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Paper Session I-A - Space Shuttle Launch Delays and Lessons Learned for RLV/X-33

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SPACE SHUTTLE LAUNCH DELAYS AND LESSONS LEARNED
FOR RLVIX-33

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Abstract

The Shuttle Program has experienced numerous launch delays over the 15-year history of launch operations. This paper presents a comprehensive tabulation of those delays along with descriptive data covering launch attempts, system/subsystem involved and a brief discussion of the cause of each delay. This historical data has been audited against NASA/JSC flight history and current records at KSC. Both number of occurrences and magnitude of each launch delay are summarized in a database format allowing analysis, sorting by system or Orbiter vehicle and chronological assessment. Trends in launch delays since return to flight and comparisons with expendable launch vehicle data are presented. A special sort is described summarizing the propulsion system delays over the history of the program. This particular analysis has application to the new X-33 / Reusable Launch Vehicle (RLV) Program due to the universal selection of L02/LH2 engines for all RLV designs. Significant lessons learned from these launch delay data are presented for comparison with the optimistic turnaround projections for X-33 and RLV.

Database Description

The STS Launch Delays Database contains all launch delays encountered from STS-1 to date including the “original manifest” launch date and all delays from that date to the actual launch date for each mission. The data is arranged in an Excel 5.0 spreadsheet and contains approximately 250 entries. Detailed data on each delay entry includes: Mission, launch sequence, delay number, Orbiter Vehicle, OV-flight number, date, delay magnitude (days, hours, minutes, seconds). For each entry the system and subsystem causing the delay and a brief description of the cause are presented.
The basic groundrules used to define a delay include all delays causing a change or slip in the planned launch date or time. Of particular interest are those delays of one day or more which are the central focus of this analysis. Delays caused by schedule remanifesting or flight-to-flight delays are accounted for but are set aside for vehicle systems evaluations. All data has been cross-checked against the Space Shuttle Mission Reports published by the Johnson Space Center and the Space Shuttle Launch Schedule and Planning Manifest maintained by the Kennedy Space Center. These sources are referred to often to confirm data accuracy.

Summary Chart Observations

Delays data sorted by major system are summarized in Fig 1. It is easily seen that the delays due to 5IL (Challenger) are so large as to cause trend distortion. Therefore the 2 years and 8 months required to return to flight (including major mods to all Orbiters) are shown here but discarded for evaluation purposes.

Looking now at the remaining program delays of one day or more, we find that a large portion, 58%, were due to delays in the liquid propulsion area (including hydrogen leaks, MPS, OMS/RCS and SSME). And, 60% of this portion is due to the SSME only. Please note the distinction between number of delays and magnitude of delays. The band along the bottom of the chart carries the number of delays in each system, the height of each bar indicates the cumulative magnitude in days of delay for each system over the program history. The high occurrence and magnitude of propulsion and engine delays does not bode well for the planned RLV program. (Note: All three contractors, seeking high Isp, have selected L02/LH2 propellants / engines.) Also, notice the weather delays data. Weather has 22 occurrences, but only a magnitude of 30 days, yielding an average of 1.36 days. All other system delays average 12.58 days per delay. This is not surprising for Florida weather; where they say: “If you don’t like today’s weather, just wait till tomorrow.” We’ve had many “24-hour scrub turnarounds” on the Shuttle program. By the way, please note: the average propulsion delay is 21.4 days, a system record. Summary data indicates 99 total delays with a cumulative magnitude of 999 days. Additional summarizing data is shown in Fig. 1; for example, it took 124 “attempts” to launch 73 missions, an average of 1.7 attempts per launch. (Note: During 1993 that average was 2.4 attempts per launch.) For our purposes an “attempt” consisted of all launch counts which reached the “go for cryo load” point, about T-6 hours.
**STS LAUNCH DELAYS - TOTAL PROGRAM**

For Delays of One Day or More


<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>NO. OF DELAYS</th>
<th>LC2 LEAKS</th>
<th>MPS</th>
<th>OMS/RCS</th>
<th>SSME</th>
<th>LAUNCHES</th>
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<tbody>
<tr>
<td>SRB</td>
<td>5</td>
<td>973</td>
<td>18</td>
<td>49</td>
<td>165</td>
<td>73</td>
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<td>LIQUID PROPULSION</td>
<td>27</td>
<td>577</td>
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<td>FLIGHT HARDWARE</td>
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<tr>
<td>GSE</td>
<td>4</td>
<td>158</td>
<td></td>
<td></td>
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<tr>
<td>WEATHER</td>
<td>22</td>
<td>28</td>
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<tr>
<td>RANGE</td>
<td>6</td>
<td>30</td>
<td></td>
<td></td>
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<tr>
<td>PAYLOAD</td>
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<td>12</td>
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<td></td>
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</tr>
<tr>
<td>CREW</td>
<td>2</td>
<td>67</td>
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<td>OPS</td>
<td>7</td>
<td>37</td>
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<tr>
<td>SLIPS*</td>
<td>21</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Figure 1 - Shuttle Launch Delays Summary By System

**Propulsion System Analysis**

Propulsion system delays dominate the system sort, including H2 leaks, when, sometimes, the source of the leak was unknown. This situation caused the summer of 1990 to be a long season when this problem affected more than a single vehicle. Also, Fig. 2 shows the 12-year history of cumulative SSME launch delays. A curious “bathtub” curve seems to emerge, indicating that we are dealing with more than simple “infant mortality” in the early years. The on-pad aborts of 1993 show their presence. It should be noted that many of these delays were brought about by failures in the instrumentation systems, not flight hardware failures. So, beware the thinking that a vehicle health management system for the next generation launcher is going to be the panacea for all propulsion problems. Instrumentation failures will continue, so number and placement of instrumentation must be judicious to enhance, not to impede new vehicle operations.
Sorts by Orbiter

A sort of the database by orbiter vehicle was performed to determine if a correlation could be made of delays per launch with the build date (i.e., is a learning curve present?). Figure 3 is a plot of delays by orbiter vehicle number. With the exception of OV 102 (Columbia, our oldest orbiter) we find a direct relationship between number of flights and number of delays, independent of the build date. Could it be that, for Columbia, we are seeing a greater number of delays per launch due to aging effects, and the other three vehicles (not yet to this age) have a linear relationship between number of launches and number of delays? However when weather delays are subtracted from the effects, the variations are not as linear (see Fig. 4). OV 103 is 1.0 delay per launch, OV 104 is the lowest at 0.73, OV 099 is 1.1, and OV 105 is 0.89.
Launch Windows

The Shuttle’s recent missions to MIR have raised the issue of probability of launch within a limited (5 minute) window. Based on data made available in the Orlando Sentinel I have compiled the chart shown in Fig. 5. As you can see, this data presents the number of missions launched on the first, second, etc. attempts as of January 1995 and the fraction of each that was launched within the first 5 minutes of the launch window. Looking at total attempts, we see that 32.5% were within the first 5 minutes and looking at only the first attempts for each of the 66 missions only 27% were within the first 5 minutes. This does not bode well for the upcoming ISSA missions, all of which have a 5-minute window due to the orbital plane change required to achieve the 51.6 degrees orbit. However, added built-in hold time prior to launch may help improve the success rate.
Comparisons with ELV Delays

When we compare existing Shuttle delays with those experienced in the expendable launch fleet (Delta, Titan and Atlas) we see similar patterns. The ELV data used here is taken from the reports presented to the Moorman Panel on Launch Modernization. Figure 6 illustrates a typical comparison. These data are formatted as “average number of delays per flight” and “average delay time per flight”. Some vary as to sample size, for example, a large Titan 11/111 sample (151 flights-many at Vandenberg) while the Atlas data is for only 13 flights. No explanation of these variations is given in the subject report. As can be seen here, Shuttle (the only manned and reusable vehicle) performed competitively with both Delta and Titan 11/111, and, for the sample illustrated, bested Atlas. Direct comparisons with Titan IV do not require comment. An interesting additional comparison was made in the Moorman Report, “Nominal Processing Time”. These timelines were subsequently analyzed for “Time off-Pad” and “Time on-Pad”. Here again, as shown in Fig. 7, Shuttle data compares very competitively, considering the manned and reusable aspects.
Figure 6 - Launch Vehicle Delays Summary

<table>
<thead>
<tr>
<th></th>
<th>Launches</th>
<th>No. of Delays</th>
<th>Total Days of Delay</th>
<th>Avg. Payload - LEO (lbs)</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>42</td>
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<td>48K</td>
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<tr>
<td></td>
<td></td>
<td></td>
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<td>52K + Crew</td>
</tr>
</tbody>
</table>

* Source of ELV Data = NSIA Space Committee Study on Launch Responsiveness (June 1994)

Figure 7 - Launch Vehicle On-Pad and Off-Pad Timelines

Based on STS CY91 - CY94
(As of June 1994) -24 Flights
* Includes Orbiter Processing

Figure 7 - Launch Vehicle On-Pad and Off-Pad Timelines
Lessons for X-33/RLV

The key messages for the vehicle and operational designs of X-33 and later RLV can be deduced from this, the only reusable space vehicle experience. Those key messages are summarized here as follows:

1) L0₂/LH₂ propulsion, its instrumentation and the control of H₂ leaks must receive major re-thinking for RLV. Unless significant gains can be assured in component reliability, maintenance requirements and robustness, “we’ll get what we’ve always got” (no matter how well we meet mass fraction criteria).

2) Launch delays will occur with RLV, the question is: What systems, what reliability values and what new designs should we invest in to achieve the RLV goals? Some feel that a comprehensive vehicle health management system will, somehow, be our panacea. They could be wrong. Many of our current problem reports revolve around instrumentation and wiring systems. Therefore, a major improvement in the reliability of these ancillary systems is required, as well.

3) RLV should, by all accounts, be more tolerant of weather delays than Shuttle. It will have no transatlantic landing sites and abort modes that are keyed on “abort-to-orbit”. It should have potentially higher cross-wind landing capability by design to cope with landing delays.

4) Since the causes of most delays are in systems which are also the major timeline hitters, it is hopeful that improved turnaround times will result in improved resistance to launch delays. However, since most of the current RLV turnaround assessments are based only on predicted reliability values, the derived improvements are by no means certain.