ORBITER OMS AND RCS TECHNOLOGY

INTRODUCTION

0 ORBITER OMS AND RCS TANKAGE HAS BEEN HIGHLY SUCCESSFUL IN SHUTTLE FLIGHTS AS OF THIS WRITING (STS-1, 2, AND 3)

0 OMS AND RCS TECHNOLOGY HAS PROVIDED A SUBSTANTIAL BASIS FOR FUTURE USES OF STORABLE PROPELLANTS

• UNDERSTANDING OF FLUID MECHANICS AND SCREEN FUNCTION
• SYNTHESIS OF LIGHT WEIGHT SUPPORT AND SCREEN STRUCTURES
• TANK QUALIFICATION IN HOSTILE ENVIRONMENTS
• SUCCESSFUL FLIGHT DEMONSTRATION OF FUNDAMENTAL MODES OF OPERATION -- TRANSLATION MANEUVERS AND REACTION CONTROL

0 REMAINING TECHNOLOGY UNEXPLORED BY OMS AND RCS APPLICATIONS IS CENTERED ON ON-ORBIT PROPELLANT TRANSFER
**OMS PROPELLANT ACQUISITION SYSTEM**

**PURPOSE**
- TO MAINTAIN PROPELLANT AT TANK OUTLET UNDER ZERO G CONDITIONS AND THEREBY ALLOW INITIAL FLOW TO START THE ENGINE; ALLOW PROPELLANT USAGE BY RCS UNDER LOW G

**CHARACTERISTICS**
- PROVIDE PROPELLANTS, FREE OF UNDISSOLVED PRESSURANT GAS/PROPELLANT VAPOR, TO THE OMS/RCS ENGINES
- PROVIDE CAPABILITY OF 10 OMS STARTS WITHOUT PROPELLANT SETTLING
- PROVIDE 454 KG (1000 LBS) OF PROPELLANT TO THE RCS PER TANK SET
- MAXIMUM STARTUP FLOW RATES KG/SEC (LBS/SEC)

<table>
<thead>
<tr>
<th></th>
<th>NTO</th>
<th>MMH</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMS POD (1 ENGINE/FEEED)</td>
<td>5.41 KG/SEC (11.93 LBS/SEC)</td>
<td>3.28 KG/SEC (7.23 LBS/SEC)</td>
</tr>
<tr>
<td>RGS POD (7 THRUSTER/FEEED)</td>
<td>5.87 KG/SEC (12.95 LBS/SEC)</td>
<td>3.68 KG/SEC (8.12 LBS/SEC)</td>
</tr>
<tr>
<td>MINIMUM PROPELLANT (START WITHOUT RCS ULLAGE BURN)</td>
<td>377 KG (831 LBS)</td>
<td>289 KG (504 LBS)</td>
</tr>
<tr>
<td>WEIGHT:</td>
<td>17.7 KG (38.9 LBS)</td>
<td></td>
</tr>
<tr>
<td>TOTAL PER VEHICLE:</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
LAUNCH MINUS 2 DAY REVIEW
OMS PROPELLANT TANK CONFIGURATION

SUPPLIER:  MCDONNELL ASTRONAUTICS COMPANY, EAST (TANK ASSEMBLY)
AEROJET MANUFACTURING COMPANY (PRESSURE VESSEL)

FWD GAGING PROBE
(L = 140 CM (55.3 IN))

ACQUISITION ASSY
GALLERY LEG (4 EACH)

AFT GAGING PROBE
(L = 103 CM
(40.63 IN))

124 CM
(49 IN)

PRESSURANT
DIFFUSER

NOMINAL OPERATING
PRESSURE
1.725 X 10^6 N/M^2 (250 PSIA)

VOL_W = 1.784 M^3
(63 FT^3)

VOL_AFT = 0.765 M^3
(27 FT^3)

COMMUNICATION
SCREEN (3 SEGMENT)

GALLERY VENT,
BULKHEAD VENT,
TANK DRAIN

GAS ARRESTER
SCREEN

TANK DRAIN

411

240 CM (94.3 IN)

ORIGINAL PAGE IS
OF POOR QUALITY
PROPELLANT ACQUISITION SYSTEM

COMMUNICATION SCREEN: 200 X 1400
TWILLED DOUBLE DUTCH WEAVE (TDDW)

SCREEN PORE SIZE = 15μ

BUBBLE POINT = 2089 N/m² (303 PSI) N₂O₄
= 3054 N/m² (443 PSI) MMH

AFT SUMP GAUGING PROBE

FITTING HORIZONTAL DRAIN

GALLERY & SUMP VENT LINES

COLLECTOR MANIFOLD

GALLERY LEGS (4 PLACES)

COLLECTOR MANIFOLD: 200 X 1400 TDDW

PROPELLANT DISCHARGE PORT

AFT TANK SUMP COMPARTMENT

GALLERY ASSEMBLY:
200 X 1400 TDDW

Space Transportation System
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Space Systems Group

Rockwell International
OMS PROPELLANT ACQUISITION SYSTEM
OPERATING MODES

- BOOST
- RCS FEED
- OMS START
- OMS BURN
OMS PROPELLANT TANKS
ACQUISITION SYSTEM DEVELOPMENT

KEY PROBLEMS ENCOUNTERED

- Failure of plain Dutch square weave screen during vibration testing
  - Coining at edge of screen panel reduced wire cross-section and therefore fatigue life

EXCESSIVE NUMBER OF IN PROCESS REPAIRS

- Stress relief of Ti welds over-stressed screens

SOLUTIONS

- Eliminated coining and employed stronger TDDW
- Revised fabrication process to eliminate stress relief after screen panel installation
**EFFECT OF BULKHEAD SCREEN FAILURE**
**TRANSLATION MANEUVERS**

- **Y, Z TRANSLATION MANEUVERS**
  - A head difference (H) is established between the forward and aft tank compartments depending on the relative quantities.
  - Liquid can flow out of the aft compartment only as fast as its volume is replaced by in flow of helium.
  - Helium in flow is a function of the effective flow area and pressure differential.
  - Maximum $\Delta p$ is 2068 N/m$^2$ (0.3 psi) and decreases as the propellant is transferred. Therefore, propellant is transferred at a relatively slow rate, even with significant screen failures.

- **-X TRANSLATION MANEUVERS**
  - Head effects even less severe.

- **RESULTING EFFECTS**
  - Credible screen failures will result in little propellant transfer.
  - Engine restarts not affected.
EFFECT OF BAND SCREEN FAILURE

FAILURE

MAXIMUM BUBBLE DUE TO 4 OME STARTS (WITH PROPELLANT AT FAR END OF TANK) AND 99.8 KG (220 LBS) OMS/RCS USAGE IS 0.156 M³ (5.5 FT³) AFT COMPARTMENT IS 0.765 M³ (27 FT³)

BAND SCREEN - PROTECTS AGAINST START DYNAMICS AND STEADY STATE G LEVELS

PERFORATED PLATE - PROTECTS AGAINST STEADY STATE G LEVELS

EFFECT OF FAILURE - MINOR

IF BUBBLE IS ADJACENT TO FAILED AREA DURING PROPELLANT SLOSH, SOME BUBBLES WILL BE PULLED IN TO FEED SYSTEM DURING INITIAL START TRANSIENTS

MAY RESULT IN A SHORT PERIOD (≃ 0.5 SEC) OF 2 PHASE FLOW ACCEPTABLE TO OMS ENGINE
EFFECT OF GAS ARRESTOR SCREEN FAILURE

- **FUNCTION**
  - Keeps bubble in gallery leg section
  - Gallery screens break down as tank empties
  - Arrestor screen prevents gas from entering system until band screen uncovered

- **EFFECT OF FAILURE - MINOR**
  - System has been qualified for bubble sizes larger than those expected from loading
  - Expulsion efficiency degraded by 1%
<table>
<thead>
<tr>
<th>Description</th>
<th>Start Date</th>
<th>End Date</th>
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</thead>
<tbody>
<tr>
<td>SCREEN PANEL TESTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BUBBLE PT., WICKING/DEWICKING, FLOW ΔP, COMPATIBILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAINLESS STEEL SCREEN/TI FOIL WELD, REDUCED B.P. WITH N$_2$O$_4$</td>
<td>4/74</td>
<td>7/76</td>
</tr>
<tr>
<td>SCREEN REPAIR TECHNIQUE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQUISITION ASSEMBLY, REDUCED SCALE</td>
<td>8/75</td>
<td>4/76</td>
</tr>
<tr>
<td>SETTLE DYN., FLUID CONTAINMENT W/OUTFLOW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQUISITION ASSEMBLY, FULL SCALE, SIM TANK</td>
<td>10/75</td>
<td>4/77 (GRD)</td>
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<tr>
<td>SYSTEM PERFORMANCE, SCREEN CONTAINMENT WITH VIB.</td>
<td></td>
<td></td>
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<tr>
<td>FLOW TRANSIENT GAS INGESTION</td>
<td>4/77</td>
<td>8/77 (FLT)</td>
</tr>
<tr>
<td>KC-135 LOW-G TESTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONE-HALF SCALE TANK, KC-135 LOW-G TESTS</td>
<td>3/76</td>
<td>7/76</td>
</tr>
<tr>
<td>TANK QUAL (TANK #2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACCEL, SHOCK, TRANSIENT, RANDOM VIB.</td>
<td>4/78</td>
<td>7/79</td>
</tr>
<tr>
<td>6 MISSION SHOCK/VIB TANK TESTS</td>
<td>7/79</td>
<td>10/79</td>
</tr>
<tr>
<td>100 MISSION SHOCK/VIB TANK TESTS</td>
<td>10/79</td>
<td>5/80</td>
</tr>
<tr>
<td>AFA 26 ACOUSTIC FATIGUE TESTS</td>
<td>4/80</td>
<td>7/81</td>
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</table>
## Flight Usage of OMS Propellant

<table>
<thead>
<tr>
<th>PROPELLANT QUANTITY (OX + FU)</th>
<th>STS-1</th>
<th>STS-2</th>
<th>STS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L POD</td>
<td>R POD</td>
<td>L POD</td>
</tr>
<tr>
<td></td>
<td>KG</td>
<td>LB</td>
<td>KG</td>
</tr>
<tr>
<td>PROPELLANT LOADED (IN TANKS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3876</td>
<td>8546</td>
<td>4258</td>
<td>9388</td>
</tr>
<tr>
<td>PROPELLANT USED BY OMS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OMS-1 BURN</td>
<td>759</td>
<td>1674</td>
<td>751</td>
</tr>
<tr>
<td>OMS-2 BURN</td>
<td>660</td>
<td>1455</td>
<td>649</td>
</tr>
<tr>
<td>OMS-3 BURN</td>
<td>240</td>
<td>530</td>
<td></td>
</tr>
<tr>
<td>OMS-3A BURN</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>OMS-3B BURN</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>OMS-4 BURN</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>DEORBIT</td>
<td>1362</td>
<td>3002</td>
<td>1338</td>
</tr>
<tr>
<td>OMS PROPELLANT USED BY RCS</td>
<td>328</td>
<td>723</td>
<td>231</td>
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<tr>
<td>TOTAL USED</td>
<td>3349</td>
<td>7384</td>
<td>3250</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>527</td>
<td>1162</td>
<td>1008</td>
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<tr>
<td>TOTAL PROPELLANT USED FROM</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LEFT POD TANKS</td>
<td>10,140 Kg (22,354 LB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIGHT POD TANKS</td>
<td>9,595 Kg (21,153 LB)</td>
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<td></td>
</tr>
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OMS PROPELLANT TANK
CERTIFICATION STATUS

- Development and qualification programs have been successfully completed.

- Certification completed for performance, structural integrity, life, and servicability for acquisition system and pressure vessel.

- Further analysis required for tank skirt fatigue life pending definition of load spectrum.
RCS TANK FUNCTION AND OPERATIONAL REQUIREMENTS

SERVICING

- Fill tanks while installed in Orbiter on launch pad
  - Provide gas ullage for thermal excursions
- Provide capability to launch off loaded
  - FRCS to 59% of capacity
  - ARCS to 65% of capacity

BOOST REQUIREMENT

- Withstand 100 missions of boost random vibration and liftoff twang
- ARCS tank propellant burn-off to 65% during powered boost phase

RCS CONTROL OPERATION

- Provide gas free propellant during any combination of thruster steady state or pulse operation during exposure to omnidirectional acceleration fields
- Mated coast/external tank separation
  - Normal mission 2.8 L/SEC (45 GPM)
  - Return to launch site - 3.4 L/SEC (54 GPM) FRCS and 4.0 L/SEC (63 GPM) ARCS
- On-orbit
  - FRCS - 2.8 L/SEC (45 GPM) - 92% expulsion efficiency
  - ARCS - 4.0 L/SEC (63 GPM) - 68% expulsion efficiency
- Entry - ARCS only
  - Low G - 2.8 L/SEC (45 GPM) to 72% expulsion
  - Low G - 2.3 L/SEC (36 GPM) to 76% expulsion
  - High G - 2.3 L/SEC (36 GPM) to 98% expulsion efficiency
.99m (39 IN) SPHERICAL DIAMETER 6AL-4V TITANIUM SHELL

- OPERATING PRESSURE
  - 1.675 x 10^6 N/m^2 (243 PSIA) NOM.
  - 2.413 x 10^6 N/m^2 (350 PSIA) MAX.
- 200 PRESSURE CYCLE LIFE
- CAPACITY
  - N_2O_4 - 675 KG (1488 LBS)
  - MMH - 422 KG (930 LBS)
  - N_2H_4 - 491 KG (1082 LBS)

STAINLESS STEEL PAD DRY WEIGHT - 32.6 KG (72 LBS)
ET SEPARATION

ASCENT

ENTRY

+Z BRAKING

Original page is of poor quality
RCS PROPELLANT TANK
KEY DEVELOPMENT PROBLEMS ENCOUNTERED

LOW G PERFORMANCE CERTIFICATION BY ANALYSIS

1. DIRECT TEST NOT FEASIBLE WITHOUT ZERO G PROPELLANT LABORATORY
2. GAS FREE EXPULSION ASSURED WHEN B.P. ≥ (ΔP_START + ΔP_S.S. ) X SF
   - ΔP_START (NUMBER OF THRUSTERS STARTING)
   - ΔP_S.S. = ΔP_E + ΔP_Y + ΔP_H + ΔP_VIS
3. LIMITED OPERATION WITH GAS INGESTION PERMITTED WHEN ΔPREHEAT > (ΔP_S.S.) X SF
4. INITIAL PERFORMANCE CERTIFIED TO STEADY STATE REQUIREMENTS WITH 1.15 SF
   - MATH MODELS VALIDATED BY 1-G ELEMENT AND SUB ASSEMBLY TESTS
   - LOW-G EXPULSIONS SIMULATED BY 1-G MASKED SCREEN TESTS
5. UNEXPECTED EFFECTS OF START TRANSIENT ON TANK OPERATION CAUSED CAUTION
   - SF RAISED TO 1.5
   - TOTAL GAS INGESTION LIMITED TO 164 CC (10 in³) PER MISSION
6. MISSION REQUIREMENTS REDUCED TO ACCOMMODATE START TRANSIENT CAPABILITIES
   - LIMITED SRC THRUSTER USAGE TO 3 (WAS) 5
   - LIMITED ARCS THRUSTER USAGE TO 5 (WAS) 7
      - REQUIRES OVERFILL OF ARCS TANKS TO KEEP GAS OUT OF LOWER COMPARTMENT

ON-ORBIT SCREEN DRYOUT

1. CAUSED BY CONVECTIVE MASS TRANSFER (PRESSURANT FLOW OVER SCREENS)
2. RESOLVED BY SWIRL DIFFUSER
DEVELOPMENT OF PAD BUBBLE POINT VERIFICATION TECHNIQUE INHIBITED BY N₂O₄ SCREEN DRYOUT

- SPECIAL CONTROLS AND TECHNIQUES DEVELOPED

SCREEN REPAIR TECHNIQUES REQUIRED TO SEAL PORE OPENINGS CREATED DURING MANUFACTURING

- SILVER/TIN SOLDER USED
- MMH CONTAMINATED WITH FREON CORRODES SILVER SOLDER
- PRESENCE OF FREON CONTAMINATION QUALITATIVELY SCREENED WITH SOLDER REPAIR DOTS

PAD SENSITIVITY TO SHOCK AND VIBRATION ENVIRONMENT UNKNOWN

- UNCERTAIN DURING HANDLING, TRANSPORTATION, AND BOOST ENVIRONMENTS
- PAD STRAIN GAGED AND SUBJECTED TO QUALIFICATION TEST ENVIRONMENTS
- STRESS AND FATIGUE ANALYTICAL MODELS UPDATED BASED ON RESPONSE DATA DURING ENVIRONMENTAL TESTS

TANK GIRTH WELD AND REPAIR

- SPECIAL TESTS WERE CONDUCTED TO VERIFY WELD STRESS/STRAIN CHARACTERISTICS OF MISMATCHED WELD LANDS
- TECHNIQUES WERE DEVELOPED TO REPAIR OR REPLACE INTERNAL PAD BY CUTTING TANK APART AND REPLACEMENT OF UPPER HEMISPHERE
## Flight Usage of RCS Propellant

### Propellant Quantity (OX + FU)

<table>
<thead>
<tr>
<th></th>
<th>STS-1</th>
<th>STS-2</th>
<th>STS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>L</td>
<td>R</td>
</tr>
<tr>
<td>LOADED</td>
<td>KG</td>
<td>888</td>
<td>999</td>
</tr>
<tr>
<td>ASCENT</td>
<td>KG</td>
<td>68</td>
<td>68.5</td>
</tr>
<tr>
<td></td>
<td>LB</td>
<td>(150)</td>
<td>(151)</td>
</tr>
<tr>
<td>ON-ORBIT</td>
<td>KG</td>
<td>186</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>LB</td>
<td>(410)</td>
<td>(225)</td>
</tr>
<tr>
<td>DE-ORBIT</td>
<td>KG</td>
<td>16</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>LB</td>
<td>(36)</td>
<td>(12)</td>
</tr>
<tr>
<td>FRCS DUMP</td>
<td>KG</td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td>LB</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ENTRY</td>
<td>KG</td>
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<td>243</td>
</tr>
<tr>
<td></td>
<td>LB</td>
<td>-</td>
<td>(535)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>KG</td>
<td>270</td>
<td>419</td>
</tr>
<tr>
<td>BUDGETED</td>
<td>KG</td>
<td>218</td>
<td>312</td>
</tr>
<tr>
<td></td>
<td>LB</td>
<td>(480)</td>
<td>(689)</td>
</tr>
</tbody>
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Space Transportation System
Development & Production Division
Space Systems Group

Rockwell International
RCS PROPELLANT TANK
CERTIFICATION STATUS

STRUCTURAL QUALIFICATION

- Tank shells qualified for 100 mission life
- OV-102 pad qualified for 17 mission life
- OV-099 and subs pad being qualified to 100 mission life
  - ARCS - July 1982
  - FRCS - July 1983

PERFORMANCE CERTIFICATION

- OV-102 tanks certified for limited thruster usage
  - FRCS 2SS + 3P
  - ARCS 1SS + 3P
  - CAN BE RECERTIFIED TO 2SS + 4P

- OV-099 and subs to be certified
  - FRCS - same as OV-102
  - ARCS - 1SS + 5P
  - WSTF test - November 1982
  - Certification analyses - March 1983
CONCLUSIONS

- SUCCESSFUL FLIGHTS OF ORBITER HAVE PROVEN THE VIABILITY OF SURFACE TENSION DEVICES FOR SHUTTLE APPLICATION

- EXTRAPOLATION TO OTHER APPLICATIONS INVOLVING STORABLE PROPELLANTS SHOULD BE A SUBSTANTIALLY EASIER TASK BECAUSE OF OMS AND RCS TECHNOLOGY