National Aeronautics and Space Administration

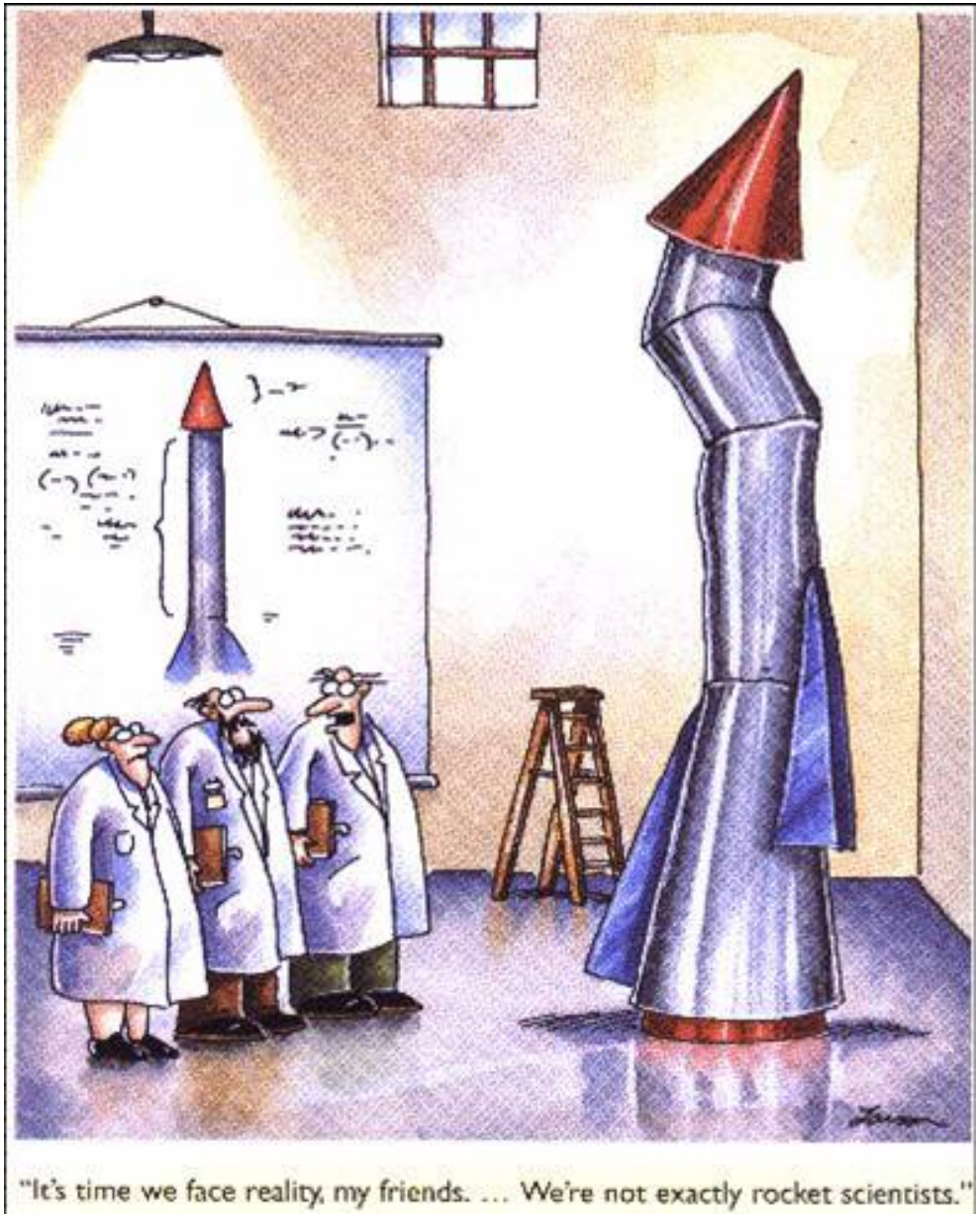


Ares I-X Flight Test
Designed for Data

AIAA – Hampton Roads Section
Axel T. Mattson Lecture
22 March 2011

Jay Brandon
Ares I-X GN&C Lead

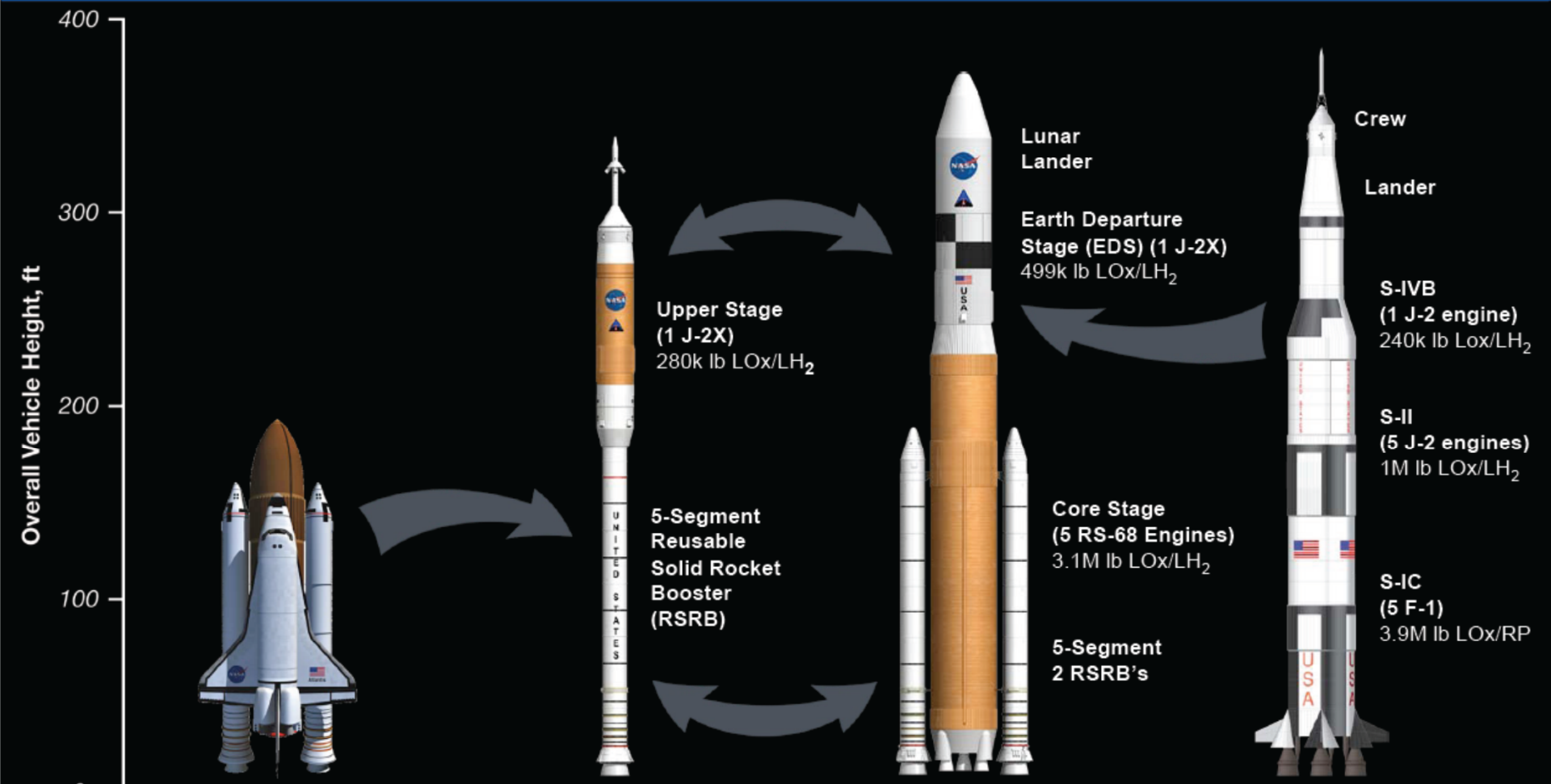
Airplane Flight Dynamicists…



- **Maybe Not Rocket Scientists – BUT**
  - Successful First Flight of a new Launch Vehicle
  - First application of system ID maneuvers during ascent of a launch vehicle
  - Unprecedented data from launch vehicle test flight

Building on a Foundation of Proven Technologies

- Launch Vehicle Comparisons -



Space Shuttle

Height: 184.2 ft
Gross Liftoff Mass: 4.5M lb

55k lbm to LEO

Ares I

Height: 321 ft
Gross Liftoff Mass: 2.0M lb

48k lbm to LEO

Ares V

Height: 358 ft
Gross Liftoff Mass: 7.3M lb

117k lbm to TLI
144k lbm to TLI in Dual-Launch Mode with Ares I
290k lbm to LEO

Saturn V

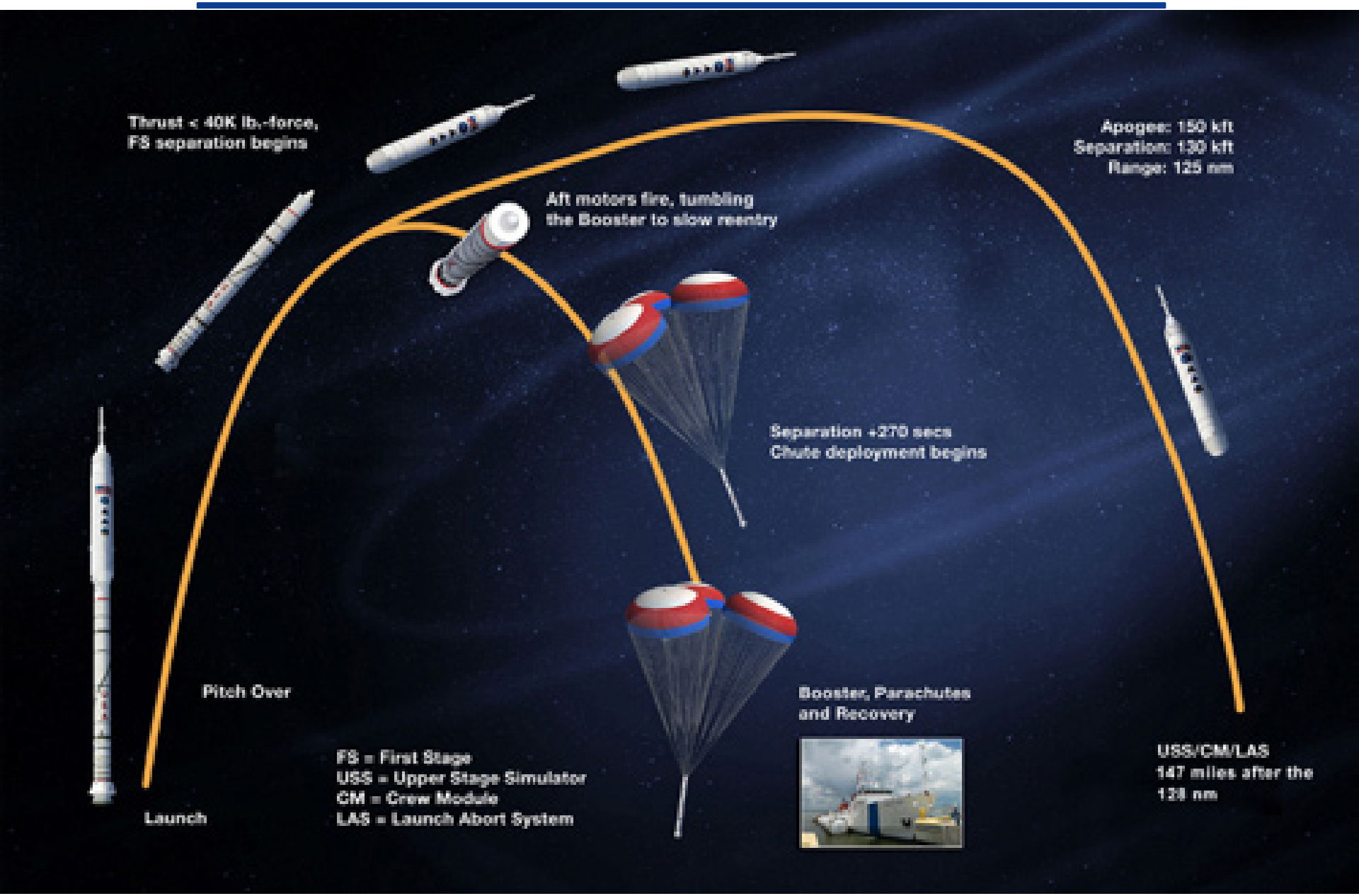
Height: 364 ft
Gross Liftoff Mass: 6.5M lb

99k lbm to TLI
262k lbm to LEO

Ares I-X Flight Test History (GN&C View…)

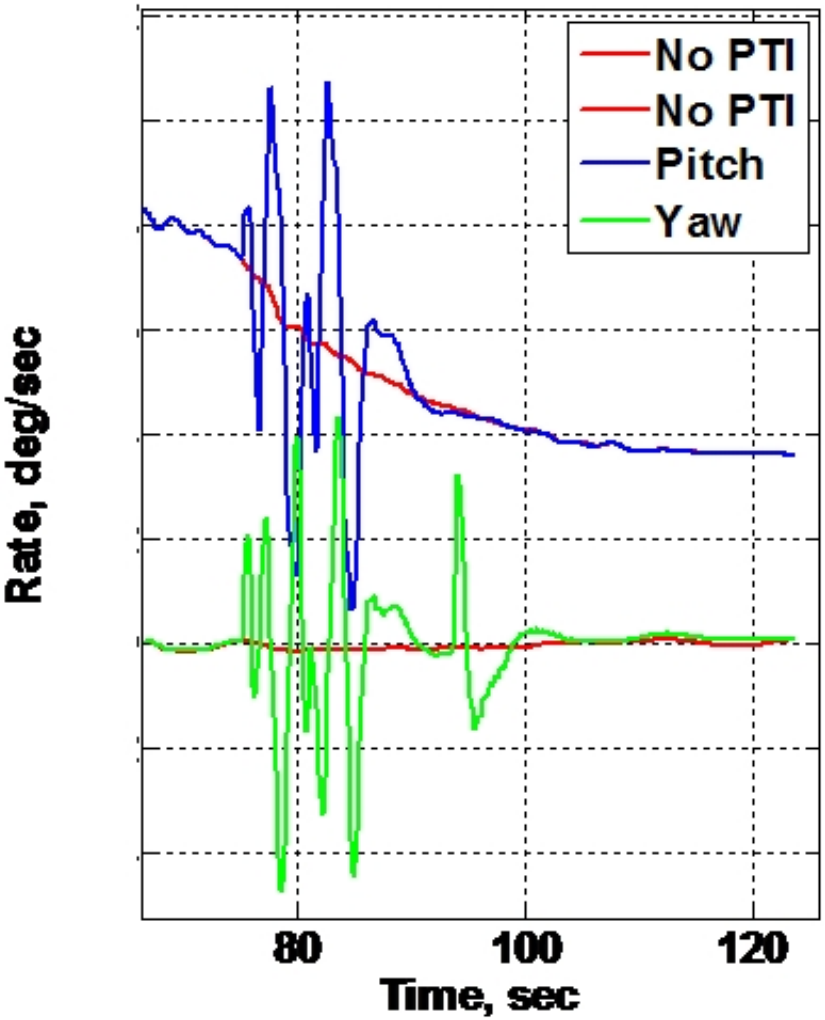
- **CLV Capture Team**
  - Flight Dynamics Part of Initial Planning starting July 2005
  - November 2005 – DF-1 planning started
    - $200M bogey
    - 12/08 bogey
    - Prepare to "break things" – manage expectations
    - Proposed, "Design for Data" PID and instrumentation requirements
- **DF-1, SFT, AFT, ADFT-1, ADFT-0, Ares I-1, Ares I-X - In development beginning Jan 06**
  - Conducted static aero stability studies
- **Structures/Controls Interaction Tiger Team Feb 06**
  - Determine controllability and similitude requirements for relevant flight test effort
- **First Loads Issues (on crawler) Began… Mar 06**
- **Ares I-1 Avionics Kick off Aug 06**
  - FDWG established – LaRC lead
  - First FDWG mtg – 8/24/06
- **FCS Architecture Developed Feb 07**
  - Whiteboard – documented by camera…
- **Plethora of Activities and Decisions Since…**
  - Stage sep
  - Instrumentation (air data, photogrametry, etc.)
  - Config design requirements (RoCS, CG's, sep plane, etc.)
  - Fly-away maneuver
  - **FLIGHT – OCTOBER 28, 2009**

ARES I-X FLIGHT TEST PROFILE



System ID Maneuvers

- **Plan to design for data – not just fly the trajectory**
  - Much better chance to get useful data for model and design tool validation
  - Unique approach for launch vehicles
  - Derived from airplane flight test techniques
- **Type of systems to characterize**
  - Flight control system performance
  - Structural dynamics
  - Aerodynamics (roll torques & traditional aero S&C)
- **Approach**
  - Small pre-determined Programmed Test Inputs (PTI) to TVC
  - Simultaneous sweeps in pitch and yaw – mutually orthogonal inputs from 0.2 – 2.5 Hz
  - Engage at flight conditions of special interest
  - Minimal impact to trajectory and loads



Ares I-X

- **Tallest Rocket in the World**
  - Third tallest ever
- **Highest Slenderness Ratio Ever Flown**
- **Most Aerodynamically Unstable Rocket Ever Flown**
- **First New NASA Launch Vehicle in ~30 Years**
- **Made With Borrowed Materials…**
  - Solid Rocket Motor – out-of-date Shuttle RSRM
  - FS parts from 30 Shuttle flights - some parts flown on as many as 5 missions
  - RoCS – disassembled from Peace Keeper ICBM's
  - BDM's and BTM's – Old Shuttle BSM motors
  - Avionics – Atlas V



Roll Out

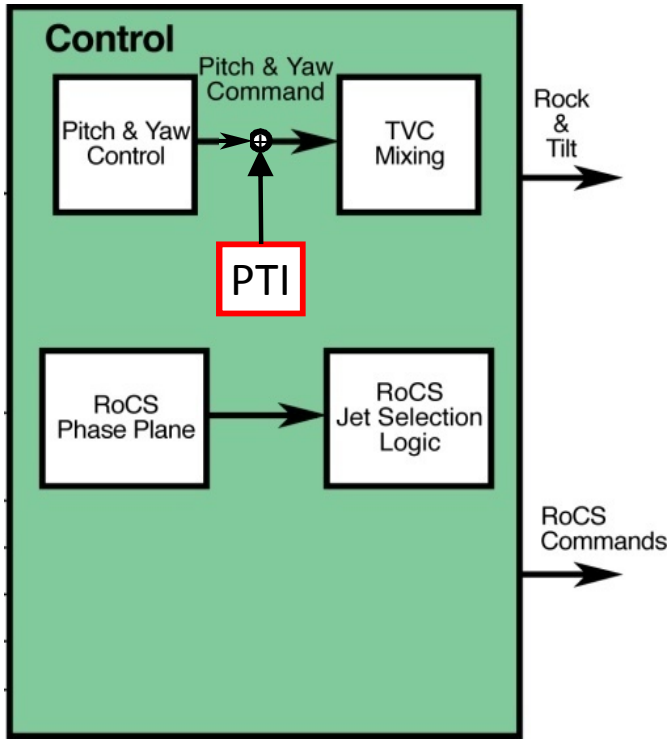


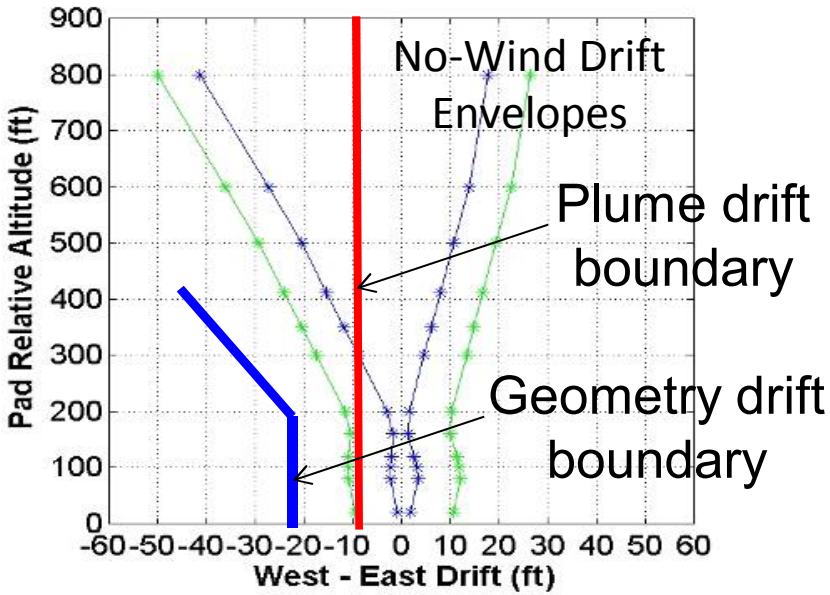


- Shuttle MLP
- 4 Bolts on Aft Skirt
- No Supports
- No Problem!

Fly-Away Maneuver

- **Late-Breaking Issue**
  - Large potential plume loads on FSS
- **Addressed Through PTI Commands**
  - Pitches rocket downrange about 2 degrees in first 4 seconds

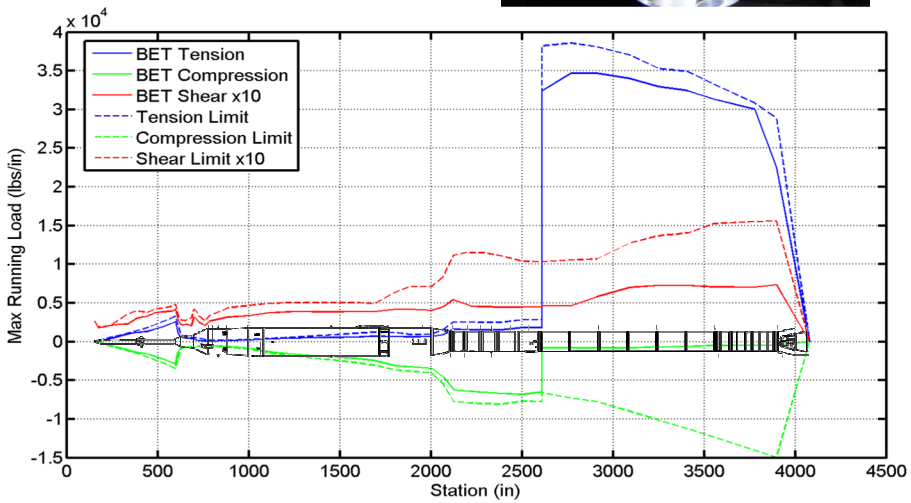




Launch

- **Tuesday Oct 27**
  - Loads
  - Clouds
  - Probe Cover
  - Ship
  - Triboelectrification
  - Wind





- **Wednesday Oct 28**
  - Lightning
  - Rain
  - Loads
  - Triboelectrification



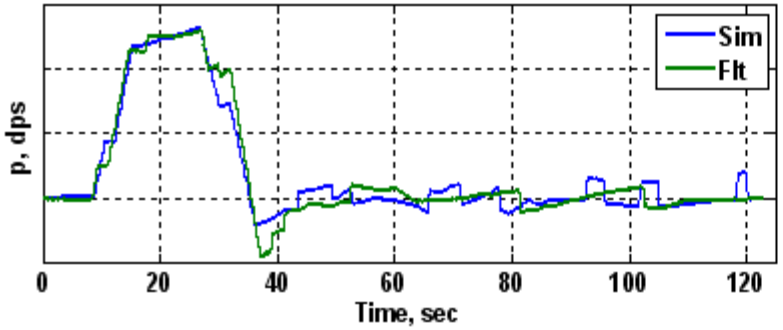
Flight

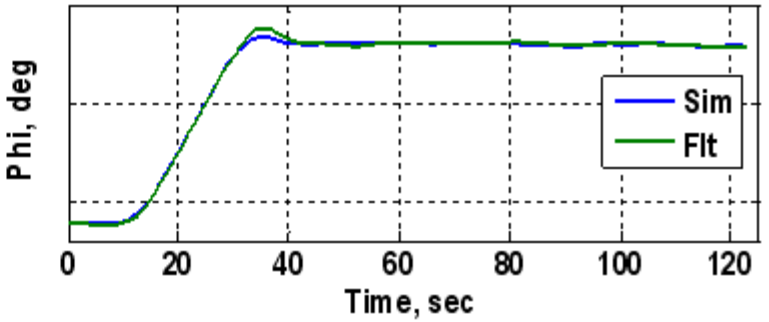
- **Fly-Away**
  - Prevented structural damage at high levels on the FSS
  - Increased heat/blast damage compared to Shuttle
- **Roll Maneuver**
  - Very little external roll torque
  - Looks like run simulation run with no RSRM torque model included
  - Well controlled and stable
  - Jet interaction effects less than models showed
- **PTI's**
  - Executed as planned
  - Relatively low noise on sensors – far lower than sim model used for design
- **Thrust Tail-Off**
  - "Heroic-effort" stage of flight seen
  - More dynamics than expected believed due to slag effects
- **Stage Separation – Nominal**
- **FS Recovery – Issues**
  - FS successfully recovered – along with onboard data recorders

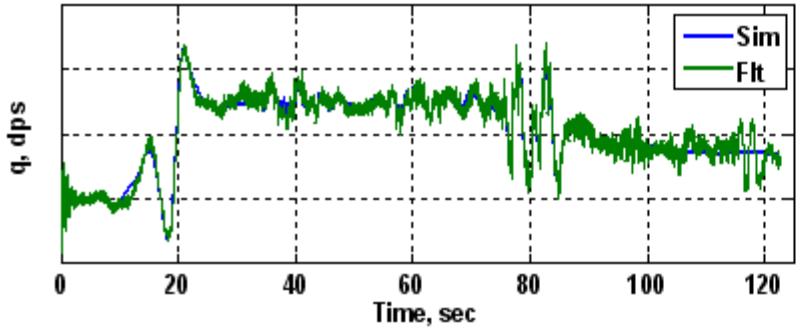


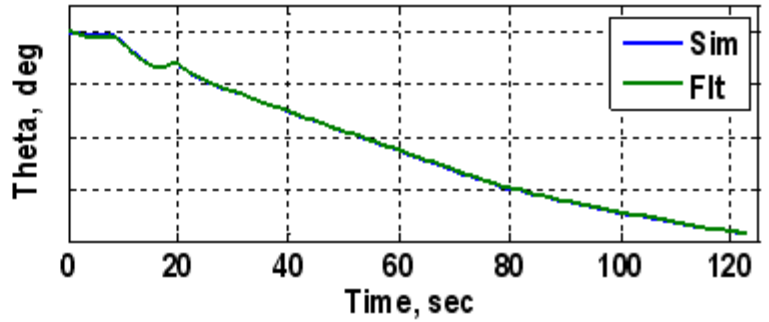
Comparisons of Simulation and Flight

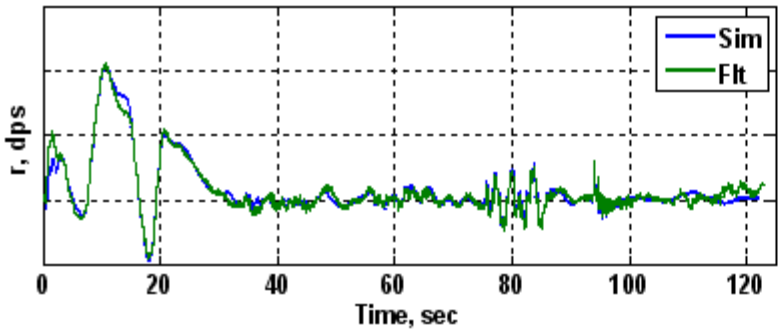
Vehicle Rates and Attitude Angles

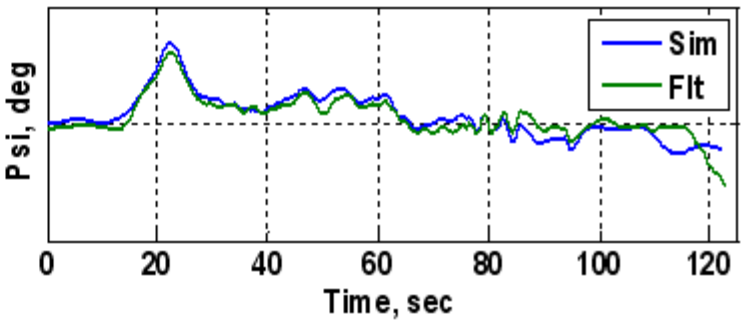




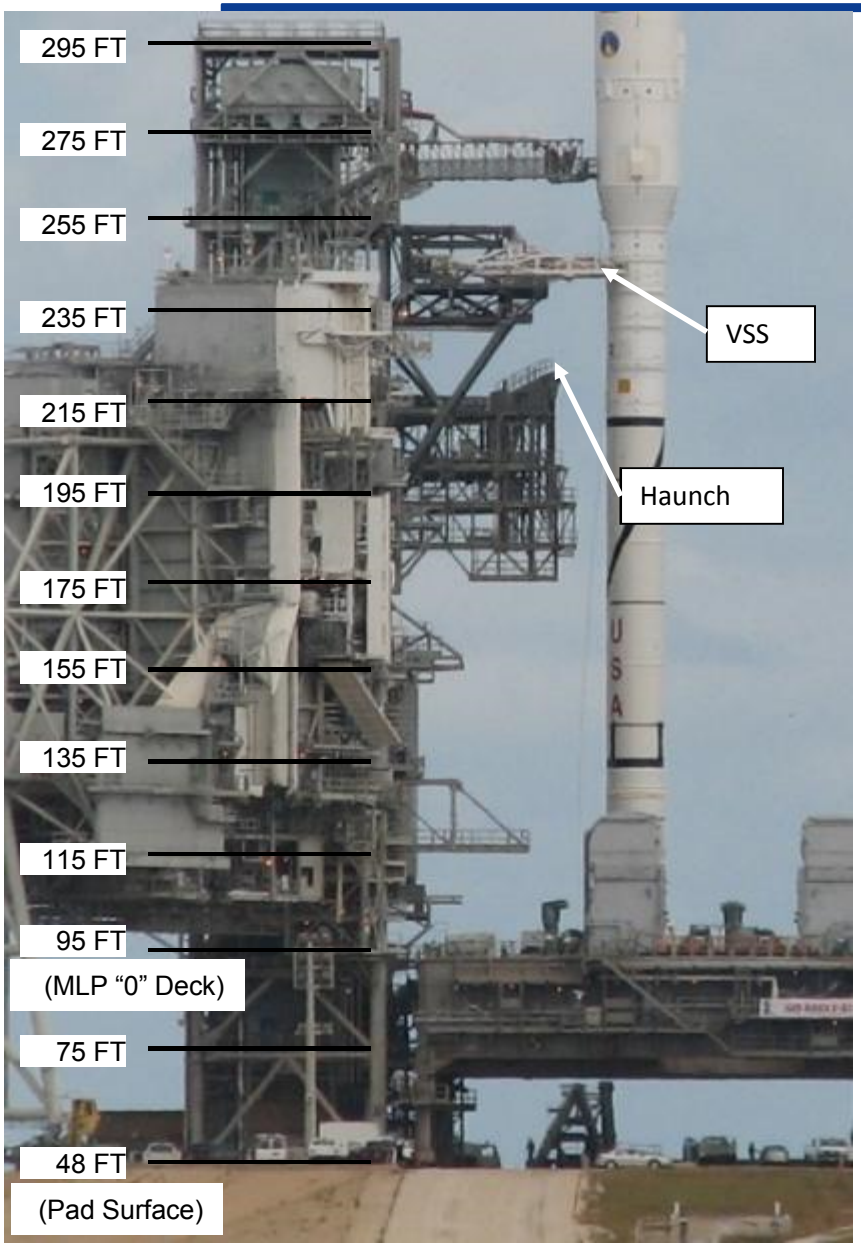






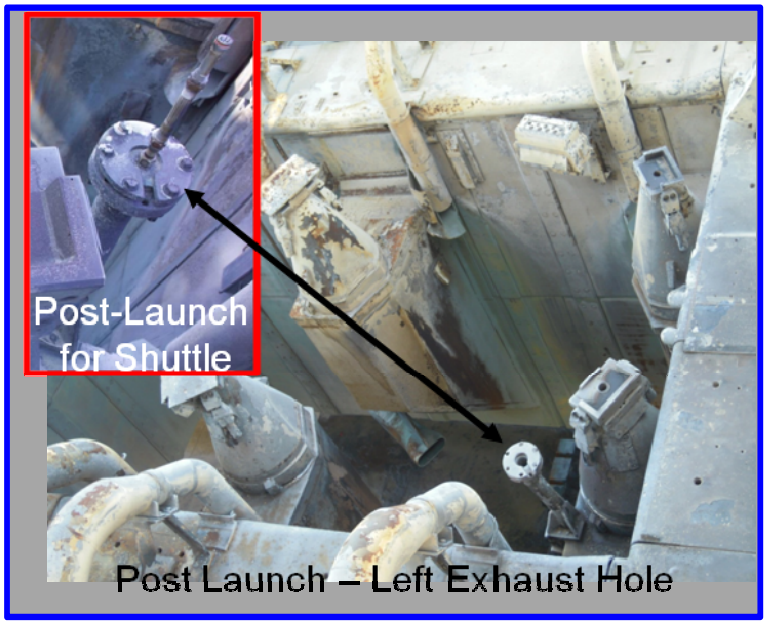


Pad Damage Assessment



- **Purpose of FAM was to Protect Structure Around Pad**
- **Primary Concern was Loads On Upper Structure**
- **Expected More Blast Damage Low**





FSS 115’ Level: Electrical Box & ECS Duct

Electrical Box



Electrical Box



ECS Duct



FSS 260’ Level: Vehicle Stabilizer System (VSS)

Pre-Launch



FSS 260' Level: Vehicle Stabilizer System (VSS)

Post-Launch

MONEY SHOT!



Summary

- **Design-For-Data Flight Test Approach Executed**
  - 700+ parameters from DFI
  - 1700+ parameters from OFI
  - System ID maneuvers flown – **First for this vehicle class!**
- **Fly-Away Maneuver Demonstrated**
  - Successfully reduced blast damage at upper levels
  - More heat related damage than Shuttle
  - More blast damage at low levels – as expected
- **Robust Flight Control System Design**
  - Changes of models and dates – no re-design required
  - Flight successful even with model uncertainties
- **Initial Comparisons Show Excellent Results**
  - Flown as expected
  - FCS margins as predicted
  - Very small roll torques during flight
  - Jet interaction effects – Test data for modeling
  - Structural damping apparently lower than models
  - TV model, and modeling of thrust/forces during tailoff need investigation
- **Successfully Demonstrated Control and Met All Flight Dynamics Related Requirements**



Summary Video Assembly, Roll Out, Flight

