Project Orion Abort Flight Test

Orion Pad Abort 1 Flight Test: Simulation Predictions versus Flight Data

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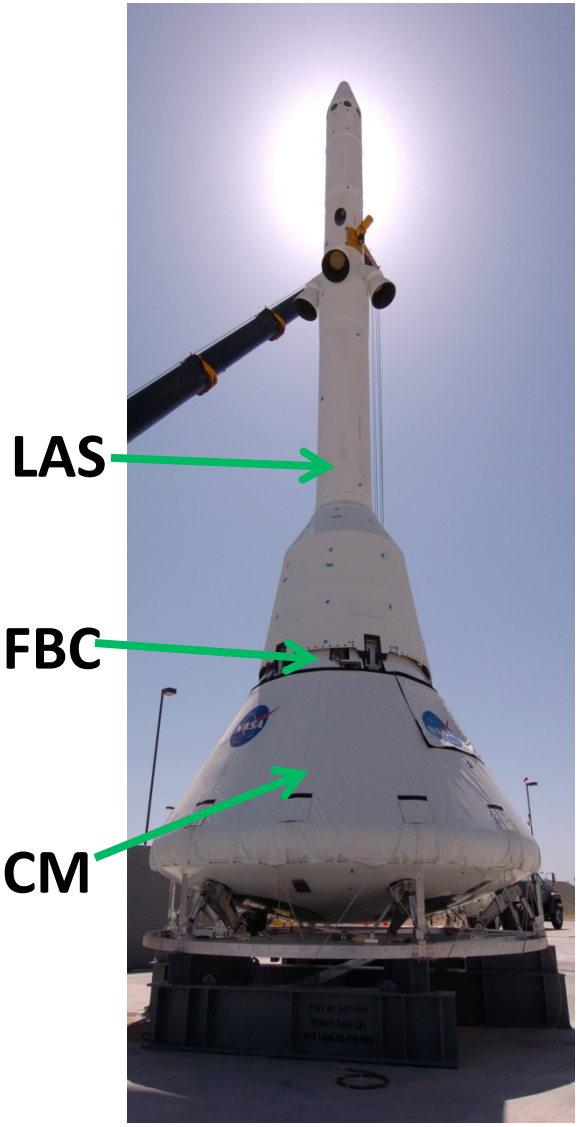
Introduction

- Simulation Overview
- Pre-Flight Predictions
- Pad Abort 1 Flight Test Video
- Pad Abort 1 Flight Test Data
- Post-Flight Modeling
- Summary

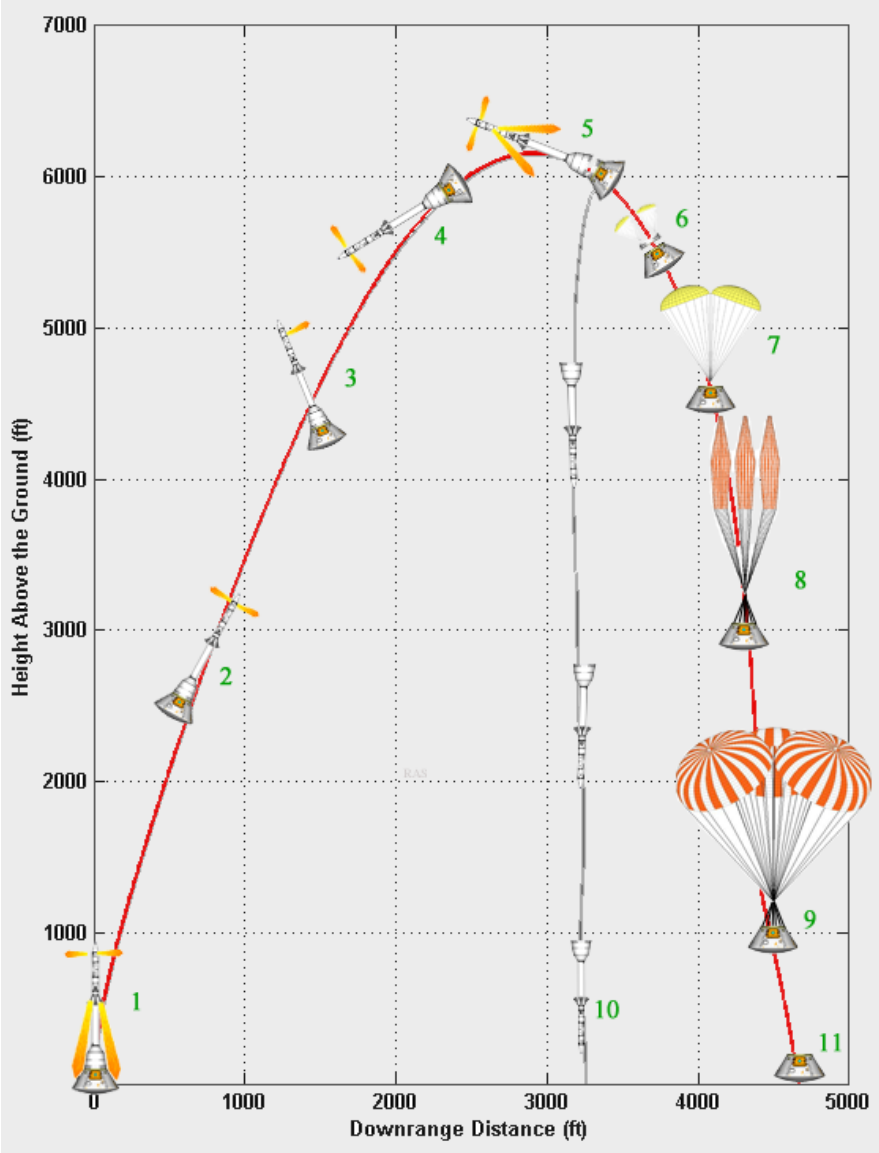
Simulation Overview

- Two simulations developed concurrently
  - Osiris: Developed by Lockheed Martin
  - ANTARES: Developed by NASA Johnson Space Center
- Models Crew Module (CM), Launch Abort System (LAS), and Forward Bay Cover (FBC)
- Simulation dispersions include:
  - Aerodynamic uncertainties
  - Mass properties
  - Atmospheric conditions including winds
  - Parachute variations



Timeline of Events

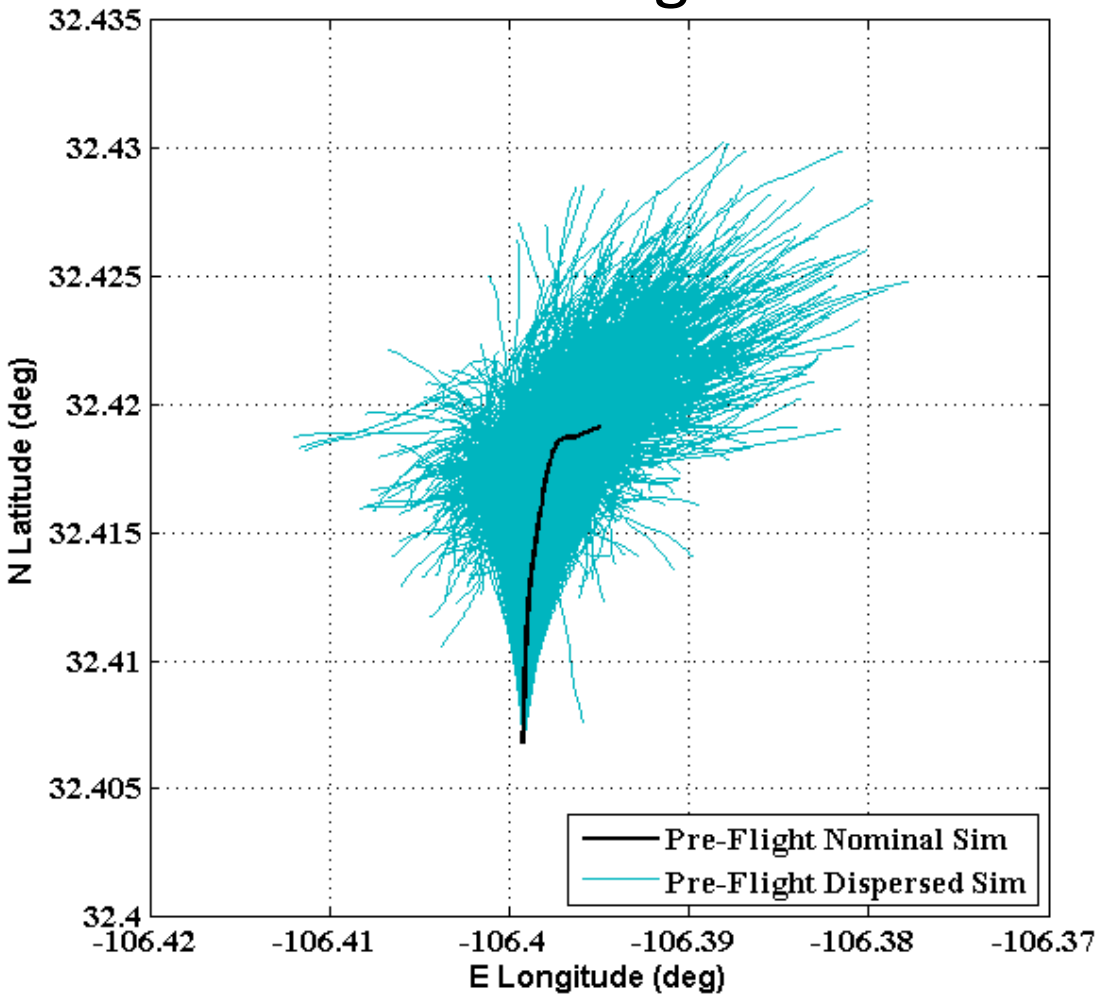
Event	Description	Predicted Time
1	Launch	0.0
2	Abort Motor Burnout	5.5
3	Reorientation Started	10.1
4	Reorientation Complete	16.7
5	LAS Jettison	21.0
6	FBC Jettison	22.2
7	Drogue Chute Deployment	24.6
8	Main Chute Deployment	30.6
9	Main Chute Full Inflation	49.6
10	LAS Touchdown	60.0
11	CM Touchdown	112.0



Pre-Flight Predictions

- Nominal trajectory is due North
- Mean WSMR winds in May are ENE
- 3σ dispersions show a wide variety of possible ground tracks

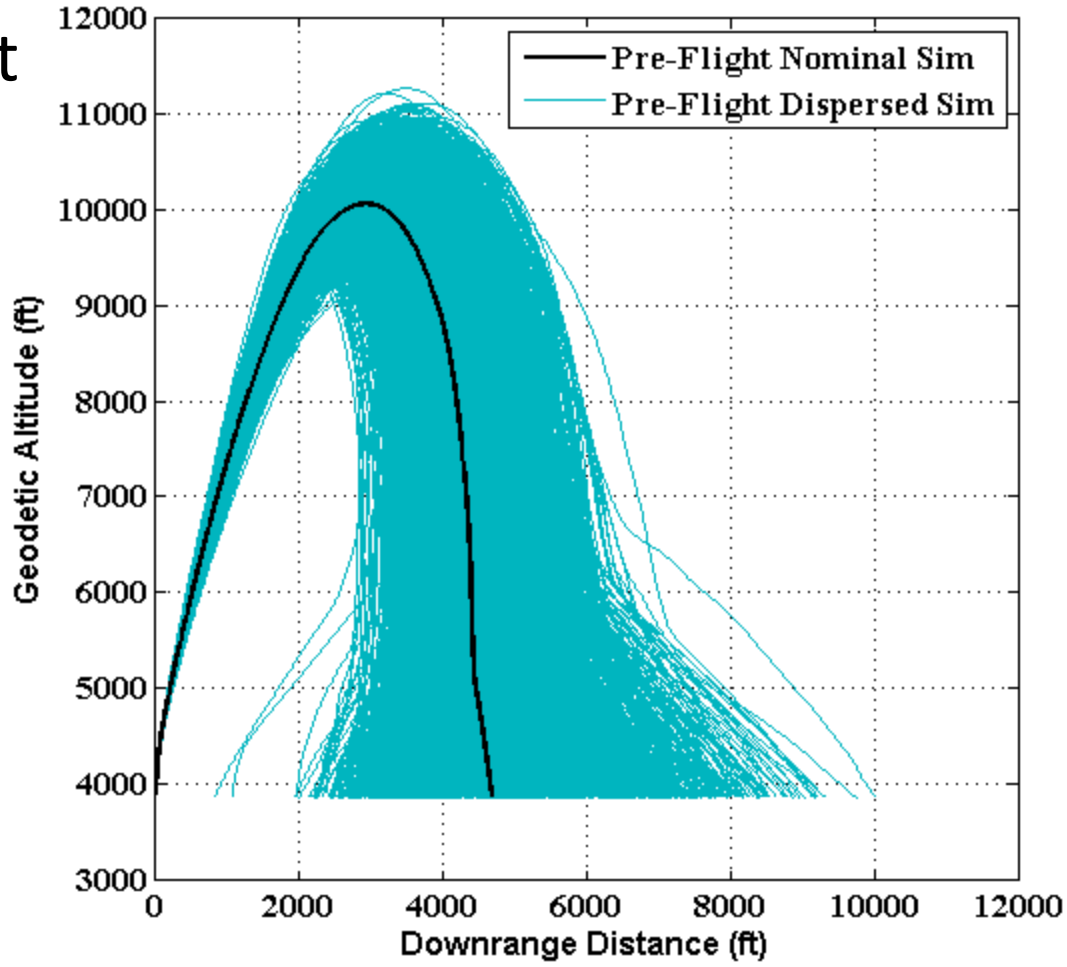
Latitude versus Longitude Track



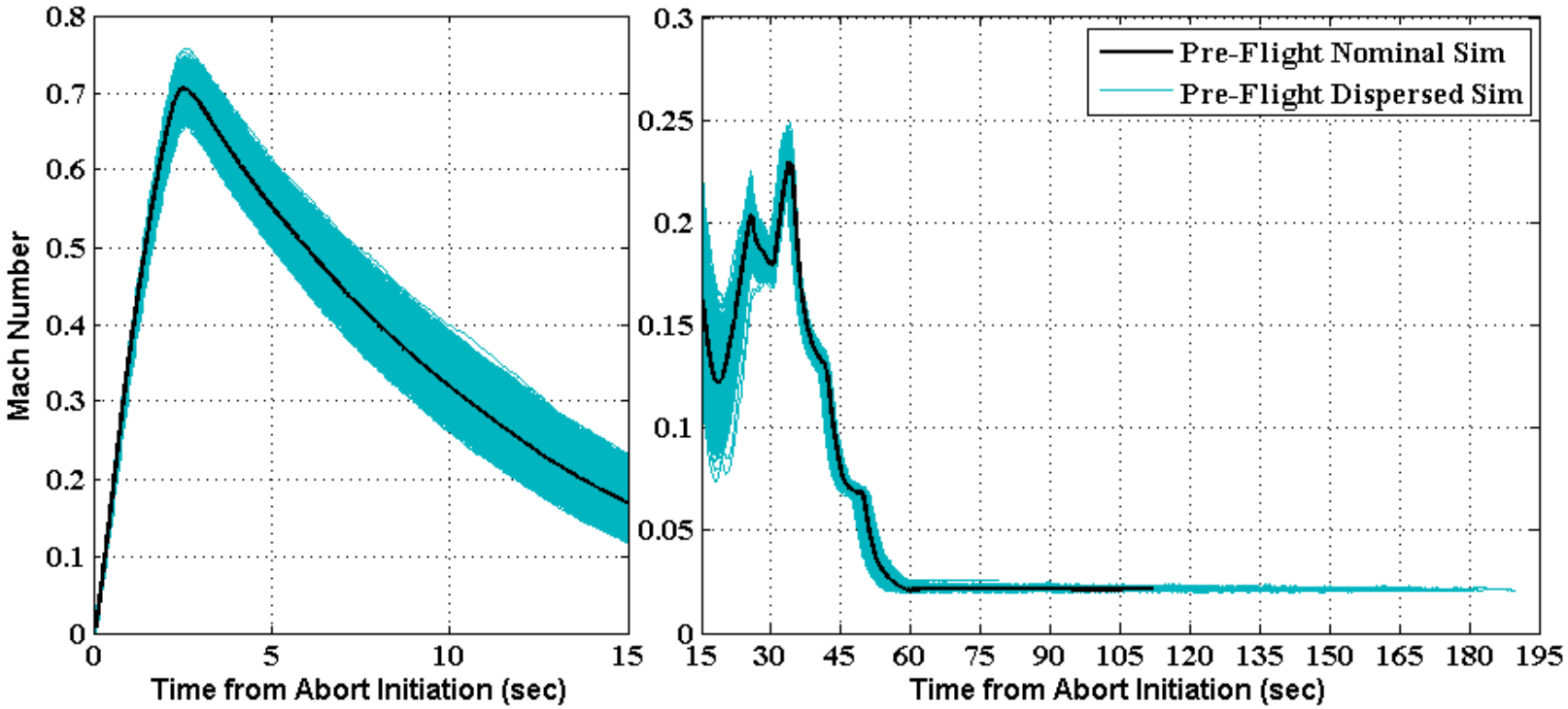
Pre-Flight Predictions

- Apogee
  - Nominal: 10,058 ft
  - Min: 9,173 ft
  - Max: 11,264 ft
- Touchdown
  - Nominal: 4,667 ft
  - Min: 827 ft
  - Max: 10,013 ft

Altitude versus Downrange

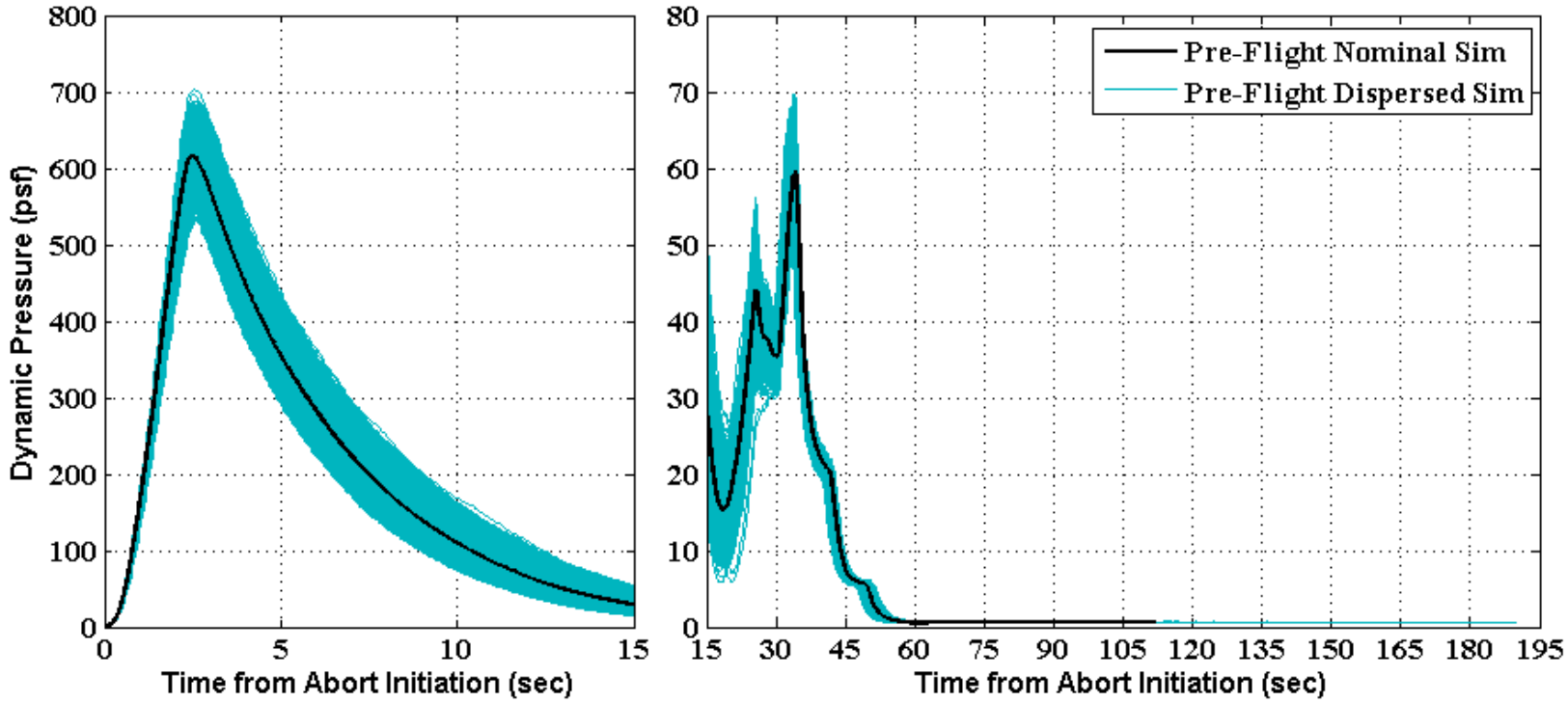


Pre-Flight Predictions



- Peak Mach Number
  - Nominal: 0.71
  - Minimum Dispersed: 0.66
  - Maximum Dispersed: 0.76

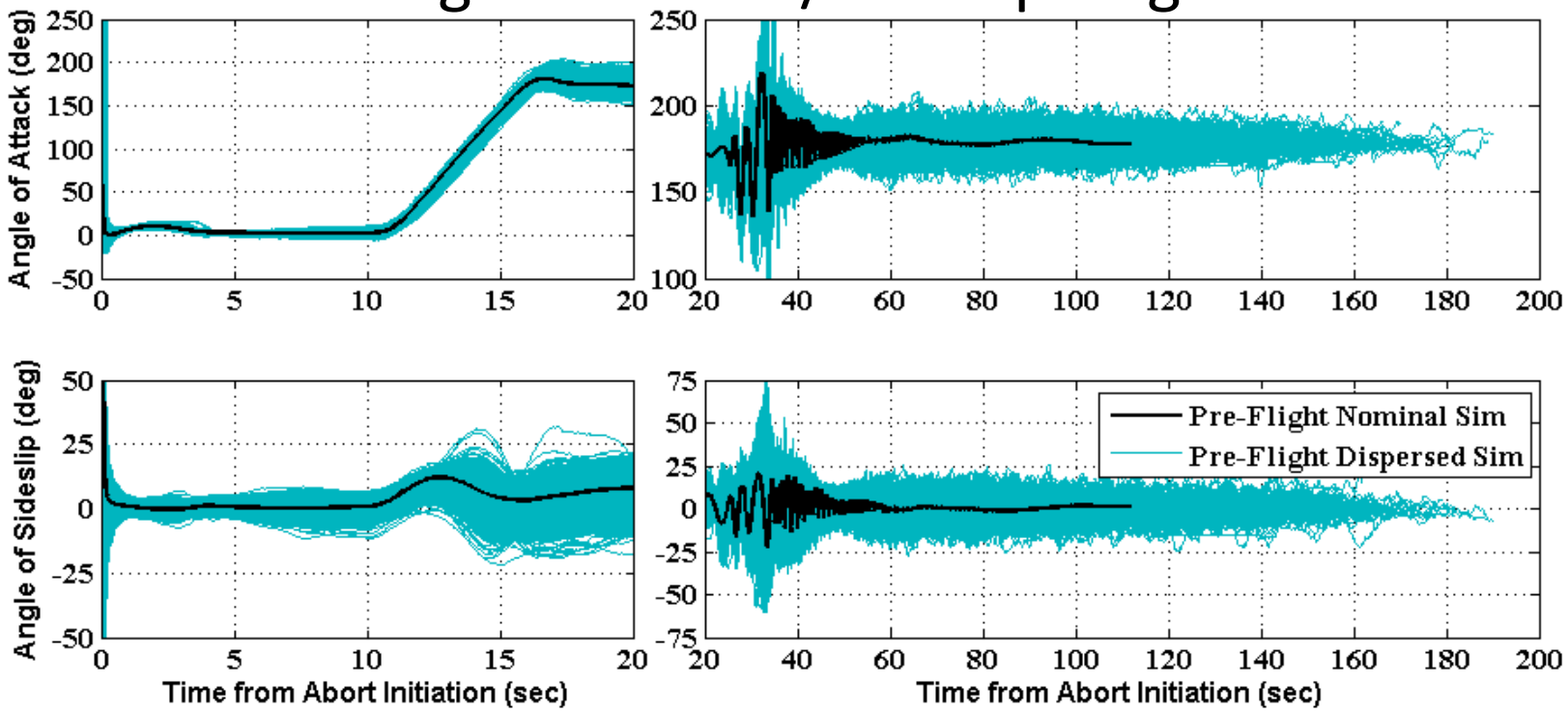
Pre-Flight Predictions



- Peak Dynamic Pressure
  - Nominal: 616 psf
  - Minimum Dispersed: 532 psf
  - Maximum Dispersed: 703 psf

Pre-Flight Predictions

Angle of Attack/Sideslip Angle



- All trajectories are predicted to be convergent
- Some oscillation predicted under parachutes

Flight Video

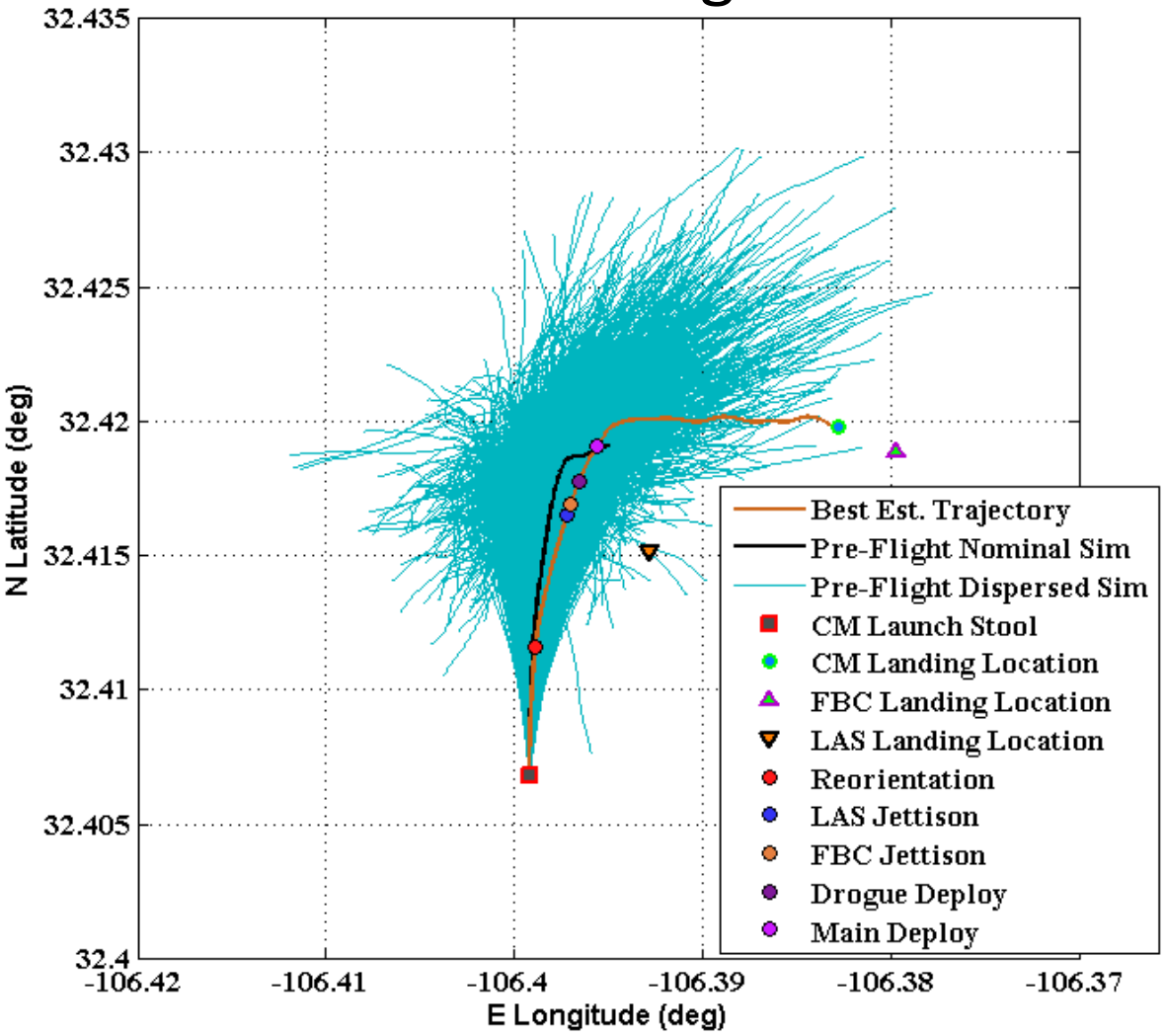
- Orion Pad Abort 1 Flight Video

Post-Flight Animation

Flight Data

Description	Actual Time
Launch	0.0
Abort Motor Burnout	2.7
Reorientation Started	10.2
Reorientation Complete	17.0
LAS Jettison	21.0
FBC Jettison	22.2
Drogue Chute Deployment	24.6
Main Chute Deployment	30.2
Main Chute Full Inflation	50.4
CM Touchdown	134.4

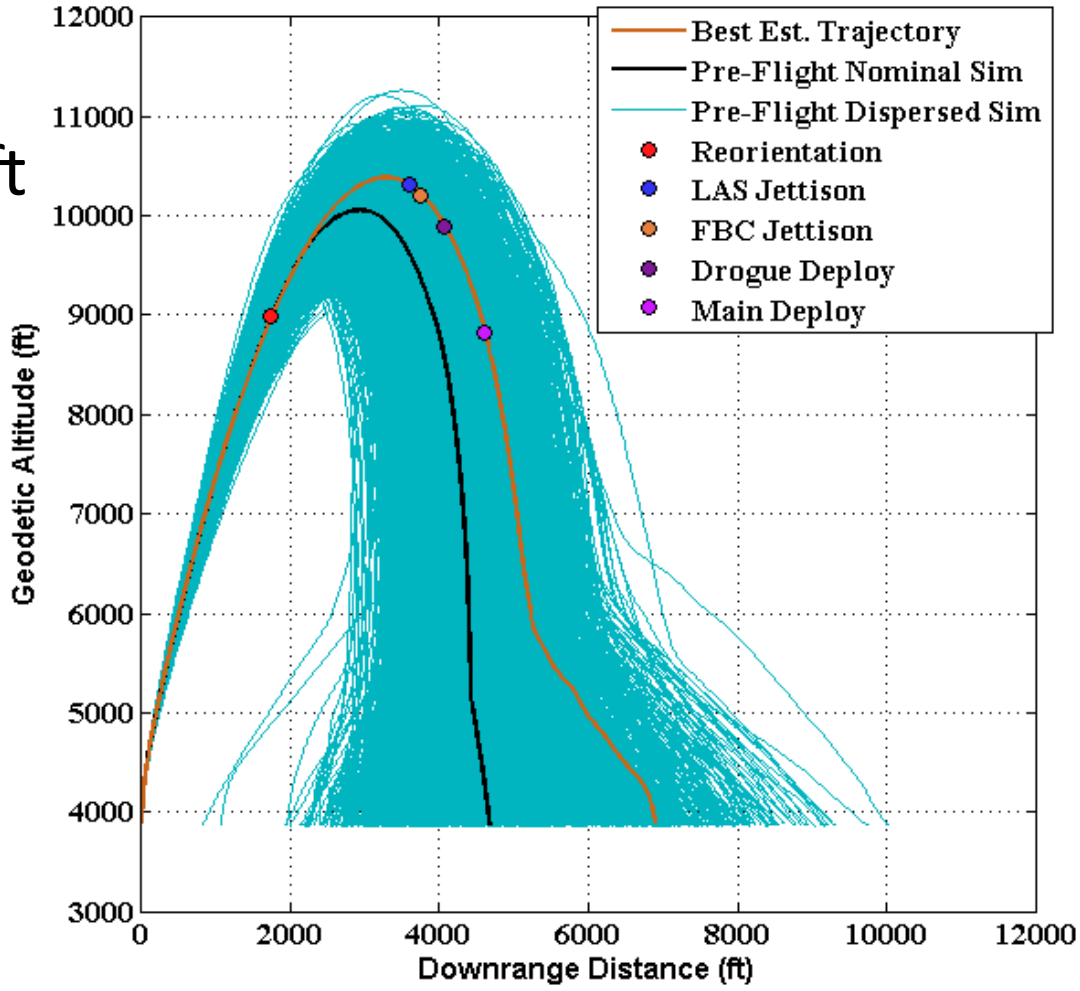
Latitude versus Longitude Track



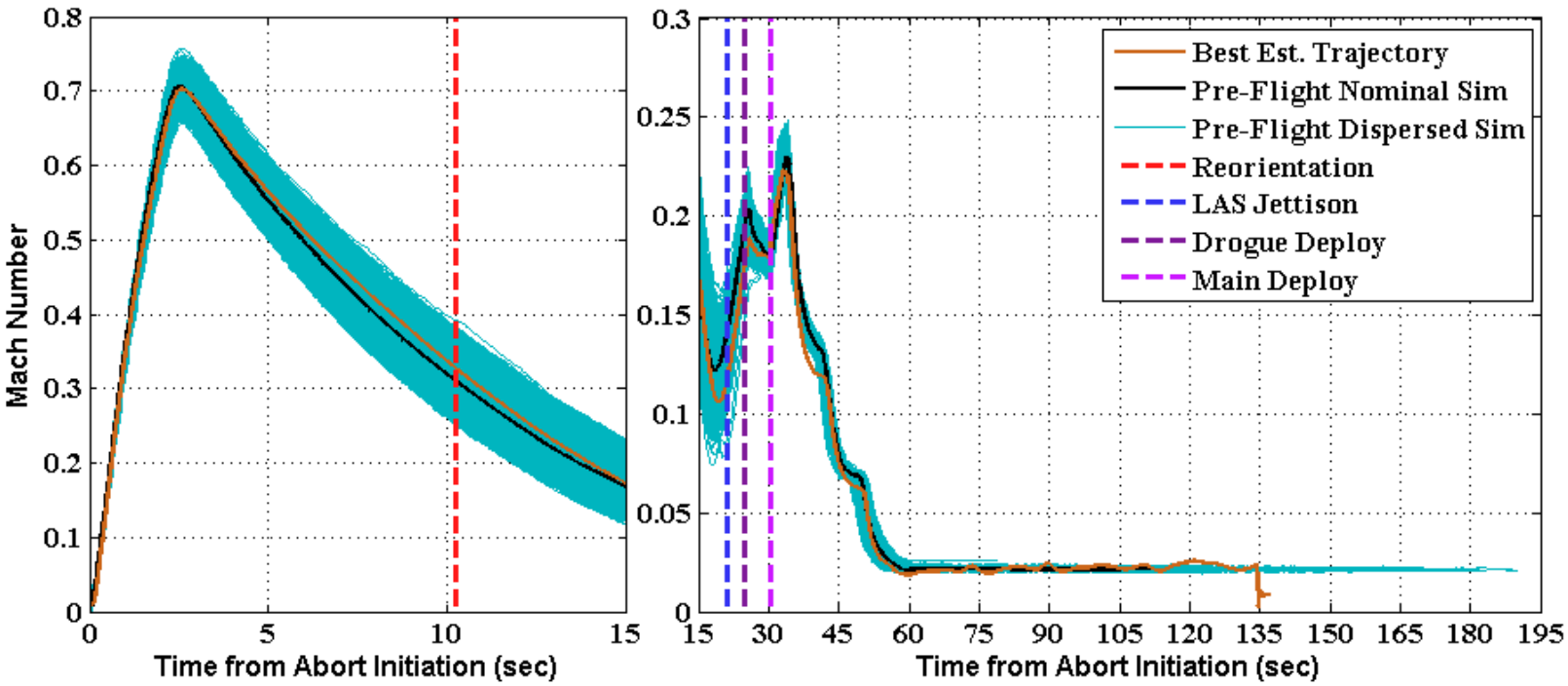
Flight Data

- Apogee
  - BET: 10,386 ft
  - Nominal: 10,059 ft
  - Min: 9,173 ft
  - Max: 11,265 ft
- Touchdown
  - BET: 6,912 ft
  - Nominal: 4,667 ft
  - Min: 827 ft
  - Max: 10,013 ft

Altitude versus Downrange

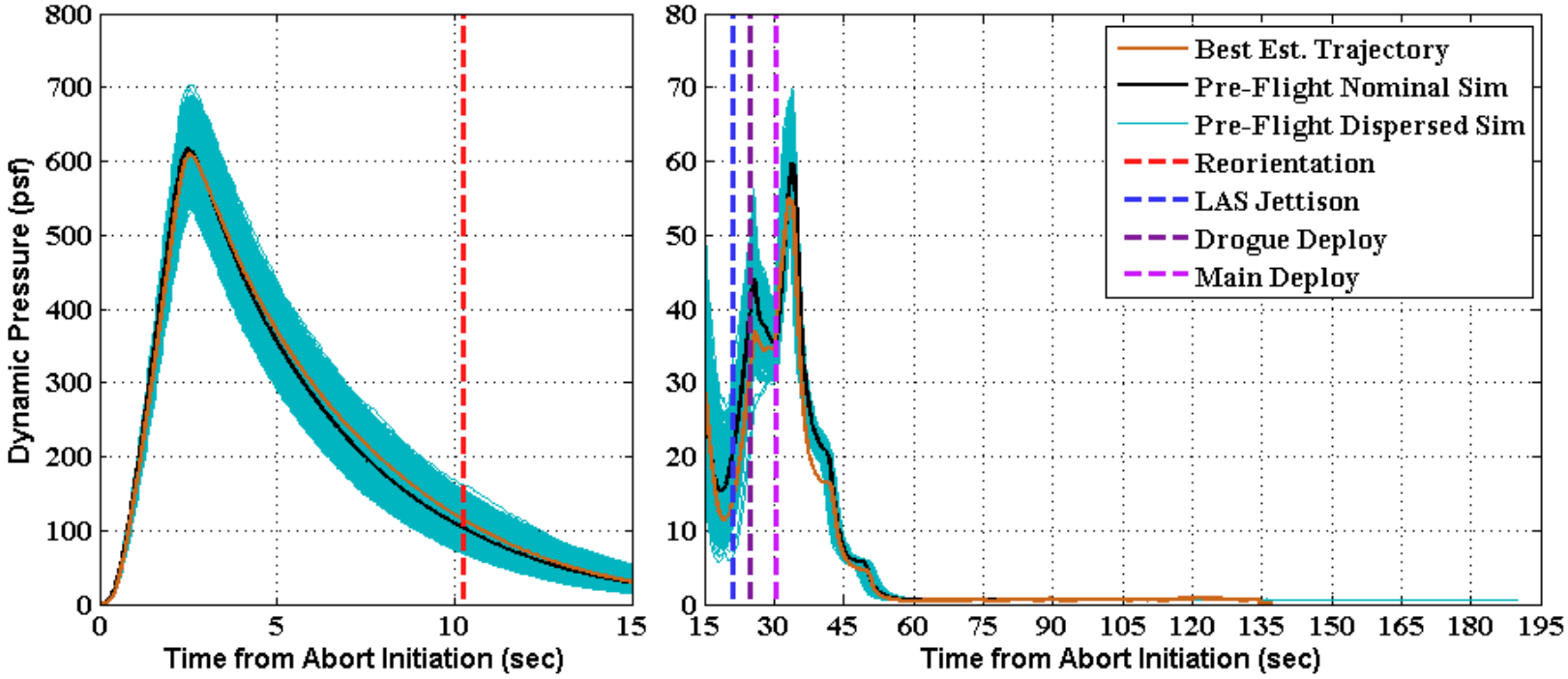


Flight Data



- Peak Mach Number
  - Best Estimated Trajectory: 0.70
  - Pre-Flight Estimated Nominal: 0.71
  - Pre-Flight Estimated Minimum: 0.66
  - Pre-Flight Estimated Maximum: 0.76

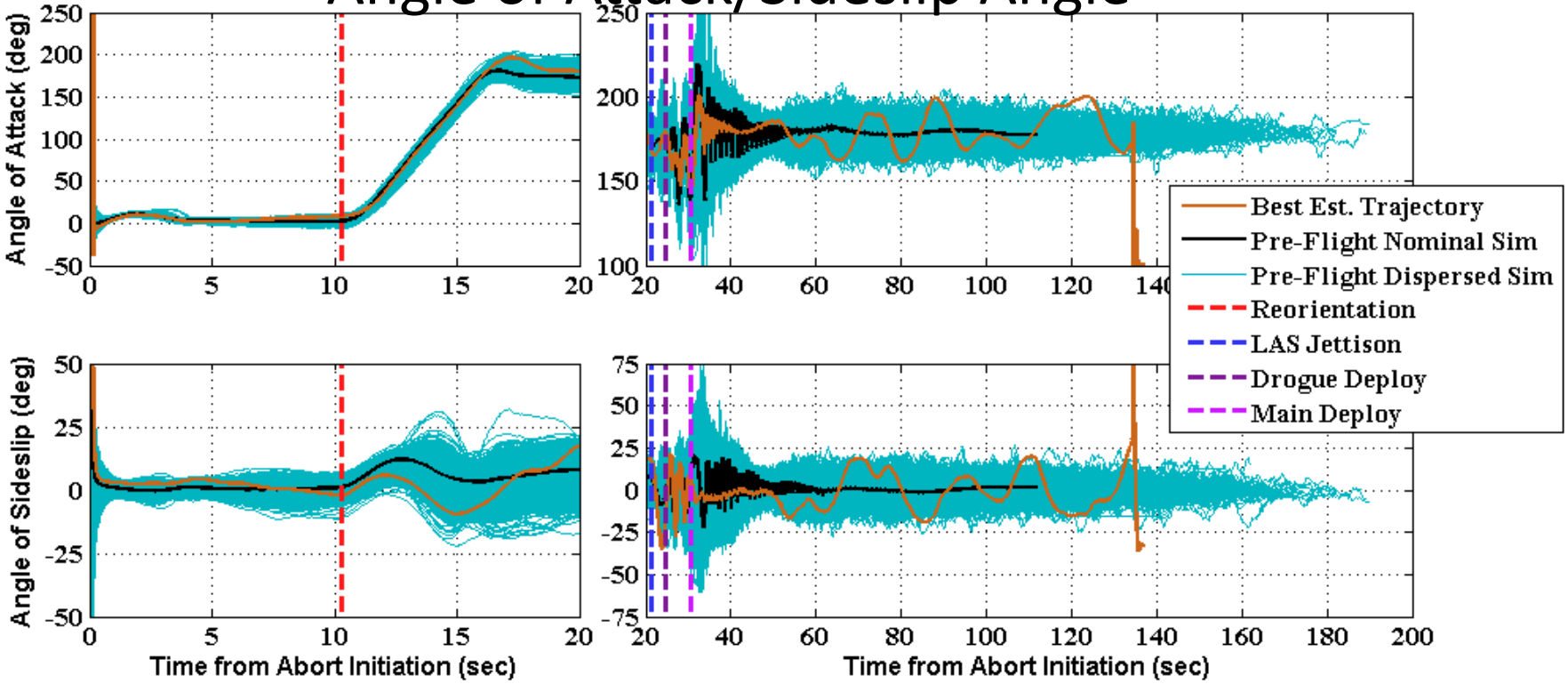
Flight Data



- Peak Dynamic Pressure
  - Best Estimated Trajectory: 609 psf
  - Pre-Flight Estimated Nominal : 616 psf
  - Pre-Flight Estimated Minimum: 532 psf
  - Pre-Flight Estimated Maximum: 703 psf

Flight Data

Angle of Attack/Sideslip Angle



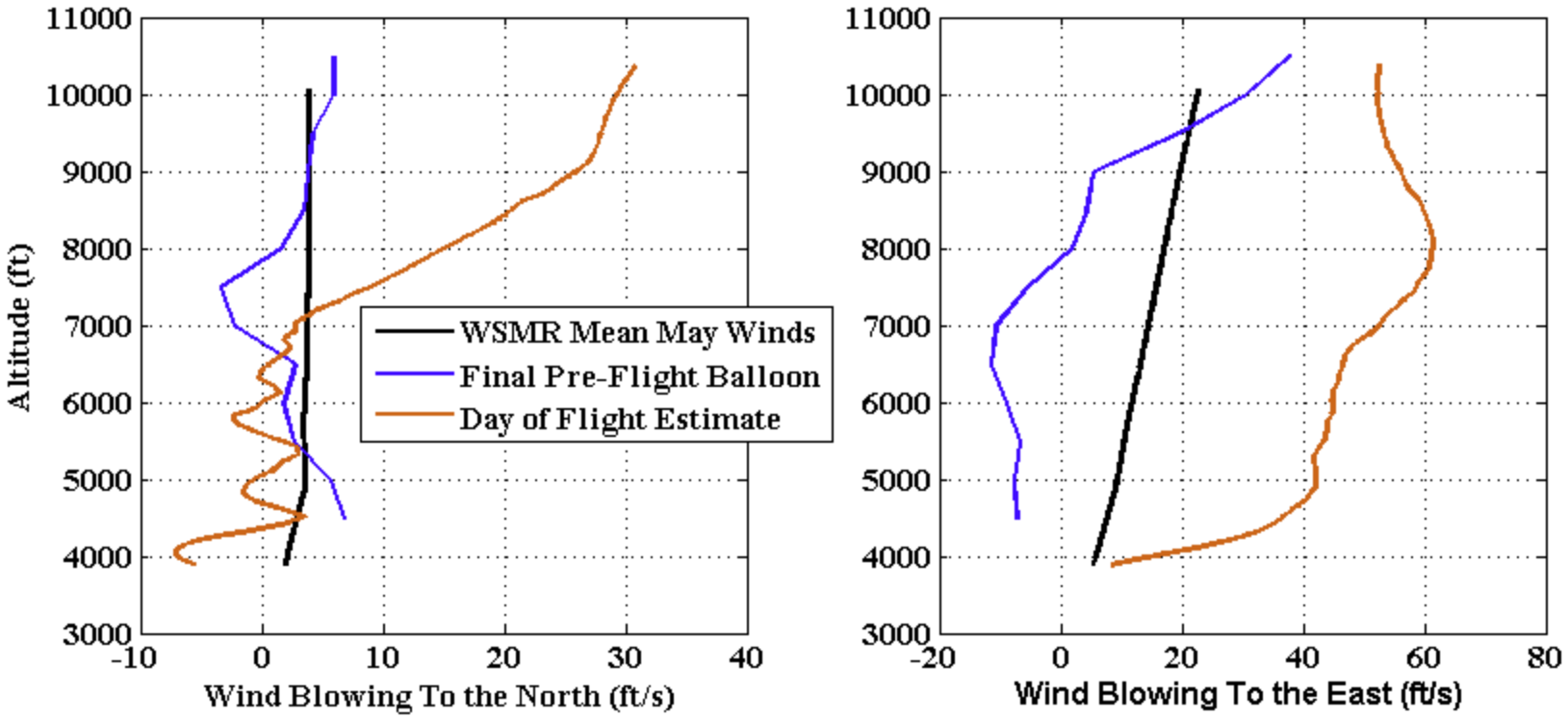
- Some oscillation under the parachutes (as predicted)
- Best Estimated Trajectory showed less oscillation
- LAS and FBC jettison events imparted uneven forces on the CM

Post-Flight Modeling

- Matching nominal simulation to flight data requires simulation model updates
- Most updates to the nominal simulation also effected the dispersed simulations
- Incorporated simulation updates
  - Day of flight atmosphere and winds
  - Abort motor thrust profile
  - Forward bay cover parachute deployment timing
  - Abort motor temperature at ignition
  - Jettison motor temperature at ignition
  - Attitude control motor back-pressure correction
  - CM aerodynamic uncertainties
  - Mass properties estimation
- Unincorporated simulation updates
  - Aerodynamic reconstruction

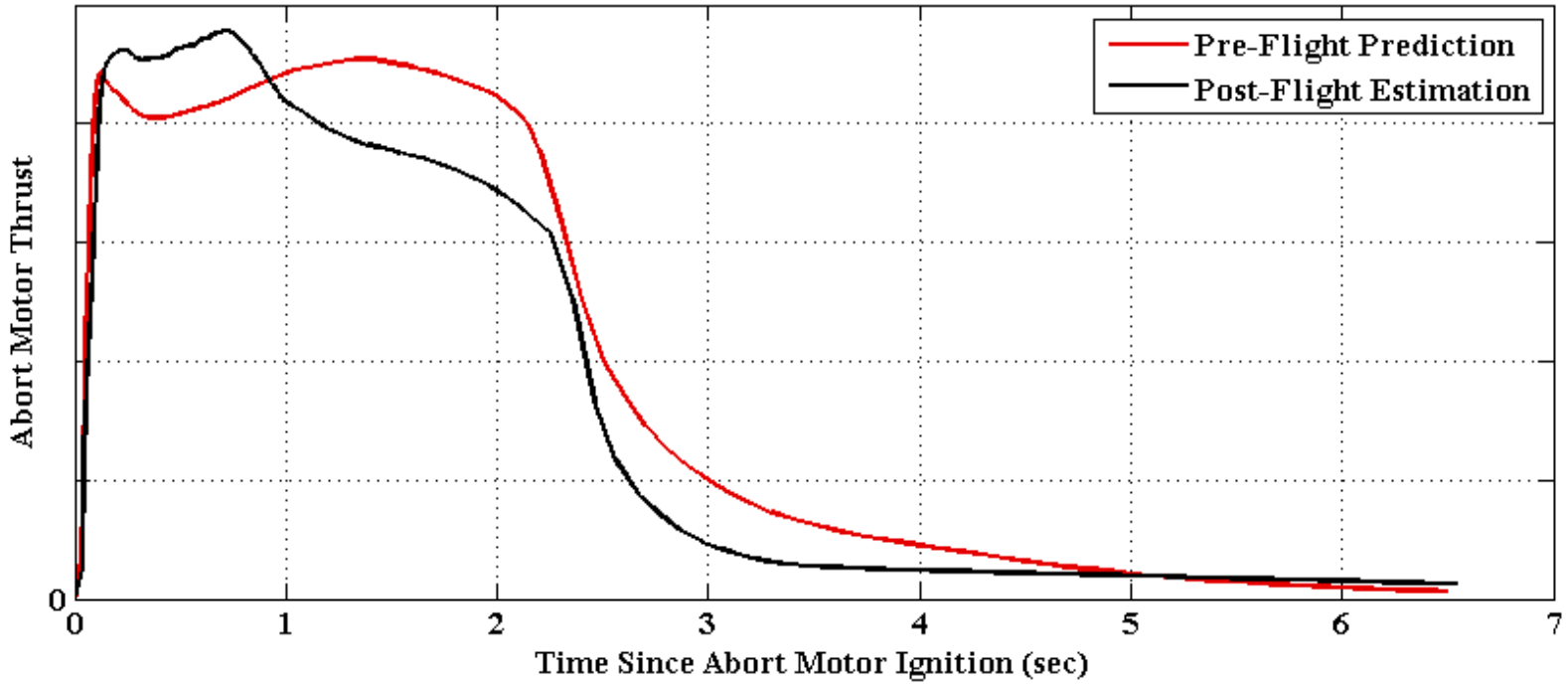
Post-Flight Modeling

- Day of flight atmosphere and winds
  - Actual winds were higher than predicted
  - Estimated winds were applied to nominal simulation



Post-Flight Modeling

- Abort Motor Thrust Profile
  - Abort motor thrust instrumentation did not function correctly
  - Abort motor thrust profile estimated from flight performance, aerodynamic data, and static motor test fires
  - Updates applied to nominal and dispersed simulations

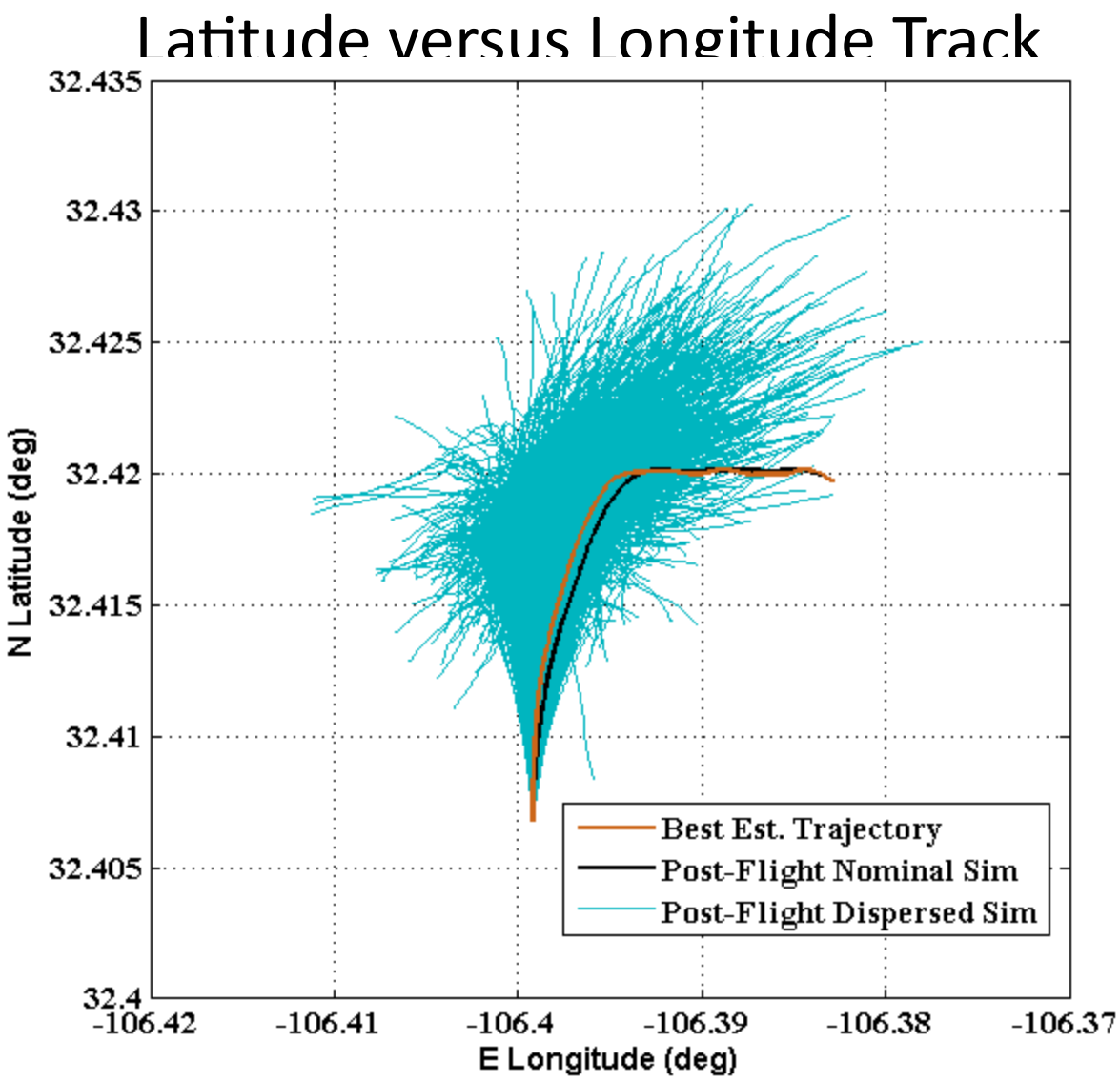


Post-Flight Modeling

- Forward Bay Cover Parachute Deployment
  - FBC parachutes did not immediately inflate
  - Video playback provided an estimated 1.3 sec delay in inflation
  - Update applied to nominal and dispersed simulation

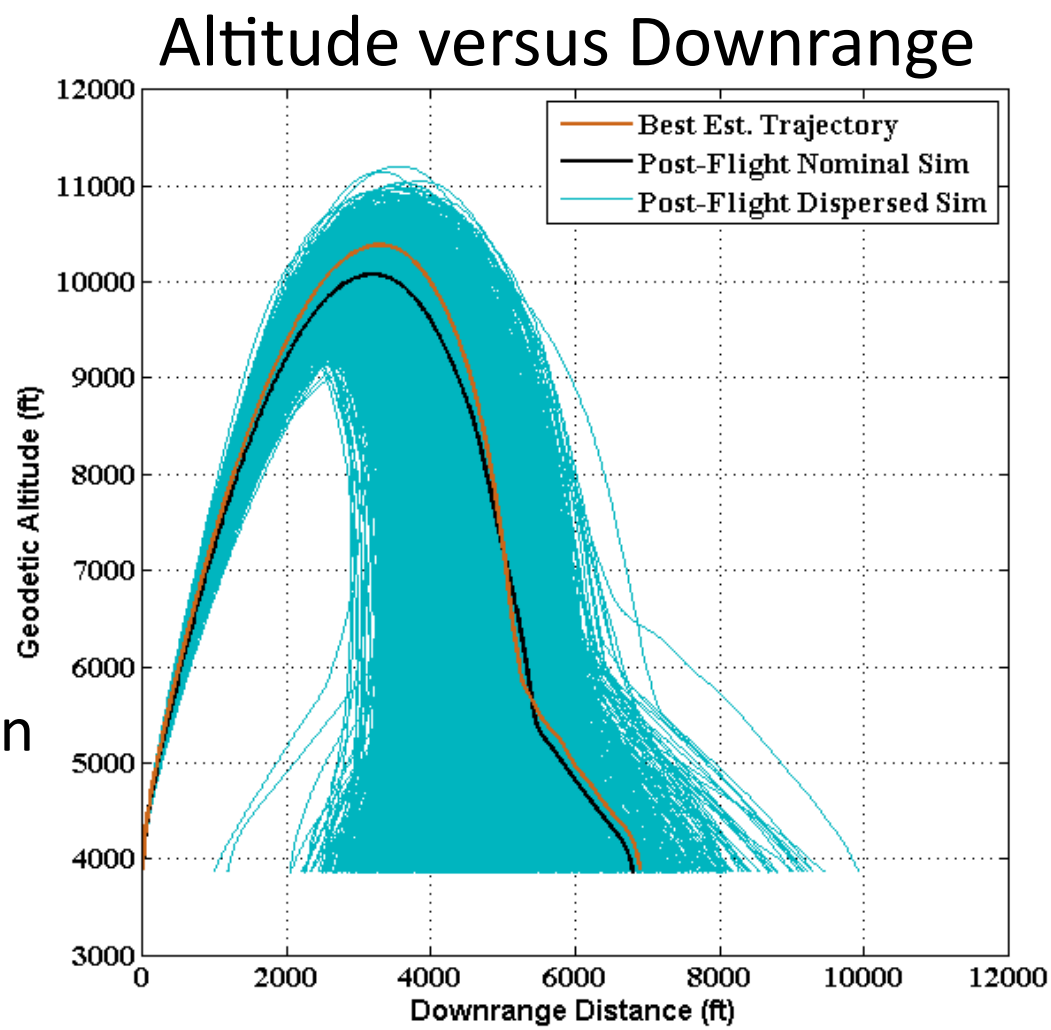
Post-Flight Simulations

- Nominal trajectory approximates Best Estimated Trajectory
- 3σ dispersions show a similar variety of possible ground tracks
- Mean difference between Nominal Sim and BET improved:
  - Latitude: 90%
  - Longitude: 74%

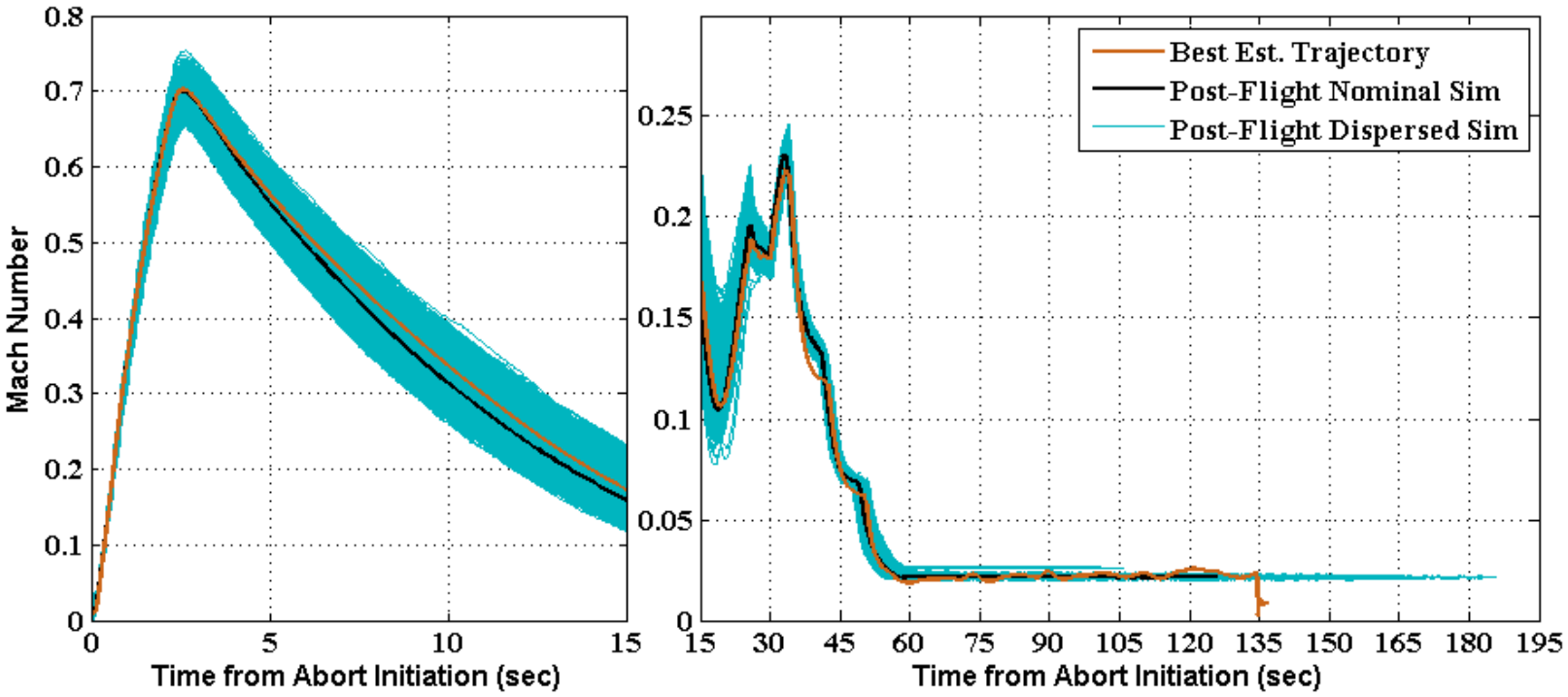


Post-Flight Simulations

- Apogee
  - BET: 10,386 ft
  - Nominal: 10,079 ft
  - Min: 9,123 ft
  - Max: 11,208 ft
- Touchdown
  - BET: 6,912 ft
  - Nominal: 6,795 ft
  - Min: 985 ft
  - Max: 9,927 ft
- Mean difference between Nominal Sim and BET improved:
  - Apogee: 26%
  - Touchdown: 78%

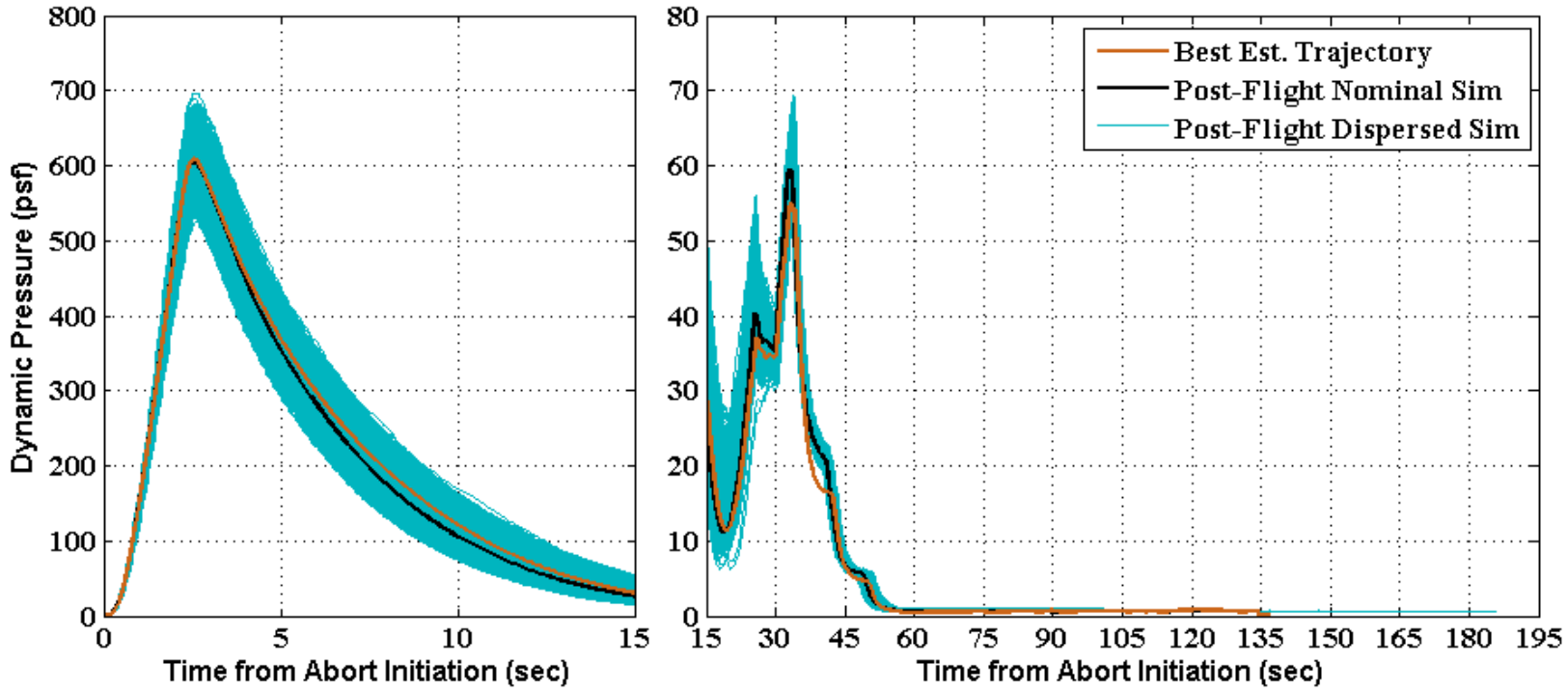


Post-Flight Simulations



- Peak Mach Number
  - Best Estimated Trajectory:0.70
  - Nominal: 0.70
  - Minimum Dispersed: 0.65
  - Maximum Dispersed: 0.75
  - Mean difference between Nominal Sim and BET improved: 21%

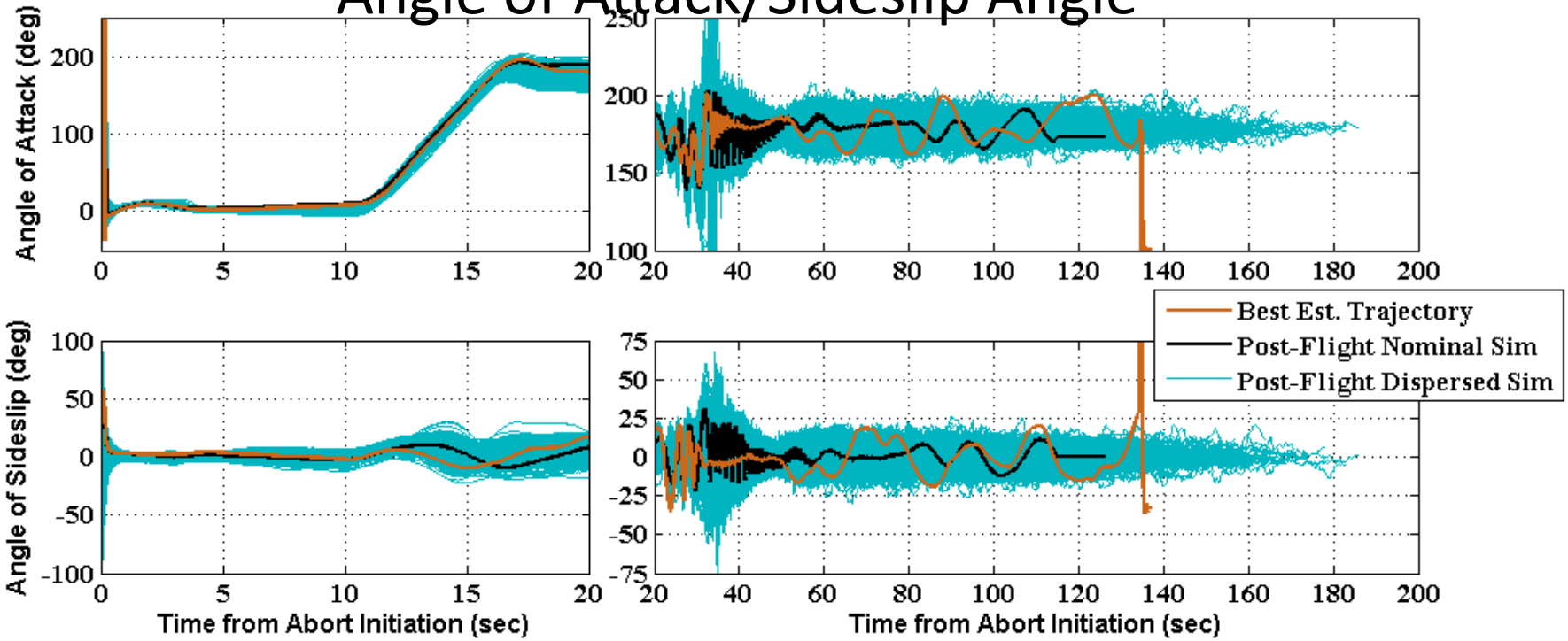
Post-Flight Simulations



- Peak Dynamic Pressure
  - Best Estimated Trajectory: 609 psf
  - Nominal: 603 psf
  - Minimum Dispersed: 526 psf
  - Maximum Dispersed: 697 psf
  - Mean difference between Nominal Sim and BET improved: 25%

Post-Flight Simulations

Angle of Attack/Sideslip Angle



- All trajectories are predicted to be convergent
- Simulation predicts more oscillation predicted under parachutes than Best Estimated Trajectory
- Mean difference between Nominal Sim and BET improved (before LAS jettison):
  - Alpha: 40%
  - Beta: 4%

Summary

- Pre-flight simulation estimates for PA-1 showed a wide variety of possible scenarios
- Data from a variety of sources was used to refine the simulation models
- The refined simulation provides a closer approximation to the PA-1 flight data
- Questions