Reconstruction of the Stardust Entry

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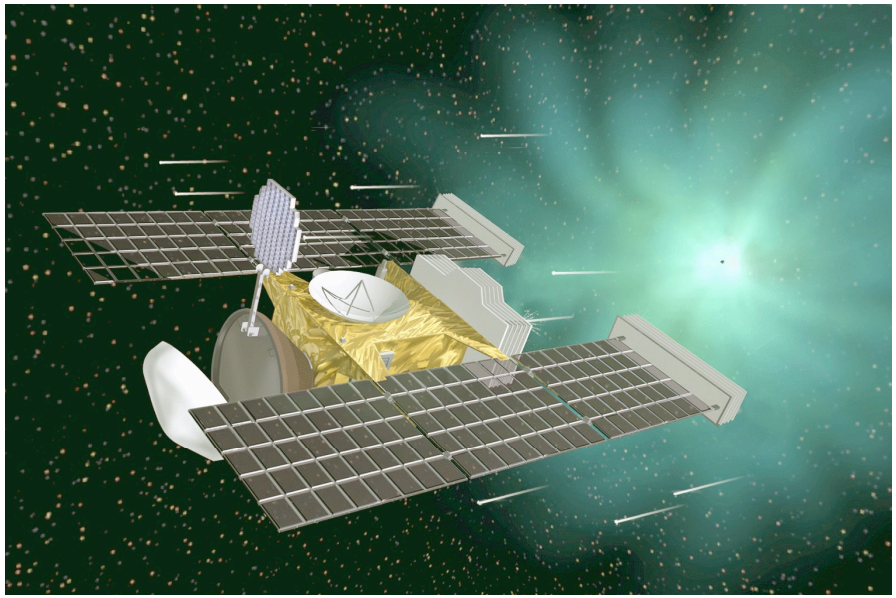
Mission Background

- Stardust was the Forth of NASA's Discovery Class Mission
  - Launched February 7, 1999
  - Return cometary samples from the comet Wild-2, along with interstellar particles
  - First mission to return samples from a comet
- Maneuver and targeting procedures placed capsule on desired entry flight-path on morning of January 15, 2006 at 09:56:42.3 UTC
  - Successfully landed under parachute at Utah Test and Training Range (UTTR)
  - First direct entry from an interplanetary trajectory to fly & land over continental US
- Overview of the entry reconstruction to assess comparison between pre-entry prediction and actual flight



Stardust Sample Return Capsule Configuration

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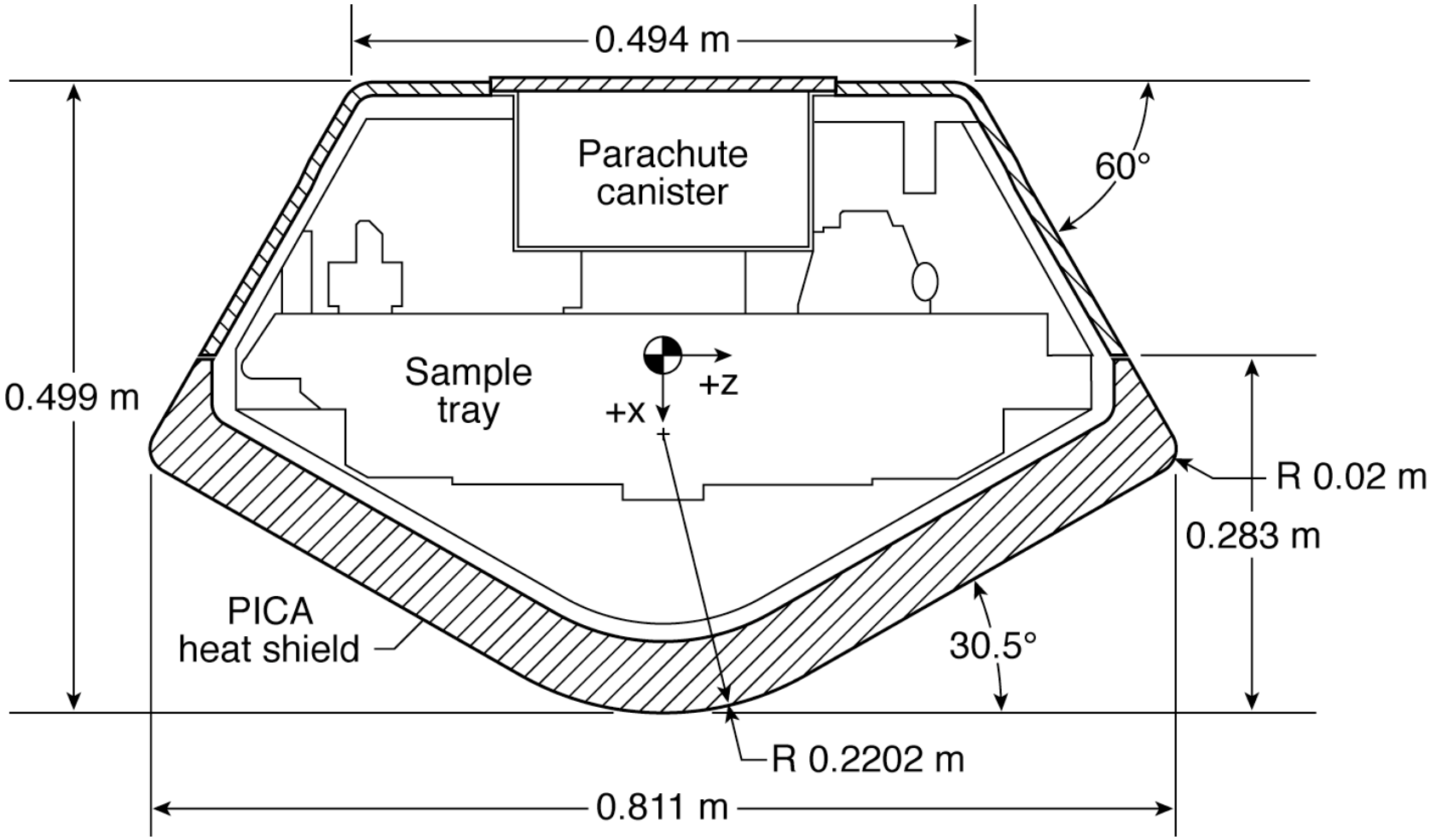
Capsule mass = 45.8 kg



Nominal Stardust Capsule Entry Sequence

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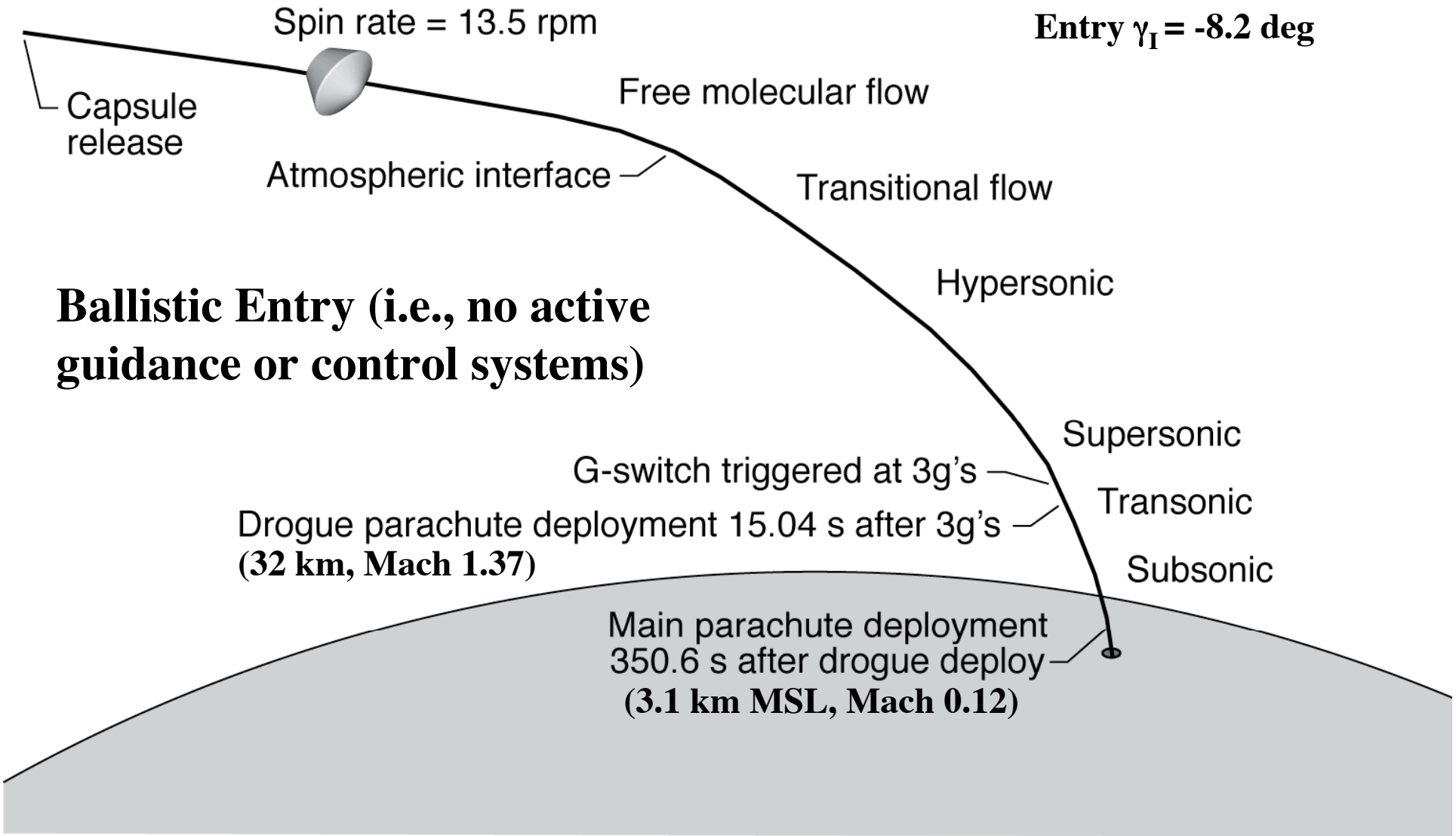
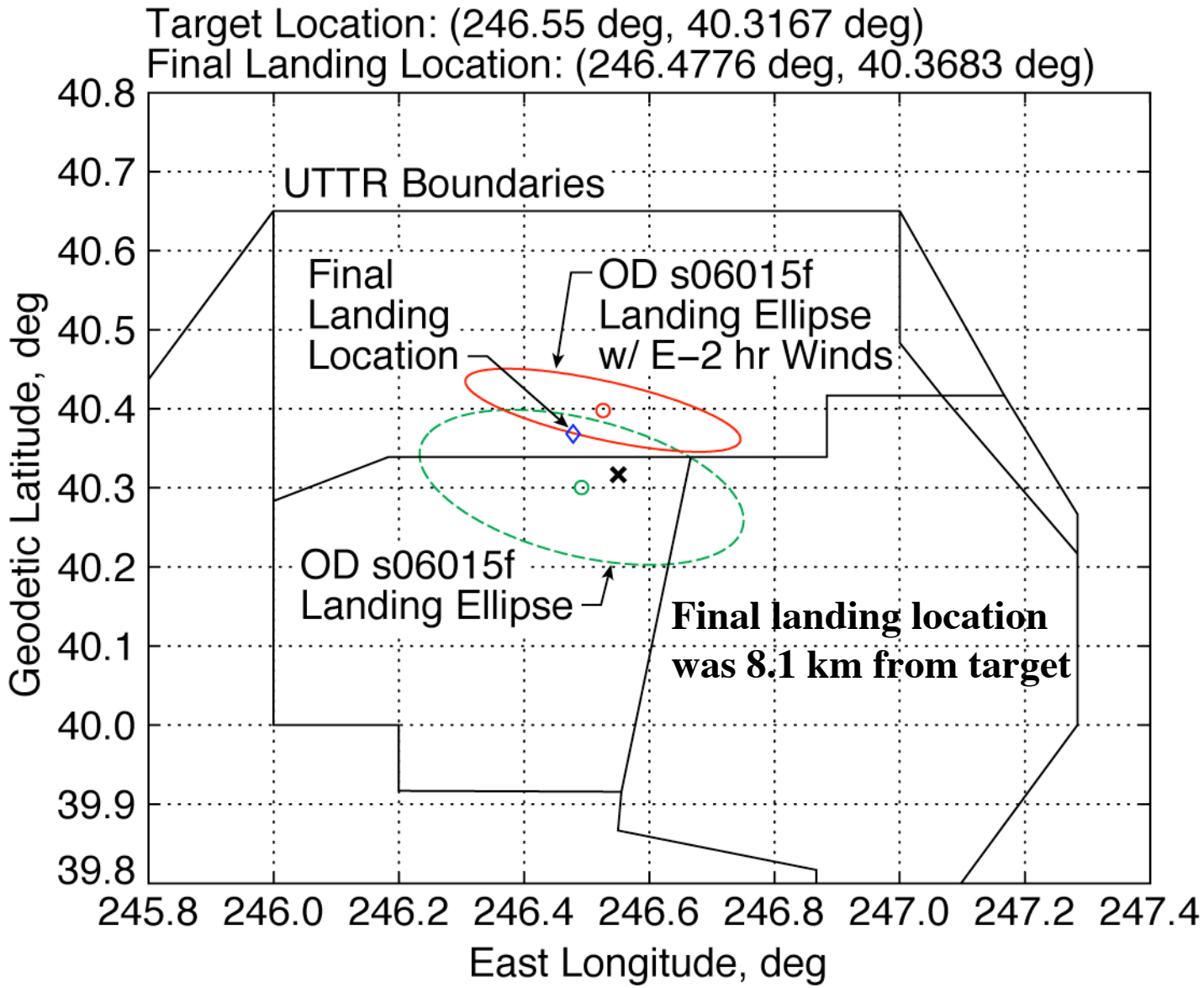
Entry V_I = 12.9 km/s

Entry γ_I = -8.2 deg



Ballistic Entry (i.e., no active guidance or control systems)

Final Capsule Landing Location



Stardust Reconstruction Effort

- Stardust capsule landed very close to the desired target
  - Understanding hypersonic flight performance is of great interest
  - Specifically, assessing how the pre-entry predictions of flight dynamics, aerodynamics, and aerothermodynamics

- Only limited data exists to perform reconstruction
  - No onboard sensors on capsule
  - Only available data source is from UTTR radar tracking stations
    - Video and tracking data
  - Balloon measurement of atmospheric properties up to 35 km two hours prior to entry

Northward Wind Component Comparison to GRAM-95 Model

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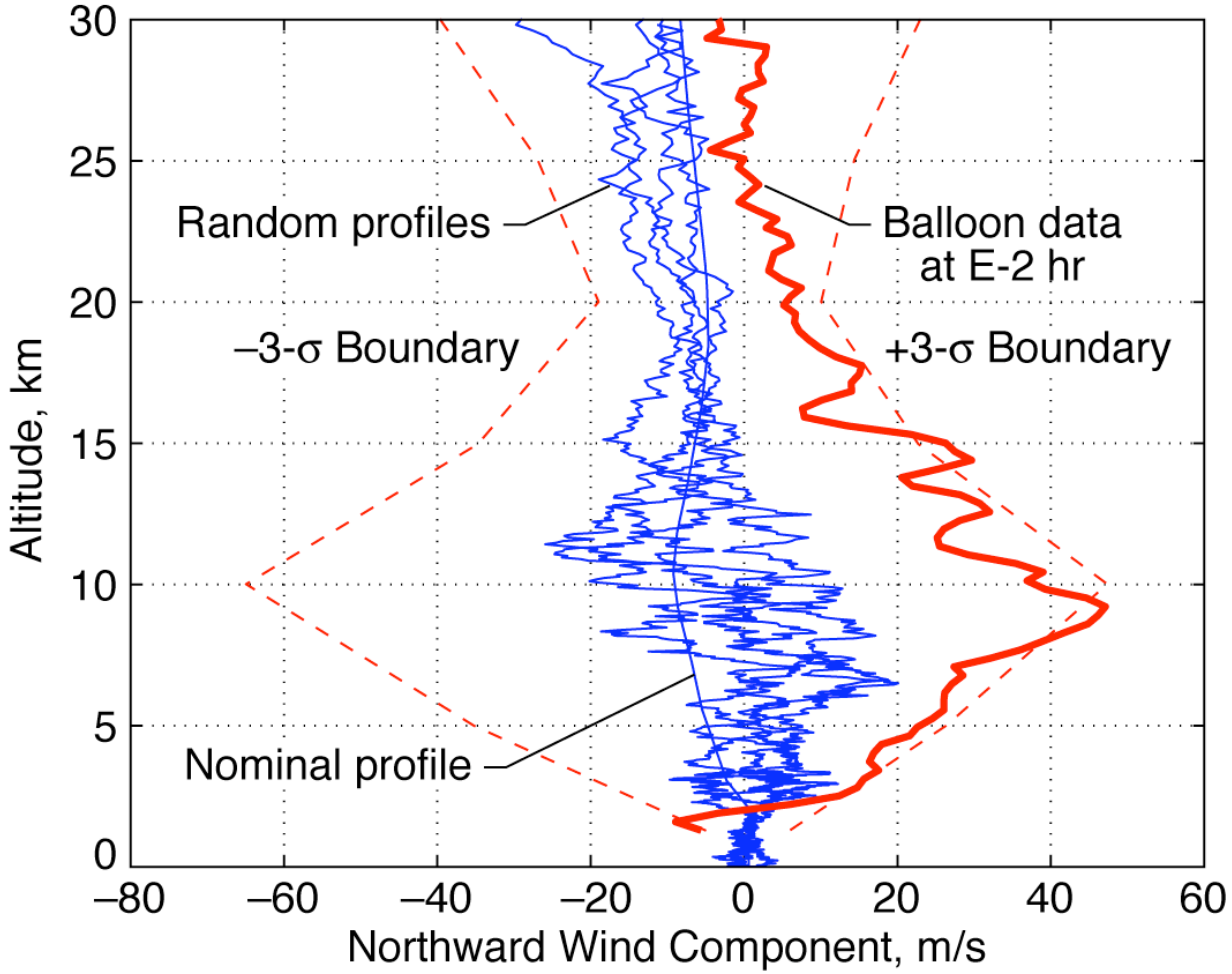
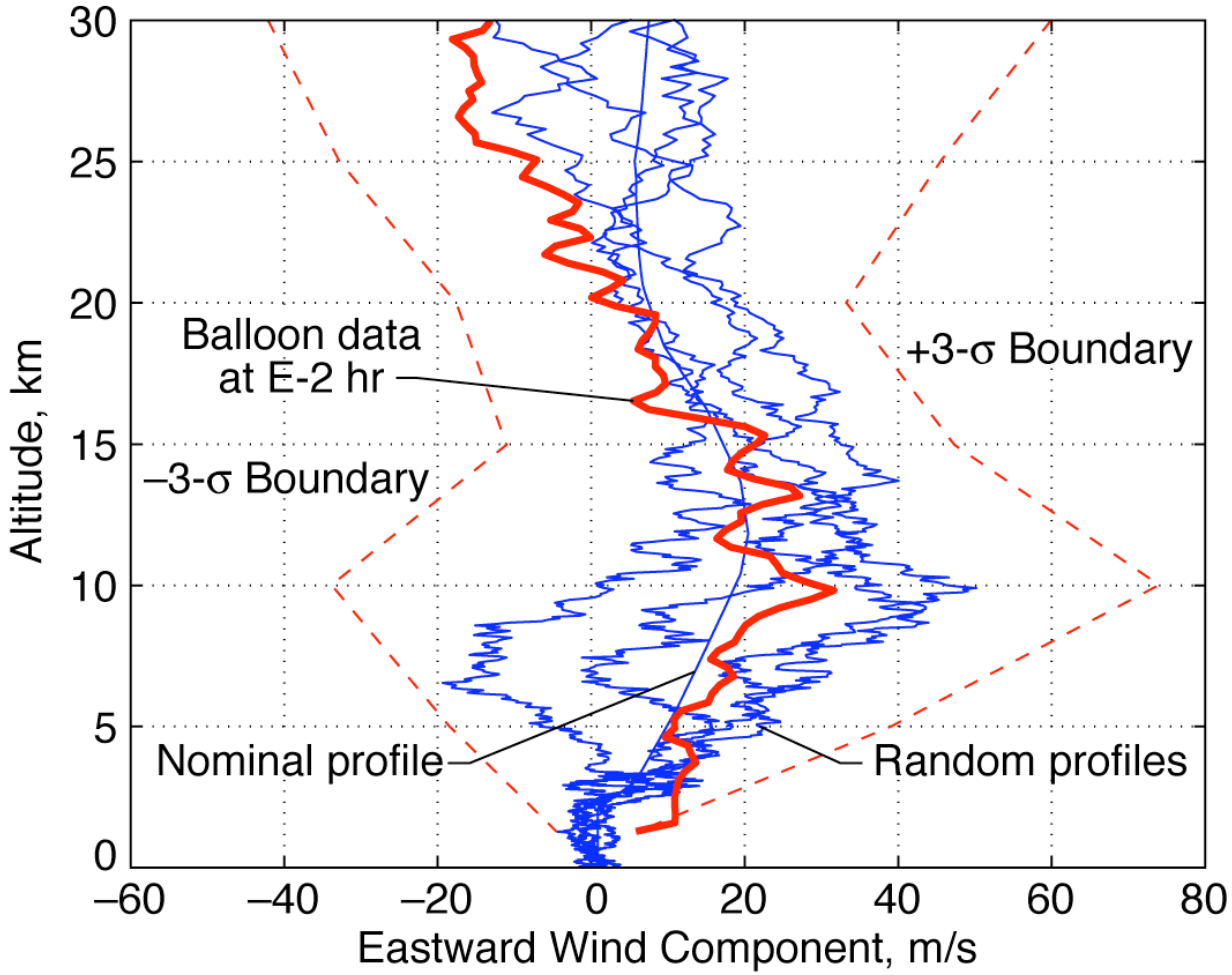
- Sustained wind to the North observed (~40 m/s at 10 km)
  - Blizzard moving through Utah during landing
- Corresponds to 3-σ profile from GRAM-95 variations

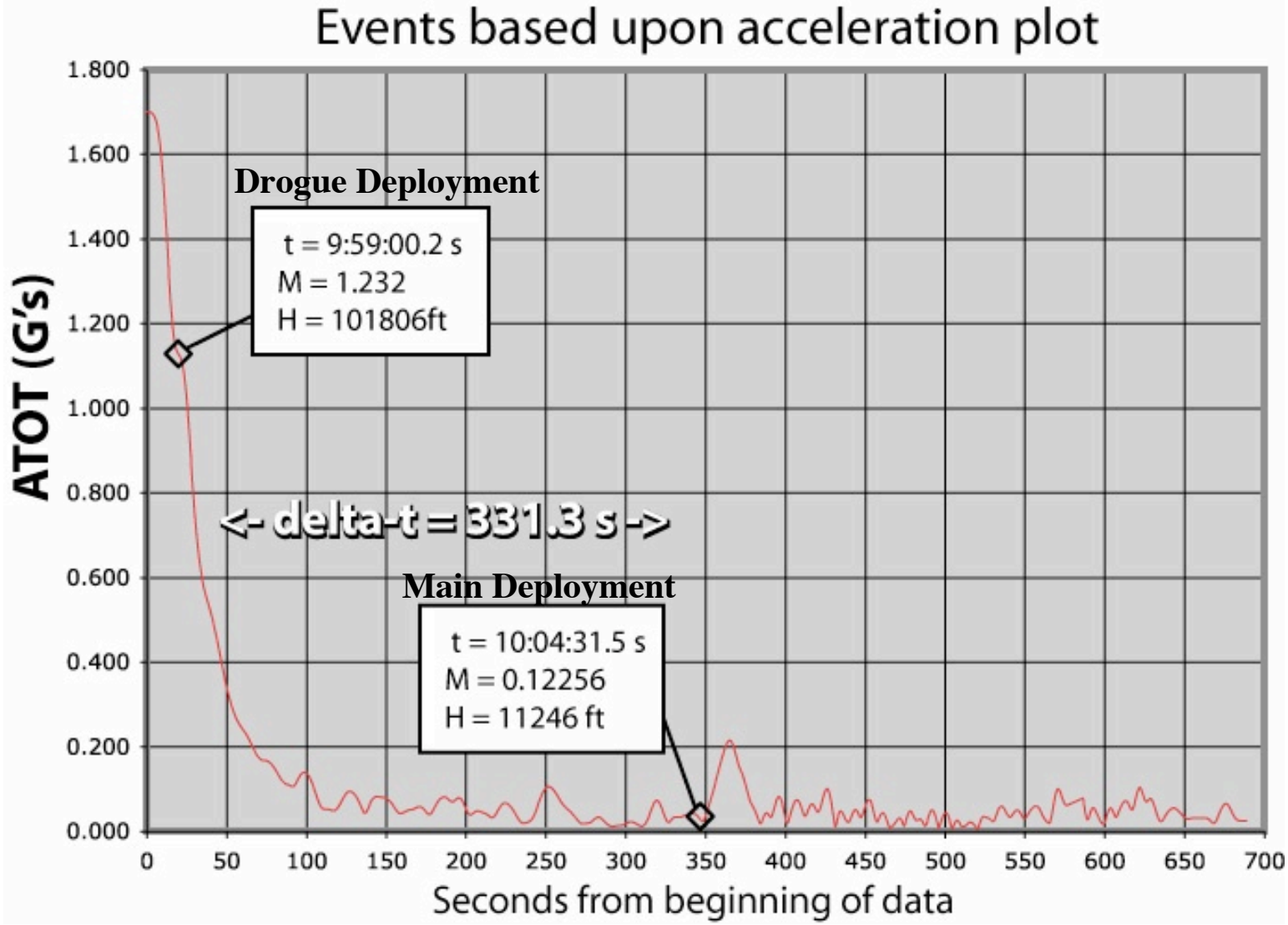


Eastward Wind Component Comparison to GRAM-95 Model

- Eastward wind observed was a little larger than nominal from GRAM-95



Deceleration Profile from UTTR Tracking Data



- Time between drogue and main deployment < timer setting of 350.6 s

Assessment underway to determine if main deployed on backup baroswitch.

Trajectory Reconstruction

- Since there was no onboard sensor data, a “traditional” trajectory reconstruction cannot be performed
  - Therefore, a Best Estimated Trajectory (BET) is calculated
- For hypersonic flight, only two data sources were available
  - Final Navigation entry state at atmospheric interface
  - Latitude and longitude data from UTTR radar tracking stations at time of drogue deployment (pre-entry prediction of 133 s from entry)
    - Tracking data indicates drogue deployment time at 137.9 s from entry
    - Actual deployment time 4.9 s later than predicted (within pre-entry Monte Carlo dispersion prediction of ± 7.4 s)
- With, confidence in these two endpoints a hypersonic trajectory can be calculated using the pre-entry simulation

Trajectory Reconstruction (cont'd)

- Within the trajectory simulation, a multiplier on capsule drag was applied as the control parameter to determine the variation needed to patch the two endpoint conditions
  - An drag increase of 0.83% is calculated
    - Therefore, pre-entry prediction was very close to actual flight
  - Altitude is within 3 m between BET and tracking data
  - Mach number is within 0.02 between BET and tracking data
- The 0.83% increase in drag can arise form multiple sources
  - Mis-prediction in entry state, capsule C_D, or atmospheric density
  - Final entry state was confirmed to be extremely accurate by STRATCOM
  - No measure of density available above 35 km
  - So, relative contributions between density and C_D cannot be determined

Stardust Best Estimated Trajectory

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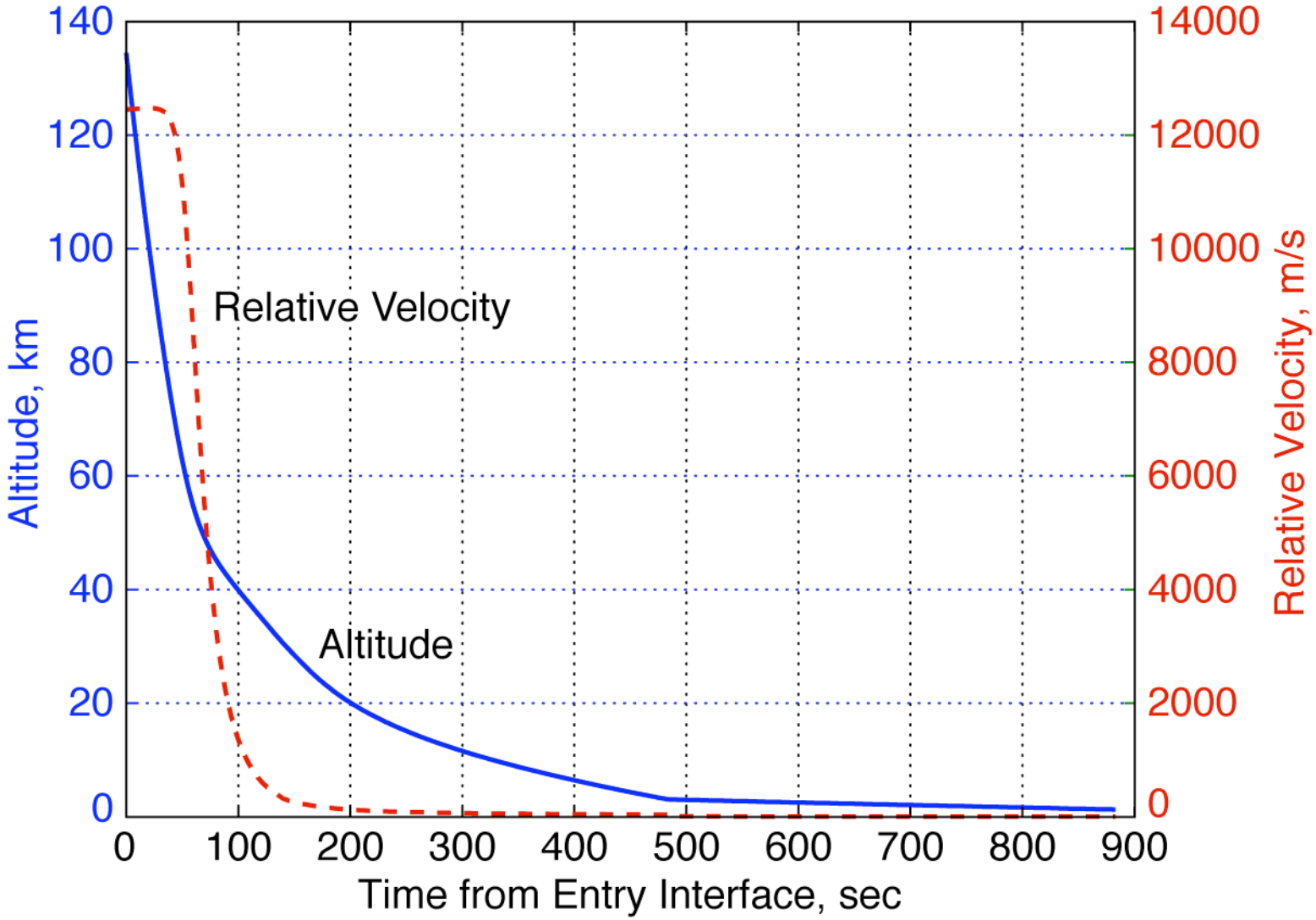

Stardust Trajectory from Radar Tracking Data

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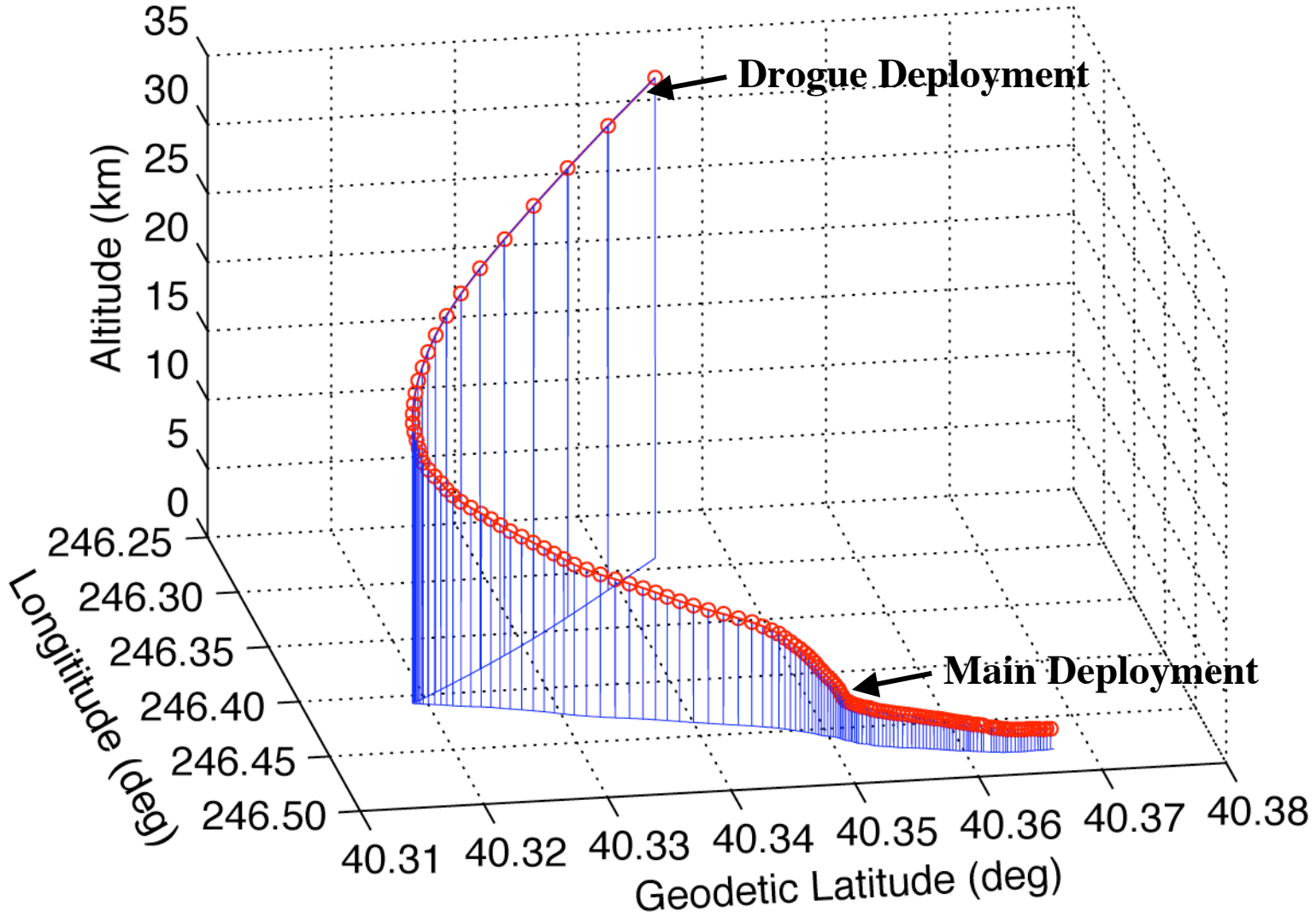

Hypersonic Capsule Attitude Assessment

- Since there was no onboard sensor data, capsule hypersonic attitude cannot be determined
  - Attitude must be inferred from observation of recovered heatshield
- There is very little, if any, charring of the shoulder region or aftbody of TPS
  - Inspection of forebody shows charring patterns that imply symmetry heating
  - Observations suggest that attitude must have been only a few degrees
  - Pre-entry simulation predicted angle-of-attack of 2.6° with a maximum of 5.4°
- Overall observations support the assertion that the aerodynamics database reasonably predicted hypersonic static stability

Stardust Capsule Heatshield Inspection

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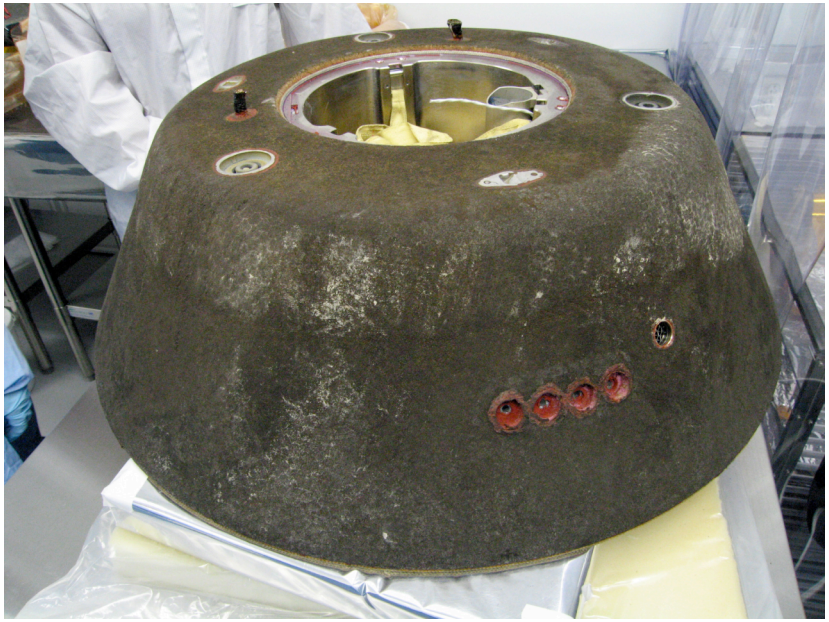
Very little aftbody charring



Symmetrical forebody charring

- Heatshield inspection suggests hypersonic attitude must have been small

Successful Entry!!!

Entry trajectory prediction was used to vector airplane for real-time aerothermodynamic environment observations during entry

Summary

- An overview of the reconstruction analyses is described
- Reconstructed trajectory was close to pre-entry prediction
  - Drag was within 1%
  - Drogue deployment time was 4.9 s later than predicted (within Monte Carlo pre-entry predicted dispersion of ± 7.4 s)
- Observations of the recovered heatshield indicated small attitude during hypersonic flight
- Overall assertion is that the Stardust entry flight performance was close to the pre-entry predictions
- Consequently, the design principles and methodologies utilized for the flight dynamics, aerodynamics, and aerothermodynamics analyses were corroborated