This document contains excerpts from the Expendable Launch Vehicles (ELV) Independent Assessment Report (title page shown below). Only those sections which relate to the PBMA element **Pre-Operations Integration and Test** are displayed.

The complete report is available through the PBMA web site, Program Profile tab.

Expendable Launch Vehicles

Independent Assessment of NASA Expendable Launch Vehicle Safety & Mission Assurance Processes

NASA Headquarters
Office of Safety & Mission Assurance
August 30, 1999

3.2 Probable Causes and Assurance Process Gap Analysis

ELV Failure Case Studies and Gap Analysis

	ELV Failure Description	General Comments	NASA ELV Assurance Process Or Activity That May Have Prevented This Mishap	Subjective Assessment High/Medium/Low Probability of Mishap Prevention
1.	**Delta II: 13 Jan 97-Booster Failure** Damage or flaw in the Graphite Epoxy Motor case. Undetected during pre-launch testing.	Manufacturing flaws or latent defects difficult to uncover if missed by contractor. In-plant NASA representatives participate in hardware pedigree reviews.	NASA/ELV Mfg. verification processes, i.e., pedigree reviews, build reviews, and test data reviews not likely to have detected a flaw in a motor case.	Low
2.	**Titan IV-A20: 12 Aug 98-Booster Cable Short** Intermittent shorts on vehicle power bus. Harness insulation was flawed prior to launch and escaped detection during preflight inspections.	Fundamental design issue or poor quality workmanship on just this vehicle.	NASA/ELV Design Verification and/or Mfg. Verification Activities would not likely have detected these failures. DCMC would be most likely to detect the potential failure mode. DCMC supports both NASA and DOD.	Low
3.	**Delta III: 26 Aug 98-Booster Failure** Human error in assumptions regarding applicability of Delta II software on the Delta III vehicle.	Used Delta II software on a Delta III, i.e. wrong application of software. Delta II control software assumed 4 Hz structural vibration modes would be damped (converging toward zero). Classic “heritage trap”.	NASA/ELV mission analysis group looks closely at changes to core vehicle software.	Medium

4.	**Titan IV-B27: 9 Apr 99-IUS Failure (DoD)** IUS failed to separate properly. Electrical connector in the separation system failed to disengage. Poorly defined work procedure (involving thermal insulation and tape wrap) identified as root cause.	NASA operational pre-launch/launch review processes are in place. Launch site NASA presence at KSC is an added plus.	NASA/ELV Pre-Flight Verification & Test processes incorporate "Walkdown" activities which may or may not have found the error.	Low/Medium
5.	**Athena: 27 Apr 99-Booster Fairing Failure** Shroud failed to separate. Shock unplugged electrical connection. Electrical signal not received.	Greater than anticipated shock associated with initial fairing separation resulted in incomplete final separation. Apparently a design defect - design verification and test failure. Coupled loads analyses should have fully characterized the separation event.	If the vehicle was qualified under NPD 8610.7 then KSC Engineering would not likely have required special fairing/separation qualification testing which might have detected the problem.	Low/Medium
6.	**Titan IV-B32: 30 Apr 99-Upper Stage Centaur Software Failure (DoD)** Incorrect flight constant was manually entered into the Centaur software. Human error.	Centaur flight software verification failure. Software experts consulted at GRC do not believe that KSC or GRC would have detected the coding error. One lessons learned, identified by GRC in the failure review, is to have the controls team evaluate the frequency response (Bode Plots) of "implemented software" to verify proper performance.	It is not likely that the NASA/ELV mission analysis group working with LMA would have detected this failure mode. The LMA controls group verified the filter constants (through simulation) but the constant was coded improperly (manual entry) by the software group. The FAST simulation does not exercise the Inertial Measurement System (IMS) software where the error occurred.	Low

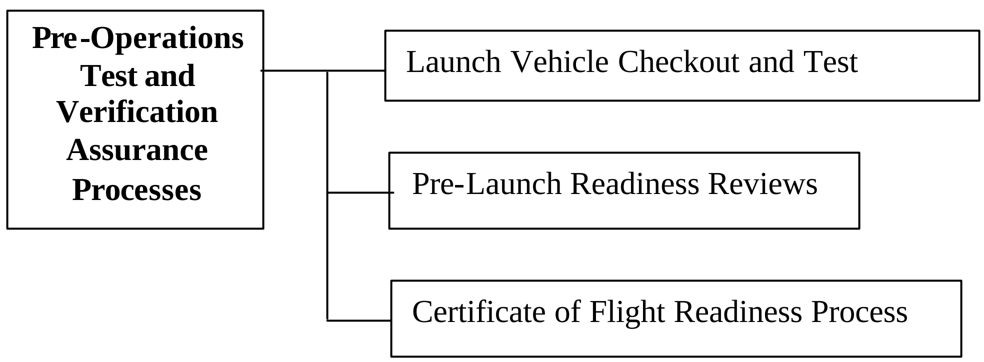
7.	**Delta III: 4 May 99- RL-10B Failure (DoD)** New manufacturing process (engine brazing process) coupled with higher than expected flight loads may have caused the rupture of the combustion chamber.	New (improved) inspection and NDE requirements have been imposed (ultrasound and x-ray) as corrective actions. New manufacturing process changes receive active scrutiny from KSC/ELV program management.	NASA/ELV design verification and/or manufacturing verification assurance activities may or may not have insisted on rigorous manufacturing process qualification and certification for a second tier supplier (P&W).	Low/Medium
8.	**Atlas-Centaur (AC-62): 09 Jun 84-Upper-Stage Failed To Boost (NASA)** Leak occurred in the LO2 tank. Incorrect clearance between inter-stage adapter and tank. High pressure in tanks at separation.	Failure difficult to mitigate through insight processes.	NASA GRC managed pre-commercial assurance approaches employed at this time. Very unlikely that diminished “insight role” would have detected.	Low
11.	**Titan 34D (D-9): 18 Apr 86-SRM Failure (DoD)** Motor case insulation unbonded in one of the vehicle’s two SRMs. Hardware quality control need to be tightened.	Poor manufacturing process stability and control.	Current NASA/ELV manufacturing verification (in-factory quality) processes (DCMC) used the same people used by USAF.	Low
13.	**Titan 34D (D-3): 02 Sep 88-Transtage Failed To Re-Ignite (DoD)** Fuel tank and pressurization lines damaged from repairs or shrapnel impact during pre-launch activities.	One of two causes. Corrective actions included requiring validation and approval of repair procedures. Also cited was improved manufacturing and parts control.	NASA/KSC pre-flight testing assurance processes may or may not have required contractor to show data validating his repair process.	Low

14.	**Titan III (CT-2): 14 Mar 90-Intelsat VI Failed To Separate From 2nd Stage** Wiring team mis-wired the harness. The satellite never received the separation signal.	Commercial Titan generic composite system test (CST) failed to detect mis-wired configuration.	NASA/KSC pre-flight testing would require use of a spacecraft specific test protocol and would likely have found this error.	Medium
15.	**Atlas-Centaur (AC-70): 18 Apr 91-One Centaur Engine Did Not Achieve Full Thrust** Air ingested into the turbo-pump liquefied and froze in the C-1 engine LH_2 pump and gearbox.	Failure difficult to detect by any secondary insight process. Design and new inspection/procedural corrective actions. New inspections and procedural changes were identified to eliminate debris in the fuel line.	NASA/ELV design engineering processes would have looked closely at a design change. Non-design change failure mode (latent defect) in design would not likely have been detected.	Low
17.	**Atlas-Centaur (AC-71): 22 Aug 92** Centaur C-1 engine failed due to the ingestion of air into the turbo-pump.	Difficult failure scenario to detect. Design and new inspection/procedural corrective actions.	NASA/ELV ERB would have carefully considered return to flight rationale, although a latent design defect would not likely have been detected by NASA/ELV engineering activities.	Low/Medium
19.	**Titan IV (K-11): 02 Aug 93-Solid Rocket Motor Exploded** Propellant cut during restrictor repair. The repair was more extensive than had ever been attempted on such a motor segment.	Repairs to safety of flight items are reviewed by NASA representatives. While KSC ELV engineering does not have a solid rocket motor expert they may have sought support from MSFC.	NASA/ELV manufacturing engineering and flight assurance in-plant personnel working with KSC/Engineering may have disallowed use of the segment.	Medium

20.	**Pegasus XL (STEP -1): 27 Jun 94-Inaccurate Estimation Of The Vehicle Aerodynamics**. Erroneous aerodynamic predictions were used to design the flight control autopilot system. Insufficient design verification testing.	Too great a dependence on analysis and modeling coupled with marginal validation of model are root causes.	For first-time vehicle use or newly qualified vehicles there is a greater likelihood that KSC ELV engineering would detect this design defect.	Medium
23.	**LMLV-1 (DLV): 15 Aug 95-Thrust Vector Actuation Mechanism Malfunctioned** Erroneous feedback signal caused by reduction of electrical resistance in cables. Cables heated by hydraulic oil ignition. Redesigned hydraulic oil expulsion, improved thermal protection for cables and TVA components.	Three fundamental design failures contributed to vehicle loss. Improper design verification testing is a contributing factor.	NASA/ELV design and engineering processes would not likely have identified these failure modes in a commercial launch mode. If qualifying vehicle for first flight it is possible that NASA would have identified design problems.	Low/Medium
24.	**Conestoga 1620: 23 Oct 95-Unintended Thrust Vector Actuation Signal Was Sent To The Castor IVB Nozzle Actuator** No software filters to reduce noise to the onboard navigation computer.	Fundamental design flaws in hydraulics, software, and vehicle modal analysis. Latent design defects. If first flight or qualification flight NASA MSFC (in support of KSC engineering) may have detected design defects.	NASA design/engineering may or may not have identified failure modes in initial vehicle qualification. Post initial qualification NASA would not have been in a mode to capture a latent design defect.	Medium

A.8 Pre-Operations Test and Verification Assurance Processes

Critical NASA assurance activities include the witnessing and verification (insight) of tests and procedures involved in launch vehicle assembly at the launch site and final integration and test on the launch pad. Certain key tests are considered NASA approval items in the early stages of integration. During the final six to nine days on the pad NASA involvement is almost entirely on an approval basis. NASA ELV/engineering, SMA/flight assurance, SMA/quality assurance personnel, and SMA/safety personnel are involved in monitoring on-pad integration activities including final test and check-out of the vehicle. In addition to the test and verification activities, NASA employs a well-documented and proven launch readiness review process culminating in the signing of a CoFR.



<u>Launch Vehicle Checkout and Test</u>

LMA/Atlas Example - The key event in the Atlas pre-flight preparation is the Wet Dress Rehearsal (WDR) in which cryogenic propellants are loaded, tanks are pressurized, and the entire countdown sequence is carried out all the way to launch. The WDR is then followed by a “tiger team” activity lasting a week in which all WDR data are reviewed and all non-conformances are evaluated and corrected. NASA engineering and flight assurance personnel also participate by shadowing LMA personnel performing vehicle walkdown/checklist activities.

LMA/Titan IV Cassini Example: NASA Flight Assurance - NASA GRC Flight Assurance Managers (FAM) attended the ground operations, system integration, and management working group meetings and the integration of Cassini to the vehicle and the pad. They reviewed processing problems encountered during vehicle processing at CCAFS for the first Titan IVB (TIVB-24). This data was used to determine possible processing problems on the Cassini vehicle. They compared Vertical Integration Building (VIB) processing and testing changes made between the TIVB-24 and TIVB-33 core vehicles to confirm all necessary processing and testing was planned and documented. FAM’s (as well as KSC-based engineers) participated in the final vehicle readiness reviews of procedures and test data, along with out-of-sequence processing documents. In addition, FA and engineering reviewed all nonconformance and work around documents for possible impacts or oversight of prospective problems.

Typical Launch Service Pre-flight Test and Checkout - The scope of NASA insight and approval in a typical pre-launch test and verification flow is captured in the abstracted sections below derived from the KSC/ELV engineering electrical/mechanical pre-launch test verification and walkdown plan. While not formally documented as a KDP, this plan is typical of the operational level documentation applied to ELV Programs at KSC. All of these activities typically involve ELV/Program discipline engineers and SMA flight assurance and/or quality assurance managers.

- monitor key launch vehicle and payload transportation and handling offload and hardware receiving events
- monitor major system level tests (i.e., propulsion, controls, hydraulics, electrical flight simulation, etc.)
- monitor solid motor build
- observe payload processing events (i.e., fitting attachment , spin balance, etc.)
- observe upper stage motor processing, build-up, balancing, mating, and ordnance installation
- monitor spacecraft processing, weigh/mate operations, installation of clampband, and erection
- monitor all stage erection and mating activity
- monitor spacecraft erection and mate
- monitor mated major systems tests (power-off stray voltage checks, etc.)
- participate in all vehicle walkdown activities

SMA Verification Activities - As part of the pre-launch readiness verification process SMA/FA will typically:

- verify that all high level test data is “in family” (e.g., engine hotfire test data)
- review all special attention items and verify that all fleet issues are resolved pertinent to the relevant hardware
- verify that any open items or incomplete hardware is properly tracked
- verify that all special inspections to this point have been performed satisfactorily
- verify that all waivers and deviations to this point are closed
- provide surveillance of hazardous/high-risk operations

Pre-Launch Readiness Reviews

NMI 8610.24, "Expendable Launch Vehicle (ELV) Launch Services Prelaunch Reviews" establishes the ELV prelaunch review process necessary to assess and certify the readiness for launch of the launch vehicle including separately provided upper stages and supporting launch services provided by commercial companies or by DoD. In accordance with NASA accountability for program mission success, NASA management assesses and certifies the readiness of the launch vehicle (and payload) preparatory to launch through a structured prelaunch review process. Required reviews include:

Center Director's Launch Readiness Review (CD/LRR) - The CD/LRR is held to assess the readiness of the ELV and/or upper stages to proceed with launch site operations. The CD/LRR is chaired by the NASA Center Director of the field installation responsible for management of the NASA Launch Services Projects, or his/her designee, and is held approximately one to two months before launch.

Associate Administrator's Mission Readiness Review (MRR) - The MRR is held to certify the readiness to proceed toward launch countdown. The MRR is chaired by the Associate Administrator for Space Science (AA/SS) and the Associate Administrator of the spacecraft program office (when other than AA/SS), or their designees. The MRR is held at NASA Headquarters after the CD/LRR and approximately one month before launch.

L-4 Review - KSC conducts a Flight Readiness Review (approximately L-4) which is performed prior to the initiation of the final preparations for launch. These reviews include the description of the launch service, mission-unique and first flight items, and anomaly closures from previous missions. At the conclusion of these meetings a poll is conducted to assure that all parties responsible for mission success agree with proceeding to the next milestone.

Launch Readiness Review (LRR) - The LRR is held to update the mission status and closeout actions from the previously held CD/LRR and MRR, and certify the readiness to proceed with initiation of the launch countdown. The LRR is chaired by the NASA Center Directors of the field installations responsible for management of the NASA Launch Services Projects, or his/her designee, and is held approximately two days before launch at the launch site.

Mission Director's Flight Readiness Review (FRR) - The FRR is held to update the mission status, closeout actions from the LRR, authorize approval to proceed into launch countdown, and sign the CoFR. The FRR is chaired by the Mission Director and is held the day before or day of launch at the launch site. Following the FRR and initiation of launch countdown, the final critical milestone before launch is the commit-to-launch poll. The poll, conducted by the NASA Launch Manager for the Mission Director approximately five minutes before launch, asks representatives from all organizational participants to reconfirm their readiness to launch.

NASA may conduct other reviews as appropriate and necessary in preparation for launch. These may include, but are not limited to, Mission Requirements Reviews, Critical

Design Reviews, Design Certification Reviews, Preship Reviews, Ground Operations Reviews, and Project and Launch Manager's Reviews. Generally, the mission spacecraft undergoes a parallel prelaunch review process with both the spacecraft and ELV jointly reviewed in the MRR, LRR, and FRR.

Certification of Flight Readiness Process

Following the completion of the Flight Readiness Review, a CoFR is signed by the following parties:

- NASA Spacecraft Mission Director
- NASA Launch Manager (NLM)
- USAF Spacelift Commander
- Launch Service Provider

The NASA SMA organization signs the back-up CoFR that supports the signature of the NASA Launch Manager.

During the launch countdown, the NASA Launch Manager polls the following parties:

- Spacecraft Mission Director
- NASA SMA
- NASA Mission Integration Manager
- NASA Chief Engineer
- NASA Advisory Team

SMA Role in the CoFR Process - Past procedure for obtaining SMA signature on the CoFR has represented an informal collation of information. However, it is anticipated that future SMA CoFR processes will be fully documented and formally incorporate criteria describing the basis for the concurrence (i.e., knowledge and understanding of assurance process implementation.)