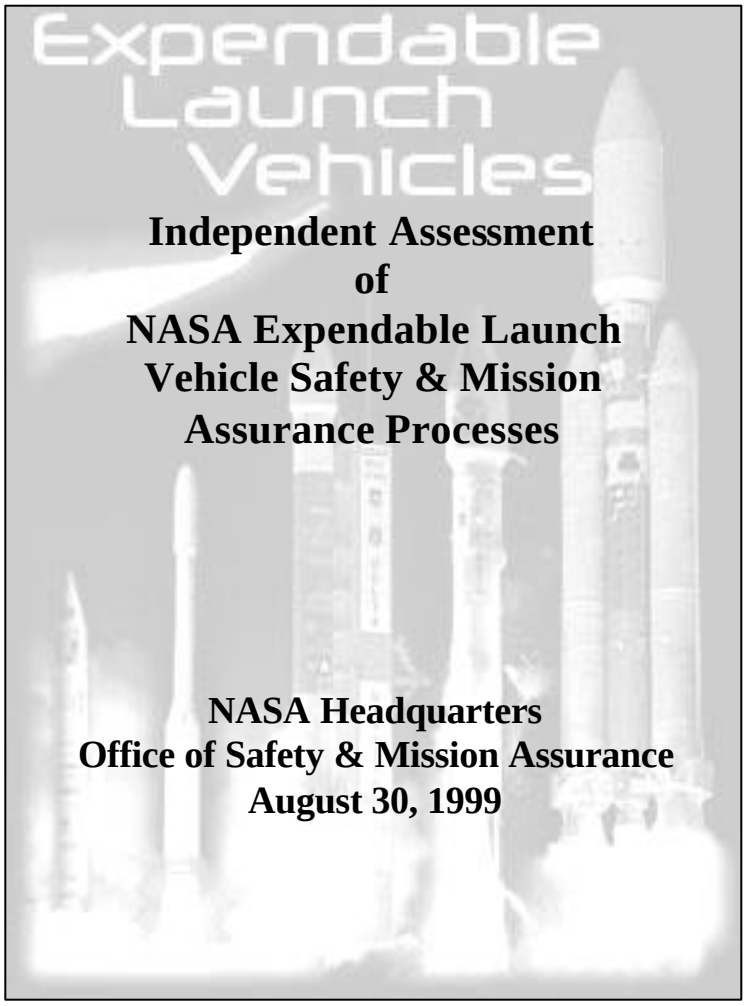
This document contains excerpts from the Expendable Launch Vehicles (ELV) Independent Assessment Report (title page shown below). Only those sections which relate to the PBMA element **Manufacturing** are displayed.

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



1.2.5 Current ELV Contracts, Prime Contractors, and Principal Manufacturing Sites

Intermediate Expendable Launch Vehicle Services (IELVS) Class

- Atlas (IIA/IIAS/AIII) - Lockheed Martin, Denver, Colorado
- Delta III - Boeing, Huntington Beach, California, and Pueblo, Colorado

Medium Expendable Launch Vehicle Services (MELVS) Class

- Delta II - Boeing, Huntington Beach, California, and Pueblo, Colorado

MED-LITE (ML) Class

- Taurus XL - Orbital Sciences Corporation, Chandler, Arizona, and Dulles, Virginia
- Delta (D3 and D4) - Boeing, Huntington Beach, California, and Pueblo, Colorado

Small Expendable Launch Vehicle Services (SELVS) and Ultra-lite Expendable Launch Vehicle Services (UELVS) Class

- Pegasus - Orbital Sciences Corporation, Chandler, Arizona, and Dulles, Virginia
- Athena I - Lockheed Martin, Denver, Colorado
- LK0 - Coleman Research Corporation, Orlando, Florida

An expanded discussion of the present ELV launch service contracts is provided in Section A.2.

3.2 Probable Causes and Assurance Process Gap Analysis

ELV Failure Case Studies and Gap Analysis

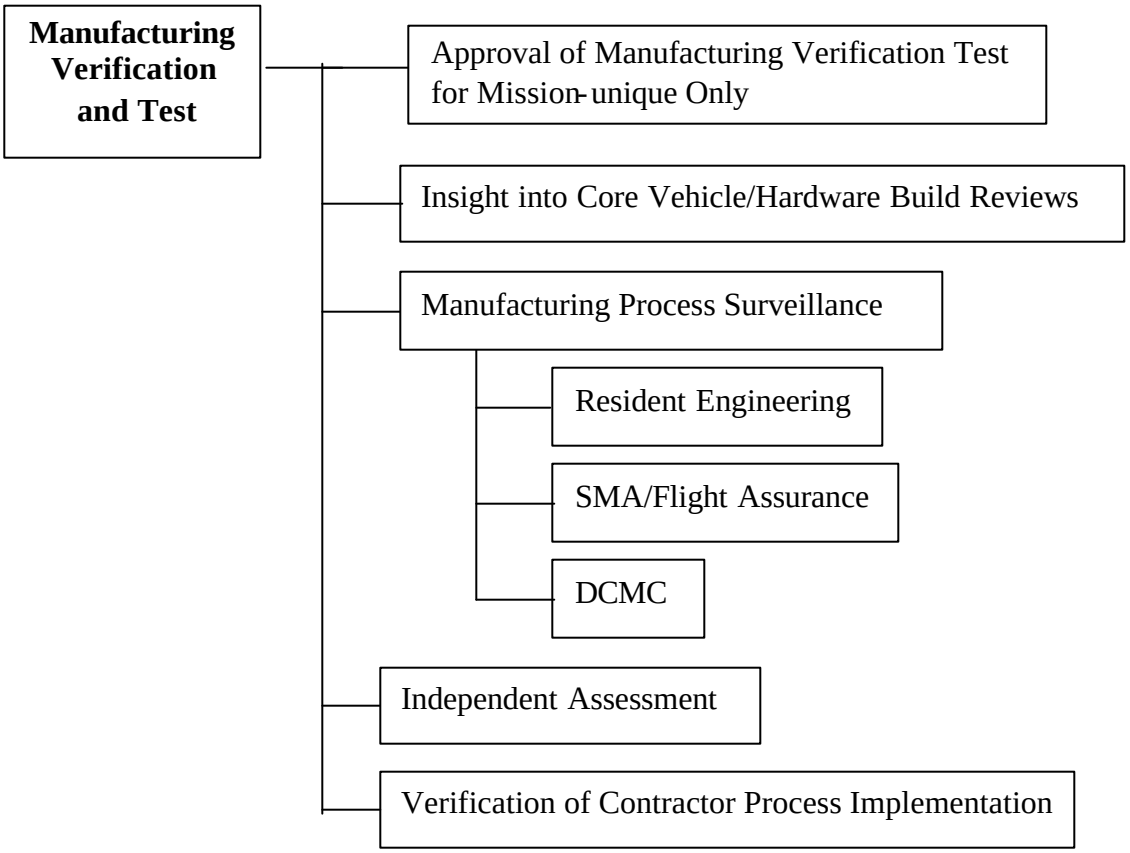
	ELV Failure Description	General Comments	NASA ELV Assurance Process Or Activity That May Have Prevented This Mishap	Subjective Assessment High/Medium/Low Probability of Mishap Prevention
1.	Delta II: 13 Jan 97-Booster Failure Damage or flaw in the Graphite Epoxy Motor case. Undetected during pre-launch 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

	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
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
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
9.	**Titan 34D (D-7): 28 Aug 85-1st Stage Engine Shut Down (DoD)** Large oxidizer and fuel leaks and turbopump assembly failure.	Three separate and independent failures. Corrective actions were design changes and manufacturing processes.	NASA/ELV design verification and mfg. verifications not likely to have prevented this launch failure.	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

	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
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
21.	**Pegasus XL (Step-3): 22 Jun 95-2nd Stage Nozzle Was Confined And Could Not Gimbal Properly** Incorrectly installed skid imparted side force on interstage ring. Ring restricted movement of nozzle. Configuration control practices improved.	Manufacturing assembly errors within Orbital processes.	NASA/ELV manufacturing assurance activities would not likely have been able to detect these errors.	Low
25.	**Pegasus XL (HETE/SAC-B): 04 Nov 96-Shock Of Stage 2-To-3 Separation Induced Damage To Transient Battery (TB)** Corrective action calls for a new TB assembly procedure to include quality assurance verification and new inspection criteria.	This was a first time use of Pegasus dual-satellite capability. Pre-launch the battery was take apart, inspected and reassembled. An unknown failure mode within the battery was identified as the root cause.	NASA GSFC ELV engineering did not detect the failure mode. Even though KSC/ELV engineering focuses on first time use of new designs it is unlikely that KSC would have detected human error in assembly of the battery harness.	Low

A.6 Manufacturing Verification and Test Assurance Processes

Manufacturing assurance processes begin with NASA approval authority for NASA mission-unique hardware test and qualification activities. It is worth noting that this represents only a very small percentage of the integrated launch system. Core vehicle assurance comes through the insight process centered on participation in tests, hardware build reviews, and pedigree reviews. In some cases independent assessment performed by the Aerospace Corporation is conducted to certify proper disposition of problems encountered in production (build paper). Another element of insight is manufacturing surveillance carried out by DCMC in support of NASA and other customers. Limited formal verification of contractor assurance process implementation is conducted at the present time. Discussions are underway to find resources necessary to routinely verify implementation of the many assurance processes certified under ISO 9001, and/or listed in contract quality plans, systems effectiveness plans, or equivalent contract assurance requirements.



Approval of Manufacturing Verification Test for Mission-Unique Only

Current NASA ELV Program engineering field offices are located at the following facilities:

- Lockheed-Martin, Denver, Colorado
- Boeing Corporation, Huntington Beach, California
- Boeing Corporation, Pueblo, Colorado
- Boeing Corporation, El Paso, Texas
- Orbital Corporation, Chandler, Arizona
- Vandenberg Air Force Base, Resident Office

The teams have cognizance of all prime flight critical mechanical and electrical hardware assemblies. Responsibilities include monitoring the current configuration of all prime flight critical mechanical and electrical hardware assemblies, tracking all future Class I modifications and the effects of those modifications on vehicle integration, and the qualification baseline and system reliability. Resident offices are also responsible for evaluating the qualification baseline and acceptance test program for mission-peculiar hardware and first flight items. Resident offices perform hardware pedigree reviews and provide recommendations to NASA concerning all discrepancies involving flight critical assemblies, including any in depth mechanical and electrical analyses necessary to characterize the impact of the discrepancy on mission reliability.

As required, resident engineers perform technical evaluations of the launch vehicle manufacturer's technical reports, quality reports, procedures, and drawings. They also participate in management, engineering, quality, and product reviews in addition to attending meetings on hardware design, manufacturing, testing, inspection, anomaly resolution, and major component pre-ship reviews. Engineering offices place special emphasis on mission-peculiar hardware and flight critical first flight items.

Insight into Core Vehicle/Hardware Build Reviews

LMA/Atlas Example of Supplier Management - The Atlas build reviews are referred to as "Mission Success Reviews." The Denver engineering resident office routinely participates in MSR's at key Atlas/Centaur suppliers. Suppliers that are routinely audited using the MSR process are:

- Honeywell
- Harlingen
- Pratt & Whitney
- Rocketdyne
- Lockheed (Binghamton, New York)
- Marconi
- Thiokol
- Plant 19 (former General Dynamics Tank facility in San Diego

Denver resident office personnel routinely participate in production/manufacturing integrated product teams (e.g., Centaur tank, Atlas tank, and fairing), including LMA and component suppliers.

Boeing/Delta Example of Manufacturing Production Review - Boeing also conducts a series of build reviews which provide an opportunity for NASA engineering and flight assurance personnel to gain valuable insight into core vehicle production issues. Major hardware component build reviews are conducted for the launch vehicle elements/activities listed below. NASA engineering (KSC and residents) as well as flight assurance participate in all Hardware Acceptance Reviews (HAR's) at the Delta prime contractor and major subcontractors.

Typical Delta HAR's are:

- Second Stage Engine
- Main Engine
- Fit-check
- Graphite-Epoxy Motors (GEM's)
- Booster Vehicle Subsystem
- Turnover Review
- Interstage
- Second Stage & Fairing
- Critical Design Review
- Mission Modification Review
- Design Certification Review

LMA/Titan Hardware Production Oversight - While not a requirement under existing MOA's between NASA and the Air Force, the Denver resident engineer office participates in Titan II build reviews. The HAR's give NASA and the Aerospace Corporation the opportunity to review all the build documentation, and nonconformance data on the respective hardware. The HAR's provide valuable insight to the different processes and function of the vehicle and its major components. These reviews are coordinated by the Aerospace Corporation with full participation from NASA. All hardware produced for Titan is reviewed prior to shipment either from the MEC or from LMA in Denver to CCAFS. Flight assurance personnel participated in all the HAR's for the core vehicle and its major element contractors (MEC's).

<u>Manufacturing Process Surveillance</u>

Denver Resident Office Quality Assurance Functions and Tasks - The Denver engineering resident office monitors traditional quality assurance activities including:

- quality assurance issues
- systems engineering issues
- avionics issues

The resident office engineers also participate in Parts Control Board (PCB) and Material Review Board (MRB) meetings as well as in the LMA ISO 9001 Working Group.

SMA/Flight Assurance (LMA Example) - The KSC/FA organization, through its resident assurance engineer (SAIC contractor) in Denver, routinely participates in the production process at Denver. Some of the items covered by the resident assurance representative are engineering review board meetings on Class I design changes, problem report reviews and closure, major nonconformances documented during production, and other miscellaneous activities. The resident assurance engineer also participates via telecon with some of the flight assurance and engineering meetings at KSC. The FAM also monitors the manufacture of the Titan core vehicle, the Centaur upper stage, and the SRMU's. Activities include Class I design changes, nonconformances during manufacture that required an MRB disposition, and general processing concerns at each facility. The FAM also participates in the System Effectiveness Reviews required of LMA by the Air Force. These reviews are held to understand processing problems and initiatives both at LMA and its four MEC's. Further, the FAM conducts monthly reviews of Corrective Action Problem Summaries (CAPS) initiated by LMA and/or its MEC's. These reviews are held to determine the adequacy of CAPS closures by the contractor. The FAM also attends all of the HAR's conducted on the Titan core, Centaur, and the MEC's. These reviews are held to review the build documentation, nonconformance data, and test results for the major components of the Titan IV vehicle. These are held in parallel with like reviews conducted by Aerospace Corporation.

LMA System Effectiveness Reviews (SER's) - In the past, under GRC management, engineering and flight assurance personnel participated in LMA System Effectiveness Reviews (a review of the product assurance system) conducted in accordance with the in-place Air Force contracts for both Titan and Atlas launch vehicles. These reviews are held on a semi-annual basis and are used to address issues and concerns on the Titan program that affect mission assurance, and to review programs and initiatives being implemented by LMA and/or its MEC's. These reviews provided NASA with valuable insight to the LMA mission assurance activities as well as the opportunity to meet their counterparts at LMA. It is noted that these reviews are evolving toward an ISO-style internal-audit format. It remains to be seen whether or not KSC/ELV/SMA will provide the resources necessary to routinely support these reviews.

Defense Contract Management Command (DCMC) Surveillance - There is not yet, in-place, a coordinated KSC/SMA approach defining DCMC's role within an overall assurance management strategy. Current DCMC letters of delegation (LOD) represent agreements which were in place under GSFC and GRC management of ELV's. KSC/SMA is currently developing a new LOD for the Boeing/Delta program.

DCMC Support for Atlas and Titan - Titan and Atlas production and daily events are monitored by the DCMC. The DCMC has offices at LMA in Denver as well as all the major suppliers. The DCMC role at LMA facilities reflects strong USAF influence in developing requirements and is oriented toward surveillance of a single quality process across multiple government customers. They act only in an oversight role for Atlas vehicles and they do not have hardware approval authority (with the exception of Titan vehicles) at Denver or with the suppliers. In the case of LMA, DCMC is currently working under a GRC LOD. The thrust of the LOD is direction to conduct surveillance. The surveillance plan is the key document delineating specific surveillance activities.

The current implementation plan includes audit, manufacturing process surveillance, reliability and maintainability process review, software surveillance, engineering design and development evaluation, observation of the Material Review Board Process (MRB), configuration management surveillance, transportation and shipping process reviews and other administrative support assignments.

DCMC Support for Boeing - The first line of manufacturing assurance is afforded by the ISO 9001 certified processes described in the Boeing PAIP. The contractor has primary responsibility for implementing those processes and assuring that they remain stable, capable, and in control. NASA SMA/FA has insight, albeit limited by available surveillance resources, into prime contractors and major subcontractors through the DCMC personnel resident at manufacturing facilities. The quality assurance functions to be performed on the Boeing/Delta program are set forth in an LOD between NASA and DCMC. The current LOD provides DCMC support of approximately 7000 hours per year at Huntington Beach and 680 hours per year at the Pueblo manufacturing facility. All DCMC personnel report to the UNISYS Flight Assurance Manager at Huntington Beach, California.

DCMC support typically includes such activities as tracking nonconformances and corrective actions, auditing compliance to the contractor's quality and product assurance plans and processes, conducting parts reviews and inspections, witnessing assembly and test operations, attending contractor-established reviews and monitoring the MRB.

Independent Assessment

Manufacturing activities are subject to periodic independent assessment of hardware fabrication and test. Two examples are provided below:

Boeing/Delta - Aerospace Independent Assessment Example - Each NASA Delta vehicle is subject to an independent contractor (Aerospace Corporation) review of all build paper and test paper deviations, problem reports, non-conformances, or other discrepancies encountered during either fabrication or testing. This review examines disposition of these discrepancies. The Aerospace Corporation refers to this assurance activity as a pedigree review. The pedigree review activity encompasses both hardware and software manufacture/development, and test. The Aerospace Corporation/FUSE review specifically highlighted issues or concerns (all resolved) related to Stage II propulsion, Stage II pneumatics, Stage II regulators, Stage I vernier engines, Stage I solenoid valves, Stage I engine structures, Stage I and II power and control systems, Stage I and II batteries, and vehicle software.

LMA/Titan II Example – Aerospace Independent Assessment Example - The Aerospace Corporation provides independent assessment to the USAF in connection with the manufacturing and test of Titan II and Titan IV hardware and software. The following paragraphs, abstracted from the NASA-managed Titan IIG-7 mission report, characterize the scope and depth of an Aerospace Corporation build review:

"Aerospace personnel have been involved in the refurbishment and processing of Titan IIG-7, from initiation of core modifications, to processing and acceptance testing of the liquid rocket engines, and acceptance testing of guidance, control and electrical components. Factory testing, as well as launch site acceptance and major system testing, have been reviewed and evaluated for anomalous out-of-family performance. Pedigree packages and qualification testing data on critical components have been reviewed and those components have been found acceptable for flight. Ground systems, facilities, and equipment have been reviewed and their capability to support launch processing have been verified. Aerospace participated with the contractor, LMA, in the Vehicle Readiness Review Team effort to review all processing activity at the launch site, including anomalies and their resolution. All payload integration activities and analyses have been reviewed and the booster to satellite vehicle interface requirements have been identified and verified."

"All systems analyses have been verified, including loads and dynamics, separation, trajectories, and thermal and dynamic environments. Post-flight analysis of previous Titan vehicles and an assessment of the lessons learned were conducted for potential impacts to Titan IIG-7. All Corrective Action Problem Summary (CAPS) impacts were technically evaluated, and have been lifted for this vehicle. The Titan IIG-7 TAG reference trajectory has been validated, and the booster stage II aimpoint and steering data, trajectory performance database, FMH K-factors, propellant margin requirements, ground station telemetry coverage, radio frequency environment, and range safety data have been independently validated, and are acceptable for flight."

"Aerospace is the sole provider of outside verification and validation of Software, Guidance Navigation & Controls (GN&C) and loads for Titan II. The Titan II Flight Program, version XX-U001-7.1-08, was verified by the Aerospace Corporation for the Titan IIG-12 / NOAA-K mission. The binary diskette for the flight code was verified by Aerospace and delivered to the launch site for independent verification of the flight software load on Titan IIG-7. The flight parameters diskettes and the primary and back-up IMU calibration diskettes that are used for independent software load verification for the Titan IIG-7 mission have been verified and validated. All flight parameters are verified to be consistent with the contractor-provided scientific-formatted listing of the flight and IMU parameters. The Titan IIG-7/QuikSCAT booster GN&C/Software mission assurance activities have been completed, certifying that the booster flight software meets mission requirements and supports the mission in the areas investigated."

Verification of Contractor Process Implementation

LMA - NASA "Over the Shoulder Audit" - A past practice of the GRC flight assurance organization, NASA FA managers would participate in LMA internal audits (including major subcontractors) scheduled for the year to verify contractor process implementation and to validate the fidelity of the LMA audit process. Again, it remains to be seen whether or not the SMA/ELV/FA organization will provide resources necessary to resume this surveillance activity.

Boeing - Internal Audit - NASA previously did not participate in Boeing internal audits conducted in preparation for the formal recurrent ISO certification audits. SMA FA now requires DCMC representatives to participate in Boeing internal audits as a means to verify process implementation.