This appendix contains the basic timeline data that was used to reconstruct the final minutes of Columbia’s re-entry on February 1, 2003. The version in this appendix contains all of the timeline events, but in condensed form.

The timeline organized the re-entry data. As such, this appendix contains no conclusions or recommendations. A visual presentation of the timeline has also been included on the CD that contains this appendix. It shows the timeline laid over a map of the United States along the ground track that Columbia flew during the re-entry.
APPENDIX D.9

Data Review and Timeline Reconstruction Report

Don L. McCormack, Jr., NASA Team Leader, David W. Camp, Boeing Co-Team Leader, and Joyce Seriale-Grush, NASA Co-Team Leader

This information is being distributed to aid in the investigation of the Columbia mishap and should only be distributed to personnel who are actively involved in this investigation.
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### Appendices

- Appendix A STS-107 Timelines
  - A.1 Summary Entry Timeline
  - A.2 Master Entry Timeline
- Appendix B STS-107 Master Entry Timeline Supporting Data
- Appendix C Graphical Version of the STS-107 Entry Timeline
- Appendix D Subsystem Data Review Summary Report
- Appendix E Measurement Data for Timeline Events
- Appendix F List of Contributors

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The timeline also included nominal Orbiter events, a time reference from entry interface (EI) and ground-track locations so that the off-nominal events could be more easily placed into the proper time and space reference. The timeline also included orbital events from the entry interface (EI) and ground-track locations so that the off-nominal events could be more easily placed into the proper time and space reference.

The primary purpose of the Data Review and Timeline Reconstruction Team was to identify off-nominal performance from a review of the available flight data, document the timeline events and make the timeline available to the pertinent Technical Integration Team sub-teams. Detailed analysis to determine the cause of the event was then performed by the pertinent sub-teams.

The scope of the data review included all available real-time telemetry from Columbia and all recorded data from the Orbiter experiments (OEX) recorder. Available data from all mission phases – ascent, on-orbit, and entry – were reviewed for the discovery of timeline events. The vast majority of the off-nominal events were discovered in the review of entry data and subsequently the entry timeline is the principle product. The few off-nominal events discovered during the ascent data review were delivered to personnel in the Space Shuttle Program (SSP) Systems Integration group who were responsible for ascent timeline reconstruction.

The primary timeline that groups events and shows only the more significant events to organizations, and the JSC Astronaut Office.

The Data Review and Timeline Reconstruction Team consisted of a core group that were responsible for the generation of the timeline and conducting the data reviews. The data reviews were performed by various Orbiter subsystem managers (SSMs) and/or subsystem engineers (SSEs). The data review and the reconstruction of the timeline began the first hours following the Columbia accident. The team's purpose was to review the available telemetry and recorded data from the Orbiter experiments (OEX) recorder in the Mission Evaluation Room (MER). From these reviews the initial versions of the entry timeline were developed. More formal data reviews were subsequently conducted at the Boeing Houston facility. These reviews were supported by personnel from Boeing Technical Management and Systems (Boeing), the Johnson Space Center (JSC) Engineering Directorate, the JSC Mission Operations Directorate (MOD), and JSC contractor Safety, Reliability and Quality Assurance (SRQA) organizations, and the JSC Astronaut Office.

The timeline is documented in the Appendices. In Appendix A.1 is a summary entry timeline that groups events and shows only the more significant events. This timeline was used to develop the main entry timeline that shows all of the entry events. Appendix B provides supporting data for the entry timeline. Appendix C documents a graphical version of the entry timeline that is based on the summary entry timeline. The results of the subsystem data reviews are documented in Appendix D. Appendix E provides measurement data (description, source, size, location, range, sample rate) for each of the measurements associated with events on the timeline. Finally, Appendix F lists the names of many of the people who contributed in some way to this effort.

Utilizing the results of thorough reviews of all available flight data, as well as the review of videos of Columbia’s entry and the results of the aerodynamic reconstruction, the Data Review and Timeline Reconstruction Team developed a thorough STS-107 entry timeline. This timeline provided a basis for the investigation and as such proved to be a valuable tool in the investigation of the Columbia accident.
time telemetry data. Initially, a separate entry timeline was developed from the OEX data. As with the timeline developed with the real-time telemetry data, the early revisions of this timeline were considered preliminary as the events on the timeline matured through the process of more thorough and complete data reviews. Revision 17 of the entry timeline subsequently merged revision 16 of the entry timeline with the entry timeline developed from the OEX data. Revision 17 of the entry timeline was baselined at the OVE WG on May 7, 2003. In the weeks leading up to the release of this final report, minor changes were made to the entry timeline. These changes were primarily editorial in nature but did include changes to dates and associated times just prior to breakup of the vehicle. Therefore the version of the timeline documented in Appendix A of this report is revision 19 of the entry timeline.

Throughout the process, a graphical version of the timeline was developed and maintained. Additionally, each revision of the timeline was distributed to each of the Technical Integration Team sub-teams and other organizations involved in the Columbia investigation. The Vehicle Data Mapping Team developed several products to more graphically illustrate the events during entry. The timeline was also used by the Scenario and Fact Database Teams and was used for the development of integrated ground track/timeline charts generated by organizations in JSC Engineering and MOD.

5.0 RESULTS

The Data Review and Timeline Reconstruction Team conducted data reviews of all available data from all phases of the STS-107 mission. From the results of these reviews and inputs from the Image Analysis and the Integrated Entry Environments teams, an entry timeline was developed.

Revision 19 of the entry timeline is documented in the Appendices. In Appendix A, a summary version of the entry timeline that groups events and shows only the more significant events to present the timeline in a more manageable form. In Appendix A.2 is the master entry timeline that shows all of the entry events. A great amount of data was compiled and reviewed in support of this effort. Although all of that data is not documented here, Appendix B provides a brief verbal description and supporting data for each of the events on the entry timeline.

Appendix C documents a graphical version of the entry timeline that is based on the summary entry timeline. Note that other graphical versions were developed by other teams/organizations. The Vehicle Data Mapping Team developed both 2D and 3D products to visually show the events and organizations in JSC/Engineering and MOD integrated the entry timeline into ground back map.

The results of the subsystem data reviews are documented in Appendix D. The reports summarize the results of the data reviews conducted by each of the subsystem teams. The reports cover all mission phases and indicate that although there was evidence of the impending catastrophic failure in the data, all of Columbia’s active systems were performing nominally until the final minute prior to breakup. Appendix E provides measurement data (description, source, type, location, range, sample rate) for each of the measurements associated with events on the timeline.

Finally, Appendix F lists the names of many of the people who contributed in some way to this effort.

6.0 CONCLUSIONS

Utilizing the results of thorough reviews of all available flight data, as well as the review of videos of Columbia’s entry and the results of the aerodynamic reconstruction, the Data Review and Timeline Reconstruction Team developed a thorough STS-107 entry timeline. This timeline provided a basis for the investigation and as such proved to be a valuable tool in the investigation of the Columbia accident.
October 2003

Note: Rev 19 BASELINE updates Rev 18 with the eastern most debris events (over Texas) and is the timeline used for the Final Report.

EI

Sum GMT

data

No. GMT Day 32

6.4  13:44:09 EI+0 EI Entry Interface (400,000 ft) Mach 24.57

10.6  13:53:03 EI+534 X Left Outboard Elevon Wide Band Accelerometers - onset of signal saturation

11.2  13:53:26 EI+557 Approx Veh Grd Location: 38.7 N / -123.5 W

11.21  13:53:29 X Left Wing Front Spar at RCC Panel 9 - initiation of off-nominal trend in strain (small increase) followed by a more significant off-nominal signature to failure at EI+495

11.24  13:53:29 X Left Fuselage Side Surface Temp BP3605T - start of off-nominal increasing trend

6.45  13:49:49 X 4 Left OMS Pod Surface temps - Start of off-nominal temperature trend - cooler rise rate when compared to previous flights of same inclination

11.24  13:53:29 EI+560 X Left Fuselage Side Surface TC BP3604T - Start of slightly off-nominal erratic trend

11.25  13:53:31 EI+1120 X Left OMS Pod Surface 2X - Start of erratic trend

11.27  13:53:40 EI+1210 X Left OMS Pod Surface 2X - Start of erratic trend

7.4  13:52:16 EI+489 X Left Wing Spar Cap Lwr L103 (Xo 1040 Spar - Lower Cap) - off-nominal increase in strain indication followed by gradual decrease over approx 330 seconds interval until measurement failure at ~EI+935

8.75  13:52:18 EI+495 X Left Wing Front Spar at RCC Panel 9 - strain gage goes erratic for approximately 20 seconds

9  13:52:25 EI+500 X Left Outboard Elevon Wide Band Accelerometers - off-nominal vibration response

13.1  13:53:50 EI+730 X Left Wing Lower Surface Thermocouple BP2510T begins off-nominal temp increase

13.3  13:53:52 EI+810 X Left Outboard Elevon Wide Band Accelerometers - peak vibration response

13.32  13:54:10 EI+873 X Left Outboard Elevon Wide Band Accelerometers - peak vibration response

7  13:50:19 EI+370 X Left Wing Lower Surface Thermocouple BP2510T begins off-nominal temp increase

The measurement subsequently fails at approximately EI+520 sec

13.4  13:54:37 EI+903 X Left Outboard Elevon Wide Band Accelerometers - peak vibration response

7.75  13:52:18 EI+489 X Left Wing Spar Cap Lwr L103 (Xo 1040 Spar - Lower Cap) - off-nominal increase in strain indication followed by gradual decrease over approx 330 seconds interval until measurement failure at ~EI+935

8.7  13:52:41 EI+496 X Left Outboard Elevon Wide Band Accelerometers - off-nominal vibration response

EI+625, followed by temperature drop and subsequent off-nominal higher-than-expected strain indications observed in these gages

7.8  13:52:25 EI+496 X Left Outboard Elevon Wide Band Accelerometers - off-nominal vibration response

8.75  13:52:18 EI+495 X Left Wing Front Spar at RCC Panel 9 - strain gage goes erratic for approximately 20 seconds

9  13:52:25 EI+502 X Left Outboard Elevon Wide Band Accelerometers - off-nominal vibration response

13  13:54:10 EI+873 X Left Outboard Elevon Wide Band Accelerometers - peak vibration response

15.32  13:54:34 EI+1003 X Left Outboard Elevon Wide Band Accelerometers - post peak vibration response

30 sec) for aileron).
Appendix A1 - STS-107 Mishap Investigation - Summary Time Line

Appendix A2 - STS-107 Mishap Investigation - Master Time Line

Appendix A3 - STS-107 Mishap Investigation - FARS Time Line

Note: Rev. 18 BASELINE updates Rev. 17 with the eastern most debris events (over Texas) and is the timeline used for the Final Report.

No. GMT

27.7 13:39:28.559 EI-280.4 Start of OEX PCM Data Block

10.2 13:29:57.000 EI-5 Entry Interface minus 5 minutes (304 PRO) AEROject DAP  (entry FCS) and Entry Guidance are activated upon transition to Mach 10.0, and the rudder until below Mach 5.0.

9.4 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

8.6 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

7.8 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

7.0 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

6.2 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

5.4 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

4.6 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

3.8 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

3.0 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

2.2 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

1.4 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

0.6 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

0.8 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

-0.2 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-1.0 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-2.2 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

-3.4 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-4.6 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-5.8 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

-7.0 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-8.2 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-9.4 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

-10.6 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-11.8 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-13.0 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

-14.2 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-15.4 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-16.6 13:39:31.000 EI-727 / EI-764 Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret

-17.8 13:39:29.955 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures

-19.0 13:34:14.055 EI-714 / EI-735 Left Lower/Upper Wing Skin Temps - Trending down (2) Indication of potential measurement failures
### Appendix A.2 - STS-107 Mishap Investigation - Master Time Line

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<td>V07T9480A - Fuslg LWR Surf TC BP1602TR V07T9489A - Fuslg Aft Penetration Area TC BP3325T V07T9522A - Fuslg Aft Penetration Area TC BP3325T V07T9636A - Left Wing upper surface TC BP4860T</td>
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Note: Rev 19 BASELINE updates Rev 18 with the eastern most debris events (over Texas) and is the timeline used for the Final Report.
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</tr>
<tr>
<td>32.4</td>
<td></td>
<td></td>
<td></td>
<td>32.6 11.7 X</td>
<td>13:53:48 EI+570 Inertial sideslip angle (Beta) exceeds flight history. The steady state navigation derived sideslip angle is determined from the inertial navigation system and is not assigned to the flight deck.</td>
</tr>
<tr>
<td>32.8</td>
<td></td>
<td></td>
<td></td>
<td>32.10 11.7 X</td>
<td>13:53:50 EI+572 Right Main Gear Brake Line Temp C - Start of off nominal trend due to higher than expected combustion chamber pressures.</td>
</tr>
<tr>
<td>32.10</td>
<td></td>
<td></td>
<td></td>
<td>32.12 11.7 X</td>
<td>13:53:52 EI+574 Right Main Gear Brake Line Temp C - Start of off nominal trend due to higher than expected combustion chamber pressures.</td>
</tr>
</tbody>
</table>

Note: Rev 19 BASELINE updates Rev 18 with the eastern most debris events (over Texas) and is the timeline used for the Final Report.

*Note: These measurements were observed off-nominal but it was inconclusive if the measurements were failing at that time.
### Appendix A.2 - STS-107 Mishap Investigation - Master Time Line

#### Integ Time Line Team - REV 19 BASELINE  6/5/2003  1 PM

Note: Rev 19 BASELINE updates Rev 18 with the eastern most debris events (over Texas) and is the timeline used for the Final Report.

<table>
<thead>
<tr>
<th>Seq Number</th>
<th>MSID / ID</th>
<th>GMT</th>
<th>EI</th>
<th>Milestone</th>
<th>Entry Event</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.7</td>
<td>11.5</td>
<td>13:53:54 / 58</td>
<td>EI+585</td>
<td></td>
<td>Debris Shower A. No evidence of RCS jet firings (ref Atlas data and plots).</td>
<td></td>
</tr>
<tr>
<td>32.8</td>
<td>11.5</td>
<td>13:54:00 / 04</td>
<td>EI+591</td>
<td></td>
<td>Debris #4 - Fourth report of debris observed leaving the Orbiter. Seen just aft of Orbiter envelope.</td>
<td></td>
</tr>
<tr>
<td>33.3</td>
<td>13.5</td>
<td>13:54:11 EI+602</td>
<td>Reversal in growth trend of derived roll moment coefficient. Observed moment changed from a negative slope to a positive slope. Derived by analysis.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.02</td>
<td></td>
<td>13:54:20 +/- 10</td>
<td></td>
<td></td>
<td>Debris #9 - Report of debris observed leaving the Orbiter. Seen just aft of Orbiter envelope inside the head of a plasma anomaly. No evidence of RCS jet firings (ref Atlas data and plots).</td>
<td></td>
</tr>
<tr>
<td>33.5</td>
<td>11.3</td>
<td>13:54:14 / 22 EI+605</td>
<td>Unexpected Return link comm drop-out. On upper left aft antennae (TDRS 171/W).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.6</td>
<td>15.3</td>
<td>13:54:22 EI+616</td>
<td>Approx Veh Grd</td>
<td></td>
<td>Debris #13 - Report of debris observed leaving the Orbiter. Event trend deviates from the predicted trim setting at this point in the trajectory, indicating that flight control is reacting to asymmetric aerodynamic conditions that are varying over time. (GMT is approximate (13:54:20 +/- 10 seconds).</td>
<td></td>
</tr>
<tr>
<td>36.5</td>
<td>15.3</td>
<td>13:54:33.3 / 33.9 EI+624.3</td>
<td></td>
<td></td>
<td>Debris #11A - Report of debris observed leaving the Orbiter Seen just aft of Orbiter envelope.</td>
<td></td>
</tr>
<tr>
<td>36.8</td>
<td>15.34 X 13:54:39 ~EI+630</td>
<td>Left Wing X1040 Spar Web - shows increase in strain. Note: Adjacent sensor V12G9165A did not sensor and seq 54.1 for next event of this sensor.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36.6</td>
<td>15.3</td>
<td>13:54:35 / 37 EI+626</td>
<td></td>
<td></td>
<td>Debris #6 - Very bright debris seen leaving the Orbiter Seen just aft of Orbiter envelope. Also, Unusually high temp rise with respect to STS-87 &amp; 109. Went to 2.9 F/min from 0 F/min.</td>
<td></td>
</tr>
<tr>
<td>37.5</td>
<td></td>
<td>13:54:53 EI+644</td>
<td>MLG LH Outbd Wheel Temp - start of off nominal trend 2 bit flips up (ref #56.5 when temp starts to trend down)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.8</td>
<td>13:55:12 EI+663</td>
<td>Sys 3 LMG Brake Sw Vlv Ret Line Temp (FWD) - start of off nominal trend</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.9</td>
<td>13:55:17 EI+670</td>
<td>Debris #7 - Seventh report of debris observed leaving the Orbiter Seen just aft of Orbiter envelope.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.8</td>
<td>13:55:22 EI+684</td>
<td>Unusual Temp Rise (Rise rate higher than STS-109 &amp; 87). Rise rate increased from 2.7 F/min (typical) to 5.4 F/min.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.5</td>
<td></td>
<td>13:55:55 EI+706</td>
<td>Approx Veh Grd</td>
<td></td>
<td>Debris #14A - Event 6 and 14 are visually the biggest, brightest events and therefore may indicate the most significant changes to the Orbiter of the western debris events. No evidence of RCS jet firings (ref Atlas data and plots).</td>
<td></td>
</tr>
<tr>
<td>42.75</td>
<td></td>
<td>13:55:56 EI+707</td>
<td>Approx Veh Grd</td>
<td></td>
<td>Debris #14B</td>
<td></td>
</tr>
<tr>
<td>42.8</td>
<td></td>
<td>13:55:57 EI+708</td>
<td>Approx Veh Grd</td>
<td></td>
<td>Debris #14C</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix A.2 - STS-107 Mishap Investigation - Master Time Line

#### Seq Sum OEX GMT EI Milestone Entry Event Remarks

<table>
<thead>
<tr>
<th>Seq No</th>
<th>Data</th>
<th>GMT</th>
<th>EI</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53.5</td>
<td>16.8</td>
<td>--</td>
<td>13:57:53.5 / 55.5</td>
<td>EI+824.5 / EI+826.5 (Occurred over eastern AZ and NM.)</td>
</tr>
<tr>
<td>54.2</td>
<td>15.45</td>
<td>--</td>
<td>13:56:08 / 12</td>
<td>EI+719 / EI+720 (Temp rise rate change from 1.5 F/min to 8.8 F/min (stayed at this rate to LOS))</td>
</tr>
<tr>
<td>55.2</td>
<td>16.5</td>
<td></td>
<td>13:56:53</td>
<td>EI+764 Sys 3 Left Main Gear Strut Actuator Temp - Temp rise rate change Temp rise rate change from 1.7 F/min to 12.9 F/min (stayed at this rate to LOS)</td>
</tr>
<tr>
<td>58.7</td>
<td>--</td>
<td>13:58:32 / 59:22</td>
<td>EI+863 / EI+864</td>
<td>MLG LH Inbd Tire Pressure 1 - pressure trending down (to OSL) Trending to OSL following 7 sec LOS</td>
</tr>
<tr>
<td>62</td>
<td></td>
<td></td>
<td>13:58:39</td>
<td>MLG LH Outbd Wheel Temp - OSL</td>
</tr>
<tr>
<td>63.5</td>
<td>25.5</td>
<td>13:58:40</td>
<td>EI+871</td>
<td>BFS Fault Msg (4) - Tire Pressures - First Message 32/13:58:39.94 - SM0 Tire P LOB</td>
</tr>
<tr>
<td>65.5</td>
<td>23</td>
<td>13:58:43</td>
<td>EI+874</td>
<td>MLG LH Inbd Tire Pressure 2 - start of pressure trending down</td>
</tr>
<tr>
<td>66</td>
<td>25</td>
<td>13:58:48</td>
<td>EI+879</td>
<td>MLG LH Inbd Wheel Temp - OSL</td>
</tr>
<tr>
<td>51</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>17</td>
<td>13:57:43</td>
<td>EI+814</td>
<td>Left Upper Wing Skin Temp - OSL</td>
</tr>
<tr>
<td>70.3</td>
<td>27.5</td>
<td>13:59:23</td>
<td>EI+914</td>
<td>Loss of MCC real-time data to the workstations in the FCR and the MCC in the CNR</td>
</tr>
<tr>
<td>70.5</td>
<td>--</td>
<td>13:59:22</td>
<td>EI+913</td>
<td>Sys 2 LH Brake Switching Vlv Return Temp (AFT) - start of sharp increase in off nominal trend</td>
</tr>
</tbody>
</table>
| 70.7   | 27.7 | 13:59:26 / 59:28 | EI+917 / EI+919 | Abrupt increase in off-nominal aero increments. Abrupt increase in rate of change of pitching moment and lift. }

---

### Notes:

- **Seq No**: Sequential number of the event.
- **Data**: Data associated with the event.
- **GMT**: Greenwich Mean Time.
- **EI**: Event Identifier.
- **Remarks**: Additional information or remarks about the event.

---

**COLUMBIA REPORT VOLUME II**

**OCTOBER 2003**

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**Appendix A.2 - STS-107 Mishap Investigation - Master Time Line**

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**COLUMBIA ACCIDENT INVESTIGATION BOARD**

**RECORD VOLUME II - OCTOBER 2003**

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**COLUMBIA REPORT VOLUME II**

**OCTOBER 2003**

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**Appendix A.2 - STS-107 Mishap Investigation - Master Time Line**
**Seq Sum OEX GMT EI Milestone Entry Event Remarks**

<table>
<thead>
<tr>
<th>No.</th>
<th>No. Data</th>
<th>GMT</th>
<th>Day</th>
<th>32 secs</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>--</td>
<td>13:59:36</td>
<td>EI+927</td>
<td>Growth in Bank attitude error Up until this time the flight control had been able to maintain the Bank error around 5°. The increasing aerodynamic moments on the vehicle would change sign. Aerodynamic forces due to sideslip are now reinforcing aerodynamic asymmetry.</td>
</tr>
<tr>
<td>93</td>
<td>--</td>
<td>13:59:37.3</td>
<td>EI+928.3</td>
<td>Aerojet DAP Requests Fourth Right Yaw RCS Jet (R1R) This additional jet is required to counteract excitation via a wiring short condition. The RCS jet fired, as expected and stayed on to end of first 5-sec period of reconstructed data at 032/13:59:37.4 GMT.</td>
</tr>
<tr>
<td>73</td>
<td>--</td>
<td>13:59:31.7</td>
<td>EI+922.7</td>
<td>Speedbrake channel 4 OI position measurement indicated 73.3° 29.3° -- with approx -2.5 deg of aileron trim. The rate of change of aileron trim had reached 74.3 29.3° -- -- 13:59:32 EI+923</td>
</tr>
<tr>
<td>95</td>
<td>--</td>
<td>13:59:37.396</td>
<td>EI+928.396</td>
<td>End of 5 second period of reconstructed data</td>
</tr>
<tr>
<td>96</td>
<td>--</td>
<td>13:59:39</td>
<td>EI+930</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>--</td>
<td>13:59:34.561</td>
<td>EI+925.561</td>
<td>Speedbrake force fight begins (continues to LOS) Indicates opening of all bypass valves (due to RPC B trip removing power) on ASA 4. Since the speedbrake is at zero but is being commanded to &quot;over-close&quot; position (-10) this results in a force fight between channels 1, 2, 3 and channel 4.</td>
</tr>
<tr>
<td>99</td>
<td>--</td>
<td>14:00:01.900</td>
<td>EI+952.900</td>
<td>BFS Fault Message annunciation - L RCS LEAK Data located in BFS fault message buffer.</td>
</tr>
<tr>
<td>100</td>
<td>--</td>
<td>14:00:01.900</td>
<td>EI+952.900</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>--</td>
<td>13:59:36</td>
<td>EI+923</td>
<td>Flight Data传输开始 receiving data from Earth Station; it is the first valid data after the 22 second gap of no data available. The aerodynamic moments on the vehicle would change sign. Aerodynamic forces due to sideslip are now reinforcing aerodynamic asymmetry.</td>
</tr>
<tr>
<td>89</td>
<td>--</td>
<td>13:59:34</td>
<td>EI+925</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>--</td>
<td>14:00:01.900</td>
<td>EI+952.900</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>--</td>
<td>13:59:34</td>
<td>EI+925</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>--</td>
<td>14:00:01.900</td>
<td>EI+952.900</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix A.2 - STS-107 Mishap Investigation - Master Time Line

<table>
<thead>
<tr>
<th>Seq</th>
<th>No.</th>
<th>Data</th>
<th>GMT</th>
<th>Day</th>
<th>32 secs</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>43</td>
<td>--</td>
<td>14:00:02.654</td>
<td>EI+953.654</td>
<td>PASS Fault Message annunciation - L RCS LJET Data is potentially error prone. Data located in PASS fault message. Generated when a</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>44</td>
<td>--</td>
<td>14:00:02.660</td>
<td>EI+953.660</td>
<td>Beginning of 2 second period of post-LOS data. GMT derived by MER data personnel.</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>45</td>
<td>--</td>
<td>14:00:03.470*</td>
<td>EI+954.470*</td>
<td>BFS Fault Message annunciation - L OMS TK P Data located in BFS fault message buffer</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>45</td>
<td>--</td>
<td>14:00:0n.nnn*</td>
<td>EI+954.637</td>
<td>PASS Fault Message annunciation - L RCS PVT Data is potentially error prone. Data located in BFS fault message buffer</td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>45</td>
<td>--</td>
<td>14:00:03.637</td>
<td>EI+954.637</td>
<td>PASS Fault Message annunciation - L RCS PVT Data is potentially error prone. Data located in BFS fault message buffer</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>46</td>
<td>--</td>
<td>14:00:05.988</td>
<td>EI+963.988</td>
<td>OEX PCM loss of sync: APU s were running and WSB cooling was evident (although potentially overcooling). MPS integrity was still</td>
<td></td>
</tr>
<tr>
<td>107</td>
<td>46</td>
<td>--</td>
<td>14:00:06.988</td>
<td>EI+963.988</td>
<td>OEX PCM loss of sync: APU s were running and WSB cooling was evident (although potentially overcooling). MPS integrity was still</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>47</td>
<td>X</td>
<td>14:00:13.439</td>
<td>EI+964.439</td>
<td>OEX PCM loss of sync: APU s were running and WSB cooling was evident (although potentially overcooling). MPS integrity was still</td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>47</td>
<td>X</td>
<td>14:00:13.439</td>
<td>EI+964.439</td>
<td>OEX PCM loss of sync: APU s were running and WSB cooling was evident (although potentially overcooling). MPS integrity was still</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>48</td>
<td>X</td>
<td>14:00:19.44</td>
<td>EI+970.44</td>
<td>FDM1 A end of data deleted Rationale for deletion: moved to 99.5 after further review of the videos</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>48</td>
<td>X</td>
<td>14:00:19.44</td>
<td>EI+970.44</td>
<td>FDM1 A end of data deleted Rationale for deletion: moved to 99.5 after further review of the videos</td>
<td></td>
</tr>
</tbody>
</table>

---

### Appendix C - STS-107 Summary Entry Timeline

<table>
<thead>
<tr>
<th>GMT</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:44</td>
<td>Catastrophic Event of an unknown nature (formally referred to as “Main Body Breakup) consisting of a sudden brightening of the Orbiter envelope followed by a definitive change in the character of the trail</td>
</tr>
<tr>
<td>45:39</td>
<td>Experience off-nominal early temperature trends (warmer temperature rise rate compared to previous flights of OV-102 at the same inclination)</td>
</tr>
<tr>
<td>46:39</td>
<td>Left Wing Front Spar at RCC Panel 9 - initiation of off-nominal trend in strain (small increase) compared to previous flights of OV-102 at the same inclination)</td>
</tr>
<tr>
<td>48:59</td>
<td>Left OMS Pod Surface temperatures start an off-nominal temperature trend - cooler rise rate when compared to previous flights of OV-102 at the same inclination)</td>
</tr>
</tbody>
</table>

---

**Note:** Rev 19 BASELINE updates Rev 18 with the eastern most debris events (over Texas) and is the timeline used for the Final Report.
D.30 AIR DATA TRANSDUCER ASSEMBLY HARDWARE PERFORMANCE EVALUATION

32-second (LOS+32) period of reconstructed data, showed nothing off nominal. Data during entry through the initial Orbiter loss of signal (LOS), prior to the systems having lost all hydraulic main-pump pressure.

During entry, all APU parameters were nominal at loss-of-data. Analysis of the 32-second period of reconstructed data were comprised of an initial 5-second period, followed by a 25-second period of no data, concluding with a final 2-second period of data. The 5-second and 2-second data periods contained many data hits, which required extensive evaluation to extract valid data.

The APU subsystem performed nominally during all phases on-orbit and ascent phases.

APU subsystem performance was nominal during the pre-launch/ascent phase. APU 1 operated satisfactorily during the flight control subsystem (FCS) checkout.

Specifically with regard to the last 2 seconds of the reconstructed data, the APU 1 RPM signature was somewhat different than normal, and warranted special review, including consultation with the vendor, Hamilton Sundstrand Corp. (HSC). The portion of the cycle obtained is only the ramp-down, or turbine wheel spin-down. It was different from other cycles in that it started at a higher speed (112.9-percent) and ramped down slower (105.5-percent at end of data and still decreasing).

From an operational viewpoint, the APU is speed-controlled by a digital controller operating an on-off valve that sends pulses of fuel to the APU at a frequency of approximately once per second. The actuation of an elevator or any other increase in hydraulic load will cause the valve-pulsing frequency as well as the valve-on time to increase because of the increased hydraulic load. The controller set points for normal-speed operation are 102-104 percent, which results in a
Appendix D

Subsystem Data Review Summary Report

D.3.0 Hydraulics/Water Spray Boiler Subsystem Performance Evaluation

D.3.1 Executive Summary

The hydraulics/water spray boiler (HYD/WSB) subsystem performed nominally during all phases of the mission. However, evidence of the event that led to the loss of the Orbiter was apparent in hydraulic subsystem parameters during the entry. Initially, this evidence was the loss of data from four left-hand elevon return-line temperature sensors and the anomalous temperature rise of eight temperature sensors in the left-hand wheel well. Finally, this evidence included the indication that the hydraulic subsystem had been breached and all three systems were lost.

All HYD/WSB subsystem parameters were functioning normally and all subsystem parameters were within nominal range up until vehicle LOS. The HYD/WSB MER personnel were aware of the off-scale low (OSL) indication on the four left-hand elevon return line temperature sensors when the OSL indication occurred in flight. Post-flight analysis indicated that a total of 12 hydraulic subsystem thermal sensors had anomalous indications. These sensors included the four left-hand elevon return-line temperature sensors that went OSL, and eight temperature sensors in the left-hand wheel well that indicated off-normal increases in temperature. The off-normal responses indicated by the 12 hydraulic subsystem temperature sensors is not indicative of any anomaly in the HYD/WSB subsystem operation but are an indication of an entry thermal event that led to the loss of the Orbiter.

The post-LOS reconstructed data covered a time period of 32 seconds and consisted of 5 seconds of data followed by a gap of 25 seconds followed by a final 2 seconds of data. Although both the 5 - and 2-second data strings provided additional insight, both segments are characterized by, in some cases, multiple data hits. The final 2 seconds of data indicated that sometime in the previous 25-second gap, the hydraulic subsystem was apparently breached. The final 2 seconds of data indicated hydraulic subsystem main pump (system) pressure at 0 psig on all three systems. The hydraulic reservoir pressures likewise indicated 0 psig and indicated reservoir quantities of 0 percent.

D.3.2 Pre-launch/Ascent Performance

The hydraulics/water spray boiler (HYD/WSB) subsystem performed nominally during the pre-launch and ascent phases of the mission.

Appendix D

Subsystem Data Review Summary Report

D.1 Executive Summary

The hydraulics/water spray boiler (HYD/WSB) subsystem performed nominally during all phases of the mission. However, evidence of the event that led to the loss of the Orbiter was apparent in hydraulic subsystem parameters during the entry. Initially, this evidence was the loss of data from four left-hand elevon return-line temperature sensors and the anomalous temperature rise of eight temperature sensors in the left-hand wheel well. Finally, this evidence included the indication that the hydraulic subsystem had been breached and all three systems were lost.

All HYD/WSB subsystem parameters were functioning normally and all subsystem parameters were within nominal range up until vehicle LOS. The HYD/WSB MER personnel were aware of the off-scale low (OSL) indication on the four left-hand elevon return line temperature sensors when the OSL indication occurred in flight. Post-flight analysis indicated that a total of 12 hydraulic subsystem thermal sensors had anomalous indications. These sensors included the four left-hand elevon return-line temperature sensors that went OSL, and eight temperature sensors in the left-hand wheel well that indicated off-normal increases in temperature. The off-normal responses indicated by the 12 hydraulic subsystem temperature sensors is not indicative of any anomaly in the HYD/WSB subsystem operation but are an indication of an entry thermal event that led to the loss of the Orbiter.

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D.3.2 Pre-launch/Ascent Performance

The hydraulics/water spray boiler (HYD/WSB) subsystem performed nominally during the pre-launch and ascent phases of the mission.

Appendix D

Subsystem Data Review Summary Report

D.1 Executive Summary

The hydraulics/water spray boiler (HYD/WSB) subsystem performed nominally during all phases of the mission. However, evidence of the event that led to the loss of the Orbiter was apparent in hydraulic subsystem parameters during the entry. Initially, this evidence was the loss of data from four left-hand elevon return-line temperature sensors and the anomalous temperature rise of eight temperature sensors in the left-hand wheel well. Finally, this evidence included the indication that the hydraulic subsystem had been breached and all three systems were lost.

All HYD/WSB subsystem parameters were functioning normally and all subsystem parameters were within nominal range up until vehicle LOS. The HYD/WSB MER personnel were aware of the off-scale low (OSL) indication on the four left-hand elevon return line temperature sensors when the OSL indication occurred in flight. Post-flight analysis indicated that a total of 12 hydraulic subsystem thermal sensors had anomalous indications. These sensors included the four left-hand elevon return-line temperature sensors that went OSL, and eight temperature sensors in the left-hand wheel well that indicated off-normal increases in temperature. The off-normal responses indicated by the 12 hydraulic subsystem temperature sensors is not indicative of any anomaly in the HYD/WSB subsystem operation but are an indication of an entry thermal event that led to the loss of the Orbiter.

The post-LOS reconstructed data covered a time period of 32 seconds and consisted of 5 seconds of data followed by a gap of 25 seconds followed by a final 2 seconds of data. Although both the 5 - and 2-second data strings provided additional insight, both segments are characterized by, in some cases, multiple data hits. The final 2 seconds of data indicated that sometime in the previous 25-second gap, the hydraulic subsystem was apparently breached. The final 2 seconds of data indicated hydraulic subsystem main pump (system) pressure at 0 psig on all three systems. The hydraulic reservoir pressures likewise indicated 0 psig and indicated reservoir quantities of 0 percent.

D.3.2 Pre-launch/Ascent Performance

The hydraulics/water spray boiler (HYD/WSB) subsystem performed nominally during the pre-launch and ascent phases of the mission.
bootstrap accumulator pressures were between 3050 psia and 3200 psia, which
valve return line initiated an anomalous rise in temperature. This was the last of
within nominal ranges (2700 - 3400 psia). All three hydraulic system reservoir
1 minute, 1 second, at 32:13:57:54 G.m.t., the system 2 left-hand brake switch
cases, by multiple data hits. The initial 5 seconds of post-LOS reconstructed data
provided additional insightful data, both segments were characterized, in some
5-second data period, and no data on any of these sensors were indicated in the
Loss-of-signal from the vehicle occurred at 32:13:59:32 G.m.t., at which time all
HYD/WSB parameters were all within nominal ranges and maintained apparent
Although showing evidence of the event leading to the loss of the Orbiter, the
HYD/WSB parameters were all within nominal ranges and maintained apparent
nominal operation up until the final 2 seconds of reconstructed data that indicated
all three hydraulic systems had been lost.

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1. Left MLG system 3 brake return line sensor; and
2. Left MLG brake-line temperature sensors C and B, and the

The final 2 seconds of data indicated that sometimes in the previous 25-second
data gap, the hydraulic subsystems were apparently breached. The final
2 seconds of data indicated hydraulic system main pump (system) pressure at
1 psia on all three systems. The hydraulic system reservoir pressures likewise
indicated 1 psia and indicated reservoir quantities of 0 percent on all three
systems. Each of the three hydraulic system bootstrap accumulators showed a
pressure below 2000 psia on the liquid side of the bellows, indicating that a less-
than nominal pressure was still locked up downstream of each of the system
pressure valves. The nominal bootstrap accumulator reservoir pressure following a
nominal main pump shutdown is not less than 2075 psia and is controlled by the
priority valve system 1 - 1070 psia, system 2 - 1050 psia and system 3 - 1080 psia.
The fact that the three bootstrap accumulator pressures was less than 2075 psia is consistent with the hydraulic system reservoir pressures being at 1 psia and reservoir quantities at 0 percent. The water spray boiler lubrication oil return line temperatures during the 32-second period of
reconstructed data is attributed to reduced APU loads because of breached and
deployed hydraulic systems. The APUs were spinning empty pumps without
a load or pressure sometime during the 25-second period of LOS. The APU spin
data are consistent with White Sands Test Facility test data for a deployed
hydraulic pump. Deployed hydraulic systems and off loading the APUs are
consistent with decreasing APU bearing and lubrication oil outlet temperatures as
well as water spray boiler lubrication oil return temperatures and increasing water
spray boiler hydraulic heat exchanger temperatures. The data indicate that the
water spray boilers did not experience a typical overheat/overload condition.

In summary, typical mission entry data in the timeframe of the observed anomaly indicates MLG wheel well thermal sensors leveling off to trending downward, not
rising as occurred during the STS-107 event. Based on the data analysis, it is
believed that the loss of the four elevon actuator return line thermal sensors to
GSL was due to the destruction of the instrumentation wiring at some point in the
wire routing. Discussions have led to the understanding that the wiring bundle
carrying the left-hand elevon actuator instrumentation wiring is routed from the
actuators to the vehicle left sidewall and around the outboard perimeter of the
left-hand wheel well. The eight hydraulic subsystem sensors that indicated an
anomalous temperature rise are located on hydraulic lines in the left-hand wheel
well aft-portion inboard sidewall and on the left MLG strut and actuator. The
maximum temperature change from the initiation of the temperature rise occurred
on the left MLG brake-line temperature sensor A, indicating a rise from

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approximately 124 °F to 172 °F (44 °F change). This was also the highest
temperature recorded in the left-hand wheel well prior to LOS. The minimum
temperature change occurred on the left MLG brake-line temperature D,
indicating a rise from 88 °F to 100 °F (12 °F change). The left MLG strut actuator
temperature indicated a temperature of 76 °F at LOS.

Now showing evidence of the event leading to the loss of the Orbiter, the
HYD/WSB parameters were all within nominal ranges and maintained apparent
nominal operation up until the final 2 seconds of reconstructed data that indicated
all three hydraulic systems had been lost.

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D.4.0 MAIN PROPULSION SYSTEM PERFORMANCE EVALUATION

D.4.1 Executive Summary

The main propulsion subsystem (MPS) performed nominally during all phases of
the mission. During entry, all MPS parameters were nominal until loss of data.

D.4.2 Prelaunch/Ascent Performance

The MPS performed nominally during the pre-launch and ascent phases of the
mission. No MPS anomalies or significant events were noted in the review of the
ascent data.

D.4.3 On-Orbit Performance

The MPS performed nominally during the on-orbit phase of the mission. No MPS
anomalies or significant events were noted during the review of the on-orbit data.

D.4.4 Entry Performance

The MPS performed nominally during the entry phase of the mission. No MPS
anomalies or significant events were noted during the review of the entry data.

MPS helium system decay from reconfiguration until LOS was nominal. Some
of the faults for the helium systems for 55032 and 2 and 3 are located on the left side of
the meldbox. These systems did not indicate any temperature or associated
pressure rise in the systems prior to LOS.

The LHT manifold was vented to vacuum for the duration of the flight prior to
opening the return to launch site (RTL) dump valves, so no pressure decay was
noted upon opening the valves.

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Pre-launch/Ascent Performance

The OMS performed nominally during the pre-launch and ascent phases of the mission. No deviations or significant events related to the OMS were noted during the review of the ascent data.

D.6.2 Pre-launch/Ascent Performance

The OMS performed nominally during the pre-launch and ascent phases of the mission. No deviations or significant events related to the OMS were noted during the review of the ascent data.

D.5.1 Executive Summary

The orbital maneuvering subsystem (OMS) performed nominally during all phases of the mission. During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data.

D.5.3 On-Orbit Performance

The OMS performed nominally during the on-orbit data. No deviations or significant events related to the OMS were noted during the review of the on-orbit data.

D.5.4 Entry Performance

During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data. At that time, there was a significant loss of instrumentation on the left OMS pod.

D.6.3 On-Orbit Performance

The overall performance of the forward RCS and the left and right RCS was nominal, with no exceptions prior to LOS at 32:13:59:32 G.m.t. The left OMS experienced a loss of instrumentation when data came back for approximately 2 seconds before the final LOS at 32:14:00:05 G.m.t.

D.6.4 Entry Performance

During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data. The left OMS pod during the 25-second data gap prior to the final 2-second period of reconstructed data.

The reaction control subsystem (RCS) performed nominally during all phases of the mission. During entry, the RCS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data. At that time, there was a significant loss of instrumentation on the left OMS pod.

D.6.1 Executive Summary

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D.3.0 ORBITAL MANEUVERING SUBSYSTEM PERFORMANCE EVALUATION

D.3.1 Executive Summary

The overall performance of the forward RCS and the left and right RCS was nominal, with no exceptions prior to LOS at 32:13:59:32 G.m.t. The left OMS pod, housed in the left OMS pod, had experienced a significant loss of instrumentation, for some unknown reason, when data came back for approximately 2 seconds before the final LOS at 32:14:00:05 G.m.t.

D.3.2 Pre-launch/Ascent Performance

The overall performance of the forward RCS and the left and right RCS was nominal during entry with no exceptions prior to LOS at 32:13:59:32 G.m.t. The left OMS pod, housed in the left OMS pod, had experienced a significant loss of instrumentation, for some unknown reason, when data came back for approximately 2 seconds before the final LOS at 32:14:00:05 G.m.t.

D.5.2 Pre-launch/Ascent Performance

The OMS performed nominally during the pre-launch and ascent phases of the mission. No deviations or significant events related to the OMS were noted during the review of the ascent data.

D.6.2 Pre-launch/Ascent Performance

The OMS performed nominally during the pre-launch and ascent phases of the mission. No deviations or significant events related to the OMS were noted during the review of the ascent data.

D.6.3 On-Orbit Performance

The overall performance of the forward RCS and the left and right RCS was nominal during entry, with no exceptions prior to LOS at 32:13:59:32 G.m.t. The left OMS pod, housed in the left OMS pod, had experienced a significant loss of instrumentation, for some unknown reason, when data came back for approximately 2 seconds before the final LOS at 32:14:00:05 G.m.t.

D.6.4 Entry Performance

During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data.

D.3.1 Executive Summary

The orbital maneuvering subsystem (OMS) performed nominally during all phases of the mission. During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data. At that time, there was a significant loss of instrumentation on the left OMS pod.

D.5.3 On-Orbit Performance

The OMS performed nominally during the on-orbit data. No deviations or significant events related to the OMS were noted during the review of the on-orbit data.

D.5.4 Entry Performance

During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data. At that time, there was a significant loss of instrumentation on the left OMS pod.

D.6.3 On-Orbit Performance

The overall performance of the forward RCS and the left and right RCS was nominal, with no exceptions prior to LOS at 32:13:59:32 G.m.t. The left OMS pod, housed in the left OMS pod, had experienced a significant loss of instrumentation, for some unknown reason, when data came back for approximately 2 seconds before the final LOS at 32:14:00:05 G.m.t.

D.6.4 Entry Performance

During entry, the OMS performance was nominal and without incident until the final 2 seconds of the 32-second period of reconstructed data.
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broken helium line). Thus, the following two possible scenarios are provided and both are equally valid because of the paucity of data.

1. The first scenario is based on the premise that the left RCS had a leak that resulted in a quantity divergence of greater than 9.5-percent PVT between the fuel and oxidizer and, thus, generated the first message. This leak would be of such magnitude that the resulting propellant tank(s) would not be capable of supporting thrustor firings causing the left thrustor (LT) message. Finally, enough propellant leaked out that the resulting propellant tank pressures fell outside the reasonable limits and the PVT gaging calculation was suspended for the left RCS (the third message, L RCS PVT).

2. The second scenario is based on the premise that there was no leak. Instead, system instrumentation was being lost. In this scenario, some instrumentation loss caused a degradation of the PVT calculation and generated the first message. Then instrumentation for the thrustors themselves was lost and this was reflected in the general purpose computer (GPC) being unable to confirm that the thrustors were firing in response to the reaction jet driver (RJD) output, thus the second message. Enough instrumentation was finally lost that the PVT gaging calculation was suspended for the left RCS, which resulted in the third message.

In response to questions that have been asked on the subject of calculating the amount of RCS propellant used, and therefore, gage the amount of thrustor activity during the 26-second data gap between the final 2-second period of reconstructed data. Inadequate data exists from the left RCS oxidizer system to determine a final quantity. The left RCS fuel has one more measurement than the oxidizer, but that measurement is still not enough to accurately gage the propellant quantity. The gage readings are present just before final LOS (end of 2-second period of reconstructed data) and show the oxidizer and fuel quantities as 17.8 percent PVT and 31.8 percent PVT, respectively. This difference of more than 9.5 percent PVT shows that the left RCS leak message was generated, and the Master Alarm had been triggered. However, inadequate data exist from the telemetry to determine with any degree of certainty the cause the left RCS PVT message.

PASS data from the right RCS during the period from 32:13:59.36 G.m.t. to 32:14:00.01 G.m.t., shows that the fuel cells were operating. The gage response to the reaction jet driver (RJD) outputs; thus the second right RCS message. Enough instrumentation was finally lost that the PVT gaging calculation was suspended for the right RCS, which resulted in the third message.

D.7.1 Executive Summary

The fuel cell powerplant (FCP) subsystem performed nominally during all phases of the mission. During entry, all FCP parameters were nominal until 2 seconds prior to the final loss-of-data. The fuel cell subsystem performance during the period from 32:13:59.36 G.m.t. to 32:14:00.01 G.m.t. were nominal. There are no direct or indirect findings or associations with the problem that caused the loss of the vehicle.

During the last 2 seconds of the 32-second period of reconstructed data, the fuel cell 3 hydrogen/water pump was operating on 2 phases ac current rather than the usual 3 phases. All loads on the fuel cells were increasing, the oxygen purge vent line temperature was experiencing an unexpected rise, and there were conflicting indications that manifold 1 had lost oxygen pressure (possibly instrumentation). No gross system operation anomalies are confirmed in the last 2 seconds of the reconstructed data. The changes of fuel cell parameters appear to be a result of other events that were taking place on the vehicle.

D.7.2 Pre-launch/Ascent Performance

The FCP subsystem performed nominally during the pre-launch and ascent phases of the mission. During powered flight, the electrical load peaked to approximately 23 kW immediately prior to Solid Rocket Booster (SRB) separation. All fuel cell measurements (current, voltage, temperatures, pressure, flow rates, and sub-slab differential voltages) were nominal. The fuel cell water relief and purge system temperatures were nominal. There were nominal heater cycles on the fuel cell alternate water lines.

During vent door opening at approximately T-18 seconds during pre-launch operations, the fuel fell 2 hydrogen (H2) motor status jumped for one data sample approximately 0.1 V from 0.59 to 0.69 V. This change did not violate the Launch Commit Criteria (LCC) limit of 1.0 V. The voltage returned to the normal level on the next data sample one second later. Fuel cell operation continued to be nominal. This indication appears to be associated with the suspected ac bus 2 phase-b anomaly.

D.7.3 On-Orbit Performance

The FCP subsystem performed nominally during the on-orbit phase of the mission.

The voltage change discussed in the previous paragraph was also observed during a seat adjustment as well as during the payload bay door opening. These indications appear to be associated with the suspected ac bus 2 phase-b anomaly.

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D.7.4 Entry Performance

The fuel cell powerplant (FCP) subsystem performed nominally during the entry phase of the mission. During entry, all FCP parameters were nominal until 2 seconds prior to the final loss-of-data. The fuel cell subsystem performance during the period from 32:13:59.36 G.m.t. to 32:14:00.01 G.m.t. were nominal. There are no direct or indirect findings or associations with the problem that caused the loss of the vehicle.

During the last 2 seconds of the 32-second period of reconstructed data, the fuel cell 3 hydrogen/water pump was operating on 2 phase ac current rather than the usual 3 phases. All loads on the fuel cells were increasing, the oxygen purge vent line temperature was experiencing an unexpected rise, and there were conflicting indications that manifold 1 had lost oxygen pressure (possibly instrumentation). No gross system operation anomalies are confirmed in the last 2 seconds of the reconstructed data. The changes of fuel cell parameters appear to be a result of other events that were taking place on the vehicle.

During the last 2 seconds of the 32-second period of reconstructed data, it was unreliable because of data loss with many fuel cell kilowatt outputs missing from the "STS-107" EDIT data. The basic conclusions derived are:

1. Fuel cell 3 hydrogen separator/water pump was operating on 2 phases based upon the pump motor status reading of about 4.5 Vdc.
2. All 3 fuel cells deployed load increases. Fuel cell 1 increased about 120 amps; fuel cell 2 increased about 44 amps; fuel cell 3 increased about 48 amps.
3. Fuel cell 3 and main bus C voltage both experienced a 0.5 Vdc drop during the last portion of the 2-second data before the final LOS.
4. Fuel cell oxygen purge-line temperature rose 84°F from the LOS + 5 second data to the last 2 seconds of data. Only 1 sample of fuel cell telemetry was deemed to be of good quality by the Data Verification Team (DVT).
5. PSID oxygen manifold 1 pressure indicated off-scale low and fuel cell 1 coolant pressure (provides fuel cell indication of oxygen pressure) indicated OSL. No manifold 2 pressure indication was available to verify the readings. No other confirming cues were present to verify the loss of oxygen pressure in the manifold such as the fuel cell 1 oxygen manifold flow meter indicating good reactant flow; no other fuel cell coolant pressure data were available to track pressure; no tank pressure data were available.

Nominal H2 tank heater cycles in tanks 1 and 2 occurred to maintain nominal manifold pressure to support fuel cell operations. The D2 manifold pressure was decaying at a nominal rate to support fuel cell operations and crew breathing. No oxygen tank heater cycles were required during entry up to the end of the 32-second period of reconstructed data, but nominal heater cycles were
During the last 2 seconds of the 32-second period of reconstructed data, the fuel cell product water line temperatures were beginning to decrease in a nominal fashion due to convective cooling caused by entering the atmosphere.

The fuel cell voltage, temperatures, pressure, flow-rates, and substack voltages were nominal.

**D.8.3  On-Orbit Performance**

All of the PRSD system tank pressure cycles that were regulated by internal electrical heater operation were nominal, and were controlled by the heater AUTO function. All of the tank internal fluid and heater assembly temperatures were nominal for the entire on-orbit operation. The EDC pallet was activated throughout the on-orbit operations, and was deactivated during descent preparations.

A hydrogen manifold pressure spike occurred when manifold pressure control was switched to H2 tank 3 after H2 tanks 4 and 5 were depleted. This was a nominal signature seen previously in all orbiters when control is switched from low-quantity tanks to high-quantity tanks with colder, denser fluid. The manifold pressure did not reach the manifold relief valve crack pressure.

The Operations and Maintenance Requirements and Specification Document (OMRSSD) in-flight checkout of the tank heater current sensors was performed. Nominal sensor operation was verified on all of the tank heaters except for O2 manifold 1. The heater sensor for O2 tank 7 was deactivated. An O2 offload was performed to reduce the nominal oxygen pressure (possibly instrumentation). No gross system operation anomaly is confirmable in the last 2 seconds of data. The changes of PRSD parameters appear to be a result of other events that were taking place on the vehicle.

**D.9.4  Entry Performance**

The PRSD subsystem oxygen (O2) and hydrogen (H2) tank sets 1 and 2 heater switches were in nominal ascent configuration. The O2 and H2 tanks 1 and 2 A heaters were in AUTO. All of the seven other tank set heater switches were configured to OFF. All four manifold isolation valves were open. The extended duration Orbiter (EDO) pallet, installed in the all part of the payload bay with four tank sets, was deactivated. An O2 offload was performed to reduce the nominal end-of-mission (EOM) tanking weight. Oxygen tanks 1, 2 and 3 were offloaded by approximately 100 lb each and tanks 4 and 5 were offloaded by approximately 25 lb each for a total O2 offload of approximately 350 lb.

The main buses were unfult for ascent. The main bus B (OMB) to main bus C (OMC) crosstie was performed at 16:16:28 G.m.t. The hydrogen manifold pressures did not reach their tank 1 and 2 control band during the ascent-data evaluated.

All tank internal fluid and heater assembly temperatures were nominal.
D.12.1 Executive Summary

The supply and wastewater management (SWWM) subsystem performed nominally during all phases of the mission. During entry, all SWWM parameters were nominal at loss-of-data.

D.12.2 Pre-launch/Ascent Performance

Review of the SWWM pre-launch/ascent data indicated nominal system performance with no anomalous conditions observed.

D.12.3 On-Orbit Performance

Review of the SWWM on-orbit data indicated nominal system performance with no anomalous conditions observed.

D.12.4 Entry Performance

The SWWM subsystem indicated nominal operation during the entry phase and no anomalous conditions were noted. Flash evaporator water use was observed in the analysis of the data. No SWWM anomalous conditions were noted in the data.

D.13.1 Executive Summary

The airlock subsystem performed nominally during all phases of the mission. During entry, all airlock subsystem parameters were nominal at loss-of-data.

D.13.2 Pre-launch/Ascent Performance

Review of the airlock subsystem pre-launch and ascent data indicated nominal system performance with no anomalous conditions observed.

D.13.3 On-Orbit Performance

Review of the airlock subsystem on-orbit data indicated nominal system performance with no anomalous conditions observed.

D.13.4 Entry Performance

The airlock subsystem performed nominally during the entry phase of the mission. No in-flight anomalies were identified in the data analysis.
D.14.0 SMOKE AND FIRE SUPPRESSION SUBSYSTEM PERFORMANCE EVALUATION

D.14.1 Executive Summary

The smoke and fire suppression subsystem performed nominally during all phases of the mission. During entry, all smoke and fire suppression subsystem parameters were nominal at loss-of-data.

D.15.2 Pre-launch/Ascent Performance

Review of the smoke and fire suppression subsystem pre-launch and ascent data indicated normal system performance with no anomalous conditions observed.

D.15.3 On-Orbit Performance

Review of the smoke and fire suppression subsystem on-orbit data indicated normal system performance with no anomalous conditions observed.

D.16.2 Pre-launch/Ascent Performance

The mechanical subsystem performed nominally during all phases of the mission. During entry, all mechanical subsystem parameters were nominal at loss-of-data.

There were two unexplained occurrences of additional current draw on ac bus 1, but it is not believed that these were in any way related to the loss of the crew and vehicle.

D.16.3 On-Orbit Performance

The overall performance of the mechanical systems was nominal during the on-orbit phase of the mission and no anomalies were noted. The port radiator was deployed and slowed twice, and all involved mechanisms operated in nominal dual-motor time with all limit switches transferring properly.

D.16.4 Entry Performance

The overall performance of the mechanical systems was nominal during the entry phase up to the loss of the vehicle. There were two unexplained occurrences of additional current draw on ac bus 1, but it is not believed that they were in any way related to the loss of the crew and vehicle.

Motor control assembly (MCA) operational status (Op Stat) indications show that the appropriate MCA relays were operating to supply ac power to the motors. During deorbit preparation and entry, all mechanisms operated in nominal dual-motor time with all limit switches and op stats transferring properly.
During vent door closure, a 0.1-second period of additional current draw was
changes occurred in these indications within the 0.7-second time period.
switch and op stat data is only 1 Hz, it is impossible to determine whether any
could not be determined that would explain why one door drive motor would run
without the bulkhead latches running as well. Because the sample rate for limit
switch and op stat data is only 0.1 Hz, it is impossible to determine whether any
occurred on ac bus 1. The amplitude and signature of the trace
upon close of the port door. During this time, there was no significant change in the
typical operating environment for which the primary oxygen valve is used.
were not able to determine how this could have happened.

All data reviewed indicated nominal performance of mechanical systems
hardware from deorbit preparations through entry and LOS+32. The two
unexplained occurrences of additional current draw on ac bus 1 are not believed
in any way related to the loss of the crew and vehicle.

The left MLG down-lock indication transferred on at 32:13:59:05.877 G.m.t. and
remained on throughout. This appeared to be an erroneous output because all
other available data indicated that the gear was up and locked during this time.
Based on redundant sensors and other indications, all observed anomalies
appear to be due to instrumentation failures and not hardware. The following is
a discussion of the instrumentation data of the landing system.

The left-hand inboard (LHIB) 1 and left-hand outboard (LHOB) 1 tire-pressure
measurements went OSL (230 psi). The trend toward OSL started at
32:13:58:14.194 G.m.t. and LHOB 1 went OSL at 32:13:58:34.225 G.m.t. Prior to
this trend, the pressures were at a nominal value of 350 to 355 psi, which is
consistent with the expected pressures adjusted for wheel well environmental
conditions given the post top-off tire pressure and leak rate obtained prior to
launch. Both LHIB and LHOB wheel temperature measurements went OSL (-75 °F).

The right-hand inboard (RHIB) 1 and right-hand outboard (RHOB) 1 tire-pressure
measurements appeared to dip approximately 3 psi and then recover to
a nominal 355 psi. The trend toward OSL started at 32:13:56:35.730 G.m.t. for the LHIB and at
32:13:58:33.201 G.m.t. for the LHOB. The LHIB went OSL at 32:13:58:41.219 G.m.t. and the RHOB went OSL at 32:13:58:39.763 G.m.t. Prior to
this event, the temperatures were at a nominal 35 °F. These data were
consistent with the on-orbit thermal conditioning performed to maintain minimum
nominal end of mission (NEMO) tire pressures.

The right-hand inboard (RHIB) 1 and right-hand outboard (RHOB) 1 tire-pressure
measurements appeared to dip approximately 3 psi and then recover to
a nominal 355 psi. The trend toward OSL started at 32:13:56:35.730 G.m.t. for RHIB 1 and at 32:13:58:33.201 G.m.t. for RHOB 1. This condition lasted for approximately 10 seconds after which the pressure recovered until LOS. Prior to
this event, the pressures were at a nominal value of 350 to 355 psi, which is
consistent with the expected pressures adjusted for wheel well environmental
conditions given the post top-off tire pressure and leak rate obtained prior to
launch. The left MLG down-lock indication transferred on at 32:13:59:05.877 G.m.t. and
trended toward OSL for the next 25 seconds of reconstructed data. All other indications
showed the gear was still up and locked during this time. Testing of the proximity
sensor circuit has shown that it is possible for this indication to fail in this manner
when wires are burned through.

At the beginning of the post-LOS 25-second data gap, the left MLG brake line
pressure and temperature measurement went OSL (278 °F). Although the data has been
determined to contain no errors, this is considered an erroneous measurement
because the brake line B measurement, which is located inside the A associations,
indicated exactly the same value (118.5 °F) as before the gap. In addition, there is no significant change in the C and D measurements, which are
located on the wheel well near the hydraulic switching valves.

The left-hand inboard (LHIB) and left-hand outboard (LHOB) wheel temperature
measurements went OSL prior to LOS. There are no redundant measurements
for wheel temperature. Prior to the failure of the instrumentation, all indications
were in the nominal range for landing.
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D.19.4 Entry Performance

Off-nominal indications were identified in the last 32 seconds of reconstructed data. These are:

1. The 5-seconds of the reconstructed data had numerous data hits throughout the period. Based on the ASA-4 failure times during the 5 seconds of reconstructed data, three signatures were found on the aft main buses that could be a 5-ampere remote power controller (RPC) trip signatures. The RPCs performed as designed.
2. In the 2-second period of reconstructed data, some of the EPDC data were missing, some data were available for only one data sample and some data were in conflict with confirming data. Three conclusions from the data are:
   a. There was a general upward shift in fuel cell and forward main bus amperes and a general downward shift in main bus voltages;
   b. Several confirming parameters indicate that the ac 3 phase A inverter was disconnected from its ac bus, and there was an increasing high voltage and current load on ac 3 phases B and C;
   c. The fuel cell 1 amperes and single data samples indicate the possibility of a high load on ac 1 phase C.

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D.19.0 ELECTRICAL POWER DISTRIBUTION AND CONTROL SUBSYSTEM PERFORMANCE EVALUATION

D.19.1 Executive Summary

The electrical power distribution and control (EPDC) subsystem performed nominally except for the sluggish ac 2 bus phase B current response initially noted post-ascent. During entry, all EPDC subsystem parameters were nominal at loss-of-data.

The ac 2 phase B sluggish current response (STS-107 MER Problem 1) was not present during PLBD closing or during entry, and had no affect on the Orbiter contingency. Prior to the last 2 seconds of reconstructed entry data, no EPDC measurements were lost, and there were no ac or dc bus shorts or losses.

D.19.2 Pre-launch/Ascent Performance

The EPDC subsystem pre-launch and ascent responses were nominal with the exception of the in-flight anomaly discussed in the following paragraph. This in-flight anomaly had no impact on mission accomplishment.

During vent-door opening, PLBD opening and Ku-band antenna deployment, the ac 2 bus phase B current exhibited a sluggish response. The phase B current increased to about one-half of the expected value, then increased to its nominal value within 0.5 to 1.5 seconds. During this time period, the ac 2 bus phases A and C current increased a similar amount. During steady-state periods, there were periodic occurrences of smaller magnitude signals of the same type (phase B dropping, phases A and C increasing). As before, most of these occurrences lasted between 0.5 and 1.5 seconds, and the phase B drop was between 0.2 and 0.3 amperes (between 3 and 4 telemetry counts). Water-loop pump cycling on the ac 2 bus sometimes triggered the described response. The occurrence of this condition was very sporadic and unpredictable. During a couple of 24-hour periods, no occurrences were noted. The cause of this anomaly was believed to be the ac 2 bus phase B inverter or the wiring between the ac 2 phase B inverter and panels 1A and 1AT/GC.

D.19.3 On-Orbit Performance

The EPDC subsystem on-orbit operations were nominal with the exception of the anomaly discussed in the previous section. This in-flight anomaly had no impact on mission accomplishment.

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Appendix D
Subsystem Data Review Summary Report

D.20.0 DATA PROCESSING SYSTEM PERFORMANCE EVALUATION

D.20.1 Executive Summary

The data processing system (DPS) pre-launch, ascent and on-orbit operations were nominal. During entry, all DPS parameters were nominal at loss-of-data.

D.20.2 Pre-launch/Ascent Performance

No unexpected general-purpose computer (GPC) errors occurred during pre-launch or ascent operations. The mass memory unit (MMU) hardware was used successfully during the DPS 1 transition at T-20 minutes on launch day as the program was obtained from MMU 1 area 1 on the tape. Prior to launch, the Kennedy Space Center (KSC) performed a dump and compare of the entire software of GPC 1 with no miscompares identified. The multiple-instrument/multiuser (MIMU) hardware performance was satisfactory as exhibited in the data review conducted after the contingency.

D.20.3 On-Orbit Performance

All DPS hardware performed satisfactorily during the on-orbit operations, and no in-flight anomalies were noted in the analysis of the data.

D.20.4 Entry Performance

The DPS entry operations were nominal. Fault messages were generated and are discussed in the appropriate sections of this appendix.

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D.21.2 Pre-launch/Ascent Performance

At all times, the Solid Rocket Booster (SRB) thrust vector controllers (TVC), MPS TVC, and aerosurface actuators were positioned exactly as the GPC commands were given with normal driver currents, secondary differential pressures, and elevon primary differential pressures. The reaction jet driver (RJD) operation was also normal with no thruster fail indications or other anomalies noted. The rotational hand controller (RHC) and translation hand controller (THC) were both used and exhibited normal channel tracking.

At no time during the ascent of STS-107 did the flight controls fail to accomplish the task of implementing GPC commands. Actuator positions closely tracked GPC commands, and at no time did secondary differential pressures exceed the fault detection mechanism approach the limits that would initiate a failure response.

D.21.3 On-Orbit Performance

The flight control hardware on-orbit performance was nominal. No anomalies were found in the data. The limited aerosurface data available also showed no anomalies. Flight control hardware performance during the on-orbit flight control system checkout was nominal. No anomalies were found in any of the tests or checkout prior to entry.

D.21.4 Entry Performance

The FCS performance during the entry phase was nominal until the final seconds before LOS.

The STS-107 aerosurface actuator performance was nominal until the final second before LOS, when the ASA 4 anomaly began to appear. Aerosurface position indications read zero volts. Also in the same time period (32:13:59:34.318 G.m.t.), as indicated by secondary differential pressure data, the force fight began when the bypass valve on channel 4 reopened (non-bypassed state) and allowed the servo valve to become active.

At 32:13:59:34.536 G.m.t., speedbrake channel 1, 2, and 3 secondary differential pressures indicate a force fight against channel 4. The secondary differential pressure on channel 4 was at null. The isolation valve power RPC was tripped at this point, removing power from the bypass valves on all actuators for channel 4. At 32:13:59:35:07 G.m.t., the actuator fail flag from ASA 4 had turned off.

At approximately 32:14:00:04 G.m.t., prior to final LOS, aerosurface switching valves are indicated to be in their secondary positions, while the valves are expected to be in their primary positions with zero hydraulic pressure in all three hydraulic systems. In the same time period (32:14:00:04 G.m.t.), all aerosurface position indications read zero volts. Also in the same time period, ASA 1, 2 and 3 RPC indications show that they are off while the ASA 1, 2 and 3 power-on commands show on. In the same time period (32:14:00:04 G.m.t.), there are valid hydraulic reservoir temperatures, nutator/speedbrake actuator return line temperatures, right elevon actuator temperatures, body flap temperatures and MPS TVC return line temperatures, but no valid left elevon actuator temperatures or hydraulic return line temperatures.

Appendix D Subsystem Data Review Summary Report

D.22.0 INERTIAL MEASUREMENT UNIT PERFORMANCE EVALUATION

D.22.1 Executive Summary

The inertial measurement unit (IMU) pre-launch, ascent and on-orbit operations were nominal. During entry, all FCS parameters were nominal at loss-of-data.

D.22.2 Pre-launch/Ascent Performance

The IMU pre-launch and ascent performance was nominal. The IMUs measured and reflected the Orbiter changes in attitude and velocity due to the nominal ascent activities. Review of the IMU pre-launch and ascent data did not show any anomalous conditions.

D.22.3 On-Orbit Performance

The IMU on-orbit operations were nominal. The IMUs measured and reflected the Orbiter changes in attitude and velocity due to the nominal on-orbit operations. Review of the IMU on-orbit data did not show any anomalous conditions.

D.22.4 Entry Performance

The overall performance of the three IMUs during entry was nominal. The IMUs measured and reflected the Orbiter changes in attitude and velocity due to the nominal entry activities. The deadband firing and energy reduction maneuvers were accurately tracked by all three IMUs. The post-LOS data indicated continued nominal velocity changes, but large attitude changes were noted between the first few seconds of data and the small sample of data at the end.
**Appendix D**

**Subsystem Data Review Summary Report**

**D.25.0 S-BAND SUBSYSTEM PERFORMANCE EVALUATION**

**D.25.1 Executive Summary**

All S-Band subsystems and processors including S-Band phase-modulated (PM) system 2 and S-Band frequency modulated (FM) system 1 performed nominally during the pre-launch, ascent and on-orbit operations. During entry, all S-Band systems remained powered on to support the crew during re-entry. The S-Band PM system string 2 provided nominal S-Band Orbiter telemetry and air-to-ground (A/G) voice communication coverage in the post-de-orbit phase. All S-Band subsystems and processors including S-Band phase-modulated (PM) system 2 and S-Band frequency modulated (FM) system 1 operated nominally until powered off at SpaceHab deactivation prior to the de-orbit maneuver. During on-orbit operations, the S-Band FM system was occasionally powered off for operations recorder dumps via ground stations and powered off again when not in use. The S-Band PM systems string 2 provided nominal S-Band Orbiter telemetry and A/G voice communication coverage in the Tracking and Data Relay Satellite (TDRS) mode during the majority of the on-orbit phase. There were no off-nominal telemetry indications from any S-Band subsystems or processors.

**D.25.3 On-Orbit Performance**

The overall performance of the C&T subsystems was nominal during the on-orbit phase. The payload signal processor (PSP) was configured for SpaceHab support, and operated nominally until powered off at SpaceHab de-activation prior to the de-orbit maneuver. During on-orbit operations, the S-Band FM system was occasionally powered off for operations recorder dumps via ground stations and powered off again when not in use. The S-Band PM systems string 2 provided nominal S-Band Orbiter telemetry and A/G voice communication coverage in the Tracking and Data Relay Satellite (TDRS) mode during the majority of the on-orbit phase. There were no off-nominal telemetry indications from any S-Band subsystems or processors.

**D.25.4 Entry Performance**

The overall performance of the C&T subsystems hardware during entry was nominal. The S-Band communications coverage via the TDRS was as good as anticipated and very comparable to previous Shuttle entries at the same orbital inclination of 39 degrees. There were several S-Band return-link data drops during entry from 32:13:50:00 G.m.t. to 32:13:56:00 G.m.t. that cannot be explained. The antenna look-angles to the TDRS were not unexpected based on the antenna look angles to the TDRS. There were no S-Band return link data drops during entry from 32:13:50:00 G.m.t. to 32:13:56:00 G.m.t. that cannot be explained.

The backup Link Controller (LKC) functioned nominally through the on-orbit phase. The overall performance of the communications and tracking (C&T) subsystems was nominal during the majority of the on-orbit phase. There were no deviations or significant events observed in the A/G voice communication and telemetry coverage. All S-Band systems were powered on at 32:09:30:05 G.m.t., and were functioning nominally prior to loss of signal (LOS). The TACAN systems had locked on to various ground stations during the pass over the United States prior to the de-orbit maneuver and that was nominal operation. The TACAN systems were in the search mode, but were out-of-range of the KSC ground station when LOS occurred at 32:13:55:32:17 G.m.t. The TACAN systems remained in the search mode during the extra 32 seconds of telemetry data that were later recovered. At 32:13:47:37 G.m.t., radar altimeter 1 locked on to radar altimeter 2 and remained locked until 32:13:49:33 G.m.t., when one sample indicated 5200 feet was observed. Radar altimeter 1 remained locked on to radar altimeter 2 and remained locked until 32:13:55:34:30 G.m.t., when one sample indicating 5200 feet was observed. The 800 feet and 5200 feet indications were pronounced to be invalid and were disregarded. The radar altimeter 1 locked on to radar altimeter 2 and remained locked until 32:13:49:33 G.m.t., when one sample indicating 5200 feet was observed. The 800 feet and 5200 feet indications were pronounced to be invalid and were disregarded. The radar altimeter
The overall performance of the Ku-Band subsystem was nominal at loss-of-data.

The OI and Orbiter experiments (OEX) recorder subsystems performed nominally throughout the STS-107 pre-launch and ascent phases. No significant events or findings were found during the data analysis.

The D&C subsystem was in the normal configuration and exhibited nominal operation during the pre-launch and ascent phase. All pre-launch master alarm occurrences were attributable to expected operations.

During entry operations, several of the hydraulic measurements failed to off-scale-low. These were:
- Hydraulic system 3 left outboard elevon return line temperature
- Hydraulic system 1 left-hand inboard elevon actuator return line temperature
- Hydraulic system 1 left outboard elevon return line temperature
- Hydraulic system 2 left outboard elevon return line temperature

All tire pressure and temperature measurements for the left-hand MLG were then observed to have drifted lower and failed to OSL. The left-hand outboard tire pressure 1 began drifting lower at 32:13:58:34 G.m.t., and failed OSL at 32:13:58:38 G.m.t. The left-hand inboard tire pressure 1 began drifting lower at 32:13:58:40 G.m.t., and failed OSL at 32:13:58:45 G.m.t. The left-hand inboard wheel temperature began drifting lower at 32:13:58:35 G.m.t., and failed OSL at 32:13:58:40 G.m.t. The left-hand inboard pressure began drifting lower at 32:13:58:35 G.m.t., and failed OSL at 32:13:58:40 G.m.t.

The downlisted data for the caution and warning master alarm telemetry data. During the entry phase with the downlisted caution and warning master alarm data.

The D&C subsystem exhibited nominal operation during the entry phase, including the additional 32-second period of reconstructed data. During the entry phase up to the additional 32-second time frame, the master alarms announced were correlated to the individual subsystems that triggered the alarms. The downlisted data for the caution and warning master alarm subsystem shows evidence of the master alarm annunciating continuously from 32:13:59:33:863 to 32:14:00:04:760 G.m.t., which includes the additional 32-second period of reconstructed data. The data review indicates several subsystems could have triggered the master alarm. Each individual subsystem with possible master alarm triggers has been evaluated for validity of the master alarm data relative to that subsystem performance. A review of the BPS data reveals a correlation of the events with the downlisted caution and warning master alarm telemetry data.
Appendix D
Subsystem Data Review Summary Report
D.29.0 MULTIFUNCTION ELECTRONIC DISPLAY SUBSYSTEM PERFORMANCE EVALUATION

D.29.1 Executive Summary
The overall performance of the MEDS was nominal during the pre-launch, ascent and on-orbit phases with no in-flight anomalies identified during the analysis of the data. During entry, all MEDS subsystem parameters were nominal at loss-of-data.

D.29.2 Pre-launch/Ascent Performance
The overall performance of the MEDS was nominal during the pre-launch and ascent phases. There were no significant deviations from the nominal/expected operation of the MEDS subsystem during the pre-launch/ascent period. All downloaded Edge Key inputs reflect those that would be expected during normal operations.

D.29.3 On-Orbit Performance
The overall performance of the MEDS was nominal during the on-orbit operations. There were no significant deviations from the nominal/expected operation of the MEDS subsystem during the on-orbit period. All downloaded Edge Key inputs reflect those that would be expected during normal operations.

D.29.4 Entry Performance
The MEDS subsystem operation was nominal during the entry until loss-of-data and LOS.

Appendix D
Subsystem Data Review Summary Report
D.30.0 AIR DATA TRANSUCER ASSEMBLY HARDWARE PERFORMANCE EVALUATION

D.30.1 Executive Summary
The air data transducer assembly (ADTA) hardware performed satisfactorily during the entry phase of the mission. The ADTA probes were not deployed so no data were received on that subsystem operation.

D.30.2 Pre-launch/Ascent Performance
The ADTA is not deployed during the ascent phase and no data were received.

D.30.3 On-Orbit Performance
The ADTA is not deployed during the on-orbit phase and no data were received.

D.30.4 Entry Performance
The ADTA performed nominally during FCS checkout and from power-on for descent through loss of signal. Pressure indications from all 16 ADTA transducers were well within redundancy management (RM) limits, and all mode/status word indications were satisfactory. Data also shows that the air data probes (ADPs) were not deployed during this phase of entry. Probe temperatures were in the normal range for stowed ADPs.

The ADTA data is not used by GN&C until the crew manually enables the data around Mach 3.5. The air data probes remain stowed until around Mach 5 during entry. At the time of LOS, the ADTA transducers were reading within ±0.040 inch Hg between transducers connected to the same-side air data probe and ±0.005 inch Hg between transducers connected to opposite-side air data probes. The ADTAs were reading the ambient pressure inside the forward RCS cavity and responding to very small changes in pressure due to vehicle motion and attitude. Pressures from the left probe were slightly higher than pressures from the right, but these differences are not abnormal of ADTA performance during this phase of flight. Data during a similar portion of entry from STS-109 and STS-110 have been reviewed as comparisons.

ADTA data was not being used at the time of vehicle loss and could not have been a factor in the mishap. In addition, the ambient ADTA data shows no indication of abnormal vehicle GN&C.
A great many people participated in the review and analysis of flight data from STS-107. The following is a list of some of the many people who contributed to the review of the STS-107 data and the generation of the entry timeline. The Data Review and Timeline Team thanks all of those who contributed to this effort and apologizes to those who have been inadvertently left off this list.

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