Volume II
Appendix D.9
Data Review and Timeline Reconstruction Report

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.

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APPENDIX D.9

Data Review and Timeline Reconstruction Report

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NSTS 37376
June 3, 2003

Data Review and Timeline Reconstruction Team Final Report

in support of the *Columbia* Accident Investigation

June 3, 2003

Submitted by:

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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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EXECUTIVE SUMMARY

The Date Review and Timeline Reconstruction Team was one of many Technical Integration Team sub-teams created in support of the Orbiter Vehicle Engineering (OVE) Working Group (WG) investigation into the *Columbia* accident. The team's charter was to review the available telemetry and recorded data from *Columbia* and develop a timeline of events leading up to the loss of *Columbia* and its crew.

This report defines and documents the process that the Data Review and Timeline Reconstruction Team used to develop the STS-107 entry timeline. It also defines and documents the team's products and interfaces.

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 ground rule established by the Data Review and Timeline Reconstruction team was that the team was to identify off-nominal performance from a review of the available flight data, describe that off-nominal performance as events on a timeline and make the timeline available to the pertinent Technical Integration Team sub-teams. Detailed analysis to determine the cause of the events was then performed by the pertinent sub-teams.

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 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 the various Orbiter subsystem managers (SSMs) and/or subsystem engineers (SSEs). The data review and the reconstruction of the timeline began in the first hours following the *Columbia* accident. It began with quick look reviews of subsystem entry data conducted in the Mission Evaluation Room. 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 SSMs/SSEs), the Johnson Space Center (JSC) Engineering Directorate, the JSC Mission Operations Directorate (MOD),

the JSC and contractor Safety, Reliability and Quality Assurance (SR&QA) 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 to present the timeline in a more manageable form. Appendix A.2 is the master entry timeline that shows all of the entry events. Appendix B provides supporting data for the events on 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, 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.

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.

1.0 INTRODUCTION

The Date Review and Timeline Reconstruction Team was one of many Technical Integration Team sub-teams created in support of the Orbiter Vehicle Engineering (OVE) Working Group (WG) investigation into the *Columbia* accident. The team's charter was to review the available telemetry and recorded data from *Columbia* and develop a timeline of events leading up to the loss of *Columbia* and its crew.

The primary source of data for the timeline reconstruction was real-time telemetry from *Columbia* and recorded data from the Orbiter experiments (OEX) recorder that was discovered during the search for debris. Individual subsystem teams reviewed the data for off-nominal events based on the team's knowledge of expected subsystem performance and the comparison of STS-107 flight data with previous flight data.

The review included flight data from throughout the mission; ascent, on-orbit and entry. Obviously, the vast majority of off-nominal events were discovered in the review of entry data and those events are documented in the entry timeline. This timeline was baselined and configuration controlled by the OVE WG. The few off-nominal events discovered during the ascent data review were delivered to personnel in the Systems Integration group who were responsible for ascent timeline reconstruction. There were no off-nominal events related to the *Columbia* accident discovered in the review of on-orbit data.

Another source of data included the evaluation of videos received from individuals across the western United States who had recorded *Columbia's* entry. From these videos, debris shedding events were characterized and documented in the entry timeline. Additionally, aerodynamic events derived by the analysis of the entry trajectory were included in the timeline. These events show the changes in aerodynamic coefficients during entry. Finally, 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.

2.0 PURPOSE AND SCOPE

This report defines and documents the process that the Data Review and Timeline Reconstruction Team used to develop the STS-107 entry timeline. It also defines and documents the team's products and interfaces.

The scope of the data review included all available real-time telemetry from *Columbia* and all recorded data from the 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. There were no off-nominal events related to the *Columbia* accident discovered in the review of on-orbit data.

In addition to the development of the timeline (Appendix A), a graphical version of the entry timeline was developed (Appendix B), a data package was compiled with data for each event on the timeline (Appendix C), a report summarizing the results of the subsystem data reviews was generated (Appendix D), and a table with measurement information for each measurement referenced on the entry timeline was generated (Appendix E).

3.0 GROUND RULES AND ASSUMPTIONS

The primary ground rule established by the Data Review and Timeline Reconstruction team was that the team was to identify off-nominal performance from a review of the available flight data, describe that off-nominal performance as events on a timeline and make the timeline available to the pertinent Technical Integration Team sub-teams. Detailed analysis to determine the cause of the events was then performed by the pertinent sub-teams.

There are exceptions to that ground rule in that two classes of events are actually the products of the analyses conducted by two of the sub-teams. The Image Analysis Team screened over 140 videos received from the public. Approximately 25 contained good records of debris emanating from *Columbia's* plasma envelope. The Image Analysis Team's emphasis was to obtain the most accurate times possible for the debris observations. A characterization of those observations and the times at which they occurred were included in the entry timeline.

Additionally, the Integrated Entry Environments team derived events for the timeline from entry trajectory reconstruction analyses. These events characterized changes in aerodynamic coefficients that occurred over the final 7-minutes of *Columbia's* entry.

Finally, 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.

4.0 PROCESS DEFINITION

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 the various Orbiter subsystem managers (SSMs) and/or subsystem engineers (SSEs). The data review and the reconstruction of the timeline began in the first hours following the *Columbia* accident. It began with quick look reviews of subsystem entry data conducted in the Mission Evaluation Room. 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 SSMs/SSEs), the Johnson Space Center (JSC) Engineering Directorate, the JSC Mission Operations Directorate (MOD), the JSC and contractor Safety, Reliability and Quality Assurance (SR&QA) organizations, and the JSC Astronaut Office. The initial focus of the review was on the entry data but it subsequently expanded to include ascent and on-orbit data. The review also included a 32-second period of real-time telemetry data that was not initially accepted by the Orbiter Data Reduction Complex (ODRC) due to the high bit error rate. This period of data was reconstructed so that it could be processed by the ODRC for review. The 32-second period consisted of approximately 5-seconds of data at the start of the period, an approximate 25-second data gap, and approximately 2-seconds of data at the end of the period.

The early revisions of entry timeline were considered preliminary as the events on the timeline matured through the process of more thorough and complete data reviews. Revision 12 of the timeline was subsequently baselined at the OVE WG on February 10, 2003, for configuration control. From that point on, changes could only be made to the timeline by re-baselining revisions at the OVE WG.

Timeline events were also received from two other sources, the Image Analysis Team and the Integrated Entry Environments Team. The Image Analysis Team screened videos received from the public, of which approximately 25 contained good records of debris emanating from *Columbia's* plasma envelope. From these videos, the team was able to characterize off-nominal events with a description of the events and the times at which they occurred. The Integrated Entry Environments team derived events for the timeline from entry trajectory reconstruction analyses that characterized changes in aerodynamic coefficients that occurred over the final 7-minutes of *Columbia's* entry.

In March, the OEX recorder was found and the data on the recorder was recovered. On the last weekend of March, the review of that data was begun. The process followed was that same as that established for the review of the real-

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 debris event 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 groups 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.1 is 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 track maps.

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.

A.1-1
Integ Time Line Team - REV 19 BASELINE

Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

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

Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
1	13:10:39	EI+2010		TIG-5	APU 2 Start		
2	13:15:30	EI-1719		TIG	OMS TIG		
3	13:18:08	EI-1561			OMS End of Burn		
4	13:31:25	EI-764		EI-13	APU 1 Start		
5	13:31:29	EI-760			APU 3 Start		
5.5	13:39:28.559	EI-280.4	X		Start of OEX PCM Data Block		
6	13:44:09	EI+0		EI	Entry Interface (400,000 ft)	Mach 24.57	
6.1	13:45:39 / 48:59	EI+90 / EI+290	X		16 Temperature Sensors on the lower surface to the left of or at the centerline experience off-nominal early temperature trends (warmer temperature rise rate compared to previous flights of OV-102 at the same inclination)		V09T9849A V07T9784A V07T9666A V07T9786A V07T9468A V07T9787A V07T9470A V07T9788A V07T9711A V07T9478A V07T9713A V07T9480A V07T9785A V09T9845A V09T9231A V07T9489A
6.15	13:48:39	EI+270	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 secs	The measurement began to fail at approximately EI+495 sec	V12G9921A X1106.0 Y-229.0 ZMID
6.2	13:48:59	EI+290	X		Left Wing RCC Panel 9 Lower Attach Clevis (between RCC 9 and 10) - initiation of an off-nominal temperature trend (early temperature increase compared to previous flights of same inclination)	The measurement began to fail at approximately EI+492 sec	V09T9910A X1112.0 Y-239.0 Z289.0
6.3	13:49:32	EI+323			Start of initial roll		
6.4	~13:49:39*	~EI+330*	X		Left Wing Front Spar Caps Strain Gage shows early off nominal downward trend	*Note: PCM3 entry data is in snapshot format (not continuous). Time indicated is at start of data segment where off-nominal signature is first observed, therefore event may have started earlier than noted.	V12G9169A X1107 Y232 Z?
6.45	13:49:49 / 49:59	EI+340 / EI+350	X		4 Left OMS Pod Surface temps - Start of off-nominal temperature trend - cooler rise rate when compared to previous flights of same inclination	Followed by the start of a warmer-than-expected temperature trend beginning in the EI+510 to EI+540 sec range	V07T9976A V07T9978A V07T9220A V07T9972A
QBAR = ~15 psf (~0.10 psi); Mach 24.4					------ 32:13:50:00 ------	EI + 351 sec; WLE Stagnation Temp: ~2520 F (STS-107 Nom EOM Design Pred)	
6.5	13:50:00 / 43	EI+351 / EI+394			Five events of unexpected return link comm drop-out (Comm events 1-5)	On upper left aft antenna (TDRS 171/W). Appears off-nominal based on previous flt data. Comm loss not continuous thru period indicated.	
6.7	13:50:09	EI+360	X		Left PLBD Surface TC BP3703T - Start of off-nominal temperature trend - cooler rise rate when compared to previous flights of same inclination	Followed by large increase in temperature at EI + 570 seconds	V07T9925A X1138.5 YLH Z441.4
6.9	13:50:19	EI+370	X		Left Wing Lower Surface Thermocouple BP2510T begins off-nominal temp increase from ~2000 deg F to ~2200 deg F over approx 50 seconds followed by a momentary 100 deg F temperature spike	The measurement subsequently fails at approximately EI+496 sec	V07T9666A X1121.1 Y-235.5 ZLWR
7	13:50:53	EI+404		Start of Peak Heating		Determined by analysis	
QBAR = ~19 psf (~0.13 psi); Mach 24.1					------ 32:13:51:00 ------	EI + 411 sec; WLE Stagnation Temp: ~2650 F	
7.2	13:51:14	EI+425	X		Left Wing Front Spar at RCC Panel 9 - start of off-nominal increasing temperature trend	Increasing trend continues until the measurement starts to fail at approximately EI+520 sec	V09T9895A X1102.2 Y-239.0 Z239.0
7.25	13:51:14	EI+425	X		Left Wing RCC Panel 9 Lower Attach Clevis (between RCC 9 and 10) - start of a more rapid off-nominal increasing temperature trend	Increases until the measurement starts to fail at approximately at EI + 492 secs	V09T9910A X1112.0 Y-239.0 Z289.0
7.3	deleted					Rationale for deletion: Upon further evaluation of the data, it was determined that the remote sensor signatures had been seen in previous flights and/or could be explained by known events.	
7.35	deleted					Rationale for deletion: Moved to seq # 11.37 after further analysis.	
7.37	13:51:49	EI+460	X		OMS-L Pod HRSI Surf T3-AFT - Start of off-nominal higher-than-expected temperature trend when compared to previous flights of same inclination	Sensor sees a sharp temp increase at EI+910 and goes erratic at EI+940	V07T9223A X1437.2 Y-126 Z422

A.1-2
Integ Time Line Team - REV 19 BASELINE

Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

6/5/2003 1 PM

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Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
QBAR = ~22 psf (~0.15 psi); Mach 23.7					------ 32:13:52:00 ------	EI + 471 sec; WLE Stagnation Temp: ~2700 F	
7.4	deleted					Rationale for deletion: Moved to seq # 8.75 after further analysis.	
7.45	13:52:09 / 52:55	EI+480 / EI+486			Four events of unexpected return link comm drop-out (Comm events 6-9)	On upper left aft antenna (TDRS 171/W). Appears off-nominal based on previous flt data. Comm loss not continuous thru period indicated.	
7.46	13:52:09 / 52:49	EI+480 / EI+520	X		Nose Cap RCC Attach OutBoard Clevis (Chin Panel) - Temporary change in slope, then returns to "nominal" Note: Adjacent sensor V09T9888 (on centerline) does not show this signature		V09T9889A X262.0 Y-23.0 LWR
7.47	13:52:16	EI+487	X		Two Left Wing and 1 Right Wing Surface Pressure measurements show signs of failure	First OEX data to show signs of failure	V07P8038A V07P8086A V07P8151A
7.48	13:52:16 / 53:17	EI+487 / EI+522	X		All of the active measurements (does not include PCM 3 data in snapshot mode) running in the wire bundles along the left wing leading edge show signs of failure - 18 measurements		18 of 18 measurements
7.49	13:52:16 / 56:24	EI+487 / EI+735	X		The vast majority of left wing OEX measurements show signs of failure during this time period - this includes all left wing temperature and pressure measurements and all strain measurements aft of Xo 1040 with the exception of three strain measurements on the upper surface of the LMLG compartment Additionally, 30 right wing pressure measurements show signs of failure		Multiple measurements
7.5	13:52:17	EI+488		Approx Vehicle Ground Location: 39.0 N / -129.2 W	Altitude 236,800 ft / Mach 23.6 - Over the Pacific Ocean, approx 300 miles West of California Coastline	Approx vehicle position when first off-nominal data was seen; Data source: STS-107 GPS Trajectory Data	
7.7	13:52:17	EI+488	X		LMG Brake Line Temps (D) - small increase in temperature ("bit flip up")	Initiation of temp rise ("bit flip up") - may be nominal based on rise rate comparison w/ flight experience	V58T1703A
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		V12G9048A
7.77	13:52:24	EI+495	X		Left Wing Front Spar at RCC Panel 9 - strain gage goes erratic for approximately 20 second - measurement appears to be failing	Subsequent data is suspect	V12G9921A X1106.0 Y-229.0 ZMID
7.8	13:52:25	EI+496	X		Left Outboard Elevon Wide Band Accelerometers - off-nominal vibration response (approximately 2G peak-to-peak) V08D9729A - L OB Elevon Z-Vib (MUX1B Ch 2)		V08D9729A
7.85	13:52:29	EI+500	X		OMS-L Pod HRSI Surf T1-AFT - Start of slightly off-nominal erratic trend when compared to previous flights of same inclination	Followed by drop in temperature at EI + 570 seconds and subsequent erratic temperature changes	V07T9219A X1507.1 Y-126.0 Z422.0
7.9	13:52:31	EI+502	X		Left Outboard Elevon Wide Band Accelerometers - off-nominal vibration response (approximately 3G peak-to-peak) V08D9729A - L OB Elevon Z-Vib (MUX1B Ch 2)		V08D9729A
8	deleted					Rationale for deletion: moved to seq #8.7	
8.5	13:52:32/55	EI+503			Supply H2O Dump Nozzle Temps (A, B) (2) and Vacuum Vent Temp (1) - transient (15 and 23 seconds, respectively) increase in typical rise rates.	GMT shown indicates initial rise duration. Supply H2O Dump Nozzle temps took additional 48 secs to return to nominal temp rise; vacuum vent temps took additional 40 secs to return to nominal rise.	V62T0440A V62T0439A V62T0551A
8.6	13:52:34	EI+505	X		OMS-L Pod HRSI Surf T2-AFT - Start of off-nominal lower-than-expected temperature trend (compared to previous flights of same inclination) until sensor sees a sharp temp increase at EI+910 and goes erratic at EI+940		V07T9222A X1486.9 Y-126 Z422.0
8.65	13:52:39 / 53:09	EI+510 / EI+540	X		4 Left OMS Pod Surface temps - Change in existing off-nominal temperature trend (following a cooler rise rate than expected, the temperature trend that is significantly warmer when compared to previous flights of same inclination)		V07T9976A V07T9978A V07T9220A V07T9972A
8.7	13:52:41	EI+512			LMG Brake Line Temps (A, C) (2) - start of off nominal trend	Unusual Temperature Increase	V58T1700A V58T1702A
8.75	13:52:44 / 52:50	EI+515 / EI+521			First clear indication of off-nominal aero increments	Delta yawing and rolling moment coefficients indicate off-nominal trends. Derived by analysis.	n/a

A.1-3
Integ Time Line Team - REV 19 BASELINE

Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

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

Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
8.8	deleted					Rationale for deletion: inadvertently added to summary timeline	
9	deleted						
10	13:52:59	EI+530			Left INBD Elevon Lower Skin Temp (1) - OSL	Began trending down 3 secs earlier	V09T1006A
QBAR = ~25.5 psf (~0.18 psi); Mach 23.2					------ 32:13:53:00 ------	EI + 531 sec; WLE Stagnation Temp: ~2800 F	
10.5	deleted					Rationale for deletion: Merged with seq # 8.75 after further analysis.	
10.6	13:53:03	EI+534	X		Left Outboard Elevon Wide Band Accelerometers - onset of signal saturation indicating likely measurement failure (approximately 10G peak-to-peak - off-scale)		V08D9729A
11	13:53:10 / 36	EI+541 / EI+567			Hydraulic System Left Outbd / Inbd Elevon Return Line Temps (4) - OSL	OSL was preceded by Nominal Temp rise.	V58T0394A V58T0193A V58T0157A V58T0257A
11.1	deleted					Rationale for deletion: alpha modulation time tag updated - moved to seq #11.25	
11.2	13:53:26	EI+557		Approx Veh Grd Location: 38.7 N / -123.5 W	Altitude 231600 ft / Mach 23.0 - Crossing the California Coastline	Data source: STS-107 GPS Trajectory Data	
11.21	13:53:29	EI+560	X		Left Fuselage Side Surface Temp BP3605T - start of off-nominal increasing temperature trend from ~180 deg F to 400 deg F	Trend followed by temperature drop and rise	V07T9253A X1000.7 Y-105 Z354.5
11.22	13:53:29	EI+560	X		Left PLBD Surface TC BP3603T - Start of slightly off-nominal erratic temperature trend when compared to previous flights of same inclination		V07T9913A X1003.8 YLH Z441.3
11.23	13:53:29	EI+560	X		Left PLBD Surface TC BP3703T - start of off-nominal temperature rise, peaking at EI+625, followed by temperature drop and subsequent off-nominal higher-than-expected temperature signature		V07T9925A X1138.5 YLH Z441.4
11.24	13:53:29	EI+560	X		Left Fuselage Side Surface TC BP3604T - Start of slightly off-nominal erratic temperature trend when compared to previous flights of same inclination		V07T9903A X1006 Y-105 Z398.4
11.25	13:53:31	EI+562		Alpha Modulation	Angle of attack (alpha) modulation active		V90H0803C
11.3	13:53:32 / 54:22	EI+563 / EI+565			Two events of unexpected return link comm drop-out (Comm events 10-11)	On upper left aft antenna (TDRS 171/W). Appears off-nominal based on previous flt data. Comm loss not continuous thru period indicated.	
11.35	13:53:37	EI+568	X		Xo 1040 Spar (MLG Forward Wall Spar) Strain Gage - Upper Cap - start of off-nominal increase in strain indication (over an approximate 115 second interval) followed by sudden decrease		V12G9049A X1040 Y-135 ZUPR
11.37	13:53:38	EI+569			Inertial sideslip angle (Beta) exceeds flight history.	The steady state navigation derived sideslip angle becomes out-of-family as compared to previous flight data at this point in the trajectory.	V90H2249C
11.4	13:53:44	EI+575	X		OMS-L Pod HRSI Surf T1-AFT - Start of off-nominal lower-than-expected temperature trend when compared to previous flights of same inclination	Sensor goes erratic at EI+940	V07T9219A X1507.1 Y-126.0 Z422.0
11.5	13:53:45 / 54:11	EI+576 / EI+602			1st reported debris (5) observed leaving the Orbiter just aft of Orbiter envelope (Debris # 1 thru 5)	EOC video # EOC2-4-0055, 0056, 0064, 00136 & 0201. No evidence of jet firings near events.	n/a
QBAR = ~29 psf (~0.20 psi); Mach 22.7					------ 32:13:54:00 ------	EI + 591 sec; WLE Stagnation Temp: ~2850 F	
12	deleted						
13	13:54:10 / 55:12	EI+601 / EI+663			Left Main Gear Brake Line Temp B (1) / Strut Actuator Temp (1) / Sys 3 LMG Brake Sw Vlv Ret Line Temp (FWD) (1) - start of off nominal trend	Unusual Temperature Increase	V58T1701A V58T0842A V58T0405A
13.5	13:54:11	EI+602			Reversal in growth trend of derived roll moment coefficient	Observed roll moment changed from a negative to positive slope (derived by analysis).	n/a

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Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

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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

Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
14	13:54:20	EI+611			Start of slow aileron trim change	The aileron trim setting observed in flight first deviates from the predicted trim setting at this pt in trajectory (GMT is approximate (+/- 10 sec) for aileron).	V90H1500C (aileron trim)
15	13:54:22	EI+613			Mid Fuselage LT BondLine Temp at x1215 (1) & LH Aft Fus Sidewall Temp at x1410 (1) - start of off nominal trend	Unusual increase in temperature rise rate	V34T1106A V09T1724A
15.2	13:54:29	EI+620	X		Left Fuselage Side Surface temp BP3605T peaks and starts downward trend		V07T9253A X1000.7 Y-105 Z354.5
15.3	13:54:33.3 / 54:37	EI+624.3 / EI+628			Flash #1 - Orbiter envelope suddenly brightened (duration 0.3 sec), leaving noticeably luminescent signature in plasma trail; plus Debris # 6 - report of very bright debris observed leaving the Orbiter just aft of the Orbiter envelope.	EOC video # EOC2-4-0026, 0034, & 0009B. R3R and R2R jet firings occurred near events. Debris events 6 & 14 are visually the biggest, brightest events & therefore may indicate the most significant changes to the Orbiter of the western debris events.	n/a
15.32	13:54:34	EI+625	X		Left Fuselage Side Surface temp BP3703T peaks and starts downward trend		V07T9925A X1138.5 YLH Z441.5
13.33	13:54:39	~EI+630	X		Strain Gages Centered on the Upper Surface of the Left MLG Wheel Wheel - Higher-than-expected strain indications observed in these gages	Note: PCM3 entry data is in snapshot format (not continuous), therefore event may have occurred earlier than noted	V12G9156A, V12G9157A, V12G9158A
13.34	13:54:39	~EI+630	X		Left Wing X1040 Spar Web - shows increase in strain	Note: Adjacent sensor V12G9165A did not show similar "off-nominal" signature at this time, also, PCM3 entry data is in snapsho format (not continuous), therefore event may have occurred earlier than noted	V12G9166A V12G9167A (V12G9165A-nominal)
QBAR = ~34.5 psf (~0.24 psi); Mach 22.1					------ 32:13:55:00 ------	EI + 651 sec; WLE Stagnation Temp: ~2900 F	
15.35	13:55:04 / 55:29	EI+655 / EI+680			Debris # 7, 7A, & 8 thru 10 observed leaving the Orbiter just aft of Orbiter envelope. Debris 8, 9, & 10 were seen aft of the Orbiter envelope inside Debris Shower A (next event listed).	EOC video # EOC2-4-0005, 0017, 0021, 0028, 0030, 0098 & 0161. No evidence of jet firings near events.	n/a
15.37	13:55:22 / 55:28	EI+673 / EI+679			Debris Shower A - Report of debris shower seen just aft of Orbiter envelope.	Seen just aft of Orbiter envelope. Over the course of these four seconds a luminsecent section of plasma trail is observed which appears to contain a shower of indefinite particles and multiple, larger discrete debris that includes Debris 8, 9, and 10.	Saw debris: EOC2-4-0098, 0161, 0005, 0030 Saw shower: EOC2-4-0017, 0021, 0028
15.4	deleted					Rationale for deletion: Upon further evaluation of the data, it was determined that the remote sensor signatures had been seen in previous flights and/or could be explained by known events.	
15.43	13:55:33 / 56:03	EI+684 / EI+714			Two events of return link comm drop-outs (Comm events 12 & 13)	On upper right aft antenna (TDRS 171/W). Uncertain if off-nominal based on previous flight data. Comm loss not continuous thru period indicated.	
15.44	deleted					Rationale for deletion: Moved to 15.46 after further review of the data	
15.45	13:55:35 / 56:12	EI+686 / EI+723			Debris # 11, 11A, 11B, 11C & 12 thru 15 observed leaving the Orbiter just aft of Orbiter envelope. Debris #11B & #11C events were both seen at the head of a parallel plasma trail aft of the Orbiter envelope. Debris #12 event was preceded and followed by secondary plasma trails. Debris #13 event was followed by momentary brightening of plasma trail adjacent to debris. Debris #14 event consisted of very bright debris observed leaving the Orbiter.	EOC video # EOC2-4-0005, 0017, 0021, 0028, 0030, 0050, & 0098. No evidence of jet firings near events. (Nearest jet firings occur at 56:17.) Debris events 6 & 14 are visually the biggest, brightest events & therefore may indicate the most significant changes to the Orbiter of the western debris events.	n/a
15.46	13:55:36	EI+687	X		Xo 1040 Spar (MLG Forward Wall Spar) Strain Gage - Upper Cap - sudden drop in strain followed by gradual increase until erratic signature at approximately EI+930		V12G9049A X1040 Y-135 ZUPR

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Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

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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

Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
15.5	13:55:41	EI+692			Mid Fuselage Port (Left) Sill Longeron Temp at X1215 - start of off nominal trend	Unusual Temperature Increase	V34T1118A
QBAR = ~40 psf (~0.28 psi); Mach 21.4					------ 32:13:56:00 ------		EI + 711 sec; WLE Stagnation Temp: ~2900 F
16	13:56:03 / 56:24	EI+714 / EI+735			Left Lower/Upper Wing Skin Temps - Trending down (2)	Indication of potential measurement failures	V09T1002A V09T1024A
16.5	13:56:16 / 56:53	EI+727 / EI+764			Hyd Sys 1 LMG Uplock Actuator Unlock Line Temp; Sys 3 LMG Brake Sw Vlv Ret Line Temp (FWD); LMG Brake Line Temp C; LMG Brake Line Temp B; Sys 3 Left Main Gear Strut Actuator Temp - all show a temp rise rate change.	Significant increase in temp rise rate on all four lines	V58T0125A V58T1701A V58T0842A V58T0405A V58T1702A
16.55	13:56:30 / 56:55	EI+741 / EI+766			First Roll Reversal initiation / completion		V90H1044C
16.6	deleted					Rationale for deletion: Comm dropout (event 14) is deleted since probably nominal due to completion of roll reversal resulting in elevation angle nearing 60 deg's (vertical tail interfence w/comm).	
QBAR = ~42 psf (~0.29 psi); Mach 20.7					------ 32:13:57:00 ------		EI + 771 sec; WLE Stagnation Temp: ~2900 F
16.65	13:57:09	EI+780	X		Fuselage Side Surf Thermocpl BP3976T - start of off-nominal trend (temp increase followed by temp drop / rise)		V07T9270A X1486.1 Y-124.8 Z307.1
16.67	13:57:09	EI+780	X		Fuselage Lower Surface BF Thermocpl BP220T - start of off-nominal trend (shallow temp drop)		V07T9508A X1560 Y-111.1 Z LWR
16.7	13:57:19 / 24	EI+790 / EI+795			MLG LH Outbd Tire Pressures 1 & 2 - start of small increase in pressures	Not seen in previous flights	V51P0570A V51P0572A
16.8	13:57:19 / 58:01.5	EI+790 / EI+832.5			Debris # 16 (very faint debris) observed leaving just aft of Orbiter followed by two events of assymmetrcial brightening of the Orbiter shape (Flares 1 and 2). (Occurred over eastern AZ and NM.)	Debris #16: EOC video # EOC2-4-00148-2. Flares #1 & 2: EOC2-4-00148-4. Observations by personnel from the Starfire Optical Range (Kirtland Air Force Base, NM).	n/a
17	13:57:28 / 57:43	EI+799 / EI+814			Left Lower/Upper Wing Skin Temps (2) - OSL		V09T1002A V09T1024A
18	deleted						
19	13:57:54				Sys 2 LH Brake Sw Vlv Return Temp (1)	Unusual Temperature Increase	V58T0841A
QBAR = ~52.5 psf (~0.36 psi); Mach 19.8					------ 32:13:58:00 ------		EI + 831 sec; WLE Stagnation Temp: ~2880 F
20	13:58:03				Start of sharp aileron trim Increase	GMT is approximate (+/- 10 sec)	V90H1500C
20.3	13:58:04	EI+835	X		Left fuselage side surface temp BP3605T starts off-nominal temperature increase		V07T9253A X1000.7 Y-105 Z354.5
20.5	13:58:04 / 58:19	EI+835 / EI+850			Increase in off-nominal aero increments.	Substantial increase in rate of change of rolling and yawing moment increments and initial indication of off-nominal pitching moment increment. Derived by analysis.	n/a
21	deleted						
22	deleted						
22.5	13:58:16	EI+847			LMG Brake Line Temp D - Temp rise rate change	Significant increase in temp rise rate.	V58T1703A
23	13:58:32 / 58:54	EI+863 / EI+885			MLG LH Inbd / Outbd Tire Pressures (4) - Decay to OSL		V51P0570A V51P0573A V51P0571A V51P0572A
24	deleted						
25	13:58:39 / 58:48	EI+870 / EI+879			MLG LH Inbd/Outbd Wheel Temps (2) - OSL		V51T0574A V51T0575A
25.5	13:58:40	EI+871			BFS Fault Msg (4) - Tire Pressures - 1st Message		
26	13:58:56	EI+887			BFS Fault Msg (4) - Tire Pressures - Last Message		

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Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

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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

Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
QBAR = ~63.5 psf (~0.44 psi); Mach 18.7					------ 32:13:59:00 ------		EI + 891 sec; WLE Stagnation Temp: ~2850 F
27	13:59:06				Left Main Gear Downlocked Indication - Transferred ON		V51X0125E
27.3	13:59:09 / 59:39	EI+900 / EI+930	X		Several left side temperature measurements show a rapid increase in temperature followed by erratic behavior and subsequent loss of the measurements at approximately EI+940		V07T9925A V07T9976A V07T9972A V07T9978A V07T9976A V07T9222A V07T9903A V07T9223A V07T9913A
27.5	13:59:23	EI+914			Loss of MCC real-time data to the workstations in the FCR and MER		
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, rolling, and yawing increments. Magnitude of aero increments starting to exceed ability of aileron to laterally trim the vehicle. Derived by analysis.	n/a
28	13:59:30.66 / 59:30.68	EI+921.66 / EI+921.68			Start of two yaw jets firing (R2R and R3R)	Fired continuously until end of data at 13:59:37.4	V79X2634X V79X2638X
29	13:59:31	EI+922			Observed elevon deflections at LOS	Left: -8.11 deg (up) Right: -1.15 deg (up)	
29.3	13:59:31.4 / 59:34.5	EI+922.4 / EI+925.5			Several events and PASS and BFS FSM messages during this time period all indicate the failure signature of ASA 4	ASAs responded appropriately. However, signature is indicative of failure of ASA 4.	V57H0253A (5 Hz)
29.5	13:59:32	EI+923			Observed aileron trim at LOS	-2.3 degrees	
30	deleted						
31	deleted						
32	deleted						
32.5	13:59:32	EI+923		Approx Veh Grd Location: 32.9 N / -99.0 W	Altitude ~200700 ft / Mach ~18.1 - Near Dallas TX	Approximate Vehicle Ground Location at Loss of Signal based on GMT; Data source: STS-107 GPS Trajectory Data	n/a
33	13:59:32.136	EI+923.136		LOS	Last valid downlink frame accepted by ODRC - OI / BFS / PASS. Start of reconstructed data.	Nominal loss of comm at this GMT (for ~15 sec max based on previous flt data)	
34	deleted						
35	13:59:35/36	EI+926 / EI+927			Sideslip on vehicle changes sign.	The event occurred between the two times listed. Aerodynamic forces due to sideslip are now reinforcing aerodynamic asymmetry.	n/a
36	13:59:36	EI+927			Growth in Bank attitude error	Up until this time the flight control had been able to maintain the Bank error around 5 deg.	
37	13:59:36.8	EI+927.8			Aerojet DAP Requests Third Right Yaw RCS Jet (R4R)	This additional jet is required to counteract the increasing aerodynamic moments on the vehicle. Fired continuously until end of data at 13:59:37.4	
38	13:59:37.3	EI+928.3			Aerojet DAP Requests Fourth Right Yaw RCS Jet (R1R)	This additional jet is required to counteract the increasing aerodynamic moments on the vehicle. Fired continuously until end of data at 13:59:37.4	
39	13:59:37.n	EI+928.n			Last aileron data	The aileron position is now approx -5.2 deg with approx -2.5 deg of aileron trim. The rate of change of aileron trim had reached the maximum allowed by the flight control system.	n/a
40	13:59:37.396	EI+928.396		End of 5-second period of reconstructed data	End of first 5-seconds of the 32-second period of post-LOS data. Start of approximately 25 seconds of no data available	GMT derived by MER data personnel	n/a
40.5	13:59:39 / 14:00:19	EI+930 / EI+970	X		Beginning at EI+930 and continuing until the loss of sync on OEX data (EI+964.4 for PCM and EI+970.4 for FDM), essentially all of the OEX data for the entire vehicle becomes erratic and fails		
40.7	13:59:46 / 48	EI+937 / EI+939			Debris A observed leaving the Orbiter - Large debris seen falling away from the Orbiter envelope.	EOC videos # EOC2-4-0018, -0024, -0209-B, -0221-3 and -0221-4	
41	13:59:46.347 / 14:00:01.900*	EI+937.347 / EI+952.900			PASS Fault Message annunciation - ROLL REF PASS Fault Message annunciation - L RCS LEAK BFS Fault Message annunciations - L RCS LEAK (2)	*Time info corrupted on some of the events.	
41.5	14:00:01 / 04	EI+952 / EI+955			Debris B and C observed leaving the Orbiter	EOC video EOC2-4-0024 (for both B and C)	

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Appendix A.1 - STS-107 Mishap Investigation - Summary Time Line

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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

Sum No.	GMT GMT Day 32	EI sec	OEX data	Milestone	Entry Event	Remarks	MSID
QBAR = nn psf; Mach nn					------ 32:14:00:00 ------		EI + 951 sec; WLE Stagnation Temp: ~2800 F
42	deleted					Rationale for deletion: moved to 40.7 after further review of the videos	n/a
43	14:00:02.654	EI+953.654			PASS Fault Message annunciation - L RCS LJET		
44	14:00:02.660	EI+953.660		Beginning of 2-second period of reconstructed data	Start of last 2-seconds of the 32 second period of post-LOS data.		
					During this final 2 second period of reconstructed data, the data indicates the following systems were nominal: APUs were running and WSB cooling was evident. MPS integrity was still evident. Fuel cells were generating power and the PRSD tanks/lines were intact. Comm and navaids systems in the forward fuselage were performing nominally. RSB, Body Flap, main engine, and right wing temps appeared active. ECLSS performance was nominal. During this final 2 second period of reconstructed data, the data indicates the following systems were off-nominal: All three Hyd systems were lost. The left inbd/outbd elevon actuator temps were either OSL or no data exists. Majority of left OMS pod sensors were either OSH or OSL or no data exists. Elevated temps at bottom bondline centerline skin forward and aft of the wheel wells and at the port side structure over left wing were observed. EPDC shows general upward shift in Main Bus amps and downward shift in Main Bus volts. AC3 phase A inverter appeared disconnected from the AC Bus. GNC data suggests vehicle was in an uncommanded attitude and was exhibiting uncontrolled rates. Yaw rate was at the sensor maximum of 20 deg/sec The flight control mode was in AUTO. (Note that all Nav-derived parameters (e.g., alpha) are suspect due to high rates corrupting the IMU state.)		
45	14:00:03.470 / 14:00:03.637*	EI+954.470 / EI+954.637			BFS Fault Message annunciation - L OMS TK P BFS Fault Message annunciation - Indeterminant BFS Fault Message annunciation - SM1 AC VOLTS PASS Fault Message annunciation - L RCS PVT	* Time info corrupted on some of the events.	
46	14:00:03.637	EI+954.637			PASS Fault Message annunciation - DAP DOWNMODE RHC	The s/w process which logs the PASS message runs every 1.92 seconds, so this event could have occurred as early as 14:00:01.717 GMT. However, during the 2 sec period, available vehicle data indicates RHC was in detent and DAP was in AUTO.	
47	14:00:04.826	EI+955.826		End of 2-second period of reconstructed data	Last identifiable OI Downlink frame		n/a
47.5	14:00:13.439	EI+964.439	X		OEX PCM loss of sync		
48	deleted					Rationale for deletion: moved to 41.5 after further review of the videos	n/a
48.3	14:00:17.8/18.8	EI+968.8 / EI+969.8			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 and disintegration of the main orbiter envelope into multiple pieces	EOC videos MIT-DVCAM-0001, EOC2-4-018, -0024, -0209-B, -0221-3 and -0221-4	
48.5	14:00:19.44	EI+970.44	X		FDM1 A end of data		
49	deleted					Rationale for deletion: moved to 48.3 after further review of the videos	n/a
50	14:00:53	EI+1004		End of Peak Heating		Determined by analysis	

(yellow) = Nominal/Expected Event or Performance

A.2-1
Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
1	1	–	13:10:39	EI-2010	TIG-5	APU 2 Start - Low Press		
2	2	–	13:15:30	EI-1719	TIG	OMS TIG		
3	3	–	13:18:08	EI-1561		OMS End of Burn		
4	--	–	13:26:09	EI-1080		FRCS Dump Start		
5	--	–	13:27:12	EI-1017		FRCS Dump Complete		
6	4	–	13:31:25	EI-764	EI-13	APU 1 Start - Low Press		
7	5	–	13:31:29	EI-760		APU 3 Start - Low Press		
8	--	–	13:31:57	EI-732		APU 1 Norm Press		
9	--	–	13:31:59	EI-730		APU 2 Norm Press		
10	--	–	13:32:01	EI-728		APU 3 Norm Press		
11	--	–	13:32:29	EI-700		SSME Engine Stow sequence start	Sequence was completed with closure of TVC Iso Vlv 1 at 13:33:30 GMT.	
12	--	–	13:39:09	EI-300	EI-5	Entry Interface minus 5 minutes (304 PRO)	Aeroject DAP (entry FCS) and Entry Guidance are activated upon transition to OPS 304. Entry Guidance provides open-loop attitude commands (angle of attach = 40 deg, roll = 0 deg) to the entry FCS until sufficient drag is available to begin closed-loop guidance operations.	V90Q8001C
13	--	–	13:39:11	EI-298		Speedbrake close & Rudder cmded to zero	The speedbrake is not used until below Mach 10.0, and the rudder until below Mach 5.0.	
13.5	5.5	X	13:39:28.559	EI-280.4		Start of OEX PCM Data Block		
14	6	–	13:44:09	EI+0	EI	Entry Interface (400,000 Ft)	Historical reference point to reflect initiation of atmospheric flight (Mach 24.6)	
15	--	--	deleted				Rationale for deletion: currently there is no relevant aero event at qbar=0.5 psf so not required for this timeline.	
15.5	6.1	X	13:45:39 / 48:59	EI+90 / EI+290		16 Temperature Sensors on the lower surface to the left of or at the centerline experience off-nominal early temperature trends (warmer temperature rise rate compared to previous flights of OV-102 at the same inclination) V09T9849A-OB Elevon Gap LWR Surface Edge Temp V07T9666A-Wing Lower Surface TC BP2510T V07T9468A-Fuselage Lower Surface TC BP1300T V07T9470A-Fuselage Lower Surface TC BP1301T V07T9711A-Wing Lower Surface TC BP2867T V07T9713A-Wing Lower Surface TC BP2876T V07T9785A-LH Outboard Lwr Elevon Fwd Surface V09T9231A-Outboard Elevon, Mid Gap, Fwd Temp V07T9784A-LH LWR AFT Fuselage Surface Temp V07T9786A-Fuselage Pen Region TC BP3074-1T V07T9787A-Aft Fuselage Lower Aft Surface Temp V07T9788A-Body Flap LH Lwr Outboard Fwd Temp V07T9478A-Fuselage Lower Surface TC BP1600T V07T9480A-Fuselage Lower Surface TC BP1602TR V09T9845A-Outboard Elevon, Mid Gap, FWD Temp V07T9489A-Fuselage LWR Surface TC BP1900T	X1429.1 Y-315.3 ZLWR X1121.1 Y-235.5 ZLWR X618 Y0 ZLWR X620 Y-51 ZLWR X1262.0 Y-369.3 ZLWR X1402.0 Y-375.3 ZLWR X1396.1 Y-372.2 ZLWR X1430.1 Y-316 ZLWR X1442.0 Y-117.0 ZLWR X1387.0 Y-229.0 ZLWR X1513 Y-113 ZLWR X1530.0 Y-119.4 ZLWR X1003.8 Y0.0 ZLWR X1004.1 Y-99.8 ZLWR X1430.4 Y-316 ZLWR X1391.5 Y0.0 ZLWR	V09T9849A V07T9784A V07T9666A V07T9786A V07T9468A V07T9787A V07T9470A V07T9788A V07T9711A V07T9478A V07T9713A V07T9480A V07T9785A V09T9845A V09T9231A V07T9489A

A.2-2

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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
16	--	--	13:47:52	EI+223	Qbar 2.0 psf	Elevon, BF active	The elevons (elevator and aileron) and body flap are first used for vehicle attitude control. Although the body flap is active at this time, actual motion does not occur until 4-seconds later due to time delays and hysteresis in the forward command path.	
16.3	6.15	X	13:48:39	EI+270		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 secs	The measurement began to fail at approximately EI+495 sec	V12G9921A X1106.0 Y-229.0 ZMID
16.6	6.2	X	13:48:59	EI+290		Left Wing RCC Panel 9 Lower Attach Clevis (between RCC 9 and 10) - initiation of an off-nominal temperature trend (early temperature increase compared to previous flights of same inclination)	The measurement began to fail at approximately EI+492 sec	V09T9910A X1112.0 Y-239.0 Z289.0
17	--	--	deleted					
17.5	--	--	13:49:07	EI+298	ISLECT = 2	Closed-Loop Guidance	Entry guidance initiates closed-loop roll commands to converge drag to the reference drag profile.	
17.7	--		deleted				Rationale for deletion: After further review of the data, it was concluded that this event was not off-nominal	
18	--	--	13:49:16	EI+307	Qbar 10 psf	Roll Jets Deactivated	Roll control is achieved solely through aileron and yaw jet commands from this point forward.	
19			deleted					
20	6.3	--	13:49:32	EI+323		Initial Roll	Entry guidance determines that a non-zero roll is required to achieve the targeted drag level. (Mach 24.5)	V90H1044C
20.1	6.4	X	~13:49:39*	~EI+330*		Left Wing Front Spar Caps Strain Gage shows early off nominal downward trend	*Note: PCM3 entry data is in snapshot format (not continuous). Time indicated is at start of data segment where off-nominal signature is first observed, therefore event may have started earlier than noted.	V12G9169A X1107 Y232 Z?
20.2	6.45	X	13:49:49 / 59	EI+340 / EI+350		4 Left OMS Pod Surface temps - Start of off-nominal temperature trend - cooler rise rate when compared to previous flights of same inclination V07T9976A-Left OMS Pod TC BP0731T V07T9220A-OMS-L Pod LRSI Surface Temp-FWD V07T9978A-OMS-L Pod Thermocouple BP0732T V07T9972A-Left OMS Pod TC BP0749T	Followed by the start of a warmer-than-expected temperature trend beginning in the EI+510 to EI+540 sec range (seq 24.96) X1342.5 Y-128.5 Z462.6 X1321.0 YLH Z464.0 X1359.6 Y-135.1 Z463.1 X1324 Y-98 Z488	V07T9976A V07T9220A V07T9978A V07T9972A

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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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
QBAR = ~15 psf (~0.10 psi); Mach 24.4						------ 32:13:50:00 ------	EI + 351 sec; WLE Stagnation Temp: ~2520 F (STS-107 Nom EOM Design Pred)	
20.3	6.5	--	13:50:00 / 43	EI+351 / EI+394		Five events of unexpected Return link comm drop-out. Event 1 - 13:50:00 (1 sec); Event 2 - 13:50:04 / 06; Event 3 - 13:50:16/22: Event 4 - 13:50:25/28; Event 5 - 13:50:42 (1 sec)	On upper left aft antenna (TDRS 171/W). S Band comm drop-outs considered out-of-family based on comparison with previous 102 flight data at 39 degrees, into KSC, descending node and similar look angles to TDRS. Note: Observed Forward link (cmd link) dropout associated with events 3 and 4 (normal response due to switch to/from auxiliary oscillator instead of Fwd link frequency).	
20.35	6.7	X	13:50:09	EI+360		Left PLBD Surface TC BP3703T - Start of off-nominal temperature trend - cooler rise rate when compared to previous flights of same inclination	Followed by large increase in temperature at EI + 570 seconds	V07T9925A X1138.5 YLH Z441.4
20.4	6.9	X	13:50:19	EI+370		Left Wing Lower Surface Thermocouple BP2510T begins off-nominal temp increase from ~2000 deg F to ~2200 deg F over approx 50 seconds followed by a momentary 100 deg F temperature spike	The measurement subsequently fails at approximately EI+496 sec	V07T9666A X1121.1 Y-235.5 ZLWR
20.5	--	--	13:50:30	EI+381	1st Entry Heating Indication Noted in OI Telemetry	Nominal Rise in Center Line Bond Temp (1) due to Entry Heating	Aft fuselage center bottom bond line	V09T1702A
21	7	--	13:50:53	EI+404	Start of Peak Heating		Determined by analysis. The peak heating period represents the approximate time period during which the heating rate has flattened out at or near its maximum value.	
21.5			deleted				Rationale for deletion: The signatures of the STS-107 remote sensor events were very subtle. Upon further evaluation of the data, it was determined that the remote sensor signatures had been seen in previous flights and/or could be explained by known events. The events are therefore not considered to be anomalous.	
QBAR = ~19 psf (~0.13 psi); Mach 24.1						------ 32:13:51:00 ------	EI + 411 sec; WLE Stagnation Temp: ~2650 F	
21.7	7.2	X	13:51:14	EI+425		Left Wing Front Spar at RCC Panel 9 - start of off-nominal increasing temperature trend	Increasing trend continues until the measurement starts to fail at approximately EI+520 sec	V09T9895A X1102.2 Y-239.0 Z-239.0
21.9	7.25	X	13:51:14	EI+425		Left Wing RCC Panel 9 Lower Attach Clevis (between RCC 9 and 10) - start of a more rapid off-nominal increasing temperature trend	Increases until the measurement starts to fail at approximately at EI + 492 secs (ref seq 16.6 for 1st off-nominal event and seq 24.12 for failure)	V09T9910A X1112.0 Y-239.0 Z289.0
22		--	delete				Rationale for deletion: Moved to seq 31.3 (Due to wind effects, it is more appropriate to compare this parameter against previous flights for identification of off-nominal performance instead of simply referencing the point at which Beta goes and stays negative.)	

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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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
22.2	7.37	X	13:51:49	EI+460		OMS-L Pod HRSI Surf T3-AFT - Start of off-nominal higher-than-expected temperature trend when compared to previous flights of same inclination	Sensor sees a sharp temp increase at EI+910 and goes erratic at EI+940	V07T9223A X1437.2 Y-126 Z422
QBAR = ~22 psf (~0.15 psi); Mach 23.7						------ 32:13:52:00 ------	EI + 471 sec; WLE Stagnation Temp: ~2700 F	
22.5		--	deleted				Rationale for Deletion: Moved to seq #26.3 (Accounted for wind effects in the aero increment derivation process).	
22.6	7.45	--	13:52:09 / 15	EI+480 / EI+486		Unexpected Return link comm drop-out (Event 6)	On upper left aft antenna (TDRS 171/W). S Band comm drop-out considered out-of-family based on previous flt data (same remarks as seq # 20.3 above).	
22.8	7.46	X	13:52:09 / 49	EI+480 / EI+520		Nose Cap RCC Attach OutBoard Clevis (Chin Panel) - Temporary change in slope, then returns to "nominal" Note: Adjacent sensor V09T9888 (on centerline) does not show this signature		V09T9889A X262.0 Y-23.0 LWR
23			deleted					
23.3	--	--	13:52:15	EI+486	2nd Entry Heating Indication Noted in OI Telemetry	Nominal Rise in Center Line Bond Temps (2) due to Entry Heating	Mid Fus Lower "Mid" Skin Temp Mid Fus Bottom Center Bond Line Temp X1214	V34T1110A V34T1112A
23.35	7.47	X	13:52:16	EI+487		Two Left Wing and 1 Right Wing Surface Pressure measurements show signs of failure V07P8038A - L Wing Upper Surface Press (WB 3 to LE) V07P8086A - L Wing Lower Surface Press (WB 3) V07P8151A - R Wing Lower Surface Press	First OEX data to show signs of failure	V07P8038A V07P8086A V07P8151A
23.4	7.48	X	13:52:16 / 53:17	EI+487 / EI+522		All of the active measurements (does not include PCM 3 data in snapshot mode) running in the wire bundles along the left wing leading edge show signs of failure - 18 measurements	Note: Pressure measurement V07P8038A noted in seq 23.35 is included in this grouping	V07P8010A V07P8022A V07P8023A V07P8024A V07P8025A V07P8026A V07P8037A V07P8038A V07P8044A V07P8058A V07P8071A V07P8072A V07P8073A V07P8074A V09T9895A V09T9910A V07T9666A V12G9921A
23.45	7.49	X	13:52:16 / 56:24	EI+487 / EI+735		The vast majority of left wing OEX measurements show signs of failure during this time period - this includes all left wing temperature and pressure measurements and all strain measurements aft of Xo 1040 with the exception of three strain measurements on the upper surface of the LMLG compartment Additionally, 30 right wing pressure measurements show signs of failure	Note: The pressure measurements noted in seq 23.35 are included in this grouping	Multiple measurements
23.5	7.5	--	13:52:17	EI+488	Approx Vehicle Ground Location: 39.0 N / -129.2 W	Altitude 236,800 ft / Mach 23.6 - Over the Pacific Ocean, approx 300 miles West of California Coastline	Approx vehicle position when first off-nominal data was seen; Data source: STS-107 GPS Trajectory Data	

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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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
24	7.7	--	13:52:17	EI+488		LMG Brake Line Temp D - On wheel well inbd sidewall (aft of sw vlvs) - Small increase in temperature ("bit flip up")	Initiation of temp rise ("bit flip up") - may be nominal based on rise rate comparison with flight experience (similar temp response has been observed at this time frame on a small percentage of flights). Reference seq # 54.5 for next V58T1703A event.	V58T1703A
24.1	7.75	X	13:52:18	EI+489		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 approximately EI+935		V12G9048A
24.12	--	X	13:52:21 / 24.8	EI+492 / EI+495.8		2 Left Wing temperature sensors begin an off-nominal response that appears to be an indication of the measurements (sensors/wiring) failing: V09T9910A - Wing LE 55 LWR attach clevis RCC10 V07T9666A - Wing LWR SURF TC	These measurements are included in the grouping of the event noted in seq 23.45 - all left wing temperature sensor failures are shown on the timeline X1112.0 Y-239.0 Z289.0 WB-Run 1 X1121.1 Y-235.5 ZLWR WB-Run 1	
24.14	--	X	13:52:22	EI+493		Unusual Upward Shift (in one sample) of 3 Thermocouples and Downward Shift (in one sample) of 2 Thermocouples Upward Shift: V07T9480A - Fuslg LWR Surf TC BP1602TR V07T9489A - Fuslg LWR Surf TC BP1900T V07T9492A - Fuslg LWR Surf TC BP1602TR Downward Shift: V07T9522A - Fuslg Aft Penetration Area TC BP3325T V07T9636A - Left Wing upper surface TC BP4860T	All sensors receive a common 5 V power excitation via Channel 89 of PCM MUX 1	V07T9480A X1004.1 Y-99.8 ZLWR V07T9489A X1391.5 Y0.0 ZLWR V07T9492A X1511.1 Y1.3 ZLWR V07T9522A X649.3 Y-105.0 Z354.8 V07T9636A X1357.8 Y-358.0 ZUPR
24.16	7.77	X	13:52:24	EI+495		Left Wing Front Spar at RCC Panel 9 - strain gage goes erratic for approximatly 20 second - measurement appears to be failing	Subsequent data is suspect	V12G9921A X1106.0 Y-229.0 ZMID
24.18	7.8	X	13:52:25	EI+496		Left Outboard Elevon Wide Band Accelerometer - off-nominal vibration response (approximately 2G peak-to-peak) V08D9729A - L OB Elevon Z-Vib (MUX1B Ch 2)		V08D9729A
24.2	--	X	13:52:29	EI+500		Approx 10% of right wing strain gages shows small off-nominal data trend (flattening of signal followed by normal data increase or a increase in strain alone)		Multiple measurements
24.22	--	X	13:52:29	EI+500		Left Wing Lower Surface Thermocouple BP2570T - Start of approx 80 deg F drop in temperature over 20 seconds		V07T9674A X1353.1 Y-236.4 ZLWR
24.24	7.85	X	13:52:29	EI+500		OMS-L Pod HRSI Surf T1-AFT - Start of slightly off-nominal erratic trend when compared to previous flights of same inclination	Followed by drop in temperature at EI + 570 seconds and subsequent erratic temperature changes	V07T9219A X1507.1 Y-126.0 Z422.0

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Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
24.26	7.9	X	13:52:31	EI+502		Left Outboard Elevon Wide Band Accelerometer - off-nominal vibration response (approximately 3G peak-to-peak) V08D9729A - L OB Elevon Z-Vib (MUX1B Ch 2)		V08D9729A
24.28	--	X	13:52:31.3 / 38.4	EI+502.3 / EI+509.4		5 Left Wing temperature sensors begin an off-nominal response that appears to be an indication of the measurements (sensors/wiring) failing: V07T9786A - LH INBD LWR Elevon Fwd Surf V09T9893A - Wing Elevon Cove LWR Surf Temp V09T9894A - Wing Elevon Cove UPR Sur Temp V09T9860A - Elevon Cove Insul Surf 90 V09T9231A - Elevon LWR PLUG TEMP 1 (Surface)	These measurements are included in the grouping of the event noted in seq 23.45 X1387 Y-229 ZLWR WB-Run 3 X1383.8 Y-372.2 Z290.9 WB-Run 3 X1381.7 Y-372.2 Z293.9 WB-Run 3 X1379.4 Y-419.7 ZBOT WB-Run 1 X1443.5 Y-232.2 LWR WB-Run 1	V07T9786A V09T9860A V09T9893A V09T9231A V09T9894A
24.3	7.45	--	13:52:25 / 31	EI+496 / EI+502		Two events of unexpected Return link comm drop-out Event 7 - 13:52:25/26; Event 8 - 13:52:29/31	On upper left aft antenna (TDRS 171/W). S Band comm drop-out considered out-of-family based on previous flt data (same remarks as seq # 20.3 above).	
24.5			deleted					
24.7			deleted					
24.8	8.5	--	13:52:32	EI+503		Supply H2O dump Nozzle temps A/B show temporary increase in temp rise rate (15 second duration of high rise rate).	High rise rate is bounded by data loss. Increase in rise rate not observed on previous flights. GMT shown indicates start of initial rise duration. Reference event seq no. 26.6 for termination of event.	V62T0440A V62T0439A
24.9	8.5	--	13:52:32	EI+503		Vacuum vent temp shows temporary increase in temp rise rate (23 second duration of high rise rate).	High rise rate is bounded by data loss. Increase in rise rate not observed on previous flights. GMT shown indicates start of initial rise duration. Reference event seq no. 26.65 for termination of event.	V62T0551A
24.93	8.6	X	13:52:34	EI+505		OMS-L Pod HRS1 Surf T2-AFT - Start of off-nominal lower-than-expected temperature trend (compared to previous flights of same inclination) until sensor sees a sharp temp increase at EI+910 and goes erratic at EI+940		V07T9222A X1486.9 Y-126 Z422.0
24.96	8.65	X	13:52:39 / 53:09	EI+510 / EI+540		4 Left OMS Pod Surface temps - Change in existing off-nominal temperature trend (following a cooler rise rate than expected, the temperature trend that is significantly warmer when compared to previous flights of same inclination) V07T9976A-Left OMS Pod TC BP0731T V07T9220A-OMS-L Pod LRSI Surface Temp-FWD V07T9978A-OMS-L Pod Thermocouple BP0732T V07T9972A-Left OMS Pod TC BP0749T	Previous event seq 20.2 X1342.5 Y-128.5 Z462.6 X1321.0 YLH Z464.0 X1359.6 Y-135.1 Z463.1 X1324 Y-98 Z488	V07T9976A V07T9978A V07T9220A V07T9972A

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Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
25	8.7	--	13:52:41	EI+512		LMG Brake Line Temp A - On strut facing MLG door - start of off nominal trend	Initiation of temp rise - off nominal based on rise rate comparison with flight experience.	V58T1700A
25.5			deleted					
26	8.7	--	13:52:41	EI+512		Left Main Gear Brake Line Temp C - Start of off nominal trend	Unusual Temp Rise	V58T1702A
26.3	8.75	--	13:52:44 / 52:50	EI+515 / EI+521		First clear indication of off-nominal aero increments	Delta yawing moment coefficient indicates off-nominal trend at 13:52:44; delta rolling moment coefficient at 13:52:50. Derived by analysis.	n/a
26.5			deleted					
26.6	8.5	--	13:52:47	EI+518		Supply H2O dump Nozzle temps A/B return to typical rise rates.	High rise rate is bounded by data loss. GMT shown indicates end of initial rise duration. Temp took additional 48 seconds to return to nominal temp rise (53:35 GMT).	V62T0440A V62T0439A
26.63	7.45	--	13:52:49 / 55	EI+520 / EI+526		Unexpected Return link comm drop-out (Comm event 9)	On upper left aft antennae (TDRS 171/W). S-Band comm drop-out considered out-of-family based on previous flt data (same remarks as seq # 20.3 above).	
26.64	--	X	13:52:49.5 / 52:51.4	EI+520.5 / EI+522.4		2 Left Wing temperature sensors begin an off-nominal-response that appears to be an indication of the measurements (sensors/wiring) failing: V09T9895A - Wing Front Spar Panel 9 Temp V09T9849A - Outboard ELEVON, Lower Surface Edge	These measurements are included in the grouping of the event noted in seq 23.45 X1102.2 Y-239.0 Z-239.0 WB-Run 3 X1429.1 Y-315.3 ZLWR WB-Run 1	V09T9895A V09T9849A
26.65	8.5	--	13:52:55	EI+526		Vacuum vent temp returns to typical rise rate.	High rise rate is bounded by data loss. GMT shown indicates end of initial rise duration. Temp took additional 40 seconds to return to nominal temp rise (53:35 GMT).	V62T0551A
26.7	--	--	13:52:56	EI+527		Left INBD Elevon Lower Skin Temp - Start of off nominal trend	Temp trending down	V09T1006A
27	10		13:52:59	EI+530		Left INBD Elevon Lower Skin Temp - OSL		V09T1006A
27.1	--	X	13:52:59.4 / 53:07.4	EI+530.4 / EI+538.4		5 Left Wing temperature sensors begin an off-nominal-response that appears to be an indication of the measurements (sensors/wiring) failing: * V07T9785A - LH OTBD LWR Elevon Fwd Surf V07T9711A - Wing LWR SURF TC V07T9636A - Wing L Upper Surf Thermocouple V09T9845A - Outboard ELEVON, MID GAP, Fwd * V07T9713A - Wing LWR SURF TC *Note: These measurements were observed off-nominal in the EI+485 / 488 period but it was inconclusive if the measurements were failing at that time	These measurements are included in the grouping of the event noted in seq 23.45 X1396.1 Y-372.2 ZLWR WB-Run 1 X1362.0 Y-369.3 ZLWR WB-Run 1 X1357.8 Y-358.0 ZUPR WB-Run 4 X1440.4 Y-316 ZLWR WB-Run 1 X1402.0 Y-375.3 ZLWR WB-Run 1	V07T9785A V09T9845A V07T9711A V07T9713A V07T9636A

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Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
QBAR = ~25.5 psf (~0.18 psi); Mach 23.2						------ 32:13:53:00 ------		EI + 531 sec; WLE Stagnation Temp: ~2800 F
27.2		--	deleted				Rationale for deletion: This event moved/merged with new sequence # 26.3 (Accounted for wind effects in aero increment derivation process).	
27.5	--	--	13:53:02	EI+533		Hyd Syst 1 LH INBD Elevon Actr Ret Ln Temp - start of off nominal trend Hyd Syst 3 LOE Ret LN Temp - start of off nominal trend	Temp trending down Temp trending down	V58T0157A V58T0394A
27.7	10.6	X	13:53:03	EI+534		Left Outboard Elevon Wide Band Accelerometer - onset of signal saturation indicating likely measurement failure (approximately 10G peak-to-peak - off-scale) V08D9729A - L OB Elevon Z-Vib (MUX1B Ch 2)		V08D9729A
28	11	--	13:53:10	EI+541		Hyd Syst 3 LOE Ret LN Temp - OSL	OSL was preceded by Nominal Temp rise	V58T0394A
29	11	--	13:53:11	EI+542		Hyd Syst 1LH INBD Elevon Actr Ret Ln Temp - OSL	OSL was preceded by Nominal Temp rise	V58T0157A
29.3			deleted				Rationale for deletion: alpha modulation time tag updated - moved to seq #29.7	
29.5	11.2	--	13:53:26	EI+557	Approx Veh Grd Location: 38.7 N / -123.5 W	Altitude 231600 ft / Mach 23.0 - Crossing the California Coastline	Data source: STS-107 GPS Trajectory Data	
29.55	11.21	X	13:53:29	EI+560		Left Fuselage Side Surface Temp BP3605T - start of off-nominal increasing temperature trend from ~180 deg F to 400 deg F	Trend followed by temperature drop and rise (ref seq 36.2 for next event of this sensor)	V07T9253A X1000.7 Y-105 Z354.5
29.6	11.22	X	13:53:29	EI+560		Left PLBD Surface TC BP3603T - Start of slightly off-nominal erratic temperature trend when compared to previous flights of same inclination		V07T9913A X1003.8 YLH Z441.3
29.63	11.23	X	13:53:29	EI+560		Left PLBD Surface TC BP3703T - start of off-nominal temperature rise, peaking at EI+625, followed by temperature drop and subsequent off-nominal higher-than-expected temperature signature		V07T9925A X1138.5 YLH Z441.4
29.66	11.24	X	13:53:29	EI+560		Left Fuselage Side Surface TC BP3604T - Start of slightly off-nominal erratic temperature trend when compared to previous flights of same inclination		V07T9903A X1006 Y-105 Z398.4
29.7	11.25	--	13:53:31	EI+562	Alpha Modulation	Angle of attack (alpha) modulation active	Entry Guidance enables limited delta angle of attack commands from the reference angle of attack to promote improved convergence to the reference drag profile.	V90H0803C
30	11	--	13:53:31 / 53:34	EI+562 / EI+565		Hyd Syst 1 LOE Return Line Temp - OSL	OSL was preceded by Nom Temp rise plus data loss 3 sec's prior to event	V58T0193A
30.2	11.3	--	13:53:32 / 34	EI+563 / EI+565		Unexpected Return link comm drop-out (Comm event 10)	On upper left aft antennae (TDRS 171/W). S-Band comm drop-out considered out-of-family based on previous flt data (same remarks as seq # 20.3 above).	

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Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
30.3	–	--	13:53:34 / 55:57	EI+565 / EI+668	2nd Entry Heating Indication Noted in OI Telemetry	Nominal Rise in Center Line Bond Temps (3) due to Entry Heating	13:53:34 - V09T1016A (Mid Fus Bot Port BL T X 620); 13:54:00 - V09T1022A (Mid Fus Bot Port BL T X 777); 13:55:57 - V09T1624A (Fwd Fus Lwr Skin Bot CL T)	V09T1016A V09T1022A V09T1624A
30.5	–	--	13:53:34	EI+565		Hyd Sys 2 LIE Return Ln Temp - Start of Off Nominal Trend	Temp trending down	V58T0257A
31	11	--	13:53:36	EI+567		Hyd Sys 2 LIE Return Ln Temp - OSL		V58T0257A
31.25	11.35	X	13:53:37	EI+568		Xo 1040 Spar (MLG Forward Wall Spar) Strain Gage - Upper Cap - start of off-nominal increase in strain indication (over an approximate 115 second interval) followed by sudden decrease	Reference seq 41.2 for next event of this sensor	V12G9049A X1040 Y-135 ZUPR
31.3	11.37	--	13:53:38	EI+569		Inertial sideslip angle (Beta) exceeds flight history.	The steady state navigation derived sideslip angle becomes out-of-family as compared to previous flight data at this point in the trajectory.	V90H2249C
31.5			deleted					
31.7			deleted					
32			deleted					
32.05	11.4	X	13:53:44	EI+575		OMS-L Pod HRSI Surf T1-AFT - Start of off-nominal lower-than-expected temperature trend when compared to previous flights of same inclination	Sensor goes erratic at EI+940	V07T9219A X1507.1 Y-126.0 Z422.0
32.1	11.5	--	13:53:45 / 47	EI+576 / EI+578		Debris #1 - First report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope one second after a plasma anomaly which consisted of a noticeably luminescent section of the plasma trail. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0064 EOC2-4-0056 EOC2-4-0201 Plasma anomaly: EOC2-4-0136
32.3	11.5	--	13:53:46 / 50	EI+577 / EI+581		Debris #2 - Second report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0064 EOC2-4-0056 EOC2-4-0201
32.5	–	--	13:53:46	EI+577		LMG Brake Line Temp A - On strut facing MLG door - Start of off nominal trend (temp rise rate change)	Temp rise rate change from 1.4 F/min to 5.5 F/min and increasing to LOS	V58T1700A
32.6	–	X	13:53:47.6	EI+578.6		1 temperature sensor begins an off-nominal response that appears to be an indication of the measurement (sensor/wiring) failing: V07T9674A - Wing LWR SURF TC	This measurement is included in the grouping of the event noted in seq 23.45 X1353.1 Y-236.4 ZLWR WB-Run 4	V07T9674A

A.2-10
Integ Time Line Team - REV 19 BASELINE

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

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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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
32.7	11.5	–	13:53:54 / 58	EI+585 / EI+589		Debris #3 - Third report of debris observed leaving the Orbiter. Event followed by momentary brightening of plasma trail.	Seen just aft of Orbiter envelope followed one second later by a plasma anomaly which consisted of a noticeably luminescent section of the plasma trail. No evidence of RCS jet firings (ref Atlas data and plots).	Debris: EOC2-4-0055, 0056 Plasma Anomaly: EOC2-4-0064, 0136
QBAR = ~29 psf (~0.20 psi); Mach 22.7 ------ 32:13:54:00 ------ EI + 591 sec; WLE Stagnation Temp: ~2850 F								
32.8	11.5	–	13:54:00 / 04	EI+591 / EI+595		Debris #4 - Fourth report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0056 EOC2-4-0055
32.9	11.5	–	13:54:07 / 11	EI+598 / EI+602		Debris #5 - Fifth report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope at the head of a plasma anomaly. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0056 EOC2-4-0055
33	13	–	13:54:10	EI+601		LMG Brake Line Temp B - Start of off nominal trend	Temp Increase	V58T1701A
33.3	13.5	–	13:54:11	EI+602		Reversal in growth trend of derived roll moment coefficient	Observed moment changed from a negative slope to positive slope. Derived by analysis.	n/a
33.5	11.3	–	13:54:14 / 22	EI+605 / EI+613		Unexpected Return link comm drop-out (Comm event 11)	On upper left aft antennae (TDRS 171/W). S-Band comm drop-out considered out-of-family based on previous flt data (same remarks as seq # 20.3 above).	
34	14	–	13:54:20	EI+611		Start of slow aileron trim change	The aileron trim setting observed in flight first 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))	V90H1500C
34.5			deleted				Rationale for deletion: Moved to seq #33.3, time tag updated	
35	15	–	13:54:22	EI+613		M-FUS LT BL Temp at x1215 - start of off nominal trend (increased rise rate)	Unusual Temp Rise (Rise rate higher than STS-109 & 87). Rise rate increased from 1 F/min (typical) to 7.5 F/min.	V34T1106A
35.2	15	–	13:54:22	EI+613		LH Aft Fus Sidewall Temp at x1410 - start of off nominal trend (increased rise rate)	Unusual Temp Rise (Rise rate higher than STS-109 & 87). Rise rate increased from 2.7 F/min (typical) to 5.4 F/min.	V09T1724A
35.5	13	–	13:54:24	EI+615		Sys 3 Left Main Gear Strut Actuator Temp - start of off nominal trend	Unusual Temp Rise	V58T0405A
35.7	–	–	13:54:25	EI+616	Approx Veh Grd Location: 38.3 N / -119.0 W	Altitude 227400 ft / Mach 22.5 - Crossing the California / Nevada State Line	Data source: STS-107 GPS Trajectory Data	
35.8	–	–	13:54:26	EI+617		S-Band switched from upper left aft antennae to upper right aft antenna.	TDRS 171/W	

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

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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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
36			deleted					
36.2	15.2	X	13:54:29	EI+620		Left Fuselage Side Surface temp BP3605T peaks and starts downward trend	Ref seq 29.55 for previous event of this sensor and seq 54.1 for next event of this sensor	V07T9253A X1000.7 Y-105 Z354.5
36.5	15.3	–	13:54:33.3 / 33.9	EI+624.3 / EI+624.9		Flash #1 - Orbiter envelope suddenly brightened (duration 0.3 sec), leaving noticeably luminescent signature in plasma trail	Note: R3R and R2R 0.24 sec jet firings occurred at 13:54:33.52 / 33.76 and 13:54:33.54 / 33.78 respectively (ref: RCS Atlas analysis and plots).	EOC2-4-0055 EOC2-4-0034 EOC2-4-0009B EOC2-4-0066 EOC2-4-0070
36.55	15.32	X	13:54:34	EI+625		Left Fuselage Side Surface temp BP3703T peaks and starts downward trend	Ref seq 29.63 for previous event of this sensor and seq 70.1 for next event of this sensor	V07T9925A X1138.5 YLH Z441.5
36.6	15.3	–	13:54:35 / 37	EI+626 / EI+628		Debris #6 - Very bright debris seen leaving the Orbiter	Seen just aft of Orbiter envelope. Also, reference RCS jet firing note in item # 36.5 above. Debris events 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.	EOC2-4-0055 EOC2-4-0034 EOC2-4-0009B EOC2-4-0066 EOC2-4-0070
36.7	15.33	X	13:54:39	~EI+630		Strain Gages Centered on the Upper Surface of the Left MLG Wheel Wheel - Higher-than-expected strain indications observed in these gages	Note: PCM3 entry data is in snapshot format (not continuous), therefore event may have occurred earlier than noted	V12G9156A, V12G9157A, V12G9158A
36.8	15.34	X	13:54:39	~EI+630		Left Wing X1040 Spar Web - shows increase in strain	Note: Adjacent sensor V12G9165A did not show similar "off-nominal" signature at this time, also, PCM3 entry data is in snapshot format (not continuous), therefore event may have occurred earlier than noted	V12G9166A V12G9167A (V12G9165A-nominal)
37			deleted					
37.5			deleted					
37.7	–	–	13:54:53	EI+644		MLG LH Outbd Wheel Temp - start of off nominal trend	2 bit flips up (ref #56.5 when temp starts to trend down)	V51T0574A
QBAR = ~34.5 psf (~0.24 psi); Mach 22.1 ------ 32:13:55:00 ------ EI + 651 sec; WLE Stagnation Temp: ~2900 F								
37.75	15.35	–	13:55:04 / 06	EI+655 / EI+657		Debris #7 - Seventh report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0030
37.8	13	–	13:55:12	EI+663		Sys 3 LMG Brake Sw Vlv Ret Line Temp (FWD) - start of off nominal trend	Temp Increase	V58T0842A
37.9	15.35	–	13:55:17 / 19	EI+668 / EI+670		Debris #7A - Report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope	EOC2-4-0161
38			deleted					
39			deleted					
40	–	–	13:55:21	EI+672	Drag 11 ft/sec^2	Drag Measurement Incorporation	Incorporation of drag-derived altitude into the vehicle navigation state.	

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

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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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
40.02	15.35	--	13:55:21 / 25	EI+672 / EI+676		Debris #8 - Report of debris observed leaving the Orbiter.	Seen just aft of Orbiter envelope inside the aforementioned Debris Shower A. No evidence of RCS jet firings (ref Atlas data and plots).	Debris: EOC2-4-0030, 0098, & 0161
40.05	15.37	--	13:55:22 / 28	EI+673 / EI+679		Debris Shower A - Report of debris shower seen just aft of Orbiter envelope.	Seen just aft of Orbiter envelope. Over the course of these four seconds a luminescent section of plasma trail is observed which appears to contain a shower of indefinite particles and multiple, larger discrete debris that includes Debris 8, 9, and 10.	Saw debris: EOC2-4-0098, 0161, 0005, 0030 Saw shower: EOC2-4-0017, 0021, 0028
40.1			deleted				Rationale for deletion: moved to 40.02 after further review of the videos	
40.2	15.35	--	13:55:24 / 28	EI+675 / EI+679		Debris #9 - Report of debris observed leaving the Orbiter.	Seen just aft of Orbiter envelope inside the aforementioned Debris Shower A. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0005, 0098
40.3	15.35	--	13:55:25 / 29	EI+676 / EI+680		Debris #10 - Report of debris observed leaving the Orbiter	Seen well aft of Orbiter envelope inside the aforementioned Debris Shower A. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0005
40.4			deleted				Rationale for deletion: The signatures of the STS-107 remote sensor events were very subtle. Upon further evaluation of the data, it was determined that the remote sensor signatures had been seen in previous flights and/or could be explained by known events. The events are therefore not considered to be anomalous.	
40.5	--	--	13:55:32	EI+683	Approx Veh Grd Location: 37.4 N / -114.1 W	Altitude 223400 ft / Mach 21.8 - Crossing the Nevada / Utah State Line	Data source: STS-107 GPS Trajectory Data	
40.6	15.43	--	13:55:33 / 35	EI+684 / EI+686		Return link comm drop-out (Comm event 12)	First comm drop out after switched to upper right aft antennae (TDRS 171/W). While uncommon to have a drop out at this point, inconclusive if drop-out is off-nominal based on previous flt data.	
41			deleted					
41.2			deleted				Rationale for deletion: Moved to 41.55 after further review of the data	

A.2-13
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Appendix A.2 - STS-107 Mishap Investigation - Master Time Line

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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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
41.5	15.45	--	13:55:35 / 39	EI+686 / EI+690		Debris #11 - Report of debris observed leaving the Orbiter	Appears at the head of a secondary parallel plasma trail well aft of Orbiter envelope. A second piece of debris is also seen in the secondary plasma trail. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0050, EOC2-4-0098
41.55	15.46	X	13:55:36	EI+687		Xo 1040 Spar (MLG Forward Wall Spar) Strain Gage - Upper Cap - sudden drop in strain followed by gradual increase until erratic signature at approximately EI+930	Reference seq 31.25 for previous event of this sensor	V12G9049A X1040 Y-135 ZUPR
41.6	15.45	--	13:55:38 / 40	EI+689 / EI+691		Debris #11A - Report of debris observed leaving the Orbiter	Seen just aft of Orbiter envelope.	EOC2-4-0098
41.7	15.45	--	13:55:38 / 42	EI+689 / EI+693		Debris #11B - Report of debris observed leaving the Orbiter	Seen at head of a parallel plasma trail aft of the Orbiter envelope.	EOC2-4-0098
42	15.5	--	13:55:41	EI+692		Mid Fus Port (Left) Sill Longn Temp at x1215 - start of off nominal trend	Unusually high temp rise with respect to STS-87 & 109. Went to 2.9 F/min from 0 F/min.	V34T1118A
42.2	15.45	--	13:55:42 / 46	EI+693 / EI+697		Debris #11C - Report of debris observed leaving the Orbiter	Seen at head of a parallel plasma trail well aft of the Orbiter envelope.	See debris & parallel trail: EOC-4-0098 See parallel plasma trail only: EOC2-4-0028, 0050
42.3	15.45	--	13:55:44 / 46	EI+695 / EI+697		Debris #12 - Report of debris observed leaving the Orbiter. Event was preceded and followed by secondary plasma trails.	Seen aft of Orbiter envelope. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0028, 0050, 0098
42.5			deleted				Rationale for deletion: Moved to seq # 42.75 (mislocated in timeline based on GMT associated with event)	
42.7	15.45	--	13:55:54 / 58	EI+705 / EI+708		Debris #13 - Report of debris observed leaving the Orbiter. Event was followed by momentary brightening of plasma trail adjacent to debris.	Seen well aft of Orbiter envelope. No evidence of RCS jet firings (ref Atlas data and plots).	EOC2-4-0005, 0017, 0021, 0161
42.75	--	--	13:55:55	EI+706	Approx Veh Grd Location: 37.0 N / -112.4 W	Altitude 222100 ft / Mach 21.5 - Crossing the Utah / Arizona State Line	Data source: STS-107 GPS Trajectory Data	
42.8	15.45	--	13:55:57 / 59	EI+708 / EI+710		Debris #14 - Very bright debris observed leaving the Orbiter.	Seen just aft of Orbiter envelope. Debris events 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).	EOC2-4-0005, 0017, 0021, 0028, 0030

A.2-14

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

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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
QBAR = ~40 psf (~0.28 psi); Mach 21.4						------ 32:13:56:00 ------		EI + 711 sec; WLE Stagnation Temp: ~2900 F
42.9	15.43	–	13:56:00 / 03	EI+711 / EI+714		Return link comm drop-out (Comm event 13)	On upper right aft antennae (TDRS 171/W). While uncommon to have a drop out at this point, inconclusive if drop-out is off-nominal based on previous flt data. Note: No further comm drop-out events are listed in the timeline thru LOS, since are not considered out-of-family at this time.	
43	–	–	13:56:02	EI+713	Qbar 40 psf	Aft RCS Pitch Jets Deactivated	Pitch control is soley achieved through elevator and body flap commands from this point forward.	
44	16	–	13:56:03	EI+714		Left Lower Wing Skin Temp - start of off nominal trend	Temp reading trending down (potential sensor/wire damage)	V09T1002A
44.2	15.45	–	13:56:08 / 12	EI+719 / EI+723		Debris #15 - Report of debris observed leaving the Orbiter.	Seen just aft of Orbiter envelope. Nearest jet firings: R2R jet firing at 032:13:56:17.30 / 56:17.54 for 0.24 seconds, & R3R jet firing at 032:13:56:17.28 / 56:17.52 for 0.24 seconds. (Ref: RCS Atlas data analysis and plots).	EOC2-4-0017
44.5	16.5	–	13:56:16	EI+727		Hyd Sys 1 LMG UpLK Actr Unlk Ln Temp - Temp rise rate change	Temp rise rate change from 0.7 F/min (nominal) to 3.9F/min and increasing to LOS	V58T0125A
44.6	16.5	–	13:56:17	EI+728		Sys 3 LMG Brake Sw Vlv Ret Line Temp (FWD) - Temp rise rate change	Temp rise rate change from 1.5 F/min to 8.8 F/min (stayed at this rate to LOS)	V58T0842A
44.7	16.5	–	13:56:20	EI+731		LMG Brake Line Temp C - Temp rise rate change	Temp rise rate change from 1.3 F/min to 9.9 F/min (stayed at this rate to LOS)	V58T1702A
44.8	16.5	–	13:56:22	EI+733		LMG Brake Line Temp B - Temp rise rate change	Temp rise rate change from 2.1 F/min to 9.1 F/min increasing to LOS	V58T1701A
45	16	–	13:56:24	EI+735		Left Upper Wing Skin Temp - start of off nominal trend	Temp reading trending down (potential sensor/wire damage)	V09T1024A
46	16.55	–	13:56:30	EI+741		1st Roll Reversal Initiation	Entry guidance changes the sign of the roll command to redirect the vehicle back towards the center of the delta azimuth (heading error) corridor.	V90H1044C
46.5	–	–	13:56:45	EI+756	Approx Veh Grd Location: 36.1 N / -109.0 W	Altitude 219000 ft / Mach 20.9 - Crossing the Arizona / New Mexico State Line	Data source: STS-107 GPS Trajectory Data	
46.7	16.5	–	13:56:53	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)	V58T0405A
47	16.55	–	13:56:55	EI+766	Roll Reversal #1	1st Roll Reversal Complete	Actual roll achieves desired roll command.	V90H1044C

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

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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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
47.5			deleted				Rationale for deletion: Comm dropout (event 14) is deleted since probably nominal due to completion of roll reversal resulting in elevation angle nearing 60 degrees.	
48			deleted				Rationale for deletion: IMU Velocity increase reflects accelerations imparted during roll reversal. Same signature observed on STS-109. Nominal event.	
QBAR = ~42 psf (~0.29 psi); Mach 20.7						------ 32:13:57:00 ------		EI + 771 sec; WLE Stagnation Temp: ~2900 F
49	–	–	13:57:nn			Bodyflap deflection up 3 degrees	Matches nominal aero simulation	V90H6410C
49.5			deleted					
49.51	16.65	X	13:57:09	EI+780		Fuselage Side Surf Thermocpl BP3976T - start of off-nominal trend (temp increase followed by temp drop / rise)		V07T9270A X1486.1 Y-124.8 Z307.1
49.53	16.67	X	13:57:09	EI+780		Fuselage Lower Surface BF Thermocpl BP220T - start of off-nominal trend (shallow temp drop)		V07T9508A X1560 Y-111.1 Z LWR
49.55	16.8	–	13:57:19 / 29	EI+790 / EI+800		Debris # 16 - Very faint debris observed leaving just aft of Orbiter. (Occurred over eastern AZ and NM.)	Observations by personnel from the Starfire Optical Range (Kirtland Air Force Base, NM). Note: nearest jet firings: L2L jet firing at 032:13:56:54.71 / 57:01.12 & 032:13:57:46.35 / 57:53.12 & L3L jet firing at 032:13:56:54.66 / 57:01.07 & 032:13:57:46.33 / 57:53.10 (all 4 occurred during data dropouts & were determined based on injector temps alone). Also, R2R at 032:13:57:43.94 / 57:44.42 & R3R at 032:13:57:43.92 / 57:44.40 for 0.48 secs ea. (Ref Atlas data analysis and plots.)	EOC2-4-0148-2
49.6	16.9	–	13:57:19	EI+790		MLG LH Outbd Tire Pressure 1 - start of off nominal trend	Bit flip up - off nominal thru comparison with previous flights	V51P0570A
49.7	16.9	–	13:57:24	EI+795		MLG LH Outbd Tire Pressure 2 - start of off nominal trend	Bit flip up - off nominal thru comparison with previous flights	V51P0572A
50	17	–	13:57:28	EI+799		Left Lower Wing Skin Temp - OSL		V09T1002A
51	–	–	deleted				Rationale for deletion: Originally indicated as "Start of Roll trim in elevons". Inserted independently early in the investigation, but is better defined by sequence no. 54. "Roll trim" is better indicated with aileron trim.	
52	17	–	13:57:43	EI+814		Left Upper Wing Skin Temp - OSL		V09T1024A
53	19	–	13:57:54	EI+825		Sys 2 LH Brake Switching Vlv Return Temp (AFT) - start of off nominal trend	Temp increase	V58T0841A

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

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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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
53.5	16.8	--	13:57:53.5 / 55.5	EI+824.5 / EI+826.5		Flare 1: Assymmetrical brightening of Orbiter shape observed. (Occurred over eastern AZ and NM.)	Observations by personnel from the Starfire Optical Range (Kirtland Air Force Base, NM). Note: nearest jet firings: Same as seq no. 49.55 plus L2L at 032:13:58:00.50 / 01.46 & L3L at 032:13:58:00.48 / 01.44 (in both cases there was no start up data, but good tail off/shutdown) - 0.96 sec pulse each. Also, R2R at 032:13:58:03.18 / 09.16 & R3R at 032:13:58:03.18 / 09.16 - (in both cases firings occurred during data dropouts and were determined by injector temps). (Ref Atlas analysis and plots.)	EOC2-4-0148-4
53.7	16.8	--	13:57:59.5 / 58:01.5	EI+830.5 / EI+832.5		Flare 2: Assymmetrical brightening of Orbiter shape observed. (Occurred over eastern AZ and NM.)	Observations by personnel from the Starfire Optical Range (Kirtland Air Force Base, NM). Note: same jet firing information as for event seq no.s 49.55 & 53.5. (Ref Atlas analysis and plots.)	EOC2-4-0148-4
QBAR = ~52.5 psf (~0.36 psi); Mach 19.8						------ 32:13:58:00 ------		EI + 831 sec; WLE Stagnation Temp: ~2880 F
54	20	--	13:58:03	EI+834		Start of "sharp" aileron trim increase	An abrupt increase in the rate of change in the aileron trim occurs near this time, indicating flight control is now compensating for increasingly asymmetric aerodynamics. This trend continues to LOS. (GMT is approximate (13:58:03+/-10 seconds).)	V90H1500C
54.1	20.3	X	13:58:04	EI+835		Left fuselage side surface temp BP3605T starts off-nominal temperature increase	Ref seq 36.2 for previous event of this sensor	V07T9253A X1000.7 Y-105 Z354.5
54.3	20.5	--	13:58:04 / 58:19	EI+835 / EI+850		Increase in off-nominal aero increments.	Substantial increase in rate of change of rolling (13:58:04) and yawing (13:58:19) moment increments and initial indication of off-nominal pitching moment increment (13:58:05). Derived by analysis.	n/a
54.5	22.5	--	13:58:16	EI+847		LMG Brake Line Temp D - Temp rise rate change	Temp rise rate change from 0.9 F/min to 11.7 F/min (stayed at this rate to LOS)	V58T1703A
55			deleted					
55.5			13:58:20	EI+851	Approx Veh Grd Location: 34.2 N / -103.1 W	Altitude 209800 ft / Mach 19.5 - Crossing the New Mexico / Texas State Line	Data source: STS-107 GPS Trajectory Data	
56			deleted					
57	23	--	13:58:32	EI+863		MLG LH Outbd Tire Pressure 1 - pressure trending down (to OSL)	Trending to OSL following 7 sec LOS (initiation time not exact) - ref #60	V51P0570A
58	23	--	13:58:32	EI+863		MLG LH Inbd Tire Pressure 1 - pressure trending down (to OSL)	Trending to OSL following 7 sec LOS (initiation time not exact) - ref #64	V51P0571A
58.5	--	--	13:58:32	EI+863		MLG LH Outbd Wheel Temp - temperature trending down (to OSL)	Trending to OSL following 7 sec LOS (initiation time not exact) - ref #62	V51T0574A

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

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

Seq No.	Sum No.	OEX Data	GMT / GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
58.7	--	--	13:58:32 / 59:22	EI+863 / EI+913		Sys 2 LH Brake Switching Vlv Return Temp (AFT) - temp rise rate change	Temp rise rate change from 2.5 F/min to 40.0 F/min until 13:59:22 (temp peak) - ref #70.5	V58T0841A
59	--	--	13:58:36	EI+867		MLG LH Inbd Wheel Temp - start of temperature trending down (to OSL)	Start of trend to OSL - ref #66	V51T0575A
60	23	--	13:58:38	EI+869		MLG LH Outbd Tire Pressure 1 - OSL		V51P0570A
61			deleted				Rationale for deletion: Moved to seq no. 63.5 after further data review.	
62	25	--	13:58:39	EI+870		MLG LH Outbd Wheel Temp - OSL		V51T0574A
63	23	--	13:58:39	EI+870		MLG LH Outbd Tire Pressure 2 - start of pressure trending down (to OSL)	Start of trend to OSL - ref #68	V51P0572A
63.5	25.5	--	13:58:40	EI+871		BFS Fault Msg (4) - Tire Pressures - First Message	32/13:58:39.94 - SM0 Tire P LOB 32/13:58:41.84 - SM0 Tire P LIB 32/13:58:49.54 - SM0 Tire P LIB 32/13:58:56.26 - SM0 Tire P LOB	
64	23	--	13:58:40	EI+871		MLG LH Inbd Tire Pressure 1 - OSL		V51P0571A
65	--	--	13:58:41	EI+872		MLG LH Inbd Tire Pressure 2 - start of off nominal trend	Press rose ~3.5 psia in 2 sec's	V51P0573A
65.5	23	--	13:58:43	EI+874		MLG LH Inbd Tire Pressure 2 - start of pressure trending down		V51P0573A
66	25	--	13:58:48	EI+879		MLG LH Inbd Wheel Temp - OSL		V51T0575A
67	23	--	13:58:48	EI+879		MLG Inbd Tire Pressure 2 - OSL		V51P0573A
68	23	--	13:58:54	EI+885		MLG LH Outbd Tire Pressure 2 - OSL		V51P0572A
69	26	--	13:58:56	EI+887		BFS Fault Msg (4) - Tire Pressures - Last Message		
QBAR = ~63.5 psf (~0.44 psi); Mach 18.7						------ 32:13:59:00 ------		EI + 891 sec; WLE Stagnation Temp: ~2850 F
70	27	--	13:59:06	EI+897		Left Main Gear Downlocked Indication - Transferred ON	Uplock indicated no change	V51X0125E
70.1	27.3	X	13:59:09 / 59:39	EI+900 / EI+930		Several left side temperature measurements show a rapid increase in temperature followed by erratic behavior and subsequent loss of the measurements at approximately EI+940 V07T9925A - L Fus Side Surf TC BP7303T (on PLBD) V07T9972A - OMS-L Pod TC BP0749T V07T9976A - OMS-L Pod TC BP0731T V07T9903A - L Fus Side Surf TC BP3604T V07T9913A - L Fus Side Surf TC BP3603T (on PLBD) V07T9976A - OMS-L Pod Thermocouple BP0731T V07T9978A - OMS-L Pod Thermocouple BP0732T V07T9222A - OMS-L Pod HRS1 Surf T2-AFT V07T9223A - OMS-L Pod HRS1 Surf T3-AFT		V07T9925A X1138.5 YLH Z441.4 V07T9972A X1324 Y-98 Z488 V07T9976A X1342.5 Y-128.5 Z462.6 V07T9903A X1006 Y-105 Z398.4 V07T9913A X1003.8 YLH Z441.3 V07T9976A X1342.5 Y-128.5 Z462.6 V07T9978A X1359.6 Y-135.1 Z463.1 V07T9222A X1486.9 Y-126 Z422.0 V07T9223A X1437.2 Y-126 Z422.0
70.3	27.5	--	13:59:23	EI+914		Loss of MCC real-time data to the workstations in the FCR and MER		
70.5	--	--	13:59:22	EI+913		Sys 2 LH Brake Switching Vlv Return Temp (AFT) - start of sharp downward temperature trend	Temp trending down until loss of signal - ref #81	V58T0841A
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 (13:59:28), rolling (13:59:28) and yawing (13:59:26) increments. Magnitude of aero increments starting to exceed ability of aileron to laterally trim the vehicle. Derived by analysis.	n/a

A.2-18
Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
71	28	--	13:59:30.66	EI+921.66		Start of R2R yaw firing	Last pulse before LOS (stayed on to end of first 5-sec period of recon data at 032/13:59:37.4 GMT)	V79X2634X
72	28	--	13:59:30.68	EI+921.68		Start of R3R yaw firing	Last pulse before LOS (stayed on to end of first 5-sec period of recon data at 032/13:59:37.4 GMT)	V79X2638X
73	29	--	13:59:31	EI+922		Observed elevon deflections at LOS	Left: -8.11 deg (up); Right: -1.15 deg (up)	V90H7505C V90H7555C
73.1	29.3	--	13:59:31.400	EI+922.4		FCS Channel 4 Aerosurface position measurements start trending towards their null values	Indicates worsening failure of transducer excitation via a wiring short conditions	V57H0253A (5 Hz)
73.2	29.3	--	13:59:31.478	EI+922.5		All FCS Channel 4 Bypass valves close (indicating bypassed)	Leading indicator of ASA fail (high-rate data)	V58P0915A
73.3	29.3	--	13:59:31.7	EI+922.7		Speedbrake channel 4 OI position measurement indicated successively 19, 20, 24 degrees over last three samples prior to LOS (should be closed / 0°).	Speedbrake was commanded to "overclose" (-10 degrees), position measurements for Channels 1 thru 3 were 0 degrees. Secondary delta pressure on Ch 4 went to zero, which indicates that the channel was bypassed. This is real data and the ASAs were responding appropriately.	V57H0253A (5 Hz)
73.5	29.5	--	13:59:32	EI+923		Observed aileron trim at LOS	Trim: -2.3 deg (V96H2045C - V90H1500C)	
74	--	--	13:59:32	EI+923		M-FUS LT BL Temp at x1215 - LOS	LOS	V34T1106A
74.5	--	--	13:59:32	EI+923		LH Aft Fus Sidewall Temp at x1410 - LOS	LOS	V09T1724A
75	--	--	13:59:32	EI+923		LMG Brake Line Temp A - LOS	LOS at 172.2 F	V58T1700A
76	--	--	13:59:32	EI+923		LMG Brake Line Temp B - LOS	LOS at 154.2 F	V58T1701A
77	--	--	13:59:32	EI+923		LMG Brake Line Temp C - LOS	LOS at 104.8 F	V58T1702A
78	--	--	13:59:32	EI+923		LMG Brake Line Temp D - LOS	LOS at 88.3 F	V58T1703A
79	--	--	13:59:32	EI+923		Left Main Gear Strut Actuator Temp - LOS	LOS at 76.3 F	V58T0405A
80	--	--	13:59:32	EI+923		Hyd Sys 1 LMG Uplk Actr Unlk Ln Temp - LOS	LOS at 52.2 F	V58T0125A
81	--	--	13:59:32	EI+923		Sys 2 LH Brake Sw Vlv Return Temp (AFT) - LOS	LOS at 62.8 F	V58T0841A
82	--	--	13:59:32	EI+923		Sys 3 LMG Brake Sw Vlv Return Line Temp (FWD) - LOS	LOS at 67.3 F	V58T0842A
82.7	32.5	--	31:59:32	EI+923	Approx Veh Grd Location: 32.9 N / -99.0 W	Altitude ~200700 ft / Mach ~18.1 - Near Dallas TX	Approximate Vehicle Ground Location at Loss of Signal based on GMT; Data source: STS-107 GPS Trajectory Data	
82.8	29.3	--	13:59:32.130	EI+923.130		FCS Channel 4 fail flags raised (1 Hz) on all aerosurface actuators	Lagging indicator of ASA position measurement discrepancy	V79X3263X V79X3278X V79X3268X V79X3334X V79X3273X V79X3339X
83	33	--	13:59:32.136	EI+923.136	LOS (Loss of Signal)	Last valid downlink frame accepted by ODRC - OI / BFS / PASS (This time has been referred to as "LOS" thoughout the investigation.) Start of reconstructed data	Upper Right Aft (URA) Quad Antenna was selected by BFS Antennae Manage S/W to communicate with TDRS-W. The pointing angle to TDRS-W was off the Orb tail at -65 degs and trending further into blockage. Prev experience / eng calcs predict probable loss of comm at elevation angles greater than -60 degrees. Loss of comm at this GMT is therefore considered nominal.	

A.2-19
Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
84	29.3	--	13:59:32.195	EI+923.195		ASA 4 RPC A&C Trip Indication	Lagging indicator of ASA transducer excitation short condition	V79X4210E V76X4211E
85			deleted				Rationale for deletion: moved to 85.6 after further data review.	
85.5	29.3	--	13:59:32.598	EI+923.598		Left Outboard bypass valve reopens. A force fight between channels 1/2/3 and channel 4 begins, resulting in a difference of up to 0.5 degrees observed between the left outboard and inboard elevons	Indicates a short in bypass valve has grown sufficient to drop below voltage threshold of valve; RPC B is current limiting.	V58P0865A
85.6	29.3	--	13:59:33.680	EI+924.680		BFS Fault Message annunciation (1) - FCS CH 4	TDRS-E Data. Error is detected by ATVC/ASA hardware when sensed delta pressure across actuator exceeds a limit indicating the FCS channel is no longer driving the actuator. FCS CH 4 failure will annunicate for any of the following: LIB / LOB / RIB / ROB elevon actutor 4, rudder actuator 4, speedbrake actuator 4, SSME 1/2/3 P/Y Actuator D, & L/R SRB R/T actuator D.	
86	29.3	--	13:59:33.863	EI+924.863		PASS Fault Message annunciation (1) - FCS CH 4	TDRS-E Data	
87			13:59:33.976	EI+924.976		Master Alarm noted		
88	29.3	--	13:59:34.518	EI+925.518		Left Outboard force fight ends, driver currents go to zero. (RPC B trip indication).	Leading indicator of RPC B trip / ASA power down. I.e., indicates opening of all bypass valves (due to RPC B trip removing power) on ASA 4. Force fight goes away since actuators are already at the last commanded position (so channel 4 has no hyd load on the servo asking for position change).	V58P0865A
89	29.3	--	13:59:34.561	EI+925.561		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 "over-close" position (-10) this results in a force fight between channels 1,2,3 and channel 4.	V57P0260A V57P0261A V57P0262A
90	35	--	13:59:35/36	EI+926 / EI+927		Sideslip on vehicle changes sign.	The event occurred between the two times listed. Just prior to initial LOS the magnitude of the negative Sideslip started to decrease and between 59:34 and 59:37 sideslip grew from -.6 to +.8 deg. With this change, the normal roll and yaw moments on the vehicle would change sign. Aerodynamic forces due to sideslip are now reinforcing aerodynamic asymmetry.	

A.2-20
Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
91	36	--	13:59:36	EI+927		Growth in Bank attitude error	Up until this time the flight control had been able to maintain the Bank error around 5 deg. Aerojet DAP drops left wing to compensate for increasing aerodynamic moments, creating a bank attitude error.	
92	37	--	13:59:36.8	EI+927.8		Aerojet DAP Requests Third Right Yaw RCS Jet (R4R)	This additional jet is required to counteract the increasing aerodynamic moments on the vehicle. The RCS jet fired, as expected and stayed on to end of first 5-sec period of recon data at 032/13:59:37.4 GMT.	
93	38	--	13:59:37.3	EI+928.3		Aerojet DAP Requests Fourth Right Yaw RCS Jet (R1R)	This additional jet is required to counteract the increasing aerodynamic moments on the vehicle. The RCS jet fired, as expected and stayed on to end of first 5-sec period of recon data at 032/13:59:37.4 GMT.	
94	39		13:59:37.n	EI+928.n		Last aileron data	The aileron position is now approx -5.2 deg with approx -2.5 deg of aileron trim. The rate of change of aileron trim had reached the maximum allowed by the flight control system.	
95	40	--	13:59:37.396	EI+928.396	End of 5 second period of reconstructed data	End of first 5-seconds of the 32-second period of post-LOS data. Start of approximately 25 seconds of no data available	GMT derived by MER data personnel	
95.5	40.5	X	13:59:39 / 14:00:19	EI+930 / EI+970		Beginning at EI+930 and continuing until the loss of sync on OEX data (EI+964.4 for PCM and EI+970.4 for FDM), essentially all of the OEX data for the entire vehicle becomes erratic and fails		
95.8	40.7	--	13:59:46 / 48	EI+937 / EI+939		Debris A observed leaving the Orbiter - Large debris seen falling away from the Orbiter envelope.		EOC2-4-0018 EOC2-4-0024 EOC2-4-0209-B EOC2-4-0221-3 EOC2-4-0221-4
96	41	--	13:59:46.347	EI+937.347		PASS Fault Message annunciation - ROLL REF	Message retrieved from PASS "fault message buffer" received between 14:00:04 and 14:00:05. Data is potentially error prone. The ROLL REF message is triggered when Roll command req'd to fly reference profile falls below 37 degs. Message generation less than 10 secs (5 guidance cycles) after start of 4 yaw jets firing suggests unexpected reduction in Lift to Drag ratio.	

A.2-21
Integ Time Line Team - REV 19 BASELINE

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

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
							Note: BFS does not have this message in the Fault message stack. It is likely that BFS annunciated this message during the 25 second gap of no data, but that if it was annunciated it was pushed out of the downlist stack by additional fault messages (at least 5) annunciated during the gap.	
97	41	–	13:59:52.114	EI+943.114		PASS Fault Message annunciation - L RCS LEAK	Data located in PASS fault message buffer. Data is potentially error prone. Generated when difference between left aft RCS oxidizer and fuel thermodynamically derived quantities is more than 9.5% PVT. Indicates a leak of either helium and/or propellant OR the temperature/pressure sensor readings used to compute the quantities are erroneous.	
97.3	41.5	–	14:00:01 / 03	EI+952 / EI+954		Debris B observed leaving the Orbiter	Time is for debris first seen well aft of Orbiter envelope.	EOC2-4-0024
QBAR = nn psf; Mach nn						------ 32:14:00:00 ------		EI + 951 sec; WLE Stagnation Temp: ~2800 F
98	41	–	14:00:01.540*	EI+952.540		BFS Fault Message annunciation - L RCS LEAK	Data located in BFS fault message buffer. Data is potentially error prone. Generated when difference between left aft RCS oxidizer and fuel thermodynamically derived quantities is more than 9.5% PVT. Indicates a leak of either helium and/or propellant OR the temperature/pressure sensor readings used to compute the quantities are erroneous. *Time info corrupted.	
99	41	–	14:00:01.900*	EI+952.900		BFS Fault Message annunciation - L RCS LEAK	Data located in BFS fault message buffer. Data is potentially error prone. *Time info corrupted.	
99.5	41.5	–	14:00:02 / 04	EI+953 / EI+955		Debris C observed leaving the Orbiter	Time is for debris first seen well aft of Orbiter envelope.	EOC2-4-0024
100			deleted				Rationale for deletion: moved to 95.8 after further review of the videos	

A.2-22

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
101	43	--	14:00:02.654	EI+953.654		PASS Fault Message annunciation - L RCS LJET	Data is potentially error prone. Data located in PASS fault message. Generated when a left firing RCS jet on the left OMS pod has failed with a FAIL OFF, FAIL ON, or FAIL LEAK.	
102	44	--	14:00:02.660	EI+953.660	Beginning of 2 second period of reconstructed data	Start of last 2-seconds of the 32 second period of post-LOS data.	GMT derived by MER data personnel.	
						CAUTION: Data from this period is suspect because multiple bit errors were evident in this reconstructed data. Many of the parameters were 1 Hz data and therefore only one data sample was available. Where possible, high rate data and/or corroborating data were used to draw subsystem performance conclusions. However, some of the conclusions drawn below may be in error or misinterpreted. During this final 2 second period of reconstructed data, the data indicates the following systems were<u>nominal</u>: APUs were running and WSB cooling was evident (although potentially overcooling). MPS integrity was still evident. Fuel cells were generating power and the PRSD tanks/lines were intact. Comm and navaids systems in the forward fuselage were performing nominally. RSB, Body Flap, main engine, and right wing temps appeared active. With the exception of an apparent FES shutdown, ECLSS performance was nominal. During this final 2 second period of reconstructed data, the data indicates the following systems were<u>off-nominal</u>: All three Hyd systems were lost (zero pressure/zero rsvr qty's). The left inbd/outbd elevon actuator temps were either OSL or no data exists. WSB's appeared to be overcooling APU lube oil. The FES appeared to have shutdown. Majority of left OMS pod sensors were either OSH or OSL or no data exists. Multiple BFS and PASS fault message annunciations for left pod hardware were found in the buffer. (Note: All of the left RCS fault messages could be result of a real leak or loss of instrumentation. The OMS fault message could be a real loss of pressure or instrumentation problem. There is not enough data to determine the true cause of the messages associated with the left OMS pod.) Elevated temps at bottom bondline centerline skin forward and aft of the wheel wells and at the port side structure over left wing were observed. EPDC shows general upward shift in Main Bus amps and downward shift in Main Bus volts. AC3 phase A inverter appeared disconnected from the AC Bus. GNC data suggests vehicle was in an uncommanded attitude and was exhibiting uncontrolled rates. Yaw rate was at the sensor maximum of 20 deg/sec. The flight control mode was in AUTO. (Note that all Nav-derived parameters (e.g., alpha) are suspect due to high rates corrupting the IMU state.) Based on the nominal and off-nominal system performance described above, it appears that the fwd/mid/aft fuselage, right wing, and right pod were still intact.		
103	45	--	14:00:03.470*	EI+954.470*		BFS Fault Message annunciation - L OMS TK P	Data located in BFS fault message buffer after acquisition of data. Data is potentially error prone. *Time info corrupted. Note: Error is annunciated when left OMS oxidizer tank ullage pressure (V43P4221C) or fuel tank ullage pressure (V43P4321C) is out of limits high or low. Oxidizer limits - High: 288 psi; Low 234 psi; Fuel limits - High: 288 psi; Low: 234 psi.	

A.2-23

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

Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
103.5	45	--	14:00:0n.nnn			BFS Fault Message annunciation - Indeterminant		
104	45	--	14:00:0n.nnn*			BFS Fault Message annunciation - SM1 AC VOLTS	Occurred after L OMS TK P message. Data is potentially error prone. *Time info corrupted. Note: Error message indicates that AC Bus 3 phase A, B, or C voltage (V76V1700A, V75V1701A, V76V1702A) is out of limits high or low. Low limit for all 3 parameters is 108VAC; High limit is 123VAC.	
105	45	--	14:00:03.637	EI+954.637		PASS Fault Message annunciation - L RCS PVT	Data is potentially error prone. Data located in PASS fault message. Generated when RCS Quantity software does not have enough input data to calculate a quantity. At least one input and its backup are not within valid ranges.	
106	46	--	14:00:03.637	EI+954.637		PASS Fault Message annunciation - DAP DNMODE RHC	Data located in PASS fault message buffer. Generated when the Flight Control System (DAP) downmodes from AUTO to CSS via an RHC deflection passed a threshold. The software process which logs the PASS message runs every 1.92 seconds, so event could have occurred as early as 14:00:01.717 GMT. The fault message was corroborated by an initialization flag for the DAP CSS roll stick function indicating that CSS was entered during the data gap. However, during this final 2 sec period, available vehicle data indicates RHC was in detent & DAP was in AUTO. Data is potentially error prone. Note: BFS downlist bits indicating CSS mode are initialized to "ON" for entry because BFS does not have an "Auto" mode, is always CSS, and will drive the eyebrow panel lights ON if engaged. These bits are always on in BFS through all of OPS 3 until touchdown.	
107	47	--	14:00:04.826	EI+955.826	End of 2 second period of reconstructed data	Last identifiable OI Downlink frame	GMT derived by MER data personnel. Last recognizable Downlist frame (BFS & PASS) was approx 60 ms earlier.	

A.2-24

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

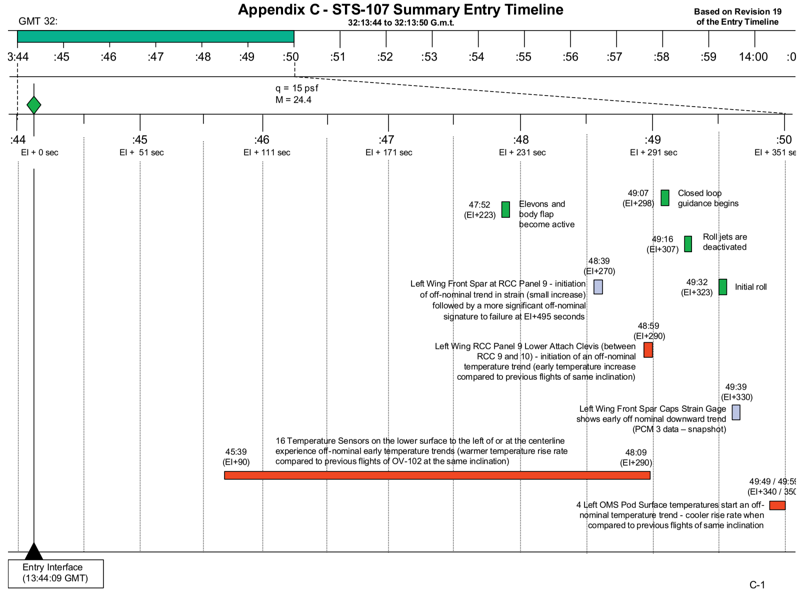
Seq No.	Sum No.	OEX Data	GMT GMT Day 32	EI secs	Milestone	Entry Event	Remarks	MSID / ID
107.1	--	--	14:00:05.2 / 06.2	EI+956.2 / EI+957.2		Late Flash 1	Sudden brightening of the Orbiter envelope	EOC2-4-0018 EOC2-4-0024 EOC2-4-0209-B EOC2-4-0221-3 EOC2-4-0221-4
107.15	--	--	14:00:06.2 / 07.2	EI+957.2 / EI+958.2		Late Flash 2	Sudden brightening of the Orbiter envelope, followed by a shower of debris seen aft of the Orbiter envelop during the next 4 seconds (shower seen only in EOC2-4-0221-4)	EOC2-4-0018 EOC2-4-0024 EOC2-4-0209-B EOC2-4-0221-3 EOC2-4-0221-4
107.2	--	--	14:00:08 / 12	EI+959 / EI+963		Debris D	Debris first seen slightly aft of Orbiter envelope and begins generating its own trail	EOC2-4-0018 EOC2-4-0209-B EOC2-4-0221-3 EOC2-4-0221-4
107.25	--	--	14:00:09 / 13	EI+960 / EI+964		Debris E	Debris first seen aft of Debris "D"	EOC2-4-0209-B EOC2-4-0221-3 EOC2-4-0221-4
107.3	--	--	14:00:10 / 14	EI+961 / EI+965		Debris F	Debris first seen aft of Orbiter envelope, which for a short time begins generating its own trail	EOC2-4-0209-B EOC2-4-0221-4
107.4	--	--	14:00:13 / 17	EI+964 / EI+968		Debris Shower	Multiple debris seen immediately aft of the orbiter envelope over the next 2 seconds	EOC2-4-0209-B EOC2-4-0221-5
107.5	47.5	X	14:00:13.439	EI+964.439		OEX PCM loss of sync		
108			deleted				Rationale for deletion: moved to 97.3 after further review of the videos	
109			deleted				Rationale for deletion: moved to 99.5 after further review of the videos	
109.3	48.3	--	14:00:17.8/18.8	EI+968.8 / EI+969.8		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	Numerous debris seen aft of Orbiter envelope over the next 10 seconds, followed by disintegration of the main Orbiter envelope into multiple pieces	MIT-DVCAM-0001 EOC2-4-0018 EOC2-4-0024 EOC2-4-0209-B EOC2-4-0221-3 EOC2-4-0221-4
109.5	48.5	X	14:00:19.44	EI+970.44		FDM1 A end of data		
110			deleted				Rationale for deletion: moved to 109.3 after further review of the videos	
111	50	--	14:00:53	EI+1004	End of Peak Heating		Determined by analysis. The peak heating period represents the approximate time period during which the heating rate has flattened out at or near its maximum value.	

= Expected/Nominal performance or event nn = data still needed

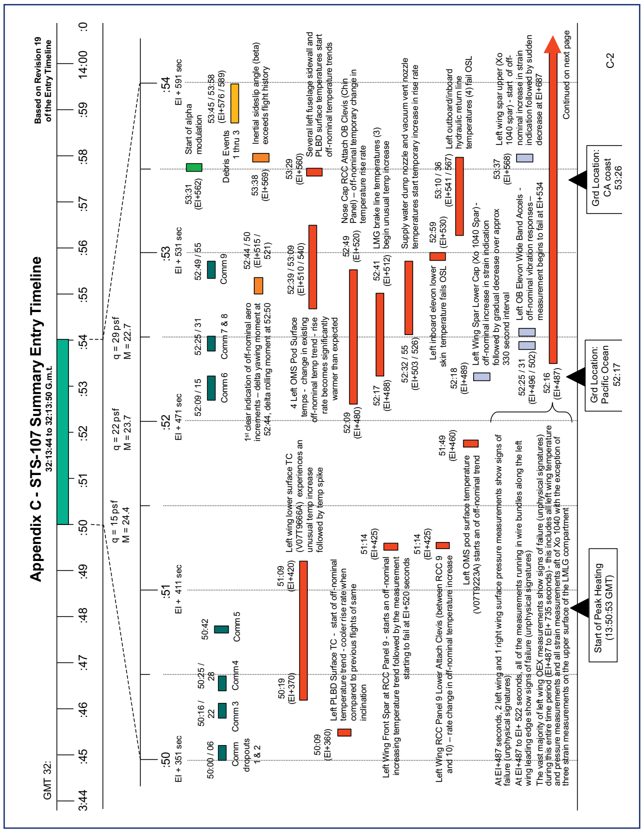
Appendix C - STS-107 Summary Entry Timeline

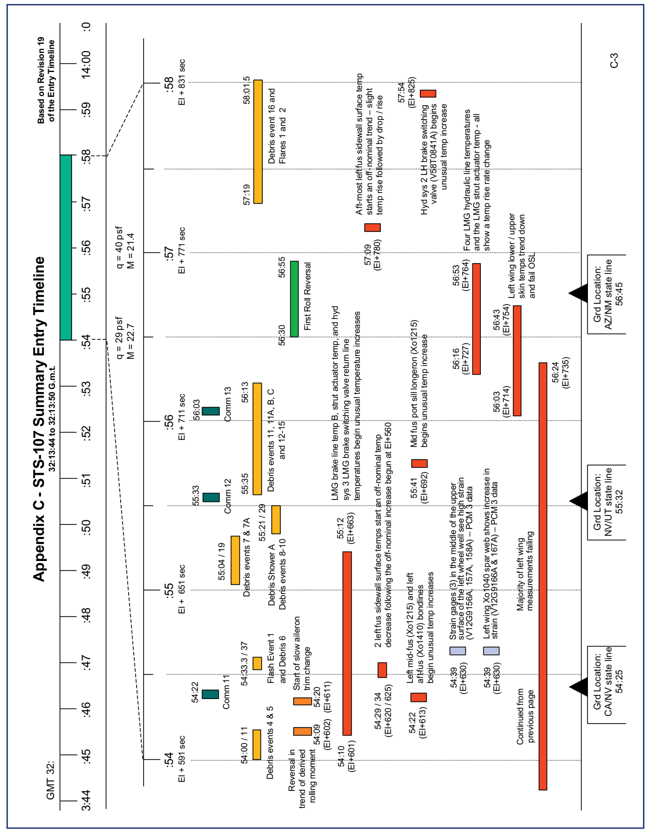
32:13:44 to 32:13:50 G.m.t.

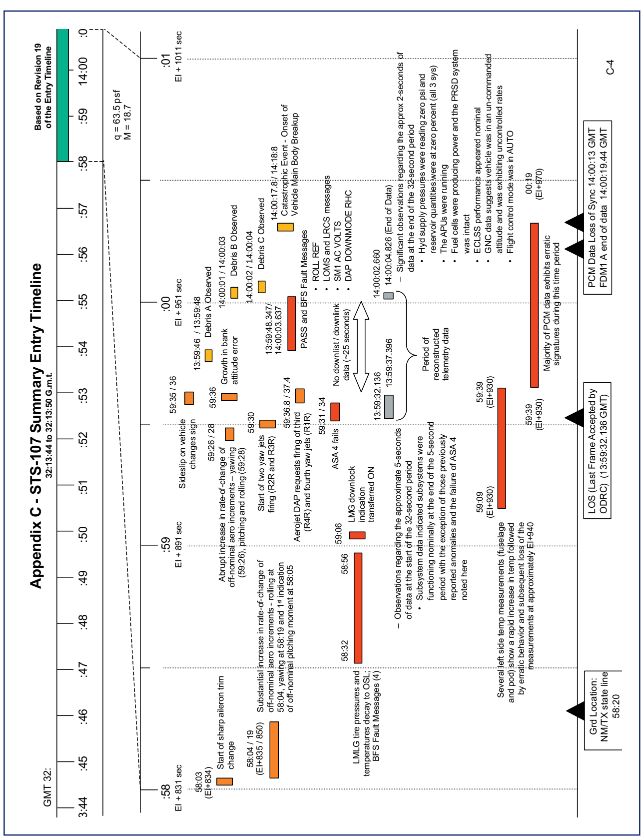
Based on Revision 19 of the Entry Timeline



C-1







Appendix D
Subsystem Data Review Summary Report

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D.30 AIR DATA TRANSDUCER ASSEMBLY HARDWARE PERFORMANCE EVALUATION

D.1.0 INTRODUCTION

The results of the subsystem data reviews are documented in Appendix D. The report summarizes the results of the data reviews conducted by each of the subsystem teams. The report covers all mission phases and indicate that although there was evidence in the data of the impending catastrophic failure, all of the *Columbia* vehicle active systems were performing nominally until the final minute prior to breakup.

D2.0 AUXILIARY POWER UNIT PERFORMANCE EVALUATION

D2.1 Executive Summary

The auxiliary power unit (APU) subsystem performed nominally during all phases of the mission. During entry, all APU parameters were nominal at loss-of-data.

Data during entry through the initial Orbiter loss of signal (LOS), prior to the 32-second (LOS+32) period of reconstructed data, showed nothing off nominal except for one-bit data hits in nine measurements. Data obtained from the final 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. Evaluation concluded that all three APUs were operating properly at normal speed through the final loss of all data (LOS+32 seconds) with all three hydraulic systems having lost all hydraulic main-pump pressure.

The APU subsystem had no off-nominal events, deviations from nominal, or unusual data other than one-bit data hits through the initial LOS period. Analysis indicates that no APU subsystem hardware contributed directly or indirectly, or was in any way associated with the cause of the loss of the Orbiter.

D2.2 Pre-launch/Ascent Performance

APU subsystem performance was nominal during the pre-launch/ascent phase. Two minor observations are noted in the following paragraphs.

A small-temperature-drop in the APU 2 injector tube temperature, which was recorded at approximately 16:15:39 G.m.t., was initially reported as caused by a suspected loose spring clip. However, following an investigation of the hydraulic loads data during this period and a comparison with data from the previous mission (STS-109) of this vehicle, it has now been concluded that the temperature drop was a normal APU response to a drop in hydraulic load.

Movement of a small amount of hydrazine in the APU 2 fuel pump seal cavity drain line is suspected to have caused a small temperature rise and drop in the APU fuel pump drain line temperature 2 near main engine cutoff (MECO). This event is not considered to be anomalous.

D2.3 On-Orbit Performance

APU subsystem performance was nominal during the on-orbit phase. The APU heater systems maintained all APU systems within the nominal temperature

range. APU 1 operated satisfactorily during the flight control subsystem (FCS) checkout.

D2.4 Entry Performance

The APU subsystem had no off-nominal events, deviations from nominal, or unusual data other than one-bit data hits through the final loss of data at 32:14:00:04 G.m.t. (LOS +32 seconds). Analysis indicates that no APU subsystem hardware contributed directly or indirectly, or was in any way associated with the cause of the loss of the Orbiter.

The thrust vector control (TVC) isolation valves of two of the three hydraulic systems are opened during hydraulic normal pressure to stow the Space Shuttle main engine (SSME). These periods of load on the corresponding APUs are evidenced in the APU turbine-speed and chamber-pressure plots. APU performance was nominal during the stowing of the SSMEs on the STS-107 mission.

Subsystem performance during the final 32-second period (LOS+32) of reconstructed data was within specifications and was as expected except for lower APU lubrication oil and bearing temperatures in the final 2-second period. This may be attributed to loss of all hydraulic loads as a result of loss of all hydraulic main pump pressure in all three hydraulic systems and/or possibly to a hydraulic water spray boiler (WSB) overcooling condition.

The APU group performed a review of the APU 1 revolutions per minute (RPM) signature during the final 2-second segment of the 32 seconds period of reconstructed data. The latest version (07) of the 32-second period of reconstructed data was used, and all APU parameters were re-reviewed. The 5-second segment and final 2-second segment indicate that the three APUs were functioning nominally to the end of data (32:14:00:05 G.m.t.).

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 elevon 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 turbine-speed-band of about 102-110 percent, based on the designed valve response time and a programmed controller response time. When APU high-speed operation is selected in the cockpit, the controller set points are 112-114 percent, with resulting turbine-speed-band of about 112-117 percent.

The 112.9-percent data point is not indicative of high-speed operation, but is assessed as a data hit (bad data) for the following reasons:

1. The speed continues to ramp down below the high-speed set points and high-speed band;
2. The drop from 112.9 to 109.6 percent is 5 time-bit values, but would be only one or two for a real spin-down;
3. The remaining good data (109.6-105.5 percent) is a good, smooth, normal-speed signature, but at a slower spin-down rate, and it did not reach the lower set point by the end-of-data. This latter fact is the result of the loss of hydraulic fluid in the hydraulic system sometime during the 25-second gap in the period of reconstructed data. The APU is spinning an empty pump without load or pressure; this same effect was seen during an APU test at White Sands Test Facility June 5, 2001, when the hydraulic pump lost fluid and ran for 21 seconds before shutdown;
4. The 112.9-percent data point was extracted from a section of telemetry data for which a low-level of confidence exists for its accuracy;
5. The high-speed switch-scan data showed normal speed for APU 1. The switch-scan data were suspect for APU 2, and the switch-scan data were not available for APU 3; and,
6. No APU caution and warning indications occurred throughout the entry run, thus giving additional confirmation that the three APUs were operating nominally in normal speed and were not switched (commanded) to high speed.

However, in the remote possibility that the 112.9-percent data point were real data, it could possibly be explained by events in the Orbiter causing the controller set point to drift, degrading the valve response time, or perhaps causing a mechanical binding that could induce a shut off valve internal leak to the gas generator. It would not be indicative of high-speed operation.

In summary, the turbine speed was nominal for all three APUs up until loss of data at 32:14:00:04.7 G.m.t., and was indicative of normal speed. In addition, APU 2 exhibited a chamber pressure pulse that ended at this time; this pulse was typical of normal-speed pulses. Switch scans did not show a switch to high-speed. Although a switch position change could have been executed during the 25-second gap, the subsequent three RPM signatures and the one pulse signature indicate normal speed. The hydraulic system reservoirs were shown to have no oil at this time (last two seconds), with the APUs driving empty pumps, lubricated by residual hydraulic fluid.

D.3.0 HYDRAULICS/WATER SPRAY BOILER SUBSYSTEM PERFORMANCE EVALUATION

D3.1 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 nominally and all subsystem parameters were within nominal ranges 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-nominal increases in temperature. The off-nominal 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 insightful data, both segments were characterized by, in some cases, multiple data hits. The final 2 seconds of data indicated that sometime in the previous 25-second data gap, the hydraulic subsystems were apparently breached. The final 2 seconds of data indicated hydraulic subsystem main pump (system) pressure at 0 psia on all three systems. The hydraulic reservoir pressures likewise indicated 0 psia and indicated reservoir quantities of 0 percent on all three systems.

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.

Circulation pump operation during pre-launch was nominal. Two bootstrap accumulator recharges occurred during the pre-launch operations. The first recharge occurred in system 1 (2192 to 2465 psia) and the second in system 3 (2143 to 2465 psia).

The three HYD/WSB systems were activated at T minus 5 minutes prior to launch. During ascent, the three thrust vector control (TVC) isolation valves were open. The three priority valves cracked within the required time limit of less than 1 second. The three hydraulic systems pressures were within the required range of 3050 - 3200 psia. The reseating of the priority valves at APU shutdown was nominal.

The water spray boiler system cores were loaded with approximately 5.0 lb of the additive mixture (53-percent water; 47-percent Propylene Glycol Monomethyl Ether (PGME). The WSB-ready indication was exhibited on all three WSB systems shortly after the water spray boiler gaseous nitrogen (GN_2) isolation valves were opened during pre-launch operations. Nominal WSB cooling performance was observed on all three HYD/WSB systems. System 3 initiated spray cooling approximately 6 seconds after MECO while systems 2 and 1 started approximately 32 seconds and 1 minute 32 seconds after MECO, respectively. No APU lubrication oil overcooling or undercooling conditions occurred. Water spray boiler water usage during ascent for spray cooling was within allowable limits.

D.3.3 On-Orbit Performance

The HYD/WSB subsystem performed nominally throughout the on-orbit phase of the mission. No deviations from the nominal were observed during the on-orbit operations.

D.3.4 Entry Performance

The HYD/WSB subsystem performed nominally throughout the entry phase of the mission until loss of data. The data review indicates that no HYD/WSB subsystem hardware contributed directly or indirectly, or was in any way associated with the cause of the loss of the Orbiter. However, evidence of the event that led to the loss of the Orbiter was apparent in hydraulic subsystem parameters and is discussed in this section.

Post-mission analysis of the HYD/WSB subsystem data involved plotting high-rate data for all system parameters and examining the high-rate data for any anomalous indications. The data analysis indicated a thermal effect in the Orbiter vehicle left-hand main landing gear (MLG) wheel well as indicated by eight hydraulic system thermal sensors. It was determined that all HYD/WSB entry/landing operations and thermal sensor responses appeared nominal up to 32:13:52:17 G.m.t. Analysis of the data indicated that the left MLG brake-line

temperature sensor D began an anomalous rise in temperature at 32:13:52:17 G.m.t. Within 24 seconds, at 32:13:52:41 G.m.t., the left MLG brake-line temperature sensors A and C also initiated a temperature rise.

Four Orbiter vehicle left-side elevon actuator hydraulic return-line thermal sensors indicated an off-scale low (OSL) temperature of –76 °F. The sensors indicating OSL were as follows:

1. System 3 left outboard elevon (LOE) actuator return line;
2. System 1 left inboard elevon (LIE) actuator return line;
3. System 1 LOE actuator return line; and
4. System 2 LIE actuator return line.

The hydraulic system reservoir fluid quantities and all HYD/WSB subsystem temperatures and pressures appeared stable, indicating no subsystem leaks or instability. At that time, the water spray boilers were operating and the spray cooling was nominal. Initial discussions of the situation led to the conclusion that the data dropout of the elevon actuator return lines was caused by a dedicated signal conditioner (DSC) card dropout. Continued monitoring of the in-flight data indicated nominal HYD/WSB subsystem operation, despite the four elevon return-line temperature-sensor dropouts. The data analysis indicated that the four elevon-actuator sensor dropouts were slightly staggered within a time span of approximately 26 seconds, beginning at 32:13:53:10 G.m.t. The system 3 LOE actuator return-line and the system 1 LIE actuator return-line went OSL within 1 second of each other followed by the system 1 LOE actuator return-line and the system 2 LIE actuator return-line going OSL within 2 seconds of each other beginning 24 seconds after the first sensor began going OSL (system 3 LOE actuator return line) and 1 minute, 19 seconds following the first indicated anomalous temperature sensor rise indication in the left MLG wheel well.

Within 10 seconds of the last elevon-actuator return-line sensor going OSL, the left MLG brake-line temperature sensor A began an increase in rise rate, 1 minute, 5 seconds following the initial temperature increase on this sensor. Within 23 seconds, at 32:13:54:10 G.m.t., the left MLG brake-line temperature-sensor B initiated a temperature increase, the first anomalous response indicated on this sensor. Within the next 1 minute, 2 seconds, the left MLG strut actuator sensor and the left MLG system 3 brake-line return line temperature also initiated an indicated rise in temperature. At this point, it was 2 minutes, 55 seconds elapsed time since the first anomalous thermal sensor temperature increase indicated in the left-hand wheel well.

At 32:13:56:16 G.m.t., 3 minutes and 59 seconds after the first anomalous condition was noted in the hydraulic subsystem, the left MLG uplock actuator sensor initiated an anomalous rise in temperature. Within the next 37 seconds, the following four thermal sensors exhibited a change to an increasing rate of rise in temperature:

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

At this point, it was 4 minutes, 36 seconds since the first anomalous thermal sensor temperature increase was indicated in the left-hand wheel well. Within 1 minute, 1 second, at 32:13:57:54 G.m.t., the system 2 left-hand brake switch valve return line initiated an anomalous rise in temperature. This was the last of the eight anomaly-affected sensors in the left-hand wheel well to indicate a rise in temperature. At 32:13:58:16 G.m.t., the left MLG brake-line temperature sensor D indicated a change to a rapid increase in the temperature. Sixteen seconds later, the system 2 left-hand brake switch valve return line also initiated a rapid increase in the temperature rise-rate. This sensor indicated the most rapid rise rate of all the left-hand wheel-well thermal sensors, indicating a rate of approximately 40 °F/min. This occurred at an elapsed time of 6 minutes, 15 seconds since the first hydraulic subsystem thermal sensor temperature increase was indicated in the left-hand wheel well.

Loss-of-signal from the vehicle occurred at 32:13:59:32 G.m.t., at which time all hydraulic subsystem sensor downlink data were lost. The elapsed time from the indication of the first sensor temperature indicating an anomalous temperature rise in the left-hand wheel well to LOS was 7 minutes, 15 seconds. At LOS, all of the thermal sensors within the left-hand wheel well, though rising, were all still below redline limits.

It should also be noted that, unlike other sensors that were still trending upward at LOS, the system 2 brake switching-valve return-line temperature sensor and the left MLG brake-line temperature sensor A, which had exhibited the greatest temperature rise rate, very briefly flattened and then exhibited a decrease (approximately 3 °F) prior to LOS. The reason for this is unknown.

The post-LOS period of 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 insightful data, both segments were characterized, in some cases, by multiple data hits. The initial 5 seconds of post-LOS reconstructed data indicated that all three hydraulic subsystem main pump pressures were still within nominal ranges (2700 - 3400 psia). All three hydraulic system reservoir volumes were within nominal range (46 - 90 percent) as were reservoir pressures (60 - 95 psia) and temperatures (less than 220 °F). All three hydraulic system bootstrap accumulator pressures were between 3050 psia and 3200 psia, which is within the nominal range. The eight left-hand wheel well thermal sensors discussed previously indicated relatively flat temperatures during the initial 5-second data period, and no data on any of these sensors were indicated in the

final 2 seconds of data. All water spray boiler data was within the nominal range during the initial 5 seconds of post-LOS data. The water spray boiler system 1, 2, and 3 GN_2 tank pressures indicated nominal pressures of 2537 psia, 2452 psia and 2506 psia, respectively, at LOS.

The final 2 seconds of data indicated that sometime 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 0 psia on all three systems. The hydraulic system reservoir pressures likewise indicated 0 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 priority valves. The nominal bootstrap accumulator reseat pressure following a nominal main pump shutdown is not less than 2675 psia and is controlled by the priority valve (system 1 - 1970 psia, system 2 - 1920 psia and system 3 - 1860 psia). The fact that the three bootstrap accumulator pressures was less than 2675 psia is consistent with the hydraulic system reservoir pressures being at 0 psia and reservoir quantities at 0 percent. The water spray boiler system 1, 2, and 3 GN_2 tank pressures still indicated pressure integrity during the final 2 seconds of post-LOS data, and the pressures were 2530 psia, 2450 psia, and 2510 psia, respectively, at the last salvaged data bit. The decreasing 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 depleted 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 depleted hydraulic pump. Depleted 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 overshoot/overcool 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 OSL 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

approximately 124 °F to 172 °F (48 °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.

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.

D4.0 MAIN PROPULSION SYSTEM PERFORMANCE EVALUATION

D4.1 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 tanks for the helium systems for SSME 2 and 3 are located on the left side of the midbody. These systems did not indicate any temperature or associated pressure rise in the systems prior to LOS.

The LH_2 manifold was vented to vacuum for the duration of the flight prior to opening the return to launch site (RTLS) dump valves, so no pressure decay was noted upon opening the valves.

D.5.0 ORBITAL MANEUVERING SUBSYSTEM PERFORMANCE EVALUATION

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. At that time, there was a significant loss of instrumentation on the left OMS pod.

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.5.3 On-Orbit Performance

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

The overall performance of the left and right OMS 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.

Starting at 32:13:59:30 G.m.t. (just prior to LOS), all the OMS parameters were reading nominal values and the values remained at nominal levels until 32:13:59:37.4 G.m.t. (end of the first 5-second period of reconstructed data). When data came back at 32:14:00:03 G.m.t., it was seen that most of the pressure and temperature measurements in the left OMS pod were reading an off-nominal value. In most cases, the data were at an off-scale low value, although some off-scale high measurements were observed. Some measurements were not available at all because of the intermittent nature of the data caused by data hits. However, there was one good reading of the left OMS engine GN_2 pressure that had the same reading as at 32:13:59:36 G.m.t. (during the first 5-second period of reconstructed data).

The data during this final 2-second period of reconstructed data can be interpreted as showing the left OMS as having been breached because the available pressure data show the systems at dramatically reduced pressures. This interpretation is also supported by three primary avionics software system (PASS) fault summary messages concerning the left RCS and one backup flight system (BFS) fault message concerning the left OMS that was not on the PASS summary. There were no fault messages, or at least none in the buffer, for the right OMS. The fault messages, the criteria the GPCs use to generate them, and possible causes/interpretations of the messages are detailed in the following paragraphs.

There was no PASS message in the Queue for the left OMS; however, the BFS had an L OMS TK P message that was time-tagged at 32:14:00:03.470 G.m.t. The time tag is suspect data because of data errors in the time-word. The PASS will annunciate this message when the propellant tank ullage pressures are either high (> 288 psia) or low (< 234 psia). The BFS will annunciate this message for the propellant tank ullage pressures being either high (> 288 psia) or low (approximately 234 psia), or if the helium or GN_2 tanks fall below 1500 psia or 1200 psia, respectively, or the GN_2 accumulator pressure falls below 299 psia or exceeds 434 psia.

The error code for this message showed it was either the oxidizer and/or fuel tank that caused this message to be generated. There were no BFS data for the helium or GN_2 system during the final 2 seconds of the reconstructed data before the final LOS. On the PASS, there was only one data sample for only one left OMS tank pressure during this time period that was the left OMS oxidizer ullage pressure of 37.6 psia at 32:14:00:03 G.m.t. If this value drove the BFS fault, however, the PASS should have also annunciated a fault message, but none was recorded.

Since there were no right OMS fault messages and no left OMS pod data were available immediately prior to the final LOS, it is clear that something occurred in the left OMS pod during the 25-second data gap prior to the final 2-second period of reconstructed data. Without more data, any further explanations are speculation.

D.6.0 REACTION CONTROL SUBSYSTEM PERFORMANCE EVALUATION

D.6.1 Executive Summary

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.

The overall performance of the forward RCS and the left and right RCS was nominal, with no exceptions prior to LOS at 032:13:59:32 G.m.t. The left RCS, 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 (reconstructed data period) before the final LOS at 032:14:00:05 G.m.t.

D.6.2 Pre-launch/Ascent Performance

No deviations or significant events related to the RCS were noted during the review of the pre-launch and ascent data.

D.6.3 On-Orbit Performance

No deviations or significant events related to the RCS were noted during the review of the on-orbit data.

D.6.4 Entry 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 RCS, 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.

At 32:13:59:52.114 G.m.t., the PASS had a message that there was a leak in the left RCS. Subsequently at 32:14:00:01.54 G.m.t. and 32:14:00:03.47 G.m.t., the BFS had messages of a left RCS leak. A low-level of confidence exists for the time tags for the two BFS messages. This message is generated when the difference between the oxidizer and fuel quantities, as calculated by the RCS quantity monitor software, is greater than 9.5 percent based on pressure, volume and temperature (PVT) derived values. The unit percent-PVT is used to distinguish the quantity from percent gage where the latter implies a physical gage (found within the OMS tanks) and the former implies a thermodynamically derived value (in this case, the RCS quantity).

At 32:14:00:02.654 G.m.t., the PASS had a message that a thruster in the left RCS had failed (L RCS LJET). No similar message was received from the BFS. This message is generated when an RCS thruster on the left OMS pod has failed. This can be a fail off, fail on, or fail leak. The crew would use their computer to determine the failure mode.

At 32:14:00:03.637 G.m.t., the PASS had a message that the left RCS PVT was not operating correctly (L RCS PVT). The BFS does not generate this message. This message is generated when the RCS quantity monitor software does not have enough input data to process, and therefore cannot calculate a quantity for either the oxidizer or fuel tanks. This means that at least one input and its backup have fallen outside the reasonableness limits for those particular inputs, and the software has suspended the quantity calculation.

The obvious analysis of the RCS leak message is that there was a leak, either oxidizer or fuel or both. However, there are also other things that can generate the message because the quantity message is based on tank pressures and temperatures. If the temperatures and/or the pressures give erroneous readings that satisfy the reasonableness limits, then the software will treat the values as good and calculate a quantity. For the data from STS-107 at LOS (approximately 032:13:59:32 G.m.t.), if both the left RCS oxidizer and fuel tank temperatures gave erroneous readings of 120 °F instead of the actual 80 °F, then the quantity monitoring software would have computed quantities which differed from each other by 9.5 percent PVT and a leak message would have been generated. However, if an input falls outside the reasonableness limits for that particular input, then the software uses a backup input. This allows a less accurate quantity to be calculated. In the previous example, the 120 °F temperature for the propellant tank is still within the reasonableness limits.

During the review of entry data past the first LOS at 032:13:59:32 G.m.t., it was determined that the left RCS data were nominal until approximately 32:13:59:37 G.m.t. (end of the 5-second period of reconstructed data). When data returned for a brief time at approximately 32:14:00:03 G.m.t. (final 2-second period of reconstructed data), the analysis showed that most of the left RCS operational instrumentation (OI) data and the limited downlist data that was available had values of OSL, OSH (off-scale high) or an off-nominal value. The data from the right RCS and the forward RCS on the other hand had nominal values, with a limited number of exceptions.

The analysis indicates that something caused the loss of data from the left RCS. The LEAK and PVT messages could have been caused by a mere lack of data resulting from the wires being severed by some means. The messages could also have been caused by an actual leak either through thruster valves (a thruster valve that did not completely close), or because of a breach of the system (ruptured propellant tank, broken propellant line, ruptured helium tank, 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 thruster firings causing the left thruster (LJET) message. Finally, enough propellant leaked out that the resulting propellant tank pressures fell outside the reasonableness 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 thrusters themselves was lost and this loss resulted in the general purpose computer (GPC) being unable to confirm that the thrusters were firing in response to the reaction jet driver (RJD) outputs; thus the second message. Enough instrumentation was finally lost that the PVT gauging 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 thruster activity during the 25-second data gap before 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 32:14:00:03 G.m.t. shows that the quantities changed by an average value of 7.4-percent PVT. For the right RCS, there are no PASS pressure or temperature data for any tank during the final 2-second period of reconstructed data. The downlisted PASS quantities for the oxidizer and fuel tanks had values of 35.2-percent PVT and 31.2-percent PVT, respectively, while the BFS values were 33-percent PVT and 32-percent PVT, respectively. The cause of this

difference is that the BFS uses slightly different quantity equations and initial conditions than the PASS.

The BFS had values for the helium P2 and propellant tank outlet pressures and tank quantities for the right RCS during the final 2-second period of reconstructed data. Using the available BFS pressures and adding the bias seen earlier in the mission to estimate the redundant pressure measurement, and assuming the tank temperatures had not changed in the previous 30 seconds, the PASS algorithm computes values of 31.8-percent PVT and 30.2-percent PVT in the oxidizer and fuel tanks, respectively. These values are reasonably close to the BFS values. These results give some confidence in the data quality of the downlisted propellant quantities. Since STS-1, it has been observed that periods of heavy RCS propellant usage cause the PVT gaging program to show a lower-than-actual quantity, because the helium and propellant temperature readings are slow to show the actual average temperatures. Once the thruster usage ceases, these temperatures “move” toward the actual average temperature of the tank contents, and the calculated propellant quantities likewise change in the direction of the actual propellant quantities. This phenomenon is referred to as “bounce- back”.

An estimate of the bounce-back effect can be made from the forward RCS quantity bounce-back ratio seen after the forward RCS dump on STS-107. For this case, it is seen that for every 1-percent of propellant used the gage indicates 1.2775-percent PVT used. The 2, 3, and 4 thruster flow-rates found in the Shuttle Operational Data Book (SODB) are also used. As there are no data available to show how many thrusters actually fired and for how long, an estimation of the total thruster-on time for the right RCS during the LOS before the final 2-second period of reconstructed data is shown in the following table. The estimate is bounded using different propellant flow rates both with and without the bounce back effect. The results are given for seconds of time beyond 32:13:59:36.6 G.m.t.

Number of Thrusters Firing	Without PVT Bounce-Back	With PVT Bounce-Back
2	26 seconds	20 seconds
3	18 seconds	14 seconds
4	13 seconds	10 seconds

As for the forward RCS, with the exception of the ullage pressures that appear to be data hits, the pressures and temperatures of all the forward RCS tanks were unchanged from their former values when data was acquired for the final 2 seconds of reconstructed data.

D.7.0 FUEL CELL POWERPLANT SUBSYSTEM PERFORMANCE EVALUATION

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. There were no gross system operation anomalies that could be confirmed in the final 2 seconds of reconstructed data. The changes seen appear to be a result of other events that were taking place on the vehicle.

D7.2 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-stack 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 (H_2) 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 B-phase 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.

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 32:13:00 G.m.t. through LOS + 5 seconds of the reconstructed data 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 anomaly is confirmable 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 hits with many fuel cell telemetry measurements 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 displayed 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); and
5. PRSD 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 reactant flow meter indicating good reactant flow; no other fuel cell coolant pressures had dropped; no tank pressures had dropped.

Nominal H_2 tank heater cycles in tanks 1 and 2 occurred to maintain nominal manifold pressure to support fuel cell operations. The O_2 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 occurring prior to the entry phase. All tank internal fluid and heater assembly temperatures were nominal.

The total Orbiter power produced by the three fuel cells was nominal for LOS + 5 second data at about 20.5 kW. All fuel cell measurements (current, voltage, temperatures, pressure, flow-rates, and substack voltages) were nominal. The fuel cell water relief nozzle temperature was increasing as expected after entry interface because of aerothermal heating. The fuel cell product water line temperatures were beginning to decrease in a nominal fashion due to convective cooling caused by entering the atmosphere.

During the last 2 seconds of the 32-second period of reconstructed data, the total Orbiter power level had increased to about 23 kW. Current on all 3 three fuel cells was increasing; fuel cell 3 had 2 phase ac operation on its hydrogen/water pump; an off-nominal 84 °F rise in the oxygen purge vent line temperature was noted; and fuel cell 1 coolant pressure and oxygen manifold pressure 1 were reading OSL.

D.8.0 POWER REACTANT STORAGE AND DISTRIBUTION SUBSYSTEM PERFORMANCE EVALUATION

D.8.1 Executive Summary

The power reactant storage and distribution (PRSD) subsystem performed nominally during all phases of the mission. During entry, all PRSD parameters were nominal at loss-of-data. The PRSD subsystem performance during the period from 32:13:00 G.m.t. through the LOS + 5-second period of reconstructed data were nominal. There are no direct or indirect findings or associations with the problem.

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, the oxygen purge vent line temperature was experiencing an unexpected rise, and conflicting indications were observed that manifold 1 had lost 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.8.2 Pre-launch/Ascent Performance

The PRSD subsystem oxygen (O_2) and hydrogen (H_2) tank sets 1 and 2 heater switches were in nominal ascent configuration. The O_2 and H_2 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 aft part of the payload bay with four tank sets, was deactivated. An O_2 offload was performed to reduce the nominal end-of-mission (EOM) landing 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 O_2 offload of approximately 350 lb.

The main buses were untied for ascent. The main bus B (MNB) to main bus C (MNC) crosstie was performed at 16:16:56:48 G.m.t., for nominal on-orbit SpaceHab load distribution. The water line heaters were on the A system.

The O_2 and H_2 manifold and tank pressure decay rates were nominal to support fuel cell operations and crew breathing. The oxygen manifold pressures reached the tank 1 and 2 control band and these tanks began nominal heater cycles 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.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 EDO pallet was activated throughout the on-orbit operations, and was deactivated during deorbit preparations.

A hydrogen manifold pressure spike occurred when manifold pressure control was switched to H_2 tank 3 after H_2 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 (OMRSD) in-flight checkout of the tank heater current sensors was performed. Nominal sensor operation was verified on all of the tank heaters except for O_2 tank 7. During this test, the O_2 tank 7 heater-A manual-command failed to energize the A heater. Later in the mission, however, the heater sensor for O_2 tank 7 was verified during tank heater operation in the AUTO mode.

D.8.4 Entry Performance

The overall entry performance of the PRSD subsystem was nominal, with the exception of several abnormalities seen in the last 2 seconds of the 32-second period of reconstructed data that was recovered. These abnormalities are the rise in temperature of the fuel cell purge line and the conflicting indications that O_2 manifold 1 had lost pressure. These abnormalities are discussed in section D.7.4. Events that occurred during the entry timeline period were evaluated. The 32:13:00 G.m.t. through LOS + 5-second data was confirmed to be nominal system operations and PRSD measurements experienced no data loss. Other than some telemetry parameters beginning to become unreliable because of data hits before the 25-second period on no data, all PRSD measurements were nominal.

D.9.0 ATMOSPHERIC REVITALIZATION SUBSYSTEM PERFORMANCE EVALUATION

D.9.1 Executive Summary

The atmospheric revitalization subsystem (ARS) performed nominally during all phases of the mission. During entry, all ARS parameters were nominal at loss-of-data.

D.9.2 Pre-launch/Ascent Performance

The ARS performed nominally during the pre-launch and ascent phases of the mission. No anomalous conditions were noted in the data during this phase of operations.

D.9.3 On-Orbit Performance

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

D.9.4 Entry Performance

The ARS performed nominally during the entry phase of the mission. No anomalous conditions were noted in the data during this phase of operations.

D.10.0 PRESSURE CONTROL SUBSYSTEM PERFORMANCE EVALUATION

D.10.1 Executive Summary

The pressure control subsystem (PCS) performed nominally during all phases of the mission. During entry, all PCS parameters were nominal at loss-of-data.

D.10.2 Pre-launch/Ascent Performance

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

D.10.3 On-Orbit Performance

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

D.10.4 Entry Performance

The PCS operated nominally during the entry phase. Additionally, subsystem performance gave no indications of anomalous performance in other subsystems.

The 14.7-psia cabin pressure regulator inlet valves were closed and the pressure control system was inactive for nominal cabin pressurization for entry with the exception of oxygen supply to the Launch and Entry Helmets (LEH) and g-suits. Nominal activation and oxygen use by the crew for the g-suits was evident in the data evaluated.

There were no data for most of the 32-second period of reconstructed data following LOS. Based on the limited data for all measurements (PPO_2, O_2 percent, cabin pressure, cabin temperature and $PPCO_2$), the cabin parameters were nominal at the end of the first 5-second period of data and it appears that the cabin pressure integrity was intact throughout the 32-second period of reconstructed data.

D.11.0 ACTIVE THERMAL CONTROL SUBSYSTEM PERFORMANCE EVALUATION

D.11.1 Executive Summary

The active thermal control subsystem (ATCS) performed nominally during all phases of the mission. During entry, all ATCS parameters were nominal at loss-of-data.

D.11.2 Pre-launch/Ascent Performance

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

D.11.3 On-Orbit Performance

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

D.11.4 Entry Performance

The ATCS performed nominally during the entry phase of the mission. Normal flash evaporator water use was observed in the analysis of the data. No ATCS anomalous conditions were noted in the data.

D.12.0 SUPPLY AND WASTE WATER MANAGEMENT SUBSYSTEM PERFORMANCE EVALUATION

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

D.12.3 On-Orbit Performance

Review of the SWWM subsystem 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 observed.

An out-of-family condition was observed in the supply water dump nozzle and vacuum vent nozzle temperatures during entry. Supply water dump nozzle entry heating rates on temperature sensors A and B increased from 33.5 °F per minute to 43.25 °F per minute. After 2 minutes and 17 seconds, the increase rate changed to 30.47 °F per minute. Vacuum vent nozzle entry heating rate increased from 0.88 °F per minute to 7.49 °F per minute in 26 seconds and then changed to 1.33 °F per minute. All past flight entry nozzle temperatures were reviewed, and there was no past flight with similar signatures to those observed on STS-107.

The wastewater dump nozzle temperature was nominal throughout this period. Due to the physical proximity of the wastewater dump nozzle to the other two nozzles, it might be expected that all three nozzles would behave similarly to the aerodynamics of entry. This inconsistency between the three nozzle temperatures may provide further clues as to the aerodynamic/aerothermal events and timing of those events during STS-107.

D.13.0 AIRLOCK SUBSYSTEM PERFORMANCE EVALUATION

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.13-2 Pre-launch/Ascent Performance

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

D.13.3 On-Orbit Performance

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

D.13.4 Entry Performance

The smoke and fire suppression subsystem performed nominally during the entry phase of the mission. No in-flight anomalies were identified in the data analysis.

D.15.0 PASSIVE THERMAL CONTROL SUBSYSTEM PERFORMANCE EVALUATION

D.15.1 Executive Summary

The passive thermal control subsystem performed nominally during all phases of the mission. During entry, some passive thermal control subsystem parameter temperatures were off-nominal at loss-of-data.

From the real-time operational instrumentation (OI) data, it could be seen that abnormal temperature rises occurred in the left main landing gear compartment and left-side structure, and that sensors failed on the hydraulic actuator return-lines of the left inboard and outboard elevons, lower elevon bondline and left upper and lower wing bondlines. Also, an off-nominal signature (change in temperature rise rate) occurred in the supply water dump nozzle and vacuum vent nozzle.

From the operational experiment (OEX) recorder data, many off-nominal thermal responses were noted. These included off-nominal temperature-rises of the left wing front spar at reinforced carbon carbon (RCC) panel 9 and the left wing RCC panel 9 lower-outboard attachment clevis. Additionally, there were off-nominal temperature responses of several thermal protection subsystem (TPS) surface measurements on the left side of the vehicle and all of the left wing temperature measurements failed.

D.15.2 Pre-launch/Ascent Performance

The passive thermal control subsystem pre-launch and ascent temperature responses were nominal and compared favorably with those of previous missions. No in-flight anomalies were identified in the evaluation of the data for this phase of the mission.

D.15.3 On-Orbit Performance

The on-orbit performance of the passive thermal control subsystem was nominal and compared favorably with that of previous missions. The on-orbit temperature responses for the bottom bondline and main landing gear were nominal. Attitude adjustments were made for the nominal end-of-mission thermal conditioning for water production and radiator protection concerns. This attitude change had no adverse effect on the vehicle thermal performance. Heaters enabled for the deorbit phase of the mission operated nominally. No in-flight anomalies were identified in the evaluation of the data.

D.15.4 Entry Performance

The entry performance of the passive thermal control subsystem was nominal with the exception of abnormal temperature rises and temperature sensor failures.

During entry, the bondline structure OI data increases in temperature because of entry heating. From plots comparing the STS-107 bondline temperature response with selected flights, the right-hand side fuselage and bottom centerline temperature responses were nominal. However, the left-hand side fuselage temperature data responded nominally with three exceptions that were:

1. Mid fuselage compartment sidewall temperature at Xo1215;
2. Mid fuselage sill longeron temperature at Xo1215; and
3. Aft fuselage compartment sidewall temperature at X1410.

At 32:13:54:22 G.m.t., the temperature rise rates at these locations began faster than previously experienced on comparison flights. Also, uneven temperature responses occurred between port and starboard side at the same Xo location; symmetrical heating and temperature rise rates were expected.

The temperature rises on the portside fuselage structure measurements (mid sidewall, longeron, and aft sidewall) indicate higher-than-nominal environmental heating.

From the OEX data, off-nominal temperature responses were noted very early during entry. The left wing front spar at RCC panel 9 started an off-nominal increasing temperature trend at 32:13:48:59 G.m.t. [entry interface (EI) plus 270 seconds), and the left wing RCC panel 9 lower outboard attachment clevis started an off-nominal increasing temperature trend at 32:13:48:59 G.m.t. Within the next 70 seconds, the TPS surface temperatures on the left side of the vehicle and the left OMS pod began off-nominal responses when compared to previous flights. This response continued to LOS. Finally, during the period from 32:13:52:21 to 32:13:53:47 G.m.t., all of the left wing temperature measurements failed.

D.16.0 MECHANICAL SUBSYSTEM PERFORMANCE EVALUATION

D.16.1 Executive Summary

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.16.2 Pre-launch/Ascent Performance

No anomalies were noted in the mechanical systems during the pre-launch and ascent phases of the mission. All mechanisms operated in nominal dual-motor time with all limit switches transferring properly.

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 stowed twice, and all involved mechanisms operated in nominal dual-motor time with all limit switches transferring properly.

During the vent-door opening, payload bay door (PLBD) opening and Ku-band antenna deployment, an intermittent signature occurred on ac bus 2, phase B where the current was slow to increase at motor startup. This anomaly is discussed in D.19.0 Electrical Power Distribution and Control subsystem section of this appendix.

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 payload bay door (PLBD) closure, after starboard door closure had been stopped for the nominal alignment check, a 0.7-second period of additional current draw occurred on ac bus 1. The amplitude and signature of the trace appear to correspond to starboard door drive motor 1. However, a scenario 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 1 Hz, it is impossible to determine whether any changes occurred in these indications within the 0.7-second time period.

During vent door closure, a 0.1-second period of additional current draw was noted on ac bus 1 phases A and C. It is possible that a momentary limit switch failure could have caused a motor to drive for this short period. Because the ac current sample rate is 0.1 Hz and the op stat and limit switch data sample rate is only 1 Hz., this could have occurred without showing up in the phase B, op stat, or limit-witch data.

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.

D.17.0 LANDING AND DECELERATION SUBSYSTEM PERFORMANCE EVALUATION

D.17.1 Executive Summary

The landing and deceleration 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 landing and deceleration parameters during the entry.

1. Left-hand MLG tire pressure measurements failed OSL prior to LOS;
2. Left-hand inboard and left-hand outboard wheel temperature measurements went OSL prior to LOS; and
3. Left MLG down-lock indication transferred and remained on through LOS.

D.17.2 Pre-launch/Ascent Performance

This system was not active throughout the pre-launch and ascent phases of the flight, and no anomalies were noted in the data that was reviewed.

D.17.3 On-Orbit Performance

This system was not active throughout the on-orbit phase of the flight, and no anomalies were noted in the data that was reviewed. All data reviewed indicated nominal performance of landing and deceleration hardware throughout the on-orbit phase.

D.17.4 Entry Performance

The overall performance of the landing/deceleration subsystem was nominal throughout entry and the LOS+32-second period of reconstructed data with the exceptions noted in the following paragraphs.

The left-hand main landing gear tire pressure measurements failed off-scale-low (OSL) prior to loss of signal (LOS). The data review showed that the loss of the primary measurements occurred prior to the loss of the secondary measurements. This appears to indicate an instrumentation failure as opposed to a loss of tire pressure.

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.

The left MLG down-lock indication transferred on at 32:13:59:05.877 G.m.t. and remained on through LOS. 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 psia). The trend toward OSL started at 32:13:58:33.171 G.m.t. for both measurements. The LHOB 1 went OSL at 32:13:58:40.194 G.m.t. and LHIB 1 went OSL at 32:13:58:38.225 G.m.t. Prior to this event the pressures were at a nominal value of 350 to 355 psia, which is consistent with the expected pressures adjusted for wheel-well environmental conditions given the post top-off tire pressures and leak rates obtained prior to launch.

Both LHIB and LHOB wheel temperature measurements went OSL (-75 °F). The trend toward OSL started at 32:13:58:35.730 G.m.t. for the LHIB and at 32:13:58:33.201 G.m.t. for the LHOB. The LHIB went OSL at 32:13:58:44.219 G.m.t. and the LHOB went OSL at 32:13:58:39.783 G.m.t. Prior to this event, the temperatures were at a nominal 35 °F. The data were consistent with the on-orbit thermal conditioning performed to maintain minimum nominal end of mission (NEOM) 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 psia. The first pressure drop started at 32:13:58:37.316 G.m.t. for RHIB 1 and at 32:13:58:38:304 G.m.t. for the RHOB 1. This condition lasted for approximately 10 seconds after which the pressures recovered until LOS. Prior to this event, the pressures were at a nominal value of 350 to 355 psia, which is consistent with the expected pressures adjusted for wheel-well environmental conditions given the post top-off tire pressures and leak rates obtained prior to launch.

The LHIB 2 and LHOB 2 tire pressure measurements went OSL (230 psia). The trend toward OSL started at 32:13:58:33.171 G.m.t. for both of these measurements. The LHIB 2 went OSL at 32:13:58:44.192 G.m.t. and LHOB 2 went OSL at 32:13:58:54.189 G.m.t. Prior to this event, the pressures were at a nominal value of 350 to 355 psia, which is consistent with the expected pressures adjusted for wheel well environmental conditions given the post top-off tire pressures and leak rates obtained prior to launch.

The RHOB 2 tire-pressure measurement appeared to dip approximately 3 psi and then recovered to a nominal 355 psia. The pressure drop started at 32:13:58:45.199 G.m.t. This lasted for approximately 10 seconds after which the

pressure recovered until LOS. Prior to this event, the pressure was at a nominal 355 psia, which is consistent with the expected pressure 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 lasted through the LOS+32 period 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 temperature A measurement, located on the strut, indicated 103 ° F, while at the end of the gap it indicated 278 °F. Although the downlinked data has been verified to contain no errors, this is considered an erroneous measurement because the brake line B measurement, which is located beside the A measurement, indicated exactly the same value (118.6 °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 wall near the hydraulic switching valve.

Appendix D
Subsystem Data Review Summary Report

D.18.0 PURGE, VENT, AND DRAIN SUBSYSTEM PERFORMANCE EVALUATION

D.18.1 Executive Summary

The purge, vent and drain (PV&D) subsystem and hazardous gas detection subsystem (HGDS) performed nominally during all phases of the mission. During entry, all PV&D and HGDS parameters were nominal at loss-of-data. The vehicle drain system is passive; there is no telemetry to monitor or review.

D.17.2 Pre-launch/Ascent Performance

The PV&D subsystem and HGDS performed nominally during the pre-launch and ascent phases of the mission. The purge temperatures and flow rates were set to predetermined levels and stayed within nominal tolerances. Orbiter circuit 2 was supplied with a higher-than-normal flow rate (225 lb./min) because of the extended duration Orbiter (EDO) pallet requirement agreed to in the payload integration plan. The higher flow rate was within Orbiter purge system certification. During the T minus 9-minute hold, the circuit 2 flow-rate was reduced to 170 lb./min to alleviate the need for a post-flight inspection of the Orbiter T-0 purge-circuit quick-disconnect flappers. The inspection is required if separation occurs at a flow rate at or above 180 lb./min.

D.17.3 On-Orbit Performance

The PV&D subsystem and HGDS performed nominally during the on-orbit phase of the mission, as the subsystems are inactive during the on-orbit period.

D.17.4 Entry Performance

The PV&D subsystem and HGDS performed nominally during the entry phase of the mission.

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Appendix D
Subsystem Data Review Summary Report

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 effect 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 ampere (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 L4 and MA73C.

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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Subsystem Data Review Summary Report

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 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 increasingly 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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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 OPS 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 multiplexer/demultiplexer (MDM) 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.21.0 FLIGHT CONTROL SYSTEM HARDWARE PERFORMANCE EVALUATION

D. 21.1 Executive Summary

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

The 32-second period of reconstructed data indicate that there was an anomaly involving aerosurface actuator (ASA) 4. This condition has been evaluated and determined to be the result of a wiring short in the aft of the left wing.

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 used in 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 did follow GPC commands, even after the occurrence of the ASA 4 anomaly and until LOS + 5 seconds. Aerosurface actuator secondary differential

pressures were well below the bypass level and normal until the ASA 4 anomaly appeared.

At 32:13:59:31.7 G.m.t., aerosurface channel 4 positions either were at their null value or were transitioning toward their null value. Less than one second later at 32:13:59:32.396 G.m.t., the power was current-limiting and the voltage had dropped sufficiently for both remote power controllers (RPCs) for ASA 4 to drive the RPC trip measurement (1 Hz). Secondary differential pressure data indicates channel 4 on the right outboard elevon, right inboard elevon, left inboard elevon, left outboard elevon, rudder, and speedbrake were bypassed. The channel 4 fail flag was raised on the right outboard elevon, right inboard elevon, left inboard elevon, left outboard elevon, rudder, and speedbrake at 32:13:39:32.1 G.m.t. (1-Hertz measurement).

The channel 4 driver currents on the right outboard elevon, right inboard elevon, left inboard elevon, left outboard elevon, and speedbrake were non-zero (driving the channel 4 servo valve). A force fight occurred between channel 4 and the other 3 channels on the left outboard elevon from 32:13:59:32.597 G.m.t. to 32:13:59:34.318 G.m.t., as indicated by secondary differential pressure data. This 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 32:13:59:35.077 G.m.t., the actuator fail flags from ASA 4 had turned off.

At approximately 32:14:00:04 G.m.t., just 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, rudder/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.

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 deorbit 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.

D.23.0 STAR TRACKER SUBSYSTEM PERFORMANCE EVALUATION

D.23.1 Executive Summary

The star tracker subsystem was powered off during ascent and no subsystem data are available. The star tracker subsystem performance on-orbit was nominal. The star tracker was powered off during entry.

D.23.2 Prelaunch/Ascent Performance

The star tracker subsystem was powered off during ascent and no subsystem data are available.

D.23.3 On-Orbit Performance

The star tracker subsystem performance on-orbit was nominal. Review of the star tracker subsystem data from the on-orbit period indicated no anomalous or off-nominal performance.

D.23.4 Entry Performance

The star tracker subsystem was powered off during entry and no subsystem data are available.

D.24.0 NAVIGATIONAL AIDS SUBSYSTEM PERFORMANCE EVALUATION

D.24.1 Executive Summary

All navigational aids subsystem (NAVAIDS) operations were nominal during the pre-launch, ascent and on-orbit operations. During entry, all NAVAIDS parameters were nominal at loss-of-data. Based on the analysis of the data, the conclusion is that the NAVAIDS were nominal and had no involvement in the catastrophic failure that preceded the loss of the *Columbia* during the entry phase of the STS-107 mission.

D.24.2 Pre-launch/Ascent Performance

The overall performance of the NAVAIDS was nominal during pre-launch and ascent operations. All three tactical air navigation (TACAN) systems remained locked on to KSC during the ascent and broke lock when the station was out of range. The NAVAIDS were powered off after the operational sequence (OPS) 2 transition.

D.24.3 On-Orbit Performance

The NAVAIDS are normally powered off during the on-orbit phase until the transition to OPS 8 for the FCS checkout approximately 24 hours prior to the predicted landing. All of the NAVAIDS successfully passed the self-test during the FCS checkout. The NAVAIDS were then powered off after the OPS 2 transition. No deviations or significant events were observed in the NAVAIDS performance.

D.24.4 Entry Performance

All NAVAIDS subsystems 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 channel 111X ground stations during the pass over the United States just 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 32:13:59:32:174 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 plasma. At 32:13:47:39 G.m.t., radar altimeter 2 locked on to plasma. At 32:13:48:53 G.m.t., radar altimeter 2 broke lock on the plasma and remained un-locked until 32:13:59:26:20 G.m.t., when one sample indicating 800 feet was observed. Radar altimeter 1 remained locked on to the plasma until 32:13:58:45:00 G.m.t., and then broke lock until 32:13:59:34:30 G.m.t., when one sample indicating 5200 feet was observed. The 800 feet and 5200 feet indications were proven to be invalid and were disregarded. The radar altimeter

data were compared with the data from previous OV-102 missions, including STS-109, STS-93 and STS-90. Similar radar altimeter signatures were observed for these flights when compared with the data from STS-107. The radar altimeter performance was determined to be nominal. The three microwave-scanning-beam landing systems (MSBLS) were powered on but were out-of-range of the KSC ground station and did not lock on. The MSBLS indications were nominal. The MSBLS were still out-of-range of the ground station during the extra 32 seconds of telemetry data that were later recovered.

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 phases of STS-107. During entry, all S-Band subsystem and processor parameters were nominal at loss-of-data.

D.25.2 Pre-launch/Ascent Performance

The overall performance of the communications and tracking (C&T) subsystems during the pre-launch and ascent phase was nominal. The payload signal processor (PSP) was configured and tested satisfactory during pre-launch and then powered off per procedures prior to launch. S-Band PM system string 1 and 2 and the S-Band FM system were powered on and a checkout of these systems was completed prior to-launch. The S-Band PM system string 2 provided nominal S-Band Orbiter telemetry and air-to-ground (A/G) voice communication overage during the pre-launch, launch, and ascent phases. 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 PSP was powered on, configured for SpaceHab support, and operated nominally until powered off at SpaceHab de-activation prior to the deorbit maneuver. During on-orbit operations, the S-Band FM system was occasionally powered on 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 either of the S-Band PM subsystems in any operational mode and S-Band communication coverage was nominal throughout the on-orbit phase.

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 dropouts 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 during this period would not typically result in dropouts. Data dropouts after this period until the final LOS

were not unexpected based on the antenna look angles to the TDRS. There were no off-nominal telemetry indications from any C&T subsystem.

The recovered data after the 25-second LOS indicated the BFS software commanded a switch from the upper right aft (URA) antenna to upper right forward (URF) antenna at 32:14:00:04 G.m.t., and there were instrumentation indications of the execution of the commanded switch. This conclusion was based on the two antenna switch discretes and the analog value of power amplifier (PA) reflected power, which were consistent with the performance characteristics the URF antenna.

D.26.0 Ku-BAND SUBSYSTEM PERFORMANCE EVALUATION

D.26.1 Executive Summary

The overall performance of the Ku-Band subsystem was nominal with no in-flight anomalies found during data analysis. During entry, all Ku-band subsystem parameters were nominal at loss-of-data.

D.26.2 Pre-launch/Ascent Performance

The overall performance of the Ku-Band subsystem during the pre-launch and ascent phases was nominal. The Ku-Band deployed assembly was stowed for ascent. Telemetry and operations indicate that the Ku-Band was still in its nominal ascent position prior to on-orbit deployment.

D.26.3 On-Orbit Performance

The overall performance of the Ku-Band subsystem during the on-orbit phase was nominal. The Ku-Band assembly was deployed at 16:17:54 G.m.t. in the expected dual motor time of 23 seconds. All telemetry measurements indicated the Ku-Band deployed assembly transitioned from the stowed to the deployed position. The Ku-Band system was activated at 16:17:58 G.m.t., passed the self-test, and functioned properly throughout the mission until it was nominally stowed and powered off at 32:01:47 G.m.t.

D.26.4 Entry Performance

The Ku-Band deployed assembly was stowed for entry. Telemetry indicates that the Ku-Band was still in its nominal position during entry.

D.27.0 INSTRUMENTATION SUBSYSTEM PERFORMANCE EVALUATION

D.27.1 Executive Summary

The overall performance of the instrumentation subsystem during the pre-launch, ascent and entry was nominal with no in-flight anomalies identified during the data analysis. During entry, all instrumentation subsystem parameters were nominal at loss-of-data.

D.27.2 Pre-launch/Ascent Performance

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.

D.27.3 On-Orbit Performance

The overall performance of the instrumentation subsystem during the on-orbit phase was nominal. Review of the OI subsystem on-orbit data indicated no in-flight anomalies or anomalous conditions in the subsystem performance.

D.27.4 Entry Performance

The overall performance of the instrumentation subsystem during the entry phase was nominal until loss of signal. There were no indications of any anomalous performance in any of the subsystem hardware. A number of individual measurements failed or had anomalous readings in the minutes immediately prior to loss of signal. All of these are apparently related to the accident.

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; and
Hydraulic system 2 left outboard elevon return line temperature.

All tire pressure and wheel 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 32:13:58:33 G.m.t. and failed OSL at 32:13:58:40 G.m.t. The left-hand inboard wheel temperature began drifting lower at 32:13:58:35 G.m.t., and failed OSL at 32:13:58:45 G.m.t. The left-hand inboard tire pressure began drifting

lower at 32:13:58:41 G.m.t. and failed OSL at 32:13:58:48 G.m.t. The left-hand outboard wheel temperature began drifting lower at 32:13:58:35 G.m.t., and failed OSL at 32:13:59:40 G.m.t. The left-hand outboard tire pressure 2 began drifting lower at 32:13:58:39 G.m.t., and failed OSL at 32:13:58:54 G.m.t.

The failed measurements used multiple dedicated signal conditioners (DSC) with no more than one affected measurement using a single DSC card. Similarly multiple MDM cards in more than one MDM were used. The failed tire-pressure measurements used two different strain gage signal conditioners (SGSC).

Temperatures in the area of the midbody DSC's and SGSC remained nominal (50-55 °F) until loss of data. As the measurements utilized multiple DSC's, the source of the failures is not believed to be related to a signal conditioner. Temperatures at the wheel itself were increasing but not high enough to cause transducer failure. Furthermore, the staggered loss of the individual measurements suggests that the failures were measurement failures, rather than actual loss of tire pressure.

The source of the failures is consequently believed to be in the wire harnesses between the wheel area and the midbody. Since the measurements did not exhibit the characteristics observed with breakage of the wheel separation harness, it is more likely to be due to heat-related degradation of the wiring harnesses in the vicinity of the left-hand wheel well.

Review of the post-LOS data did not alter the conclusions reached, and no additional anomalies were identified.

The OEX recorder was recovered and the data were successfully retrieved indicating that the hardware performed nominally. These data were extremely helpful to the investigation as data were recorded until the breakup of the vehicle. The vast majority of the left-wing measurements failed apparently because of heat-related degradation of wiring harnesses in the left wing.

D.28.0 DISPLAYS AND CONTROLS SUBSYSTEM PERFORMANCE EVALUATION

D.28.1 Executive Summary

Review of the Displays and Controls (D&C) subsystem pre-launch, ascent and on-orbit data indicated nominal system performance with no anomalous conditions observed. During entry, all D&C subsystem parameters were nominal at loss-of-data.

D.28.2 Pre-launch/Ascent Performance

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.

D.28.3 On-Orbit Performance

The D&C subsystem performed nominally during the on-orbit phase of the mission.

D.28.3 Entry Performance

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 annunciated 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 subsystems performance. A review of the BFS 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 downlisted 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 was nominal. There were no significant deviations from the nominal/expected operation of the MEDS subsystem during the on-orbit period; all downlisted 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.

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Appendix D
Subsystem Data Review Summary Report

D.30.0 AIR DATA TRANSDUCER ASSEMBLY HARDWARE PERFORMANCE EVALUATION

D30.1 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 deorbit 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 ± 0.080 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 atypical 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.

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Appendix E
STS-107 Mishap Investigation Timeline Instrumentation Data

Note: nn = no data

No.	MSID / ID No.	OEX	OI	Type	Title	Location X	Location Y	Location Z	Range OSL	Range OSH	Sample Rate	Units
1	V07P8038A	X		Press	L Wing Upper Surface Press (WB 3)	1334	-423.5	UPR	0	16	10 sps	PSIA
2	V07P8086A	X		Press	L Wing Lower Surface Press (WB 3)	1353.4	-419.1	LWR	0	16	10 sps	PSIA
3	V07P8151A	X		Press	Right Wing Lower Surface Press	1271.8	137.8	LWR	0	15	10 sps	PSIA
4	V07T9219A	X		Temp	OMS-L Pod HRSI Surf T1-AFT	1507.1	-126	422	0	1740	1 sps	Deg F
5	V07T9220A	X		Temp	OMS-L Pod LRSI Surface Temp-FWD	1321	LH	464	0	1740	1 sps	Deg F
6	V07T9222A	X		Temp	OMS-L Pod HRS1 Surf T2-AFT	1486.9	-126	422	0	1740	1 sps	Deg F
7	V07T9223A	X		Temp	OMS-L Pod HRS1 Surf T3-AFT	1437.2	-126	422	0	1740	1 sps	Deg F
8	V07T9253A	X		Temp	Left Fuselage Side Surface Temp BP3605T	1000.7	-105	354.5	0	900	1 sps	Deg F
9	V07T9270A	X		Temp	Fuselage Side Surface Thermocouple BP3976T	1560	-111.1	LWR	0	1740	1 sps	Deg F
10	V07T9468A	X		Temp	Fuselage Lower Surface Thermocouple X619	618.9	0	LWR	500	2700	10 sps	DegF
11	V07T9470A	X		Temp	Fuselage Lower Surface Thermocouple X620	620.1	-51.1	LWR	500	2700	10 sps	DegF
12	V07T9478A	X		Temp	Fuselage Lower Surfac Thermocouple X1004	1003.8	0	LWR	500	2700	10 sps	DegF
13	V07T9480A	X		Temp	Fuselage Lower Surface TC BP1602TR	1004.1	-99.8	LWR	500	2700	10 sps	Deg F
14	V07T9489A	X		Temp	Fuselage Lower Surface TC BP1900T	1391.5	0	LWR	500	2700	10 sps	Deg F
15	V07T9492A	X		Temp	Fuselage Lower Surface TC BP1602TR	1511.1	1.3	LWR	500	2700	10 sps	Deg F
16	V07T9508A	X		Temp	Fuselage Lower Surface Thermocouple	1560.3	-111.1	LWR	0	2400	10 sps	Deg F
17	V07T9522A	X		Temp	Fuslg Aft Penetration Area TC BP3325T	649.3	-105	354.8	0	1300	1 sps	Deg F
18	V07T9636A	X		Temp	Left Wing Upper Surface TC BP4860T	1357.8	-358	UPR	0	900	1 sps	Deg F
19	V07T9666A	X		Temp	WING LWR SURF THERMOCOUPLE BP2510T	1121.7	-235.5	LWR	0	2400	10 sps	Deg F
20	V07T9674A	X		Temp	Left Wing Lower Surface Thermocouple	1353.1	-236.4	LWR	500	2700	10 sps	Deg F
21	V07T9711A	X		Temp	Left Wing Lower Surface Thermocouple	1362	-369.3	LWR	0	2400	10 sps	Deg F
22	V07T9713A	X		Temp	WING LWR SURF ELEVON TC BP2876T	1402	-375.3	LWR	0	3000	1 sps	Deg F
23	V07T9784A	X		Temp	Left Half Lower Aft Fuselage Surface	1443	-117	LWR	0	2400	10 sps	DegF
24	V07T9785A	X		Temp	Left Half OTBD Lower Elevon Forward Surface	1396.1	-372.2	LWR	0	3000	1 sps	Deg F
25	V07T9786A	X		Temp	Left Half INBD Lower Elevon Forward Surface	1387	-229	LWR	0	3000	1 sps	Deg F
26	V07T9787A	X		Temp	AFT FUS LWR AFT SURFACE	1513	-116	LWR	0	2400	10 sps	DegF
27	V07T9788A	X		Temp	BODY FLAP LH LWR OTBD FWD	1530	-119.4	LWR	0	2400	10 sps	DegF
28	V07T9903A	X		Temp	Left Fuselage Side Surface TC BP3604T	1006	-105	398.4	0	1300	1 sps	Deg F
29	V07T9913A	X		Temp	FUSLG SIDE SURFACE TC BP3603T	1003.8	LH	441.3	0	1300	1 sps	Deg F
30	V07T9925A	X		Temp	FUSLG SIDE SURFACE TC BP3703T	1138.5	LH	441.4	0	1740	1 sps	Deg F
31	V07T9972A	X		Temp	Left OMS Pod TC BP0749T	1324	-98	488	0	1300	1 sps	Deg F
32	V07T9976A	X		Temp	Left OMS Pod TC BP0731T	1342.5	-128.5	462.6	0	1740	1 sps	Deg F
33	V07T9978A	X		Temp	OMS-L Pod Thermocouple BP0732T	1359.6	-135.1	463.1	0	1300	1 sps	Deg F
34	V08D9729A	X		Vibe	LFAF L OTBD ELVN-OTBD Z-VIB AOW018	1429.4	-435	nn	0	20	500 sps	GP-P
35	V09T1002A		X	Temp	Left Lower Wing Skin Temp	1280.1	240	LWR	-200	450	1 sps	Deg F
36	V09T1006A		X	Temp	Left INBD Elevon Lower Skin Temp	1441.9	-234.5	101.9	-200	450	1 sps	Deg F
37	V09T1016A		X	Temp	Mid Fus Bot Port BL Temp X620 - Center Line	620	-52.4	BOT	-200	450	1 sps	Deg F
38	V09T1022A		X	Temp	Mid Fus Bot Port BL Temp X 777 - Center Line	777	-52.5	BOT	-200	450	1 sps	Deg F
39	V09T1024A		X	Temp	Left Upper Wing Skin Temp	1280.1	240	UPR	-200	450	1 sps	Deg F
40	V09T1624A		X	Temp	Fwd Fus Lwr Skin Bot Center Line Temp	560	2	277	-200	450	1 sps	Deg F
41	V09T1724A		X	Temp	LH Aft Fus Sidewall Temp at x1410	1410	nn	340	-200	450	1 sps	Deg F
42	V09T9231A	X		Temp	Elevon LWR PLUG TEMP 1 (Surface) P171	1443.5	-232.2	LWR	0	3000	1 sps	Deg F
43	V09T9845A	X		Temp	Outboard ELEVON, MID GAP, Fwd	1440.4	-316	LWR	0	2400	10 sps	Deg F

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Appendix E
STS-107 Mishap Investigation Timeline Instrumentation Data

Note: nn = no data

No.	MSID / ID No.	OEX	OI	Type	Title	Location X	Location Y	Location Z	Range OSL	Range OSH	Sample Rate	Units
44	V09T9849A	X		Temp	Outboard ELEVON, Lower Surface Edge	1429.1	-315.3	LWR	0	2400	10 sps	Deg F
45	V09T9889A	X		Temp	RCC ATTACH OUTBD CLEVIS	262	-23	LWR	-200	1500	1 sps	DegF
46	V09T9893A	X		Temp	Wing Elevon Cove LWR Surface Temp	1383.8	-372.2	290.9	0	2400	10 sps	Deg F
47	V09T9894A	X		Temp	Wing Elevon Cove UPR Surface Temp	1381.7	-372.2	293.9	0	2400	10 sps	Deg F
48	V09T9895A	X		Temp	Wing Front Spar Panel 9 Temp	1102.2	-239	-239	-200	450	1 sps	Deg F
49	V09T9910A	X		Temp	Wing LE 55 LWR attach clevis RCC10	1112	-239	289	-200	1500	1 sps	Deg F
50	V12G9048A	X		Strain	L WING SPAR CAP LWR L103	1040	-135	LWR	-1000	1000	10 sps	uin/in
51	V12G9049A	X		Strain	L WING SPAR CAP UPR L104	1040	-135	UPR	-1000	1000	10 sps	uin/in
52	V12G9156A	X		Strain	LEFT WING UPR SKIN STN X X1115 Y136	1115	-136	UPR	-2000	1500	10 sps	uin/in
53	V12G9157A	X		Strain	LEFT WING UPR SKIN STN Y X1115 Y136	1115	-136	UPR	-1500	1000	10 sps	uin/in
54	V12G9158A	X		Strain	LEFT WING UPR SKIN STN XY X1115 Y136	1115	-136	UPR	-1250	1250	10 sps	uin/in
55	V12G9165A	X		Strain	LEFT WING SPAR WEB STN Z X1040 Y132	1040	-132	MID	-2000	2000	10 sps	uin/in
56	V12G9166A	X		Strain	LEFT WING SPAR WEB STN YZ X1040 Y132	1040	-132	MID	-2000	2000	10 sps	uin/in
57	V12G9167A	X		Strain	LEFT WING SPAR WEB STN Y X1040 Y132	1040	-132	MID	-2000	2000	10 sps	uin/in
58	V12G9169A	X		Strain	LEFT WING FRONT SPAR CAPS X1107 Y232	1107	232	nn	-1000	2000	10 sps	uin/in
59	V12G9921A	X		Strain	LEFT WING FRONT SPAR WEB INNER L120	1106	-229	MID	-1500	1000	10 sps	uin/in
60	V34T1106A		X	Temp	M-FUS LT BL Temp at x1215	1215	-105	355	-200	450	1 sps	DegF
61	V34T1118A		X	Temp	Mid Fus Port (Left) Sill Longn Temp at x1215	1215	-97	410	-200	450	1 sps	DegF
62	V51P0570A		X	Press	MLG LH OUTBD TIRE PRESS 1	1074	-160	nn	230	401	1 sps	PSIA
63	V51P0571A		X	Press	MLG LH Inbd Tire Pressure 1	1074	-115	nn	230	401	1 sps	PSIA
64	V51P0572A		X	Press	MLG LH Outbd Tire Pressure 2	1074	-160	nn	230	401	1 sps	PSIA
65	V51P0573A		X	Press	MLG LH Inbd Tire Pressure 2	1074?	-115?	nn	230	401	1 sps	PSIA
66	V51T0574A		X	Temp	MLG LH Outbd Wheel Temp	1074	-160?	nn	-75	175	1 sps	Deg F
67	V51T0575A		X	Temp	MLG LH Inbd Wheel Temp	1074	-115	nn	-75	175	1 sps	Deg F
68	V51X0125E		X	Position	Left Main Gear Downlocked Indication	1189	-135	nn	0	1	1 sps	Event
69	V57H0253A		X	Derived	SPEED BRAKE ACTR CHAN 4 POSN	n/a	n/a	n/a	0	98.6	5 sps	DEG
70	V57P0260A		X	Press	SPEED BRAKE DELTA PRESS 1	(Below Vert Fin/Rudder areas)			-3000	3000	25 sps	PSID
71	V57P0261A		X	Press	SPEED BRAKE DELTA PRESS 2	(Below Vert Fin/Rudder areas)			-3000	3000	25 sps	PSID
72	V57P0262A		X	Press	SPEED BRAKE DELTA PRESS 3	(Below Vert Fin/Rudder areas)			-3000	3000	25 sps	PSID
73	V58P0865A		X	Press	LEFT OUTBD ELEVON SEC DELTA PRESS 4 (see Notes (*))	1365	-212	116	-3000	3000	25 sps	PSID
74	V58P0915A		X	Press	RIGHT INBD ELEVON SEC DELTA PRESS 4 (see Notes (*))	1365	387	108	-3000	3000	25 sps	PSID
75	V58T0125A		X	Temp	Hyd Sys 1 LMG UpLK Actr Unlk Ln Temp	1159	-123.5	436	-75	300	1 sps	Deg F
76	V58T0157A		X	Temp	Hyd Syst 1 LH INBD Elevon Actr Ret Ln Temp	1350	-219	118	-75	300	1 sps	Deg F
77	V58T0193A		X	Temp	Hyd Syst 1 LOE Return Line Temp	1377	-367	436	-75	300	1 sps	Deg F
78	V58T0257A		X	Temp	Hyd Syst 2 LIE Return Line Temp	1348	-219	116	-75	300	1 sps	Deg F
79	V58T0394A		X	Temp	Hyd Syst 3 LOE Return Line Temp	1368	398	nn	-75	300	1 sps	Deg F
80	V58T0405A		X	Temp	LEFT MAIN GEAR STRUT ACTUATOR TEMP	1182.5	-116	315.5	-75	300	1 sps	Deg F
81	V58T0841A		X	Temp	HYD 2 LH AFT BRAKE SW VLV RTN LN TEMP	1173	-107	313	-75	300	1 sps	Deg F
82	V58T0842A		X	Temp	HYD 3 LH FWD BRAKE SW VLV RTN LN TEMP	1156.5	-109.5	313.7	-75	300	1 sps	Deg F
83	V58T1700A		X	Temp	LMG Brake Line Temp A (on strut facing MLG door)	1116	-140.4	282.8	-75	300	1 sps	Deg F
84	V58T1701A		X	Temp	LMG Brake Line Temp B	1116	-139.6	282.8	-75	300	1 sps	Deg F

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Appendix E
STS-107 Mishap Investigation Timeline Instrumentation Data

Note: nn = no data

No.	MSID / ID No.	OEX	OI	Type	Title	Location X	Location Y	Location Z	Range OSL	Range OSH	Sample Rate	Units
85	V58T1702A		X	Temp	Left Main Gear Brake Line Temp C	1140	-108	309	-75	300	1 sps	Deg F
86	V58T1703A		X	Temp	LMG Brake Line Temp D	1183	-108	312	-75	300	1 sps	Deg F
87	V62T0439A		X	Temp	SUPPLY H2O DUMP NOZZLE TEMP B	620	-105	342.46	0	400	1 sps	DegF
88	V62T0440A		X	Temp	SUPPLY H2O DUMP NOZZLE TEMP A	620	-105	342.46	0	400	1 sps	DegF
89	V62T0551A		X	Temp	VACUUM VENT TEMP	620	-105	335.96	-75	300	1 sps	DegF
90	V79X2634X		X	Position	RJDA 1 JET R2R DRIVER (see Note 1)	n/a	n/a	n/a		On	25 sps	Event
91	V79X2638X		X	Position	RJDA 2 JET R3R DRIVER (see Note 1)	n/a	n/a	n/a		On	25 sps	Event
92	V79X3263X		X	Position	LEFT INBOARD ELEVON ACTR 4 FAIL	(Located @ ASA4, Avionics Bay 6)				Fail	1 sps	Event
93	V79X3268X		X	Position	LEFT OTBOARD ELEVON ACTR 4 FAIL	(Located @ ASA4, Avionics Bay 6)				Fail	1 sps	Event
94	V79X3273X		X	Position	RIGHT INBOARD ELEVON ACTR 4 FAIL	(Located @ ASA4, Avionics Bay 6)				Fail	1 sps	Event
95	V79X3278X		X	Position	RIGHT OTBOARD ELEVON ACTR 4 FAIL	(Located @ ASA4, Avionics Bay 6)				Fail	1 sps	Event
96	V79X3334X		X	Position	RUDDER ACTR 4 FAIL OUTPUT	(Located @ ASA4, Avionics Bay 6)				Fail	1 sps	Event
97	V79X3339X		X	Position	SPEED BRAKE ACTR 4 FAIL	(Located @ ASA4, Avionics Bay 6)				Fail	1 sps	Event
98	V76X4210E		X	Position	PCA FLT CONT ASA 4 RPC C ON	1320	-15	292	Off	On	1 sps	Event
99	V76X4211E		X	Position	PCA FLT CONT ASA 4 RPC A ON	1320	55	372	Off	On	1 sps	Event
100	V90H0803C		X	Derived	COMMANDED ANGLE OF ATTACK (ALPCMD)	n/a	n/a	n/a	-45	45	1 sps	DEG
101	V90H1044C		X	Derived	COMMANDED ROLL ANGLE (ROLLC)	n/a	n/a	n/a	0	360	1 sps	Special
102	V90H1500C		X	Derived	PRELIM AILERON CMD(DCSP)	n/a	n/a	n/a			1 sps	DEG
103	V90H6410C		X	Derived	SELECTED BODY FLAP FDBK (DBF) (see Note 2)	n/a	n/a	n/a	-5	5	5 sps	VDC
104	V90H7505C		X	Derived	SELECTED LIB ELEVON (ELVLI) FDBK (see Note 3)	n/a	n/a	n/a	-5	5	5sps	VDC
105	V90H7555C		X	Derived	SELECTED RIB ELEVON (ELVRI) FDBK (see Note 3)	n/a	n/a	n/a	-5	5	5sps	VDC

Notes: sps = sample per second.
(*) = MSID is physically located on the Left/Right Elevon actuator.

Note 1 They are calling a Discrete=0 or Off as Off-Scale Low and Discrete=1 or On as Off-Scale High.

Note 2 While this is listed in the database as VDC, it is not downlisted as such. What is downlisted is the count value for the selected 16 bit MDM hardware word. A value of +5.00 VDC which is +500 counts in the sign +9 bits is a count value of +32,000 counts in the sign +15 bits. Dividing by 64 converts to the sign +9 bit value and dividing by 100 counts/VDC converts to VDC. Thus, we put a calibration Coefficient in the Calibration Data of 1/6400 (1.5625E-04). Back then we could not enter the number directly. Instead we had to put in data and let the computer calculate the Calibration Coefficients. Thus it came out as 1.5619999E-04 or 1/6402.049065 (close enough). That is in the Shuttle Data Tape so it gets converted to VDC on the ground. With MCC Calibrations it is converted to percent.

Note 3 Same as Note 2 except with MCC Calibrations, Selected Elevon FDBK is converted to degrees (DEG).

Appendix F
List of Contributors

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 of this list.

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