Risk-Based Explosion Assessment

Internal Explosion of Exploration Upper Stage in Vehicle Assembly Building

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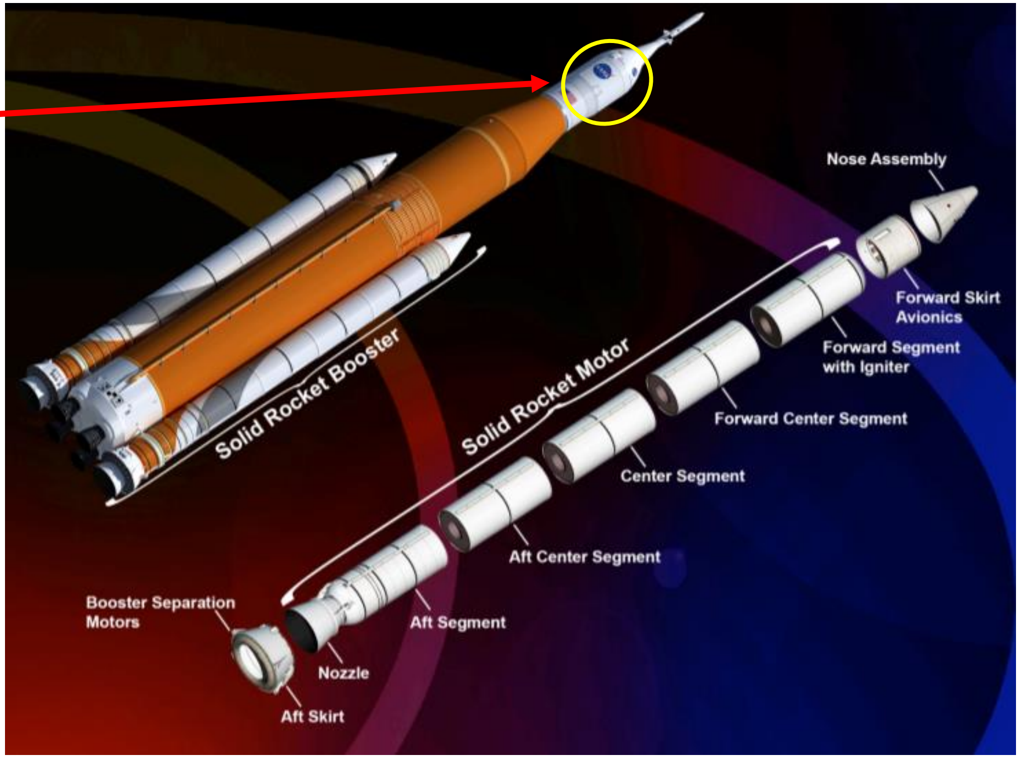
Outline

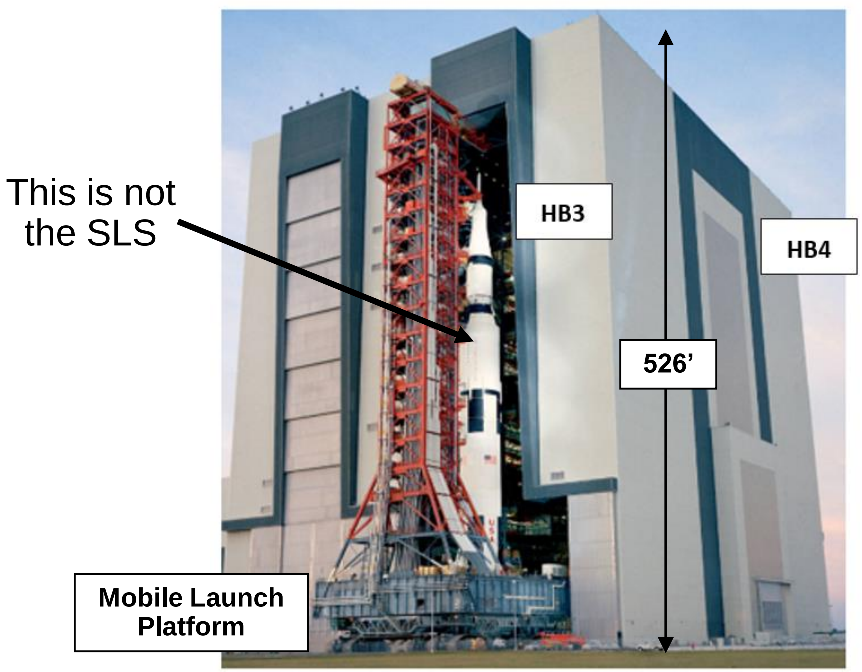
- **Problem Description**
- **Exploration Upper Stage (EUS) explosion accident during processing**
  - ***Yield***
  - ***Fragmentation***
- **Fragmentation Analysis**
- **Mitigation**

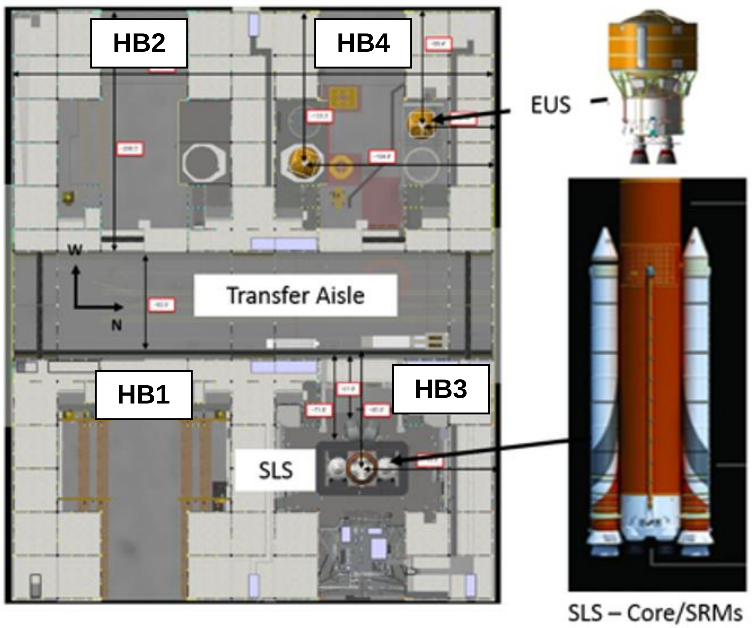
Space Launch System



Problem Description

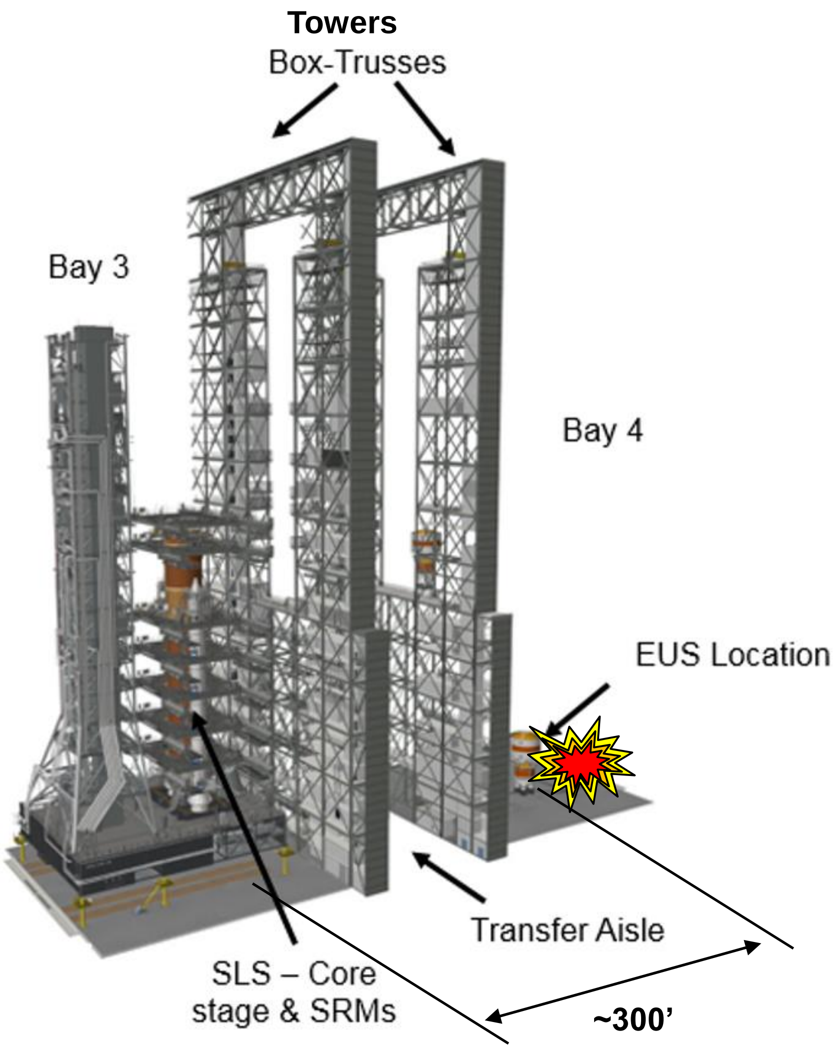
- **NASA is building the Space Launch System (SLS), their most powerful rocket, to send astronauts on deep space missions**
- **SLS is being assembled in VAB High Bay 3 (Kennedy Space Center)**
  - ***Height = 365’; 1st Stage Core Dia = 28’; SRM Dia = 12’***
- **NASA plans to co-process the EUS in Bay 4 while the SLS Core/SRMs are processed in Bay 3**





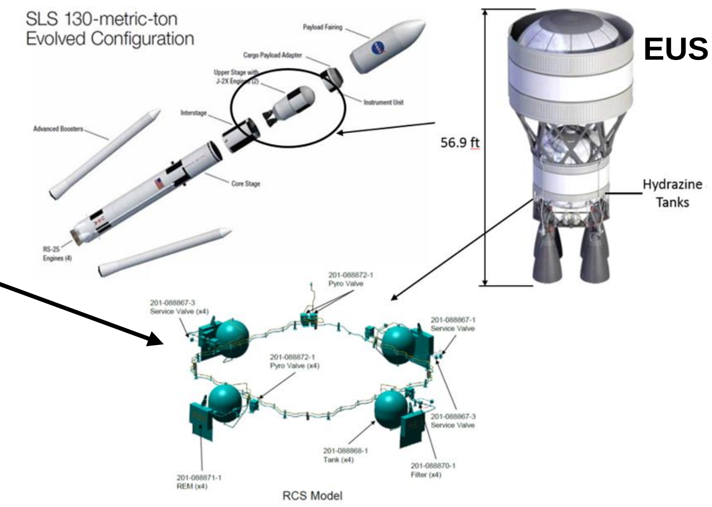
Problem Description

- The SLS Core/SRMs in Bay 3 are separated from the EUS in Bay 4 by two “tower” structures that border the Transfer Aisle
- An accident during processing of the EUS in Bay 4 could hazard the SLS in Bay 3
- ACTA was tasked to determine the consequences of a hypergol explosion during EUS fueling:
  - *Air Blast*
  - *Fragmentation*
- This briefing focuses on fragmentation effects as it is the controlling hazard



Explosion Accident/Yield

- **The EUS when integrated with the SLS sits above the interstage adapter**
- **The EUS uses 4 small hydrazine tanks (at 50 psi) to feed a thrust system**
  - ***Each tank contains X lb for a total = XXXX lbs***
- **Thrust is produced by passing the hydrazine over a catalytic surface**
- **NASA was concerned that an "Unknown Delayed Detonation Transition (XDT) could occur resulting in an explosion/over-pressurization (see footnote)**
- **The NASA explosives safety standard does not have yield factors for pure hydrazine: To be conservative, a decision was made to use the yield factors for a hydrazine fuel/oxidizer mix**
- **In addition, the higher yield factor for a Range Launch accident (10%) was used**
- **The EUS hypergol accident yield is therefore:**
  - ***Yield = 10% * XXXX lbs , TNT***



ENERGETIC LIQUIDS	TNT EQUIVALENCE	
	STATIC TEST STANDS	RANGE LAUNCH
LO_2/LH_2	*See Note 6*	*See Note 6*
LO_2/LH_2 + LO_2/RP-1	Sum of (see Note 6 for LO_2/LH_2) + (10% for LO_2/RP-1)	Sum of (see Note 6 for LO_2/LH_2) + (20% for LO_2/RP-1)
LO_2/RP-1	10 %	20% up to 500,000 pounds plus 10% over 500,000 pounds
IRFNA/UDMH [7]	10%	10%
N_2O_4/UDMH + N_2H_4 [7]	5%	10%
N_2O_4 liquid oxidizer + PBAN solid fuel (Hybrid propellants)	15% [8]	15% [8]
Nitromethane (alone or in combination)	100%	100%
Otto Fuel II	100% [9]	
Ethylene Oxide	100% [10]	100% [10]

In July, 2007, an "explosion" resulted from a mono-propellant (nitrous oxide) fueling test at Scaled Composites in Mojave, CA. Although the actual cause was not determined, some experts believe that there were contaminants present or the flow through various orifices resulted in the creation of gas pockets that led to an over-pressurization/explosion. This event could be labeled as an XDT.

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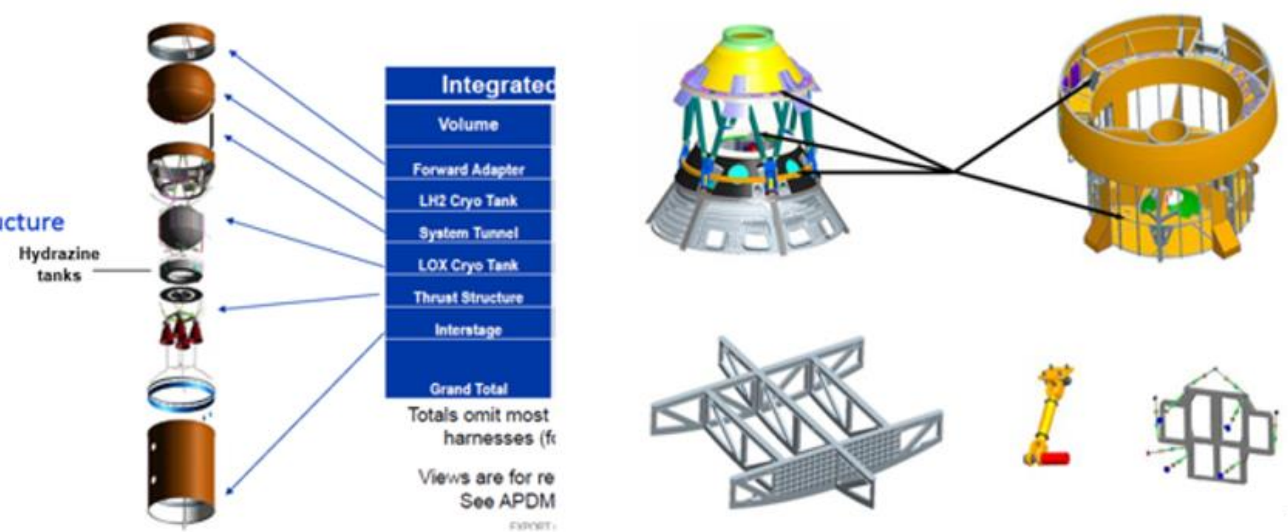
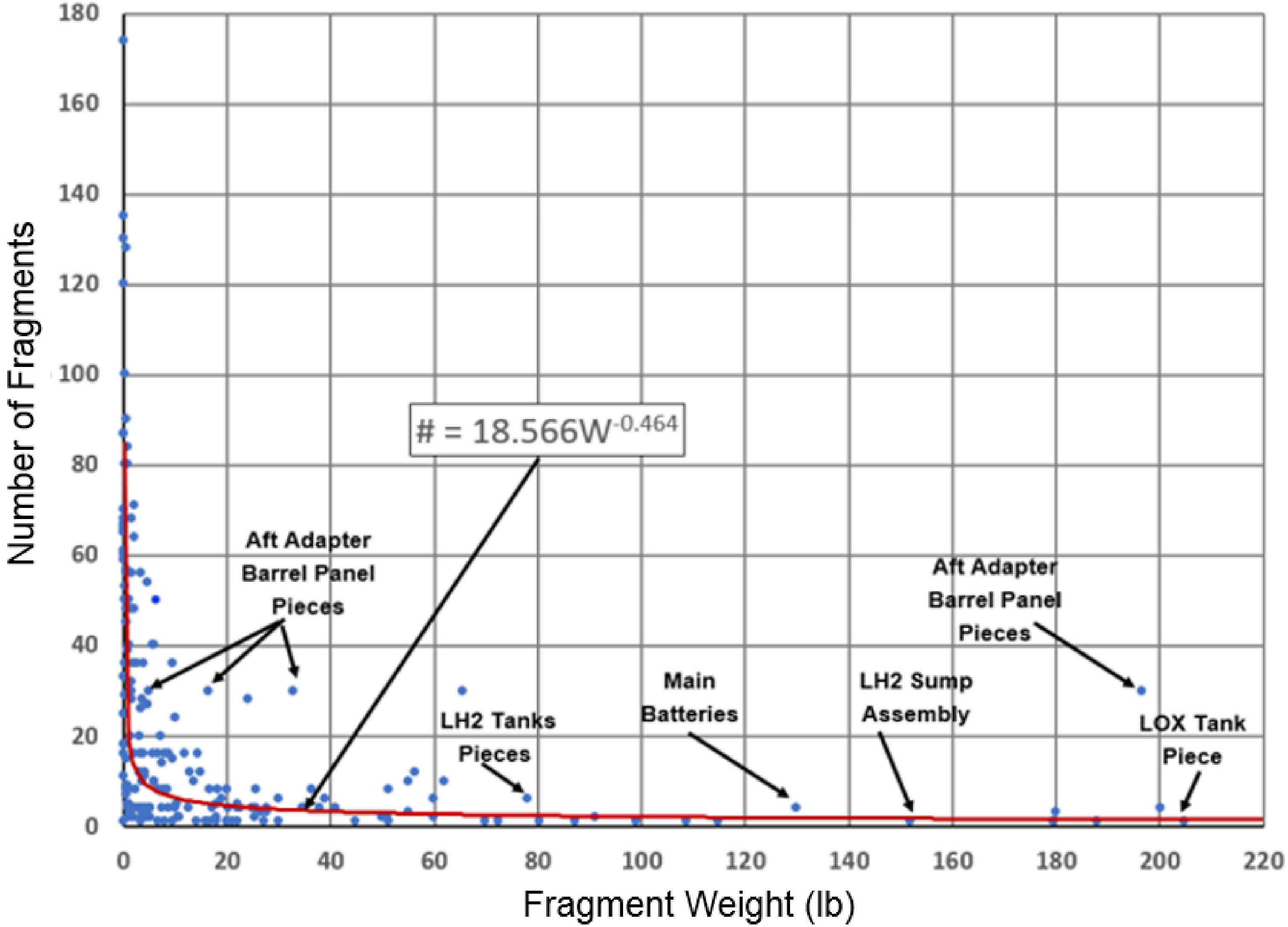
Fragmentation Model

- **A fragment list was developed consistent with the EUS structural configuration:**
  - ***Subsystem, component and sub-component locations, shapes & weights were based on structural drawings/3D renderings***
    - **These were placed into fragment "groups" (e.g., 4 LOX tank struts)**
    - **The total fragment list consists of 220 groups and over 2,300 individual pieces**
  - ***Shapes were used to define drag coefficient vs. mach number***

- Forward Adapter
- Tunnels
- LH2 Tank Assembly
- Integrated Midbody
  - Helium Tanks
  - Midbody Primary Structure
- LOX Tank
- Equipment Shelf
- Thrust Structure
  - Engines
  - Primary Structure
  - Heat Shield



EUS Fragment List Summary



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Fragment Velocity (1)

- **The method used to determine a fragment's group takeoff velocity is based on a "Modified Gurney" (MG) approach**
- **The Gurney method is used to predict the velocity of weapons where the propellant fills the entire volume of a heavy-walled casing**
- **The MG method uses an "effective" propellant density to account for the lack of confinement typical of spacecraft explosions**

$$\frac{U}{\sqrt{2E_g}} = \left[\frac{m}{c} + \frac{n}{n+2}\right]^{-\frac{1}{2}}$$

$$\sqrt{2E_g} = 0.887\varphi^{0.5}{\rho_o}^{0.4} = Gurney\ Velocity$$

$$\varphi = N\sqrt{MQ} \qquad \rho_o = \frac{c}{V}$$

- U = mean fragment velocity
- M = total mass of fragments
- C = mass of hydrazine
- n = shape factor integer (cylinder =2, sphere = 3)
- N = moles of gaseous products per gram hydrazine
- M = molecular weight of gases
- Q = Heat of hydrazine detonation
- V = volume within which hydrazine release explodes

Fragment Velocity (2)

- **Real fragments have a wide range of masses, surface-to-weight ratios; and, light-weight pieces will tend to accelerate more than dense pieces, drag forces will be different, etc.**
- **To compute fragment "group" velocities:**
  - ***The Total Kinetic Energy (TKE) is computed across all fragment groups***
  - ***The total fragment "face" area (TFA) of all fragment groups is then computed***
  - ***A fraction of the TKE is allocated to each fragment group based on the ratio of its face area to the TFA (KE_{frag_group})***
  - ***Finally, the fragment group velocity is computed from:***

$$KE_{frag\_group} = 1/2 * Mass_{frag\_group} * (V_{frag\_group})^2$$

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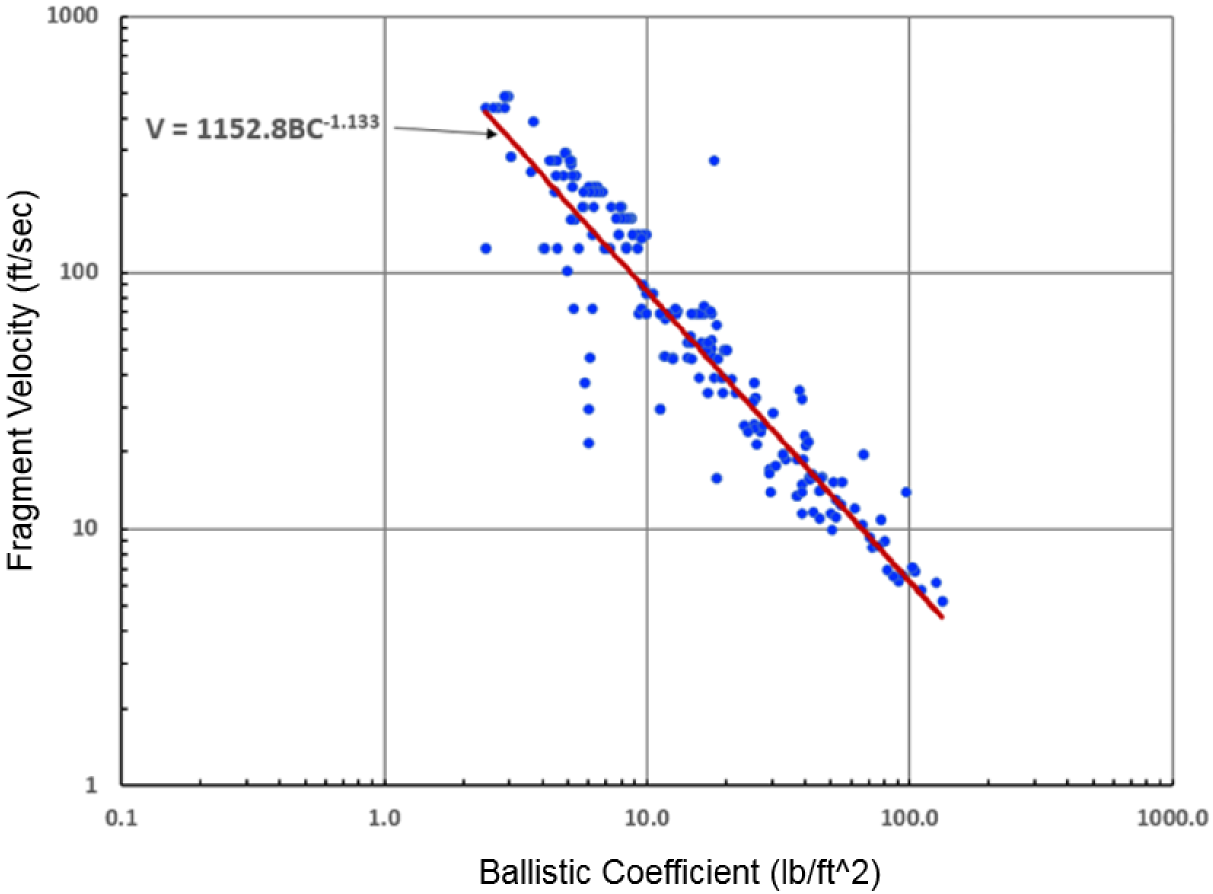
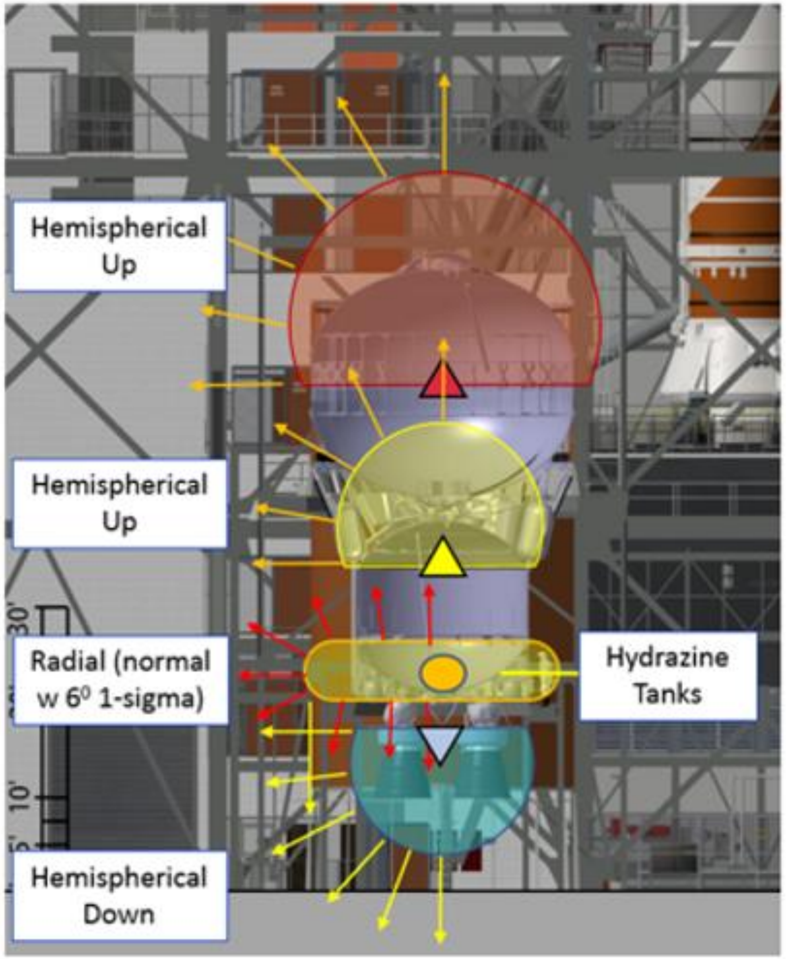
Fragment Velocity (3)

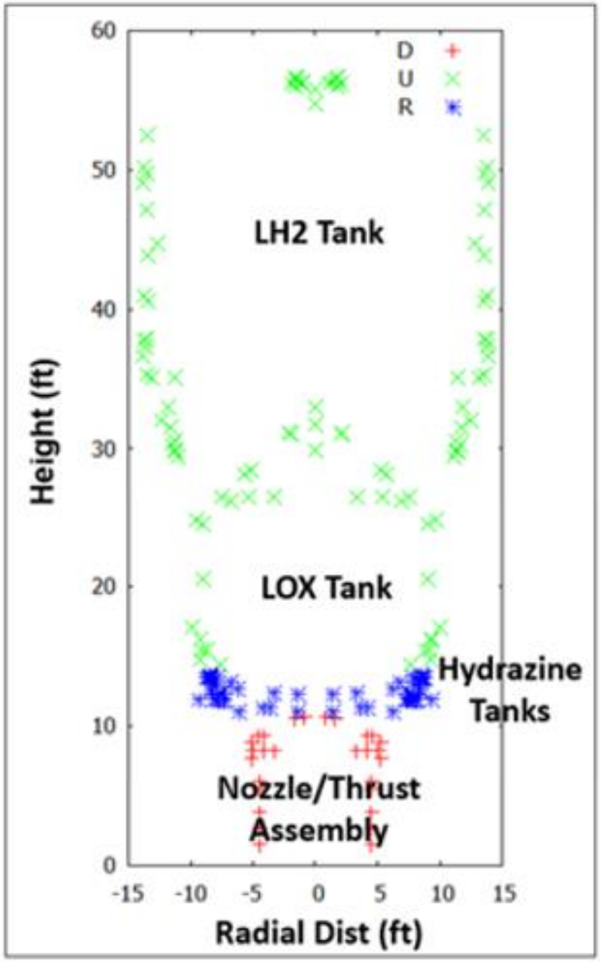
- **Ballistic Coeff = $W_{frag}/(C_d*Area)$**
  - ***Frags w/ higher BC's will travel further downrange given the same takeoff $\overrightarrow{\text{velocity}}$***
- **Note that EUS fragment group velocities range from 10 – 500 ft/sec**
- **These velocities are consistent with spacecraft accident and test data**



Fragmentation Takeoff

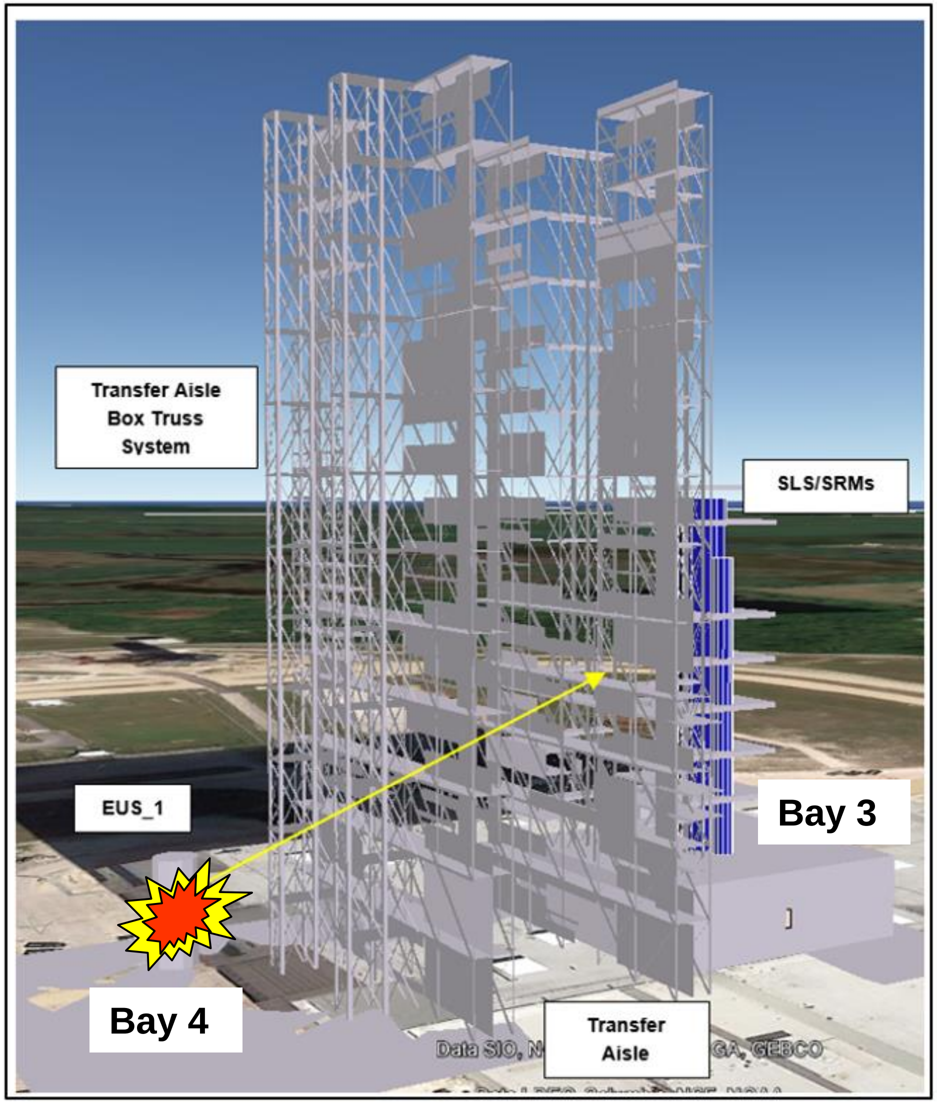
- **Fragments from each group are located in X, Y, Z with takeoff directions defined by 3D distributions**





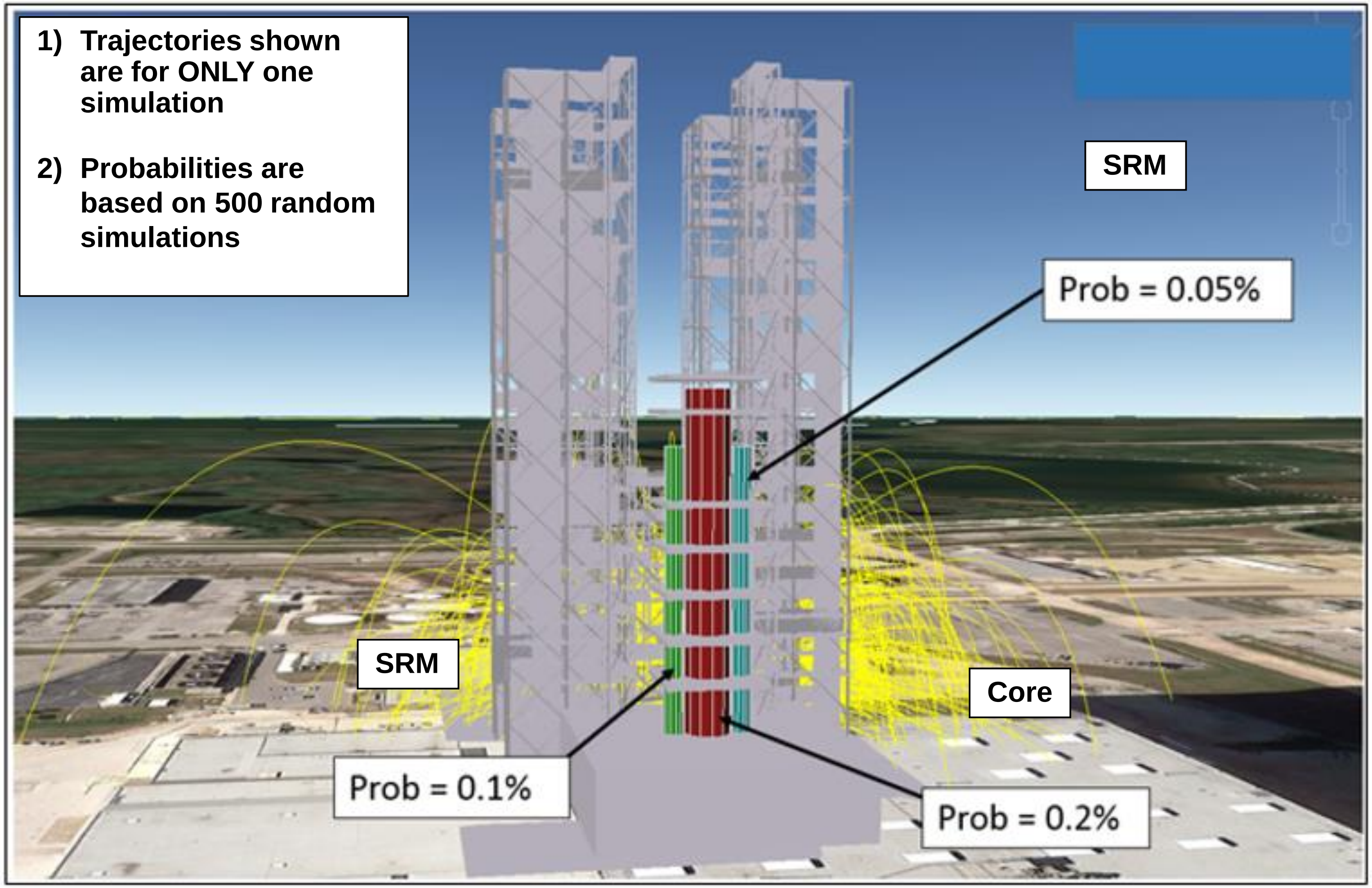
Fragment Throw Simulation (1)

- **The intervening Transfer Aisle (TA) tower structure between the EUS in Bay 4 & the SLS in Bay 3 was modeled in detailed**
- **During an EUS explosion simulation:**
  - ***Each of the 2,300 drag-corrected fragment trajectories was computed***
  - ***Collison detection algorithms were used to determine if a fragment impacted the TA structure***
    - **Fragment shapes were considered**
  - ***SLS core & SRM impacts >10 ft-lb were recorded***



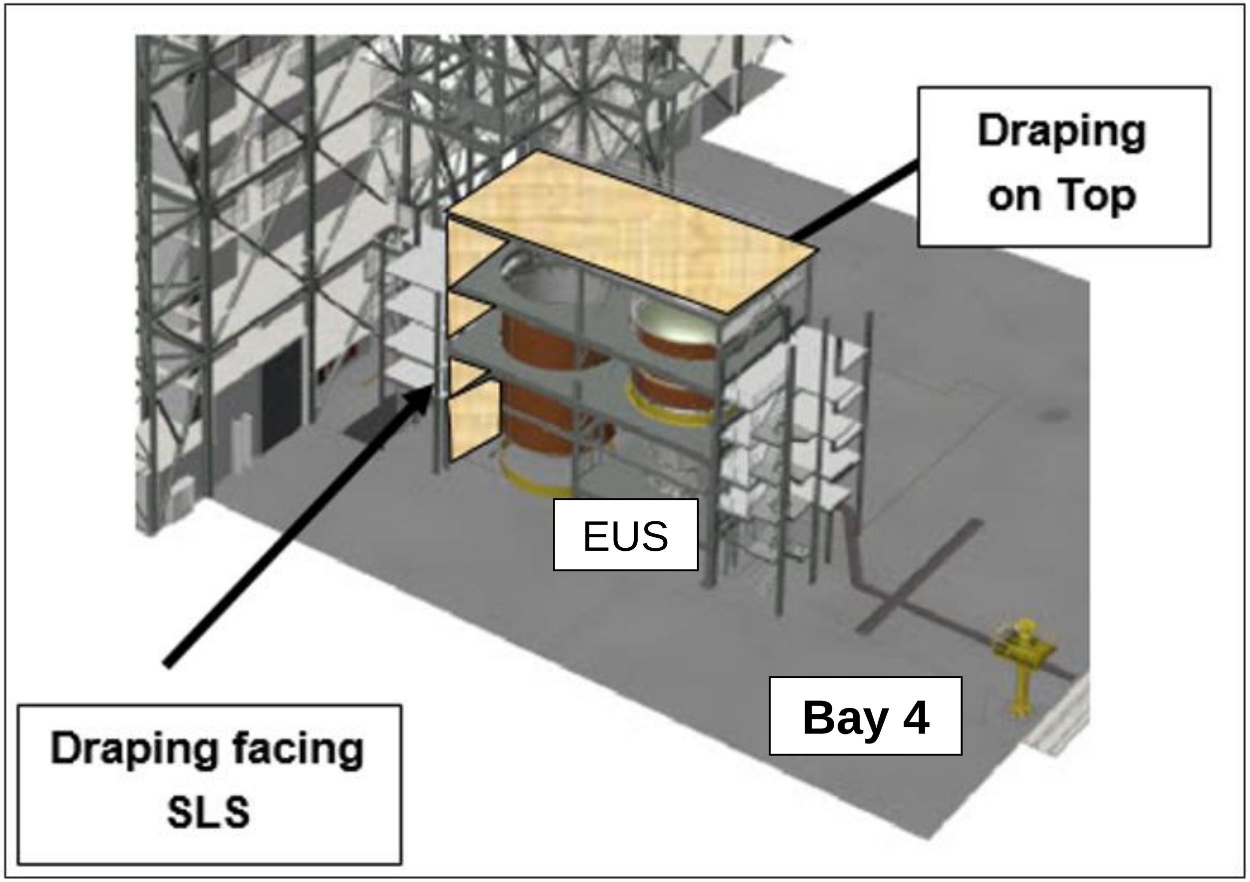
Fragment Impact Probability

- Hundreds of random simulations were run: each simulation varied a fragment's mass, ballistic coefficient, as well as takeoff location, direction & velocity
- The number of SLS core/SRM impacts was recorded for each simulation and then averaged to determine the expected number of impacts and the probability of impact



Potential Mitigation

- **To prevent any probability of fragment impacts to the SLS Core/SRMs, NASA is considering the installation of draping over the EUS work stand (kevlar, wire mesh)**

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