Orion PA-1 Thermal Flight Operations and Lessons-Learned

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Agenda

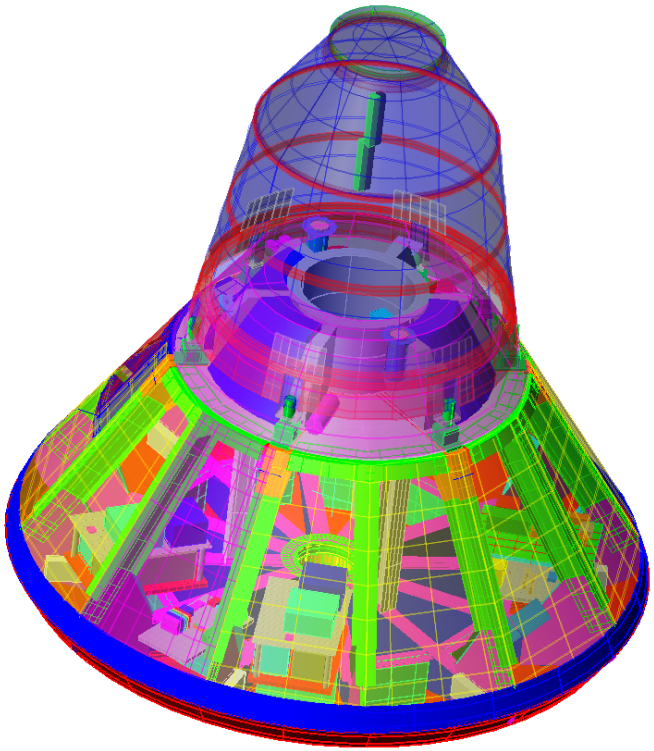
- Orion PA-1 Thermal Background
- Pre-launch Preparations
- Operations for PA-1
- Preliminary Results
- Lessons Learned
- Final Thoughts

Orion Pad Abort 1 Thermal Background

- Orion Pad Abort 1 (PA-1) Flight Test occurred on May 6th, 2010 at White Sands Missile Range (WSMR) in New Mexico
- First test of the Orion vehicle – primarily a test of the Orion Launch Abort System (LAS)
- Thermal control achieved through combination of active and passive systems
  - Passive control for systems after launch (rely on thermal mass) and for LAS during ~7-hour period before launch (white paint)
  - Active control through conditioned air circulated within the crew module (CM) and around the LAS under its protective cover
  - Thermal protection system (TPS) for outer surfaces of LAS (cork)
- Detailed thermal model developed with Thermal Desktop

Pre-Launch Preparations

- Based on a detailed thermal model, developed a set of launch and operational constraints
  - Temperature monitoring through use of developmental flight instrumentation (DFI) and operational flight instrumentation (OFI)
  - Model was independently peer reviewed
- LAS was designed for KSC, not the more extreme WSMR environment
  - Environmental differences between KSC and WSMR lead thermal team to recommend use of a thermal protective cover for LAS and use of conditioned air in CM (with T-0 disconnect) and within cover
- Multiple rehearsals – just thermal team early, then with larger operational team closer to launch
- Launch count recycle analysis performed
- Thermal team also spent significant time on visual displays for the Mobile Operations Facility (MOF)
- CM ECS testing prior to stacking operations



PA-1 Integrated Thermal Model

Propellant Mean Bulk Temperature

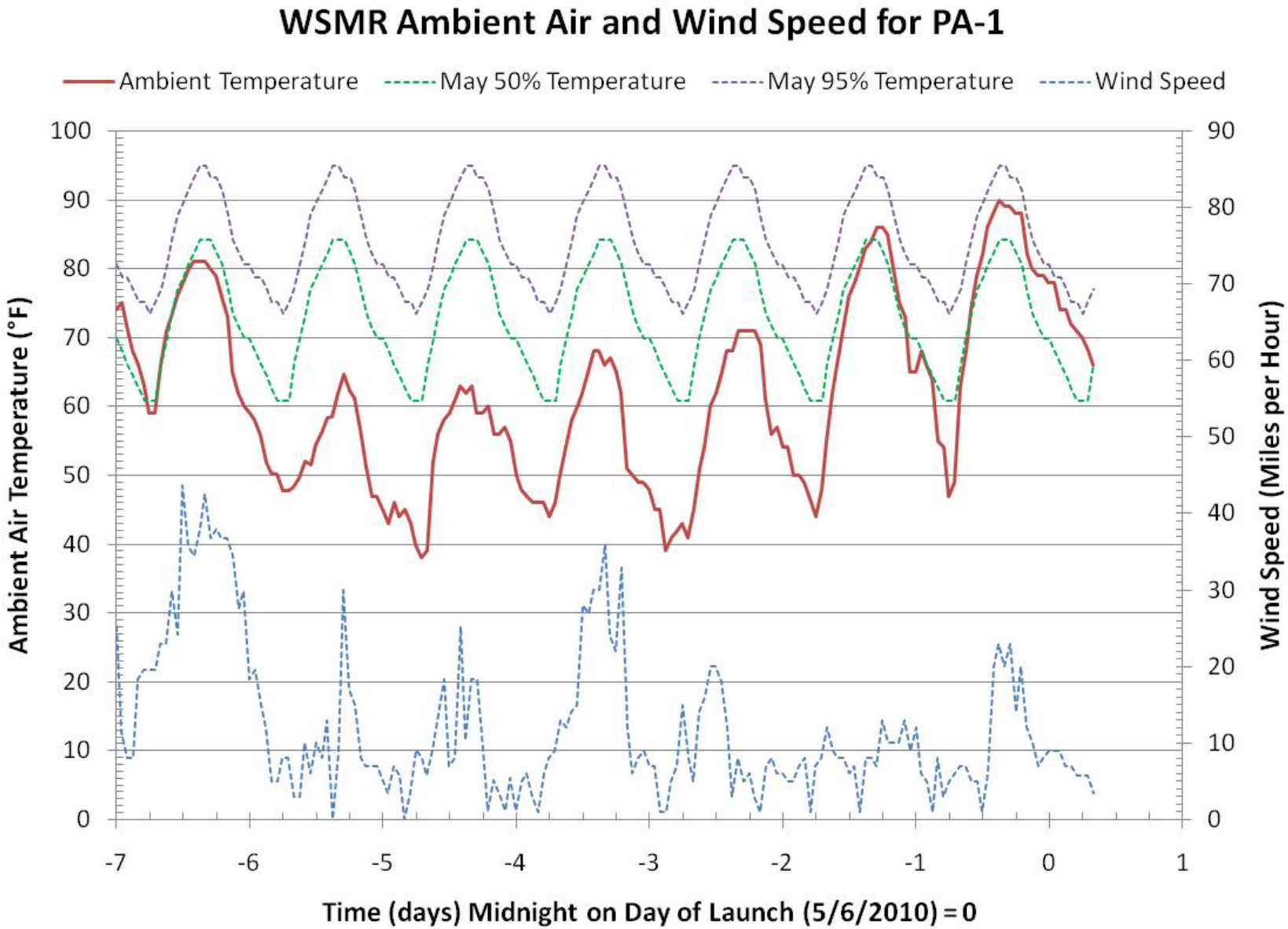
- Propellant Mean Bulk Temperature (PMBT) was driving thermal performance constraint for PA-1
  - All three motors had constraints on PMBT, but abort motor had tightest constraints (40°F to 67°F) due to structural temperature limits and vehicle structural load limits (motor thrust vs. temp profile)
- Because of its importance, thermal team developed reduced model of abort motor so day-of-flight, real-time PMBT predictions could be made
  - This model could run in several seconds on a laptop
  - Took inputs from measured and predicted weather conditions (air temperature, sky conditions, and wind speed) and turned them into boundary conditions for the model
  - Output calculated abort motor PMBT for current time, T-0, and T+4 hours to cover possible recycle of the countdown (0700 to 1100 local time)

PA-1 Day of Flight Operations

- Thermal team consisted of several distributed subteams:
  - Thermal Seat in MOF watching temperature limits (Darrel Lamb)
  - Thermal team doing PMBT predictions and reporting those results at regular intervals (Dave Buffington and Joe Gasbarre)
  - Backup thermal group mirroring PMBT predictions and performing pre-launch predictions while WSMR team is down (LM Denver)
- Thermal team used reduced model, weather predictions, and engineering judgment to provide input for decision to remove LAS cover (at ~L-7 hrs)
- Winds, sky cover estimate, and air temperature were given to the thermal team from the weather officer
  - Data drops occurred at L-3 days, L-2 days, L-24 hrs, L-12 hrs, L-6 hrs, and L-3 hrs
  - Included both measured and predicted up to that point

LAS Thermal Protective Cover

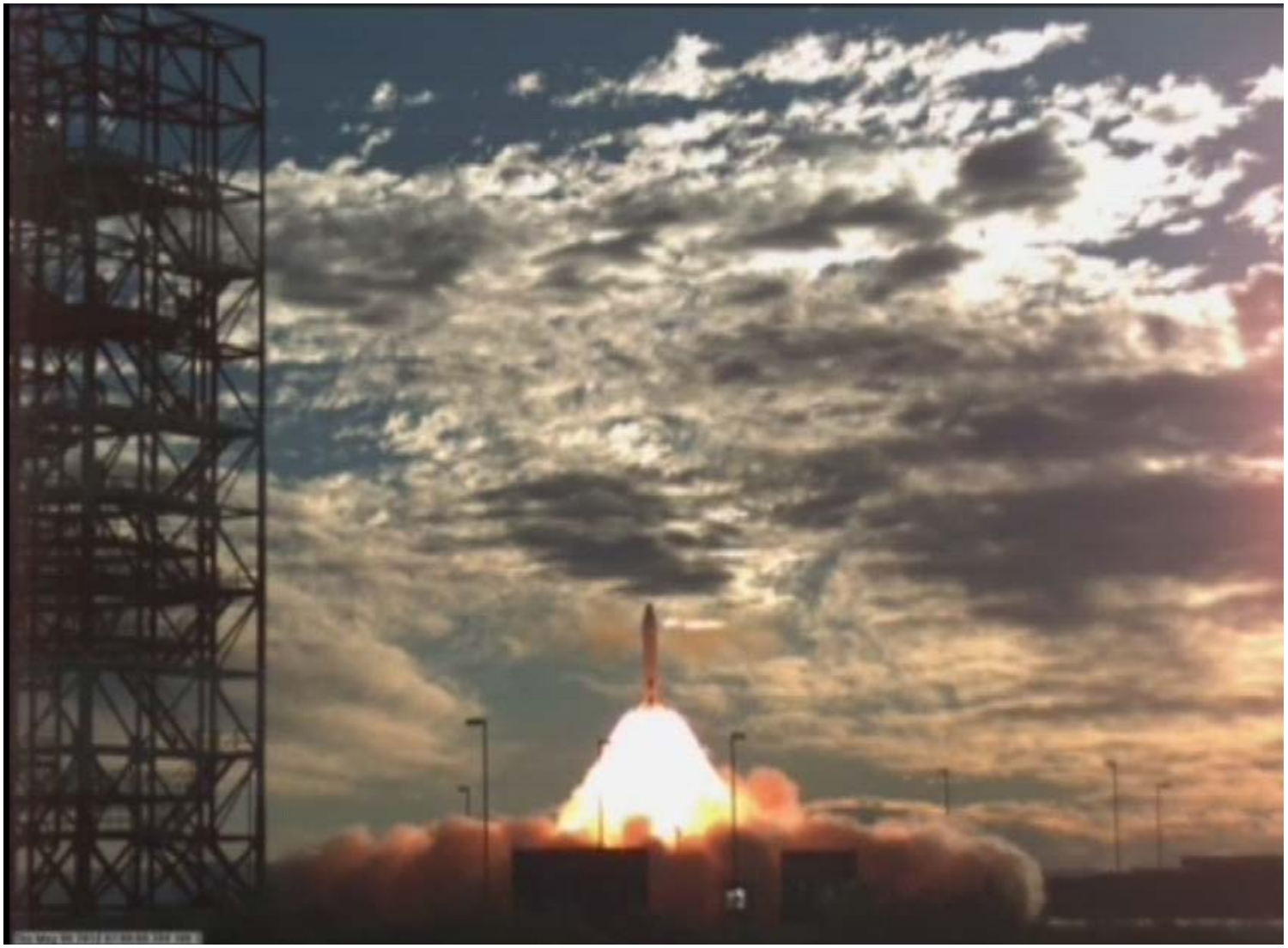
Launch Environment



PA-1 Day of Flight Operations

- Thermal team relayed PMBT prediction results over the launch network every 30 min starting at L-3 hrs (call to stations) plus whenever requested by launch director
  - PMBT predictions were based on the L-3 hr weather data and the measured abort motor case temps up to the point of the prediction
  - Last prediction was made at ~L-15 min showing AM PMBT being at 60°F at time of launch
- Numerous checks from MOF thermal representative at various intervals, including calls on when to switch to CM internal power and power-up the LAS attitude control motor (ACM) which were both driven by thermal constraints
  - Last poll of MOF occurred at ~L-5 min
- Launch occurred as scheduled at ~0700 local time

Orion PA-1



Orion PA-1

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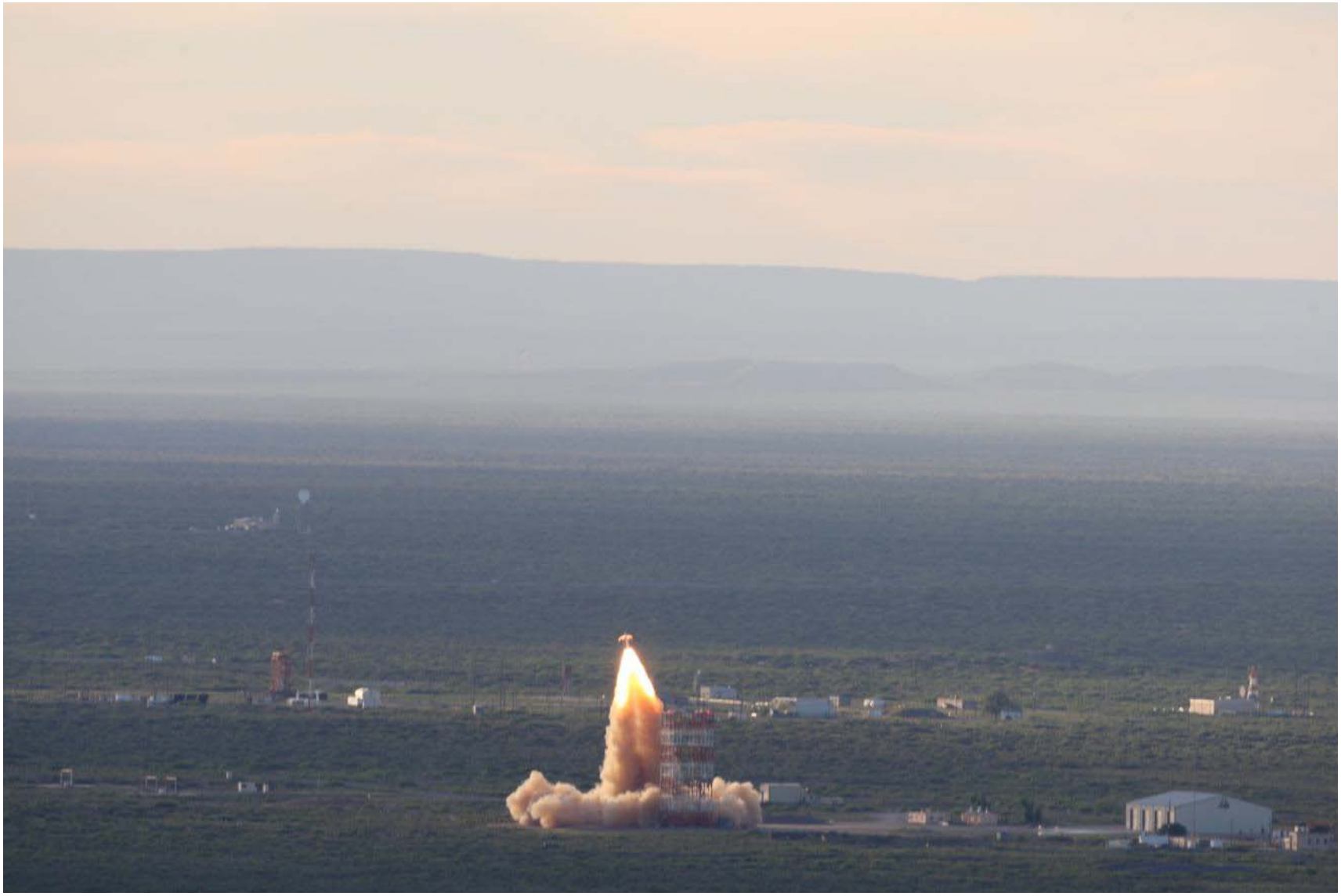

Orion PA-1

Results

- Launch was nominal in all major aspects – deemed highly successful
- All LAS motors remained within their PMBT ranges
- All internal components kept within temperature limits
  - All avionics boxes survived landing, so “L+30 min powered” timeline analysis was useful (no one thought they would survive landing loads!)
  - CM Internal air remained below 72°F for the entire timeline
- Abort motor plume heating persisted longer than expected and rolled over much more of the vehicle
  - Heating on heatshield was much higher than expected
  - Will definitely influence burnout profile modeling for future flights
- ACM temperatures were generally nominal, but hybrids and valves had some as-yet unexplained temperature deviations
- Some instrumentation abnormalities noted on ACM batteries and abort motor case sensors

Lessons Learned Summary

- Review all component thermal cycle testing procedures to check for standard testing practices and adequate test instrumentation
- Include Flight Instrumentation on any powered components (solid rocket motor controllers, etc.)
- Define launch commit criteria philosophy and risk areas for operations early in the process and get team buy-in
- For this particular vehicle and launch location, the active cooling and protective cover were very helpful and should be included for later test flights
- Reduced models for use during flight operations are very helpful – consider implementing such models and testing them against the full-fidelity model throughout the design process
- Decisions on implementation of design feature that allow for more launch opportunities or protect the vehicle from the environment should be discussed and made early in the design cycle

Final Thoughts

- Well-integrated ("badge-less") team was an asset
  - Thermal team was pointed to several times by the management team as an example of government-contractor integration
- Many of the experiences should translate well to future test flights (let's hope!) and flight operations
- Acknowledgements to:
  - Integrated Orion Thermal Team
  - Justin Fox, Orbital Sciences
  - Warren Davis, LaRC/AS&M
  - Davis Hackenberg and rest of PA-1 flight ops team
  - Don Reed, Griff Corpening, and rest of FTO management team
  - Kevin Rivers, Dave McGowan, and rest of LAS management team

QUESTIONS?