Orion Abort Flight Test

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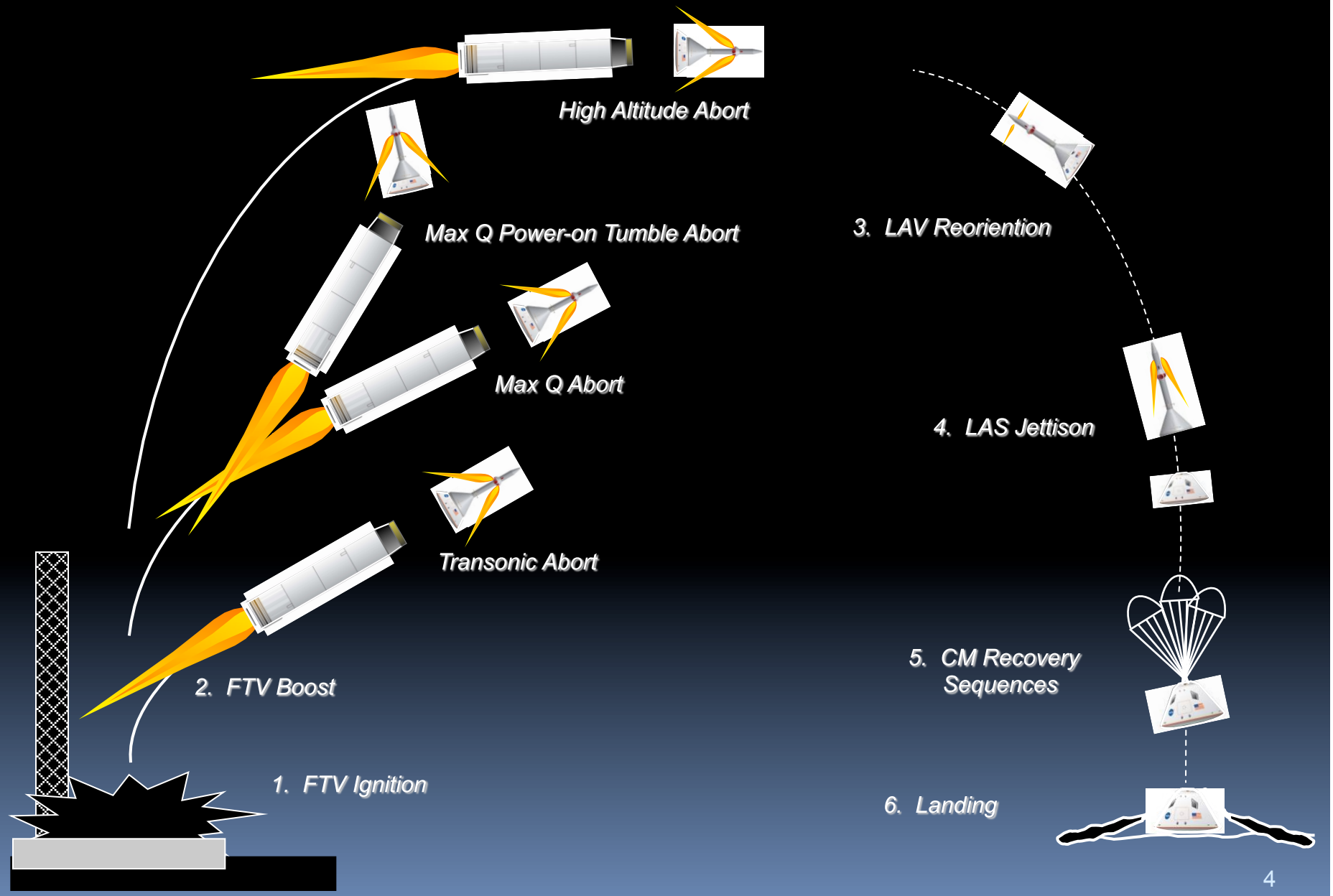
Recent Abort Flight Test Events

- Pad Abort 1 flight test occurred on 6 May 2010 from White Sands Missile Range in New Mexico

Abort Flight Test

- Orion's Launch Abort System (LAS) provides an emergency escape system for the crew
- Abort Flight Test Objectives:
  - Provide adequate testing to demonstrate proper performance and function of the LAS throughout the required flight envelope
  - Validate key abort models
    - LAS performance and functionality
    - Parachute system performance and functionality
    - Separation aerodynamics
    - Separation mechanism performance
  - Pathfinder for Orion system integration and ground operations procedures

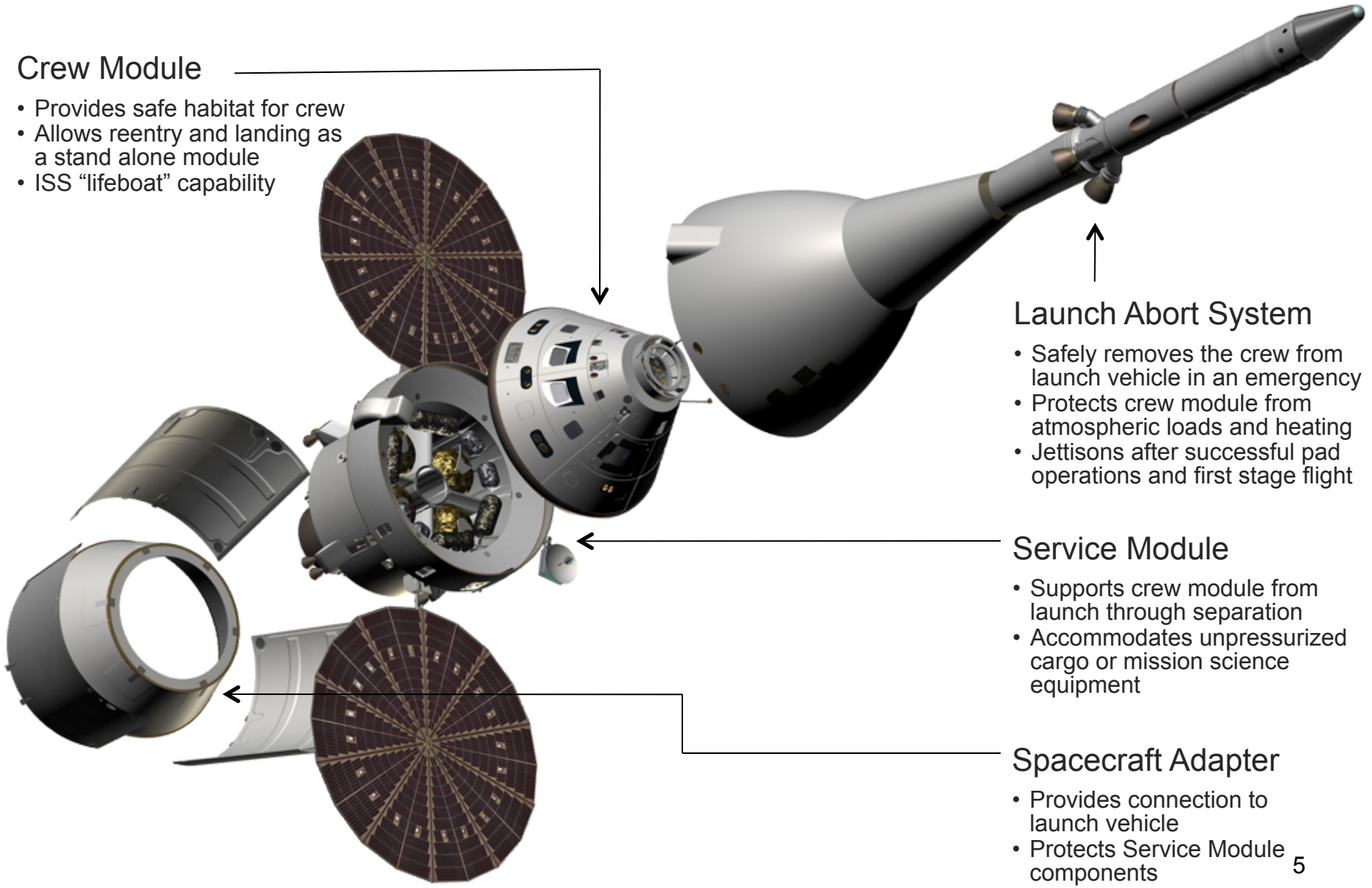
Notional Ascent Abort Scenarios



Orion Spacecraft Overview

Crew Module

- Provides safe habitat for crew
- Allows reentry and landing as a stand alone module
- ISS “lifeboat” capability



Launch Abort System

- Safely removes the crew from launch vehicle in an emergency
- Protects crew module from atmospheric loads and heating
- Jettisons after successful pad operations and first stage flight

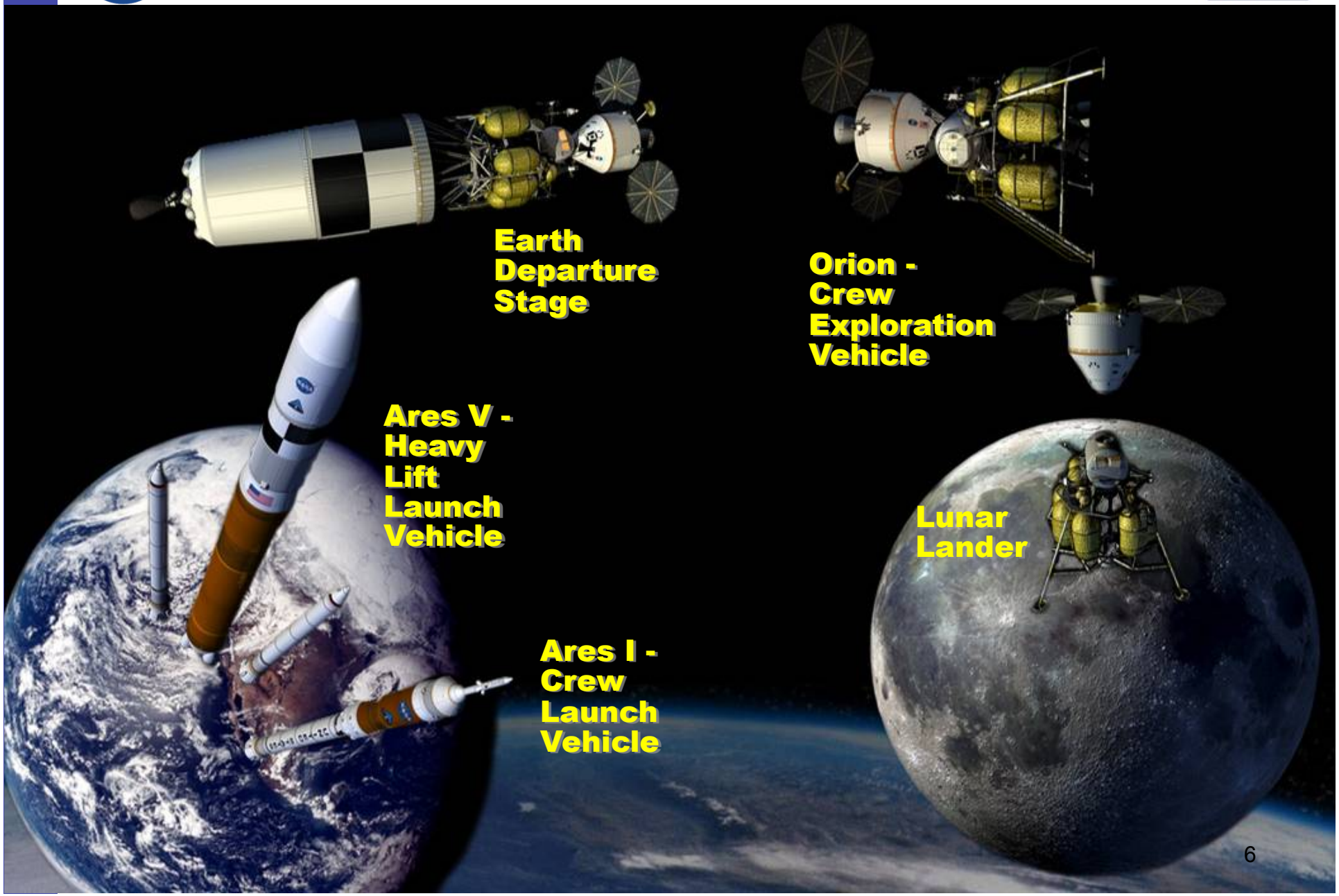
Service Module

- Supports crew module from launch through separation
- Accommodates unpressurized cargo or mission science equipment

Spacecraft Adapter

- Provides connection to launch vehicle
- Protects Service Module components

Components of Program Constellation



Launch Abort System (LAS) and Crew Module (CM)

Nose Cone

Attitude Control

Jettison

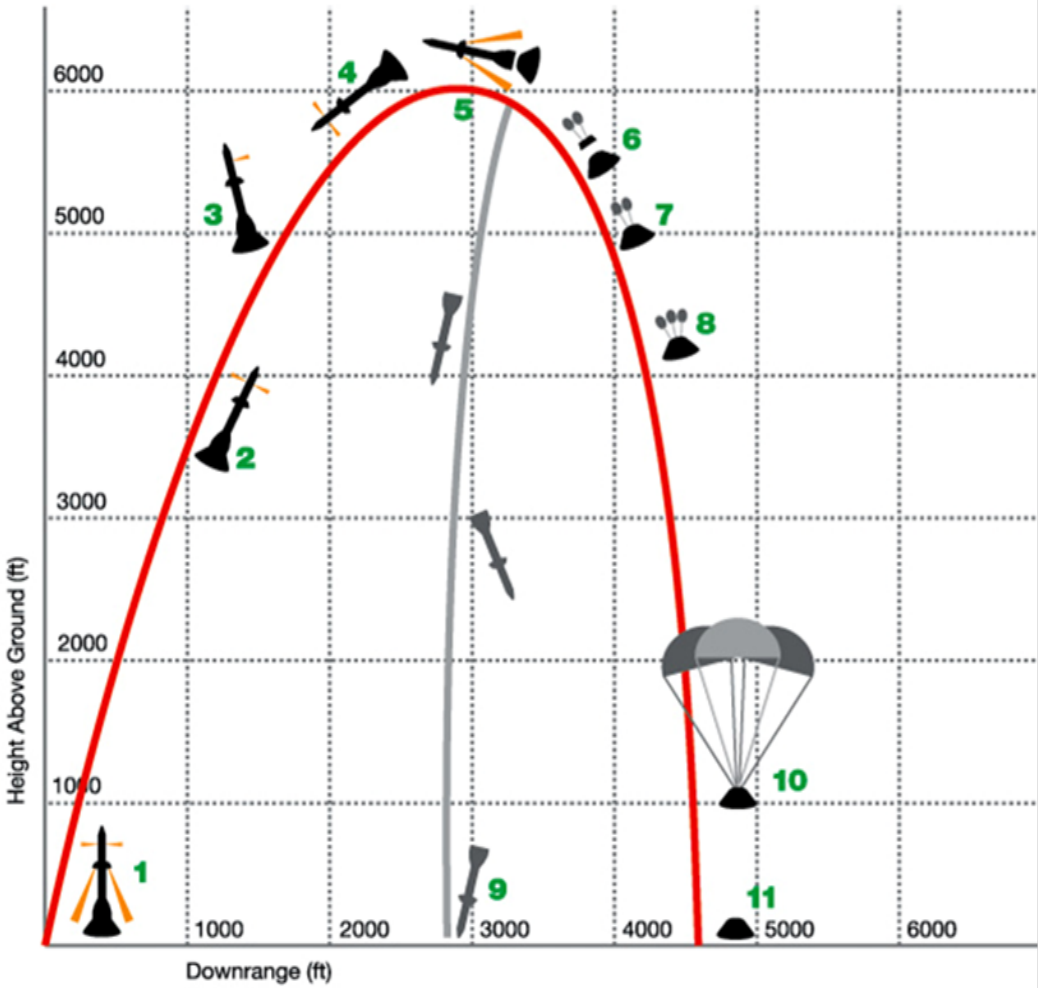
Abort

Abort Motor Test Firing

Jettison Motor Firing

Attitude Control Motor Firing

Pad Abort 1 (PA-1)Trajectory Cartoon



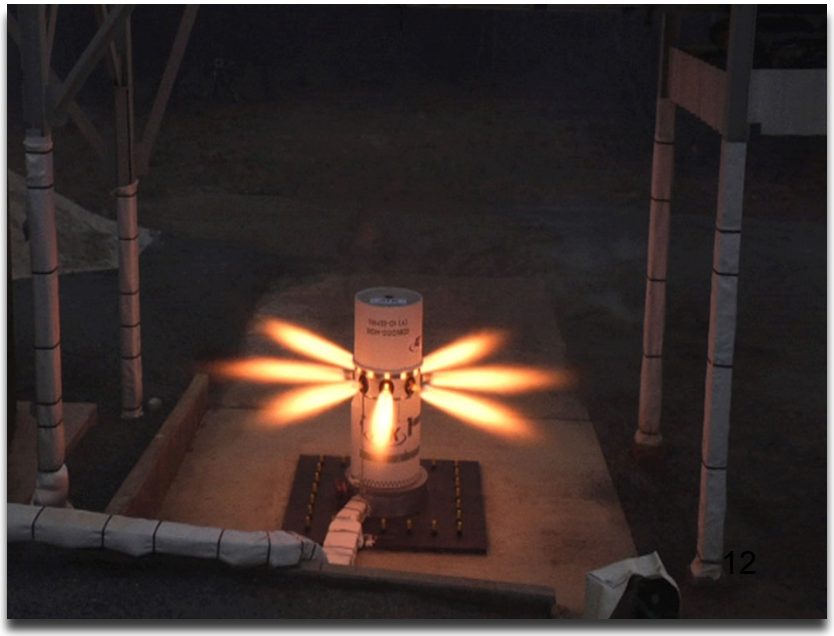
Event

1. AM/ACM ignition
2. AM burnout
3. Begin re-orientation
4. End re-orientation
5. LAS Jettison
6. FBC jettison
7. Drogue mortar fire
8. Pilot mortar fire
9. LAS touchdown
10. Reach 33 ft/sec descent rate
11. CM touchdown

PA-1 test at White Sands was designed to fly a due North trajectory,
At KSC, the pad abort trajectory 'dog-legs' towards the ocean

Launch Abort Vehicle (LAV) Controller Info

- For PA-1, LAV controller was developed by Orbital-Dulles
  - PID controller, had heritage from Pegasus
  - On-board gain scheduling based on mass properties changes
  - Roll-yaw coupling (p-beta) which used a yaw command to dampen roll rates
  - Timer-based guidance
    - 0-2 seconds; open-loop pitch-over to get downrange; commanded pitch & yaw
    - 2-10 seconds; downrange guidance; commanded alpha & beta
    - 10-21 seconds; reorientation guidance; commanded alpha & beta
    - All commands turned into attitude rate commands in FSW before they were passed to the ACM controller



Mobile Operations Facility (MOF) Overview

Telemetry, video, timing distribution, and processing equipment racks (7)

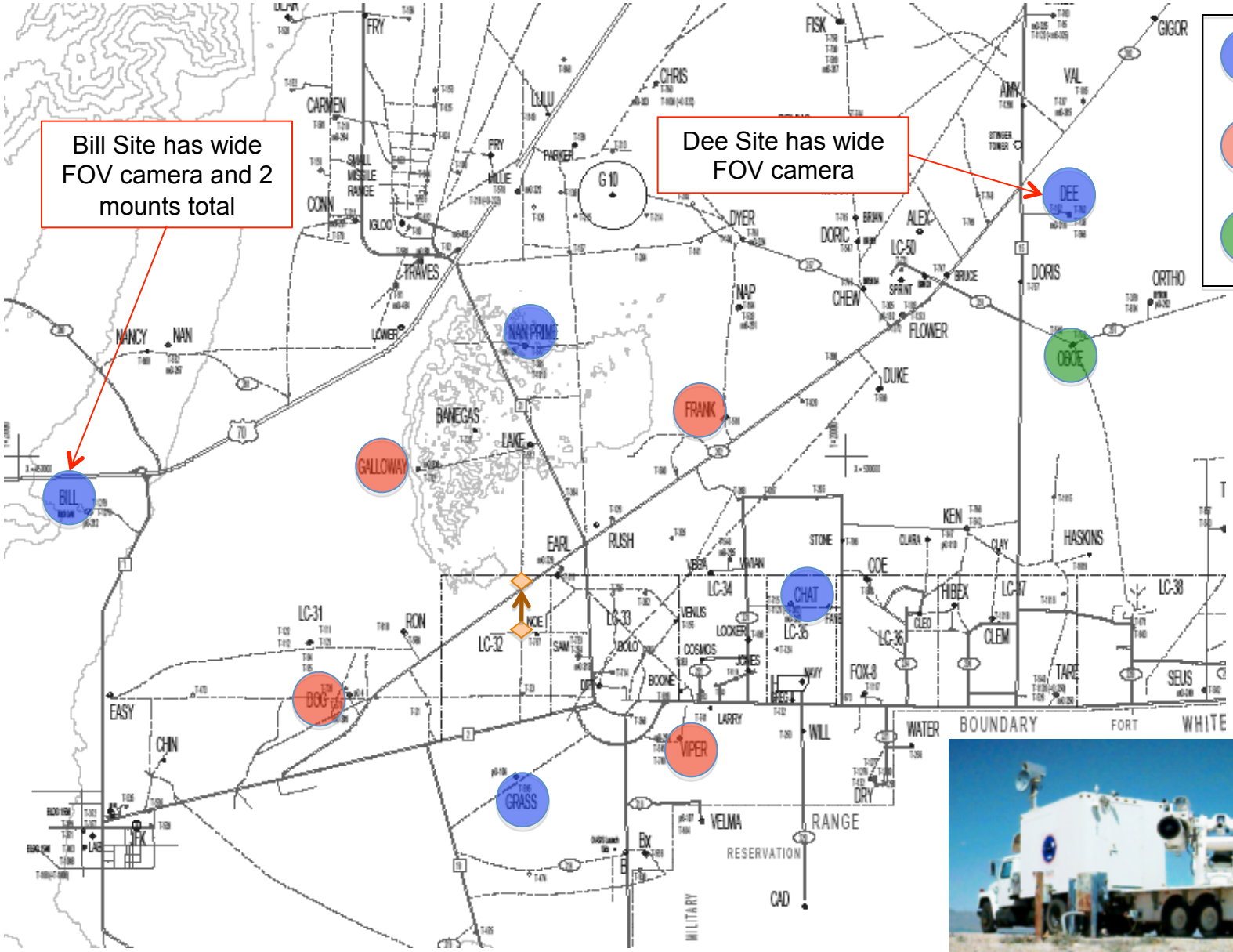
LM Command, Control, and Monitoring System racks - not shown (3.5)

Video Monitors (4)

Workstation displays (21)

Intercom panels (18)

WSMR Tracking Optics



Footage from various video sites

- PA-1 Compilation video

Personal Experiences / Lessons Learned

- Launch Fever, noun: An unwillingness to miss an important deadline despite known problems.
  - High speed film camera in crew module
  - SIGI-2 issues
  - ACM controller issues
  - Coyote
- Managing emotions associated with the launch
  - Went through various failure scenarios
    - Tip-over risk
    - High vibration associated with the initial pull-away
    - Risk of loss of controller authority with jet interaction
    - Risk of parachute failure
  - Stress near T-0
    - Coping techniques
- Estimating probability of mission success
  - 81 unique PA-1 related risks

Lessons Learned (continued)

- Project pace & travel (4 years)
- Number of different organizations involved – always complicated
  - Flight Test Office was the responsible flight test organization
  - On some level, you needed to be Al Haig-like
- Lessons Learned take awhile to process, then recognize & identify
  - Project collected Lessons Learned just after launch
  - Lessons Learned in wind placard story

Lessons Learned – wind placards story

- Surprised at how 'basic' things became issues that grew quickly out of control (the 'how-did-we-get-here?' phenomenon)*
  - Wind placards were an example of this
    - Early on, LM Mission Analysis group identified an issue with the winds modeling in GRAM-99 with the WSMR RRA (wasn't consistent with weather balloon data, RRA data from the 1980's)
    - FTO agreed to go with the WSMR RRA from GRAM-2007 put into GRAM-99, our concern was that the weather balloon data hadn't been blessed by the Air Force organization (AFCCC) that certifies RRAs
    - Using this RRA caused the LM Mission Analysis group to develop placards that were very restrictive, and it became a lot of work to get these placards expanded to reasonable operational levels
    - Control room operations were down to a minimal staff (due to MOF size), support personnel were available, but communication was sometimes spotty

* Still working to define all the lessons learned here

Lessons Learned (continued)

Azimuth Clockwise from 0° North (degrees) Meteorological Convention (Azimuth Defines Direction Wind is Blowing From)	Altitude Above WGS-84 Reference Ellipsoid (ft)														
	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000	10500	11000
1-10	10.0	10.7	13.0	13.4	15.0	16.7	17.3	17.5	19.8	21.2	22.6	23.4	23.0	23.0	23.0
11-20	10.1	11.0	12.8	13.9	15.2	15.8	16.8	19.0	20.5	22.1	24.4	24.9	25.5	25.5	25.5
21-30	10.7	11.7	13.6	13.7	14.4	15.5	16.7	17.3	19.1	20.4	21.1	22.0	22.7	22.7	22.7
31-40	10.3	12.5	13.9	14.5	15.1	15.7	17.1	17.6	19.0	18.5	18.5	19.7	17.6	17.6	17.6
41-50	11.4	12.4	13.5	13.9	15.4	16.8	16.6	17.8	17.4	17.0	17.6	18.6	18.4	18.4	18.4
51-60	11.1	13.0	13.3	14.3	14.6	16.2	16.4	15.4	16.1	16.6	17.1	17.2	17.2	17.2	17.2
61-70	11.7	12.1	12.8	13.2	14.5	15.1	15.2	14.9	15.3	14.7	14.5	15.3	16.4	16.4	16.4
71-80	11.4	11.7	12.8	12.9	12.8	14.6	14.8	14.0	14.2	14.7	15.7	15.7	17.0	17.0	17.0
81-90	10.7	11.3	12.5	12.4	13.0	13.6	14.2	13.6	13.6	14.8	16.5	17.0	17.9	17.9	17.9
91-100	10.1	11.9	11.3	11.2	12.3	13.0	12.6	13.0	13.9	14.4	13.9	14.8	15.7	15.7	15.7
101-110	11.0	10.4	11.9	12.0	13.3	12.7	13.1	13.5	14.4	12.6	14.8	12.9	12.8	12.8	12.8
111-120	8.8	10.2	10.2	11.0	11.5	12.1	13.3	12.0	11.1	12.1	11.4	11.5	12.2	12.2	12.2
121-130	8.4	9.8	10.7	9.6	9.8	10.3	10.0	13.0	11.9	10.4	11.0	14.1	11.8	11.8	11.8
131-140	8.3	8.3	8.4	9.6	10.3	12.6	8.9	9.5	10.2	9.9	13.0	10.3	9.1	9.1	9.1
141-150	7.3	8.7	8.5	8.9	9.9	12.1	11.6	11.5	12.4	12.6	12.2	10.5	9.3	9.3	9.3
151-160	8.2	9.6	11.0	10.9	11.0	11.2	12.2	11.7	12.5	12.4	13.3	13.6	12.2	12.2	12.2
161-170	8.7	10.5	10.9	12.4	12.0	12.4	12.6	12.7	13.4	12.8	13.5	13.9	14.3	14.3	14.3
171-180	9.4	11.0	12.4	12.7	13.0	14.5	14.5	14.5	14.6	14.6	15.1	15.9	16.0	16.0	16.0
181-190	10.4	11.7	13.8	14.2	15.2	15.6	15.4	15.1	16.4	16.2	16.6	17.1	16.6	16.6	16.6
191-200	11.8	13.7	15.8	15.3	15.7	18.6	18.3	17.6	18.8	18.2	18.7	19.8	18.5	18.5	18.5
201-210	12.6	14.8	15.8	16.9	17.8	19.2	19.3	20.4	20.8	22.4	21.8	23.2	23.7	23.7	23.7
211-220	13.8	15.9	17.5	18.1	19.2	21.2	21.9	22.9	24.1	25.0	25.1	26.0	25.9	25.9	25.9
221-230	14.4	16.4	18.8	20.5	21.3	24.3	25.0	25.8	27.7	29.3	30.7	33.2	33.4	33.4	33.4
231-240	15.4	17.6	20.1	21.2	23.1	25.3	26.4	28.7	29.6	31.5	33.4	35.9	36.1	36.1	36.1
241-250	15.8	19.5	20.9	23.1	24.8	26.9	27.8	29.0	31.3	32.9	34.4	37.2	38.4	38.4	38.4
251-260	16.3	18.3	21.3	22.5	24.4	26.3	27.5	30.1	32.2	34.7	36.1	37.9	39.5	39.5	39.5
261-270	14.4	16.0	19.7	19.8	21.5	24.2	26.3	26.6	30.0	31.4	33.0	35.9	37.5	37.5	37.5
271-280	12.1	14.2	15.6	19.0	20.7	21.9	23.9	24.7	26.3	29.4	31.8	32.1	34.6	34.6	34.6
281-290	10.7	12.5	14.1	15.6	17.5	19.9	20.9	22.0	23.5	27.4	27.8	29.8	32.4	32.4	32.4
291-300	9.3	10.9	11.8	13.6	15.4	17.3	18.2	20.4	22.4	23.1	23.4	24.6	26.2	26.2	26.2
301-310	9.7	10.0	11.8	14.6	14.0	15.6	17.2	19.0	20.2	21.4	22.8	23.0	26.2	26.2	26.2
311-320	9.7	9.2	11.8	12.4	14.2	16.2	17.4	17.4	19.1	20.1	22.2	24.3	25.5	25.5	25.5
321-330	8.9	10.7	10.7	11.7	14.3	15.2	16.6	19.1	19.3	20.9	21.5	24.5	25.5	25.5	25.5
331-340	8.4	9.6	11.1	13.2	13.8	15.6	17.5	17.2	19.6	22.1	24.0	24.2	27.5	27.5	27.5
341-350	8.7	10.5	12.0	12.6	14.2	15.2	16.3	19.3	19.5	21.3	23.6	23.0	25.9	25.9	25.9
351-360	8.5	9.6	11.7	14.0	14.8	16.1	16.4	17.4	19.8	20.4	22.0	24.7	26.6	26.6	26.6

Proposed wind placard table, not the actual table used for launch

Weather go/no-go call plan progression

- Plan A: GNC & Dryden meteorologist would make the call
- Plan B: at their request, involved LM Mission Analysis personnel in weather center; GNC & Dryden MET still make the call
- Plan C: Senior Ops helps GNC in control room when complex placards are developed; GNC, Dryden MET, Sr. Ops, FTA lead make the call once we see data from weather center
- Plan D: As placard issue becomes more complex & controversial, the decision gets pushed up to the Mission Management Team (MMT is Orion PM & his support staff)
  - Used 5 weather balloons on day of launch
  - Had 924 MHz profiler next to launch site
  - Flying in the windiest part of the year for White Sands (March - May)
  - 4 day launch window (Thursday – Sunday); can't go the following week due to another higher priority program's launch
  - Day before the launch, briefing MMT on weather-101

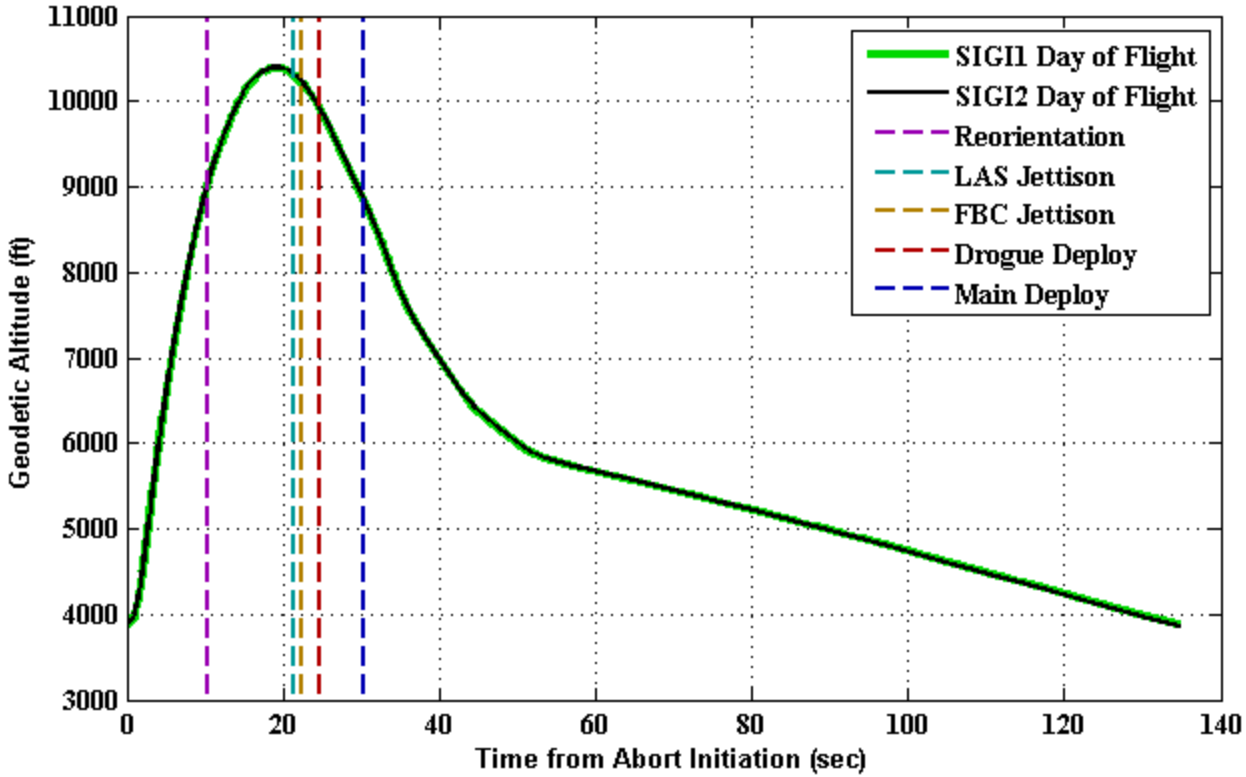
Lessons Learned (continued)

- After all that, balloon data showed that we were go for flight, but from the Ops recovery team and then from flight data, we learned that we were flying in 3-sigma GRAM winds that day

Lessons Learned (continued)

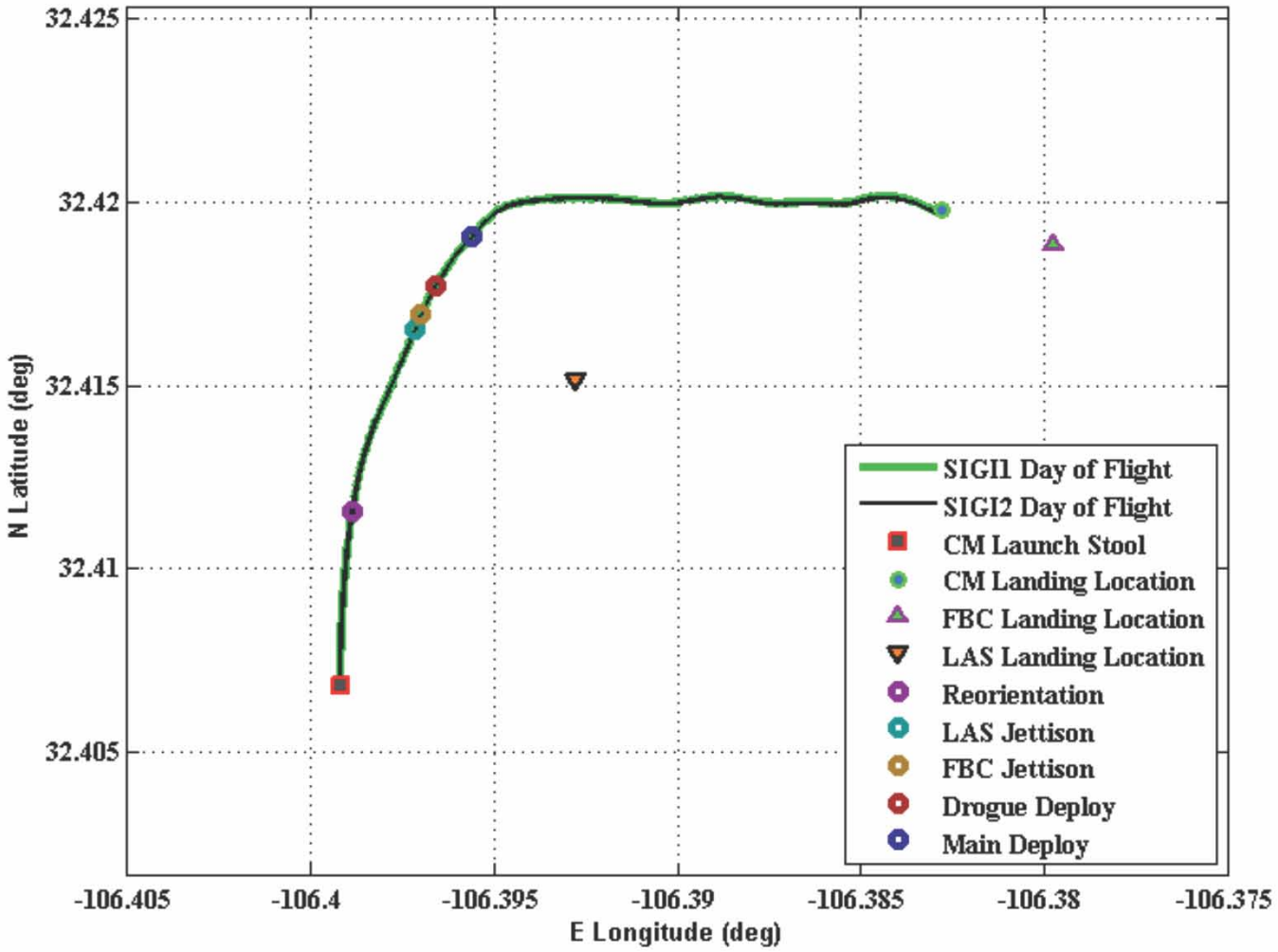
- Wind Placards
  - Don’t involve people in the process who don’t have decision making authority; or if you do involve them, make sure they have associated with them a decision maker who has authority
  - During flight operations, a data or analysis briefing needs to come with a recommendation (ties back to authority)
    - At earlier stages of the project, analysts tend to show you all the data, so decisions can be collectively made by the team – this isn’t useful or productive during operations
  - Additional LLs in work

Altitude Time History from flight



Apogee was 10,386.0 feet (geodetic)
CM downrange was 6907.5 feet (SIGI measured)
Total flight time was 134.4 seconds

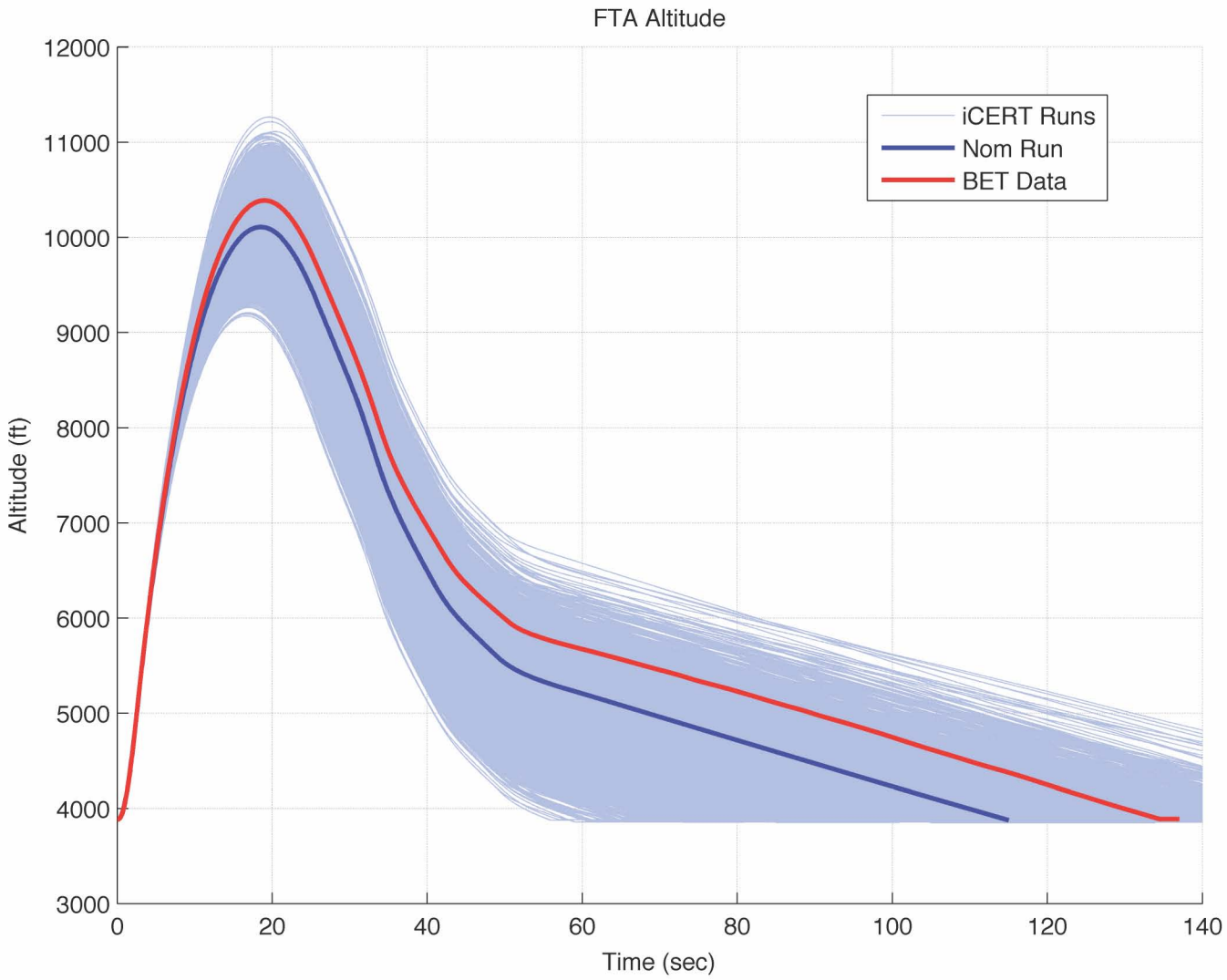
PA-1 Flight Test Ground Track



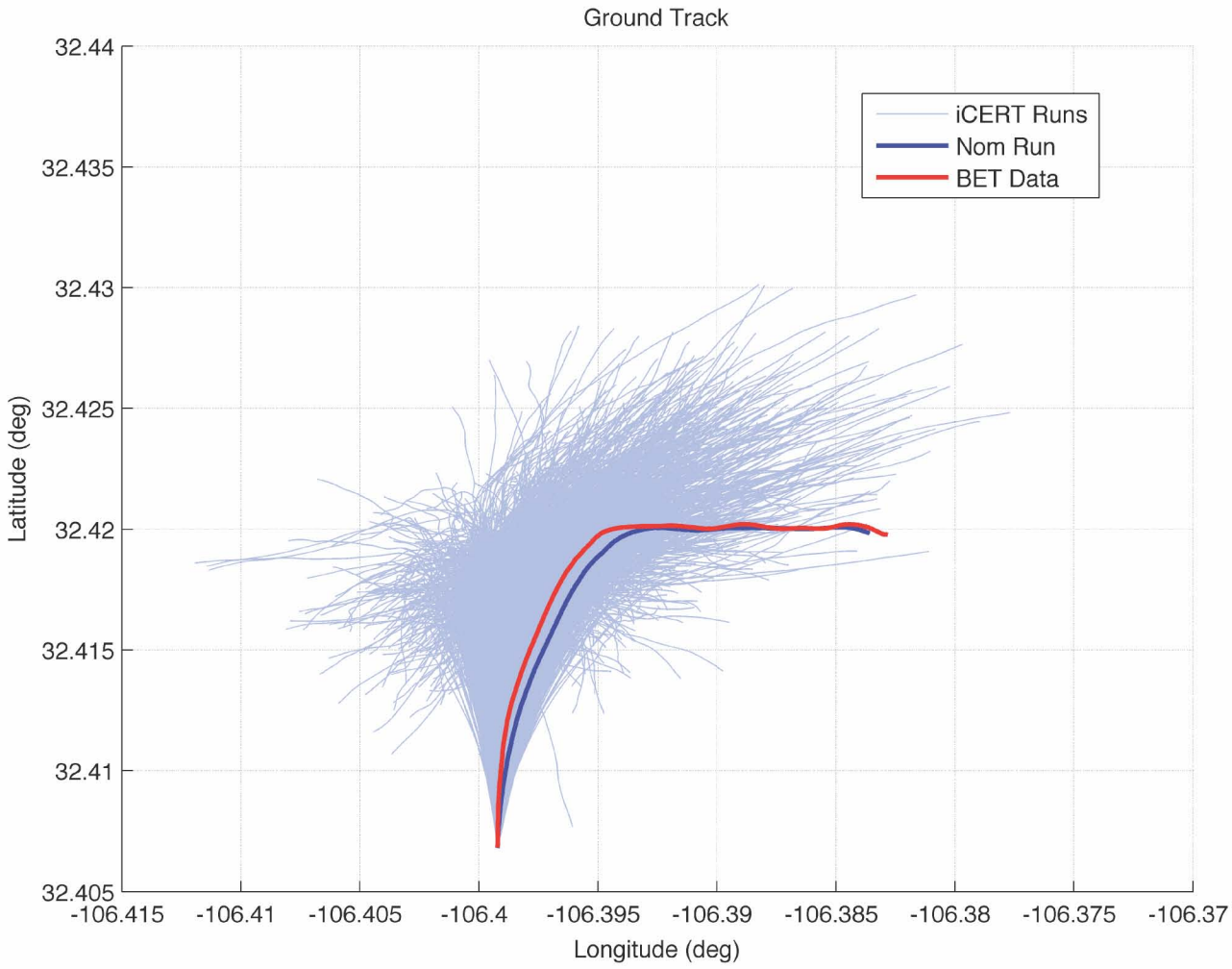
Post-flight data comparisons to simulation

- ANTARES simulation runs done using post-flight updated simulation models for
  - Abort Motor thrust profile from flight
  - Attitude Control Motor thrust profile from flight
  - Meterology day-of-flight atmospheric model
  - Mass Properties
  - Parachutes (higher fidelity models incorporated)
- Still waiting for day-of-flight aerodynamic models to come in
  - Possible that drag is not as high as pre-flight aero models predict?

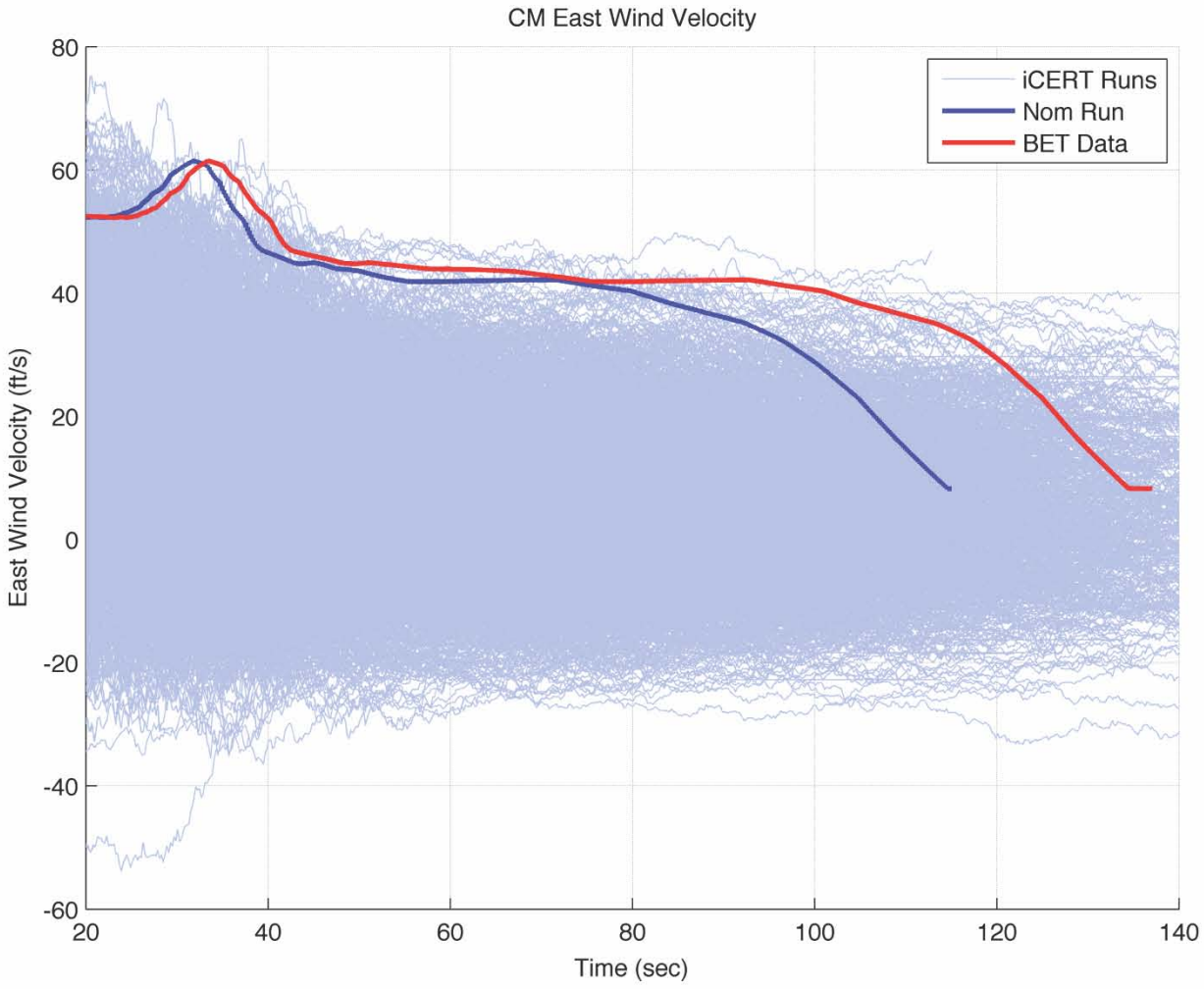
Flight Data compared to dispersed simulation runs



Ground Track



Winds blowing from West to the East



6 May 2010 – 6:09am local time

What is next for Orion & Abort Flight Test

- Orion program management has decided to pursue OFT-1 as the next flight test
  - Test is mainly an entry test, with only a nominal LAS jettison
  - OFT-1 is a un-crewed orbital test (no docking with space station)
  - FT-2 (Orion-2) is the first crewed flight test on the manifest
- AA-2 is currently being considered as a follow on test in between OFT-1 and FT-2 (Orion-1 & Orion-2)
  - AA-2 is a transonic abort (LAS abort occurs as vehicle passes through Mach 1, about 40 seconds into the ascent)
  - Would test the production LAV controller
  - Would be performed with an abort test booster (ATB)
    - Currently SR 118 Peacekeeper motor
  - Currently performing a trade study on the AA-2 launch site location
- Production launch vehicle determination expected by Oct 31

Wrap-Up

- Ops candid commentary during flight
  - Includes helicopter chase video
- Questions/Comments?