Virtual Project Management Challenge

September 22, 2015

Building Your Systems Mentality:

Using systems engineering & integration to solve project challenges

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Shuttle System Configurations and Corresponding Analyses

1) Shuttle on Ground and Liftoff

- Liftoff Loads
- Ground Winds
- Liftoff Clearances
- Acoustics
- ET Pressurization
- Main Propulsion System
- Avionics Sequencing & Timing
- Electrical Power
- Integrated Hydraulics
- Software Requirements
- Integrated Checkout Requirements

2) Post Liftoff Configuration

- Winds Aloft
- High Q Loads
- Heating – Aero & Plume
- Flutter & Buffet
- Acoustics
- SRB Separation

•Control Stability & Control Authority
•ET Pressurization & MPS
•Integrated Hydraulics
•Software Requirements
•POGO

3) Boost Configuration

•High G Loads
•Heating – Aero & Plume
•ET Pressurization & MPS
•Integrated Hydraulics
•Power
•Control Stability & Control Authority
•POGO
•Software Requirements
•ET Separation

- Evaluation of flight test results and the establishment of operational boundaries for all flight phases

STS-1 SRB Ignition Overpressure (IOP)

Problem

- Solid rocket booster (SRB) ignition overpressure (IOP) measured at the vehicle exceeded the 3-sigma liftoff design environment
  - Accelerations measured on the wing, body flap, vertical tail, and crew cabin exceeded predictions during the liftoff transient
  - Support struts for the orbiter's reaction control system (RCS) oxidizer tank buckled
- Post-flight analysis revealed that SRB IOP was much more violent than predicted

Corrective Actions

- Systems Engineering & Integration (SE&I) "Wave Committee" organized with participation of NASA and the contractors
- A 6.4% model was used to evaluate various suppression schemes
- A new scaling relation was developed based on blast wave theory
- Final fixes—all on the Ground System side
  - Redirected water spray for SRB IOP suppression toward the "source" of SRB IOP
  - Installed water troughs in the SRB exhaust duct

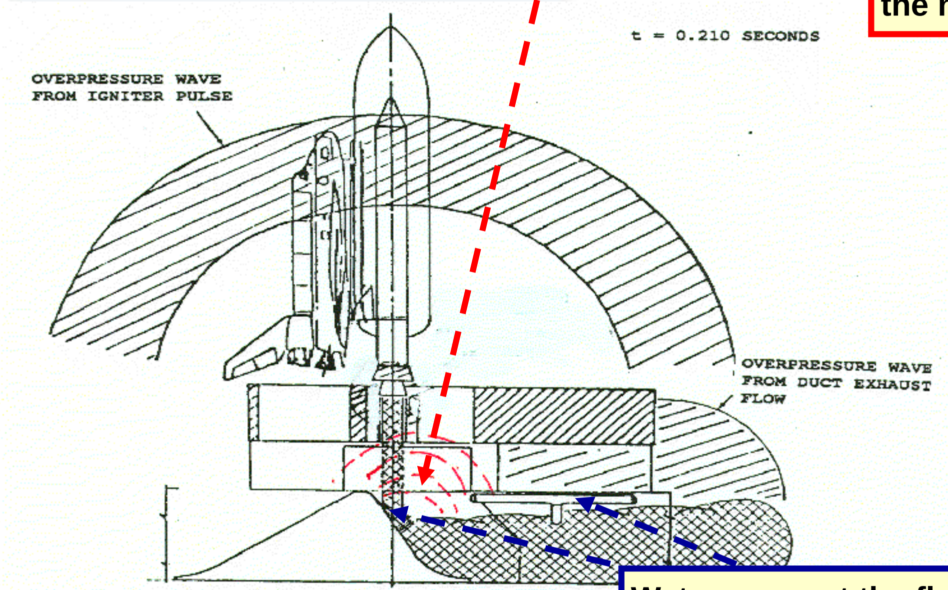
Very significant IOP reduction was achieved

Ignition Overpressure Buckles STS-1 Tank Strut

Water spray for STS-1 was designed for IOP source at flame deflector

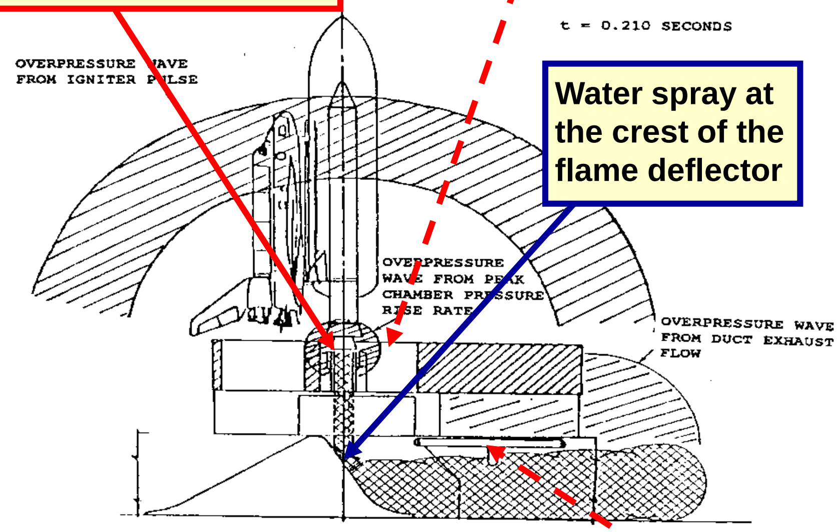
100,000 gallons per minute (GPM) of water injected into the SRB exhaust beneath the nozzle exit plane

Water troughs cover the SRB duct inlet



STS-1 Configuration

Water spray at the flame deflector and side pipes along the duct



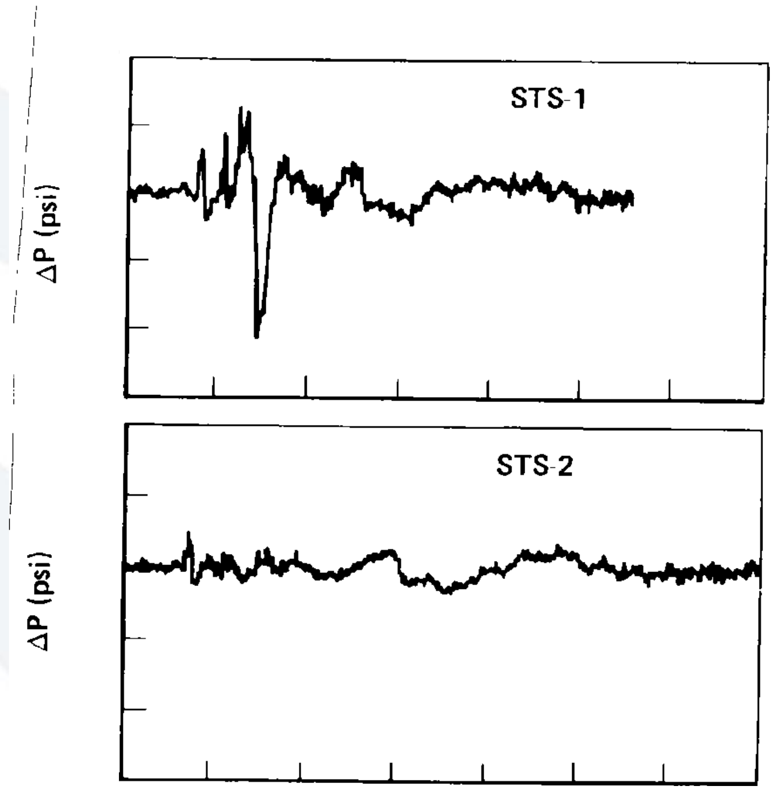
Water spray at the crest of the flame deflector

STS-2 Configuration

Water spray at the side of duct deleted

Safe Flight in STS-2 with New Water Injection

Modified Ground System Eliminated Overpressure Threat to Shuttle



Reduced overpressure by a factor of five

Role of System Engineering in Resolving Excessive Orbiter Loads Due to SRB IOP

- Perform system analysis and tests to verify adequacy of solution
  - **Preserve orbiter without redesign**
  - **Preserve SRB start transient characteristics**

Orbiter Wing Negative Margins in STS-1 During Ascent Through Max Q Region

Problem

- Plume simulation used during the wind tunnel test was flawed
  - Observed significant wing lift and vehicle lofting in STS-1
  - Measured strains showed negative structural margins
  - Vehicle lofted and flew close to the range safety boundary
- Grossly under-predicted ascent base pressures
  - Temperature effects were not modeled in cold jet plume simulation parameters used during wind tunnel testing

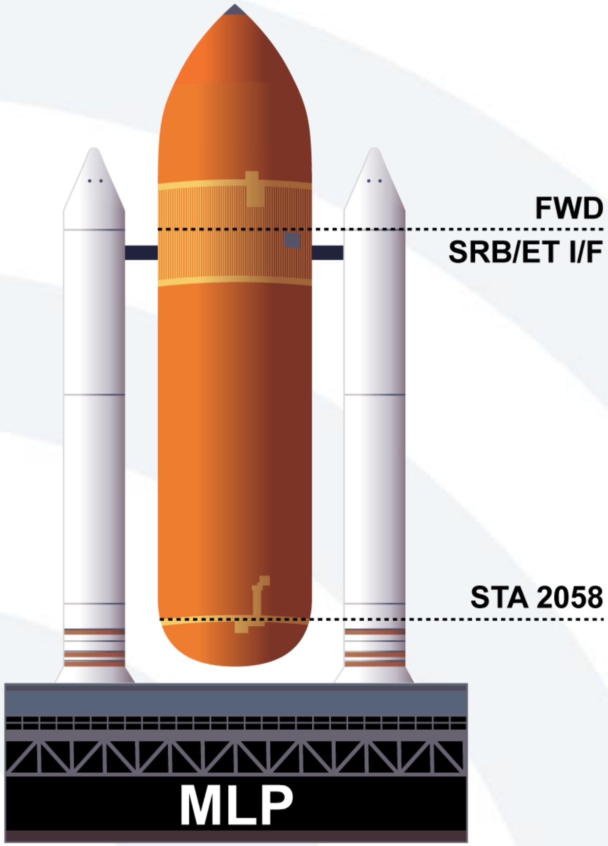
Corrective Actions

- The ascent trajectory was changed to a flight with a negative angle of attack through High Q: Elegant system-level solution
  - Negative angle of attack reduced wing lift and loads
  - Negative angle had to be evaluated for entire shuttle
  - Eliminated need for wing redesign

Role of SE&I in Resolving Wings' Negative Margins During Ascent

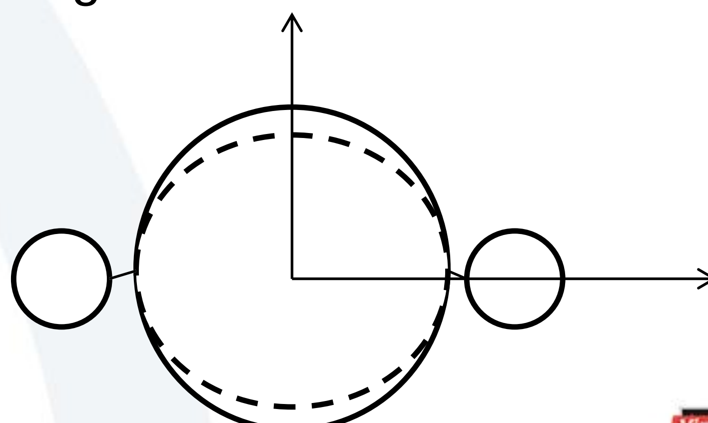
- **Ingenuous system-level solution**
  - Changing angle of attack of entire stack to a negative 3.2 deg reduced wing lift to acceptable level
  - Extensive system analysis to verify margins
- **Avoided extensive wing redesign and recertification**
- **Avoided unacceptable schedule impact**

Problem: Liquid Hydrogen (LH2) Fill Buckles Lower Dome



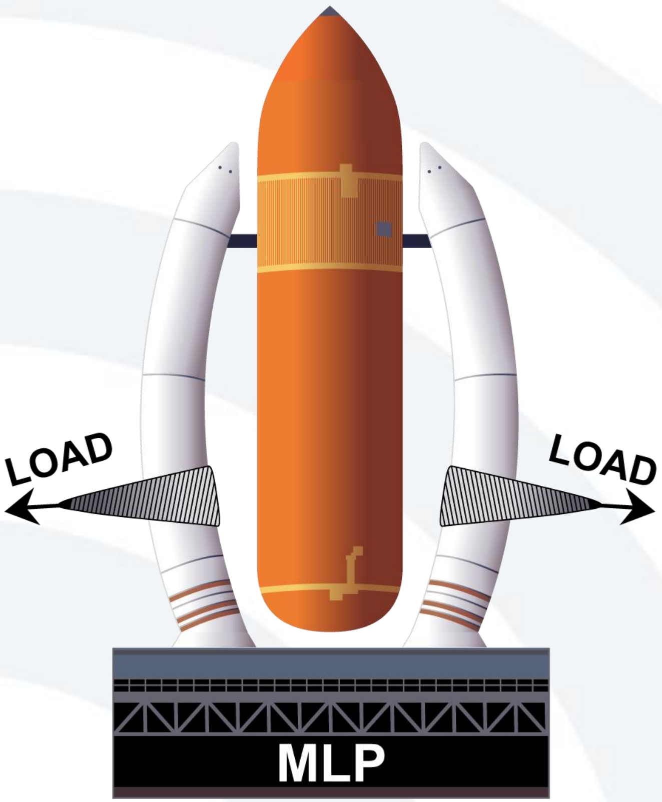
Problem description:

1. During LH2 fill, external tank (ET) diameter shrinks ~ 1in
2. SRB provides resistance in Y axis
3. 2058 frame deforms into an oval
4. Dome gores undergo elastic buckling causing dome insulation to debond



Solution: Modify Stacking Procedure

<u>Corrective Action:</u> Preload 2058 frame with compressive preload during ET/SRB mating



Procedure:

1. After mating forward ET/SRB I/F, apply load (using belly bands) to bend SRB away from 2058 frame
2. Install aft ET/SRB struts
3. Release belly bands load to put 2058 frame in compression—amount of preload is critical

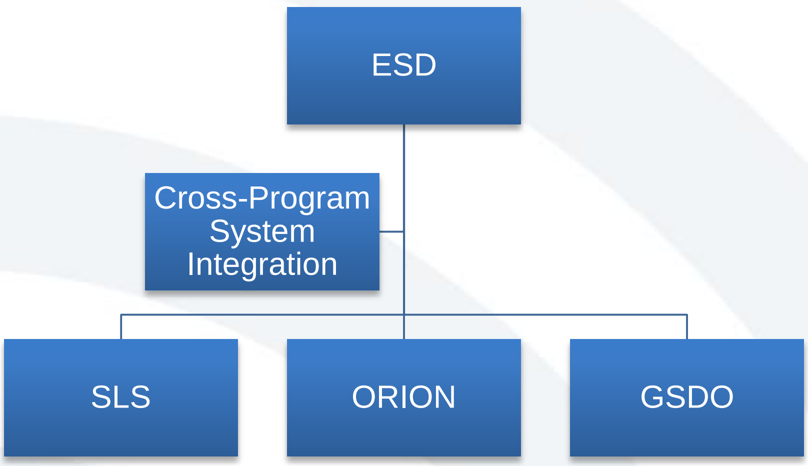
A change to stacking operation protected lower dome from buckling without impacting performance

- Ullage backpressure during loading and replenish was avoided
- Redesigning of ET lower dome was not required

SE&I Functions are Invariant Regardless of Organizational Structure

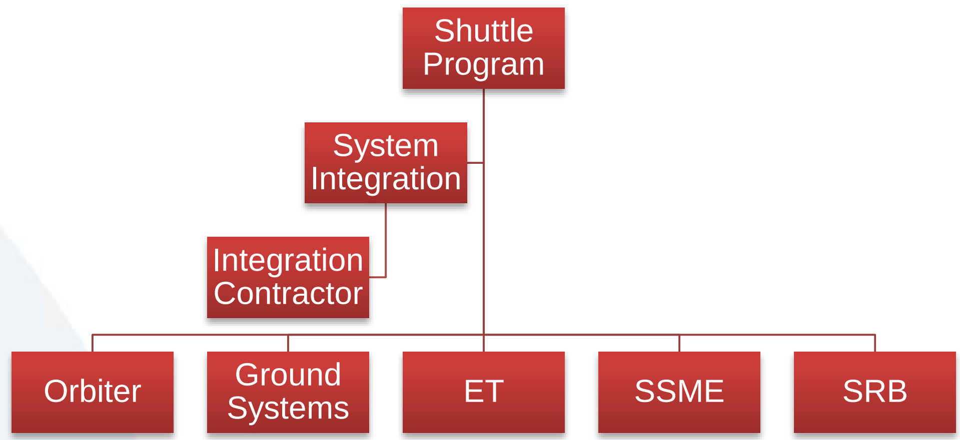
Exploration Systems and Shuttle Integration Structure

Exploration Systems



Integration work distributed among 3 programs

Space Shuttle



Integration work performed by integration contractor

Integration functions are the same

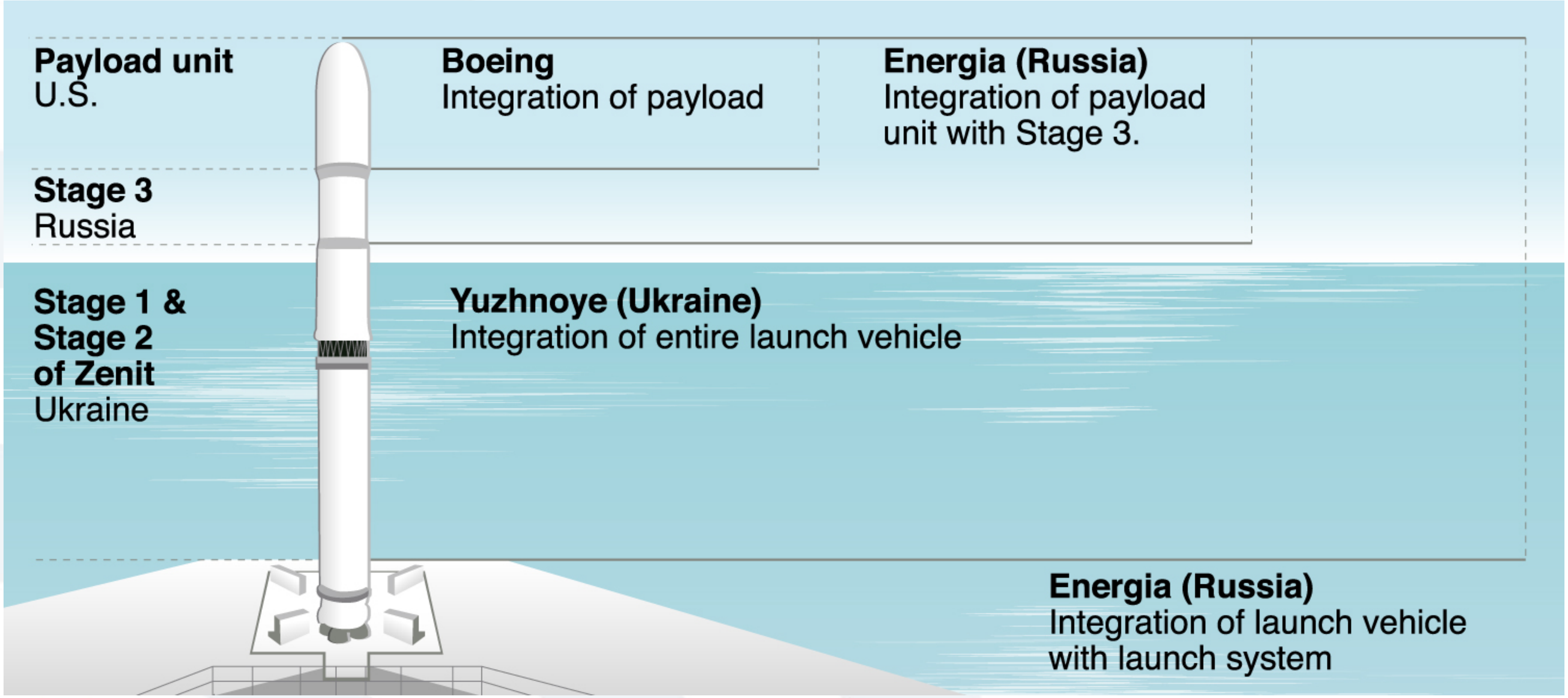
Two NASA SE&I Approaches: Shuttle and ESD

Space Shuttle SE&I	ESD SE&I
• Independent office, with its own funding, reporting to shuttle PM • NASA managed SE&I, supported by integration contractor • System-level work performed by integration contractor	• Cross-program integration team reporting to ESD director • Managing SE&I shared between CPIT and 3 programs • System-level work distributed among 3 programs

SE&I in a Commercial Program: Sea Launch

Sea Launch Integration

Example of integration of totally commercial program



Three Different Systems… Same SE&I Functions

Shuttle

SLS/Orion

Sea Launch

Summary and Takeaways

1. Every major government and commercial program benefits from a robust SE&I

2. System approach to problem resolution offers great potential for most effective corrective actions

3. Developing a system culture in program management – a key to successful execution

4. Your own “System Mentality” is likely to enhance your career

Q&A Session

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