RSRM Segment Train Derailment and Recovery

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ABSTRACT

On May 2, 2007, a freight train carrying segments of the space shuttle's solid rocket boosters derailed in Myrtlewood, Alabama, after a rail trestle collapsed. The train was carrying RSRM 98 center and forward segments (STS-120) and RSRM 99 aft segments (STS-122). Initially, it was not known if the segments had been seriously damaged. Four segments dropped approximately 10 feet when the trestle collapsed and one of those four rolled off the track onto its side. The exit cones and the other four segments, not yet on the trestle, remained on solid ground.

ATK and NASA immediately dispatched an investigation and recovery team to determine the safety of the situation and eventually the usability of the segments and exit cones for flight. Instrumentation on each segment provided invaluable data to determine the acceleration loads imparted into each loaded segment and exit cone.

This paper details the incident, recovery plan and the team work that created a success story that ended with the safe launch of STS120 using the four center segments and the launch of STS122 using the Aft exit cones assemblies.

BACKGROUND

Each flight of the Space Shuttle employs the use of two Reusable Solid Rocket Boosters. The propulsion of these boosters is provided by Reusable Solid Rocket Motors (RSRMs) which are made up of stacked segments. There are four segments per motor. These segments, which contain a solid propellant, are cast in Promatory, Utah at the ATK facility, are placed in railcars with fiberglass covers, and shipped to Kennedy Space Center.

The train configuration as it left the ATK Promatory production facility is shown below in Figure 1. This cross country trek typically takes 12 days and covers over 2000 miles and 8 states as shown in Figure 1. The Timeline for this shipment is shown in Table 1.

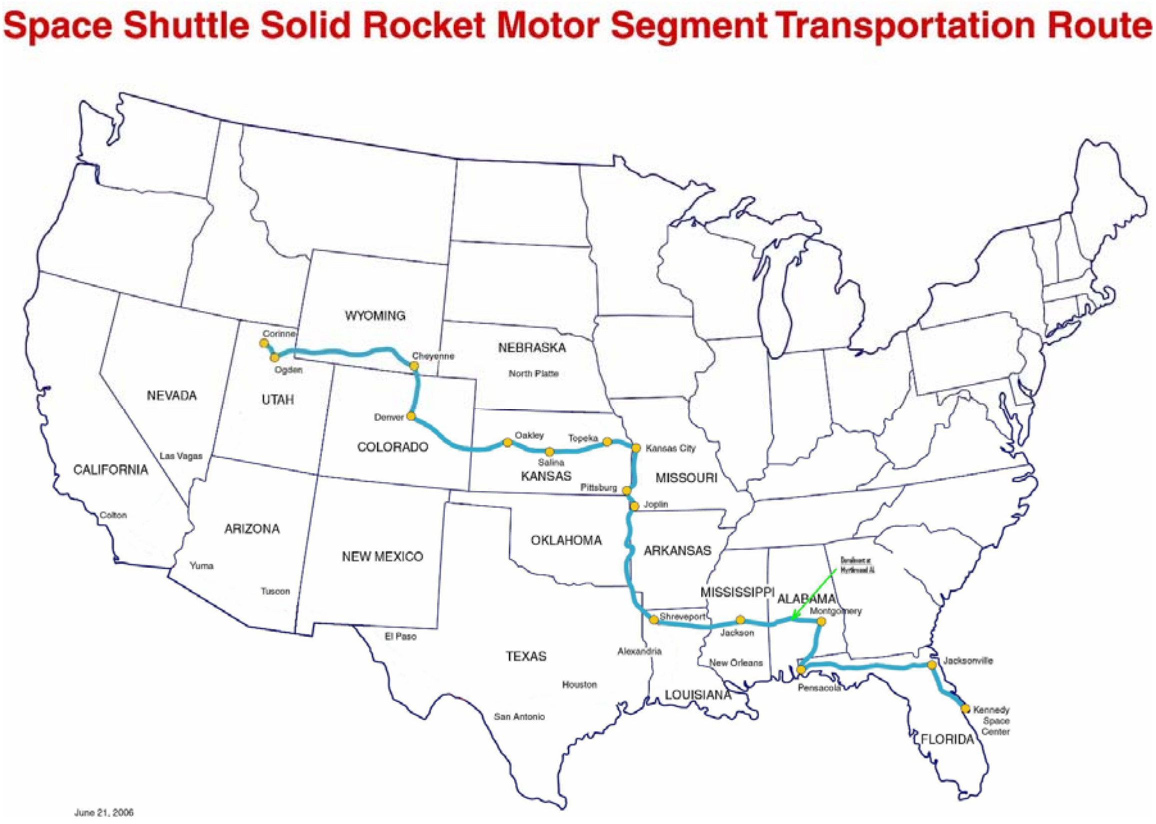

Figure 1. Space Shuttle Sold Rocket Motor Segment Transportation Route

Railroad		Date - Time		Arrival	Date - Time	Miles
UPRR	Corinne, Ut	4/24 - 16:00	~	Ogden, Ut	4/24 - 17:45	26
	Ogden, Ut	4/24 - 20:15	~	Green River, Wy	4/25 - 01:50	178
	Green River, Wy	4/25 - 20:00	~	Rawlins, Wy	4/26 - 00:50	133
	Rawlins, Wy	4/26 - 01:15	~	Speer Jct, Wy	4/26 - 08:10	175
	Speer Jct, Wy	4/26 - 08:50	~	Denver, Co	4/26 - 13:30	104
	Denver, Co	4/26 - 16:15	~	Sharon Springs, Ks	4/27 - 03:15	211
	Sharon Springs, Ks	4/27 - 04:00	~	Salina, Ks	4/27 - 19:30	244
	Salina, Ks	4/28 - 21:50	~	Kansas City, Mo	4/29 - 06:10	178
KCS	Kansas City, Mo	4/29 - 08:00	~	Pittsburg, Ks	4/29 - 11:55	128
	Pittsburg, Ks	4/29 - 12:10	~	Heavener, Ok	4/29 - 19:40	210
	Heavener, Ok	4/29 - 20:10	~	Shreveport, La	4/30 - 07:30	216
	Shreveport, La	4/30 - 08:40	~	Vicksburg, La	4/30 - 14:30	172
	Vicksburg, La	4/30 - 14:55	~	Meridian, Ms	4/30 - 21:30	141
MNBR	Meridian, Ms	5/01 - 03:00	~	Naheola, Al	5/01 - 08:20	47
	Naheola, Al	5/02 - 07:06	~	Myrtlewood, AL	5/02 - 08:45	8
					Total Miles	2171

Table 1. Summary of Shipment Timeline.

Two locomotive engines are employed and a Business car houses the team of engineers assigned to oversee the shipment as shown in Figure 2.

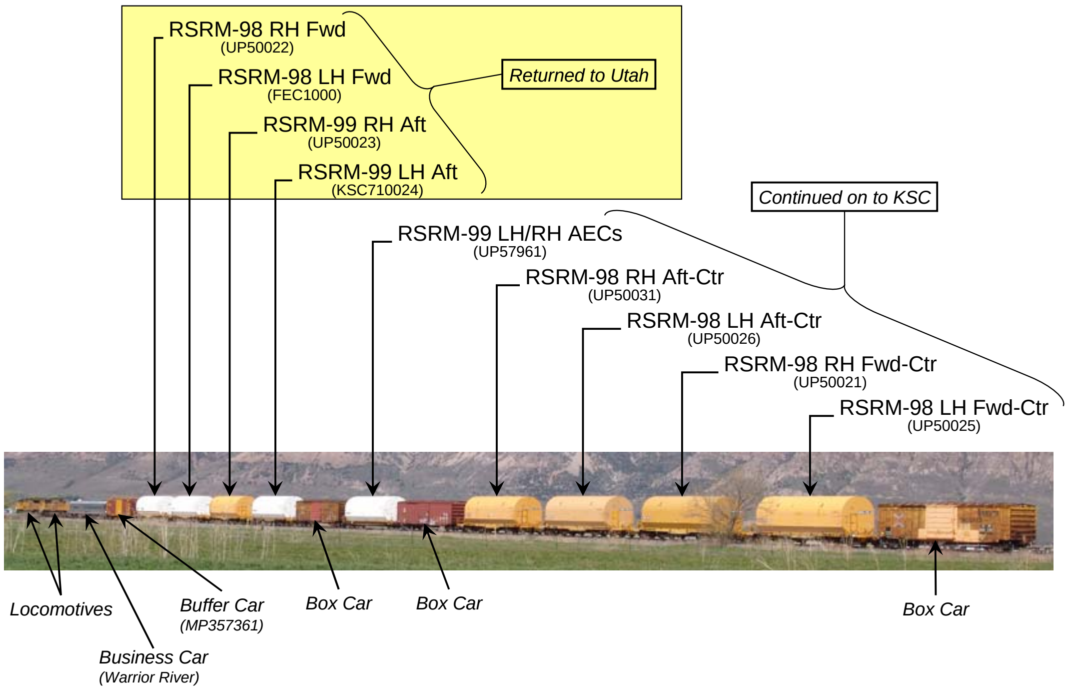

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Figure 2. Train Configuration

THE DERAILMENT

On May 2, 2007, the train carrying eight segments of the space shuttle's solid rocket boosters derailed in Myrtlewood, Alabama, after a trestle collapsed. The derailment was in a remote stretch of track near Myrtlewood, about 110 miles (175 kilometers) southwest of Birmingham. The train was carrying the RSRM 98 center and forward segments (STS-120) and RSRM 99 aft segments (STS-122). Each segment weighs approximately 300,000 lbs. and is protected by a white or yellow colored fiberglass cover during shipment. Initially, it was not known if the segments had been seriously damaged. Four segments (the 98A and 98B Forward segments and the 99A and 99B Aft Segments) dropped approximately 10 feet when the trestle collapsed, one of which rolled off the collasped trestle onto its side. Shown in Figures 3-7 below are photos taken at the site the day of the collapse.

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Michael E. Palmer / Tuscaloosa News via AP

Figure 3. Aerial Photo of Derailment Site

Figure 4. Collapsed Trestle

Figure 5. Segments On the Collapsed Trestle

Figure 6. Locomotives and Business Car

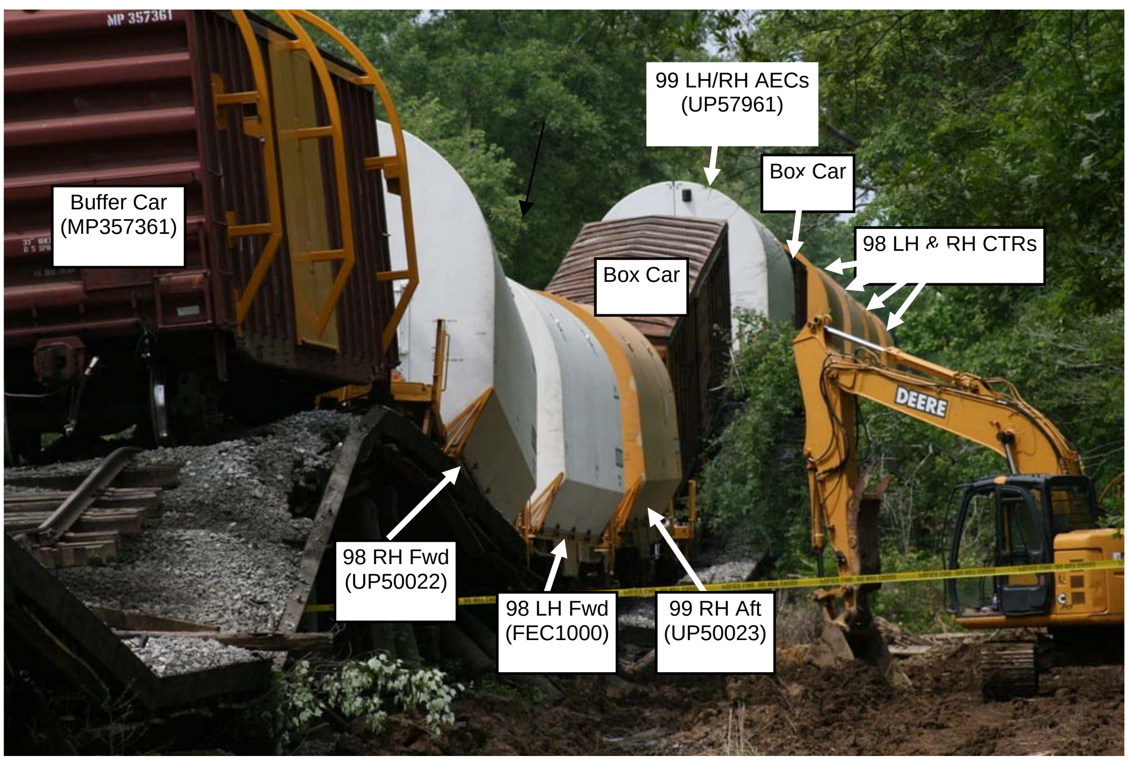


Figure 7. Position of Segments

Hours after the incident, teams from ATK, NASA, local emergency responders as well as large derailment recovery team from R.J. Corman Railroad Group arrived on the scene to begin the process of righting the locomotives, business car and rolled segment. Like building a Model HO train track, these highly specialized teams and equipment filled in the swampy ground, rebuilt the rail bed and laid short pre-built track sections to roll the involved cars to a safe holding area. The remaining cars including the four center segments were still on undamaged track and were rolled back to a secure yard several miles down the track. This coordination of people, machines, trains and train tracks is represented in Figure 8.

Figure 8. Man and Machines

THE RECOVERY

The next task was to determine the health of the four center segments and aft exit cones that remained on the undamaged track. Each rail car containing RSRM flight hardware is instrumented with electronic data recorders (EDRs) that record data from accelerometers on the segments during transport. This data from the four center cars and exit cones was downloaded and compared to historical data to determine if any out of family events occurred. The data collected are shown in Table 2.

	Forward/Aft (X) (g)	Vertical (Y) (g)	Horizontal (Z) (g)
Historical Maximum (21 thru 92)	**2.15**	**1.39**	**0.65**
98a Center Aft	**0.90***	**0.39**	**0.58**
98a Center Forward	**1.39***	**0.29**	**0.59**
98b Center Aft	**0.74***	**0.33**	**0.62**
98b Center Forward	**1.41***	**0.38**	**0.52**

Table 2. Center Segment EDR Peak Acceleration Summary

As can be seen, the data collected was well within historical limits and met all flight specifications. ATK and NASA Engineers recommended the path forward to include

- Create Disposition Logic Flow (DLF) action plans for each major component by work center (nozzle, propellant, metal hardware, etc.)
  - DLF is standard MRB tool
  - Identify concerns
  - Define actions to resolve concerns
- Extract inspection, test, and analysis actions from DLF's and define critical path
- Critical path is PLI verification

THE RESULTS

This information was presented by the NASA and ATK Chief engineers as part of the Flight Readiness Review for STS-120 with deemed acceptable for flight with no dissenting opinions.

The remaining four segments that dropped (98A and 98B Forward and 99A and 99B Aft) did show significant departures from the historical data and were returned to Utah for further evaluation and disposition after a difficult and delicate transload of the segments onto undamaged cars.

The EDR data from these segments are presented in Table 3 and in Figures 9-11. EDR data clearly shows out of family and above engineering allowable (3g) condition. It should also be noted that the EDR data may not represent the worst case due to the position of the gauge on the motor centerline.

	Forward/Aft (X) (g)	Vertical (Y) (g)	Horizontal (Z) (g)
Engineering Limits (STW9-14005)	**+/- 3.0**	**+2.0 / -1.0**	**+/- 1.5**
Historical Maximum (21 thru 92)	**2.3 (Shipment 53a Aft Seg., STS-75)**	**1.2 (Shipment 77B Aft Seg., STS-98)**	**.97 (Shipment 67B Aft Seg., STS-88)**
98a Forward Segment	**2.63***	**7.48***	**2.31***
98b Forward Segment	**1.65***	**5.26***	**1.44***
99a Aft Segment	**1.40***	**7.73***	**3.14***
99b Aft Segment	**2.07***	**8.92***	**2.77***

*** These occurred at the time of the train wreck, 2 May 2007, 8:45am MDT**

Table 2. Summary of Historical and Event G Loading.

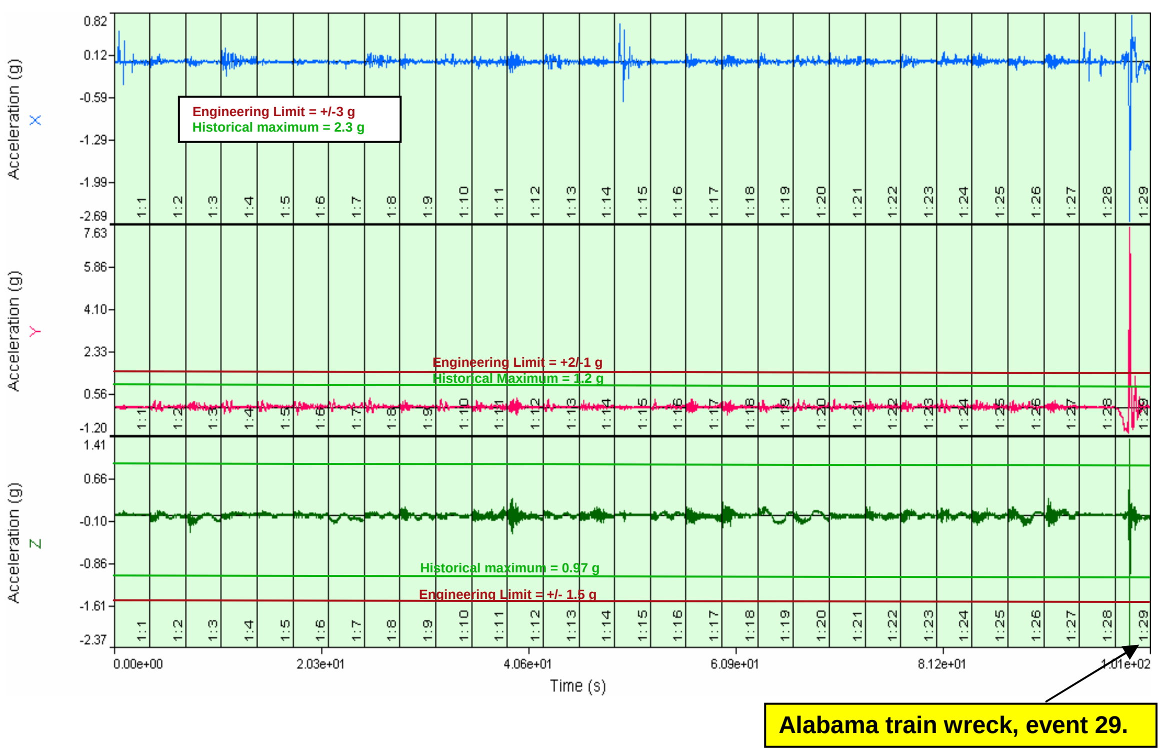


Figure 9. RSRM 98a Forward Segment EDR Data – file 98af02.udf

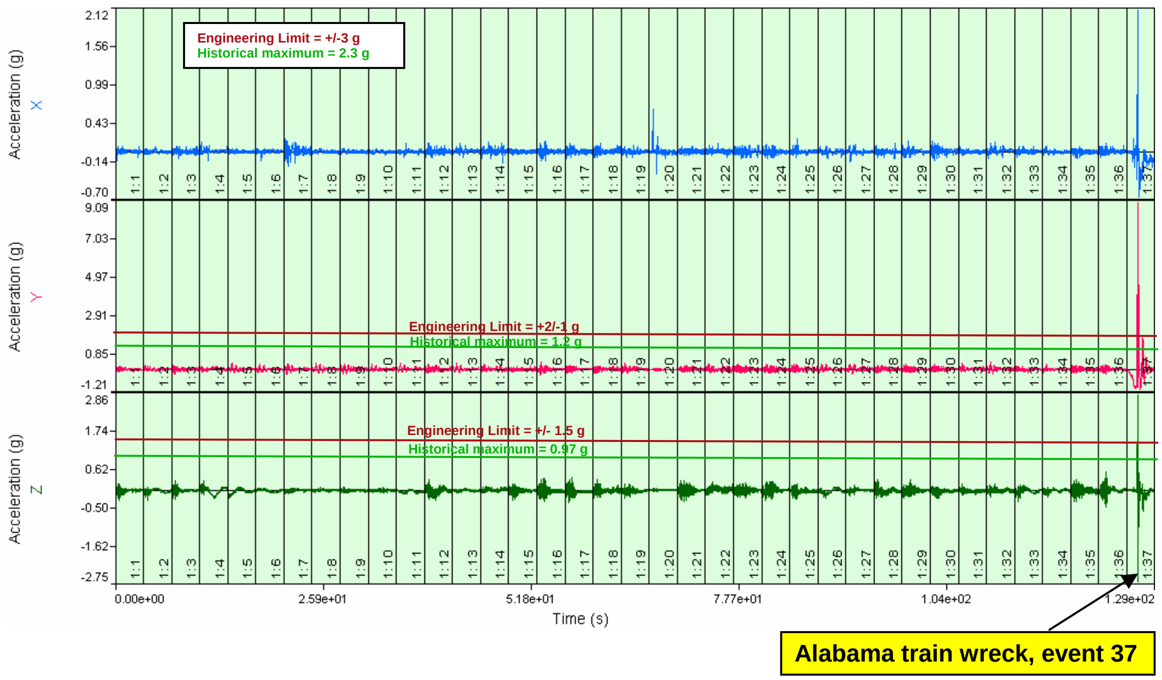
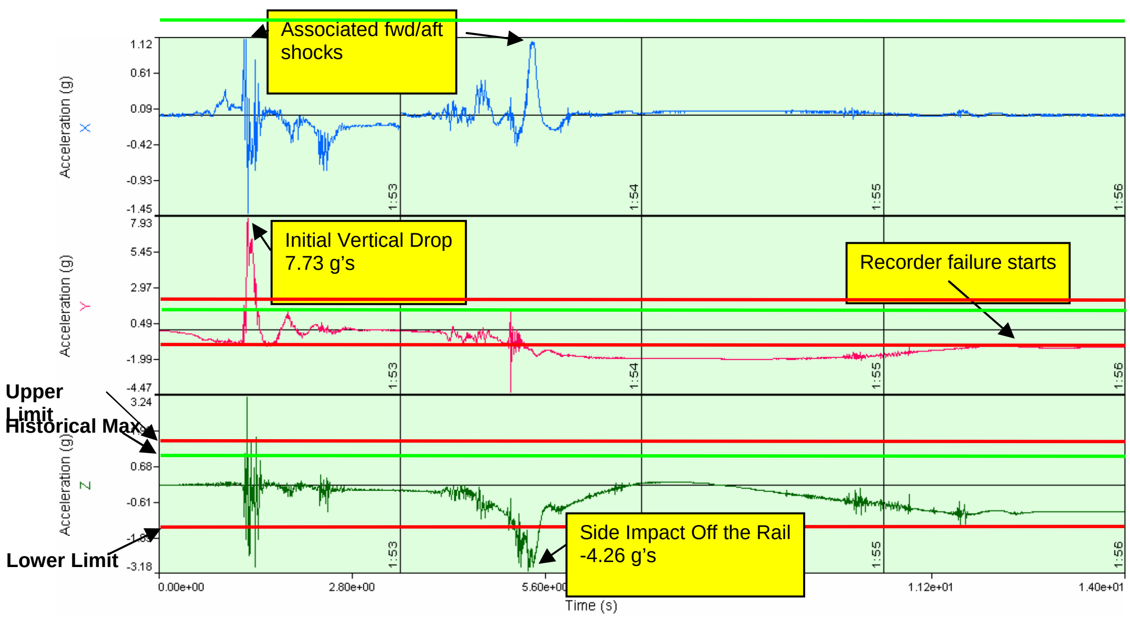


Figure 10. RSRM 99b Aft Segment EDR Data – file 99ba02.udf



Maximum transverse load was 7.73 g's during vertical drop from rail failure with an associated 1.08 g's fwd/aft.

Figure 11. 99a Aft Segment EDR Data At Crash Time

Rationale for using these segments for flight could be accomplished if technical experts found support in the following areas:

1) EDR Data
2) Physical inspection of segments
3) Confidence in NDE of out of family segments
4) Subscale testing and Analysis

EDR Data

EDR data clearly shows out of family and above engineering allowable (3g) condition. It should also be noted that the EDR data may not represent the worst case due to the position of the gauge on the motor centerline.

	Forward/Aft (X) (g)	Vertical (Y) (g)	Horizontal (Z) (g)
Historical Maximum (21 thru 92)	2.3	1.2	.97
98a Forward Segment	2.63*	7.48*	2.31*
98b Forward Segment	1.65*	5.26*	1.44*
99a Aft Segment	1.40*	7.73*	3.18*
99b Aft Segment	2.07*	8.92*	2.77*

Physical Inspection

Physical inspection of the motors can be accomplished and will Indicate gross failures in the propellant or case structural capabilities. However this will not provide access to the case to insulation or insulation to propellant bondlines.

Non-destructive Evaluation (NDE)

The NDE techniques employed for evaluation of these motors include but are not limited to radiography and Ultra-sonic techniques. These are primarily used to detect voids, cracks and inclusions in propellant and insulation. These techniques are not capable however of detecting “kissing” unbonds in the PLI system. These types of unbonds could be generated by high loads on the bondline during out of family environments (train derailment). Normally, process controls and subscale testing panels generated during the build up process serve as verification that bondlines meet requirements. Failure of a “kissing” unbond can lead to bore choking, increased propellant burning surface and potential castastrophic failure of the motor.

Subscale Testing and Analysis

If the loads to which the segments were exposed were fully understood, it is possible that subscale tests could be used to generate data that could be used in models to show margins. However, as discussed earlier, the EDR data is not conclusive and higher loads were possible in other parts of the motor. Therefore, subscale testing would not be beneficial in clearing the segments in question.

THE FINAL DESTINATION

Figure 12. STS120 Stacked and Ready.

The Center Forward and Center Aft segments for RSRM Motor set 98 are shown stacked and ready to fly in Figure 12. Launch of this motor set on STS120 is shown in Figure 13.

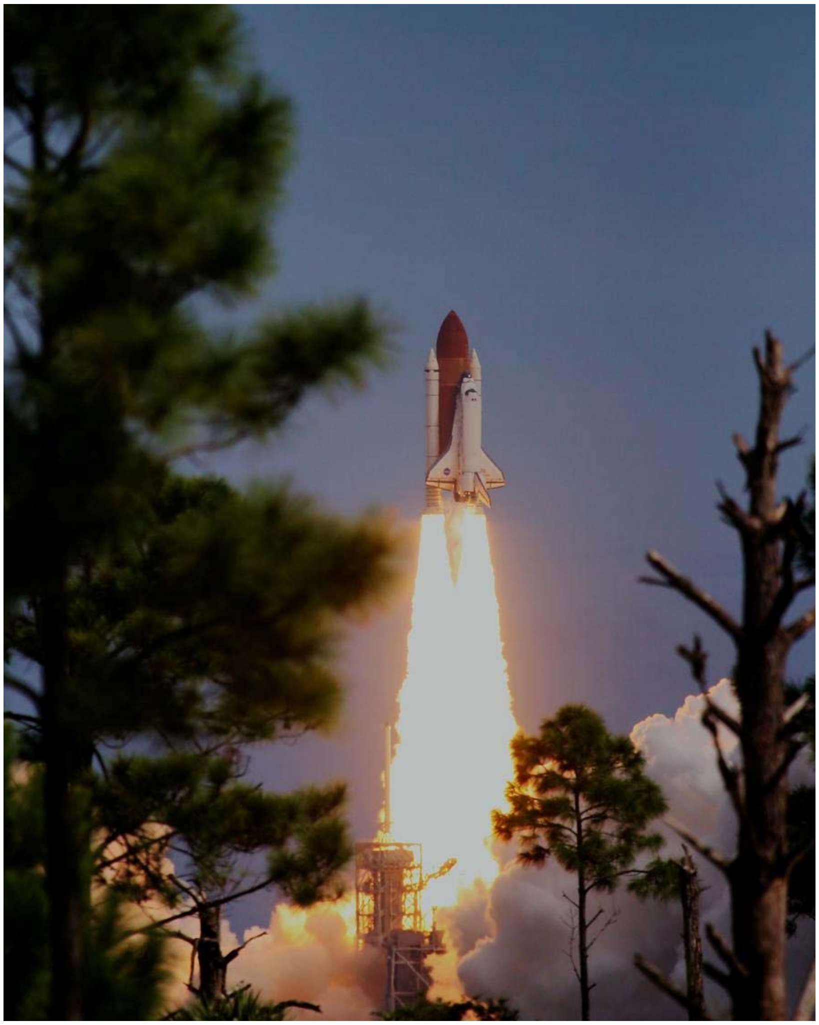


Figure 13. STS120 Liftoff.

AFT Exit Cones Cleared for STS-122

Aft exit cones 99A and 99B were in the still elevated, undamaged portion of the track and not involved in the bridge collapse area. EDR data was downloaded and evaluated and all data were below engineering allowables and well within historical maximums as shown in Table 3. Each exit cone was inspected for physical damage upon delivery to KSC thus being deemed to be acceptable for STS122.

	Forward/Aft (X) (g)	Vertical (Y) (g)	Horizontal (Z) (g)
Historical Maximum (21 thru 92)	7.83	1.66	5.05
99a Aft Exit Cone	1.96	1.28*	0.69*
99b Aft Exit Cone	1.68	1.58	0.60

Table 3. Aft Exit Cone EDR Data

CONCLUSIONS

Instrumentation used to monitor the in transit loads were crucial in allowing NASA to recover and fly the RSRM 98 Motor set on STS-120 and the Aft Exit cones on STS-122. However the real story is the quick response and the coordination and teamwork that was crucial to make it happen. Truly the team, made up of NASA, ATK, RJ Corman Railroad Group (derailment specialists), Union Pacific Railroad technical expert, Barnhart Crane and Rigging Co., and the cities of Pennington and Myrtlewood Alabama, worked as one unit with a common goal; the safe recovery of the Space Programs assets. This was done is such a profession manner that five months later, the segments safely delivered our astronauts into space.