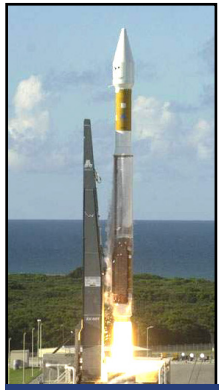
United Launch Alliance

Atlas V and Delta IV Capabilities to Support NASA's Crew Launch Program

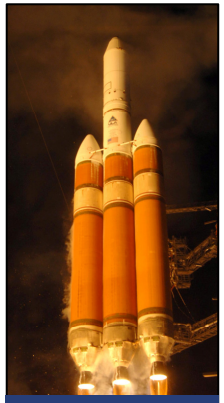
Jeff Patton,
Business Development
and Advanced Programs

ULA Operates the Nation's Expendable Launch Fleet


Atlas V 401


Delta IV Med+ (4,2)


Atlas V 551


Delta IV Heavy

- Proven Government-Industry Partnership
  - More than 50 years and 1,300 launches
  - Experienced workforce and proven management systems
- Recent, successful development experience
  - Delta IV and Atlas V developed within the last decade
- Fully operational state-of-the-art launch systems
  - ULA's stewardship has delivered 100% mission success over 39 missions

ULA is the Nation's center of expertise for expendable launch systems

100% Mission Success

United Launch Alliance

ULA Launch History

NROL-21 - 12/14/06 - Delta II
Themis - 2/17/07 - Delta II
STP-1 - 3/8/07 - Atlas V
Cosmo-1 - 6/7/07 - Delta II
NROL-30 - 6/15/07 - Atlas V
Phoenix - 8/4/07 - Delta II
Worldview-1 - 9/18/07 - Delta II
Dawn - 9/27/07 - Delta II
WGS-1 - 10/10/07 - Atlas V
GPS IIR-17 - 10/17/07 - Delta II
DSP-23 - 11/10/07 - Delta IV
Cosmo-2 - 12/9/07 - Delta II
NROL-24 - 12/10/07 - Atlas V
GPS IIR-18 - 12/20/07 - Delta II
NROL-28 - 3/13/08 - Atlas V
GPS IIR-19 - 3/15/08 - Delta II
ICO G-1 - 4/14/08 - Atlas V
GLAST - 6/11/08 - Delta II
OSTM - 6/20/08 - Delta II
GeoEye - 9/6/08 - Delta II
COSMO-3 – 10/24/08 – Delta II
NROL-26 - 1/17/09 - Delta IV
NOAA-N' - 2/5/09 - Delta II
Kepler - 3/6/09 - Delta II
GPS IIR-20 – 3/24/09 – Delta II
WGS-2 – 4/3/09 – Atlas V
STSS ATRR – 5/5/09 – Delta II
LRO/LCROSS – 6/18/09 – Atlas V
GOES O – 6/27/09 – Delta IV
GPS IIR-21 – 8/17/09 – Delta II
PAN - 9/8/09 – Atlas V
STSS Demo – 9/25/09 – Delta II
WorldView-2 – 10/8/09 – Delta II
DMSP-18 – 10/18/09 – Atlas V
Intelsat-14 – 11/23/09 – Atlas V
WGS-3 -12/5/09 – Delta IV
WISE – 12/14/09 – Delta II
SDO – 2/11/10 – Atlas V
GOES P – 3/4/10 – Delta IV

National Security : 18 **NASA/Civil : 13**
Commercial : 8

Most Recent Launches

Delta IV
GOES-P
3/4/10

Atlas V
SDO
2/11/10

Delta II
WISE
12/14/09

NASA Administrator Bolden Comments

- *"Commercial launch vehicles have for years carried all U.S. military and commercial – and most NASA – satellites to orbit. Now, as 50 years ago when we upgraded existing rockets for the Gemini program, NASA will set standards and processes to ensure that these commercially built and operated crew vehicles are safe.... They will fulfill a critical NASA need, spur industrial innovation, and free up NASA to do the bold, forward-leaning work that we need to do to explore beyond Earth."*
  - NASA Budget Press Conference, February 1, 2010
- *"There is a misconception that commercial crew means putting our astronauts in the care of untested providers. Quite the contrary, these will be the same providers who will be transporting our multi-billion dollar satellites."*
  - National Press Club, February 2, 2010
- *"Remember that we already depend on commercial companies to launch all of our nation's most precious military and national security satellites. Today commercial companies launch all government communications, weather, imaging, navigation, and intelligence satellites, upon which our lives depend, at home and abroad"*
  - National Press Club, February 2, 2010

Atlas & Delta Capabilities to Support Human Spaceflight

- Atlas & Delta heritage flying crew dates back to Mercury/Atlas and Gemini/Titan
- Atlas & Delta systems have evolved to provide reliable assured access for critical NASA, Air Force and NRO missions
- In 2002 NASA selected Atlas V and Delta IV to launch the crewed Orbital Space Plane
- In 2010 NASA selected ULA to develop Emergency Detection System (EDS) for CCDev

Existing, flight proven Atlas V & Delta IV can meet Human Space Flight Needs

Atlas & Delta Human Rating History

United Launch Alliance

NASA Orbital Space Plane Program (OSP)

NASA Human Rating Requirements NPR 8705.2A & 8705.2B

NASA Exploration Launch Studies

Commercial Human Space Flight Integration

NASA CE&R Studies

NASA ESAS Study

Bigelow Aerospace - Commercial Space Complex Business Case, Payload Integration & Deployment

Atlas Commercial Human Rating Review

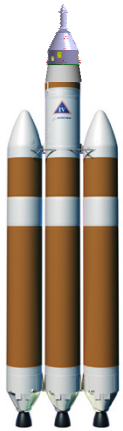
FAA-AST/Range Coordination

NASA Commercial Orbital Transportation System (COTS)

Sierra Nevada MOU Dreamchaser Technical Integration

CSF Safety WG

NASA Commercial Crew Development (CCDev)

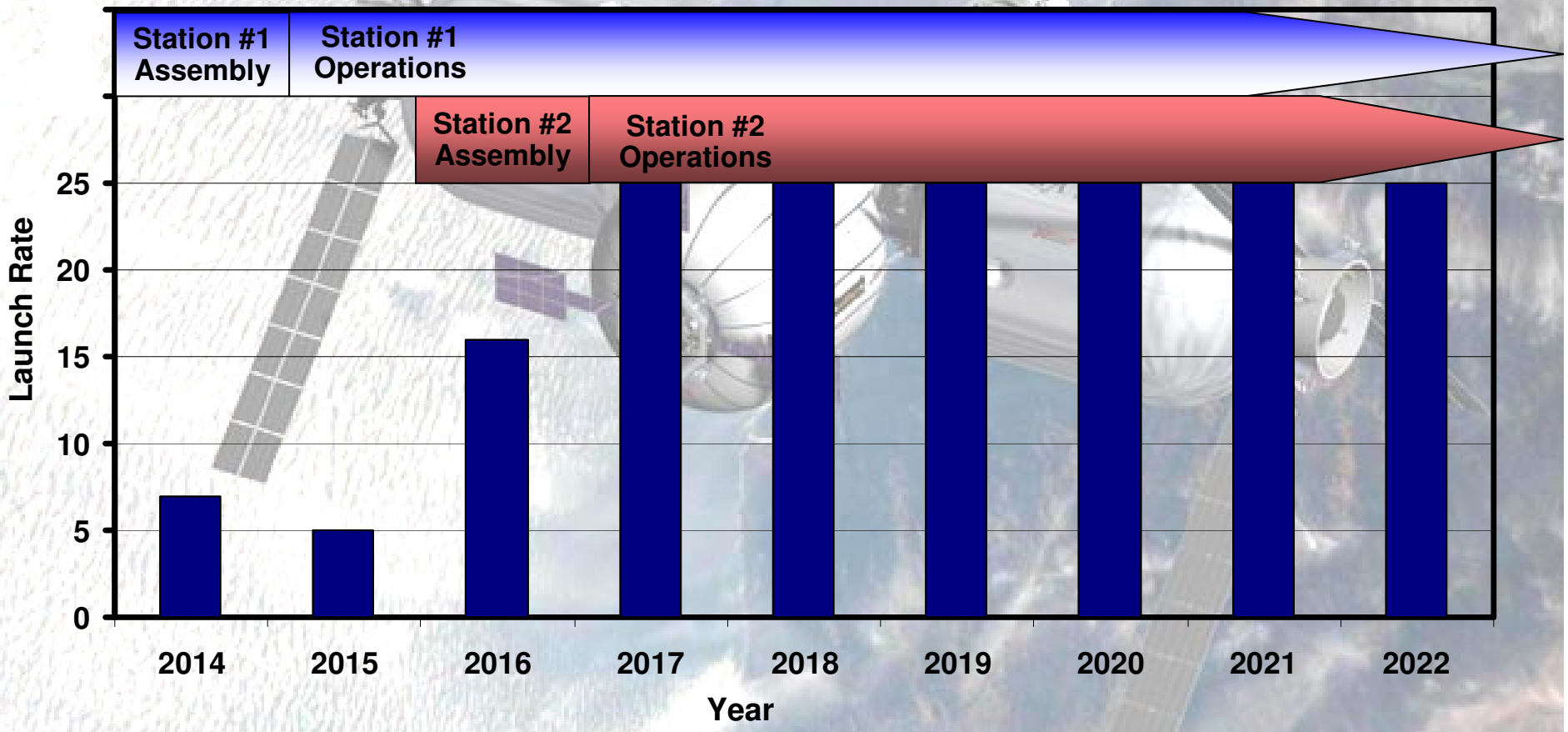


Ongoing Launch Operations

2003 2004 2005 2006 2007 2008 2009 2010

A large body of data exists on human rated EELV

Bigelow Launch Schedule



Commercial Market Represents Significant Near-Term Opportunity

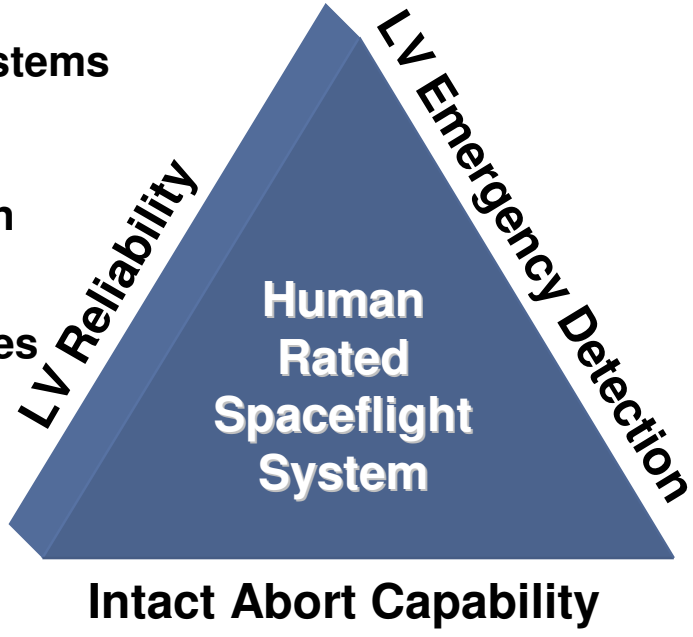
Data Courtesy of Bigelow Aerospace

System-Level Human Rating

United Launch Alliance

Reliability

- Demonstrated reliability
- Experienced people & proven management systems
- Single fault-tolerant systems
- Robust vehicle design
- Vehicle characterization
- Rigorous, closed-loop test-as-you fly processes



Emergency Detection

- Monitor critical systems using independent fault-tolerant failure sensing system
- Abort commands
- Fly instrumentation on all missions
- Already know our envts & in-family characteristics for developing EDS

Intact Abort Capability

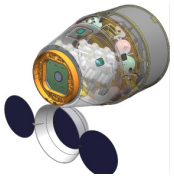
- Catastrophic LV failures minimized
- Benign abort envts.
- Black zones eliminated

Common Sense System-Level Approach

EELV Launch of a Commercial Human Spacecraft

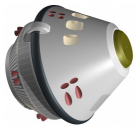
- **Human rating impacts to flight-proven existing EELV are understood**
  - **Addition of an Emergency Detection System (EDS)**
  - **Separate LC-41 VIF/MLP or LC-37A pad with crew ingress/egress**
- **Low non-recurring and recurring costs**
- **Human rated Atlas V and Delta IV offered by numerous Prime Contractors during NASA COTS and CCDev competitions**
- **Non-crewed missions provide vehicle characterization and flight data prior to first crewed mission**
- **EELV is not the critical path to launch a commercial crew transfer vehicle**

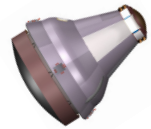
DreamChaser



Dragon

ARCTUS





Commercial

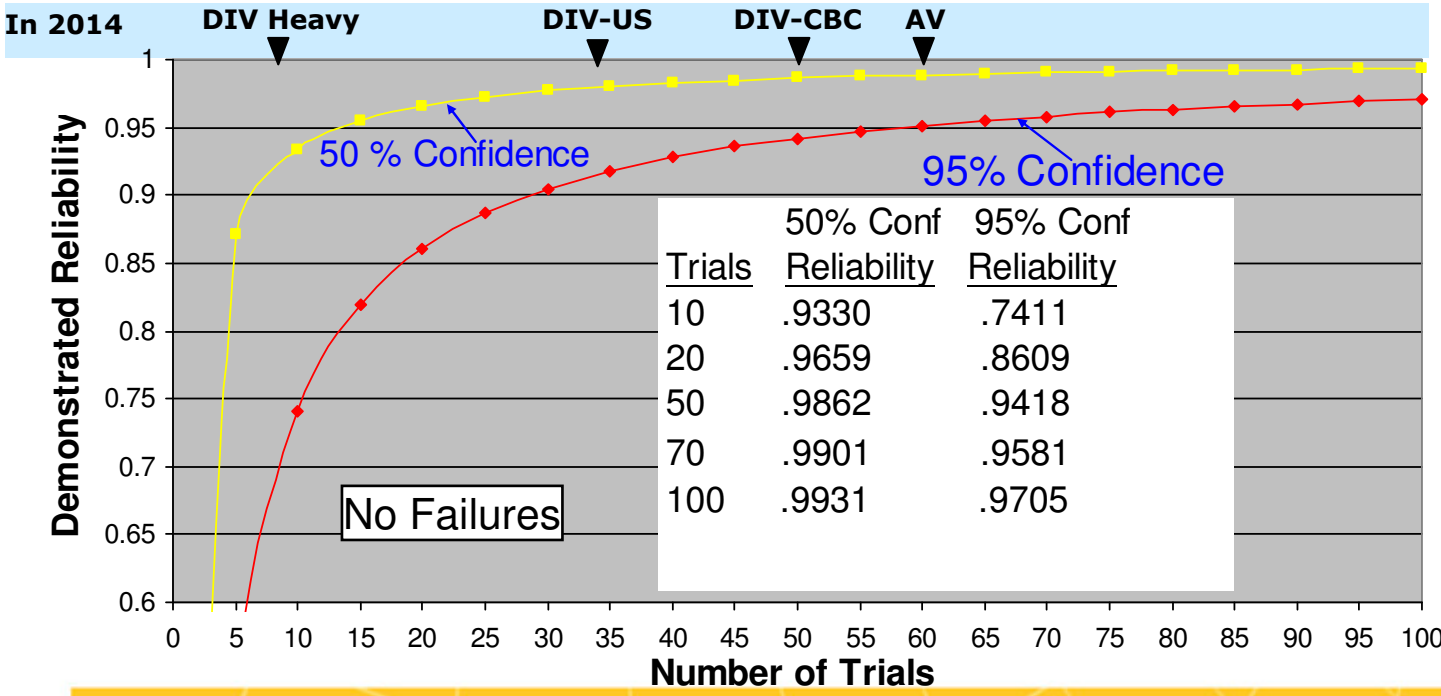
Almaz

Flight-proven EELV Provides Low-Risk Launch Solution To Launch Commercial Crew Vehicles to LEO

* Photos courtesy of Bigelow Aerospace, SpaceX, SpaceHab, Sierra Nevada, Space Development Corporation

LV Commonality Benefits

- Common family of vehicles used to fly all missions
  - Commercial, AF, NRO, Science, Human
- Flight rate 6 to 10 per year
- Demonstrates reliability much sooner than a unique vehicle
- Recurring flight data provides system characterization
- Lessons learned from each flight: people, process, product



Trials	50% Conf Reliability	95% Conf Reliability
10	.9330	.7411
20	.9659	.8609
50	.9862	.9418
70	.9901	.9581
100	.9931	.9705

Loss of Mission (LOM)
Loss of Crew (LOC)

Vehicle	Loss of Mission Requirement = 0.99 (1/100)		Loss of Crew Requirement = 0.9995 (1/2000)	
Delta IV - HLV	0.9875	80	0.9987	1600
Atlas V - HLV	0.9900	100	0.9990	2000
Atlas V - 401	0.9960	250	0.9996	5000
Atlas V - 402	0.9942	170	0.9994	3400

- Loss of Crew is LOM times the probability of abort system failure
  - Table above assumed fixed 5% probability of failure to safely abort

EELVs when combined with launch abort can meet NASAs LOM/LOC requirements

8705.2B Requirements Assessment Process

- Assessment based on current Delta IV and Atlas V designs
- Principle engineers performed a line-by-line review & compliance of 8705.2b requirements
  - Determined requirement allocation to element of system (Capsule and/or Launch Vehicle)
  - Same process completed for 8705.2A

		Atlas & Delta Compliance			
	Total Requirements	Meets/ Exceeds	Meets Intent	Non-compliant	Not Applicable (Capsule only)
Chapter 1 – Human-Rating Certification Process	28	28	0	0	0
Chapter 2 – Human-Rating Certification Requirements	50	50	0	0	0
Chapter 3 – Technical Requirements for Human Rating	31	9	4 (Atlas) 3 (Delta)	0 (Atlas) 1 (Delta)*	18

* Delta IV-H Ordnance & Avionics SPF elimination; pneumatic and hydraulic TVC redundancy to be incorporated if required by the Technical Authority as part of Human Rating development

Key Driving Human Rating Requirements Compliance –Delta Non-Compliant

8705.2A	8705.2B	Notes
Fault Tolerance		
3.1.1 Space systems shall be designed so that no two failures result in crew or passenger fatality or permanent disability (Requirement 34419).	3.2.2 The space system shall provide failure tolerance to catastrophic events (minimum of one failure tolerant), with the specific level of failure tolerance (one, two or more) and implementation (similar or dissimilar redundancy) derived from an integrated design and safety analysis (per the requirement in paragraph 2.3.7.1). Failure of primary structure, structural failure of pressure vessel walls, and failure of pressurized lines are excepted from the failure tolerance requirement provided the potentially catastrophic failures are controlled through a defined process in which approved standards and margins are implemented that account for the absence of failure tolerance.	**Some added redundancy in Delta subsystems required unless meets-intent determined by Technical Authority.**

Key Driving Human Rating Requirements Compliance – Atlas & Delta Meets Intent

8705.2A	8705.2B	Notes
Fault Tolerance		
3.1.1 Space systems shall be designed so that no two failures result in crew or passenger fatality or permanent disability (Requirement 34419).	3.2.2 The space system shall provide failure tolerance to catastrophic events (minimum of one failure tolerant), with the specific level of failure tolerance (one, two or more) and implementation (similar or dissimilar redundancy) derived from an integrated design and safety analysis (per the requirement in paragraph 2.3.7.1). Failure of primary structure, structural failure of pressure vessel walls, and failure of pressurized lines are excepted from the failure tolerance requirement provided the potentially catastrophic failures are controlled through a defined process in which approved standards and margins are implemented that account for the absence of failure tolerance.	**Atlas with an Emergency Detection System plus Abort System is two fault tolerant for credible failure modes and meets the intent of the fault tolerant requirement**
Abort for 2nd Leg of Fault Tolerance		
3.1.7 Space systems shall not use abort as the first leg of failure tolerance (Requirement 34430)	3.2.3 The space system shall provide the failure tolerance capability in 3.2.2 without the use of emergency equipment and systems.	**Atlas & Delta intends to utilize "abort" as the 2nd leg of fault tolerance for all credible failure modes**

Key Driving Human Rating Requirements Compliance – Atlas & Delta Meets Intent

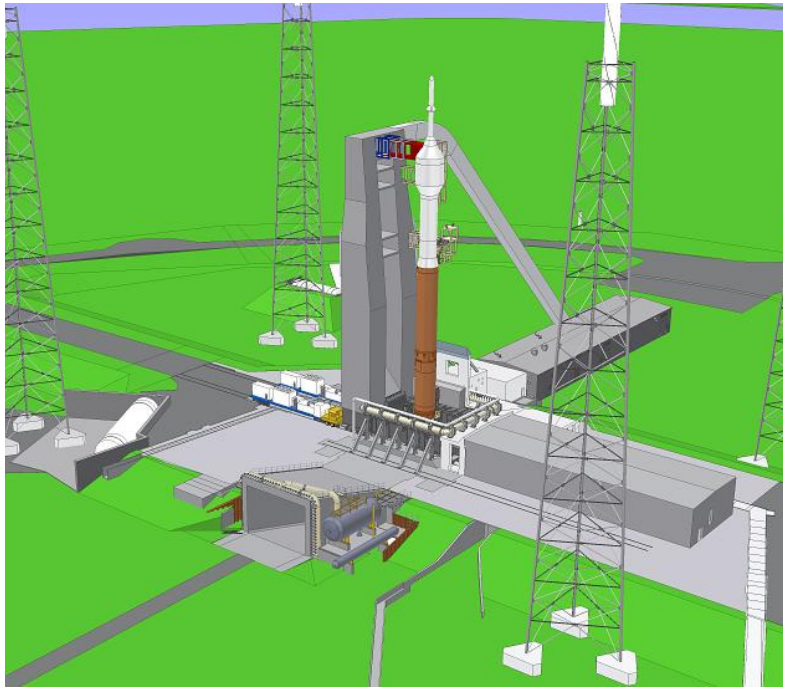
8705.2A	8705.2B	Notes
Common Cause Software Failures		
3.10.1 The system design shall prevent or mitigate the effects of common cause failures in time-critical software (e.g., flight control software during dynamic phases of flight such as ascent) (Requirement 34493).	3.2.6 The space system shall provide the capability to mitigate the hazardous behavior of critical software where the hazardous behavior would result in a catastrophic event.	❑ **Existing, flight proven Atlas & Delta flight software satisfies the intent of this requirement by the elimination of the potential for common cause failures, and has instituted a robust testing routine.** ❑ **Root cause of SW failures is human error** **- Requirements error** **- Coding error** **- HW/SW interaction not understood** ❑ **Mitigating SW errors means eliminating potential for single human error opportunities** ❑ **Recommended approach to mitigate common cause SW failures includes:** **- Independent review** **- Independent analysis** **- Independent testing (to include independent requirements development)**

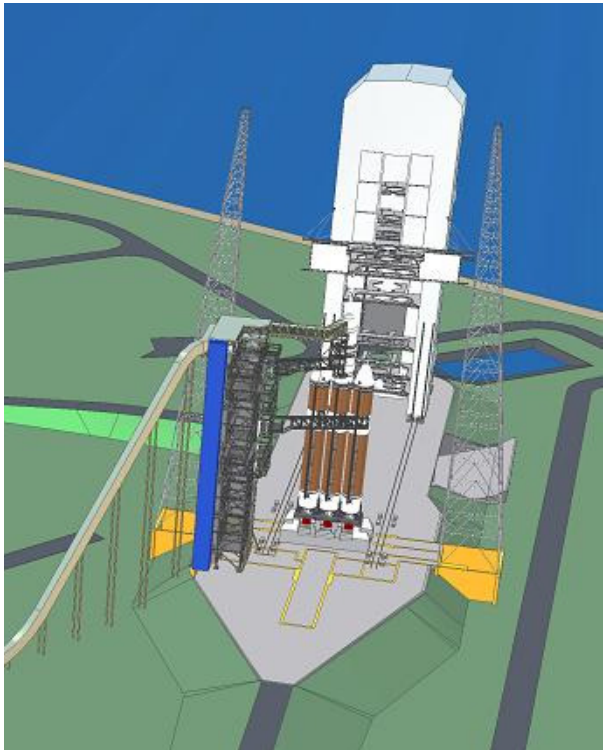
Key Driving Human Rating Requirements Compliance – Atlas & Delta Meets Intent

8705.2A	8705.2B	Notes
Manual Control During Ascent		
3.10.2 - During all phases of flight, the system shall provide the capability for manual control of flight path and attitude, when the human can operate the system within the structural, thermal, and performance margins without causing crew or passenger fatality or permanent disability (Requirement 34495).	3.4.1 The crewed space system shall provide the capability for the crew to manually control the flight path and attitude of their spacecraft, with the following exception: during the atmospheric portion of Earth ascent when structural and thermal margins have been determined to negate the benefits of manual control.	**Human control of LV limited to abort or abort targeting (similar to STS)** **Additional discussions necessary to maximize unique capabilities of Atlas and Delta**

Key Human Rating Requirements That Drive Enhancements to Atlas & Delta

8705.2A	8705.2B	Notes
Crew Ingress/Egress		
3.9.1 - The space system shall provide the crew and passengers with the capability for emergency egress to a safe haven during prelaunch activities (Requirement 34469).	3.6.1.1 The space system shall provide the capability for unassisted crew emergency egress to a safe haven during Earth prelaunch activities.	**Requires Crew Ingress/Egress.**





Required Human Rating Elements

- **8705.2B Requirements-Based Compliance Assessment Results in the Following Changes to Provide Commercial Human Spaceflight on an Atlas V or Delta IV**

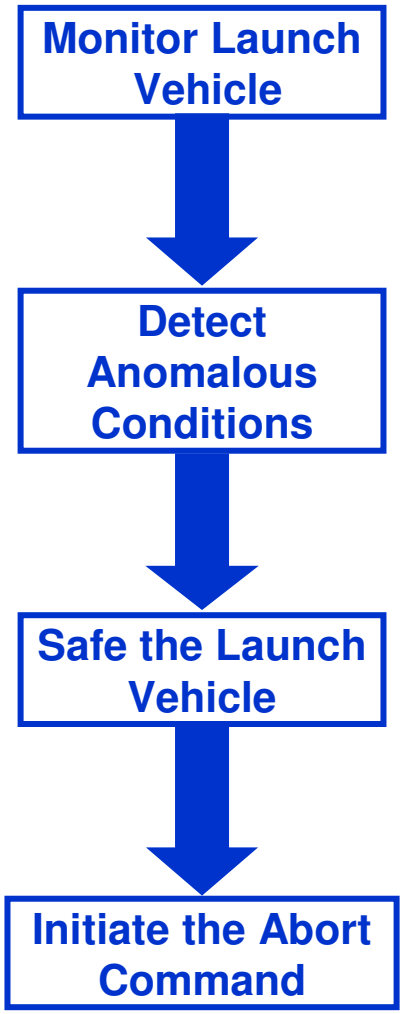
Human Rating Element	Atlas V Technical Summary *(Commercial Approach)*	Delta IV Technical Summary *(Traditional USG Approach)*
Launch Vehicle Emergency Detection System (EDS)	1. Analysis: Architecture/Sensors 2. Hardware and Software design 3. SIL & non-crewed flight testing 4. Qualification	1. Safety Tasks / Hazard Analysis 2. EDS Hardware / Software 3. Flight Instrum Devp 4. SIL Lab / Qualification
Launch Site Modifications	1. Crew ingress/egress on the MLP 2. Crew Life Support System (ECLSS) at LC-41	1. New 37A Pad incl Crew Access 2. Services 3. Development Support
Analysis and Software	1. Hazard Analysis 2. Design Margin Analysis 3. FAA requirements analysis 4. Mission Unique Analysis and Software	1. Wind Tunnel Testing 2. Loads/Structural analysis 3. Human Rating requirements analysis 4. Design Equivalency Review-HW Margins 5. Mission Unique Analysis 6. Large Ullage Slosh Modeling for LEO
System Testing & Analysis	Additional LV Margin Testing & Analysis	1. Launch Site 2. Vehicle
Flight Termination System (FTS)	Approach has been coordinated with Range. Insert destruct delay timer in current Automatic Destruct System (ADS).	

Commercial Crew Development ("CCDev") Program

- Similar to the Mercury, Gemini, and Apollo Programs, the current Atlas V and Delta IV launch vehicles will require a system to detect imminent vehicle failures and to initiate an abort
  - ULA awarded $6.7M to design, develop and test a prototype Emergency Detection System (EDS)
- ULA's proposal ranked highest during NASA evaluation
  - *"The participant demonstrated an excellent understanding of NASA Human-Rating requirements and what it will take for their proposed system to become NASA Human-Rated, increasing confidence in the proposal with respect to the assurance of crew safety and survivability."*
    - *NASA CCDev Proposal Evaluation Summary*
  - *"ULA also exhibited a strong likelihood to have its proposed technology development proposal contribute to the overall acceleration of commercial crew transportation capabilities."*
    - *NASA CCDev Proposal Evaluation Summary*
  - *"Multiple entities proposed using the Atlas V or Delta IV as the primary launch vehicle for their commercial crew transportation concept in this competition."*
    - *Geoffrey Yoder, CCDev Selection Statement*
  - *"ULA's proposal to mature aspects of these vehicles to support the commercial crew transportation market would have far reaching impacts on a number of potential commercial crew transportation service providers and was a significant strength in its proposal."*
    - *Geoffrey Yoder, CCDev Selection Statement*

CCDev
Emergency Detection System

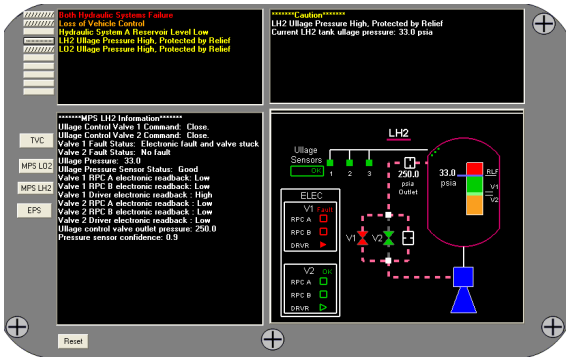
- Similar to the Mercury, Gemini, and Apollo Programs, the current Atlas V and Delta IV launch vehicles will require a system to detect imminent vehicle failures and to initiate an abort
- ULA awarded $6.7M to design, develop and test a prototype Emergency Detection System (EDS)
- ULA will use the CCDev investment and internal funds to:
  - Advance EDS algorithm development and software solutions,
  - Determine the sensor/flight computer interface,
  - Address the timing challenges of collecting and processing time-critical data, and
  - Initiate the design of the EDS/Crew display interface.



EDS Failure Scenarios

- A sample set of launch failure scenarios will be selected to exercise and demonstrate key EDS functionalities
  - Includes both catastrophic and non-catastrophic failures
  - SeaLaunch – 30 January 2007
    - Near-Pad Catastrophic, Booster Engine Performance
  - Ariane V (501) – 4 June 1996
    - Boost Phase Catastrophic, Avionics/Software Fault
  - Atlas Centaur (AC-74) – 25 March 1993
    - Boost Phase Anomaly, Non-Catastrophic, Booster Engine Performance
  - Titan/Centaur (TC-14) – 30 April 1999
    - Upper Stage Anomaly; Highly Dynamic, Flight Software Data Entry Error
- EDS prototype will be tested in the Atlas Systems Integration Laboratory (SIL)

Atlas SIL



Conceptual Situation Display for Crew Vehicle

On-Going Human Rating Studies

1. Conducted in Parallel with CCDev
   a. Refine Fault Coverage Assessment for Atlas
   b. Optimize EDS Architecture
2. Commercial Human Rating Requirements development and compliance
3. Conduct in-flight launch vehicle explosion modeling
4. Trajectory & performance optimization
5. Baseline launch site accommodations and operations
6. Investigate reliability enhancements that benefit all users

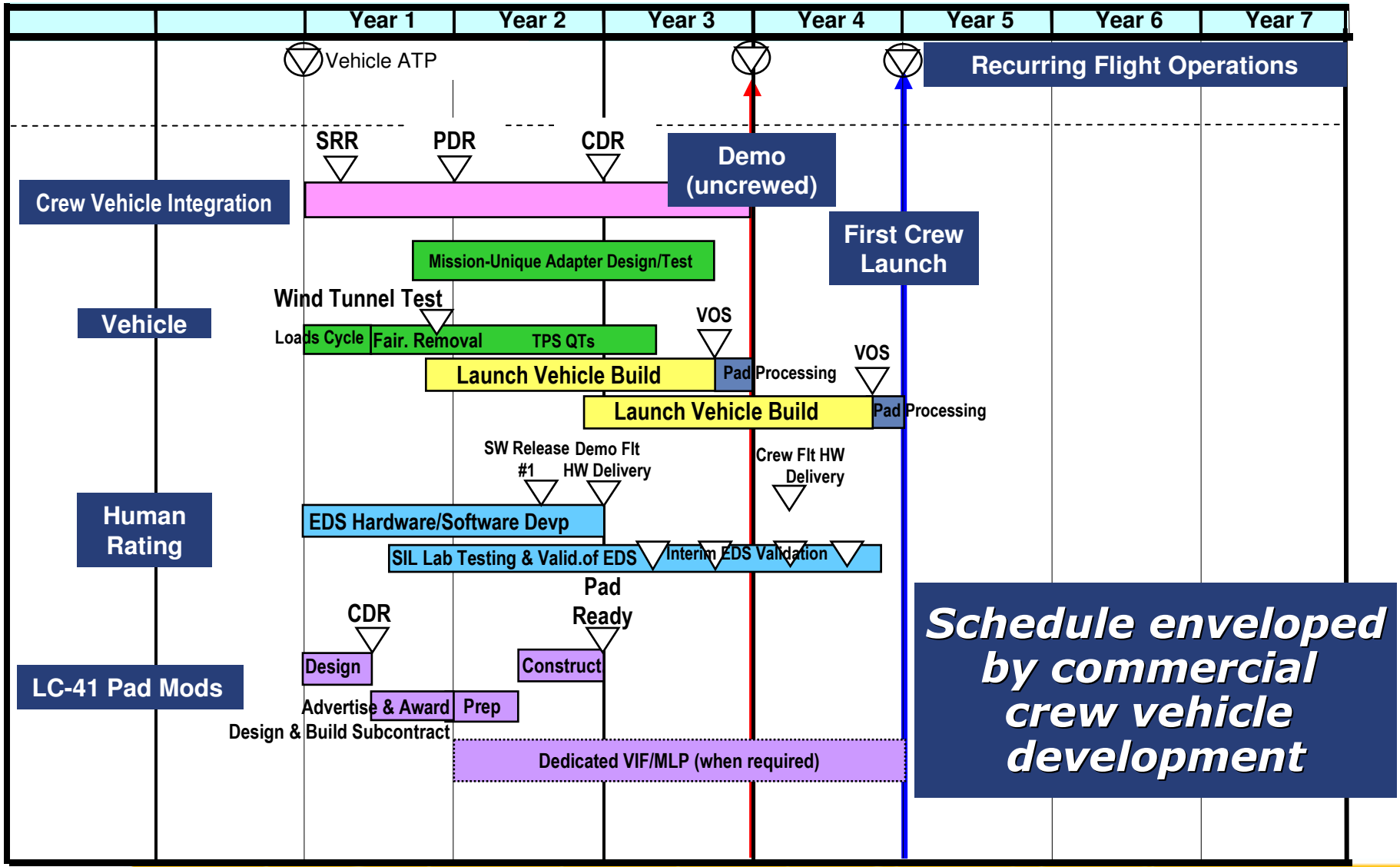
Summary

- ULA has developed a common sense approach to human rating Atlas and Delta based on a long history of customer and internally funded studies
- Our studies have shown that human rated EELVs can achieve IOC within 3 to 4 years
- CCDev significantly reduces the risk for a Commercial Crew Program

Backup

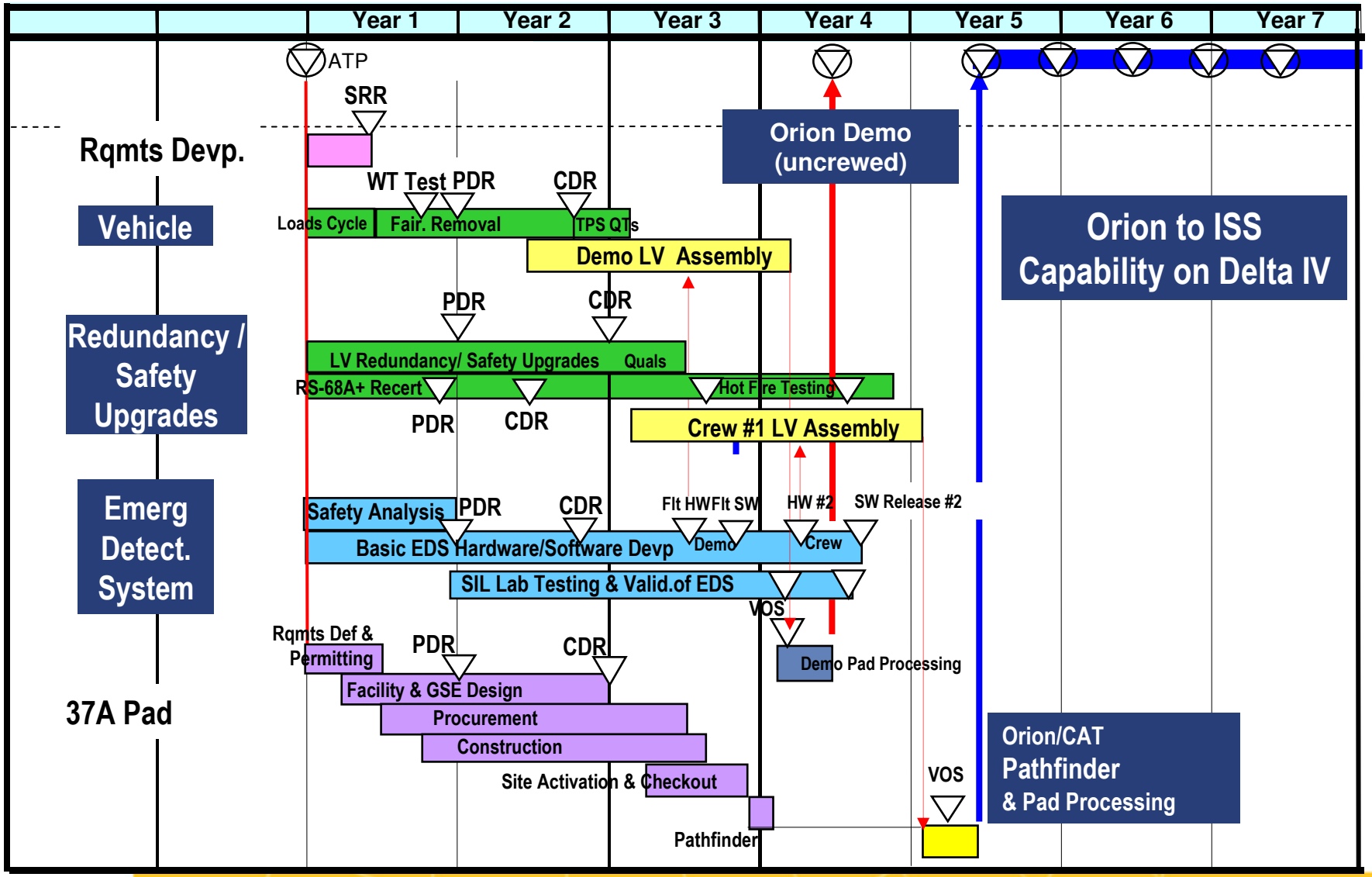
Atlas HR LV Development Schedule for Commercial Crew

United Launch Alliance



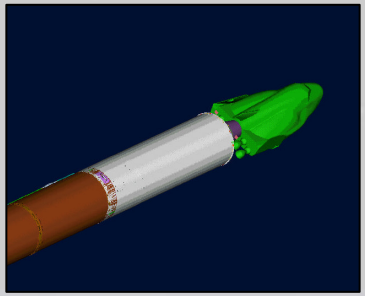
Delta IV-H Development Schedule Supports Orion for ISS Crew

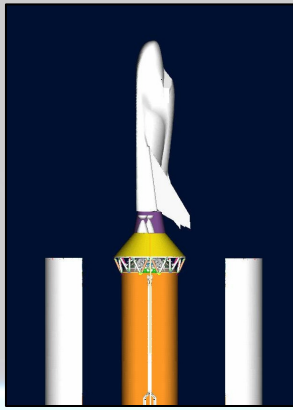
United Launch Alliance



Sierra Nevada Corporation

- **Wind Tunnel Buffet Model Development**
  - Generate preliminary buffet wind tunnel test plan, & test requirements
  - Planning for wind tunnel test
- **Structural Design**
  - Preliminary Concept Design of Centaur Encapsulation Adapter and Separation System
  - Concept Design of Payload Adapter
- **Mission Analysis**
  - Mission Design Flight Profile Refinement of trajectory requirements/constraints



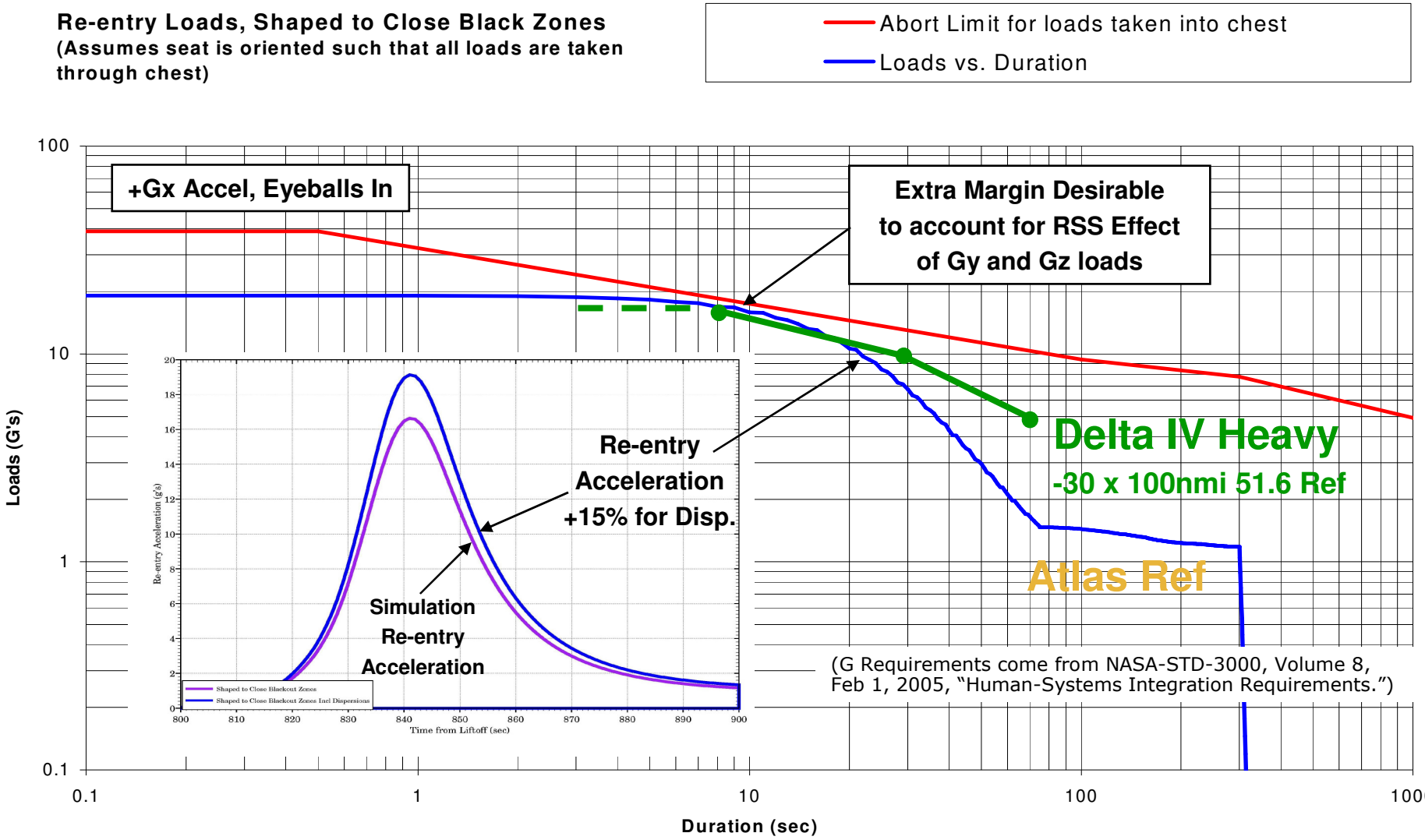


Boeing

- **Preliminary Standard Mission Integration Analyses including:**
  - **Flight Design**
  - **Aerodynamic Loads**
  - **Mass Properties**
  - **Thermodynamics**
  - **Dynamics**
  - **Coupled Loads**
  - **Interface Management**
- **Preliminary Mission Unique Analyses including:**
  - **Launch Vehicle Adapter design**
  - **EDS Incorporation reporting**
  - **Human System Integration Analysis**
  - **Unique requirements driven by an unencapsulated SC**

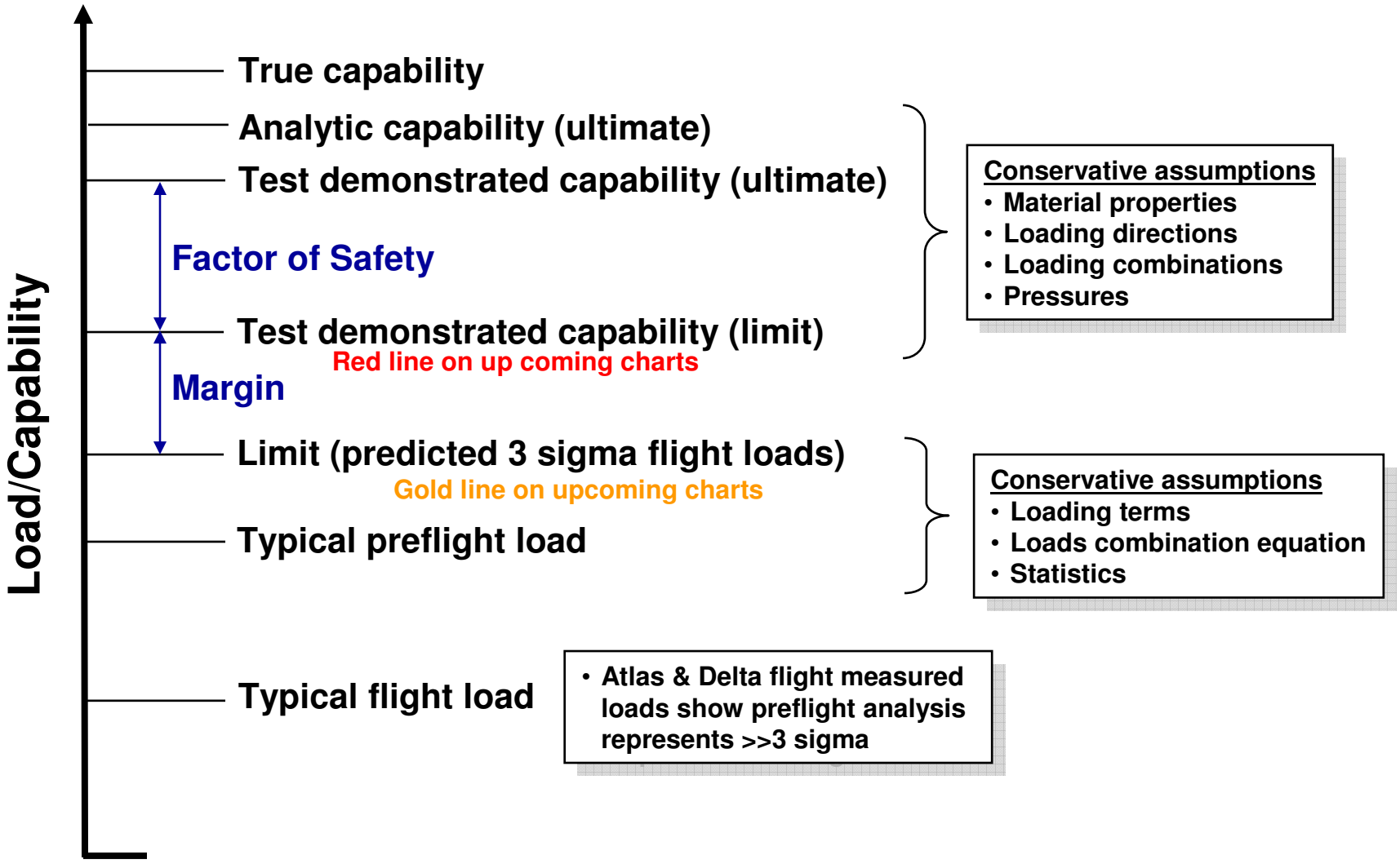
Shaped to Close Black Zones
Delta IV Heavy Compliant with Requirements

Re-entry Loads, Shaped to Close Black Zones
(Assumes seat is oriented such that all loads are taken through chest)



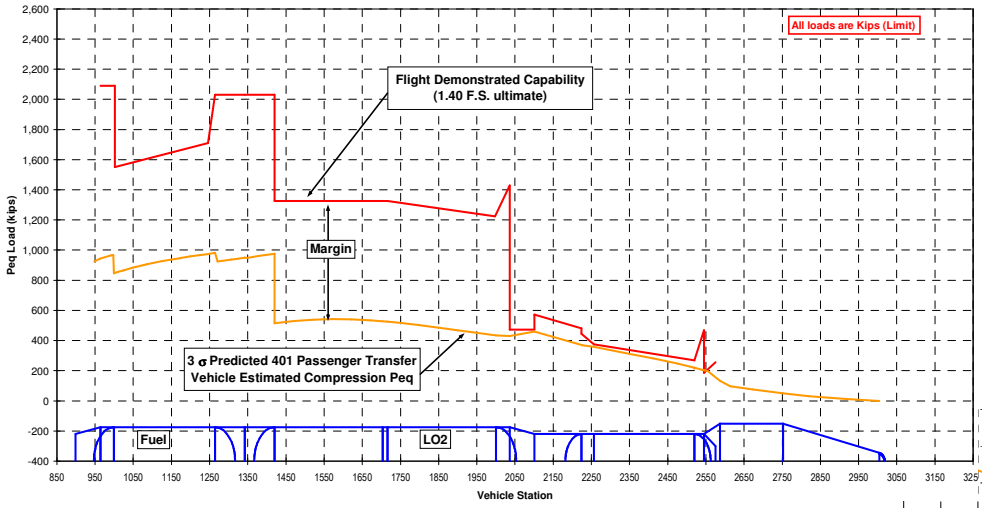
(G Requirements come from NASA-STD-3000, Volume 8, Feb 1, 2005, "Human-Systems Integration Requirements.")

1.4 Factor of Safety Compliance – Atlas & Delta Conservative Structural Margins



Atlas V Factors of Safety

- **Structural Loads Assessed to Determine Actual Margin Experienced for Baseline Vehicle**
  - **Demonstrated Flight Loads Corrected for 1.4 Factor of Safety**
  - **All Predicted Loads Below Demonstrated Capability**



Atlas V/401 Predicted Compression Loads vs Flight Demonstrated Capability

Atlas V/401 Predicted Tension Loads vs Flight Demonstrated Capability