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Produced by the NASA Center for Aerospace Information (CASI)
TC-2 POST HELIOS EXPERIMENT
DATA REVIEW AT
NASA-LeRC

31 October 1975

GENERAL DYNAMICS
Convair Division
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

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I-1
TC-2 CENTAUR MISSION OBJECTIVES

PRIMARY — INJECT TE-M-364-4/HELIOS STAGE.

SECONDARY — PERFORM POST-HELIOS CENTAUR EXTENDED FLIGHT PROPELLANT MANAGEMENT AND PROPULSION EXPERIMENTS.

- DEMONSTRATE CENTAUR CAPABILITY TO PERFORM OPERATIONAL 2-BURN MISSION WITH EXTENDED ZERO-G PARKING ORBIT COAST.

- OBTAIN DATA TO EVALUATE:
  - CENTAUR CAPABILITY TO ACCOMPLISH AN OPERATIONAL 3-BURN SYNC. ORBIT MISSION.
  - PROPELLANT BEHAVIOR DURING ZERO-G COAST OPERATIONS AND SETTLING REGIMES.
  - TANK PRESSURE PROFILES FROM COAST PHASE ENVIRONMENTS AND OPERATIONS AND PRESSURIZATION PHASES.
  - COMPONENT THERMAL HISTORIES AND THERMAL CONTROL TECHNIQUES.
  - REACTION CONTROL THRUST SYSTEM PROPELLANT SETTLING AND VEHICLE CONTROL PERFORMANCE (AND H2O2 CONSUMPTION).
  - PROPULSION RESTART SEQUENCES.
  - BOOST PUMP PERFORMANCE.
TC-2 POST HELIOS EXPERIMENT

BOOST PUMP EXPERIMENT
(25 SEC) MECO4 +280 SEC

BURN 4
(48 SECONDS)

H$_2$O$_2$ DEPLETION EXPERIMENT
4S ON AT MECO4 +506 SEC

BURN 3 (11 SECONDS)

TERMINAL ORBIT (CENTAUR)
APOGEE ALT. = 85, 597 N.MI.
PERIGEE ALT. = 952 N.MI.
## TC-2 POST-HELIOS EXPERIMENT

### SUMMARY OF SEQUENCES/SIGNIFICANT EVENTS

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TIME (SEC)</th>
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</thead>
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<tr>
<td><strong>COAST 2</strong></td>
<td></td>
</tr>
<tr>
<td>1.0 HR. ZERO-G (MECO2 RESIDUALS = 5185 LB)</td>
<td>TE-M-364-4/CENTAUR SEP'N AND CENTAUR RETROTHRUST GHe BLOWDOWN MECO2 + 72</td>
</tr>
<tr>
<td></td>
<td>START ORIENT TO -R VECTOR + 116</td>
</tr>
<tr>
<td></td>
<td>CCVAPS VENT CONTROL ON + 300</td>
</tr>
<tr>
<td></td>
<td>SELECT HIGH-GAIN ANTENNA + 33.3 MIN</td>
</tr>
<tr>
<td><strong>BURN 3</strong></td>
<td>2-S ON (START SETTLING) MES3 - 420</td>
</tr>
<tr>
<td>11 SECS FIXED (MECO3 RESIDUALS = 4399 LB)</td>
<td>4-S ON - 120</td>
</tr>
<tr>
<td></td>
<td>CCVAPS PRESS'N ON - 43</td>
</tr>
<tr>
<td></td>
<td>BOOST PUMP START - 28</td>
</tr>
<tr>
<td></td>
<td>PRE-START - 17</td>
</tr>
<tr>
<td></td>
<td>MES3 0</td>
</tr>
<tr>
<td><strong>COAST 3</strong></td>
<td>P&amp;Y H₂O₂ ENGINE WARMING FIRING MECO3 + 120 SEC</td>
</tr>
<tr>
<td>3 HRS. ZERO-G</td>
<td>INITIATE THERMAL ROLL MECO3 + 28, 56, 84, 112, 140, &amp; 168 MIN</td>
</tr>
<tr>
<td></td>
<td>S-H₂O₂ ENG, WARMING FIRING MES3 + 50 &amp; 100 MIN</td>
</tr>
<tr>
<td></td>
<td>REDUCE ALLOWABLE ATTITUDE ERRORS MECO3 + 120 MIN</td>
</tr>
<tr>
<td></td>
<td>INITIATE PROGRAMMED VENT MECO3 + 143 MIN</td>
</tr>
<tr>
<td><strong>BURN 4</strong></td>
<td>2-S ON (START SETTLING) MES4 - 420</td>
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<tr>
<td>48 SEC'S</td>
<td>4-S ON - 120</td>
</tr>
<tr>
<td>WEIGHT CUT-OFF (MECO4 RESIDUALS = 1094 LB)</td>
<td>CCVAPS PRESS'N ON - 43</td>
</tr>
<tr>
<td></td>
<td>BPS - 28</td>
</tr>
<tr>
<td></td>
<td>PRESTART - 24</td>
</tr>
<tr>
<td></td>
<td>MES4 0</td>
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</tbody>
</table>
TC-2 POST-HELIOS EXPERIMENT —  
SUMMARY OF SEQUENCES/SIGNIFICANT EVENTS

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TIME (SEC)</th>
</tr>
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<tbody>
<tr>
<td>CCVAPS PRESS'N ON</td>
<td>MECO4 + 10</td>
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<tr>
<td>CCVAPS PRESS'N OFF</td>
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<tr>
<td>4-S ENG'S ON</td>
<td>200</td>
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<td>BOOST PUMP START</td>
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<tr>
<td>PRESTART VALVES OPEN</td>
<td>300</td>
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<tr>
<td>BOOST PUMPS OFF</td>
<td>305</td>
</tr>
<tr>
<td>4-S ENG'S OFF</td>
<td>306</td>
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<tr>
<td>PRESTART VALVES CLOSED</td>
<td>505</td>
</tr>
<tr>
<td>4-S ENG'S ON</td>
<td>506</td>
</tr>
<tr>
<td>4-S ENG'S OFF</td>
<td>1606</td>
</tr>
<tr>
<td>UNLOCK VENT VALVES</td>
<td>1610</td>
</tr>
</tbody>
</table>

DIAGRAM:
- BOOST PUMP
- EXPERIMENT
- TANK
- BLOWDOWN
- EXPER'T
- H₂O₂ DEPLETION
- EXPER'T
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

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IX  BOOST PUMP POST-MECO PERFORMANCE  HUBER/MERINO
X  OVERVIEW OF OTHER SYSTEMS  HUBER

II-1
# LIQUID-VAPOR SENSOR LOCATIONS

<table>
<thead>
<tr>
<th>MEASUREMENT NUMBER</th>
<th>LOCATION</th>
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<tbody>
<tr>
<td>241X</td>
<td>2485 310</td>
</tr>
<tr>
<td>242X</td>
<td>2473 340</td>
</tr>
<tr>
<td>245X</td>
<td>2330 310</td>
</tr>
<tr>
<td>247X (1)</td>
<td>2393 70</td>
</tr>
<tr>
<td>248X (1)</td>
<td>2393 190</td>
</tr>
<tr>
<td>252X</td>
<td>2320 310</td>
</tr>
<tr>
<td>251X</td>
<td>2320 190</td>
</tr>
<tr>
<td>254X</td>
<td>2309 302</td>
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<tr>
<td>253X</td>
<td>2309 182</td>
</tr>
<tr>
<td>255X</td>
<td>2302 190</td>
</tr>
<tr>
<td>256X</td>
<td>2302 310</td>
</tr>
</tbody>
</table>

NOTES: (1)

L-V SENSOR MOUNTED PARALLEL TO LONGITUDINAL AXIS, ALL OTHER SENSORS INSTALLED NORMAL TO LONGITUDINAL AXIS.
PAYLOAD SEPARATION OCCURRED AT MECO2 +72 SEC FOLLOWING RETRO-BLOWDOWN. RE-ORIENTATION OF THE CENTAUR WAS INITIATED AT MECO2 +116 SEC. A ONE-HOUR NEAR ZERO-G COAST FOLLOWED.

ANALYSIS INDICATES THAT BETWEEN 15% AND 30% OF THE LO₂ IN THE THRUST BARREL DRAINED OUT DURING THE RETRO-BLOWDOWN MANEUVER.

AFTER THE RETRO-BLOWDOWN MANEUVER, THE LO₂ FORCED FORWARD WOULD BEGIN TO REORIENT IN ORDER TO MINIMIZE LIQUID PRESSURE. LIQUID PRESSURE AT THE NEAR ZERO-G LEVEL IS SURFACE TENSION DOMINATED.

THE STEADY STATE LO₂ ORIENTATION WHICH WOULD EVENTUALLY BE REACHED IS SHOWN. THIS CONFIGURATION ASSUMES MINIMUM DRAINING OF THE THRUST BARREL.

IT IS BELIEVED THAT THE STANDPIPE ENTRY AND BUBBLER RING WERE IMMERSED IN LO₂ THROUGHOUT COAST.
TC-2 2ND COAST STEADY STATE
LO2 PROPELLANT CONFIGURATION

- TOTAL LO2 WEIGHT = 4028 LB
- 1206 LB LO2 IN THRUST BARREL (MIN. DRAINING DURING RETROTHRUST)

VOLUME STATION

DISTANCE FROM VEHICLE CENTERLINE, IN.
IMMEDIATELY FOLLOWING MECO2, FORWARD MOVEMENT OF LH₂ WAS INDICATED BY PROGRESSIVE WETTING OF L-V SENSORS AS TABULATED BELOW:

<table>
<thead>
<tr>
<th>SENSOR STA.</th>
<th>TIME WETTED REFERENCED TO MECO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM248X</td>
<td>2393 10 SECONDS</td>
</tr>
<tr>
<td>CM247X</td>
<td>2393 18 SECONDS</td>
</tr>
<tr>
<td>CM319X</td>
<td>2410 37 SECONDS</td>
</tr>
<tr>
<td>CM241X</td>
<td>2485 62 SECONDS</td>
</tr>
</tbody>
</table>

DURING THIS COAST, CM241X WAS WET 90% OF THE TIME WHILE CM242X WAS CONTINUOUSLY DRY INDICATING THAT, ALTHOUGH A SIGNIFICANT AMOUNT OF LH₂ WAS FORCED FORWARD, THE MAJORITY REMAINED AFT.


THE L-V SENSORS JUST ABOVE THE AFT SLOSH BAFFLE (CM251/2X) INDICATED WET 75% OF THE TIME WHILE THOSE MOUNTED ON THE SLOSH BAFFLE (CM253/4X) WERE WET 25% OF THE TIME. THIS BEHAVIOR IS BELIEVED TO BE CAUSED BY DISTURBANCE OF THE LH₂ SETTLED AFT ABOUT A STEADY STATE CONFIGURATION AS SHOWN.
TC-2 LH₂ TANK STEADY STATE PROPELLANT BEHAVIOR

(SECOND COAST)

NOTE:
1. 194 FT³ AFT
2. 67 FT³ FWD

DISTANCE FROM VEHICLE CENTERLINE, IN.

II-7
FOLLOWING MECO3, VEHICLE ACCELERATION DROPS IMMEDIATELY TO $\approx 10^{-8} \, \text{g}$ RESULTING IN PROPELLANT REORIENTATION TO MINIMIZE LIQUID PRESSURE.

AT MECO3 THE LO$_2$ LEVEL IS SLIGHTLY BELOW THE TOP OF THE THRUST BARREL. A SPHERICAL GAS BUBBLE WILL BE TRAPPED WITHIN THE THRUST BARREL AND DRAINING WILL NOT OCCUR.

DUE TO THE QUANTITY OF LO$_2$ AND TANK GEOMETRY THERE ARE TWO POSSIBLE STEADY STATE CONFIGURATIONS FOR THE LO$_2$ OUTSIDE THE THRUST BARREL.


THE SECOND CONFIGURATION IS JUDGED MOST PROBABLE SINCE IT WOULD HAVE TO BE PASSED THROUGH TO ACHIEVE THE FILLET/SIDE ORIENTED CONFIGURATION. THIS, OF COURSE, MUST HAPPEN IF THE RIM OF THE THRUST BARREL IS A PERFECTLY SHARP EDGE IN ORDER TO ACHIEVE A ZERO CONTACT ANGLE. FROM A MICROSCOPIC STANDPOINT, HOWEVER, THE THRUST BARREL RIM CANNOT BE PERFECTLY SHARP AND A ZERO CONTACT ANGLE CAN BE ACHIEVED AS DEPICTED IN THE INSERT.
TC-2 3rd COAST STEADY STATE
LO₂ PROPELLANT CONFIGURATION

CONFIGURATION NO. 1

- TOTAL LO₂ WEIGHT = 3372 LB
- 1397 LB LO₂ IN THRUST BARREL

CONFIGURATION NO. 2 (MOST PROBABLE CONFIGURATION)

- TOTAL LO₂ WEIGHT = 3372 LB
- 1397 LB LO₂ IN THRUST BARREL

WALL WETTED TO STA. 379.4 (2274.1)

WALL WETTED TO STA. 404.0 (2249.5)

TOTAL LO₂ WEIGHT = 3372 LB
1397 LB LO₂ IN THRUST BARREL
OF SIGNIFICANCE IN THE LH₂ TANK WAS THE DRY INDICATION OF THE FORWARDMOST L-V SENSOR (CM241X) BETWEEN MECO3 AND THE FIRST "S" ENGINE WARMING (≈ 50 MIN.) INDICATING LITTLE, IF ANY, LH₂ FORCE FORWARD DURING THE MECO TRANSIENT.

FOLLOWING THE FIRST "S" ENGINE WARMING HOWEVER, CM241X SHOWED WETTING. FURTHER WETTINGS WERE NOTED FOLLOWING SUBSEQUENT "S" ENGINE WARMING/THERMAL ROLL ACTIVITIES. UNEXPLAINED IS THE REWETTING OF THIS SENSOR IMMEDIATELY FOLLOWING THE PLANNED VENT. APPARENTLY SOME LH₂ REMAINED IN THE VICINITY OF THE FORWARD DOOR THROUGH THE SETTLING/PLANNED VENT EVENTS.

AS DURING THE SECOND COAST THE L-V SENSORS JUST BELOW THE FORWARD SLOSH BAFFLE (CM247/8X) INDICATED PREDOMINATELY WET AGAIN IMPLYING APPROXIMATELY 37–39 FT³ OF LH₂ ATTACHED AT THE SLOSH BAFFLE.

THE L-V SENSORS JUST ABOVE THE AFT SLOSH BAFFLE (CM251/2X) INDICATED WET 50% OF THE TIME WHILE THOSE MOUNTED ON THE SLOSH BAFFLE (CM253/4X) WERE WET 12% OF THE TIME. THIS BEHAVIOR IS BELIEVED TO BE CAUSED BY DISTURBANCE OF THE AFT POSITIONED LH₂ ABOUT A STEADY STATE CONFIGURATION AS SHOWN.
TC-2 LH₂ TANK STEADY STATE PROPELLANT BEHAVIOR

NOTE:
1. 174 FT³ AFT
2. 37 FT³ AT FWD SLOSH BAFFLE
3. 9 FT³ ON FWD BULKHEAD

GENERAL DYNAMICS
Convair Division
31 Oct 75

DISTANCE FROM VEHICLE CENTERLINE, IN.
SUMMARY

LO₂ TANK
- LO₂ TANK INTERNAL CONFIGURATION IS SUCH THAT LIQUID DISTRIBUTION FAVORED COLLECTION ABOUT THE THRUST BARREL AND THE TANK MIDSECTION.
- LIQUID DISTRIBUTION ENHANCED PROPELLANT COLLECTION.
- THERE WAS NO QUENCH PRESSURE INCREASE DURING PROPELLANT SETTLING BECAUSE THE AFT BULKHEAD REMAINED WETTED DURING COAST.
- IT IS BELIEVED THAT VEHICLE DISTURBANCES (S-MOTOR WARMING FIRINGS, THERMAL MANEUVERS, ETC.) HAD LITTLE INFLUENCE ON THE LO₂ DISTRIBUTION.
- HELIUM BUBBLER PURGE PROBABLY FLOWED THROUGH A THIN FILM OF LO₂ FOR BOTH ZERO-G COASTS.
- THE STANDPIPE AND PRESSURE SENSE LINE PURGE EXITS WERE IMMERSED IN LO₂ FOR THE ONE HOUR COAST, AND WERE CLEAR OF LO₂ DURING THE THREE HOUR COAST.

LH₂ TANK
- LH₂ TANK INTERNAL CONFIGURATION IS SUCH THAT LIQUID DISTRIBUTION FAVORED COLLECTION ABOUT THE INTERMEDIATE BULKHEAD.
- LIQUID DISTRIBUTION ENHANCED PROPELLANT COLLECTION.
- THERE WAS NO QUENCH PRESSURE INCREASE DURING PROPELLANT SETTLING BECAUSE THE INTERMEDIATE BULKHEAD AND FORWARD BULKHEAD REMAINED WETTED DURING COAST.
- VEHICLE DISTURBANCES (S-MOTOR WARMING FIRINGS, THERMAL MANEUVERS, ETC.) HAD LITTLE INFLUENCE ON THE LH₂ DISTRIBUTION.
TC-5 APPLICATION

- NO PROBLEMS ARE ANTICIPATED IN COLLECTING PROPELLANTS FOLLOWING THE 5 1/4-HOUR ZERO-G COAST.

- PROPELLANT TANK VENTING PRIOR TO MEC03 WILL BE GREATER IN MAGNITUDE THAN EXPERIENCED DURING PREPROGRAMMED VENT. NO PROBLEMS ARE ANTICIPATED IN MAINTAINING PROPELLANT CONTROL DURING VENTING.

- THE 30-MINUTE AND 20-MINUTE ZERO-G COAST PERIODS FOLLOWING MEC03 AND MEC04, RESPECTIVELY, SHOULD HAVE THE LO2 AND LH2 COLLECTED AFT PRIOR TO PROPELLANT SETTLING.

- LO2 AND LH2 SHOULD REMAIN COLLECTED AFT DURING THE 2-HOUR ZERO-G COAST FOLLOWING MEC06. NO PROBLEMS ARE EXPECTED DURING THE MID-COAST VENT PERIOD.
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

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<td>II</td>
<td>PROPELLANT BEHAVIOR</td>
<td>MERINO</td>
</tr>
<tr>
<td>III</td>
<td>HELIUM USAGE</td>
<td>MERINO</td>
</tr>
<tr>
<td>IV</td>
<td>PROPELLANT TANK PRESSURIZATION</td>
<td>MERINO</td>
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<tr>
<td>V</td>
<td>PROPELLANT TANK THERMODYNAMICS</td>
<td>MERINO</td>
</tr>
<tr>
<td>VI</td>
<td>COMPONENT HEATING &amp; THERMAL CONTROL</td>
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<td>VII</td>
<td>MAIN ENGINE SYSTEM</td>
<td>HUBER</td>
</tr>
<tr>
<td>VIII</td>
<td>H₂O₂ CONSUMPTION</td>
<td>HUBER</td>
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<tr>
<td>IX</td>
<td>BOOST PUMP POST-MECO PERFORMANCE</td>
<td>HUBER/MERINO</td>
</tr>
<tr>
<td>X</td>
<td>OVERVIEW OF OTHER SYSTEMS</td>
<td>HUBER</td>
</tr>
</tbody>
</table>
HELIUM USAGE

- PURGES
- H$_2$O$_2$ EXPULSION
- MAIN ENGINES
- PROPELLANT TANK PRESSURANT
PURGES

- LH₂ TANK ENERGY DISSIPATOR
  2032 SCCM (MEASURED)
  USAGE TO MECO 4 = 0.2062 LB.

- LO₂ TANK BUBBLER
  576.6 SCCM (MEASURED)
  USAGE TO MECO 4 = 0.0576 LB.

- LO₂ TANK STANDPIPE
  1773.7 SCCM (MEASURED)
  USAGE TO MECO 4 = 0.1800 LB.

- LO₂ TANK PRESS. SENSE LINE
  425.7 SCCM (MEASURED)
  USAGE TO MECO 4 = 0.0432 LB.

- H₂O₂ SYSTEM PURGE
  251 SCCM (MEASURED)
  USAGE TO MECO 4 = 0.4175 LB.

MAIN ENGINES

- ENGINE START
  0.088 LB/START
  USAGE TO MECO 4 = 0.352 LB.

- PURGE
  26.2 SCCM
  USAGE TO MECO 4 = 0.003 LB.
H2O2 EXPULSION

0.00230 LB HELIUM/LB H2O2 EXPELLED

- 182.6 LB. H2O2 CONSUMED TO MECO2
- 330.9 LB. H2O2 CONSUMED TO MECO4

- 0.420 LB. HELIUM REQUIRED FOR H2O2 EXPULSION TO MECO2
- 0.761 LB. HELIUM REQUIRED FOR H2O2 EXPULSION TO MECO4

ACCUMULATED HELIUM USAGES

- HELIUM TOTAL TO MECO2 + 72 SECONDS = 0.718 LB.
  (CENTAUR RETRO IS EFFECTED VIA BLOWDOWN OF SMALL HELIUM BOTTLE)

- HELIUM TOTAL TO MECO4 = 2.018 LB.
PROPELLANT TANK PRESSURANT

- Usages obtained from helium bottle blowdown model
- Solenoid valve on-times accurately known
- Accuracy of bottle blowdown verified by pre-mes3 and pre-mes4 pressurization simulations

PRE-MES3 PRESSURIZATION

- Initial conditions: $P = 2639$ psia, $T = 505^\circ R$
  - $\text{H}_2$ orifice dia. = 0.0995 inches
  - $\text{O}_2$ orifice dia. = 0.0465 inches
- $\text{LH}_2$ tank valve total on-time = 18.28 seconds
- $\text{LO}_2$ tank valve total on-time = 18.06 seconds
- Figure shows good match between predictions and CF2P.
- Pressure match was obtained with nominal orifice discharge coefficients of 0.81.
- No attempt made to match bottle temperature ($\text{CF}_4T$) due to its poor temperature response.
TC-2 HELIUM BOTTLE PRESSURES
DURING THIRD PRESSURIZATION

PRESURE, PSIA

TIME FROM START PRESSURIZATION, SEC

END LH₂ TANK PRESSURIZATION
END LO₂ TANK PRESSURIZATION

FLIGHT DATA
SIMULATION

III-6
PRE-MES4 PRESSURIZATION

- INITIAL CONDITIONS: \( P = 1247 \text{ psia}, \ T = 477^\circ\text{R} \)
  - \( \text{H}_2 \) ORIFICE DIA. = 0.0995 INCHES
  - \( \text{O}_2 \) ORIFICE DIA. = 0.0465 INCHES
- \( \text{LH}_2 \) TANK VALVE TOTAL ON-TIME = 19.02 SECONDS
- \( \text{LO}_2 \) TANK VALVE TOTAL ON-TIME = 42.76 SECONDS
- FIGURE SHOWS GOOD MATCH BETWEEN PREDICTIONS AND CF2P.
- PRESSURE MATCH WAS OBTAINED WITH NOMINAL ORIFICE DISCHARGE COEFFICIENTS OF 0.81.
- NO ATTEMPT MADE TO MATCH BOTTLE TEMPERATURE (CF4T) DUE TO ITS POOR TEMPERATURE RESPONSE
TC-2 HELIUM BOTTLE PRESSURES
DURING FOURTH PRESSURIZATION

PRESSURE,
PSIA

TIME FROM START PRESSURIZATION, SECONDS

--- FLIGHT DATA
--- SIMULATION

END LH₂ TANK PRESSURIZATION
SUMMARY OF MISSION HELIUM USAGES

- TABLE CONTAINS HELIUM PRESSURANT USAGES AND PRE-FLIGHT PREDICTIONS
- WITH EXCEPTION OF FIRST AND SECOND LO2 TANK PRESSURIZATIONS, USAGES WERE WITHIN PREDICTION BAND.
- HELIUM USAGES FROM LIFFTOFF TO CENTAUR RETRO ARE:
  - PURGES + MAIN ENGINE + H2O2 EXPULSION = 0.718 LB
  - PROPELLANT TANK PRESSURIZATION = 1.718 LB
    - 2.436 LB
  BOTTLE CONDITIONS SHOW 15.00 LB - 12.63 LB = 2.37 LB
- HELIUM EXPELLED DURING CENTAUR RETRO = 4.79 LB (P=2764 PSIA, T = 530°F)
- HELIUM USAGES FROM CENTAUR RETRO TO MECO4 ARE:
  - PURGES + MAIN ENGINE + H2O2 EXPULSION = 1.300 LB
  - PROPELLANT TANK PRESSURIZATION = 4.339 LB
    - 5.639 LB.

- HELIUM REMAINING AT MECO4 IS:
  - 15.00 LB (INITIAL LOAD)
  - 2.436 LB
  - 4.790 LB
  - 5.639 LB
  - 2.135 LB

  BOTTLE CONDITIONS SHOW 2.25 LB (P = 637 PSIA, T = 438°F)

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**TC-2 MISSION HELIUM USAGE HISTORY**

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TIME FROM T-0, SEC.</th>
<th>HELIUM BOTTLE CONDITIONS&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>PRESSURANT USAGE, LB.</th>
<th>PREDICTED PRESSURANT USAGE, LB.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PSIA</td>
<td>°R</td>
<td>LB.</td>
</tr>
<tr>
<td>T-0</td>
<td>0</td>
<td>3453</td>
<td>539</td>
<td>15.00</td>
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<tr>
<td>INITIATE PRE-MES1 PRESS'N</td>
<td>437</td>
<td>3437</td>
<td>5.7</td>
<td>14.99</td>
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<td>MES1</td>
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<td>520</td>
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<tr>
<td>MEC04</td>
<td>16632.3</td>
<td>637</td>
<td>438</td>
<td>2.25</td>
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<sup>(1)</sup> TEMPERATURE AND PRESSURE ARE FOR LARGE HELIUM BOTTLE. THE TABULATED MASS REFLECTS DIFFERENT TEMPERATURE LEVELS IN THE LARGE AND SMALL BOTTLES.
APPLICATION TO TC-5 MISSION

TC-2 demonstrated that flight helium usages and helium bottle blowdown pressures during propellant tank pressurizations can be accurately simulated with existing computer programs.

Helium monitor development for TC-5 mission was due to:

- The need to guarantee 500 psia minimum helium bottle pressure through ME96, and this can only be achieved with accurate determination of helium pressurant usages,
- The knowledge that normalized curves of helium mass flow and helium bottle pressure are applicable for a wide range of mission conditions,
- The knowledge that accurate solenoid valve on-times coupled with curve fits of normalized curves will allow helium consumption to be monitored throughout the TC-5 mission.
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I  Introduction  HUBER
II Propellant Behavior  MERINO
III Helium Usage  MERINO
IV Propellant Tank Pressurization  MERINO
V Propellant Tank Thermodynamics  MERINO
VI Component Heating & Thermal Control  CHRISTENSEN
VII Main Engine System  HUBER
VIII H2O2 Consumption  HUBER
IX Boost Pump Post-MECO Performance  HUBER/MERINO
X Overview of Other Systems  HUBER

IV-1
PROPELLANT TANK PRESSURIZATION

- LO2 TANK PRESSURIZATION AND PREFLIGHT PREDICTIONS
- LH2 TANK PRESSURIZATION AND PREFLIGHT PREDICTIONS
- LO2 SUMP CONDITIONS FOR MAIN ENGINE START
- LH2 SUMP CONDITIONS FOR MAIN ENGINE START
COMPUTER CONTROLLED VENT AND PRESSURIZATION SYSTEM (CCVAPS)

LH₂ VENT VALVES

LH₂ TANK

LO₂ STANDPIPE

LO₂ TANK

LO₂ VENT VALVE

LO₂ TANK PRESSURIZATION

LH₂ TANK PRESSURIZATION

DIGITAL COMPUTER UNIT (DCU)

PRESSURE SENSORS

SEQUENCE CONTROL UNIT (SCU)

REDUNDANT LO₂

CONTROL VALVE

HELIUM STORAGE

HE STOP

NO.1 LH₂

NO.1 REDUNDANT LH₂

NO.2 LH₂

NO.2 REDUNDANT LH₂

GENERAL DYNAMICS
Convair Division
31 Oct 75

IV-3
PRE-MES1 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON TC-1 FLIGHT DATA

- PRESSURE RISE RATES, DECAY RATES, AND RECYCLES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS.

- HELIUM USAGES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS

- INITIAL PRESSURE = 32.15 PSIA

- CLOSING PRESSURE = 39.12 PSIA (PHASE 4)
  = 39.91 PSIA (PHASE 5)

- RE-OPEN CYCLES = 38.92 PSIA (PHASE 4)
  = 39.71 PSIA (PHASE 5)
LO₂ TANK MES1 PRESSURIZATION

CCVAPS LO₂ TANK PRESSURE

TIME FROM SRM IGNITION (SECONDS)
PRE-MES2 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON B2 TEST DATA
- INITIAL PRESSURE = 32.61 PSIA
- CLOSING PRESSURE = 36.11 PSIA
- RE-OPEN CYCLES = 35.91 PSIA
- PRESSURE RISE RATES LESS THAN MINIMUM PREDICTED. DIFFERENCE MAY BE DUE TO GREATER LO2 EVAPORATION IN ONE-G (B2 TESTS) THAN IN LOW-G.
- NO INFORMATION ON RE-CYCLES DUE TO LOSS OF TELEMETRY.
- A 0.33 PSID PRESSURE INCREASE OCCURRED FOLLOWING RAMP PRESSURIZATION.
- IT IS BELIEVED THAT PRESSURE INCREASE IS DUE TO LO2 EVAPORATION INTO HELIUM BUBBLES THAT RESIDE BENEATH LIQUID SURFACE.
- TC-3 DATA SUGGESTS THAT ONE RECYCLE MAY HAVE OCCURRED PRIOR TO MES2.
LO₂ TANK MES2 PRESSURIZATION

CCVAPS LO₂ TANK PRESSURE

PSIA

-34.5
-35.0
-35.5
-36.0
-36.5
-37.0

PRE-FLIGHT PREDICTION

ZONES WHERE NO DATA IS AVAILABLE

BPS
PRESTART

(-38.00) START PRESS'N TIME FROM MES2 (SECONDS)

GENERAL DYNAMICS
Convair Division
31 Oct 75
TC-3 LO₂ TANK MES2 PRESSURIZATION

CCVAPS LO₂ TANK PRESSURE

PSIA

PRESSURE AT START
• PRESS'N = 32.12 PSIA

BPS
PRESTART

TIME FROM MES2 (SECONDS)
PRE-MES3 LO2 TANK PRESSURIZATION

• PRE-FLIGHT PREDICTIONS BASED UPON THEORETICAL MODEL OF HELIUM JET FLOW BENEATH LIQUID SURFACE

• INITIAL PRESSURE = 29.89 PSIA

• CLOSING PRESSURE = 33.39 PSIA

• RE-OPEN CYCLES = 33.19 PSIA

• PRESSURE RISE RATES GREATER THAN MAXIMUM PREDICTED.

• HAVE NOT OBTAINED GOOD HELIUM USAGE AND PRESSURE RISE MATCH WITH MODEL.

• DISCREPANCY OF 24% BETWEEN ACTUAL AND PREDICTED HELIUM USAGE MAY BE DUE TO SUBSTANTIAL CHILLING OF LIQUID ABOVE BUBBLER RESULTING FROM LO2 EVAPORATION INTO HELIUM.

• THERE IS NO PRESSURE INCREASE FOLLOWING TERMINATION OF HELIUM FLOW BECAUSE THERE IS NO HELIUM BENEATH LIQUID SURFACE TO STIMULATE LO2 EVAPORATION.
LO₂ TANK MES3 PRESSURIZATION

CCVAPS LO₂ TANK PRESSURE

PSIA

- 34
- 33
- 32
- 31
- 30
- 29

TIME FROM MES3 (SECONDS)

1V-10
PRE-MES 4 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON THEORETICAL MODEL OF HELIUM JET FLOW BENEATH LIQUID SURFACE
- INITIAL PRESSURE = 32.50 PSIA
- CLOSING PRESSURE = 36.00 PSIA
- RE-OPEN CYCLES = 35.80 PSIA
- PRESSURE RISE RATES GREATER THAN MAXIMUM PREDICTED
- POST FLIGHT SIMULATIONS HAVE NOT RESULTED IN GOOD MATCH WITH HELIUM USAGE AND PRESSURE RISE RATE
- DISCREPANCY OF 24% BETWEEN ACTUAL AND PREDICTED USAGE MAY BE DUE TO SUBSTANTIAL CHILLING OF LIQUID ABOVE BUBBLER RESULTING FROM LO2 EVAPORATION INTO HELIUM
- THERE IS NO PRESSURE INCREASE FOLLOWING TERMINATION OF HELIUM FLOW BECAUSE THERE IS NO HELIUM BENEATH LIQUID SURFACE TO STIMULATE LO2 EVAPORATION.
PRE-MES1 LH2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON TC-1 FLIGHT DATA

- PRESSURE RISE RATES, DECAY RATES, AND RECYCLES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS

- HELIUM USAGES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS

- INITIAL PRESSURE = 19.92 PSIA

- CLOSING PRESSURE = 25.92 PSIA (PHASES 4 AND 5)

- REOPEN CYCLES = 25.72 PSIA (PHASES 4 AND 5)
LH₂ TANK MES1 PRESSURIZATION

CCVAPS LH₂ TANK PRESSURE

TIME FROM SRM IGNITION (SECONDS)

GENERAL DYNAMICS
Convair Division
31 Oct 75
PRE-MES2 LH2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON B2 TEST DATA
  - INITIAL PRESSURE = 20.13 PSIA
  - CLOSING PRESSURE = 23.53 PSIA
  - RE-OPEN CYCLES = 23.33 PSIA

- PRESSURE RISE RATES LESS THAN MINIMUM PREDICTED. ENERGY DISSIPATOR DIRECTED HELIUM AT LH2 SURFACE FOR B2 TESTS. THE TC-2 ENERGY DISSIPATOR DIRECTED HELIUM RADIALLY OUTWARD AT THE FORWARD BULKHEAD. HEAT TRANSFER TO FORWARD BULKHEAD COULD HAVE BEEN RESPONSIBLE FOR REDUCED TC-2 PRESSURE RISE RATE. THERE WAS NO CORRESPONDING HEAT LOSS TO FORWARD BULKHEAD DURING B2 TESTS.

- NO INFORMATION ON RE-CYCLES DUE TO LOSS OF TELEMETRY

- TELEMETRY LOSS DID NOT REVEAL A PRESSURE INCREASE FOLLOWING BOOST PUMP START.
  NOTE: TC-3 AND TC-4 FLIGHTS INDICATED ≈ 0.2 PSID INCREASE. IT IS BELIEVED THAT THE INCREASE WAS DUE TO VAPOR FLOW INTO THE TANK THROUGH THE RECIRCULATION LINE DURING CHILLDOWN OF THE PROPELLANT DUCTING.

- TC-3 DATA SUGGESTS THAT TWO RECYCLES MAY HAVE OCCURRED PRIOR TO MES2.
LH₂ TANK MES2 PRESSURIZATION

NOTE: DATA POINTS SHOWN WERE DERIVED FROM DCU OCTAL DUMP.
TC-3 LH₂ TANK MES2 PRESSURIZATION

CCVAPS LH₂ TANK PRESSURE

PRESSURE AT START
PRESS'N = 19.76 PSIA

TIME FROM MES2 (SECONDS)

IV-17
PRE-MES3 LH2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON TANK THERMODYNAMIC MODEL (PROGRAM P3995H)

- INITIAL PRESSURE = 15.93 PSIA
- CLOSING PRESSURE = 19.33 PSIA
- RE-OPEN CYCLES = 19.13 PSIA

- GOOD AGREEMENT EXISTS BETWEEN PREDICTED AND ACTUAL RAMP PRESSURE INCREASE.

- FOLLOWING BOOST PUMP START A 0.12 PSID PRESSURE INCREASE OCCURRED. THE INCREASE IS BELIEVED TO BE CAUSED BY VAPOR FLOW INTO THE TANK THROUGH THE RECIRCULATION LINE DURING CHILLDOWN OF THE PROPELLANT DUCTING.

- A VALVE RE-CYCLE OF 0.38 SECOND DURATION OCCURRED PRIOR TO MES3.
LH$_2$ TANK MES3 PRESSURIZATION

CCVAPS LH$_2$ TANK PRESSURE

TIME FROM MES3 (SECONDS)

PRE-FLIGHT PREDICTIONS

BPS

PRESTART
PRE-MES4 LH2 TANK PRESSURIZATION

- Pre-flight predictions based upon tank thermodynamic model (Program P3995H)
- Initial pressure = 21.01 PSIA
- Closing pressure = 23.91 PSIA
- Re-open cycle = 23.71 PSIA
- Pressure rise slightly greater than maximum predicted.
- Following boost pump start a 0.08 psid pressure increase occurred. The increase is believed to be caused by vapor flow into the tank through the recirculation line during chilldown of the propellant ducting.
- Pressurization was terminated by time (19 second flow duration).
LH₂ TANK MES4 PRESSURIZATION

CCVAPS LH₂ TANK PRESSURE

PSIA

TIME FROM MES4 (SECONDS)

BPS - PRESTART

PRE-FLIGHT PREDICTIONS

IV-21
LO2 SUMP TEMPERATURES

PRE-MES1

- LO2 INITIALLY SATURATED AT 31.60 PSIA
- NO VAPOR IN SUMP PRIOR TO BPS
- TEMPERATURE INCREASE BEGINS AT BPS + 8 SECONDS
- 0.77°F TEMPERATURE INCREASE BY MES1 DUE TO BEARING COOLANT AND VOLUTE FLOWS

PRE-MES3

- LO2 INITIALLY SATURATED AT TANK PRESSURE (29.89 PSIA)
- 1.56°F TEMPERATURE RISE PRIOR TO BPS INDICATES ≈ 50% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP AT BPS + 1.5 SECONDS
- TEMPERATURE INCREASE BEGINNING AT BPS + 7 SECONDS IS CAUSED BY VOLUTE AND BEARING COOLANT FLOWS
- TEMPERATURE DECAY AFTER MES INDIC...IQUID BULK IS SUBCOOLED BY ≈ 1.0 PSID BELOW INITIAL TANK PRESSURE
LO2 SUMP TEMPERATURES (Contd)

PRE-MES4

• LO2 INITIALLY SATURATED AT TANK PRESSURE (32.50 PSIA)

0.77°F TEMPERATURE RISE PRIOR TO BPS INDICATES ≈ 33% VAPOR BY VOLUME INITIALLY
IN SUMP

• WARM FLUID BEGINS FLOW OUT OF SUMP AT BPS + 1.5 SECONDS

• TEMPERATURE INCREASE BEGINNING AT BPS + 7 SECONDS IS CAUSED BY VOLUME AND
BEARING COOLANT FLOWS

• TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 1.4 PSID
BELOW INITIAL TANK PRESSURE
LO$_2$ SUMP TEMPERATURES
FOR MAIN ENGINE START

TIME FROM MES1 (SECONDS)

TIME FROM MES3 (SECONDS)

TIME FROM MES4 (SECONDS)
PRE-MES3 LO2 BOOST PUMP NPSP CONDITIONS

- LO2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 2.7 PSID AT BPS
- NPSP = 1.1 PSID AT BPS + 3 SECONDS - MINIMUM NPSP CONDITION
- NPSP = 3.3 PSID AT BPS + 4 SECONDS
  WARM LO2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NPSP = 3.7 PSID AT BPS + 7 SECONDS
  BEYOND THIS TIME VOLUME AND BEARING COOLANT FLOW BEGIN TO WARM LO2
- NPSP = 3.3 PSID AT PRESTART
- NPSP = 2.9 PSID AT MES3
- NPSP = 3.8 PSID AT MES3 + 5 SECONDS
  COLD LIQUID IS BEING PUMPED OVERBOARD.
LO₂ BOOST PUMP NPSP FOR MES3

CCVAPS LO₂ TANK PRESSURE

LIQUID VAPOR PRESSURE IN SUMP

PRESS'N  BPS  PRESTART

TIME FROM MES3 (SECONDS)

IV-27
PRE-MES4 LO2 BOOST PUMP NPSP CONDITIONS

- LO2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 0.1 PSID AT BPS
  MINIMUM NPSP CONDITION
- NPSP = 1.5 PSID AT BPS + 4 SECONDS (Prestart)
  WARM LO2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NPSP = 2.4 PSID AT BPS + 7 SECONDS
  BEYOND THIS TIME VOLUTE AND BEARING COOLANT FLOW BEGINS TO WARM LO2
- NPSP = 2.6 PSID AT MES4
- NPSP = 3.5 PSID AT MES4 + 10 SECONDS
  COLD LIQUID IS BEING PUMPED OVERBOARD
LO_2 BOOST PUMP NPSP FOR MES4

CCVAPS LO_2 TANK PRESSURE

PSIA

LIQUID VAPOR PRESSURE IN SUMP

PRESTART

PRESS'N BPS

TIME FROM MES4 (SECONDS)

IV-29
LH₂ SUMP TEMPERATURES

PRE-MES1

- LH₂ INITIALLY SATURATED AT 20.7 PSIA
- 0.09°F TEMPERATURE INCREASE INDICATES ≈ 5% VAPOR BY VOLUME INITIALLY IN SUMP
- 1.11°F TEMPERATURE INCREASE BY PRESTART DUE TO BEARING COOLANT FLOW
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 0.6 PSID BELOW INITIAL TANK PRESSURE

PRE-MES3

- LH₂ INITIALLY SATURATED AT TANK PRESSURE (15.93 PSIA)
- 1.02°F TEMPERATURE RISE PRIOR TO BPS INDICATES ≈ 43% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP BY BPS + 4 SECONDS
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 0.22 PSID BELOW INITIAL TANK PRESSURE

PRE-MES4

- LH₂ INITIALLY SATURATED AT TANK PRESSURE (21.01 PSIA)
- 0.37°F TEMPERATURE RISE PRIOR TO BPS INDICATES ≈ 18% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP BY BPS + 4 SECONDS
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 0.4 PSID BELOW INITIAL TANK PRESSURE

IV-31
LH₂ SUMP TEMPERATURES FOR MAIN ENGINE START

CP 32T LH₂ B PUMP INLET

START PRESS'N & BPS
PRESTART

TIME FROM MES1 (SECONDS)

START PRESS'N
BPS
PRESTART

TIME FROM MES3 (SECONDS)

START PRESS'N
BPS
PRESTART

TIME FROM MES4 (SECONDS)

IV-32
PRE-ME3 LH2 BOOST PUMP NPSP CONDITIONS

- LH2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 0.35 PSID AT BPS
  MINIMUM NPSP CONDITION
- NPSP = 3.2 PSID AT BPS + 5 SECONDS
  WARM LH2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NISP = 2.7 PSID AT BPS + 11 SECONDS (PRESTART)
- NPSP = 3.2 PSID AT ME3
- NPSP = 3.1 PSID AT ME3 + 5 SECONDS
LH₂ BOOST PUMP NPSP FOR MES3

CCVAPS LH₂ TANK PRESSURE

PSIA

TIME FROM MES3 (SECONDS)

1V-34
PRE-MES4 LH2 BOOST PUMP NPSP CONDITIONS

- LH2 INITIALLY SATURATED AT TANK PRESSURE

- NPSP = 0.3 PSID AT BPS
  MINIMUM NPSP CONDITION

- NPSP = 0.6 PSID AT BPS + 4 SECONDS (PRESTART)

- NPSP = 1.6 PSID AT BPS + 8 SECONDS
  WARM LH2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID

- NPSP = 1.1 PSID AT MES4

- NPSP = 1.2 PSID AT MES4 + 5 SECONDS
  COLD LIQUID IS BEING PUMPED OVERBOARD
LH₂ BOOST PUMP NPSP FOR MES4

CCVAPS LH₂ TANK PRESSURE

PSIA

TIME FROM MES4 (SECONDS)

IV-36
SUMMARY OF PROPELLANT TANK PRESSURIZATION

- PRE-MES1 PRESSURIZATION SAME AS FOR TC-1, -3, AND -4.
- PRE-MES2 PRESSURE RISE RATES LOWER THAN THE PREDICTION BAND.
- UNEXPECTED PRESSURE INCREASES OCCURRED IN BOTH TANKS FOLLOWING PRE-MES2 RAMP PRESSURIZATION. THE LH₂ TANK PRESSURE RISE WAS NOT SEEN BECAUSE OF TELEMETRY LOSS. TC-3 FLIGHT CLEARLY SHOWED THESE PRESSURE INCREASES. THIS PHENOMENON HAS BEEN EXPLAINED.
- PRE-MES3 AND 4 LO₂ TANK PRESSURE RISE RATES GREATER THAN THE PREDICTION BAND.
- PRE-MES3 AND 4 LH₂ TANK PRESSURE RISE RATES WERE SATISFACTORILY SIMULATED BY TANK MODEL.
- INITIAL QUANTITY OF VAPOR IN LO₂ SUMP (MAX OF 50%) RESULTED IN LOW NPSP AT BPS. PUMPING OF COOLER TANK FLUID PROVIDED SATISFACTORY NPSP THROUGHOUT BOOST PUMP OPERATION.
- INITIAL QUANTITY OF VAPOR IN LH₂ SUMP (MAX OF 43%) RESULTED IN LOW NPSP AT BPS. PUMPING OF COOLER TANK FLUID PROVIDED SATISFACTORY NPSP THROUGHOUT BOOST PUMP OPERATION.

TC-5 IMPLICATIONS

- PROPELLANT TANK PRESSURE REQUIREMENTS WILL BE SATISFIED FOR ALL MAIN ENGINE STARTS (UNTIL AVAILABLE HELIUM EXPENDED).
- NPSP CONDITIONS WILL BE SATISFACTORY THROUGH MES3. MES4 AND ON CONDITIONS ARE DISCUSSED IN SECTION IX.
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I  INTRODUCTION
   HUBER

II PROPELLANT BEHAVIOR
   MERINO

III HELIUM USAGE
   MERINO

IV PROPELLANT TANK PRESSURIZATION
   MERINO

V PROPELLANT TANK THERMODYNAMICS
   MERINO

VI COMPONENT HEATING & THERMAL CONTROL
   CHRISTENSEN

VII MAIN ENGINE SYSTEM
   HUBER

VIII H₂O₂ CONSUMPTION
   HUBER

IX BOOST PUMP POST-MECO PERFORMANCE
   HUBER/MERINO

X OVERVIEW OF OTHER SYSTEMS
   HUBER
V. PROPELLANT TANK THERMODYNAMICS

- LO₂ TANK ENERGY BALANCE

- LH₂ TANK ENERGY BALANCE
PREFLIGHT PREDICTIONS OF COAST PHASE
PROPELLANT TANK PressURES

- MAXIMUM PRESSURE RISE RATE DURING COAST ASSUMED:
  - MAXIMUM HEATING
  - LIQUID INSTANTANEOUSLY POSITIONED FORWARD (FOR LO₂ TANK, 750 SECOND THRUST BARREL DRAIN ASSUMED)
  - DRY TANK WALLS
  - ENERGY ABSORBED BY DRY TANK WALLS RESULTS IN LIQUID BOILING DURING PROPELLANT SETTLING

- MINIMUM PRESSURE RISE RATE DURING COAST ASSUMED:
  - MINIMUM HEATING
  - THERMODYNAMIC EQUILIBRIUM

- THE ABOVE ASSUMPTIONS WERE MADE TO MAXIMIZE THE MISSION PRESSURE ENVELOPE.
NOTE: Solid lines define the maximum and minimum predicted level. Dotted lines describe the actual flight data.
PROPELLANT TANKS PRESSURE PROFILE
THIRD COAST & FOURTH BURN

NOTE: SOLID LINES DEFINE THE MAXIMUM AND MINIMUM PREDICTED LEVELS. DOTTED LINES DESCRIBE THE ACTUAL FLIGHT DATA.

V-5
PROPELLANT TANK ENERGY BALANCE

FROM THE FIRST LAW:

\[
\begin{align*}
[(mu)_L + (mu)_g]_2 & - [(mu)_L + (mu)_g]_1 = \Delta Q_{2-1} - (hm)_g \, \text{out} - (hm)_L \, \text{out} \\
\end{align*}
\]

WHERE

- \( m \) = FLUID MASS, LB
- \( u \) = FLUID INTERNAL ENERGY, BTU/LB
- \( h \) = FLUID ENTHALPY, BTU/LB
- \( \Delta Q \) = NET HEAT INPUT TO PROPELLANT TANK, BTU

SUBSCRIPTS

- \( 2 \) = CONDITIONS AT MECO1 OR PRE-PROGRAMMED VENT
- \( 1 \) = CONDITIONS AT MECO2
- \( g \) = \( \text{GO}_2, \text{GH}_2 \)
- \( L \) = \( \text{LO}_2, \text{LH}_2 \)
- \( \text{out} \) = PROPELLANT EXPULSED FROM TANK

- \( u, h, mg, mg_{\text{out}} \) ARE DETERMINED FROM FLUID PRESSURES AND TEMPERATURES
- \( m_L \) IS KNOWN FROM PU AND ENGINE FLOW DATA
- \( \Delta Q \) CONSISTS OF TANK HEAT INPUT (+) BOOST PUMP RELATED HEAT ADDITION
- (-) HEAT LOSS THROUGH INTERMEDIATE BULKHEAD
- BOOST PUMP RELATED HEAT ADDITION:
  
  RECIRCULATION LINE FLOW (BPS TO MECO3) \( \sim \) 12 BTU (\text{LO}_2 TANK), 22 BTU (\text{LH}_2 TANK)
  
  (BPS TO MECO4) \( \sim \) 18 BTU (\text{LO}_2 TANK), 39 BTU (\text{LH}_2 TANK)

  BOOST PUMP SPINDOWN \( \sim \) 88.0 BTU PER SPINDOWN (\text{LO}_2 TANK)

  V-6 \( \sim \) 100.0 BTU PER SPINDOWN (\text{LH}_2 TANK)
PROPELLANT TANK BOUNDARIES FOR ENERGY BALANCE
LO$_2$ TANK ENERGY BALANCE

**MECO2 CONDITIONS**

- ULLAGE PRESSURE = 27.12 PSIA
- HELIUM PRESSURE = 0.45 PSIA
- GO$_2$ PRESSURE = 26.67 PSIA
- GO$_2$ TEMPERATURE = SATURATED AT 27.12 PSIA ($\Delta T_g = 0.3^\circ$R)
- GO$_2$ MASS = 153.7 LB.
- LO$_2$ VAPOR PRESSURE = 27.65 PSIA (ULLAGE PRESSURE + $\rho_{gH}$ EFFECT)
  MAXIMUM STORED ENERGY = 640 BTU (DUE TO $\rho_{gH}$ EFFECT)
- LO$_2$ MASS = 4027.6 LB (FROM PU CALCULATIONS)
- VEHICLE ACCELERATION = 2.14 G's
- FLIGHT TIME = T + 2172.93 SECONDS

**POST MECO2 CONDITIONS**

- PRESSURE RECOVERY OF 1.15 PSID CAUSED BY EVAPORATION OF 6.5 LB LO$_2$
- $0.97^\circ$R TEMPERATURE DROP INDICATES AN LO$_2$ VAPOR PRESSURE DECAY FROM 28.65 PSIA TO 27.30 PSIA AT BOOST PUMP INLET
LO$_2$ CONDITIONS AT MECO2

CCVAPS LO$_2$ TANK PRESSURE TC-2

PIA

CP 33T LO$_2$ B PUMP INLET

DGF

TIME FROM MECO2 (SECONDS)
LO₂ TANK ENERGY BALANCE

MECO 4 CONDITIONS
- ULLAGE PRESSURE = 31.09 PSIA
- HELIUM PRESSURE = 2.09 PSIA
- GO₂ PRESSURE = 29.01 PSIA
- GO₂ TEMPERATURE = 175.6 R (0.6°R SUPERHEAT)
- GO₂ MASS = 190.3 LB
- LO₂ VAPOR PRESSURE = 30.07 PSIA
- LO₂ MASS = 790.5 LB (FROM PU CALCULATIONS)
- VEHICLE ACCELERATION = 4.62 G'S
- FLIGHT TIME = T + 16631.98 SECONDS

POST MECO 4 CONDITIONS
- PRESSURE RECOVERY OF 0.51 PSID CAUSED BY EVAPORATION OF 2.2 LB LO₂
- 0.38°R TEMPERATURE DROP INDICATES A LO₂ VAPOR PRESSURE DECAY FROM 31.1 PSIA TO 29.5 PSIA AT BOOST PUMP INLET.
LO2 CONDITIONS AT MECO4

CCVAPS LO2 TANK PRESSURE TC-2

PIA

CP 33T LO2 B PUMP INLET

DGF

TIME FROM MECO4 (SECONDS)

V-11
LO₂ TANK ENERGY BALANCE

PROPELLANT CONDITIONS AT VENT TERMINATION

- ULLAGE PRESSURE = 30.82 PSIA
- HELIUM PRESSURE = 1.45 PSIA
- GO₂ PRESSURE = 29.37 PSIA
- GO₂ TEMPERATURE = 175.6°F (0.3°F SUPERHEAT)
- GO₂ MASS = 173.0 LB
- LO₂ VAPOR PRESSURE = 30.65 PSIA
- LO₂ MASS = 3350.3 LB
- VEHICLE ACCELERATION = 2.4 X 10⁻³
- FLIGHT TIME = T + 14554 SECONDS
- GO₂ VENT MASS = 12.1 LB
- HELIUM VENT MASS = 0.07 LB

POST VENT CONDITIONS

- PRESSURE RECOVERY OF 0.93 PSID CAUSED BY EVAPORATION OF 4.0 LB LO₂.
- 1.36°F TEMPERATURE DROP INDICATES AN LO₂ VAPOR PRESSURE DECAY FROM 32.92 PSIA TO 30.82 PSIA AT BOOST PUMP INLET.
LO₂ CONDITIONS DURING PRE-PROGRAMMED VENT

CCVAPS LO₂ TANK PRESSURE TC-2

VENT VALVE UNLOCKED AT 14534.3

CP 33T LO₂ B PUMP INLET

DGF

FLIGHT TIME (SECONDS)

V-13
## TEMPERATURE MEASUREMENT LOCATIONS

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<th>MEASUREMENT NUMBER (1)</th>
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<td>CF27T</td>
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**NOTES:**
- CF MEASUREMENTS (•) INTERNAL TO TANKS.
- CA MEASUREMENTS (x) MOUNTED ON EXTERNAL SURFACE OF LH₂ TANK.
**LO₂ TANK ENERGY BALANCE**

**ULLAGE TEMPERATURE CONDITIONS FROM MECO 2 TO MECO 4**

- MECO 2  ~  ULLAGE TEMPERATURE = 173.64°C

- POST MECO 2 ~ ULLAGE TEMPERATURE INCREASES TO 174.59°C
  NOTE: THE INCREASING ULLAGE TEMPERATURE WAS CAUSED BY EVAPORATION WHICH REDUCED LIQUID TEMPERATURE DURING THE SAME PERIOD.

- VENT VALVE UNLOCK ~ ULLAGE TEMPERATURE = 177.0°C
- VENT TERMINATION ~ ULLAGE TEMPERATURE DROPS TO 175.6°C
- POST VENT ~ ULLAGE TEMPERATURE INCREASES TO 176.5°C
  NOTE: ULLAGE TEMPERATURE CHANGES ARE CONSISTENT WITH VENTING OF A NEARLY SATURATED VAPOR FOLLOWED BY LO₂ EVAPORATION WHICH RESULTS IN A VAPOR TEMPERATURE INCREASE.

- MECO 4  ~  ULLAGE TEMPERATURE = 175.6°C

- POST MECO 4 ~ ULLAGE TEMPERATURE INCREASES TO 176.3°C
  NOTE: THE INCREASING ULLAGE TEMPERATURE WAS CAUSED BY EVAPORATION WHICH REDUCED LIQUID TEMPERATURE DURING THE SAME PERIOD.
LO₂ TANK ULLAGE TEMPERATURES
DURING MISSION

CF 23T O/ULLAGE ST 2230/60

DGF

MECO1

MECO2

MECO3

DGF

MECO4

VENT

VENT VALVE

V-16
NET HEAT INPUT TO LO₂ TANK

- FIRST LOW EQUATION SOLVED FOR ΔQ_NET
  - ΔQ TANK = ΔQ_NET - 88 BTU (PER F/P SPINDOWN) - RECIRC. FLOW HEAT ADDITION
  - = TANK HEAT INPUT - INTERMEDIATE BULKHEAD HEAT LOSS

MECO 2 TO MECO 4 CONDITIONS
  - ΔQ TANK = \( \dot{Q}_{2\text{ND COAST}} \times (1.0 \text{ HRS}) + \dot{Q}_{3\text{RD COAST}} \times (3.0 \text{ HRS}) \)

MECO 2 TO PRE-PROGRAMMED VENT CONDITIONS
  - ΔQ TANK = \( \dot{Q}_{2\text{ND COAST}} \times (1.0 \text{ HRS}) + \dot{Q}_{3\text{RD COAST}} \times (2.44 \text{ HRS}) \)

CALCULATED TANK HEATING RATES
- Q 2ND COAST = 2103 BTU/HR
- Q 3RD COAST = 1077 BTU/HR
NET HEAT INPUT TO LO₂ TANK VERSUS LIQUID VAPOR PRESSURE AND ULLAGE SUPERHEAT CONDITIONS

MECO₂ TO MECO₄
SUPERHEAT
0° R
1° R
2° R

MECO₂ TO PRE-PROGRAMMED VENT
SUPERHEAT
0° R
1° R
2° R

G DYNAMICS
Conair Division
31 Oct 75

MECO₄ LIQUID VAPOR PRESSURE, PSIA

- BEST ESTIMATE OF PROPELLANT CONDITION

\[ \dot{Q}_{\text{TANK}} = 2403 \text{ BTU/HR (2ND COAST)} \]
\[ = 1077 \text{ BTU/HR (3RD COAST)} \]

LIQUID VAPOR PRESSURE AT VENT TERMINATION, PSIA

- BEST ESTIMATE OF PROPELLANT CONDITION

\[ \dot{Q}_{\text{TANK}} = 2403 \text{ BTU/HR (2ND COAST)} \]
\[ = 1077 \text{ BTU/HR (3RD COAST)} \]
SUMMARY OF \( \text{LO}_2 \) TANK THERMODYNAMIC CONDITIONS FROM MECO2 TO MECO4

- Calculated tank heating rates are employed to determine intermediate state conditions.
- Tabulated intermediate state conditions are obtained from energy balance.

CONCLUSIONS

- Helium purges contributed to an increased oxygen evaporation during the coasts.
- Helium purge influence on coast phase tank pressure rise was small.
- Helium flow chilled \( \text{LO}_2 \) bulk by \( \approx 0.5^\circ R \) for 3rd pressurization and resulted in lower pressure rise rate during 3rd coast than during the 2nd coast.
- Intermediate bulkhead heat transfer rate is \( \approx 1000 \text{ BTU/HR} \).
- Near thermal equilibrium conditions were aided by \( \text{H}_2\text{O}_2 \) motor firings which resulted in \( \Delta p \) decays of up to 0.2 psid.

TC-5 APPLICATION

- Helium purge influence on coast phase tank pressure rise will be small.
- 5-1/4 hour coast pressure rise rate will be similar to the TC-2 3rd coast pressure rise rate.
- Sixth coast pressure rise rate will be two times greater than for 5-1/4 hour coast because of reduced \( \text{LO}_2 \) mass and potential for partially dry aft bulkhead.
# TC-2 Mission L2 Tank Thermodynamic Conditions

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<th>MECC2</th>
<th>PRE-MES3</th>
<th>MES3</th>
<th>MECC3</th>
<th>PRE-VENT</th>
<th>END VENT</th>
<th>POST VENT</th>
<th>PRE-MES4</th>
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<td>3.0</td>
<td>0.6</td>
<td>1.0</td>
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</table>

| **L2 Expulsion, lb.** | 1 | 71 | 570 | 2 | 0 | 0 | 0 | 57 | 2510 | 13 |
| **Vapor Vent, lb.** | 0 | 0 | 0 | 0 | 12.1 | 0 | 0 | 0 | 0 | 0 |

**Net Heat Rate To Tank, W**

- 2403
- 1077

**V-20**
LH₂ TANK ENERGY BALANCE

MECO2 CONDITIONS

- ULLAGE PRESSURE = 14.11 PSIA
- HELIUM PRESSURE = 0.13 PSIA
- GH₂ PRESSURE = 13.98 PSIA
- GH₂ TEMPERATURE = SATURATED AT 14.11 PSIA (ΔTg = 0.08⁰R)
- GH₂ MASS = 81.30 LB
- LH₂ VAPOR PRESSURE = 14.23 PSIA (ULLAGE PRESSURE + ρgh Effect
  MAXIMUM STORED ENERGY = 132 BTU (DUE TO ρgh EFFECT)
- LH₂ MASS = 1131.2 LB (FROM PU CALCULATIONS)
- VEHICLE ACCELERATION = 2.14 G'S
- FLIGHT TIME = T + 2172.93 SECONDS

POST MECO2 CONDITIONS

- PRESSURE RECOVERY OF 0.5 PSID CAUSED BY EVAPORATION OF 2.16 LB LH₂.
- 0.094⁰R TEMPERATURE DROP INDICATES AN LH₂ VAPOR PRESSURE DECAY FROM
  14.24 PSIA TO 14.00 PSIA AT BOOST PUMP INLET.
LH₂ CONDITIONS AT MECO2

CCVAPS LH₂ TANK PRESSURE

PIA

CP 32T LH₂ B PUMP INLET

DGF

TIME FROM MECO2 (SECONDS)

V-22
LH₂ TANK ENERGY BALANCE

MECO 4 CONDITIONS

- ULLAGE PRESSURE = 19.10 PSIA
- HELIUM PRESSURE = 0.52 PSIA
- GH₂ PRESSURE = 18.68 PSIA
- GH₂ TEMPERATURE = 42.4°F (4.3°F SUPERHEAT)
- GH₂ MASS = 110.1 LB
- LH₂ VAPOR PRESSURE = 19.10 PSIA
- LH₂ MASS = 329.9 LB
- VEHICLE ACCELERATION = 4.62 G'S
- FLIGHT TIME = T + 16631.98 SECONDS

POST MECO 4 CONDITIONS

- PRESSURE RECOVERY OF 0.24 PSID CAUSED BY EVAPORATION OF 0.3 LB LH₂.
- 0.188°F TEMPERATURE DROP INDICATES AN LH₂ VAPOR PRESSURE DECAY FROM 19.54 PSIA TO 19.00 PSIA AT BOOST PUMP INLET.
LH₂ CONDITIONS AT MECO4

CCVAPS LH₂ TANK PRESSURE

TC-2

PIA

CP 32T LH₂ B PUMP INLET

DGF

TIME FROM MECO4 (SECONDS)

V-24
LH₂ TANK ENERGY BALANCE

PROPELLANT CONDITIONS AT VENT TERMINATION

- ULLAGE PRESSURE = 19.88 PSIA
- HELIUM PRESSURE = 0.34 PSIA
- GH₂ PRESSURE = 19.54 PSIA
- GH₂ TEMPERATURE = 42.6⁰R (4.3⁰R SUPERHEAT)
- GH₂ MASS = 100.76 LB
- LH₂ VAPOR PRESSURE = 19.60 PSIA
- LH₂ MASS = 947.9 LB
- VEHICLE ACCELERATION = 2.4 x 10⁻³ G'S
- FLIGHT TIME = T + 14530 SECONDS
- GH₂ VENT MASS = 2.51 LB
- HELIUM VENT MASS = 0.09 LB

POST VENT CONDITIONS

- PRESSURE RECOVERY OF 0.12 PSID CAUSED BY EVAPORATION OF 0.53 LB LH₂.
- 0.09⁰R TEMPERATURE DROP INDICATES AN LH₂ VAPOR PRESSURE DECAY FROM 20.16 PSIA TO 19.88 PSIA AT BOOST PUMP INLET.

V-25
LH₂ CONDITIONS DURING PRE-PROGRAMMED VENT

CCVAPS LH₂ TANK PRESSURE

VENT VALVE UNLOCKED AT 14524.5 SECONDS
TANK PRESSURE = 20.30 PSIA

PIA

CP 32T LH₂ B PUMP INLET

DGF

FLIGHT TIME (SECONDS)

V-26
**LH₂ TANK ENERGY BALANCE**

**ULLAGE TEMPERATURE CONDITIONS FROM MECO 2 TO MECO 3**

- CF₂⁻¹T GENERALLY REFLECTS THE WARM ULLAGE CONDITIONS RESULTING FROM PRESSURIZATION WITH AMBIENT HELIUM. CF₂⁻¹T AND CF₂⁻⁷T TEMPERATURES ARE DISCUSSED BELOW. THE INDICATED TEMPERATURES HAVE BEEN INCREASED BY 0.7°C TO REFLECT ACTUAL TEMPERATURES.

- MECO 2 ~ AVERAGE ULLAGE TEMPERATURE = 36.23°C (SATURATED AT 14.11 PSIA)

- POST MECO 2 ~ AVERAGE ULLAGE TEMPERATURE = 36.43°C

**NOTE:** THE INCREASED ULLAGE TEMPERATURE WAS DUE TO THE LH₂ EVAPORATION THAT RESULTED FROM THE LOSS OF LIQUID ACCELERATION HEAD.

- 3RD PRESS’N ~ CF₂⁻¹T INCREASE = 5.3°C WHICH INDICATES WARM VAPOR ADJACENT TO PROBE.
  
  CF₂⁻⁷T INCREASE = 2.7°C WHICH RESULTS FROM ULLAGE COMPRESSION.
LH₂ TANK ULLAGE TEMPERATURES DURING MISSION

CF 24T H/ULLAGE ST 2473/330
-390
DGF
-450
MECO1 MECO2 MECO3

CF 25T H/ULLAGE ST 2387/310
-415
DGF
-425

CF 27T H/ULLAGE ST 2320/195
-415
DGF
-425

V-28
LH₂ TANK ENERGY BALANCE

ULLAGE TEMPERATURE CONDITIONS FROM PROGRAMMED VENT TO MECO4

- VENT VALVE UNLOCK ~ AVERAGE ULLAGE TEMPERATURE = 39.12°F.
- VENT TERMINATION ~ AVERAGE ULLAGE TEMPERATURE DROPS TO 38.93°F.
- POST VENT ~ AVERAGE ULLAGE TEMPERATURE REMAINS AT 38.93°F.

NOTE: THE ULLAGE TEMPERATURE DECAY IS CONSISTENT WITH THE 0.42 PSID TANK PRESSURE DECAY DURING VENTING.

- MECO4 ~ AVERAGE ULLAGE TEMPERATURE = 38.52°F.
- POST MECO4 ~ AVERAGE ULLAGE TEMPERATURE = 38.61°F.

NOTE: THE INCREASED ULLAGE TEMPERATURE WAS DUE TO THE LH₂ EVAPORATION THAT RESULTED FROM THE LOSS OF LIQUID ACCELERATION HEAD.

- CF25T AND CF27T DID NOT DETECT THE MASS OF WARM GH₂ AND HELIUM ESTIMATED AT 230 FT³, 17.2 LB AND 74°F.
LH₂ TANK ULLAGE TEMPERATURES
DURING MISSION

CF 24T H/ULLAGE ST 2473/330
TC-2

CF 25T H/ULLAGE ST 2387/310

CF 27T H/ULLAGE ST 2320/195

VENT
MECO
UNLOCK LN₂
VENT VALVE

DGF

-390
-450
-415
-425
-415
-425

04-00-00 04-20-00 04-40-00 05-00-00 05-20-00 05-40-00

V-30
NET HEAT INPUT TO LH₂ TANK

- FIRST LAW EQUATION SOLVED FOR $\Delta Q_{\text{NET}}$
- $\Delta Q_{\text{TANK}} = \Delta Q_{\text{NET}} - 100 \text{ BTU} \text{ (PER B/P SPINDOWN)} - (\text{RECIRC. + VOLUTE FLOW HEAT ADDITION})$
  = TANK HEAT INPUT - INTERMEDIATE BULKHEAD HEAT LOSS

MECO 2 TO MES 4 CONDITIONS (MES 4 OBTAINED FROM ENGINE BURN SIMULATION)
- $\Delta Q_{\text{TANK}} = \dot{Q}_{\text{2ND COAST}} \times (1.0 \text{ HRS}) + \dot{Q}_{\text{3RD COAST}} \times (3.0 \text{ HRS})$

MECO 2 TO PRE-PROGRAMMED VENT CONDITIONS
- $\Delta Q_{\text{TANK}} = \dot{Q}_{\text{2ND COAST}} \times (1.0 \text{ HRS}) + \dot{Q}_{\text{3RD COAST}} \times (2.44 \text{ HRS})$

CALCULATED TANK HEATING RATES
- $\dot{Q}_{\text{2ND COAST}} = 2270 \text{ BTU/HR}$
- $\dot{Q}_{\text{3RD COAST}} = 2270 \text{ BTU/HR}$
NET HEAT INPUT TO LH₂ TANK
VERSUS LIQUID VAPOR PRESSURE

NOTE: SUPERHEAT 3
MES4 CONDITIONS OBTAINED FROM ENGINE BURN SIMULATION.

MECO2 TO MES4

BEST ESTIMATE OF PROPELLANT CONDITION

\[ Q_{TANK} = 2270 \text{ BTU/HR} \ (2\text{nd COAST}) \]
\[ = 2270 \text{ BTU/HR} \ (3\text{rd COAST}) \]

LIQUID VAPOR PRESSURE AT VENT TERMINATION, PSIA

MECO2 TO PRE-PROGRAMMED VENT

SUPERHEAT 3

BEST ESTIMATE OF PROPELLANT CONDITION

\[ Q_{TANK} = 2270 \text{ BTU/HR} \ (2\text{nd COAST}) \]
\[ = 2270 \text{ BTU/HR} \ (3\text{rd COAST}) \]
SUMMARY OF LH₂ TANK THERMODYNAMIC CONDITIONS FROM MECO₂ TO MECO₄

- NET HEAT INPUT RATES OF 2270 BTU/HR ARE EMPLOYED TO DETERMINE INTERMEDIATE STATE CONDITIONS.
- TABULATED INTERMEDIATE STATE CONDITIONS ARE OBTAINED FROM ENERGY BALANCE.

CONCLUSIONS

- HELIUM PURGE CONTRIBUTION TO PROPELLANT TANK STATE WAS MINIMAL.
- INTERMEDIATE BULKHEAD HEAT TRANSFER RATE ≈ 1000 BTU/HR.
- LH₂ NEAR SATURATION THROUGHOUT COAST PERIODS.
- PRESSURANT HELIUM RESPONSIBLE FOR ULLAGE TEMPERATURE STRATIFICATION DURING 3RD COAST AND FOURTH MAIN ENGINE FIRING. ABOUT 17.2 LB. OF GH₂ AND HELIUM AT 74°F TEMPERATURE RESIDED AT THE FORWARD END OF THE TANK.
- H₂O₂ MOTOR FIRINGS RESULTED IN ΔP DECAYS OF UP TO 0.14 PSID, BUT DID NOT SIGNIFICANTLY COOL ULLAGE.

TC-5 APPLICATION

- 5-1/4 HOUR COAST PRESSURE RISE RATE WILL BE SIMILAR TO THE TC-2 3RD COAST PRESSURE RISE RATE.
- SIXTH COAST PRESSURE RISE RATE WILL BE TWO TIMES GREATER THAN FOR 5-1/4 HOUR COAST BECAUSE OF REDUCED LH₂ MASS.
### TC-2 Mission LH₂ Tank Thermodynamic Conditions

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<th>MECO₂</th>
<th>PRE-MES₃</th>
<th>MES₃</th>
<th>MECO₃</th>
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<th>MECO₄</th>
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<tr>
<td>Vapor Superheat, °R</td>
<td>0.08</td>
<td>1.5</td>
<td>8</td>
<td>7</td>
<td>4.7</td>
<td>4.3</td>
<td>3.8</td>
<td>6.0</td>
<td>4.3</td>
<td>4.5</td>
</tr>
</tbody>
</table>

| LH₂ Expulsion, LB.   | 0     | 48      | 112.3| 1     | 0             | 0        | 65       | 543.6| 6    |
| Vapor Vent, LB.      | 0     | 0       | 0    | 0     | 2.51          | 0        | 0        | 0    | 0    |

Net Heat Rate To Tank, BTU/HR: 2270
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I  INTRODUCTION  HUBER
II  PROPELLANT BEHAVIOR  MERINO
III HELIUM USAGE  MERINO
IV  PROPELLANT TANK PRESSURIZATION  MERINO
V  PROPELLANT TANK THERMODYNAMICS  MERINO
VI  COMPONENT HEATING & THERMAL CONTROL  CHRISTENSEN
VII  MAIN ENGINE SYSTEM  HUBER
VIII  $H_2O_2$ CONSUMPTION  HUBER
IX  BOOST PUMP POST-MECO PERFORMANCE  HUBER/MERINO
X  OVERVIEW OF OTHER SYSTEMS  HUBER

VI-1
THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHEILD
  — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  — THERMAL RESPONSE AND PERFORMANCE
- LH₂ TANK FLIGHT HEAT RATES

VI-1
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES

- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES

- TANK VENT SYSTEMS
  - THERMAL RESPONSE

- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE

- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE

- H₂O₂ SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE

- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT

- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE

- THERMAL CONTROL SUMMARY

VI-2
THERMAL AND HEAT TRANSFER

• PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
• PRELAUNCH TANK HEATING
• ASCENT THERMAL ENVIRONMENT AND RESPONSE
• SPACE AND VEHICLE INDUCED ENVIRONMENT
• FORWARD BULKHEAD MULTILAYER INSULATION
  — THERMAL RESPONSE AND PERFORMANCE
• THREE-LAYER SHIELDING
  — THERMAL RESPONSE AND PERFORMANCE
• TITANIUM STUB ADAPTER AND GROUND PLANE/SHEILD
  — THERMAL RESPONSE AND PERFORMANCE
• WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  — THERMAL RESPONSE AND PERFORMANCE
• LH₂ TANK FLIGHT HEAT RATES
CENTAUR D-1T/PAYLOAD/SHROUD MAJOR
THERMAL PROTECTION AND INSULATION SYSTEMS

![Diagram of thermal protection and insulation systems for the Centaur D-1T payload shroud major.](image_url)

**Figure 1-1**

**PAYLOAD COMPARTMENT**

- **1" ENCAPSULATED FIBEROUS INSULATION**

**SPACECRAFT (VIKING SHOWN)**

- **ENCAPSULATION BULKHEAD**

**SPACECRAFT SUPPORT TRUSS ADAPTER**

- **EQUIPMENT MODULE/STUB ADAPTER/TANK FWD BULKHEAD COMPARTMENT**
  - 1-1/2" MULTILAYER INSULATION ON FWD BULKHEAD

**SHROUD FWD SEAL/BULKHEAD**

- **RADIATION SHIELD SYSTEM ON LH₂ TANK SIDEWALL**

**SHROUD/LH₂ TANK COMPARTMENT**

- 3.0" FIBER BATTs +
  - 3.3" ENCAPSULATED FIBEROUS INSULATION

- **SHROUD/ISA ANNULUS**

**INTERSTAGE ADAPTER (ISA) ENGINE COMPARTMENT**

- **DOUBLE-WALL INTERMEDIATE BULKHEAD WITH CRYO-EVACUATED 0.2" FIBERMAT**

**SHROUD AFT SEAL/BULKHEAD**

- **LO₂ TANK AFT BULKHEAD WITH RADIATION SHIELD SYSTEM**

**EQUIPMENT MODULE/STUB ADAPTER/TANK FWD BULKHEAD COMPARTMENT**

- **EQUIPMENT MODULE/STUB ADAPTER/TANK FWD BULKHEAD COMPARTMENT**
  - 1-1/2" MULTILAYER INSULATION ON FWD BULKHEAD

- **SHROUD FWD SEAL/BULKHEAD**

- **RADIATION SHIELD SYSTEM ON LH₂ TANK SIDEWALL**

- **DOUBLE-WALL INTERMEDIATE BULKHEAD WITH CRYO-EVACUATED 0.2" FIBERMAT**

- **SHROUD AFT SEAL/BULKHEAD**

- **LO₂ TANK AFT BULKHEAD WITH RADIATION SHIELD SYSTEM**

**ENGINE COMPARTMENT**

- **RADIATION SHIELD SYSTEM ON LH₂ TANK SIDEWALL**

- **DOUBLE-WALL INTERMEDIATE BULKHEAD WITH CRYO-EVACUATED 0.2" FIBERMAT**

- **SHROUD AFT SEAL/BULKHEAD**

- **LO₂ TANK AFT BULKHEAD WITH RADIATION SHIELD SYSTEM**
PRELAUNCH GAS CONDITIONING CONTROL OF
EQUIPMENT ENVIRONMENT

THERMAL CONDITIONING CRITERIA

PAYLOAD COMPARTMENT

HELIOS:
INLET TO COMPARTMENT: 72°F ± 9°F
FLOW RATE: ≥ 50 LB/MIN.
DEW POINT: 52°F MAX.
SPACECRAFT HEAT: 850 BTU/HR MAX.
SHROUD HEAT LOAD: 7000 BTU/HR MAX.

CENTAUR ELECTRONICS COMPARTMENT

EQUIPMENT TEMPS: 40 - 100°F
DEW POINT: 45°F MAX.
SHROUD HEAT LOAD: 13,500 BTU/HR MAX.
MAKE-UP HEAT LOST TO CRYO-SINKS
PRESSURIZE AGAINST WIND INFLOW

INTERSTAGE ADAPTER/ENGINE COMPARTMENT

EQUIPMENT TEMPS: 50 - 90°F
DEW POINT: 45°F MAX.
MAKE-UP HEAT LOST TO CRYO-SYSTEMS
PRESSURIZE AGAINST WIND INFLOW

GAS REQUIREMENTS

ALL COMPARTMENTS USE AIR/GN₂ PRIOR TO/AFTER CRYOTANKING

HELIOS PAYLOAD

DESIGN
TC-2 FLIGHT
120 ± 5 LB/MIN, GN₂
120 LB/MIN
72°F
72°F
36.5°F DP MAX

90 ± 5 LB/MIN, GN₂
90 LB/MIN
72°F
35.5°F DP MAX

130 ± 5 LB/MIN, GN₂
130 LB/MIN
118°F
38°F DP MAX

FIGURE 2-1
**PAYLOAD ENVIRONMENTAL CONTROL CONDITIONS**

**COMPARTMENT TEMPERATURE REQUIREMENT**  \(72^\circ F \pm 9^\circ F\)

<table>
<thead>
<tr>
<th>DATA</th>
<th>TCD</th>
<th>LAUNCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMBIENT TEMPERATURE</td>
<td>(72^\circ F)</td>
<td>(48^\circ F)</td>
</tr>
<tr>
<td>INLET TEMPERATURE COSST</td>
<td>(72^\circ F)</td>
<td>(72^\circ F)</td>
</tr>
<tr>
<td>INSULATION INSIDE TEMPERATURES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA192T STATION 2816</td>
<td>71.5°F</td>
<td>67°F</td>
</tr>
<tr>
<td>CA193T STATION 2696</td>
<td>68.5°F</td>
<td>65°F</td>
</tr>
<tr>
<td>CA196T STATION 2672</td>
<td>75.0°F</td>
<td>70°F</td>
</tr>
<tr>
<td>CA194T STATION 2664</td>
<td>71.0°F</td>
<td>64°F</td>
</tr>
<tr>
<td>PAYLOAD AMBIENT TEMPERATURE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CY 19T STATION 2511</td>
<td>71.5°F</td>
<td>68°F</td>
</tr>
<tr>
<td>AVERAGE COMPARTMENT TEMPERATURE</td>
<td>71.5°F</td>
<td>66.8°F</td>
</tr>
<tr>
<td>COMPARTMENT GAS TEMPERATURE CHANGE</td>
<td>-0.5°F</td>
<td>-5.2°F</td>
</tr>
</tbody>
</table>
FIGURE 2-2

EQUIPMENT MODULE COMPARTMENT TEMPERATURE LOCATIONS

- S-BAND XMTR, CT61T
- DCU, CK30T
- SEQ CONT. UNIT, CC202T
- SHROUD RAD.
- SHLD, CA191T
- EQUIP. MOD.
- SKIN, CA903T
- MAIN BATTERY 3, CET110T
- IRGU, CM47T
- SIU, CS811T
- C-BAND
- XPONDER, CB1T
- MAIN BATTERY
- 2, CET109T
- RSC BATTERY
- 2, CET57T
- RSC BATTERY
- 1, CET56T
- EQUIP. MOD.
- SKIN, CA914T

S-HROUD SEAL
GAS CONDITIONING DUCT

MAIN BATTERY 1, CET108T
SIG. COND NO. 1, CT56T

EQUIP. MOD.
INSTR., CT75T
EQUIP. MOD.
SKIN, CA904T
MUX 1, CT58T

90°

S-BAND XMTR, CT62T
SEU, CB16T
IRU, C1300T
IRU (TBD MOUNT, CA905T

0/360°
**TABLE 2-11**

**EQUIPMENT MODULE COMPARTMENT PRELAUNCH TEMPERATURE SURVEY**

<table>
<thead>
<tr>
<th>MEAS. NO.</th>
<th>COMPONENT</th>
<th>TEMPERATURE, °F</th>
<th>dT/°F/HR</th>
<th>ADJUSTED STAGE-STATE TEMP, °F</th>
<th>LH₂ TANKING AT, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PRIOR TO LH₂</td>
<td>AT LIFTOFF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA905T</td>
<td>IRU OUTBOARD MOUNT</td>
<td>92</td>
<td>81</td>
<td>0</td>
<td>-9</td>
</tr>
<tr>
<td>CB1T</td>
<td>C-BAND X-PONDER</td>
<td>77</td>
<td>69</td>
<td>0</td>
<td>-8</td>
</tr>
<tr>
<td>CC202T</td>
<td>SCU HOUSING WEB</td>
<td>78</td>
<td>71</td>
<td>-2</td>
<td>-9</td>
</tr>
<tr>
<td>CI300T</td>
<td>IRU SKIN INTERNAL</td>
<td>90</td>
<td>82</td>
<td>-1</td>
<td>-9</td>
</tr>
<tr>
<td>CI316T</td>
<td>SEU INTERNAL</td>
<td>80</td>
<td>72</td>
<td>-2</td>
<td>-9</td>
</tr>
<tr>
<td>CK30T</td>
<td>D CU SKIN</td>
<td>91</td>
<td>86</td>
<td>-2</td>
<td>-9</td>
</tr>
<tr>
<td>CM47T</td>
<td>IRGU GYRO BLOCK</td>
<td>93</td>
<td>88</td>
<td>-3</td>
<td>-7</td>
</tr>
<tr>
<td>CS811T</td>
<td>SIU SKIN</td>
<td>80</td>
<td>75</td>
<td>-2</td>
<td>-6</td>
</tr>
<tr>
<td>CT56T</td>
<td>SIG CONDITIONER NO. 1</td>
<td>78</td>
<td>72</td>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td>CT58T</td>
<td>EQUIP MODULE MUX 1</td>
<td>78</td>
<td>71</td>
<td>-3</td>
<td>-6</td>
</tr>
<tr>
<td>CT61T</td>
<td>S-BAND XMTR INT-PCM</td>
<td>91</td>
<td>86</td>
<td>0</td>
<td>-5</td>
</tr>
<tr>
<td>CT62T</td>
<td>S-BAND XMTR INT-FM</td>
<td>90</td>
<td>82</td>
<td>0</td>
<td>-8</td>
</tr>
<tr>
<td>CT75T</td>
<td>EQUIP MOD INSTR BOX</td>
<td>79</td>
<td>74</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td></td>
<td><strong>AVERAGE AT</strong></td>
<td>68.59</td>
<td>61.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPARTMENT GAS INLET</td>
<td>71.5</td>
<td>72</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>CY.59</td>
<td>S/C COMP AMB AT ADPT</td>
<td>74</td>
<td>68</td>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td>CA901T</td>
<td>P/L ADAPTER</td>
<td>73</td>
<td>68</td>
<td>0</td>
<td>-5</td>
</tr>
<tr>
<td>CA903T</td>
<td>EQUIP MODULE SKIN Q4</td>
<td>71</td>
<td>42</td>
<td>0</td>
<td>-29</td>
</tr>
<tr>
<td>CA904T</td>
<td>EQUIP MODULE SKIN Q1</td>
<td>71</td>
<td>41</td>
<td>0</td>
<td>-30</td>
</tr>
<tr>
<td>CA914T</td>
<td>EQUIP MODULE SKIN +Z</td>
<td>72</td>
<td>54</td>
<td>0</td>
<td>-18</td>
</tr>
<tr>
<td>CA191T</td>
<td>R AD SHIELD ST 2485/300</td>
<td>75</td>
<td>71</td>
<td>0</td>
<td>-4</td>
</tr>
</tbody>
</table>

**ENERGY BALANCE COMPUTED HEAT RATE FROM MODULE COMPARTMENT TO LH₂ TANK BOUNDARIES AT LIFTOFF = 25,190 BTU/HR.**

VI-8
SHIELDING, HYDRAULIC, PNEUMATIC
ENVIRONMENTAL TEMPERATURE LOCATIONS

TC-2 SOLAR DIRECTION
ON ALTERNATE
THERMAL MANEUVER
ROLLS

CT59T
CH6T
CH2T
CF15T
CA304T
CI15T
CA309T
CI36T
CT77T
CH6T
CT4T
CF133T

270°

180°

AFT BULKHEAD — VIEW LOOKING FORWARD
VI-10

TC-2 SOLAR DIRECTION
ON ALTERNATE THERMAL
MANEUVER ROLLS

CT57T
CA302T
CH33T
CF30T
CF189T
CA981T
CA969T
CA986T
CA307T
CT76T
CH4T
CH10T
CF134T

FIGURE 2-4
TC-2 SOLAR DIRECTION ON ALTERNATE THERMAL MANEUVER ROLLS

H₂O₂ SYSTEM TEMPERATURE LOCATIONS

0/360°

180°

AFT BULKHEAD – VIEW LOOKING FORWARD

VI-11

FIGURE 2-5
## TABLE 2-V
INTERSTAGE ADAPTER PRELAUNCH TEMPERATURE SURVEY
CENTRAL ZONE NON-CRYOGENIC TEMPERATURES

<table>
<thead>
<tr>
<th>MEAS. NO.</th>
<th>COMPONENT</th>
<th>*LO₂ °F</th>
<th>*LH₂ °F</th>
<th>ΔT LO₂ °F</th>
<th>ΔT LH₂ °F</th>
<th>LIFT-OFF °F</th>
<th>LIFT-OFF °F/HR</th>
<th>TEMP. @ LHe °F</th>
<th>ΔT LHe °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA309T</td>
<td>LO₂ AFT BLKHD OUTER SHIELD</td>
<td>110</td>
<td>54</td>
<td>CRYO</td>
<td>48</td>
<td>35</td>
<td>0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>CA307T</td>
<td>LO₂ SUMP OUTER RAD. SHIELD</td>
<td>107</td>
<td>69</td>
<td>CRYO</td>
<td>67</td>
<td>48</td>
<td>0</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>CH36T</td>
<td>C-2 PITCH ACTUATOR BODY</td>
<td>106</td>
<td>96</td>
<td>SLOPE</td>
<td>86</td>
<td>73</td>
<td>-13</td>
<td>NOT PROJ</td>
<td></td>
</tr>
<tr>
<td>CP36T</td>
<td>LO₂ B.P. TURBINE BEARING</td>
<td>107</td>
<td>95</td>
<td>SLOPE</td>
<td>88</td>
<td>72</td>
<td>-19</td>
<td>68</td>
<td>-20</td>
</tr>
<tr>
<td>CP714T</td>
<td>LO₂ B.P. INLET LINE</td>
<td>102</td>
<td>89</td>
<td>-13</td>
<td>86</td>
<td>66</td>
<td>0</td>
<td>19</td>
<td>-20</td>
</tr>
<tr>
<td>CP711T</td>
<td>LO₂ B.P. ORIFICE HOLDER</td>
<td>101</td>
<td>86</td>
<td>-15</td>
<td>83</td>
<td>65</td>
<td>-17</td>
<td>61</td>
<td>-22</td>
</tr>
<tr>
<td>CP756T</td>
<td>H₂O₂ MANIFOLD LINE</td>
<td>110</td>
<td>95</td>
<td>SLOPE</td>
<td>93</td>
<td>79</td>
<td>-7</td>
<td>77</td>
<td>-16</td>
</tr>
</tbody>
</table>

*START
†PROJECTED STEADY-STATE CONDITIONS.
‡TEMPERATURES IN ( ) ARE ADJUSTED TO ELIMINATE HEATER EFFECT.

VI-12
# TABLE 2-V (continued)

## INTERSTAGE ADAPTER PREL. JNCH TEMPERATURE SURVEY

**CENTRAL ZONE NON-CRYOGENIC TEMPERATURES**

<table>
<thead>
<tr>
<th>MEAS. NO.</th>
<th>COMPONENT</th>
<th>*(\text{LO}_2) °F</th>
<th>*(\text{LH}_2) °F</th>
<th>(\Delta T) (\text{LO}_2) °F</th>
<th>*(\text{LHe}) °F</th>
<th>(\Delta T) (\text{LH}_2) °F</th>
<th>LIFT-OFF °F</th>
<th>(\frac{dT}{dt}) @ LHe °F/HR</th>
<th>TEMP. @ LHe °F</th>
<th>(\Delta T) LHe °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP174T</td>
<td>(\text{LO}_2) B.P. SHAFT HOUSING</td>
<td>96</td>
<td>0</td>
<td>CRYO +3</td>
<td>SPIN</td>
<td>-7</td>
<td>0</td>
<td>-</td>
<td>-20</td>
<td></td>
</tr>
<tr>
<td>CP176T</td>
<td>(\text{LO}_2) B.P. GEAR CASE</td>
<td>108</td>
<td>90</td>
<td>-SLOPE 81</td>
<td>SPIN</td>
<td>66</td>
<td>-13</td>
<td>62</td>
<td>-19</td>
<td></td>
</tr>
<tr>
<td>CP178T</td>
<td>(\text{LO}_2) B.P. DECOMP. CHAMBER</td>
<td>(106)</td>
<td>133</td>
<td>-SLOPE 128</td>
<td>SPIN</td>
<td>110</td>
<td>-13</td>
<td>106</td>
<td>-22</td>
<td></td>
</tr>
<tr>
<td>CP180T</td>
<td>(\text{LO}_2) B.P. TURBINE HSG OUTBOARD</td>
<td>97</td>
<td>87</td>
<td>-SLOPE 60</td>
<td>-</td>
<td>65</td>
<td>-13</td>
<td>61</td>
<td>-19</td>
<td></td>
</tr>
<tr>
<td>CP182T</td>
<td>(\text{LO}_2) B.P. TURBINE HSG AFT</td>
<td>100</td>
<td>85</td>
<td>-15 77</td>
<td>65</td>
<td>0</td>
<td>-</td>
<td>-12 TC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP184T</td>
<td>(\text{LO}_2) B.P. LOCK-ROTOR BOSS</td>
<td>97</td>
<td>85</td>
<td>-SLOPE 80</td>
<td>65</td>
<td>-10</td>
<td>63</td>
<td>-17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP186T</td>
<td>(\text{LO}_2) B.P. DECOMP CHAMBER TC</td>
<td>(104)</td>
<td>126</td>
<td>-SLOPE 122</td>
<td>105</td>
<td>-13</td>
<td>101</td>
<td>-21 TC</td>
<td></td>
<td></td>
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<tr>
<td><strong>AVERAGE</strong></td>
<td><strong>(102.3)</strong>*</td>
<td><strong>-14.3</strong></td>
<td><strong>-4.4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>-17.7</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Temperatures in ( ) are adjusted to eliminate heater effect.*

*VI-13*
### TABLE 2-X

**SUMMARY OF INTERSTAGE ADAPTER AND ISA/SHROUD ANNULUS**

**INDICATED COMPARTMENT AVERAGE GAS TEMPERATURE**

<table>
<thead>
<tr>
<th>ZONE</th>
<th>START LO₂</th>
<th>LO₂ TANKING</th>
<th>LH₂ TANKING</th>
<th>LONG DURATION LH₂ CHILDLDOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO. OF MEAS'S</td>
<td>TEMP °F</td>
<td>NO. OF MEAS'S</td>
<td>ΔT °F</td>
</tr>
<tr>
<td>ISA CENTRAL</td>
<td>14</td>
<td>102.8</td>
<td>3</td>
<td>-14.3</td>
</tr>
<tr>
<td>C-1 ENGINE</td>
<td>11</td>
<td>97.9</td>
<td>9</td>
<td>-11.3</td>
</tr>
<tr>
<td>C-2 ENGINE</td>
<td>10</td>
<td>99.0</td>
<td>8</td>
<td>-13.6</td>
</tr>
<tr>
<td>ISA PERIPHERY</td>
<td>19</td>
<td>101.5</td>
<td>15</td>
<td>-19.3</td>
</tr>
<tr>
<td>TOTAL ISA</td>
<td>54</td>
<td>100.6</td>
<td>35</td>
<td>-15.5</td>
</tr>
<tr>
<td>LH₂ BOOST PUMP VICINITY</td>
<td>12</td>
<td>102.9</td>
<td>6</td>
<td>-15.3</td>
</tr>
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### Table 2-XI

**Summary of Prelaunch Cryogen Heat Rates**

**From Aft Compartments Energy Balance**

<table>
<thead>
<tr>
<th>Heat Rate From</th>
<th>Temperature, °F</th>
<th>Overall Coefficient (UA)</th>
<th>Heat Rate at Liftoff</th>
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</thead>
<tbody>
<tr>
<td>Compartment</td>
<td>Comp'T</td>
<td>Sink</td>
<td>ΔT</td>
</tr>
<tr>
<td>ISA</td>
<td>LO₂</td>
<td>61.8</td>
<td>-284</td>
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<tr>
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<td>LO₂</td>
<td>53.0</td>
<td>-284</td>
</tr>
<tr>
<td>ISA</td>
<td>LH₂</td>
<td>61.8</td>
<td>-420</td>
</tr>
<tr>
<td>ANNULUS</td>
<td>LH₂ SUMP</td>
<td>71.8</td>
<td>-420</td>
</tr>
<tr>
<td>ANNULUS</td>
<td>TANK/SHROUD He</td>
<td>53.0</td>
<td>-350</td>
</tr>
<tr>
<td>ISA</td>
<td>LHe CHILL</td>
<td>61.8</td>
<td>-440</td>
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<tr>
<td>ISA</td>
<td>TITAN SKIRT</td>
<td>61.8</td>
<td>65</td>
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<tr>
<td>ISA</td>
<td>AMBIENT</td>
<td>61.8</td>
<td>48.0</td>
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<tr>
<td>ISA</td>
<td>ANNULUS</td>
<td>61.6</td>
<td>53</td>
</tr>
<tr>
<td>ANNULUS</td>
<td>AMBIENT</td>
<td>53.0</td>
<td>48.0</td>
</tr>
<tr>
<td>ELECT/HEATERS</td>
<td>ISA</td>
<td>---</td>
<td>61.8</td>
</tr>
<tr>
<td>ELECT/HEATERS</td>
<td>ANNULUS</td>
<td>---</td>
<td>71.8</td>
</tr>
</tbody>
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VI-15
THERMAL AND HEAT TRANSFER

- Prelaunch Thermal Control by Gas Conditioning and Purging
- Prelaunch Tank Heating
- Ascent Thermal Environment and Response
- Space and Vehicle Induced Environment
- Forward Bulkhead Multilayer Insulation
  - Thermal Response and Performance
- Three-Layer Shielding
  - Thermal Response and Performance
- Titanium Stub Adapter and Ground Plane/Shield
  - Thermal Response and Performance
- Wiring Module Structure/Typical Penetration
  - Thermal Response and Performance
- LH₂ Tank Flight Heat Rates
<table>
<thead>
<tr>
<th>TEST NUMBER</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PURGE RATE</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>ULLAGE PRESSURE (PSIA)</td>
<td>21.00</td>
<td>20.86</td>
<td>21.14</td>
</tr>
<tr>
<td>ELAPSED TIME 57.63 FT³</td>
<td>22.93</td>
<td>23.925</td>
<td>23.91</td>
</tr>
<tr>
<td>BOIL-OFF FROM 99.8% TO 95% (MINUTES)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH₂ DENSITY (LB/FT³)</td>
<td>4.30</td>
<td>4.30</td>
<td>4.30</td>
</tr>
<tr>
<td>HEAT OF VAPORIZATION (BTU/LB)</td>
<td>189.2</td>
<td>189.2</td>
<td>189.2</td>
</tr>
<tr>
<td>AVERAGE HEAT RATE TO LIQUID (BTU/HR)</td>
<td>123,000</td>
<td>117,900</td>
<td>118,000</td>
</tr>
<tr>
<td>Δ HEAT RATE TO FULL TANK (BTU/HR)</td>
<td>4,220</td>
<td>4,220</td>
<td>4,220</td>
</tr>
<tr>
<td>HEAT RATE TO FULL TANK LIQUID (BTU/HR)</td>
<td>127,220</td>
<td>122,120</td>
<td>122,220</td>
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<tr>
<td>AVERAGE HEAT RATE TO FULL TANK LIQUID (BTU/HR)</td>
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**TABLE 3-I**

LH₂ BOIL-OFF TESTS DURING TCD
<table>
<thead>
<tr>
<th><strong>TEST NUMBER</strong></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SHROUD PURGE RATE</strong></td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td><strong>ULLAGE PRESSURE (PSIA)</strong></td>
<td>30.95</td>
<td>30.79</td>
<td>30.79</td>
</tr>
<tr>
<td><strong>ELAPSED TIME FOR 1.64 FT³ BOIL-OFF FROM 100.2% TO 99.8% (MINUTES)</strong></td>
<td>8.74</td>
<td>12.075</td>
<td>12.055</td>
</tr>
<tr>
<td><strong>LO₂ DENSITY (LB/FT³)</strong></td>
<td>69.0</td>
<td>69.0</td>
<td>69.0</td>
</tr>
<tr>
<td><strong>HEAT OF VAPORIZATION (BTU/LB)</strong></td>
<td>90.0</td>
<td>90.0</td>
<td>90.0</td>
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<tr>
<td><strong>NET HEAT RATE TO LO₂ (BTU/HR) (W/O LHe CHILDOWN)</strong></td>
<td>71,300</td>
<td>51,600</td>
<td>51,700</td>
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<tr>
<td><strong>AVERAGE HEAT RATE (BTU/HR) (LAST TWO TESTS ONLY)</strong></td>
<td>51,650</td>
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<td></td>
</tr>
</tbody>
</table>

**HEAT RATE ADJUSTED FOR LHe CHILDOWN AND LAUNCH TEMPERATURES**

\[
\frac{521.8-176}{24.5-176} \times 51,650 = 48,300 \text{ BTU/HR}
\]

* LO₂ NET HEAT RATE NOT AFFECTED BY SMALL CHANGES IN LIQUID LEVEL SO NO ADJUSTMENT REQUIRED TO FULL TANK.
LH₂ TANK PRELAUNCH HEATING RATE BREAKDOWN
(ETU/HR)

SUMMARY OF HEAT BALANCE

TANK HEATING

<table>
<thead>
<tr>
<th>Component</th>
<th>Heating Rate</th>
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<tbody>
<tr>
<td>LIQUID</td>
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<tr>
<td>FWD BULKHEAD (AFT TO S/A MIDFRAME)</td>
<td>11,100</td>
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<tr>
<td>STUB ADAPTER (S/A)</td>
<td>9,565</td>
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<tr>
<td>SIDEWALL</td>
<td>93,205</td>
</tr>
<tr>
<td>SUMP FWD OF SEAL</td>
<td>860</td>
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<tr>
<td>SUMP AFT OF SEAL</td>
<td>890</td>
</tr>
<tr>
<td>LINES &amp; MAIN VALVES</td>
<td>6,930</td>
</tr>
<tr>
<td>INTERMEDIATE BULKHEAD</td>
<td>1,240</td>
</tr>
<tr>
<td></td>
<td>LH₂ TOTAL</td>
</tr>
<tr>
<td>ULLIAGE</td>
<td>2,600</td>
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<tr>
<td>TANK TOTAL</td>
<td>126,450</td>
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</table>

SHROUD HEATING

<table>
<thead>
<tr>
<th>Component</th>
<th>Heating Rate</th>
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<tbody>
<tr>
<td>FWD SEAL</td>
<td>8,940</td>
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<tr>
<td>AFT SEAL</td>
<td>20,310</td>
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<tr>
<td>HELIUM PURGE</td>
<td>40,250</td>
</tr>
<tr>
<td>SHROUD SIDE</td>
<td>35,830</td>
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<td></td>
<td>TOTAL</td>
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</table>

HEATING FROM SHROUD/TANK

<table>
<thead>
<tr>
<th>Component</th>
<th>Heating Rate</th>
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<tbody>
<tr>
<td>COMPT TO TANK AND VENT</td>
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<tr>
<td>STUB ADAPTER</td>
<td>9,565</td>
</tr>
<tr>
<td>SIDEWALL</td>
<td>93,205</td>
</tr>
<tr>
<td>SUMP</td>
<td>860</td>
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<tr>
<td>VENT DISCONNECT</td>
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<td></td>
<td>TOTAL</td>
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LO$_2$ TANK PRELAUNCH HEATING RATE BREAKDOWN
(BTU/HR)

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<th>Value</th>
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<tr>
<td>ISA</td>
<td>14,290</td>
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<td>AFT BULKHEAD</td>
<td>28,975</td>
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<tr>
<td>SUMP</td>
<td>1,015</td>
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<tr>
<td>LINES &amp; MAIN VALVES</td>
<td>1330</td>
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<td>TOTAL LO$_2$</td>
<td>45,610</td>
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<tr>
<td>LESS INTERMEDIATE BULKHEAD</td>
<td>-1,240</td>
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<tr>
<td>NET LO$_2$ HEAT</td>
<td>44,370</td>
</tr>
<tr>
<td>TOTAL LO$_2$</td>
<td>45,610</td>
</tr>
<tr>
<td>GOX VENT</td>
<td>1320</td>
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<tr>
<td>TOTAL FROM N$_2$</td>
<td>46,900</td>
</tr>
</tbody>
</table>

SUMMARY OF HEAT BALANCE

FIGURE 3-2
THERMAL AND HEAT TRANSFER

- Prelaunch thermal control by gas conditioning and purging
- Prelaunch tank heating
- Ascent thermal environment and response
- Space and vehicle induced environment
- Forward bulkhead multilayer insulation
  - Thermal response and performance
- Three-layer shielding
  - Thermal response and performance
- Titanium stub adapter and ground plane/shield
  - Thermal response and performance
- Wiring module structure/typical penetration
  - Thermal response and performance
- LH₂ tank flight heat rates
COMPARTMENT 4 AND 4A GAS TEMPERATURE HISTORIES

- PRELAUNCH ESTIMATE
- TC-1 FLIGHT DATA
- TC-2 FLIGHT DATA (COMPARTMENT 4 ONLY)

WEIGHTED AVERAGE
VENTING GAS AT LH₂ F&F CHUTE

TIME IN SECONDS FROM LIFTOFF

VI-23
INTERSTAGE ADAPTER ASCENT HEATING

LAUNCH PLUME HEATING USED IN SIMULATION
TIME ~ SECONDS FLUX ~ BTU/HR-FT^2
0 600
2 1200
3 2280
4 2280
5 1750
6 130
10 0

SRM JETTISON ROCKET HEATING
12G t. 12G 1300

TEMPERATURE ~ °F

TIME IN SECONDS FROM LAUNCH

POST FLIGHT SIMULATION ~ TRANSITION R_e ~ 4 \times 10^6

--- HEATING FACTOR ~ 0.6

--- HEATING FACTOR ~ 0.4
INDICATED RECIRCULATION AFT OF BOATTAIL

OTBD

STA 2209 STA 2177.9 CA85T LO₂ VENT DUCT STA 2157 STA 2146 TITAN/CENTAUR INTERFACE STA 2127.43

CA85T SKIN IN S2157/88

COOLING FROM RECIRCULATED GO₂ VENTAGE

SOME LIQUID VENTED DURING THIS PERIOD

TIME IN SECONDS FROM LIFTOFF

0 60 120 180 240 300 360 420 480

-60 0 60 120 180 240

100 0 100 0

TC-2

TC-1

VI-25

FIGURE 5-2
THERMAL AND HEAT TRANSFER

- Prelaunch Thermal Control by Gas Conditioning and Purging
- Prelaunch Tank Heating
- Ascent Thermal Environment and Response
- Space and Vehicle Induced Environment
- Forward Bulkhead Multilayer Insulation
  - Thermal Response and Performance
- Three-Layer Shielding
  - Thermal Response and Performance
- Titanium Stub Adapter and Ground Plane/Shield
  - Thermal Response and Performance
- Wiring Module Structure/Typical Penetration
  - Thermal Response and Performance
- LH₂ Tank Flight Heat Rates
TC-2 VEHICLE INDUCED THERMAL ENVIRONMENT SEQUENCES

- Shroud Jettison
- Titan Separation
- Solar (135°)
- Solar (315°)
- Solar (Aft to Sun)

- S-Engine Firing
- Recirc Motors on
- Pressurization
- Prestart Flow
- Start Boost Pumps
- Main Engine Firing
- Servo Positioner Heater

Time from Lift Off, Minutes
TC-2 SUN AND EARTH CONE AND CLOCK ANGLES FROM PREFLIGHT ACTUAL LAUNCH TIME TRAJECTORY

- SUN CLOCK ANGLE
- SUN Cone ANGLE
- EARTH CLOCK ANGLE
- EARTH CONE ANGLE

LEAVE EARTH'S SHADOW
SHROUD JETTISON

TIME FROM LAUNCH ~ MINUTES

VI-29
THERMAL AND HEAT TRANSFER

- Prelaunch thermal control by gas conditioning and purging
- Prelaunch tank heating
- Ascent thermal environment and response
- Space and vehicle induced environment
- Forward bulkhead multilayer insulation
  - Thermal response and performance
- Three-layer shielding
  - Thermal response and performance
- Titanium stub adapter and ground plane/shield
  - Thermal response and performance
- Wiring module structure/typical penetration
  - Thermal response and performance
- LH₂ tank flight heat rates
Figure VI-31
Forward bulkhead insulation temperature instrumentation.

VIEW LOOKING AFT

REFLECTIVE TAPE
TRANSODER
HARNESS WIRE
CRIMP SPLICE
55-74866-2 GORE
55-74866-1 GORE
TANK SKIN
TYPICAL SECTION
TC-2 FORWARD BULKHEAD INSULATION
EXTERIOR TEMPERATURE

TEMPERATURE ~ DEGREES FAHRENHEIT

TIME IN SECONDS FROM LIFTOFF

SHROUD JETTISON

\( \text{V CA909T} \)
\( \text{O CA910T} \)
\( \text{D CA913T} \)
TC-1 FORWARD BULKHEAD INSULATION EXTERIOR TEMPERATURE

TEMPERATURE - DEGREES FAHRENHEIT

TIME IN SECONDS FROM LIFTOFF

VI-33
HYDROGEN TANK FORWARD BULKHEAD INSULATION
TEMPERATURE PROFILE

- CHAMBER WALL
- MODULE
- INSULATION EXTERIOR

- CALORIMETER DATA
- TC-2 FLIGHT DATA

- INSULATION MID
- OFF SCALE LOW
- INSULATION INNER SURFACE
- FORWARD BULKHEAD

TIME IN MINUTES FROM LIFTOFF

VI-34
Indicated heat flux through multilayer insulation to LH₂ tank forward bulkhead during ascent.

Heat flux, BTU/HR-FT²

Time in seconds from lift-off

Fig. 79
INDICATED HEAT FLUX THROUGH MULTILAYER INSULATION TO LH₂ TANK FORWARD BULKHEAD DURING SPACE OPERATIONS

HEAT FLUX, BTU/HR-FT²

TIME IN MINUTES FROM LIFT-OFF

TC-1

TC-2

0 100 200 300 400
THERMAL AND HEAT TRANSFER

- Prelaunch Thermal Control by Gas Conditioning and Purging
- Prelaunch Tank Heating
- Ascent Thermal Environment and Response
- Space and Vehicle Induced Environment
- Forward Bulkhead Multilayer Insulation — Thermal Response and Performance
- Three-Layer Shielding — Thermal Response and Performance
- Titanium Stub Adapter and Ground Plane/Shield — Thermal Response and Performance
- Wiring Module Structure/Typical Penetration — Thermal Response and Performance
- LH₂ Tank Flight Heat Rates
Figure LH₂ tank radiation shield temperature measurements.

VI-33
**Table:**

<table>
<thead>
<tr>
<th>Measurement Number (1)</th>
<th>Location</th>
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<tbody>
<tr>
<td>CF24T</td>
<td>2473</td>
</tr>
<tr>
<td>CA288T</td>
<td>2426</td>
</tr>
<tr>
<td>CA289T</td>
<td>2426</td>
</tr>
<tr>
<td>CF25T</td>
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<td>CA290T</td>
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<td>CA291T</td>
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<td>CF27T</td>
<td>2320</td>
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<tr>
<td>CF23T</td>
<td>2230</td>
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</table>

**Notes:**

1. CF measurements (*) internal to tanks.
2. CA measurements (+) mounted on external surface of LH₂ tank.

Tank temperature measurement locations.
TANK SKIN SENSOR RESPONSE TYPICAL OF DEBONDING
HYDROGEN TANK SIDEWALL RADIATION
SHIELDING TEMPERATURES

STATION 2279 @ 293°

TIME FROM LAUNCH -- MINUTES

VI-41
HYDROGEN TANK SIDEWALL RADIATION
SHIELDING TEMPERATURES
STATION 2278 @ 203°

TIME FROM LAUNCH ~ MINUTES

VI-42
<table>
<thead>
<tr>
<th>Time Minutes</th>
<th>Temperature °R</th>
<th>Outer Shield Flux, Btu/hr-ft²</th>
<th>Mid Shield Flux, Btu/hr-ft²</th>
<th>Inner Shield Flux, Btu/hr-ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CA952T</td>
<td>CA953T</td>
<td>CA954T</td>
<td>Q_solar</td>
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<tr>
<td>125</td>
<td>554</td>
<td>554</td>
<td>419</td>
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<td>130</td>
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<tr>
<td>180</td>
<td>560</td>
<td>540</td>
<td>420</td>
<td>108</td>
</tr>
</tbody>
</table>

Thermal Maneuver Average Inner Shield-to-Tank Heat Rate = \(-13.76 \div 12\) = -1.15 Btu/hr-ft²
LH₂ TANK SIDEWALL HEAT RATE

HEAT RATE, 10000 BTU/HR

125
100
80
60
40
25
0

0 100 200 300 SECONDS

1 2 3 4 MINUTES

MECO

TIME FROM LIFT-OFF

VI-44
### SUMMARY OF 3-LAYER RADIATION SHIELDING APPLICATION AND PRE-LAUNCH CONDITIONING

<table>
<thead>
<tr>
<th>Shielding Application</th>
<th>Inter-layer Net Separator</th>
<th>Shield System Stand-Off</th>
<th>Subsurface</th>
<th>Protected Fluid or Item</th>
<th>Lift-Off Thermal Conditions</th>
<th>Indicated Space Thermal Performance</th>
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<td></td>
<td>Inter-Layer Shield Lift-Off Thermal Conditions</td>
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<td></td>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
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<td>Shield Temp °F</td>
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<td>LH₂</td>
<td>He/Cold</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td>LH₂</td>
<td>He/Cold</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LH₂</td>
<td>GN₂/70°F</td>
</tr>
<tr>
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<td></td>
<td></td>
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<td>LH₂</td>
<td>GN₂/55°F</td>
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<td></td>
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<td></td>
<td>LO₂</td>
<td>GN₂/0°F</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>LO₂</td>
<td>GN₂/65°F</td>
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<td></td>
<td></td>
<td>LO₂</td>
<td>GN₂/60°F</td>
</tr>
<tr>
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<td>LO₂</td>
<td>GN₂/Cool</td>
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<td></td>
<td></td>
<td></td>
<td>LO₂</td>
<td>GN₂/50°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂O₂</td>
<td>GN₂/65°F</td>
</tr>
</tbody>
</table>

1. Helium gas dew point is < -63.5 °F.
2. Nitrogen gas dew point entering ISA is < -20 °F.
3. Taken from TC-1 since no measurement on TC-2.
4. Resolution of low heat flux is poor.
5. Indicated heat flux through shielding compares to maximum 125 Btu/hr-ft² solar flux absorbed on outer shield.

VI-45
HYDROGEN TANK SUMP RADIATION SHIELD
TEMPERATURE PROFILE
STA 2247 @ 90°

TIME FROM LAUNCH — MINUTES
VI-46
THERMAL AND HEAT TRANSFER

- Prelaunch Thermal Control by Gas Conditioning and Purging
- Prelaunch Tank Heating
- Ascent Thermal Environment and Response
- Space and Vehicle Induced Environment
- Forward Bulkhead Multilayer Insulation
  — Thermal Response and Performance
- Three-Layer Shielding
  — Thermal Response and Performance
- Titanium Stub Adapter and Ground Plane/Shield
  — Thermal Response and Performance
- Wiring Module Structure/Typical Penetration
  — Thermal Response and Performance
- LH₂ Tank Flight Heat Rates
Figure: Stub adapter and shield temperature measurements.

VI-49
STUB ADAPTER TEMPERATURE COMPARISON

PRE-LAUNCH PREDICTIONS (1988-2-7-85, 6/9/87)

0 SECONDS

280

720

REvised BOUNDARY CONDITIONS

0 SECONDS

1. NO NITROGEN OR WATER USE

2. EXTERNAL METALIC INTERFACE COEF.
   \( \gamma = 200 \text{ BTU/HR-FT}^2 \cdot \text{F} \)

3. INTERNAL METALIC INTERFACE COEF.
   \( \gamma = 400 \text{ BTU/HR-FT}^2 \cdot \text{F} \)

4. HYDROGEN CONVExtIVE COEF.
   \( h = 50 \text{ BTU/HR-FT} \cdot \text{F} \)

5. ADAPTER SHIELD CONVEXTIVE COEF.
   \( h = 1.37 \times 2.25 \text{ BTU/HR-FT} \cdot \text{F} \)

DISTANCE FORWARD OF STATION 2434.6 - INCHES

VI-50
TC-2 STUB ADAPTER TEMPERATURES
COMPAIED TO MAXIMUM AND MINIMUM
HEATING WET WALL PREDICTIONS

MECO1  MECO2  MECO3  MECO4

TEMPERATURE - °F

TIME IN MINUTES FROM LIFTOFF

CHANGE IN SCALE
STUB ADAPTER RADIATION SHIELD TEMPERATURE HISTORIES

TIME IN HOURS-MINUTES FROM LIFTOFF

VI-52
STUB ADAPTER RADIATION SHIELD TEMPERATURE HISTORIES

TIME IN HOURS - MINUTES FROM LIFT-OFF

VI-53
TABLE 7-IV. SPACE HEATING OF STUB ADAPTER
SHIELD AT 180° (CA972T).

<table>
<thead>
<tr>
<th>TIME HR:MIN</th>
<th>TEMP °R</th>
<th>Q_SOLAR</th>
<th>Q_RE-RAD</th>
<th>Q_ADAPTER</th>
<th>Q_NET</th>
<th>Q_CALORIMETRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:05</td>
<td>257</td>
<td>0</td>
<td>-6.3</td>
<td>-0.1</td>
<td>-6.4</td>
<td>-1.5</td>
</tr>
<tr>
<td>2:06</td>
<td>275</td>
<td>91.1</td>
<td>-8.3</td>
<td>-0.2</td>
<td>82.6</td>
<td>93.2</td>
</tr>
<tr>
<td>2:07</td>
<td>315</td>
<td>91.1</td>
<td>-14.3</td>
<td>-0.5</td>
<td>76.3</td>
<td>49.0</td>
</tr>
<tr>
<td>2:09</td>
<td>355</td>
<td>91.1</td>
<td>-23.1</td>
<td>-0.9</td>
<td>67.1</td>
<td>40.9</td>
</tr>
<tr>
<td>2:12</td>
<td>395</td>
<td>91.1</td>
<td>-35.4</td>
<td>-1.4</td>
<td>54.3</td>
<td>40.0</td>
</tr>
<tr>
<td>2:16</td>
<td>435</td>
<td>91.1</td>
<td>-52.0</td>
<td>-2.1</td>
<td>37.3</td>
<td>32.4</td>
</tr>
<tr>
<td>2:23</td>
<td>475</td>
<td>91.1</td>
<td>-74.0</td>
<td>-3.0</td>
<td>14.1</td>
<td>15.0</td>
</tr>
<tr>
<td>2:30</td>
<td>495</td>
<td>91.1</td>
<td>-87.3</td>
<td>-3.6</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>2:32</td>
<td>495</td>
<td>0</td>
<td>-87.3</td>
<td>-3.6</td>
<td>-90.9</td>
<td>-71.3</td>
</tr>
<tr>
<td>2:33</td>
<td>475</td>
<td>0</td>
<td>-74.0</td>
<td>-3.0</td>
<td>-77.0</td>
<td>-55.3</td>
</tr>
<tr>
<td>2:37</td>
<td>435</td>
<td>0</td>
<td>-52.0</td>
<td>-2.1</td>
<td>-54.1</td>
<td>-28.8</td>
</tr>
<tr>
<td>2:42</td>
<td>395</td>
<td>0</td>
<td>-35.4</td>
<td>-1.4</td>
<td>-36.8</td>
<td>-20.0</td>
</tr>
<tr>
<td>2:50</td>
<td>395</td>
<td>0</td>
<td>-23.1</td>
<td>-0.9</td>
<td>-24.0</td>
<td>-11.8</td>
</tr>
<tr>
<td>3:02</td>
<td>320</td>
<td>0</td>
<td>-15.2</td>
<td>-0.5</td>
<td>-15.7</td>
<td>-5.8</td>
</tr>
</tbody>
</table>

THERMAL MANEUVER AVERAGE RATE = $\frac{-23.3 \text{ BTU/HR-FT}^2}{14} = -1.66 \text{ BTU/HR-FT}^2$
(SHIELD-TO-ADAPTER)
STUB ADAPTER HEATING HISTORY TO LH₂
THERMAL AND HEAT TRANSFER

- Prelaunch Thermal Control by Gas Conditioning and Purging
- Prelaunch Tank Heating
- Ascent Thermal Environment and Response
- Space and Vehicle Induced Environment
- Forward Bulkhead Multilayer Insulation
  — Thermal Response and Performance
- Three-Layer Shielding
  — Thermal Response and Performance
- Titanium Stub Adapter and Ground Plane/Shield
  — Thermal Response and Performance
- Wiring Module Structure/Typical Penetration
  — Thermal Response and Performance
- LH₂ Tank Flight Heat Rates
Figure Wire tunnel and aft seal plate temperature measurements.

VI-57
THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHEILD
  - THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - THERMAL RESPONSE AND PERFORMANCE
- LH2 TANK FLIGHT HEAT RATES
LH₂ TANK HEAT RATE DURING ASCENT

TIME IN SECONDS FROM LIFT-OFF

VI-60
<table>
<thead>
<tr>
<th>CONTRIBUTING AREA</th>
<th>FIRST 584-1900 SEC</th>
<th>SECOND 2173-5773 SEC</th>
<th>THIRD 5784-16584 SEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORWARD BULKHEAD AFT TO S/A MIDFRAME</td>
<td>115</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>CREVICE FORWARD TO S/A MIDFRAME</td>
<td>150</td>
<td>110</td>
<td>75</td>
</tr>
<tr>
<td>STUB ADAPTER (S/A)/RING</td>
<td>600</td>
<td>285</td>
<td>245</td>
</tr>
<tr>
<td>SIDE WALL SHIELDING</td>
<td>80</td>
<td>125</td>
<td>330</td>
</tr>
<tr>
<td>WIRING TUNNEL MODULE</td>
<td>36</td>
<td>29</td>
<td>43</td>
</tr>
<tr>
<td>RECIRCULATION LINE</td>
<td>110</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>SUMP FWD OF BULKHEAD</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>SUMP/BLKHD ATTACHMENT</td>
<td>13</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>SUMP AFT OF BULKHEAD</td>
<td>61</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td>LH₂ BOOST PUMP</td>
<td>50</td>
<td>67</td>
<td>57</td>
</tr>
<tr>
<td>FEED LINES</td>
<td>176</td>
<td>82</td>
<td>40</td>
</tr>
<tr>
<td>MAIN VALVES</td>
<td>12</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>DESTRUCTOR</td>
<td>75</td>
<td>62</td>
<td>32</td>
</tr>
<tr>
<td>H₂ VENT VALVES</td>
<td>30</td>
<td>70</td>
<td>120</td>
</tr>
<tr>
<td>H₂ VENT DUCTS</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>LH₂ PRESSURE SENSE LINES</td>
<td>3</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>FWD DOOR HARNESSES</td>
<td>7</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>HELIUM DIFFUSER</td>
<td>110</td>
<td>65</td>
<td>28</td>
</tr>
<tr>
<td>LH₂ FILL AND DRAIN PORT</td>
<td>19</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>SEAL PLATE SUPPORT STRUTS</td>
<td>60</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>TOTAL LH₂ TANK INPUT LESS INT. BLKHD</td>
<td>1720</td>
<td>1174</td>
<td>1237</td>
</tr>
</tbody>
</table>
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  — THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY
Figure Thurst section radiation shield temperature instrumentation.

VI-63
LO₂ AFT BLKHD
SHIELDING
TEMPERATURES

TIME FROM LIFT-OFF, HRS-MIN.
VI-64
LOX TANK PERIPHERAL RADIATION SHIELD
TEMPERATURE PROFILE
STATION 2236 @ 270°

TIME FROM LAUNCH ~ MINUTES
VI-66
LO$_2$ TANK PERIPHERAL SHIELD HEAT RATE

AREA = 16 ft$^2$

TIME IN MINUTES FROM LIFT-OFF

VI-67
LOX SUMP RADIATION SHIELD
TEMPERATURE PROFILE
STATION 2193 @ 60°

CENTAUR SEPARATION

1ST BURN
2ND BURN
3RD BURN
4TH BURN
BP EXP'M'T

TIME FROM LAUNCH ~ MINUTES

VI-68
**TABLE 7-XI. SUMMARY OF LO₂ TANK AVERAGE HEATING RATES DURING COASTS (Btu/HR).**

<table>
<thead>
<tr>
<th>CONTRIBUTING AREA</th>
<th>FIRST 584-1900 SEC</th>
<th>SECOND 2173-5773 SEC</th>
<th>THIRD 5784-16584 SEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYLINDRICAL SECTION 2.75&quot; HIGH</td>
<td>9</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>2240 RING</td>
<td>961</td>
<td>428</td>
<td>203</td>
</tr>
<tr>
<td>WIRING TUNNEL AFT BULKHEAD</td>
<td>61</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>3&quot; HIGH BARE PERIPHERAL AREA</td>
<td>440</td>
<td>363</td>
<td>310</td>
</tr>
<tr>
<td>6&quot; HIGH 3-SHIELD INSULATED AREA</td>
<td>24</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>FIXED/LEAKAGE SHIELDS OUTSIDE THRUST BARREL (BASIC)</td>
<td>232</td>
<td>473</td>
<td>231</td>
</tr>
<tr>
<td>BASE GAS BACK-FLOW DEGRADATION</td>
<td>157</td>
<td>62</td>
<td>9</td>
</tr>
<tr>
<td>EQUIP. CONDUCTION OUTSIDE THRUST BARREL</td>
<td>1231</td>
<td>1162</td>
<td>535</td>
</tr>
<tr>
<td>TOTAL OUTSIDE THRUST BARREL</td>
<td>3115</td>
<td>2546</td>
<td>1634</td>
</tr>
<tr>
<td>FIXED/LEAKAGE SHIELDS INSIDE THRUST BARREL (BASIC)</td>
<td>29</td>
<td>60</td>
<td>29</td>
</tr>
<tr>
<td>BASE GAS BACK-FLOW DEGRADATION</td>
<td>19</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>EQUIP. CONDUCTION BETWEEN SUMP &amp; THRUST BARREL</td>
<td>254</td>
<td>260</td>
<td>206</td>
</tr>
<tr>
<td>TOTAL BETWEEN SUMP &amp; THRUST BARREL</td>
<td>302</td>
<td>328</td>
<td>236</td>
</tr>
<tr>
<td>SUMP W/3-LAYER SHIELD BOOT</td>
<td>116</td>
<td>64</td>
<td>40</td>
</tr>
<tr>
<td>EQUIP. CONDUCTION TO SUMP</td>
<td>98</td>
<td>73</td>
<td>34</td>
</tr>
<tr>
<td>BOOST PUMP CONDUCTION TO SUMP</td>
<td>103</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>TOTAL SUMP</td>
<td>317</td>
<td>287</td>
<td>194</td>
</tr>
<tr>
<td>FEED LINES AND LO₂ BLEED LINE</td>
<td>94</td>
<td>117</td>
<td>77</td>
</tr>
<tr>
<td>MAIN VALVES</td>
<td>122</td>
<td>59</td>
<td>62</td>
</tr>
<tr>
<td>TOTAL LINES &amp; VALVES</td>
<td>216</td>
<td>176</td>
<td>139</td>
</tr>
<tr>
<td>TOTAL LO₂ TANK INPUT (INT. BULKHEAD EFFECT NOT INCLUDED)</td>
<td>3950</td>
<td>3337</td>
<td>2203</td>
</tr>
</tbody>
</table>
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY
## Propellant Heating Agrees with Predictions

<table>
<thead>
<tr>
<th></th>
<th>PreLaunch</th>
<th>1st Coast</th>
<th>2nd Coast</th>
<th>3rd Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max</td>
<td>Nom</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td><strong>LH₂ Tank</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Int. BLKHD.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>132,020</td>
<td>120,445</td>
<td>100,944</td>
<td>4241</td>
</tr>
<tr>
<td>Measured Total</td>
<td>126,450</td>
<td>BY BOILOFF</td>
<td>2953</td>
<td>2270</td>
</tr>
<tr>
<td><strong>LO₂ Tank</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Int. BLKHD.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td>49,400</td>
<td>43,346</td>
<td>36,785</td>
<td>4174</td>
</tr>
<tr>
<td>Measured Net</td>
<td>48,300</td>
<td>BY BOILOFF</td>
<td>2717</td>
<td>2403</td>
</tr>
</tbody>
</table>

*Predictions from 965-4/HT72/025 with 22-Minute First Coast Interpolated between 12- and 30-Minute Coast Predictions*
TABLE 7-XII. INDICATED INTERMEDIATE BULKHEAD HEAT TRANSFER RATE DURING SPACE OPERATIONS (Btu/HR).

<table>
<thead>
<tr>
<th></th>
<th>COAST</th>
<th>FIRST</th>
<th>SECOND</th>
<th>THIRD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LH₂ TANK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL HEAT INPUT FROM H₂ ENERGY AND MASS BALANCE</td>
<td></td>
<td>2270</td>
<td>2270</td>
<td></td>
</tr>
<tr>
<td>SUMMATION OF EXTERNAL HEAT INPUTS</td>
<td>1720</td>
<td>1174</td>
<td>1237</td>
<td></td>
</tr>
<tr>
<td>INDICATED INTERMEDIATE BULKHEAD HEAT RATE</td>
<td>1096</td>
<td>933</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LO₂ TANK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NET HEAT INPUT FROM O₂ ENERGY AND MASS BALANCE</td>
<td>2403</td>
<td>1077</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUMMATION OF EXTERNAL HEAT INPUTS</td>
<td>3950</td>
<td>3337</td>
<td>2203</td>
<td></td>
</tr>
<tr>
<td>INDICATED INTERMEDIATE BULKHEAD HEAT RATE</td>
<td>-934</td>
<td>-1126</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTERMEDIATE BULKHEAD HEAT RATE RANGE</td>
<td>1015 ± 81</td>
<td>1030 ± 97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PREDICTED RANGE FOR LH₂ WET JOINT CREVICE</td>
<td>1233 ± 309</td>
<td>1233 ± 309</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PREDICTED RANGE FOR LH₂ DRY JOINT CREVICE</td>
<td>710 ± 335</td>
<td>710 ± 335</td>
<td>-105</td>
<td></td>
</tr>
</tbody>
</table>
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES

- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES

- TANK VENT SYSTEMS
  - THERMAL RESPONSE

- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE

- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE

- H₂O₂ SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE

- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT

- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE

- THERMAL CONTROL SUMMARY

VI-75
$H_2$ VENT NOZZLE TEMPERATURE HISTORY

MAX NOZZLE 988-3-70-26

MIN NOZZLE 988-3-70-26

OSH TC-2 CF41T NOZZLE INLET 112.5°

MAX NOZZLE PLATE 988-3-71-106

LOCAL VENT

SUN ON PROBE BODY

SUN ON NOZZLE

TIME IN MINUTES FROM LIFT-OFF

VI-76
Vehicle Acceleration & LO₂ Tank Ullage Pressure

Vehicle Axial Acceleration
LO$_2$ VENT DUCT PRESSURE AND TEMPERATURE

CF188P LO$_2$ VENT DUCT PRESS

CF189T LO$_2$ VENT DUCT TEMP

TIME IN MINUTES FROM LIFTOFF
VI-78
LH₂ VENT VALVE TEMPERATURES

- SOLENOID CASE
- VENT
- UNLOCK VENT VALVE
- DISCHARGE FLANGE
- INLET FLANGE

MAXIMUM PREDICTIONS 988-3-71-95, 9883-70-78
CONTINUOUS LOCK-UP

CF317 TC-2 LH₂ VENT VALVE SOLENOID CASE
LO₂ VENT VALVE TEMPERATURES

--- MAXIMUM PREDICTIONS 988-2-71-95, 988-2-70-78, WET WALL, CONTINUOUS LOCK-UP
--- CF380T TC-2 LO₂ VENT VALVE SOLENOID CASE

TEMPERATURE, °F

MKS1 MKS2

VENT MES 4

VALVE DISCHARGE FLANGE

TANK BLOWDOWN

UNLOCK VENT VALVES

TIME IN MINUTES FROM LIFT-OFF

VI-80
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

VI-81
AFT BULKHEAD EQUIPMENT TEMPERATURE LOCATIONS

TC-2 SOLAR DIRECTION ON ALTERNATE ROLLS

0°/360°

SIG CONDITIONER
NO. 2 CT 57T

THRUST SECTION
MUX1 CT 59T

C-2 INSTR BOX
CT 77T

AFT PNEU PANEL PLATE CF133T

AFT PNEU PANEL NO. 2 CF 134T

TC-2 SOLAR DIRECTION ON ALTERNATE ROLLS

90°

270°

180°
## COMPONENT TEMPERATURES

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<tr>
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*TIME SELECTED TO ALLOW DIRECT COMPARISON TO TC-1
## COMPONENT TEMPERATURES  1-HOUR COAST

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1. UNSHADED AREA REPRESENTS QUALIFICATION RANGE, EXCEPT WHERE NOTED. SHADED AREA IS TC-2 MEASURED RANGE.
2. SCU PREDICTED TEMP IS SKIN TEMP.
3. OUT-OF-BAND TEMP RESPONSE IS IN STUDY
4. PREDICTED & QUAL TEMPS ASSUMED THERMAL MANEUVER CONDITIONS.

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SCU - SEQUENCE CONTROL UNIT
RMU - REMOTE MULTIPLEXER

VI-87
Temperature History for MV8-2 Having a White Polyurethane Paint Stripe Around Battery Case
Temperature History for MVB-1 and 3 Having a White Polyurethane Paint Exterior Surface

Time from "Going Internal", Second
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  — THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

VI-92
TABLE 10-1. HYDRAULIC SYSTEM FLIGHT TEMPERATURES.

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<th>MES1 +186 1900 S</th>
<th>MES1 +190 2173 S</th>
<th>MES2 5773 S</th>
<th>MES2 +57 5784 S</th>
<th>MES3 16564 S</th>
<th>MES3 +368 17006 S</th>
<th>MES4 +368 18242 S</th>
<th>PREDICTED TEMP. AT MECO -4</th>
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<td>CH19T</td>
<td>C-1 RECIRC MTR HSG</td>
<td>56</td>
<td>50</td>
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<td>58</td>
<td>72</td>
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<td>CH33T</td>
<td>C-1 YAW ACCU BODY*</td>
<td>80</td>
<td>76</td>
<td>75</td>
<td>92</td>
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<td>CH4T</td>
<td>C-2 HYD PWR PACK*</td>
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<td>58</td>
<td>78</td>
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<td>132</td>
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<td>CH6T</td>
<td>C-2 HYD MANIFOLD</td>
<td>48</td>
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<td>114</td>
<td>12</td>
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<td>CH36T</td>
<td>C-2 PITCH ACCU BODY*</td>
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<td>115</td>
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INDICATED MOUNT TEMPERATURES

<table>
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<tr>
<th>COMPONENT</th>
<th>CP63T C-1 THST CHM JACKET</th>
<th>CP745T C-1 ENG BELL S5000 TB</th>
<th>CP124T C-1 ENG LOX PUMP</th>
<th>CP98T C-2 THST CHM JACKET</th>
<th>CP746T C-2 ENG BELL S5000 TB</th>
<th>CP125T C-2 ENG LOX PUMP</th>
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<tr>
<td>MEAS.</td>
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*SHIELDED
**MECO4 TEMPERATURES
†ASSUMED MINIMUM WITH RECIRCULATION SYSTEM HEAT DEMAND. MINIMUM PREDICTION WOULD TURN RECIRC SYSTEM ON AT MECO -3 +5800 SEC (ACTUAL OCCURRED AT MECO3 +9626 SEC).
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  — THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

VI-94
H₂O₂ AND REACTION CONTROL SYSTEMS

H₂O₂ VENT
VALVE NO. 1

H₂O₂ VENT
VALVE NO. 2

H₂O₂ OVBD
VENT

H₂O₂ PNEUMATIC
PRESSURIZATION
VALVE (3-WAY)

RELIANCE
VALVE
(350 PSI)

AIRBORNE
Ghee

ORIFICE

PNEUMATIC
VENT

H₂O₂ SYSTEM PNEUMATIC PANEL

VI-95
<table>
<thead>
<tr>
<th>Event</th>
<th>Lift-off</th>
<th>Max w/ Heat Removal</th>
<th>Min Delay to Venting Cooling</th>
<th>Start of Flow or Impinging</th>
<th>MECCO</th>
<th>1st Coast or BPS-2</th>
<th>Settle-3 or BPS-3</th>
<th>MECCO or Peak</th>
<th>2nd Coast or BPS-2</th>
<th>Settle-4 or BPS-3</th>
<th>MECCO or Peak</th>
<th>3rd Coast or BPS-3</th>
<th>MECCO or Peak</th>
<th>Terminal Operation</th>
<th>Max/Min</th>
<th>T @ Min</th>
<th>T @ Min</th>
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<tbody>
<tr>
<td>CP 937</td>
<td>Att Control H2O2 Bottle</td>
<td>87</td>
<td>95s</td>
<td>86</td>
<td>86410</td>
<td>98520</td>
<td>68B</td>
<td>93M</td>
<td>91B</td>
<td>93M</td>
<td>91B</td>
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<td>8B</td>
<td>988282</td>
<td>846036</td>
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<tr>
<td>CP 9597</td>
<td>B/P H2O2 Bottle</td>
<td>5%</td>
<td>85s</td>
<td>86</td>
<td>86410</td>
<td>98520</td>
<td>68B</td>
<td>93M</td>
<td>91B</td>
<td>93M</td>
<td>91B</td>
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<td>CP 9570</td>
<td>H2O2 Crossover Line</td>
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<td>95</td>
<td>85</td>
<td>86410</td>
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</tr>
<tr>
<td>CP 9157</td>
<td>Terminal Operation</td>
<td>Max/Min</td>
<td>T @ Min</td>
<td>T @ Min</td>
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<td>8B</td>
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<tr>
<td>CP 937</td>
<td>Att Control H2O2 Bottle</td>
<td>87</td>
<td>95s</td>
<td>86</td>
<td>86410</td>
<td>98520</td>
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<tr>
<td>CP 9597</td>
<td>B/P H2O2 Bottle</td>
<td>5%</td>
<td>85s</td>
<td>86</td>
<td>86410</td>
<td>98520</td>
<td>68B</td>
<td>93M</td>
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<td>988282</td>
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<td>CP 9570</td>
<td>H2O2 Crossover Line</td>
<td>57</td>
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<td>98520</td>
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<td>8B</td>
<td>988282</td>
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<tr>
<td>CP 9157</td>
<td>Terminal Operation</td>
<td>Max/Min</td>
<td>T @ Min</td>
<td>T @ Min</td>
<td>8B</td>
<td>8B</td>
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</tr>
</tbody>
</table>

*Flow data indicates H2O2 temperature in °F in A/C bottle and °F in B/P bottle.

**Superscripts:**

B - indicates at boost pump start
M - indicates at engine start preparatory settling
P - indicates peak due to firing higher than MECCO
<table>
<thead>
<tr>
<th>Component</th>
<th>LiftOff</th>
<th>AT 1st Flow</th>
<th>1st Coast</th>
<th>2nd Coast</th>
<th>3rd Coast</th>
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<tbody>
<tr>
<td>Bottles (CP93, 659T)</td>
<td>95-90</td>
<td>85-82</td>
<td>89-84</td>
<td>92-87</td>
<td>93-85</td>
</tr>
<tr>
<td>Heated Full Lines (CP150, 151, 152, 153, 154, 155, 756, 831T)</td>
<td>87-70</td>
<td>101-70</td>
<td>127-89</td>
<td>160-64</td>
<td>160-63</td>
</tr>
<tr>
<td>Heated Empty Lines (CP157, 158, 159T)</td>
<td>70-68</td>
<td>75-66</td>
<td>190-87</td>
<td>190-70</td>
<td>192-65</td>
</tr>
<tr>
<td>Unheated Empty Lines (CP361, 714, 833T)</td>
<td>84-66</td>
<td>76-65</td>
<td>152-97</td>
<td>250-107</td>
<td>148-75</td>
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<tr>
<td>Shielded Line (CP156, 832T)</td>
<td>87-73</td>
<td>88-69</td>
<td>89-85</td>
<td>122-87</td>
<td>107-54</td>
</tr>
<tr>
<td>Valves, Orifice Blocks (CP710, 711, 834T)</td>
<td>78-65</td>
<td>78-63</td>
<td>113-90</td>
<td>182-96</td>
<td>155-77</td>
</tr>
<tr>
<td>Engine Chambers (CP148, 149, 375, 376, 691, 693, 836, 837T)</td>
<td>78-65</td>
<td>80-60</td>
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</table>

*CP831T OSH @ 150°F ESTIMATE 160°F PEAK.
†INCLUDES CP833T RESPONSE DURING VENTING.
<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time in Minutes from Lift-Off</th>
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<tbody>
<tr>
<td>0-100</td>
<td>0-30</td>
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<tr>
<td>100-150</td>
<td>30-60</td>
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<tr>
<td>150-200</td>
<td>60-90</td>
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<tr>
<td>200-250</td>
<td>90-120</td>
</tr>
<tr>
<td>250-300</td>
<td>120-150</td>
</tr>
</tbody>
</table>

**H₂O₂ Line Temperatures**

- **1st Burn**
- **2nd Burn**
- **3rd Burn**
PROGRESSION OF TEMPERATURE ON LINE FROM QUAD II TO LH₂ B.P. TURBINE

--- CP157T QUAD II BP LINE
----- CP833T LH₂ BP INLET LINE
--- CP361T LH₂ B.P. LINE AT INLET TO ORIFICE

TIME IN MINUTES FROM LIFTOFF

BOOST PUMP FIRING

VI-102
PROGRESSION OF TEMPERATURE ON LINE
FROM QUAD I, THROUGH QUAD IV TO LO₂ B.P. TURBINE

- --- CP156T QUAD I B.P. LINE FTG
- --- CP159T QUAD IV B.P. LINE
- --- CP714T LO₂ B.P. INLET LINE

TIME IN MINUTES FROM LIFT-OFF

BOOST PUMP FIRING
Comparison of unheated vent line thermal response for minimum heating environment with and without shield boots

1/2" Foam insulation & Stagnant H₂O₂

Solar heating starts

Thermal lag

Flight data CP832T

TC-Z (Shielded)

Minimum prediction

TC-4 (Unshielded)

Minimum prediction

Temperature, °F

Time in minutes from lift-off

VI-104
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

VI-105
C-1 ENGINE CHAMBER/BELL TEMPERATURES

TIME FROM LIFT-OFF, HRS·MIN.

VI-106
C-1 ENGINE CHAMBER/BELL TEMPERATURES (CONT)

4TH BURN | BLOWDOWN

TIME FROM LIFT-OFF, HRS-MIN

VI-107
IMPELLMENT HEAT FLUX AT STATION 2132 OUTBOARD ON BELL

- CP741T C-1 ENGINE BELL 5518 OTB
- CP742T C-2 ENGINE BELL 5518 OTB

IMPPELLMENT HEAT FLUX, BTU/HR-FT

SURFACE TEMPERATURE, °R

VI-108
IMPELLMENT HEAT FLUX AT STATION 2146 INBOARD ON BELL

CP743T  C-1 ENGINE BELL 5507 INB
CP744T  INVALID

IMPELLMENT HEAT FLUX, BTU/HR-FT$^2$

200  -  1000

SATEFACE TEMPERATURE, $^\circ$R

VI-109
IMPELLMENT HEAT FLUX THROUGH SHIELD TO LH₂ DISCHARGE/INLET LINE

- CP752T C-1 LH₂ PUMP DISCHARGE LINE
- CP754T C-1 LH₂ JACKET INLET LINE

HEAT FLUX, Btu/hr ft²

DUCT SURFACE TEMPERATURE, °R
IMPINGEMENT HEAT FLUX THROUGH SHIELD TO LH₂ PUMP DISCHARGE

6 CP 753T C-1 LH₂ PUMP HOUSING 2-STAGE

HEAT FLUX / BTU/H-AL-F²

0 100 200 300 400 500 600

SURFACE TEMPERATURE, °R

VI-111
**TABLE 12-IV. QUANTATIVE IMPINGEMENT FLUX ENVIRONMENT FROM S-ENGINES.**

<table>
<thead>
<tr>
<th>MEAS. NO.</th>
<th>DESCRIPTION</th>
<th>IMPINGEMENT SOURCE</th>
<th>SURF TEMP °F</th>
<th>MEAS. FLUX Btu/HR-FT²</th>
<th>IMPINGEMENT ANGLE DEG</th>
<th>NORMAL FLUX Btu/HR-FT²</th>
<th>PLUME LOCATION AXIAL IN.</th>
<th>RADIAL IN.</th>
<th>PREDICTION MACH NO.</th>
<th>HEAT FLUX Btu/HR-FT²</th>
<th>F*</th>
<th>BLOCKAGE</th>
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<tbody>
<tr>
<td>CP741T</td>
<td>C-1 ENG BELL S518 OTB</td>
<td>2-S-IV &gt; -160</td>
<td>410</td>
<td>65</td>
<td>970</td>
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<td>21</td>
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<td>1-S-IV &gt; -30</td>
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<td>C-2 ENG BELL S518 OTB</td>
<td>1-S-II IN ISA &gt; -30</td>
<td>123</td>
<td>65</td>
<td>289</td>
<td>81</td>
<td>21</td>
<td>25</td>
<td>310</td>
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<td></td>
<td>2-S-II &gt; -160</td>
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<td>81</td>
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<td>25</td>
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<tr>
<td>CP743T</td>
<td>C-1 ENG BELL S500 OTB</td>
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<td>59</td>
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<td>141</td>
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<td>1-S-IV &gt; -30</td>
<td>59</td>
<td>65</td>
<td>141</td>
<td>&gt;25</td>
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<td>81</td>
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<td>1-S-IV &gt; -60</td>
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<td>196</td>
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<td>81</td>
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<td></td>
<td>1-S-II &gt; -60</td>
<td>54</td>
<td>65</td>
<td>128</td>
<td>&gt;25</td>
<td>310</td>
<td>.455</td>
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<td>C-1 ENG BELL S507 INB</td>
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<td>50</td>
<td>121</td>
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<td>56</td>
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<td>2-S-II &gt; -160</td>
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<td>200</td>
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</table>

*RATIO OF MEASURED NORMAL FLUX TO PREDICTED FLUX.*
### TABLE 12-IV. QUANTITATIVE IMPINGEMENT FLUX
ENVIRONMENT FROM S-ENGINES. (Contd)

<table>
<thead>
<tr>
<th>MEAS. NO.</th>
<th>DESCRIPTION</th>
<th>IMPINGEMENT SOURCE</th>
<th>SURF TEMP °F</th>
<th>MEAS. SURF FLUX Btu/HR-FT²</th>
<th>IMPINGEMENT ANGLE DEG</th>
<th>NORMAL FLUX Btu/HR-FT²</th>
<th>AXIAL LEN. IN.</th>
<th>RADIAL LEN. IN.</th>
<th>PREDICTION MACH NO.</th>
<th>HEAT FLUX Btu/HR-FT²</th>
<th>F*</th>
<th>BLOCKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP752T</td>
<td>C-1 LH₂ PUMP DISCH LINE</td>
<td>2-S-IV</td>
<td>-160</td>
<td>270</td>
<td>10</td>
<td>274</td>
<td>30</td>
<td>20</td>
<td>18</td>
<td>3200</td>
<td>.056</td>
<td>UNDERSHLD</td>
</tr>
<tr>
<td>CP754T</td>
<td>C-1 LH₂ JKT INLET LINE</td>
<td>2-S-IV</td>
<td>-160</td>
<td>160</td>
<td>45</td>
<td>226</td>
<td>34</td>
<td>24</td>
<td>195</td>
<td>2500</td>
<td>.091</td>
<td>UNDERSHLD</td>
</tr>
<tr>
<td>CA304T</td>
<td>O₂ DUCT OUTER RAD SHIELD</td>
<td>2-S-IV to 175</td>
<td>-60</td>
<td>425</td>
<td>60**</td>
<td>850</td>
<td>22</td>
<td>24</td>
<td>24</td>
<td>720</td>
<td>1.180</td>
<td></td>
</tr>
<tr>
<td>CP159T</td>
<td>QD₄ LI₂ B/P H₂O₂ LINE</td>
<td>2-S-IV 100 to 150</td>
<td>185</td>
<td>65**</td>
<td>438</td>
<td>21</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>260</td>
<td>1.68</td>
<td></td>
</tr>
<tr>
<td>CP159T</td>
<td>QD₄ LI₂ B/P H₂O₂ LINE</td>
<td>1-S-IV 125 to 175</td>
<td>97</td>
<td>65**</td>
<td>230</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>CP292T</td>
<td>C-2 ENG PUMP SHIELD</td>
<td>1-S-II IN ISA 2-S-II</td>
<td>-180</td>
<td>685</td>
<td>50</td>
<td>1060</td>
<td>26</td>
<td>37</td>
<td>29</td>
<td>950</td>
<td>1.120</td>
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<tr>
<td>CP292T</td>
<td>C-2 ENG PUMP SHIELD</td>
<td>1-S-II -110</td>
<td>320</td>
<td>50</td>
<td>344</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

* RATIO OF MEASURED NORMAL FLUX TO PREDICTED FLUX.  
** PLUME INTERACTION WITH OBLITERATING BOTTLES AND STRUCTURE AND RESULTANT ADJACENT SHOCKS MAKES FLOW DIRECTION ILL DEFINED.
### TABLE 12-V. COMPARISON OF IMPINGEMENT HEATING ON WARM COMPONENTS DURING SPACE COAST.

<table>
<thead>
<tr>
<th>MEAS. NO.</th>
<th>COMPONENT</th>
<th>IMPINGEMENT SOURCE</th>
<th>PLUME LOCATION</th>
<th>AVG RISE RATE OVER PROLONGED INTERVAL</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>LENGTH IN.</td>
<td>RADIAL IN.</td>
</tr>
<tr>
<td>CH9T</td>
<td>C-1 RECIRC MTR HSG</td>
<td>S-IV ENGINES (SUN)</td>
<td>38</td>
<td>22</td>
</tr>
<tr>
<td>CH10T</td>
<td>C-2 RECIRC MTR HSG</td>
<td>S-II ENGINES (NO SUN)</td>
<td>38</td>
<td>22</td>
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<tr>
<td>CU240T</td>
<td>C-1 SERVOPOSITIONER</td>
<td>S-IV ENGINES (SUN)</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>CU241T</td>
<td>C-2 SERVOPOSITIONER</td>
<td>S-II ENGINES (NO SUN)</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>CF15T</td>
<td>NO. 2 HELIUM BTL TEMP</td>
<td>S-IV ENGINES (NO SUN)</td>
<td>19</td>
<td>13</td>
</tr>
</tbody>
</table>

*LIMITED IMPINGEMENT, RISE DUE TO SOLAR HEATING

AGREES WITH 1.7 °F/MIN. TOTAL RISE RATE OF 988-3-71-90 (REF 34) FOR IMPINGEMENT.

IMpingement IS BLOCKED BY He BOTTLE.

AGREES WITH 2.4 °F/MIN. TOTAL RISE RATE OF 988-3-71-90 (REF 34)

AGREES WITH AVERAGE 1.7 °F/ MIN. AT PROBE LOCATION DURING 1ST COAST FROM 965-4/HT73/006 (REF 61).

*SUBSEQUENT MAX TEMPERATURES (WITH EMPTY BOTTLE) OF 125°F DURING 2ND COAST IS DUE TO CONDUCTION SOAKOUT FROM INSULATION AND HOT SPOT, 150°F DURING 3RD COAST DUE TO CONDUCTION SOAKOUT OF ACCUMULATED SOLAR HEATING, 5.5 °F/MIN. MAX RISE DURING H2O2 DEPLETION EXPERIMENT DUE TO SOAKOUT OF ACCUMULATED SPACE HEATING AND 2-ENGINE IMPINGEMENT PLUS SUN.

VI-114
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

VI-115
FIGURE 13-1. CENTAUR LO₂ BOOST PUMP TEMPERATURES.
LO₂ Boost Pump Temperature Map History

Boost Pump Firing Intervals

CP186T Cat Bed Thermocouple
CP182T Turbine Aft Housing Thermocouple
CP36T Turbine Bearing
CP176T Gearbox
CP174T Shaft Housing
CP184T Lock Rotor Boss (Patch, Invalid)

Temperature, °F

Time in Minutes from Lift-Off

VI-117
FIGURE 13-2. CENTAUR LH₂ BOOST PUMP TEMPERATURES.
LH₂ BOOST PUMP TEMPERATURE MAP HISTORY

BOOST PUMP FIRING INTERVALS

- CP187T CAT BED (INVALID, NOT SHOWN)
- CP183T TURBINE AFT HOUSING THERMOCOUPLE
- CP127T TURBINE BEARING
- CP177T GEAR BOX
- CP175T SEAL VENT BOSS
- CP179T CAT BED (PATCH, INVALID)
- CP185T LOCK-ROTOR BOSS (PATCH, INVALID)

TIME IN MINUTES FROM LIFTOFF

VI-119
C-1 ENGINE CHAMBER TEMPERATURES
DURING THERMAL MANEUVERS

TIME IN MINUTES FROM LIFT-OFF
VI-120
ENGINE CHAMBER WEIGHT AND CIRCUMFERENTIAL AVERAGE TEMPERATURE VERSUS LONGITUDINAL DISTANCE

CIRCUmFERENTIALLY WEIGHTED TEMPERATURE
C-1 ENGINE
C-2 ENGINE

DISTANCE ALONG THRUST CHAMBER, FROM INJECTOR, INCHES
<table>
<thead>
<tr>
<th>PORTION OF CHAMBER</th>
<th>WEIGHT LB</th>
<th>T °F</th>
<th>C p BTU/LB °F</th>
<th>M C p BTU/°F</th>
<th>M C p T BTU</th>
<th>T °F</th>
<th>C p BTU/LB °F</th>
<th>M C p BTU/°F</th>
<th>M C p T BTU</th>
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</thead>
<tbody>
<tr>
<td>COMBUSTION CHAMBER/THROAT LH2 INLET MANIFOLD</td>
<td>58</td>
<td>20</td>
<td>0.105</td>
<td>6.08</td>
<td>121.8</td>
<td>-20</td>
<td>.101</td>
<td>5.86</td>
<td>117.2</td>
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<tr>
<td>TRANSITION ZONE</td>
<td>13</td>
<td>120</td>
<td>0.111</td>
<td>1.44</td>
<td>173.0</td>
<td>50</td>
<td>.107</td>
<td>1.39</td>
<td>69.5</td>
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<tr>
<td>BELL</td>
<td>31</td>
<td>200</td>
<td>0.114</td>
<td>3.54</td>
<td>708.0</td>
<td>140</td>
<td>.112</td>
<td>3.47</td>
<td>485.0</td>
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<tr>
<td>TOTAL</td>
<td>102</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEIGHTED TEMP = ( \frac{\Sigma M C p T}{\Sigma M C p} )</td>
<td>91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

MAXIMUM ALLOWABLE WEIGHTED AVERAGE TEMPERATURE = 110°F (570°F)
CENTAUR ENGINE TEMPERATURES
RPT 988-3-71-90 PREDICTED AND TC-2 FLIGHT DATA
CONTINUOUS SETTLED COAST

- C-1 ENGINE TC-2 FLIGHT DATA
- C-2 ENGINE TC-2 FLIGHT DATA
- RPT 988-3-71-50 CASE 14 MAXIMUM PREDICTED

TURBINE HOUSING (GRP 7)
LO2 PUMP HOUSING (GRP 9)
FUEL PUMP HOUSING (GRP 5)

FLIGHT TIME ~ SECONDS
VI-123

FIGURE 13-10
<table>
<thead>
<tr>
<th>Item Description</th>
<th>TC-5 Mission</th>
<th>1st 1.1/2 hr Backup</th>
<th>5 1/4 hr 30 Min</th>
<th>20 Min 5 Min 2 hr</th>
<th>TC-2 Configuration Predictions</th>
<th>14 Min 35 Min</th>
<th>96 Min 125 Min</th>
<th>0-G Orbit Coast</th>
<th>0-G Coast</th>
<th>0-G Coast</th>
<th>0-G Coast</th>
<th>0-G Coast</th>
<th>0-G Coast</th>
<th>0-G Coast</th>
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</thead>
<tbody>
<tr>
<td>TC-2 Data</td>
<td>Engine</td>
<td>C-1</td>
<td>C-2</td>
<td>C-1</td>
<td>C-2</td>
<td>C-1</td>
<td>C-2</td>
<td>C-1</td>
<td>C-2</td>
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<td>C-2</td>
<td>C-1</td>
<td>C-2</td>
<td>C-1</td>
</tr>
<tr>
<td>Fuel Turbopump Housing</td>
<td>196</td>
<td>200</td>
<td>215</td>
<td>220</td>
<td>300</td>
<td>270</td>
<td>320</td>
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<td>205</td>
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<tr>
<td>Oxidizer Turbopump Housing</td>
<td>276</td>
<td>330</td>
<td>310</td>
<td>360</td>
<td>317</td>
<td>285</td>
<td>332</td>
<td>315</td>
<td>380</td>
<td>390</td>
<td>240</td>
<td>240</td>
<td>225</td>
<td>230</td>
</tr>
<tr>
<td>Turbine Housing</td>
<td>332</td>
<td>310</td>
<td>315</td>
<td>295</td>
<td>325</td>
<td>290</td>
<td>335</td>
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<td>355</td>
<td>340</td>
<td>305</td>
<td>285</td>
<td>320</td>
<td>300</td>
</tr>
<tr>
<td>C-1 Fuel Duct @ CP751T</td>
<td>120</td>
<td>150</td>
<td>265</td>
<td>285</td>
<td>300</td>
<td>95</td>
<td>82</td>
<td>&lt;60</td>
<td>282</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-1 Oxidizer Duct @ CP750T</td>
<td>185</td>
<td>200</td>
<td>245</td>
<td>260</td>
<td>280</td>
<td>150</td>
<td>180</td>
<td>185</td>
<td>255</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

* Temperatures in ( ) are adjusted from the probe indicated temperature for gradients and probe thermal resistance effects during impingement heating to yield more realistic LO2 pump mass temperatures.

† 3 hr 0-G Coast
ENGINE INLET PROBE TEMPERATURES DURING FLIGHT

CP 53T C-1 PUMP LOX INLET

CP 61T C-2 PUMP LOX INLET

CP 60T C-1 PUMP LH2 INLET

CP 62T C-2 PUMP LH2 INLET

TIME FROM LIFT-OFF, HRS-MIN.

VI-127
THERMAL AND HEAT TRANSFER

- LO₂ TANK SHIELD INSULATION KIT
  — THERMAL RESPONSE AND LO₂ TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- H₂O₂ SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY
**THERMAL CONTROL SUMMARY**

- **PRELAUNCH PURGING AND GAS CONDITIONING PROVIDED SATISFACTORY THERMAL CONTROL OF EQUIPMENT AND PAYLOAD.**

- **INSULATIONS, NEW HEAT TRANSFER ATTENUATING STRUCTURE, AND THE NEW 3-LAYER RADIATION SHIELD SYSTEMS PERFORMED WITHIN PREDICTIONS PROVIDING EXCELLENT THERMAL PROTECTION OF CRYOGENS DURING SPACE OPERATIONS.**

- **ASCENT THERMODYNAMIC AND VENTING ENVIRONMENTS AND RESPONSES WERE WITHIN PREDICTIONS AND CONFIRMED THE ACCEPTABILITY OF H₂O₂ ENGINE FIRING WITHIN THE ISA.**

- **TANK VENT SYSTEMS THERMAL RESPONSE AND CONTROL WAS SATISFACTORY. SECOND TITAN/CENTAUR FLIGHT CONFIRMED LO₂ VENTING DURING AND AFTER PERIODS OF TANK PRESSURE AND ACCELERATION COMBINATIONS CONDUCIVE TO BULK BOILING OF THE LO₂ WHICH PUSHES LIQUID BULK FORWARD WITH SPILLAGE INTO THE STAND PIPE.**

- **THERMAL CONTROL OF EQUIPMENT WAS SATISFACTORY DURING SPACE OPERATIONS OF TC-2 DURATIONS. OVERHEATING TRENDS WERE DEVELOPING ON THE DCU AND S-BAND TRANSMITTER AGGRAVATED BY SOLAR ENTRAPMENT AND RERADIATION OBSTRUCTION BY THE HELIOS ENVIRONMENTAL SHIELD, LOCAL HIGH DENSITY OF "HOT" PACKAGES, AND THERMAL MANEUVER WITH REPEATED, MAXIMUM SOLAR ASPECT ON ALTERNATE ROLLS.**

- **HYDRAULIC SYSTEM THERMAL CONTROL WITH 3-LAYER RADIATION SHIELD BOOTS WAS SATISFACTORY.**
THERMAL CONTROL SUMMARY

- \( \text{H}_2\text{O}_2 \) system thermal control was satisfactory with heated lines and 3-layer shield boots on unheated sections and fittings. Redundant parallel flow feature was not exercised. "Hot" zones developed on heated lines in radiation trapped locations combined with maximum direct and vehicle reflected solar radiation.

- "Free" plume impingement heating rates to surfaces and exposed components were within predictions. Heating rates were sometimes higher than predicted in plumes subjected to deflection, compression, or shock interaction by adjacent vehicle surfaces.

- Engine impingement shields were less effective than assumed due to greater inflow and conductive/convective degradation by \( \text{H}_2\text{O}_2 \) exhaust products.

- Temperature rise on the \( \text{LO}_2 \) turbopump during coasts was higher than predicted due to a combination of warmer turbine at MECO, higher impingement shield heat transfer degradation, maximum solar aspect to the sun and reflection from the engine chamber. Environment/thermal model modification achieved predictive agreement with flight data.

- Engine chamber bells locally heated higher than predicted for direct solar impingement due to unidentified nickel splash coat. Chamber weighted average temperature for long space coast satisfies 570°R maximum allowable for restart.
THERMAL CONTROL SUMMARY

• BOOST PUMP THERMAL RESPONSE AND CONTROL WAS SATISFACTORY AND WITHIN PREDICTIONS INCLUDING EXTRAPOLATION OF RESPONSE TO 5-1/4 HOUR COAST.

• MAIN PROPELLANT DUCTS WITH 3-LAYER RADIATION SHIELDING RETAINED PARTIAL LIQUID FOR MOST, IF NOT ALL, OF COAST CONTRIBUTING TO WEIGHTED AVERAGE TEMPERATURE WITHIN PREDICTIONS AND PRESTART DURATIONS WITH SIGNIFICANT MARGIN.

• ADVERSE OVERHEAT TREND DURING LONG COASTS WITH VEHICLE HIGH DENSITY EQUIPMENT COMPLEMENT TO BE ALLEVIATED BY PRECESSING THERMAL MANEUVER.
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I  INTRODUCTION
II  PROPELLANT BEHAVIOR
III  HELIUM USAGE
IV  PROPELLANT TANK PRESSURIZATION
V  PROPELLANT TANK THERMODYNAMICS
VI  COMPONENT HEATING & THERMAL CONTROL
VII  MAIN ENGINE SYSTEM
VIII  $\text{H}_2\text{O}_2$ CONSUMPTION
IX  BOOST PUMP POST-MECO PERFORMANCE
X  OVERVIEW OF OTHER SYSTEMS

VII-1
MAIN ENGINE PERFORMANCE

- All important engine parameters indicated normal operating conditions during the 3rd and 4th burns.
## MAIN ENGINE PERFORMANCE PARAMETERS

<table>
<thead>
<tr>
<th>Meas No.</th>
<th>Description</th>
<th>Units</th>
<th>Burn No. 1</th>
<th>Burn No. 2*</th>
<th>Burn No. 3</th>
<th>Burn No. 4</th>
<th>Typ &quot;D&quot; Centaur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mes1</td>
<td>MECO1</td>
<td>MECO2</td>
<td>MECO3</td>
<td>MECO4</td>
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<tr>
<td>CP46P</td>
<td>C1 Thrust Chamber Press</td>
<td>psia</td>
<td>2</td>
<td>392</td>
<td>396</td>
<td>2</td>
<td>398</td>
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<tr>
<td>CP1B</td>
<td>C1 Pump Speed</td>
<td>rpm</td>
<td>0</td>
<td>12300</td>
<td>12240</td>
<td>0</td>
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<tr>
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<td>C1 Fuel Venturi Inlet Press</td>
<td>psia</td>
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<td>744</td>
<td>756</td>
<td>16</td>
<td>760</td>
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<td>C1 LO₂ Pump Discharge Press</td>
<td>psia</td>
<td>118</td>
<td>605</td>
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<td>611</td>
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<td>C1 LH₂ Pump Discharge Press</td>
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<td>996</td>
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<td>1002</td>
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<td>CP5T</td>
<td>C1 Turbine Inlet Temp</td>
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<td>-91</td>
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* MES2 Data Not Available
† Data Not Available

VII-2
MAIN ENGINE START PERFORMANCE

- Slower accelerating engines resulted in reduced start impulse during the 3rd and 4th start transients.

- C-2 engine start impulse was lowest of all flights to date.
## START IMPULSE SUMMARY (PER ENGINE)

### OBSERVED FLIGHT DATA (PWA CALCULATED)

<table>
<thead>
<tr>
<th>PWA ENGINE SPECIFICATION</th>
<th>PWA IAT DATA</th>
<th>MAX. - MIN. (AC-22 to 31 &amp; AC-34 FLIGHTS)</th>
<th>TC-2 FLIGHT</th>
<th>MAX. - MIN. (AC-25, 26, 28, 29, 31 &amp; 34 FLIGHTS)</th>
<th>TC-2 FLIGHT</th>
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</thead>
<tbody>
<tr>
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<td>TC-2 FLIGHT</td>
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<td>TC-2 FLIGHT</td>
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</tr>
</tbody>
</table>

**Legend:**
- **CORRECTED TO STANDARD CONDITIONS**
- **NOT CORRECTED TO STANDARD CONDITIONS**

**Units:**
- **LB-SEC**
- **1000**
The slower accelerating C-2 engine resulted in large (but acceptable) start impulse differentials.
# START IMPULSE DIFFERENTIAL — SUMMARY

<table>
<thead>
<tr>
<th>DERIVED FROM ENG. SPEC'N IMPULSE</th>
<th>DERIVED FROM LAT IMPULSE</th>
<th>MES1 MAX. - MIN. (AC-22 → 31 &amp; AC-34 FLIGHTS)</th>
<th>MES2 MAX. - MIN. (AC-25, 26, 28, 29, 31, &amp; 34 FLIGHTS)</th>
<th>MES3</th>
<th>MES4 TC-2 FLIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>5650 MAX.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>2260 MAX.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1523 (AC-28)</td>
<td>1746</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>846 (AVG.)</td>
<td>1033 (AVG.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>142 (AC-30)</td>
<td>37 (AC-35)</td>
<td>1909</td>
<td>2396 TC-2 FLIGHT</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>[Diagram representation]</td>
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<td>[Diagram representation]</td>
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VII-4
START IMPULSE DIFFERENTIAL EFFECTS

<table>
<thead>
<tr>
<th></th>
<th>PITCH</th>
<th>YAW</th>
<th>ROLL</th>
<th>MAXIMUM ENGINE GIMBAL ANGLE – DEGREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>MES1</td>
<td>-1.50</td>
<td>-0.12</td>
<td>-1.40</td>
<td>+1.36 (C1 PITCH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RATES DAMPED TO 0.3 DEG/SEC OR LESS BY MES1 +4 SECONDS</td>
</tr>
<tr>
<td>MES2</td>
<td>-4.30</td>
<td>-0.40</td>
<td>-3.60</td>
<td>+2.4 (C1, C2 PITCH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TLM DATA OBSCURED BY NOISE BEFORE DAMPING OF MES TRANSIENT. HOWEVER, DAMPING APPEARED IMMINENT</td>
</tr>
<tr>
<td>MES3</td>
<td>-8.0</td>
<td>+0.3</td>
<td>-4.2</td>
<td>+1.28 (C1, C2 PITCH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RATES DAMPED TO LESS THAN 0.5 DEG/SEC BY MES3 +7.5 SECONDS</td>
</tr>
<tr>
<td>MES4</td>
<td>-9.3</td>
<td>+1.2</td>
<td>-4.7</td>
<td>+1.6 (C1, C2 PITCH)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>RATES DAMPED TO LESS THAN 0.5 DEG/SEC BY MES4 +8 SECONDS</td>
</tr>
</tbody>
</table>

VII-5
MAIN ENGINE START PERFORMANCE
MES1 AND MES2

MES1

Time in seconds from 1st main engine start signal

MES2

Time in seconds from 2nd main engine start signal
MAIN ENGINE START PERFORMANCE
MES3 AND MES4

**MES3**

<table>
<thead>
<tr>
<th>Time in Seconds</th>
<th>CP46P C1 Thrust Chamber Pressure</th>
<th>CP47P C2 Thrust Chamber Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td></td>
<td></td>
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<tr>
<td>1.4</td>
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<tr>
<td>1.5</td>
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<tr>
<td>1.6</td>
<td></td>
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<tr>
<td>1.7</td>
<td></td>
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</tr>
<tr>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
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</tbody>
</table>

**MES4**

<table>
<thead>
<tr>
<th>Time in Seconds</th>
<th>CP46P C1 Thrust Chamber Pressure</th>
<th>CP47P C2 Thrust Chamber Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
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<td>1.4</td>
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<td>1.5</td>
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<td>1.6</td>
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<td>1.7</td>
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<td>1.8</td>
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<tr>
<td>1.9</td>
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</tbody>
</table>

VII-7
ENGINE INLET CONDITIONS WERE SATISFACTORY FOR ALL BURNS

MAIN ENGINE LO2 PUMPS NPSP CONDITIONS

MAIN ENGINE LH2 PUMPS NPSP CONDITIONS

ENGINE INLET CONDITIONS WERE SATISFACTORY FOR ALL BURNS

MAIN ENGINE LO2 PUMPS NPSP CONDITIONS

MAIN ENGINE LH2 PUMPS NPSP CONDITIONS
MA IN ENGINE PERFORMANCE -
CP 52P C-1 PUMP LH\textsubscript{2} INLET PRESSURE

- CP 52P C-1 PUMP LH\textsubscript{2} INLET
- SECONDS FROM MES SIGNAL

VII-9
MAIN ENGINE PERFORMANCE -
CP 54P C-2 PUMP LH₂ INLET PRESSURE

-1 0  +1  +2  +3
SECONDS FROM MES SIGNAL

PIA

50  0
C 54P C-2 PUMP LH₂ INLET

PIA

50  0
CP 54P C-2 PUMP LH₂ INLET

PIA

50  0
CP 54P C-2 PUMP LH₂ INLET

VII-10
MES4 ENGINE FUEL PUMP
INLET PRESSURE OSCILLATIONS

CP 52P C-1 PUMP LH₂ INLET

TC-2

PIA

CP121P DP ACROSS LH₂ BP

BOOST PUMP START PRESTART

TIME IN SECONDS FROM MES4

VII-11
MAIN ENGINE PERFORMANCE -
CP 51P C-1 PUMP LO2 INLET PRESSURE

CP 51P C-1 PUMP LO2 INLET

PIA

MES1

MES3

MES4

SECONDS FROM MES SIGNAL

VII-12
MAIN ENGINE PERFORMANCE -
CP 53P C-2 PUMP LO₂ INLET PRESSURE

CP 53P C-2 PUMP LO₂ INLET

PIA

CP 53P C-2 PUMP LO₂ INLET

PIA

CP 53P C-2 PUMP LO₂ INLET

PIA

SECONDS FROM MES SIGNAL

VII-13
MAINTAIN MECHINE CUT-OFF IMPULSE WAS NEAR NOMINAL

<table>
<thead>
<tr>
<th>CUT-OFF IMPULSE — LB-SEC</th>
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<tbody>
<tr>
<td>CHAMBER PRESSURE DATA</td>
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<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>MECO1</td>
</tr>
<tr>
<td>MECO2</td>
</tr>
<tr>
<td>MECO3</td>
</tr>
<tr>
<td>MECO4</td>
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MEO THRUST TRANSIENT DISTURBANCES — MAX VEHICLE RESIDUAL RATE DEG PER SEC

<table>
<thead>
<tr>
<th>PITCH</th>
<th>YAW</th>
<th>ROLL</th>
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</thead>
<tbody>
<tr>
<td>MECO1</td>
<td>-0.24</td>
<td>-0.10</td>
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<tr>
<td>MECO2</td>
<td>+0.02</td>
<td>0</td>
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<tr>
<td>MECO3</td>
<td>-0.24</td>
<td>+0.12</td>
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<tr>
<td>MECO4</td>
<td>-0.16</td>
<td>+0.34</td>
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CUT-OFF IMPULSE DIFFERENTIAL — LB-SEC

<table>
<thead>
<tr>
<th>CHAMBER PRESSURE DATA</th>
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<tbody>
<tr>
<td>MECO1</td>
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<td>MECO2</td>
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<tr>
<td>MECO3</td>
</tr>
<tr>
<td>MECO4</td>
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<tr>
<td>AVERAGE (AC30-35)</td>
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<tr>
<td>MECO1</td>
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</table>

VII-14
LH$_2$ BOOST PUMP PERFORMANCE
TURBINE INLET PRESSURE

CP28P LH$_2$ BOOST PUMP TURBINE INLET

1ST BURN

3RD BURN

4th BURN

POST MECO-4 BOOST PUMP EXPERIMENT

TIME IN SECONDS FROM BOOST PUMP START

VII-15
LH₂ BOOST PUMP PERFORMANCE
SPEED

CP16B LH₂ BOOST PUMP SPEED

1ST BURN

3RD BURN

4TH BURN

TIME IN SECONDS FROM BOOST PUMP START
**LH2 BOOST PUMP PERFORMANCE - HEAD RISE**

**CP121P DP ACROSS LH2 BOOST PUMP**

1ST BURN

PRESTART

MAIN ENGINE START

3RD BURN

PRESTART

MAIN ENGINE START

MAIN ENGINE CUTOFF

4TH BURN

PRESTART

MAIN ENGINE START

TIME IN SECONDS FROM BOOST PUMP START

VII-17
LO2 BOOST PUMP PERFORMANCE - TURBINE INLET PRESSURE

1ST BURN

3RD BURN

4TH BURN

POST MECO4 BOOST PUMP EXPERIMENT

TIME IN SECONDS FROM BOOST PUMP START

VII-18
LO$_2$ BOOST PUMP PERFORMANCE
HEAD RISE

1ST BURN

CP120P DP ACROSS LO$_2$ BOOST PUMP

3RD BURN

PSID

4TH BURN

TIME IN SECONDS FROM BOOST PUMP START
MECO4 INITIATION BASED ON VEHICLE WEIGHT

- FOURTH BURN TERMINATED BY DCU CALCULATED TOTAL VEHICLE WEIGHT BASED ON SENSED ACCELERATION.

- REQUIRED TO ASSURE ADEQUATE PROPELLANTS FOR POST MECO4 BOOST PUMP EXPERIMENT.

- TECHNIQUE DEMONSTRATED TO BE SATISFACTORY

  ▲ POST FLIGHT ESTIMATED VEHICLE WEIGHT AT MECO4 OF 6365 LB WAS 165 LB GREATER THAN TARGETED VALUE OF 6200 LB (REF. GDC REPORT 672-1-75-017)
  - ATTRIBUTED PRIMARILY TO DIFFERENCE BETWEEN NOMINAL THRUST LEVEL USED BY SOFTWARE TO COMPUTE WEIGHT AND ACTUAL THRUST LEVEL CALCULATED FROM POST-FLIGHT ANALYSIS OF ENGINE DATA.
  - PLAN TO USE BIASED WEIGHT CUTOFF LEVELS FOR TC-5.
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Author(s)</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>INTRODUCTION</td>
<td>HUBER</td>
</tr>
<tr>
<td>II</td>
<td>PROPELLANT BEHAVIOR</td>
<td>MERINO</td>
</tr>
<tr>
<td>III</td>
<td>HELIUM USAGE</td>
<td>MERINO</td>
</tr>
<tr>
<td>IV</td>
<td>PROPELLANT TANK PRESSURIZATION</td>
<td>MERINO</td>
</tr>
<tr>
<td>V</td>
<td>PROPELLANT TANK THERMODYNAMICS</td>
<td>MERINO</td>
</tr>
<tr>
<td>VI</td>
<td>COMPONENT HEATING &amp; THERMAL CONTROL</td>
<td>CHRISTENSEN</td>
</tr>
<tr>
<td>VII</td>
<td>MAIN ENGINE SYSTEM</td>
<td>HUBER</td>
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<tr>
<td>VIII</td>
<td>$\text{H}_2\text{O}_2$ CONSUMPTION</td>
<td>HUBER</td>
</tr>
<tr>
<td>IX</td>
<td>BOOST PUMP POST-MECO PERFORMANCE</td>
<td>HUBER/MERINO</td>
</tr>
<tr>
<td>X</td>
<td>OVERVIEW OF OTHER SYSTEMS</td>
<td>HUBER</td>
</tr>
</tbody>
</table>
## H₂O₂ Consumption Summary — Actual vs. Predicted

### Total H₂O₂ Consumed (LB)

<table>
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<tr>
<th>Event</th>
<th>Calculated Actual</th>
<th>Predicted*</th>
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</thead>
<tbody>
<tr>
<td>MECO1</td>
<td>18.2</td>
<td>18.1</td>
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<tr>
<td>MECO2</td>
<td>182.6</td>
<td>181.6</td>
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<td>MECO3</td>
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<td>237.4</td>
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<td>MECO4</td>
<td>331.0</td>
<td>360.7</td>
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<tr>
<td>Start Depletion</td>
<td>356.0</td>
<td>382.8</td>
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<tr>
<td>Experiment</td>
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<tr>
<td>At Depletion</td>
<td>476.0</td>
<td>476.0</td>
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*Preflight prediction corrected for actual burn times and coast times.*
HYDROGEN PEROXIDE (H₂O₂) CONSUMPTION DIFFERENCES ARE ATTRIBUTED TO 3RD COAST P/Y ENGINE USAGES

<table>
<thead>
<tr>
<th>3RD COAST MODE</th>
<th>CONSUMPTION (LB)</th>
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<tr>
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<tr>
<td>P&amp;Y CONTROL — ZERO-G</td>
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<td>THERMAL MANEUVERS (6)</td>
<td>9.3</td>
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<tr>
<td>P/Y WARMING (1)</td>
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<tr>
<td>S WARMINGS (2)</td>
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<tr>
<td>PROGRAMMED VENT (1)</td>
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<tr>
<td>2S ON (180 SEC)</td>
<td>1.3</td>
</tr>
<tr>
<td>4S ON (40 SEC)</td>
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<tr>
<td>PRE-MES4 SETTLING:</td>
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<tr>
<td>2S ON (300 SEC)</td>
<td>2.1</td>
</tr>
<tr>
<td>4S ON (119.4 SEC)</td>
<td>2.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>(24.6)</td>
</tr>
</tbody>
</table>
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I  INTRODUCTION
II PROPELLANT BEHAVIOR
III HELIUM USAGE
IV PROPELLANT TANK PRESSURIZATION
V PROPELLANT TANK THERMODYNAMICS
VI COMPONENT HEATING & THERMAL CONTROL
VII MAIN ENGINE SYSTEM
VIII H₂O₂ CONSUMPTION
IX BOOST PUMP POST-MECO PERFORMANCE
X OVERVIEW OF OTHER SYSTEMS

HUBER
MERINO
MERINO
MERINO
CHRISTENSEN
HUBER
HUBER
HUBER/MERINO
HUBER
POST-MECO LH₂ BOOST PUMP TURBINE INLET PRESSURE

CP28P LH₂ UNIT TURBINE INLET PRESSURE

PSIA

TIME IN SECS FROM MECO IX-3

AC32 MECO 1

TC2 MECO 1

TC2 MECO 2

TC2 MECO 3

TC2 MECO 4
POST-MECO LO₂ BOOST PUMP TURBINE INLET PRESSURE

CP26P LO₂ UNIT TURBINE INLET PRESSURE

ACS MECO 1

TC2 MECO 1

TC2 MECO 2

TC2 MECO 3

TC2 MECO 4

TIME IN SECS FROM MECO

IX-5
# Maximum Boost Pump Post-MECO Speeds

## Actual vs. Expected

### Observed Flight Peak RPM

<table>
<thead>
<tr>
<th>Unit</th>
<th>RPM</th>
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<tbody>
<tr>
<td>TC-2</td>
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<td>TC-4</td>
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<td>TC-6</td>
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<tr>
<td>TC-8</td>
<td>4</td>
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<tr>
<td>TC-9</td>
<td>4 WAST PUMP EXPERIMENT</td>
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<td>TC-14</td>
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<tr>
<td>TC-14</td>
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<td>TC-16</td>
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<td>TC-20</td>
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<tr>
<td>AG-36</td>
<td>1</td>
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<tr>
<td>AG-36 POST MECO2</td>
<td></td>
</tr>
</tbody>
</table>

### Review of Max Allowable versus Max Expected Turbine Speed with Redundant H₂O₂ Supply System (Ref. GDC Report ES-S-43)

#### Max Allowable Turbine Speed
- Unit-to-Unit Turbine Proof Test
- Turbine burst tests - 4 samples, failure occurring at

<table>
<thead>
<tr>
<th>Speed - RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>65,650</td>
</tr>
<tr>
<td>77,000</td>
</tr>
<tr>
<td>78,000</td>
</tr>
<tr>
<td>83,600</td>
</tr>
<tr>
<td>&gt;85,330</td>
</tr>
</tbody>
</table>

#### Max Predicted Turbine Speed
- Analytical Method 1
- Analytical Method 2
- Based on LORC test results

<table>
<thead>
<tr>
<th>LO₂ Unit</th>
<th>LH₂ Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>60,000</td>
<td>66,000</td>
</tr>
<tr>
<td>58,000</td>
<td>60,000</td>
</tr>
<tr>
<td></td>
<td>65,000</td>
</tr>
</tbody>
</table>

#### Conclusion — Max Speed Turbine is within range considered safe and acceptable
POST-MECO4 BOOST PUMP EXPERIMENT

SEQUENCE OF EVENTS

- START 4S SETTLED THRUST AT MECO4 +200 SECONDS.
- START BOOST PUMPS AT MECO4 +280 SECONDS.
- OPEN PRESTART VALVES AT MECO4 +300 SECONDS.
- STOP BOOST PUMPS AT MECO4 +305 SECONDS.
- END 4S SETTLED THRUST AT MECO4 +306 SECONDS.

PROPELLANT TANK CONDITIONS AT BOOST PUMP START

- LH₂ IS SETTLED. LO₂ IS PARTIALLY SETTLED.
- LIQUID RESIDUALS 302 LB LH₂ AND 790 LB LO₂.
- VAPOR INGESTION SHOULD NOT OCCUR DURING EXPERIMENT.
- LH₂ IN SUMP IS SATURATED AT TANK PRESSURE
  LH₂ BULK IS SATURATED AT TANK PRESSURE.
- LO₂ IN SUMP IS SATURATED AT TANK PRESSURE
  LO₂ BULK IS SUBCOOLED BY 2.1 PSID.
- AN UNKNOWN QUANTITY OF VAPOR EXISTS IN THE SUMPS AND BOOST PUMPS
  AS A RESULT OF BOILING AT MECO4.
PROPELLANT CONDITION AT START OF BOOST PUMP EXPERIMENT

ACTUAL LIQUID LEVEL AT BPS

ESTIMATED VAPOR INGESTION LEVEL

STA. 371
STA. 378.8
STA. 445.2
STA. 450.0

THRUST BARREL

IX-8
LH₂ BOOST PUMP PERFORMANCE

- No tank pressurization was provided.
- Performance appeared normal until BPS +15 seconds, at which time cavitation occurred.
- Cavitation was reflected in boost pump performance by exhibiting a loss of head rise at this time.
- A sudden drop in head pressure and a corresponding sudden increase in pump speed occurred just before prestart.
- The boost pump recovered shortly after prestart flow was initiated.

The following explanation is given for the observed boost pump operation:

- During boost pump operation bearing coolant hydrogen flowed into the sump as a two phase mixture.
- Due to the low-G condition (0.003 G's) vapor did not rise from the sump and began to accumulate.
- Cavitation occurred at BPS +15 seconds as a result of accumulated vapor spilling into boost pump inlet duct.
- Calculated vapor accumulation by BPS +15 seconds is 0.93 ft³. Maximum volume below inlet duct is 0.83 ft³.

Conclusions:

- Boost pump performance would have been normal through MES had prestart occurred at BPS +11 seconds, or earlier, as with the previous flight experience.
- For future missions prestart must occur no later than BPS +15 seconds in order to avoid cavitation.
LH$_2$ TANK PRESSURE DURING BOOST PUMP EXPERIMENT

TC-2 CCVAPS LH$_2$ TANK PRESSURE

DATA SMOOTHED BY AVERAGING
5 DATA POINTS

TANK PRESSURE = SUMP LIQUID VAPOR PRESSURE

TIME FROM BOOST PUMP EXPERIMENT START

IX-11
LO₂ BOOST PUMP PERFORMANCE
(MECO4 TO PROPELLANT SETTLING)

- LIQUID WITHIN THE THRUST BARREL BECAME UNSETTLED AFTER MECO4 DUE TO THE
  MOMENTUM OF THE VOLUTE FLOW INTO THE TANK.
  ▲ VOLUTE FLOWRATE = 21.5 GPM = 3.3 LB/SEC.
  ▲ EXIT AREA = THREE 1/4 INCH DIA. HOLES.
  ▲ EXIT VELOCITY = 47.7 FT/SEC (PURE LIQUID).

- AT MECO4 +4 SECONDS PUMP CAVITATION OCCURRED. CAVIATION WAS CAUSED BY BOILING
  AT MECO4 AND A TWO-PHASE FLUID CONDITION CREATED BY THE VOLUTE FLOW DURING
  PUMP SPINDOWN.
  ▲ 490 LB LO₂ CONTAINED WITHIN THRUST BARREL (67% VAPOR BY VOLUME CON-
    TAINED WITHIN THRUST BARREL.)
  ▲ VOLUTE FLOW MOMENTUM DURING 4 SECONDS OF SPINDOWN = 630 LB-FT SEC
  ▲ FLUID AGITATION CREATES TWO PHASE FLUID (67% BY VOLUME) MOTION OF
    1.29 FT/SEC.

- BY INITIATION OF PROPELLANT SETTLING (MECO4 +200) FLUID MOTION HAS DECAYED AND
  LIQUID COLLECTS IN THE SUMP.

- LIQUID PUMPING BEGAN AT MECO4 +203, AS EVIDENCED BY A HEAD RISE OF 27 PSID (MAX).
  CAVITATION OCCURRED 8 SECONDS LATER.
  ▲ IT IS BELIEVED THAT CAVITATION WAS CAUSED BY THE UNSETTLING INFLUENCE
    OF THE VOLUTE FLOW.
  ▲ THE VOLUTE FLOW MOMENTUM WAS ABOUT 600 LB-FT SEC DURING THE 8 SECOND
    PUMPING PERIOD.

IX-12
POST MECO4 BOOST PUMP PERFORMANCE

GENERAL DYNAMICS
Convair Division
31 Oct 75

Graph showing performance of various pumps CP15B, CP26P, CP120P, CP16B, CP28P, and CP121P. The graph includes markers for 4S ON, BPS, PRESTART, and cutoff points.

IX-13
LO₂ BOOST PUMP PERFORMANCE (EXPERIMENT)

- The pump cavitated until BPS +4.5 seconds and then pumped liquid until BPS +9.5 seconds.
  - A high vapor concentration was present at the pump at BPS.
  - Cavitation at BPS +9.5 seconds was probably caused by the volute flow (momentum input was about 600 lb- ft/ sec).
- Pump loading and unloading persisted until boost pump cutoff +100 seconds.
- Boost pump inlet temperatures indicated cooling and heating trends of 0.5°F (max) and 0.7°F (max), respectively.
- LO₂ tank pressure increased by 0.2 psid during the experiment.

CONCLUSIONS

- Volute return flow responsible for pump cavitation.
- For future missions cavitation will be a concern for engine starts at low liquid levels.
BOOST PUMP EXPERIMENT - LO₂ UNIT

CP 33T LO₂ B PUMP INLET TEMP

DGF

-282.8

-283.8

CP120P DP ACROSS LO₂ BP

PID

150

CP 16B LH₂ BOOST PUMP RPM

KPM

0 10 20 30 40 50

0 70

TIME IN SECONDS FROM BOOST PUMP START

IX-15
**TC-5 IMPLICATIONS**

**LH₂ TANK**

- THE LH₂ BOOST PUMP IS EXPECTED TO PERFORM SATISFACTORILY FOR ALL RESTARTS. THE EXPERIMENT DEMONSTRATED THAT SATISFACTORY PUMP PERFORMANCE IS POSSIBLE WITH NO PREPRESSURIZATION.

**LO₂ TANK**

- CAVITATION WILL BECOME AN INCREASING CONCERN FOR THE LATER MAIN ENGINE STARTS. POTENTIAL FLUID CONDITIONS WITHIN THE THRUST BARREL ARE GIVEN BELOW:

<table>
<thead>
<tr>
<th>EVENT</th>
<th>LH₂ MASS LB</th>
<th>PERCENT VAPOR VOL</th>
<th>ΔP REQUIRED FOR BUBBLE COLLAPSE, PSID</th>
</tr>
</thead>
<tbody>
<tr>
<td>MES4</td>
<td>1285</td>
<td>13</td>
<td>0.36</td>
</tr>
<tr>
<td>MES5</td>
<td>987</td>
<td>33</td>
<td>1.21</td>
</tr>
<tr>
<td>MES6</td>
<td>676</td>
<td>40</td>
<td>1.61</td>
</tr>
<tr>
<td>MES7</td>
<td>721</td>
<td>51</td>
<td>2.51</td>
</tr>
<tr>
<td>TC-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MES4 (TC-2)</td>
<td>1421</td>
<td>3.7</td>
<td>0.12</td>
</tr>
</tbody>
</table>
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I  INTRODUCTION     HUBER
II PROPELLANT BEHAVIOR   MERINO
III HELIUM USAGE        MERINO
IV PROPELLANT TANK PRESSURIZATION  MERINO
V  PROPELLANT TANK THERMODYNAMICS  MERINO
VI COMPONENT HEATING & THERMAL CONTROL  CHRISTENSEN
VII MAIN ENGINE SYSTEM   HUBER
VIII $H_2CO_2$ CONSUMPTION   HUBER
IX BOOST PUMP POST-MECO PERFORMANCE  HUBER/MERINO
X  OVERVIEW OF OTHER SYSTEMS  HUBER

X-1
OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM

X-2
DURING THIRD BURN THE PU VALVES WERE KEPT AT NULL BECAUSE OF THE SHORT BURN DURATION OF 11 SECONDS.

DURING FOURTH BURN THE VALVES MOVED TO THE CLOSED LIMIT SOON AFTER UNNULLING AND REMAINED AT THIS LIMIT UNTIL MECO. THIS WAS DUE TO A LARGE FUEL-RICH ERROR AT THE START OF FOURTH BURN. THE SYSTEM WOULD HAVE REQUIRED AN ADDITIONAL 40 TO 50 SECONDS OF ENGINE OPERATION TO CORRECT OUT THIS ERROR.
### FOURTH BURN PROPELLANT RESIDUAL

<table>
<thead>
<tr>
<th>TOTAL LO₂ (LB)</th>
<th>TOTAL LH₂ (LB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PREDICTED</strong></td>
<td><strong>ACTUAL</strong></td>
</tr>
<tr>
<td>725</td>
<td>791*</td>
</tr>
</tbody>
</table>

* Actual LO₂ residual was based upon LO₂ pu probe uncovery time of MECO-5.02 seconds.

† Since LH₂ probe did not uncover, actual residual was calculated from the pu error signal based upon time of LO₂ probe uncovery.
FOURTH BURN PROPELLANT UTILIZATION OPERATION

C-1 PU VALVE ANGLE VERSUS COMMANDED ANGLE

PU ERROR SIGNAL

DEGREE OF ARC

SERVOPOSITIONER
POSITIVE STOP
\( \text{LH}_2 \text{ HIGH} \)

FREEZE
PU VALVES

MECO

PU VALVE ANGLE

NULL ANGLE

BEGIN PU CONTROL

TIME IN SECONDS FROM MES 4

PU ERROR IN POUNDS LQ2

MECO

FREEZE
PU VALVES

BEGIN PU CONTROL

TIME IN SECONDS FROM MES 4

PEC

X-5
OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM
HYDRAULIC SYSTEM

- THE HYDRAULIC SYSTEM PROVIDED SATISFACTORY C1 AND C2 PRESSURES DURING THE 3RD AND 4TH BURNS AND DURING PERIODS OF RECIRCULATION PUMP OPERATION.

STEADY STATE HYDRAULIC POWER PACKAGE PRESSURES (PSIA)

<table>
<thead>
<tr>
<th></th>
<th>RECIRCULATION PUMP</th>
<th>ENGINE PUMP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE-MES3</td>
<td>PRE-MES4</td>
</tr>
<tr>
<td>C1 POWER PACK</td>
<td>142</td>
<td>142</td>
</tr>
<tr>
<td>C2 POWER PACK</td>
<td>142</td>
<td>142</td>
</tr>
</tbody>
</table>

- THE C2 RECIRCULATION PUMP WAS ACTIVATED 4 TIMES BY THERMOSTAT CONTROL (10 ± 6 DGF) NEAR THE END OF THE 3-HR COAST FOR PERIODS OF 28, 5, 6, AND 5 SECONDS. DE-ACTIVATION (EXPECTED AT 30 ± 6 DGF) OCCURRED WITHOUT SIGNIFICANT RISE OF THE MANIFOLD TEMPERATURE (CH6T). INVESTIGATION REVEALED THIS TO BE NORMAL BEHAVIOR OF THE THERMOSTAT CONTROL WHEN SUBJECTED TO A SHALLOW TEMPERATURE GRADIENT.
OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM
THE DIGITAL COMPUTER UNIT (DCU)
HARDWARE/SOFTWARE PERFORMANCE WAS SATISFACTORY

- SCU SWITCH COMMANDS WERE GENERATED IN CORRECT SEQUENCE WITH NO INADVERTENT COMMANDS.

- D/A OUTPUT AND A/D INPUT CONVERSIONS WERE PERFORMED WITHOUT INCIDENT.

- ALL SOFTWARE MODULES PERFORMED SATISFACTORILY.

- PERMANENT MEMORY CHECKSUM VALUE REMAINED CONSTANT.

- CCU FORMATTING OF PCM AND DCU DATA WAS SATISFACTORY.
NAVIGATION AND GUIDANCE FUNCTIONS PERFORMED AS PLANNED

- NAVIGATION (POSITION AND VELOCITY) PROVIDED CONTINUOUSLY THROUGH ALL COAST AND POWERED PHASES.

- CENTAUR ORIENTED TO -R VECTOR (PLUS 1 DEGREE) DURING THIRD COAST AND MAINTAINED THERE FOR REST OF FLIGHT.

- ALL SIX THERMAL ROLLS DURING THIRD COAST PERFORMED AT 28-MINUTE INTERVALS AS PLANNED.

- BOTH BURNS WERE UNGUIDED WITH:
  1. INTEGRAL CONTROL USED AFTER MES3 +7 SECONDS DURING THIRD BURN.
  2. INTEGRAL CONTROL PLUS GUIDANCE ATTITUDE VECTOR USED AFTER MES4 +7 SECONDS DURING FOURTH BURN.

- ALL ENGINE START AND CUTOFF TIMES WERE CLOSE TO NOMINAL. MECO4 WEIGHT CUTOFF CALCULATIONS WERE SATISFACTORY.

## CENTAUR ORBITS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>THIRD BURN ORBIT</th>
<th>FOURTH BURN ORBIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PALTT*</td>
<td>GUIDANCE†</td>
</tr>
<tr>
<td>EPOCH (SEC)</td>
<td>5,788</td>
<td>5,792</td>
</tr>
<tr>
<td>PERIGEE ALT (NM)</td>
<td>200.4</td>
<td>208.7</td>
</tr>
<tr>
<td>APOGEE ALT (NM)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SMA (NM)</td>
<td>-34,760</td>
<td>-34,699</td>
</tr>
<tr>
<td>ECC</td>
<td>1.104842</td>
<td>1.105268</td>
</tr>
<tr>
<td>INCLINATION (DEG)</td>
<td>29.815</td>
<td>29.918</td>
</tr>
<tr>
<td>ARG OF PERIGEE (DEG)</td>
<td>230.451</td>
<td>230.602</td>
</tr>
<tr>
<td>C3 (KM²/SEC²)</td>
<td>6.19</td>
<td>6.20</td>
</tr>
<tr>
<td>TRUE ANOMALY (DEG)</td>
<td>114.703</td>
<td>114.641</td>
</tr>
</tbody>
</table>

* GDC PRELAUNCH ACTUAL LAUNCH TIME TRAJECTORY.
† TELEMETERED DATA.
‡ GUIDANCE MINUS PALTT.
THIRD AND FOURTH BURN ORBIT INCLINATION DIFFERENCES

- THIRD AND FOURTH BURN ORBITAL INCLINATIONS WERE 0.1 AND 1.95 DEG GREATER THAN PALTT VALUES.

- NOT A PROBLEM AS GUIDANCE WAS OPEN LOOP AND PRECISE ORBITS WERE NOT REQUIRED.

- DIFFERENCES ATTRIBUTED TO OUT-OF-PLANE VELOCITIES DUE TO C.G. OFFSETS, THRUST MISALIGNMENTS, AND GUIDANCE HARDWARE ERRORS (RESOLVER CHAIN AND ASSOCIATED ELECTRONICS).

- POSTFLIGHT ANALYSIS INDICATES C.G. OFFSET WAS THE MAIN CONTRIBUTOR.
COAST PHASE AUTOPILOT

- The attitude control system maintained vehicle stability satisfactorily at or within the control thresholds throughout the coast phases.

- Alignment to -1R vector started at MECO2 + 116 seconds (maximum rate 0.1 degrees/second) and was maintained throughout the remainder of mission.

TYPICAL 0-G AVERAGE ATTITUDE CONTROL ENGINE DUTY CYCLES

<table>
<thead>
<tr>
<th>CONTROL AXIS</th>
<th>AVERAGE DUTY CYCLES (%)</th>
<th>CONTROL THRESHOLDS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POSITIVE</td>
<td>NEGATIVE</td>
</tr>
<tr>
<td>PITCH</td>
<td>0.08</td>
<td>-0.064</td>
</tr>
<tr>
<td>YAW</td>
<td>0.08</td>
<td>-0.096</td>
</tr>
<tr>
<td>ROLL</td>
<td>0.036</td>
<td>-0.036</td>
</tr>
</tbody>
</table>

* Typical measured during 1-hr coast (2565 to 3845 and 4135 to 5340 seconds).

- 180-degree thermal roll maneuvers were accomplished satisfactorily every 28 minutes during the 3-hr coast at a 2-degrees/second rate.
POWERED PHASEautopilot

- Stability was maintained throughout the third and fourth burns.

- Maximum engine deflections were 1.3 degrees (3rd burn) and 1.6 degrees (4th burn) during the start transients.

- Start transient induced rates larger than usual due to lack of payload.

MAXIMUM ATTITUDE AND RATE ERRORS DURING START TRANSIENTS

<table>
<thead>
<tr>
<th>CONTROL AXIS</th>
<th>TC-2 3RD BURN</th>
<th>TC-2 4TH BURN</th>
<th>AC-31,32,34,35,36 &amp; TC-2 2ND BURN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAX ATTITUDE</td>
<td>MAX RATE</td>
<td>AVG. MAX RATE</td>
</tr>
<tr>
<td></td>
<td>ERROR (DEG)</td>
<td>(DEG/SEC)</td>
<td>(DEG/SEC)</td>
</tr>
<tr>
<td>PITCH</td>
<td>-5.2</td>
<td>-8.0*</td>
<td>-5.8</td>
</tr>
<tr>
<td></td>
<td>-5.8</td>
<td>-9.3*</td>
<td>-0.83 ± 8.82</td>
</tr>
<tr>
<td>YAW</td>
<td>+1.6</td>
<td>+0.3</td>
<td>+2.7</td>
</tr>
<tr>
<td></td>
<td>+2.7</td>
<td>+1.2</td>
<td>-0.19 ± 1.68</td>
</tr>
<tr>
<td>ROLL</td>
<td>-1.6</td>
<td>-4.2</td>
<td>-2.5</td>
</tr>
<tr>
<td></td>
<td>-4.7</td>
<td>-2.87 ± 3.36</td>
<td></td>
</tr>
</tbody>
</table>

* Predicted worst case rate maximum = -24.5 deg/sec.

X-15
OVERVIEW OF OTHER SYSTEMS

• PROPELLANT UTILIZATION SYSTEM
• HYDRAULIC SYSTEM
• GUIDANCE AND CONTROL
• ELECTRICAL SYSTEM
• RF AND INSTRUMENTATION
• PNEUMATICS SYSTEM
# Electrical System Voltages

**MEAS. NO.** | **DESCRIPTION** | **UNITS** | **T-0** | **S/C SEP** | **MES3** | **MECO3** | **MES4** | **MECO4** | **LOS (18,960 SEC)** | **EXPECTED RANGE**
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
CE28V | BUS 1 VOLTAGE | VDC | 28.3 | 28.3 | 28.5 | 28.5 | 28.8 | 28.8 | 29.0 | 28.0 MIN @ LIFTOFF  
**28.0 ± 2 VDC INFLIGHT**
CE600V | BAT1 VOLTAGE | VDC | 28.3 | 28.3 | 28.5 | 28.6 | 28.9 | 28.9 | 28.9 | 28.0 MIN @ LIFTOFF  
**28.0 ± 2 VDC INFLIGHT**
CE609V | BAT2 VOLTAGE | VDC | 29.0 | 28.7 | 28.6 | 28.6 | 28.9 | 29.0 | 30.0 |  
CE610V | BAT3 VOLTAGE | VDC | 28.7 | 28.4 | 27.9 | 29.0 | 28.3 | 29.1 | 29.1 |  

X-17
CURRENT PROFILE (CE1C) WAS CLOSE TO EXPECTED

AMPS
100
90
80
70
60
50
40
30
20
10
0

TIME IN SECONDS FROM SRM IGNITION

SPACECRAFT SEPARATION
MES3
NOMINAL EXPECTED
TC-2 FLIGHT ACTUAL
MAXIMUM EXPECTED
MES4
BOOST PUMP EXPERIMENT

X-18
OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM
TELEMETRY DATA COVERAGE WAS CONTINUOUS
THROUGHOUT THE POST-HELIOS EXPERIMENT PHASE

TANANARIVE
CARNARVON
ORRORAL VALLEY
GUAM
HAWAII

SELECT HI GAIN ANTENNAS
TELEMETRY SIGNAL STRENGTH INCREASED APPROXIMATELY 25 DB

TIME IN SECONDS FROM SRM IGNITION

S/C SEP.
MES3
Meco3
MES4
Meco4
UNLOCK VENT VALVES

PREDICTED
ACTUAL
REPORTED

X-20
INSTRUMENTATION SYSTEM

TOTAL MEASUREMENTS INSTRUMENTED 569

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCM</td>
<td>523</td>
</tr>
<tr>
<td>FM/FM</td>
<td>23</td>
</tr>
<tr>
<td>24 BIT DCU WORDS</td>
<td>23</td>
</tr>
</tbody>
</table>

99.5% DATA RECOVERY WAS ADEQUATE FOR EVALUATION OF ALL POST-HELIOS EXPERIMENT PHASE OBJECTIVES.
## C-BAND BEACON RADAR TRACKING SYSTEM

<table>
<thead>
<tr>
<th>STATION/RADAR</th>
<th>ACQUISITION OF SIGNAL (SEC)</th>
<th>LOSS OF SIGNAL (SEC)</th>
<th>MODE*</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAP CANAVERAL/1.16</td>
<td>0</td>
<td>375</td>
<td>AB</td>
<td>The beacon was tracked continuously by one or more radar stations until</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>loss-of–signal (LOS) at Antigua (762 seconds).</td>
</tr>
<tr>
<td>MERRITT ISLAND/19.18</td>
<td>10</td>
<td>492</td>
<td>AB</td>
<td>Following Antigua LOS, no tracking of the Centaur beacon was planned</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>until acquisition-of–signal (AOS) by the Hawaii radar (5,333 seconds).</td>
</tr>
<tr>
<td>GRAND BAHAMA ISLAND/3.13</td>
<td>69</td>
<td>86</td>
<td>AB</td>
<td>The preflight RF link analysis had indicated that tracking by the Hawaii</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>270</td>
<td>OAPFB</td>
<td>radar and subsequently by the Canton Island radar would be marginal due</td>
</tr>
<tr>
<td></td>
<td>270</td>
<td>272</td>
<td>OAPFS</td>
<td>to the extreme slant range. The Hawaii station did report tracking the</td>
</tr>
<tr>
<td></td>
<td>272</td>
<td>299</td>
<td>AS</td>
<td>beacon but experienced difficulties and significant loss of data.</td>
</tr>
<tr>
<td></td>
<td>299</td>
<td>311</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>311</td>
<td>316</td>
<td>OAPFB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>343</td>
<td>365</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>368</td>
<td>513</td>
<td>OAPFB</td>
<td></td>
</tr>
<tr>
<td>GRAND TURK/7.18†</td>
<td>259</td>
<td>350</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td>ANTIGUA/91.18</td>
<td>407</td>
<td>762</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td>HAWAII/FPS–16</td>
<td>5,333</td>
<td>10,786</td>
<td>AB</td>
<td>The Canton Island station reported receiving no valid tracking data as</td>
</tr>
<tr>
<td>CANTON ISLAND</td>
<td>6,240</td>
<td>6,400</td>
<td>AB</td>
<td>the wrong range interval was being used.</td>
</tr>
<tr>
<td></td>
<td>7,567</td>
<td>7,800</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8,220</td>
<td>8,400</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8,576</td>
<td>8,636</td>
<td>AB</td>
<td></td>
</tr>
</tbody>
</table>

*MODE OF TRACK:  
AB – AUTOBEACON  
AS – AUTOSKIN  
OAPFB – ON-AXIS POWERED FLIGHT BEACON  
OAPFS – ON-AXIS POWER FLIGHT SKIN

†SWITCHED TO TE-M-364–4 BEACON AT 350 SECONDS.

‡INTERMITTENT TRACK DURING THIS PERIOD.
OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM
PNEUMATIC SYSTEM

- PROPER $\text{H}_2\text{O}_2$ BOTTLE PRESSURES PROVIDED THROUGHOUT FLIGHT.

- TANK PRESSURES MAINTAINED WITHIN EXPECTED LIMITS DURING ALL PRESSURIZATION AND VENT PHASES.

- ENGINE CONTROL PRESSURE WAS MAINTAINED WITHIN PROPER LIMITS THROUGH THE FINAL BURN.

- STARTING 480 SECONDS AFTER MECO4 THE ENGINE CONTROL PRESSURE EXHIBITED ABNORMAL FLUCTUATIONS.
ENGINE CONTROLS REGULATOR ANOMALY

ANOMALY

Regulator output pressure increased from 468 psi to 522 psi. Regulator operating limits are 440 to 475 psi.

MOST LIKELY CAUSE

Small contaminant (25µ thick) trapped between a ball and its seat within the regulator, preventing the ball from seating properly, thus increasing helium flow.

DISCUSSION

Regulator inlet pressure of 628 psi insufficient to crush contaminant. Inlet spec. is 700 to 3360 psi. The consequences of a repeat on a future flight are considered negligible.