligible HEATING AT LO₂ B/H

65 KLB (MAX RESIDUAL)

16 KLB (NOMINAL RESIDUAL)

LEGEND

- ULLAGE VAPOR

++ SUBCOOLED LIQUID

00 2 B

10155D21957

Space Operations/Integration & Satellite Systems Division

Rockwell International
LO₂ TRANSFER PRESSURE HISTORIES

- 98% RESIDUAL RECOVERY
- COMPUTER SIMULATION OF ET ULLAGE PRESSURE HISTORY
- POST-MECO ET ACCELERATION 10⁻⁴ G

LO₂ PRESSURIZATION SYSTEM PERFORMANCE FOR BRM-1
FCV ORIFICES -6500, -6510
VARIABLE CO

![Graph showing LO₂ transfer pressure histories with key points:
- ET ULLAGE PRESSURE
- PUMP ASSIST REQUIRED ABOVE ET PRESS. CURVE
- RECEIVER TANK PRESSURES (TYPICAL)
- MECO
- MECO + 20 MIN
- TIME FROM LIFTOFF (SEC)
- Pressures range from 12 to 24 PSIA, with specific pressures such as 20 KLB XFER, 3250 LB/MIN, 65 KLB XFER, and 1000 LB/MIN marked.
]
TYPICAL LO₂ VAPOR PRESSURE PROFILES

- CONSTANT TRANSFER RATE 3250 LB/MIN
- WORST CASE POST-MECO HEATING
- ET LO₂ SETTLING \( (10^{-4} \text{ 6 MINIMUM}) \)

![Graph showing typical LO₂ vapor pressure profiles with key points labeled: START 2 Ω, ET PRESS, 1/Ω AT PUMP OUTLET, 2 Ω AT PUMP INLET, START, ZERO ET ΔP, 165 KLB XFER (20 MIN), ET ΔP, LO₂ PROFILE AT MECO, MAX RESIDUAL (ZERO CARGO).]
LO$_2$ TRANSFER LINE SIZE

- MAX RESIDUAL
  - M$_1$ ~ 4500 LB/Min (AVG)
  - XFER TIME ~ 15 MIN

- DOMINATED BY ET PRESSURE DECAY

- ET TANK BOTTOM
  - M ~ 3000 LB/Min (AVG)
  - XFER TIME ~ 6 MIN

- ET PRESS DECAY BASED ON $10^{-4}$

- ET DISCONNECT
  - CLOSED AT MECO PLUS 10 SEC
  - CRYS PUMPING FROM MPS ONLY

- RECEPTOR CLOSED WHEN LIQUID SURFACE PASSES (THE NEXT, MPS RESIDUAL CRYO PUMPS INTO RECEIVER)

- 2% or 200 LB RESIDUAL LOSS (WHICHEVER GREATER)

ORIGINAL PAGE IS OF POOR QUALITY.
LH₂ TRANSFER PRESSURE HISTORIES

- PRESSURIZED XFER
- 98% RESIDUAL RECOVERY
- COMPUTER SIMULATION OF ET ULLAGE PRESSURE HISTORY
- 10⁻⁴ G POST-MECO ACCELERATION

LH₂ PRESSURIZATION SYSTEM PERFORMANCE FOR BRM-I
PRESSURANT SUPPLY CONDITIONS BASED ON JULY, 1980 INFLUENCE COEFFICIENTS
FCV ORIFICES -5400, -5410

![Graph showing LH₂ transfer pressure histories](image-url)
LH₂ TRANSFER BOOST PUMP TRADE

- WORST CASE HEATING
- 10⁻⁴ G (ET PRESS DECAY)
- 98% LH₂ RECOVERY
- INCLUDES EFFECTS OF 2 \( \phi \) FLOW

JET LOW-LEVEL C/O
(1203 LB)

BOUNDARY FOR ET PRESSURIZED XFER
(3.2 IN. DIA MINIMUM)

CENTAUR PUMP
(6700 RPM)

+3-SIGMA RESIDUAL
(3893 LB)

MAX RESIDUAL
(13 KLB)

7 MIN XFER
ZERO KW
1 KW
10 KW
10 KW
40 MIN XFER
(ZERO KW)

LH₂ RESIDUAL MASS AT MECO (1000 LB)

PRESSURIZED TRANSFER THE WAY TO GO

Space Operations/Integration & Satellite Systems Division

Rockwell International

1015SD21999
ORBITER - MAIN PROPULSION SYSTEM.

CONCEPT 'A'

LO₂ FILL & DRAIN PORT

AVIONICS BAY 5

LO₂ PROPELLANT
SCAVERNING
FEED LINE ASSEMBLY

LO₂
UMBILICAL
ASSEMBLY

LO₂
FEED
LINE

AVIONICS
BAY 4

AVIONICS
BAY 6

BOOST PUMP
(OPTIONAL)

LH₂ PROPELLANT SCAVENGING
FEED LINE ASSEMBLY

LH₂ HI-POINT BLEED PORT

LH₂ FILL & DRAIN PORT

LH₂ DUMP PORT
(DUMP LINE PUMP - OPTIONAL)

LH₂ FEED LINE

LH₂ UMBILICAL
ASSEMBLY
TORUS & RING TANK CONCEPTS

LO₂ TANK
VOL 296.93 FT³
WT 21141.42 LB

X₀ 1194
X₀ 1198.8
X₀ 1206.67

LH₂ TORSUS TANK
VOL 779.5 FT³
WT 3461 LB

ΣWₚ = 24,600 LB AT 6 : 1 MIX

LO₂ TANK
VOL 387.1 FT³
WT 27564 LB

X₀ 1194
X₀ 1198.8
X₀ 1206.67

LH₂ RING TANK
VOL 1018.0 FT³
WT 4520.0 LB

ΣWₚ = 32,000 LB AT 6 : 1 MIX

Space Operations/Integration & Satellite Systems Division

Rockwell International

101SSD21976
## REPRESENTATIVE SCAVENGING SEQUENCE

<table>
<thead>
<tr>
<th>TIME</th>
<th>EVENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/O + 100 SEC</td>
<td>START VENTING RECEIVER TANKS</td>
</tr>
<tr>
<td>MECO</td>
<td>TURN ON RCS SETTLING THRUSTERS</td>
</tr>
<tr>
<td>MECO + 10 SEC</td>
<td>VERIFY RECEIVER TANKS BELOW ONE PSIA</td>
</tr>
<tr>
<td>MECO + 15 SEC</td>
<td>CLOSE RECEIVER VENT VALVES</td>
</tr>
<tr>
<td>MECO + 60 SEC</td>
<td>OPEN ISO-VALVES TO START CHILLOWS OF LOX &amp; LH2 XFER LINES</td>
</tr>
<tr>
<td>MECO + 400 SEC</td>
<td>MONITOR SYSTEM FLOWS/TEMPS/PRESS</td>
</tr>
<tr>
<td>MECO + 480 SEC</td>
<td>STOP LOX PUMP AND CLOSE ET DISCONNECT WHEN ET LINE DEPLETED</td>
</tr>
<tr>
<td></td>
<td>(FLOW RATE &lt; 5% AS RECEIVER PRESSURE REACHES 26 PSIA). ALLOW CRYOPUMPING FROM MPS INTO RECEIVER TANK</td>
</tr>
<tr>
<td></td>
<td>STOP RCS SETTLING THRUSTS WHEN LH2 ET DEPLETED (EXCESSIVE BUBBLES IN XFER LINE) AND ALLOW LH2 SIPHON TO DRAIN (AIDED BY AERO-DRAG)</td>
</tr>
<tr>
<td>MECO + 1200 SEC</td>
<td>CLOSE LH2 ET DISCONNECT WHEN LH2 SIPHON DEPLETED (FLOW RATE &lt; 5% OR RECEIVER PRESSURE REACHES 26 PSIA). ALLOW CRYOPUMPING FROM MPS INTO RECEIVER TANK</td>
</tr>
<tr>
<td>MECO + 1400 SEC</td>
<td>OMS I BURN</td>
</tr>
<tr>
<td></td>
<td>VENT MPS PLUMBING AND SECURE XFER SYSTEM</td>
</tr>
</tbody>
</table>

### ASSUMPTIONS
- MAXIMUM RESIDUALS (65K LOX, 13K LH2)
- 8 MINUTE XFER TIME
- PRESSURIZED LH2 XFER (6 IN. DIA LINE)
- PUMPED LOX XFER (6 KW, 6 IN. DIA LINE)
- SECONDARY ZONE ET IMPACT
- SETTLING THRUST, $5 \times 10^{-3}$ G (2 PRIMARY RCS THRUSTERS)
- LH2 RECEIVER TANK PRECHILLED TO 160°F (LN2)
## Safety Considerations

<table>
<thead>
<tr>
<th>Issue</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Integrity</td>
<td>Qualify to MPS Plumbing Req</td>
</tr>
<tr>
<td>MPS Integrity</td>
<td>Multiple Isolation Valves</td>
</tr>
<tr>
<td>Valve Malfunction</td>
<td>Redundant Valving</td>
</tr>
<tr>
<td>O₂ and H₂ Leakage</td>
<td>GN₂ Purge on the Pad; Minimal Hazard in Space</td>
</tr>
<tr>
<td>Safeing for Re-Entry</td>
<td>Vent System to Space, Press to 16 PSIA with Inert Gas</td>
</tr>
<tr>
<td>ET Impact</td>
<td>Acceptable Impact Zones are Achievable</td>
</tr>
<tr>
<td>MECO Change</td>
<td>Less than 1 second change required</td>
</tr>
<tr>
<td>RCS Mods</td>
<td>Within the Complexity Level of Current System</td>
</tr>
<tr>
<td>Crew Operations</td>
<td>Minimal Action Required Before MECO</td>
</tr>
<tr>
<td>Orbiter Engine Out</td>
<td>Shuttle E/O Tolerance Increased with &quot;Dry Launch&quot; Concept</td>
</tr>
<tr>
<td>LO₂ and LH₂ Abort Dumping</td>
<td>None Required with &quot;Dry Launch&quot; Concept</td>
</tr>
</tbody>
</table>
SUMMARY

- ESTABLISHED SUBORBITAL ET PROPELLANT RECOVERY AS A VIABLE CONCEPT
  - PROPELLANT TRANSFER ACHIEVABLE WITHIN PRACTICAL TIMES
  - ULLAGE THRUSTING REQUIREMENTS CAN BE MET BY PRIMARY RCS
  - PLUMBING REQUIREMENTS CAN BE SATISFIED WITHIN ORBITER SPACE/VOLUME CONSTRAINTS
  - ET IMPACT ZONES ARE ACCEPTABLE
  - EFFECTS ON SHUTTLE PAYLOADS ARE NEGLIGIBLE
  - WIDE RANGE OF APPLICATIONS ARE POSSIBLE
    - BEST APPLICATION IS TRAFFIC DEPENDENT
  - NEXT STEP . . . FURTHER HARDWARE DEFINITION AND STUDY PRELIMINARY OF COST IMPLICATIONS
TASK 2 -- SOC ASSEMBLY OPERATIONS OBJECTIVES

- CONFIRM CAPABILITY OF RMS TO ASSEMBLE SOC

- DETERMINE ASSEMBLY OPERATIONAL IMPLICATIONS

- DETERMINE IMPLICATIONS TO SOC MODULES
TASK 2 - SOC ASSEMBLY OPERATIONS
APPROACH

SOC ASSEMBLY CONCEPT

GRAPPLE FIXTURE COORDINATES

RMS PARAMETERS

RMSKAT

ASSESS RMS MOTION PATH

ADOPT AS BASELINE

WITHIN DESIRED OPERATING RANGE?

YES

YES

COMPATIBLE WITH RMS CAPABILITIES?

NO

NO

SELECT ANOTHER LOCATION

DETERMINE IMPLICATIONS
RMS/SOC ASSEMBLY ISSUES

- RMS REACH & JOINT LIMITS DURING SOC ASSEMBLY TRAJECTORIES
  - START & FINAL END EFFECTOR LOCATIONS
  - IN-BETWEEN POINTS
- PRACTICAL LOCATION ZONES FOR GRAPPLE FIXTURES
- BERTHING ACCURACY VS GRAPPLE FIXTURE LOCATION
- ASSEMBLY AIDS -- DM, HPA, PIDA
- OPERATOR VISIBILITY
- COLLISION AVOIDANCE DURING ASSEMBLY
RMS PARAMETERS OF MAIN INTEREST

- **JOINT ANGLE LIMITS AT BERTHING**
  - NO BERTHING IN REACH LIMIT OR SINGULARITY ZONES
  - WRIST YAW ANGLE NOT GREATER THAN ± 60 DEG
  - ELBOW ANGLE NOT LESS THAN - 40 DEG

- **GRAPPLE FIXTURE LOCATION**
  - WITHIN 5% (OF PAYLOAD LENGTH) OF THE Y-Z
  - PLANE OF PAYLOAD CENTER OF MASS

- **POSITIONING ACCURACY -- RELATIVE TO ORBITER**
  - AUTO MODE: ± 9 INCHES MAX INCLUDES MECHANICAL INACCURACIES & ± 3 DEGREES MAX THERMAL DISTORTIONS
  - MAN: FUNCTION OF OPERATOR VISIBILITY
REMOTE MANIPULATOR SYSTEM KINEMATIC ANALYSIS TOOL
(RMSKAT)*

- COMPUTER PROGRAM FOR KINEMATIC EVALUATION OF RMS OPERATIONAL ENVELOPES
- RIGID BODY SIMULATIONS ONLY
- GRAPHIC FEEDBACK (SOC GRAPHICS MOD IN PROGRESS)
- TWO OPERATING MODES

**INPUT**
- START & FINAL END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM
- RMS JOINT ANGLE SPECIFICATIONS

**OUTPUT**
- RMS JOINT ANGLE READINGS AT SPECIFIED TIME INTERVALS
- END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM

*DEVELOPED WITH DISCRETIONARY FUNDS

---

Space Operations/Integration & Satellite Systems Division
Rockwell International

91SSD21819
# RMSKAT SAMPLE OUTPUT

<table>
<thead>
<tr>
<th>TIME</th>
<th>0.00 SECONDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSPOS 1</td>
<td>-1107.000</td>
</tr>
<tr>
<td>POSPOS 2</td>
<td>25.000</td>
</tr>
<tr>
<td>POSPOS 3</td>
<td>0.000</td>
</tr>
<tr>
<td>POSPOS 4</td>
<td>0.000</td>
</tr>
<tr>
<td>ATTRES 1</td>
<td>270.000</td>
</tr>
<tr>
<td>ATTRES 2</td>
<td>0.010</td>
</tr>
<tr>
<td>ATTRES 3</td>
<td>270.000</td>
</tr>
<tr>
<td>GARCH 1</td>
<td>0.000</td>
</tr>
<tr>
<td>GARCH 2</td>
<td>0.100</td>
</tr>
<tr>
<td>GARCH 3</td>
<td>0.100</td>
</tr>
<tr>
<td>GARCH 4</td>
<td>0.100</td>
</tr>
<tr>
<td>RANPOS 1</td>
<td>0.000</td>
</tr>
<tr>
<td>RANPOS 2</td>
<td>0.000</td>
</tr>
<tr>
<td>RANPOS 3</td>
<td>0.000</td>
</tr>
<tr>
<td>RANPOS 4</td>
<td>0.000</td>
</tr>
<tr>
<td>GARCH 1</td>
<td>-52.660</td>
</tr>
<tr>
<td>GARCH 2</td>
<td>99.830</td>
</tr>
<tr>
<td>GARCH 3</td>
<td>-126.970</td>
</tr>
<tr>
<td>GARCH 4</td>
<td>-77.050</td>
</tr>
<tr>
<td>RANANG 1</td>
<td>-52.660</td>
</tr>
<tr>
<td>RANANG 2</td>
<td>99.830</td>
</tr>
<tr>
<td>RANANG 3</td>
<td>-126.970</td>
</tr>
<tr>
<td>RANANG 4</td>
<td>-77.050</td>
</tr>
<tr>
<td>ARCHD 1</td>
<td>0.000</td>
</tr>
<tr>
<td>ARCHD 2</td>
<td>0.000</td>
</tr>
<tr>
<td>ARCHD 3</td>
<td>0.000</td>
</tr>
<tr>
<td>ARCHD 4</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 1</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 2</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 3</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 4</td>
<td>0.000</td>
</tr>
<tr>
<td>FORANG 1</td>
<td>209.152</td>
</tr>
<tr>
<td>FORANG 2</td>
<td>-7.877</td>
</tr>
<tr>
<td>FORANG 3</td>
<td>92.920</td>
</tr>
<tr>
<td>VELFOR 1</td>
<td>-1.720</td>
</tr>
<tr>
<td>VELFOR 2</td>
<td>0.000</td>
</tr>
<tr>
<td>VELFOR 3</td>
<td>0.020</td>
</tr>
<tr>
<td>PATOE11</td>
<td>1.000</td>
</tr>
<tr>
<td>PATOE12</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE13</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE21</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE22</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE23</td>
<td>0.000</td>
</tr>
<tr>
<td>RINSEL 1</td>
<td>0.000</td>
</tr>
<tr>
<td>RINSEL 2</td>
<td>0.000</td>
</tr>
<tr>
<td>RINSEL 3</td>
<td>0.000</td>
</tr>
<tr>
<td>XLTINE 1</td>
<td>0.000</td>
</tr>
<tr>
<td>XLTINE 2</td>
<td>0.000</td>
</tr>
<tr>
<td>XLTINE 3</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TIME</th>
<th>10.00 SECONDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSPOS 1</td>
<td>-1107.000</td>
</tr>
<tr>
<td>POSPOS 2</td>
<td>25.000</td>
</tr>
<tr>
<td>POSPOS 3</td>
<td>0.000</td>
</tr>
<tr>
<td>POSPOS 4</td>
<td>0.000</td>
</tr>
<tr>
<td>ATTRES 1</td>
<td>270.000</td>
</tr>
<tr>
<td>ATTRES 2</td>
<td>0.010</td>
</tr>
<tr>
<td>ATTRES 3</td>
<td>270.000</td>
</tr>
<tr>
<td>GARCH 1</td>
<td>0.000</td>
</tr>
<tr>
<td>GARCH 2</td>
<td>2.270</td>
</tr>
<tr>
<td>GARCH 3</td>
<td>-2.270</td>
</tr>
<tr>
<td>GARCH 4</td>
<td>0.853</td>
</tr>
<tr>
<td>RANPOS 1</td>
<td>1.530</td>
</tr>
<tr>
<td>RANPOS 2</td>
<td>-2.290</td>
</tr>
<tr>
<td>RANPOS 3</td>
<td>2.663</td>
</tr>
<tr>
<td>RANPOS 4</td>
<td>0.853</td>
</tr>
<tr>
<td>GARCH 1</td>
<td>-52.660</td>
</tr>
<tr>
<td>GARCH 2</td>
<td>99.830</td>
</tr>
<tr>
<td>GARCH 3</td>
<td>-126.970</td>
</tr>
<tr>
<td>GARCH 4</td>
<td>-77.050</td>
</tr>
<tr>
<td>RANANG 1</td>
<td>-34.977</td>
</tr>
<tr>
<td>RANANG 2</td>
<td>88.376</td>
</tr>
<tr>
<td>RANANG 3</td>
<td>-107.097</td>
</tr>
<tr>
<td>RANANG 4</td>
<td>-73.776</td>
</tr>
<tr>
<td>ARCHD 1</td>
<td>0.000</td>
</tr>
<tr>
<td>ARCHD 2</td>
<td>0.000</td>
</tr>
<tr>
<td>ARCHD 3</td>
<td>0.000</td>
</tr>
<tr>
<td>ARCHD 4</td>
<td>2.000</td>
</tr>
<tr>
<td>ROE 1</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 2</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 3</td>
<td>0.000</td>
</tr>
<tr>
<td>ROE 4</td>
<td>1.640</td>
</tr>
<tr>
<td>FORANG 1</td>
<td>261.999</td>
</tr>
<tr>
<td>FORANG 2</td>
<td>-1.113</td>
</tr>
<tr>
<td>FORANG 3</td>
<td>91.039</td>
</tr>
<tr>
<td>VELFOR 1</td>
<td>-1.720</td>
</tr>
<tr>
<td>VELFOR 2</td>
<td>0.000</td>
</tr>
<tr>
<td>VELFOR 3</td>
<td>0.920</td>
</tr>
<tr>
<td>PATOE11</td>
<td>1.000</td>
</tr>
<tr>
<td>PATOE12</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE13</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE21</td>
<td>1.000</td>
</tr>
<tr>
<td>PATOE22</td>
<td>0.000</td>
</tr>
<tr>
<td>PATOE23</td>
<td>0.000</td>
</tr>
<tr>
<td>RINSEL 1</td>
<td>0.010</td>
</tr>
<tr>
<td>RINSEL 2</td>
<td>0.006</td>
</tr>
<tr>
<td>RINSEL 3</td>
<td>3.421</td>
</tr>
<tr>
<td>XLTINE 1</td>
<td>0.000</td>
</tr>
<tr>
<td>XLTINE 2</td>
<td>0.000</td>
</tr>
</tbody>
</table>

---

Space Operations/Integration &
Satellite Systems Division

Rockwell
International

91SSD21814
### SOC Assembly -- End Effector Locations

**Alternative Scenario No. 1**

<table>
<thead>
<tr>
<th>FLIGHT NO.</th>
<th>PAYLOAD</th>
<th>INITIAL RMS END EFECTOR COORDINATES</th>
<th>WRIST ATTITUDE</th>
<th>FINAL RMS END EFECTOR COORDINATES</th>
<th>WRIST ATTITUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SM-1</td>
<td>X₀ 1053 Y₀ 129.06 Z₀ 568.88 P 270 Y 90 R 329</td>
<td></td>
<td>X₀ 671.00 Y₀ 0 Z₀ 755.00 P 0 Y 0 R 0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SM-2</td>
<td>X₀ 1035 Y₀ 129.06 Z₀ 568.88 P 270 Y 90 R 329</td>
<td></td>
<td>X₀ 963.00 Y₀ 0 Z₀ 627.00 P 270 Y 0 R 270</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>HM-1</td>
<td>X₀ 1062 Y₀ 99.92 Z₀ 586.39 P 270 Y 90 R 329</td>
<td></td>
<td>X₀ 950.00 Y₀ -84.00 Z₀ 857.00 P 0 Y 90 R 0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>HM-2</td>
<td>X₀ 1062 Y₀ 99.92 Z₀ 586.39 P 270 Y 90 R 329</td>
<td></td>
<td>X₀ 950.00 Y₀ -84.00 Z₀ 857.00 P 0 Y 90 R 0</td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>LM</td>
<td>X₀ 1186.5 Y₀ 99.92 Z₀ 586.39 P 270 Y 90 R 329</td>
<td></td>
<td>X₀ 852.50 Y₀ 165.00 Z₀ 802.64 P 0 Y 0 R 0</td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>TM</td>
<td>X₀ 750 Y₀ 0 Z₀ 400.00 P 180 Y 180 R 0</td>
<td></td>
<td>X₀ 679.50 Y₀ -407.00 Z₀ 827.64 P 90 Y 0 R 90</td>
<td></td>
</tr>
<tr>
<td>5C</td>
<td>TM</td>
<td>X₀ 750 Y₀ 0 Z₀ 400.00 P 180 Y 180 R 0</td>
<td></td>
<td>X₀ 679.50 Y₀ -407.00 Z₀ 827.64 P 90 Y 0 R 90</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>FSF</td>
<td>X₀ 1002 Y₀ 129.06 Z₀ 568.88 P 270 Y 90 R 329</td>
<td></td>
<td>X₀ 983.00 Y₀ 0 Z₀ 773.00 P 0 Y 90 R 0</td>
<td></td>
</tr>
<tr>
<td>DM INTERFACE</td>
<td></td>
<td>X₀ 621.00 Y₀ 0 Z₀ 515.00 P 0 Y 0 R 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPA INTERFACE</td>
<td></td>
<td>X₀ 679.50 Y₀ 239.00 Z₀ 520.64 P 0 Y 0 R 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### RMS Angles -- SOC Assembly

<table>
<thead>
<tr>
<th>Module</th>
<th>SY (-177.4 TO 177.4)</th>
<th>SP (9.6 TO 142.4)</th>
<th>EP (-0.4 TO -157.6)</th>
<th>WP (-116.4 TO 116.4)</th>
<th>WY (-116.6 TO 442)</th>
<th>WR (-442 TO 442)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM-1 Stowed</td>
<td>-31.54</td>
<td>50.71</td>
<td>-72.86</td>
<td>-11.92</td>
<td>-53.47</td>
<td>-28.52</td>
</tr>
<tr>
<td>SM-1 Deployed</td>
<td>-46.68</td>
<td>68.02</td>
<td>-82.50</td>
<td>51.77</td>
<td>61.30</td>
<td>17.48</td>
</tr>
<tr>
<td>SM-1 Deployed</td>
<td>-61.82</td>
<td>85.34</td>
<td>-92.14</td>
<td>115.45</td>
<td>69.13</td>
<td>63.48</td>
</tr>
<tr>
<td>SM-2 Stowed</td>
<td>-32.82</td>
<td>54.09</td>
<td>-78.37</td>
<td>-8.85</td>
<td>-52.40</td>
<td>152.65</td>
</tr>
<tr>
<td>SM-2 Deployed</td>
<td>-32.59</td>
<td>76.54</td>
<td>-85.32</td>
<td>-92.01</td>
<td>16.32</td>
<td>-55.85</td>
</tr>
<tr>
<td>HM1 Stowed</td>
<td>-30.93</td>
<td>60.48</td>
<td>-82.34</td>
<td>-12.68</td>
<td>-53.97</td>
<td>-29.10</td>
</tr>
<tr>
<td>HM1 Deployed</td>
<td>-21.64</td>
<td>78.56</td>
<td>-42.91</td>
<td>-79.48</td>
<td>61.20</td>
<td>140.00</td>
</tr>
<tr>
<td>HM2 = HM1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Stowed</td>
<td>-28.62</td>
<td>53.82</td>
<td>-72.01</td>
<td>-18.26</td>
<td>-55.85</td>
<td>148.57</td>
</tr>
<tr>
<td>LM Deployed</td>
<td>-61.31</td>
<td>75.58</td>
<td>-68.93</td>
<td>-28.61</td>
<td>-26.91</td>
<td>169.66</td>
</tr>
<tr>
<td>TM Stowed</td>
<td>-28.99</td>
<td>71.21</td>
<td>-133.56</td>
<td>-37.38</td>
<td>-16.96</td>
<td>120.45</td>
</tr>
<tr>
<td>TM Deployed</td>
<td>0.54</td>
<td>75.00</td>
<td>-97.30</td>
<td>15.80</td>
<td>30.20</td>
<td>56.70</td>
</tr>
<tr>
<td>TM Deployed</td>
<td>27.91</td>
<td>78.80</td>
<td>-61.10</td>
<td>69.10</td>
<td>43.30</td>
<td>6.90</td>
</tr>
<tr>
<td></td>
<td>56.36</td>
<td>82.58</td>
<td>-24.99</td>
<td>122.41</td>
<td>56.36</td>
<td>-70.52</td>
</tr>
</tbody>
</table>
TASK 4 -- FLIGHT SUPPORT FACILITY
OBJECTIVES

COMPARE SERVICING/CHECKOUT LOGIC & COSTS OF
SERVICING FREE FLYERS AT THE S&O FLIGHT SUPPORT
FACILITY (FSF), ON THE GROUND & FROM THE ORBITER
TASK 4 -- FLIGHT SUPPORT FACILITY

1. SURVEY LIT. FOR CANDIDATE S/C
2. SELECT REF. S/C FOR SOC STUDY
3. GROUND SERV. SCENARIOS
4. GENERATE SERV. SCENARIOS AT SOC
5. ANAL. SERV. FUNCT. & DET. IMPL.
6. INTEG. SERV. FUNCT. INTO SOC CONFIG.
7. ORBITER SERV. SCENARIOS
8. GENERATE END-TO-END COSTING
9. IDENTIFY IMPLICATIONS
10. COMPARE COSTING
ACCOMPLISHMENTS TO DATE

- UPDATED SOC REFERENCE CONFIGURATION
- SELECTED THREE REPRESENTATIVE SPACECRAFTS FOR SERVICING & COST ESTIMATES
  - SINGLE STAGE OTV
  - GEO COMMUNICATION SATELLITE
  - SPACE PROCESSING FACILITY (FREE FLYER)
- GENERATED SERVICING SCENARIOS
- COMPLETED SERVICING SCENARIO ANALYSIS & DETERMINED IMPLICATIONS
- COMPLETED MANPOWER ESTIMATES FOR SERVICING SCENARIOS
ORBIT TRANSFER VEHICLE (OTV)

MODULAR SYSTEMS. LRU PACKAGES

SPF/OTV MATING INTERFACE

MAIN ENGINE

ACS - 4 PLACES

PIDA DEVICES - 2 PLACES

- REFUELING OF A SPECTRUM OF PROPELLANTS - LO₂ / LH₂; HYDRAZINE; He & GN₂
- EXTENSIVE SERVICING & MODULE EXCHANGE OPERATIONS ARE REQUIRED
- FREQUENT VISITS TO SOC
GEOSYNCHRONOUS COMMUNICATIONS SPACECRAFT --
CONFIGURATION NO. 1

HIGH VOL. TRUNKING
30m DIA (98.5 ft)
C BAND

RADIATOR - 2 PLACES
TOTAL AREA = 58m²

52m
(171 ft)

DIRECT TO USER - 3 PLACES
6m Ku BAND

SOLAR ARRAY - 2 PLACES
TOTAL AREA = 95m²
TOTAL POWER = 13.7kW

TELECONFERENCE
10m DIA (32.8 ft)
Ka BAND

- VERY LARGE SPACECRAFT
- EXTENSIVE DEPLOYMENT & CHECK-OUT OPERATIONS
- MATING TO OTV IS THE ONLY ASSEMBLY REQUIRED
- REVISITS TO SOC ARE NOT REQUIRED
- NO REFUELING
SPACE PROCESSING FACILITY (SPF)

- VERY SMALL SPACECRAFT
- FREQUENT VISITS TO SFC
- SERVICING INCLUDE MODULE &
- COMPONENT EXCHANGE OPERATIONS
- REFUELING IS REQUIRED

COMPLETE CONTROLS
MODULE REMOVABLE

REMOVABLE AVIONIC
PACKAGES (5 PLACES)

REMOVABLE
ACS UNIT
(4 PLACES)

RETRACTABLE
SOLAR ARRAYS

MAIN BODY OF SPACECRAFT
CONTAINING BASIC FUNCTIONS
& HANDLING DEVICES -
PIDA, GRAPPLE, TRUNNIONS

COMPLETE MATERIALS
MODULE REMOVABLE

REMOVABLE MATERIALS
CANNISTERS (4 PLACES)
ORBITER
BASIC GROUNDRULES AND ASSUMPTIONS

- TRANSPORTATION VEHICLE IS STD STS

- SERVICING TO BE CONDUCTED WITHIN ORBITER OPERATIONAL & SAFETY CONSTRAINTS

- REMOTE SERVICING OPERATIONS CAPABILITY WITH EVA BACKUP

- CONTROL & DATA LINKS WITH S/C BEING SERVICED

- VOICE LINK WITH S/C OCC

- LOGISTICS & FUEL REPLENISHMENT PROVISIONS
  - UNAVAILABLE FOR COMMSAT & OTV
  - AVAILABLE FOR SPF

- RMS, DOCKING MODULE, HPA, PIDA, & FSS AVAILABLE AS ASE OPTIONS
SOC
BASIC GROUND RULES AND ASSUMPTIONS

- CONFIGURATION PER SOC/SHUTTLE INTERACTION STUDY
  & AS UPDATED FOR EXTENSION STUDY

- SERVICING TO BE CONDUCTED WITHIN SOC OPERATIONAL
  & SAFETY CONSTRAINTS AT 28.5° INCL & 200 NM ALTITUDE

- LOGISTICS & REFUELING PROVISIONS ON SOC

- CONTROL & DATA LINKS WITH S/C BEING SERVICED

- VOICE LINK WITH S/C OCC

- NON-PROPULSIVE VENT & PURGE PROVISIONS
GROUND BASED OTV
BASIC GROUND RULES AND ASSUMPTIONS

• CONTROL & DATA LINK WITH ORBITER

• LAUNCHED IN FUELED CONDITION

• STRUCTURAL STRENGTH FOR FUELED LAUNCH

• PROVISION FOR HANDLING BY ORBITER

• HEALTH, STATUS & PERFORMANCE MONITORING PROVISIONS OF OTV & ITS SUBSYSTEMS

• NON-PROPULSIVE VENT & PURGE PROVISIONS

• SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS
SPACE BASED OTV
BASIC GROUND RULES AND ASSUMPTIONS

- CONTROL & DATA LINKS WITH ORBITER & SOC
- MODULAR COMPONENT DESIGN TO FACILITATE ON ORBIT REPLACEMENT
- HEALTH, STATUS & PERFORMANCE MONITORING PROVISIONS OF OTV & ITS SUBSYSTEM
- LAUNCHED IN NON-FUELED CONDITIONS
- PROVISIONS FOR HANDLING BY SOC & ORBITER
- NON-PROPULSIVE VENT & PURGE PROVISIONS
- OTV RETURNS TO EARTH AFTER 8 MISSIONS FOR MAJOR GROUND OVERHAUL
- SINGLE STAGE -- UNMANNED OTV CONFIGURATIONS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS
COMMSAT
BASIC GROUND RULES AND ASSUMPTIONS

- LAUNCHED IN FUELED CONDITION
- CONTROL & DATA LINKS WITH SOC & ORBITER
- MANUAL OVERRIDE PROVISIONS FOR ALL MECHANISMS
- MODULAR COMPONENT DESIGN TO FACILITATE ON-ORBIT REPLACEMENT
- ACCESSIBILITY IS PRIME DESIGN REQUIREMENT
- HEALTH, STATUS & PERFORMANCE MONITORING PROVISIONS OF COMMSAT & ITS SUBSYSTEMS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS
<table>
<thead>
<tr>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIC GROUND RULES AND ASSUMPTIONS</td>
</tr>
</tbody>
</table>

- RETRACTABLE SOLAR ARRAYS
- CONTROL & DATA LINKS WITH ORBITER & SOC
- LAUNCHED IN FUELED CONDITION
- NON-PROPELLATIVE VENT & PURGE PROVISIONS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS
- MODULAR COMPONENT DESIGN TO FACILITATE ON-ORBIT REPLACEMENT
COMM SAT -- ORBITER SERVICING

SHUTTLE LAUNCH OF COMM SAT

1.0
DEPLOY COMM SAT FROM P/L BAY

2.0
MANEUVER COMM SAT

3.0
BERTH TO HOLDING FIXTURE

4.0
MATE C/O UMBILICAL

5.0
PRELIMINARY CHECKOUT OF COMM SAT

6.0
DEPLOY APPENDAGES (ANTENNAS, RADIATORS)

7.0
CHECK OUT COMM SAT

8.0
SAFE COMM SAT

9.0
DEMATE UMBILICAL

10.0
RELEASE COMM SAT

16.0

11.0
DEPLOY OTV FROM P/L BAY

12.0
MANEUVER OTV

13.0
BERTH OTV TO HOLDING FIXTURE

14.0
MATE OTV UMBILICAL

15.0
CHECK OUT OTV

17.0
MATE OTV & COMM SAT

18.0
CHECK OUT INTEGRATED SYSTEM

19.0
DEMATE OTV UMBILICAL

20.0
SEPARATE INTEGRATED SYST. FROM ORBITER

21.0
LAUNCH TO GEO

Space Operations/Integration & Satellite Systems Division
Rockwell International
COMM SAT -- SOC SERVICING

1.0 | DOCK ORBITER TO SOC

2.0 | DEPLOY COMM SAT FROM P/L BAY

3.0 | MANEUVER COMM SAT TO SOC

4.0 | BERTH COMM SAT TO SOC

5.0 | MATE C/O UMBILICAL

6.0 | PRELIMINARY CHECKOUT OF COMM SAT

7.0 | DEPLOY COMM SAT APPENDAGES

8.0 | CHECK OUT COMM SAT

9.0 | SAFE COMM SAT

10.0 | DEMATE COMM SAT UMBILICAL

11.0 | MANEUVER COMM SAT TO OTV

12.0 | DOCK ORBITER TO SOC

13.0 | DEPLOY OTV FROM P/L BAY

14.0 | MANEUVER OTV TO SOC

15.0 | BERTH OTV TO SOC FSF

16.0 | MATE OTV UMBILICAL

17.0 | CHECK OUT OTV

18.0 | MATE OTV & COMM SAT

19.0 | CHECK OUT INTEGRATED SYSTEM

20.0 | DEMATE OTV UMBILICAL

21.0 | SEPARATE INTEGRATED SYSTEM FROM SOC

22.0 | LAUNCH TO GEO

Space Operations/Integration & Satellite Systems Division

Rockwell International

91SSD21855
SPACE PROCESSING FACILITY -- SOC SERVICING

1.0
SPF RETURNS TO SOC

2.0
SAFE SPF

3.0
RETRIEVE SPF

4.0
BERTH TO SOC FSF

5.0
MATE C/O UMBILICAL

6.0
SAFE SPF

7.0
INSPECT SPF

8.0
DEPLOY OLD CANISTER OF FINISH MATERIAL

9.0
STOW OLD CANISTERS

10.0
CHECK OUT SPF

11.0
REPAIR SPF

12.0
MAINTAIN SPF

13.0
RECONFIG SPF WITH NEW CANISTERS

14.0
CHECK OUT SPF

15.0
RESUPPLY CONSUMABLES

16.0
DEMATE UMBILICAL

17.0
MANEUVER SPF FROM SOC

18.0
SEPARATE SPF FROM SOC
COMMSAT -- APPENDAGES DEPLOYMENT SCENARIO

DEPLOY HORN MAST & ANTENNA BOOMS

DEPLOY SOLAR ARRAYS

DEPLOY HORN ASSEMBLY
SPACE PROCESSING FACILITY
DELIVERY AND CHECK-OUT BY ORBITER

- PICK-UP MODULE WITH RMS
- BERTH TO HPA
- PLUG IN UMBILICAL WITH RMS
- DEPLOY SOLAR ARRAYS
SPACE PROCESSING FACILITY
DEPLOY AND RETRIEVE SPACECRAFT BY ORBITER

- REMOVE MODULE FROM HPA WITH RMS, CLEAR ORBITER AND RELEASE
- RECAPTURE MODULE WITH RMS
SPACE PROCESSING FACILITY

BERTH AND SERVICE SPACECRAFT AT ORBITER

RMS OPERATIONS

- BERITH MODULE TO HPA
- CONNECT UMBILICAL
- EXCHANGE CANNISTERS
- DISCONNECT UMBILICAL
- DEPLOY
# OTV Ground Servicing Implications

## Summary of Required Service Provisions & Equipment

<table>
<thead>
<tr>
<th>OTV</th>
<th>GSE</th>
<th>Orbiter</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Crane Interface</td>
<td>• Orbiter Processing Facility</td>
<td>• STD Orbiter Plus</td>
</tr>
<tr>
<td>• Transport Device Interface</td>
<td>• Crane</td>
<td>• PIDA</td>
</tr>
<tr>
<td>• Service Fixture Interface</td>
<td>• OTV Service Fixture with Service Correction</td>
<td>• HPA</td>
</tr>
<tr>
<td>• PIDA Interface</td>
<td>• Functional Test Station</td>
<td>• OTV Fluids Interface</td>
</tr>
<tr>
<td>• HPA Interface</td>
<td>• LRU Storage</td>
<td>• OTV Elect Interface</td>
</tr>
<tr>
<td>• Grapple Fixtures</td>
<td>• Manual Tools for Assembly/Disassembly</td>
<td></td>
</tr>
<tr>
<td>• Vertical Processing Facility</td>
<td>• Crane</td>
<td></td>
</tr>
<tr>
<td>• Facility Interface</td>
<td>• Vertical Payload Handling Device</td>
<td></td>
</tr>
<tr>
<td>• Orbiter Interface</td>
<td>• P/L Bay Interface Mockup</td>
<td></td>
</tr>
<tr>
<td>• Structural</td>
<td>• Crane</td>
<td></td>
</tr>
<tr>
<td>• Fluid</td>
<td>• Fluid Tankage &amp; Umbilicals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Rotating Service Structure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Payload Ground Handling Mechanism</td>
<td></td>
</tr>
</tbody>
</table>
# OTV-SOC Servicing Implications

## Summary of Required Service Provisions & Equipment

<table>
<thead>
<tr>
<th>OTV</th>
<th>SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>REMOTE SAFING SYSTEM</td>
<td>OTV CONTROL &amp; MONITOR STATION</td>
</tr>
<tr>
<td>COMMUNICATION &amp; DATA LINK TO SOC &amp; GROUND OCC</td>
<td>COMMUNICATION &amp; DATA LINKS TO OTV &amp; ITS GROUND OCC</td>
</tr>
<tr>
<td>NON-PROPULSIVE VENT SYSTEM</td>
<td>ACTIVE DOCKING PORT ON FSF WITH ALIGNMENT MONITORING SYSTEM</td>
</tr>
<tr>
<td>DOCKING PORT WITH ALIGNMENT TARGET</td>
<td>EXTENDABLE NON-PROPULSIVE BOOM</td>
</tr>
<tr>
<td>OTV-SOC SYSTEM INTERFACES (3-FLUID &amp; 1-ELECT), WITH DUAL QUICK DISCONNECTS</td>
<td>MOBILE MANIPULATORS (2) WITH STD END EFFECTOR &amp; SPEE</td>
</tr>
<tr>
<td>OTV-SOC STRUCTURAL INTERFACES (2 PIDA DEVICES)</td>
<td>CCTV CAMERA ON MOBILE MANIPULATORS</td>
</tr>
<tr>
<td>OTV-SOC MANIPULATOR INTERFACES (2 GRAPPLE FIXTURES)</td>
<td>OPEN CHERRY PICKER &amp; MMU</td>
</tr>
<tr>
<td>ACCESSIBLE COMPONENT DESIGN</td>
<td>RETRACTABLE UMBILICALS -- 3,FLUID &amp; 1 ELECT</td>
</tr>
<tr>
<td></td>
<td>LRU STORAGE &amp; RETRIEVAL SYSTEM</td>
</tr>
</tbody>
</table>
## COMMSAT - ORBITER SERVICING IMPLICATIONS

### SUMMARY OF REQUIRED SERVICE PROVISIONS AND EQUIPMENT

<table>
<thead>
<tr>
<th>COMMSAT</th>
<th>ORBITER</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PIDA HEAD</td>
<td>• PIDA</td>
</tr>
<tr>
<td>• GRAPPLE FIXTURE</td>
<td>• HPA</td>
</tr>
<tr>
<td>• HPA INTERFACE</td>
<td>• RETRACTABLE UMBILICAL SYSTEM</td>
</tr>
<tr>
<td>• COMMSAT-ORBITER SYSTEM CHECKOUT INTERFACE</td>
<td>• OTV COMPATIBLE WITH COMMSAT</td>
</tr>
<tr>
<td>• APPENDAGES WITH REMOTE RELEASE, DEPLOY &amp; LATCH SYSTEM</td>
<td>• OPEN CHERRY PICKER &amp; MMU</td>
</tr>
<tr>
<td>• MANUAL OVERRIDE PROVISIONS FOR ALL MECHANISMS</td>
<td>• COMMSAT CONTROL &amp; MONITER STATION</td>
</tr>
<tr>
<td>• SAFING SYSTEM</td>
<td>• COMMUNICATION &amp; DATA LINKS WITH COMMSAT &amp; ITS GROUND OCC</td>
</tr>
<tr>
<td>• COMMSAT - OTV STRUCTURAL &amp; FUNCTIONAL INTERFACES</td>
<td>• SYSTEM CONTINUITY ORBITER - OTV-COMMSAT</td>
</tr>
<tr>
<td>• ACCESSIBLE COMPONENT DESIGN</td>
<td></td>
</tr>
<tr>
<td>• COMMUNICATION &amp; DATA LINKS WITH ORBITER &amp; GROUND OCC</td>
<td></td>
</tr>
</tbody>
</table>
### COMSAT-SOC SERVICING IMPLICATIONS

#### SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

<table>
<thead>
<tr>
<th>COMMSAT</th>
<th>SOC</th>
<th>ORBITER</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PDA HEAD</td>
<td>• MANIPULATOR WITH STD END EFFCTOR</td>
<td>STD ORBITER PLUS • PDA</td>
</tr>
<tr>
<td>• GRAPPLE FIXTURE</td>
<td>• CCTV CAMERA ON MANIPULATOR</td>
<td></td>
</tr>
<tr>
<td>• BERTHING PORT WITH ALIGNMENT TARGET</td>
<td>• ACTIVE BERTHING PORT WITH ALIGNMENT MONITORING SYSTEM</td>
<td></td>
</tr>
<tr>
<td>• COMMSAT-SOC SYSTEM C/O INTERFACE</td>
<td>• RETRACTIBLE UMBILICAL SYSTEM</td>
<td></td>
</tr>
<tr>
<td>• APPENDAGES WITH REMOTE RELEASE, DEPLOY, &amp; LATCH SYS</td>
<td>• OTV COMPATIBLE WITH COMMSAT</td>
<td></td>
</tr>
<tr>
<td>• SAFING SYSTEM</td>
<td>• SYSTEM CONTINUITY SOC-OTV-COMMSAT</td>
<td></td>
</tr>
<tr>
<td>• COMMSAT-OTV STRUCTURAL &amp; FUNCTIONAL INTERFACES</td>
<td>• OPEN CHERRY PICKER &amp; MMU</td>
<td></td>
</tr>
<tr>
<td>• ACCESSIBLE COMPONENT DESIGN</td>
<td>• COMMSAT CONTROL &amp; MONITER STATION</td>
<td></td>
</tr>
<tr>
<td>• COMMUNICATION &amp; DATA LINKS WITH SOC &amp; GROUND OCC</td>
<td>• COMMUNICATION &amp; DATA LINK WITH COMMSAT &amp; ITS OCC</td>
<td></td>
</tr>
<tr>
<td>SPF</td>
<td>ORBITER</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>SPF -- ORBITER SERVICING IMPLICATIONS</td>
<td>SUMMARY OF REQUIRED SERVICE PROVISIONS &amp; EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>ORBITER</td>
<td>SPF -- ORBITER SERVICING IMPLICATIONS</td>
<td></td>
</tr>
<tr>
<td>STANDARD ORBITER PLUS</td>
<td>SUMMARY OF REQUIRED SERVICE PROVISIONS &amp; EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>SCUFF PLATES</td>
<td>SPF-ORBITER UMBILICAL</td>
<td></td>
</tr>
<tr>
<td>HPA</td>
<td>SPE</td>
<td></td>
</tr>
<tr>
<td>SPF-ORBITER UMBILICAL</td>
<td>MODULE &amp; CANNISTER STORAGE</td>
<td></td>
</tr>
<tr>
<td>SPE</td>
<td>RETRIEVAL SYSTEM</td>
<td></td>
</tr>
<tr>
<td>COMMUNICATION &amp; DATA LINK WITH SPF &amp; ITS GROUND OCC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- GRAPPLE FIXTURE |
- P IDA HEAD FITTINGS |
- SPF-ORBITER SYSTEM INTERFACE |
- MODULE LATCHING & RELEASE MECHANISM |
- EXPERIMENT CANNISTER LATCHING & RELEASE MECHANISM |
- REPLACEABLE MODULE & CANNISTER DESIGN |
- COMMUNICATION & DATA LINK WITH ORBITER & GROUND OCC
## SPF-SOC Servicing Implications

### Summary of Required Service Provisions & Equipment

<table>
<thead>
<tr>
<th>SPF</th>
<th>SOC</th>
<th>Orbiter</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Grapple Fixture</td>
<td>• SPF Control &amp; Monitor Station</td>
<td>• Std Orbiter Plus</td>
</tr>
<tr>
<td>• PIDA Head Fittings</td>
<td>• Communication &amp; Data Links with SPF &amp; Its Ground OCC</td>
<td>• Scuff Plates</td>
</tr>
<tr>
<td>• SPF-SOC Syst Interface</td>
<td>• Mobile Manipulator with Std End Effector &amp; SPEE</td>
<td>• HPA</td>
</tr>
<tr>
<td>• Module Latching &amp; Release Mechanism</td>
<td>• CCTV Camera on Mobile Manipulator</td>
<td>• Module &amp; Cannister Storage</td>
</tr>
<tr>
<td>• Experiment Cannister Latching &amp; Release Mechanism</td>
<td>• Open Cherry Picker &amp; MMU</td>
<td></td>
</tr>
<tr>
<td>• Replaceable Module &amp; Cannister Design</td>
<td>• Retractable Umbilicals with Refueling Provisions</td>
<td></td>
</tr>
<tr>
<td>• Communication &amp; Data Link with SOC &amp; Ground OCC</td>
<td>• Module &amp; Cannister Storage &amp; Retrieval System</td>
<td></td>
</tr>
</tbody>
</table>
CHECKOUT/SERVICING TIMELINE
OTV TURNAROUND AT SOC
(INCL P/L MATE)

FUNCTION
RETURN OTV TO SOC (1)
SAFE OTV M.E. & PROXIMITY MANEUVER (2)
DOCK OTV TO SOC (3)
SAFE OTV ACPS (4)
MANEUVER TO FSF (5)
MATE C/O UMBIL (6)
SAFE & INSPECT OTV (7)
TEST OTV (8)
PERFORM SCHED MAINTENANCE (9)
PERFORM UNSCHED MAINTENANCE (10)
MAINTAIN OTV (11)
CHECKOUT OTV (12)
RESUPPLY CONSUMABLES (13)
MATE OTV & P/L (14)

ELAPSED TIME (HOURS)
0 5 10 15 20 25 30

- DELAYS AND REST/SLEEP PERIODS NOT INCLUDED

ORIGINAL PAGE OF POOR QUALITY
SPACE PROCESSING FACILITY
ORBITER TURNAROUND OPERATIONS -- TIMELINE

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAFE &amp; SHUTDOWN SPF</td>
<td>(8)</td>
</tr>
<tr>
<td>ACQUIRE SPF - RMS</td>
<td>(9)</td>
</tr>
<tr>
<td>BERTH SPF TO ORBITER</td>
<td>(10, 11)</td>
</tr>
<tr>
<td>SAFE &amp; INSPECT SPF</td>
<td>(12, 13)</td>
</tr>
<tr>
<td>UNLOAD &amp; STOW CANNISTERS</td>
<td>(14, 15)</td>
</tr>
<tr>
<td>TEST SPF</td>
<td>(16)</td>
</tr>
<tr>
<td>UNSCHED MAINT &amp; C/O</td>
<td>(17, 17.1)</td>
</tr>
<tr>
<td>SCHED MAINT</td>
<td>(18)</td>
</tr>
<tr>
<td>LOAD MATERIALS CANNISTERS</td>
<td>(19)</td>
</tr>
<tr>
<td>CHECKOUT CANNISTER CONTROLS</td>
<td>(20)</td>
</tr>
<tr>
<td>SERVICE FUELS</td>
<td>(21)</td>
</tr>
<tr>
<td>READY SPF - SEPARATION</td>
<td>(22)</td>
</tr>
<tr>
<td>SEPARATE SPF</td>
<td>(23, 24)</td>
</tr>
<tr>
<td>MOVE ORBITER FROM SPF</td>
<td>(25, 25.1)</td>
</tr>
</tbody>
</table>

ELAPSED TIME (HOURS)
## SPACE PROCESSING FACILITY
### TURNAROUND OPERATIONS AT SOC

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RETURN SPF TO SOC</td>
<td>(1)</td>
</tr>
<tr>
<td>SAFE &amp; DOCK</td>
<td>(2,3)</td>
</tr>
<tr>
<td>SAFE &amp; SHUTDOWN</td>
<td>(4)</td>
</tr>
<tr>
<td>UNLOAD MAT'LS</td>
<td>(5)</td>
</tr>
<tr>
<td>SAFE &amp; INSPECT</td>
<td>(6)</td>
</tr>
<tr>
<td>TEST</td>
<td>(7)</td>
</tr>
<tr>
<td>SCHED. MAINT</td>
<td>(8)</td>
</tr>
<tr>
<td>UNSCHED. MAINT</td>
<td>(9)</td>
</tr>
<tr>
<td>CHECKOUT</td>
<td>(10)</td>
</tr>
<tr>
<td>LOAD - MATERIALS</td>
<td>(11)</td>
</tr>
<tr>
<td>LOAD MODULE C/O</td>
<td>(12)</td>
</tr>
<tr>
<td>SERVICE - FUELS</td>
<td>(13)</td>
</tr>
<tr>
<td>READY &amp; SEPARATE</td>
<td>(14,15)</td>
</tr>
<tr>
<td>PLACE AT SAFE DIST.</td>
<td>(16)</td>
</tr>
</tbody>
</table>

**Elapsed Time (Hours)**
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>NO. CREW</th>
<th>AVG</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTV - GROUND</td>
<td>4.3</td>
<td>3 - 6</td>
<td></td>
</tr>
<tr>
<td>OTV - SOC</td>
<td>3.8</td>
<td>3 - 5</td>
<td></td>
</tr>
<tr>
<td>COMM SAT - ORBITER</td>
<td>2.4</td>
<td>2 - 4</td>
<td></td>
</tr>
<tr>
<td>COMM SAT - SOC</td>
<td>2.6</td>
<td>2 - 5</td>
<td></td>
</tr>
<tr>
<td>SPACE PROCESSING - ORBITER</td>
<td>3.5</td>
<td>2 - 4</td>
<td></td>
</tr>
<tr>
<td>SPACE PROCESSING - SOC</td>
<td>3.5</td>
<td>3 - 4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MAN-HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTV - GROUND</td>
<td>576.0</td>
</tr>
<tr>
<td>OTV - SOC</td>
<td>99.7</td>
</tr>
<tr>
<td>COMM SAT - ORBITER</td>
<td>164.8</td>
</tr>
<tr>
<td>COMM SAT - SOC</td>
<td>199.6</td>
</tr>
<tr>
<td>SPACE PROCESSING - ORBITER</td>
<td>106.0</td>
</tr>
<tr>
<td>SPACE PROCESSING - SOC</td>
<td>103.4</td>
</tr>
</tbody>
</table>
SUMMARY

COMPLETED TASKS

• GENERATED SERVICING SCENARIOS FOR 3 REF S/C
  (6 SERVICING CONDITIONS)

• ANALYZED ALL SERVICING SCENARIOS & DETERMINED IMPLICATIONS

• ESTIMATED SERVICING TIMELINES FOR 4 OF THE 6 CONDITIONS

TASKS TO BE COMPLETED

• ESTIMATE TIMELINES FOR COMMSAT SERVICING AT ORBITER & SOC

• PREPARE PRELIMINARY DESIGN LAYOUT OF SOC FSF & INTEGRATING
  RESULTS OF SERVICING SCENARIO ANALYSIS

• GENERATE & COMPARE SERVICING COST DATA
CONCLUSIONS AND PLANS

- FLEET UTILIZATION ANALYSIS HAS BEEN STARTED...
  - IMPORTANT RESULTS ARE EXPECTED

- SACC ASSEMBLY ANALYSIS UNDERWAY...
  - COMPUTER INTERACTIVE GRAPHICS WILL GIVE
    HIGH CONFIDENCE TO CLEARANCE GEOMETRIES

- ET PROPELLANT SCAVENGING PROVEN FEASIBLE...
  - AMPLE TRANSFER TIME
  - ET IMPACT SATISFIED
  - NO SIGNIFICANT STS PAYLOAD IMPACT
  - ACCEPTABLE SAFETY STANDARDS CAN BE MET
  - WIDE RANGE OF APPLICATION SCENARIOS IS POSSIBLE

- FLIGHT SUPPORT FACILITY ANALYSIS WELL UNDERWAY...
  - SERVICING IMPLICATIONS IDENTIFIED
  - SERVICING TIMELINES AND COST DATA ARE BEING GENERATED
  - KEY INSIGHTS INTO COST EFFECTIVENESS OF VARIOUS SERVICING
    SCENARIOS WILL BE GAINED