Volcanic Ash Distribution Rig (VADR) Development

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- Calspan/DNA First Round
- Early Discussions
- Moving Forward for VIPR III
- GE Peebles Test Operations (PTO)
- VADR Integration

Early Work with Calspan and DNA

- 1980's-90's Calspan was contracted to support the Defense Nuclear Agency (DNA; 1971-1996) conducting research on various turbine engines for:
  - Volcanic ash
  - Nuclear dust effects

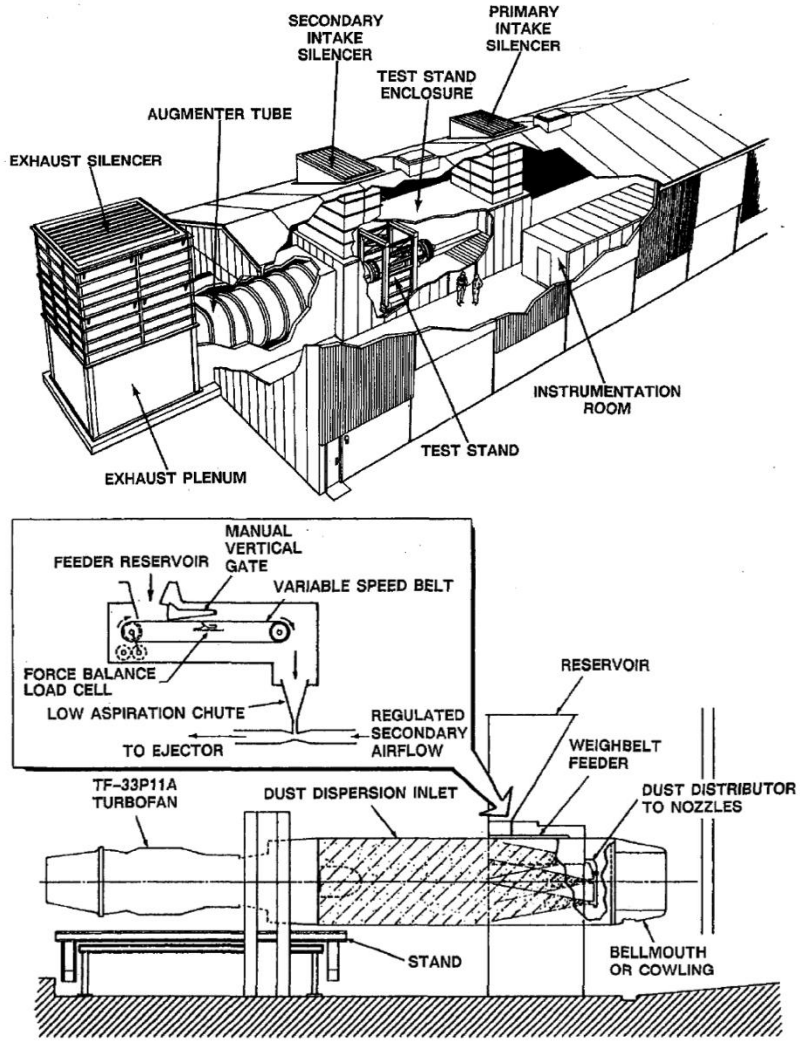
- Facilities were developed/used at both:
  - Calspan NY
  - Edwards AFB CA

- This data was not readily available nor time allotted for review prior to conducting NASA Vehicle Integrated Propulsion Research (VIPR)

- ~25 Papers related to Calpsan/DNA work were found during and post VIPR and in review regarding previous testing

Calspan Dust Injection System

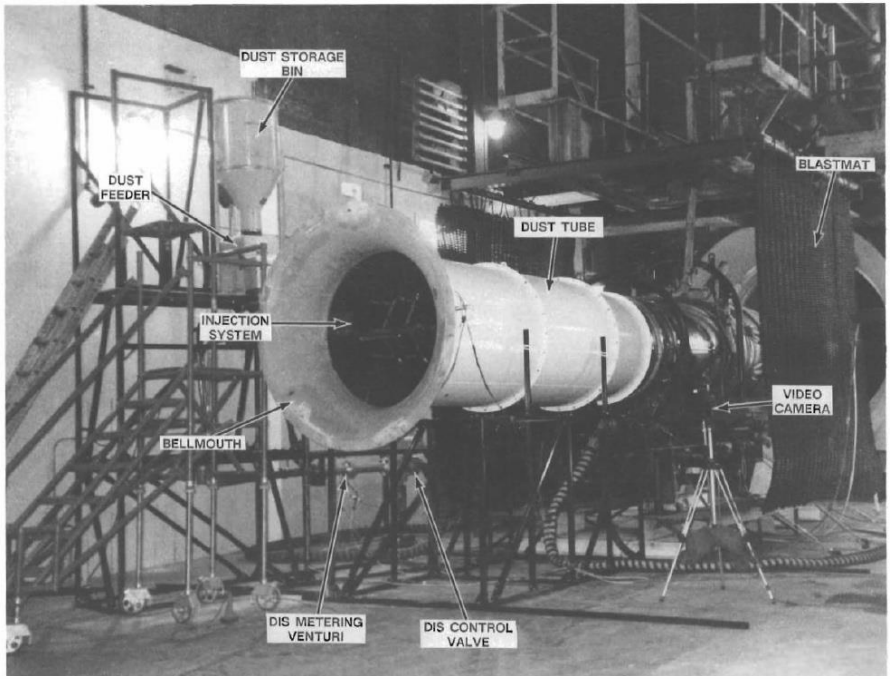
- Fan face concept used bell mouth inlet
- Ingestion rakes were part of bell mouth inlet
- Belt feed technique utilized
- Auger system developed and tested for use at EAFB

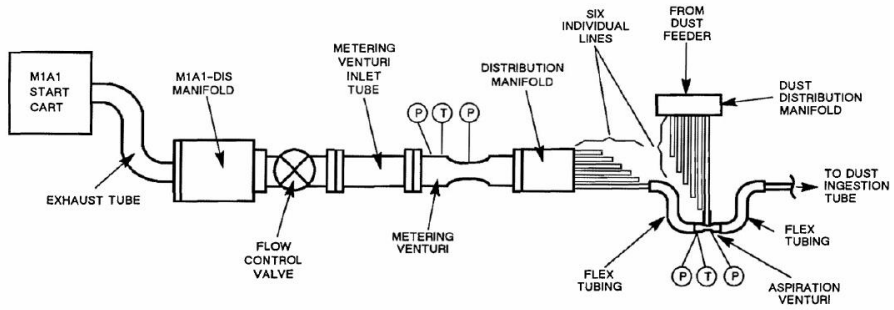


Dunn/Baran/MiatechImages. ASME Large engine research cell, 1996, Operation of Gas Turbine Engines in Volcanic Ash Clouds

Edwards AFB Test Cell

- Papers reviewed indicate auger feed system used in lieu of belt feed
- Similar feed to what was used in VIPR III





Baran/Dunn. DNA-TR-92-The Response of a YF101-GA-100 Engine to a “Most Probable” Nuclear Dust Environment (U), 1992

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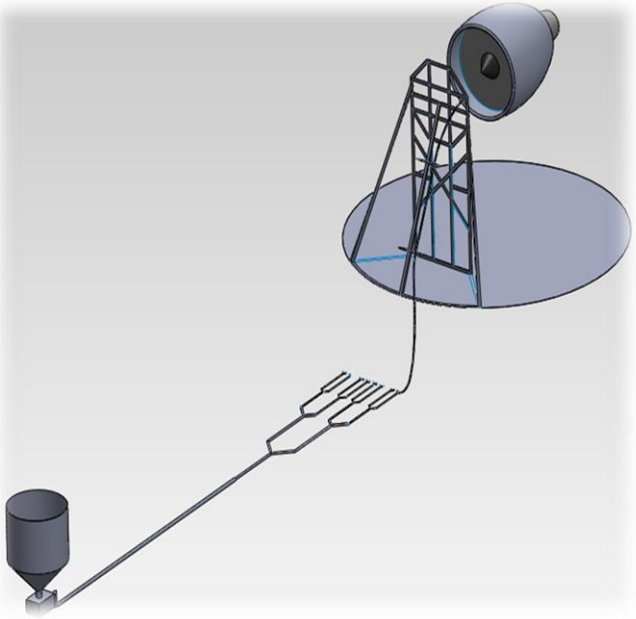
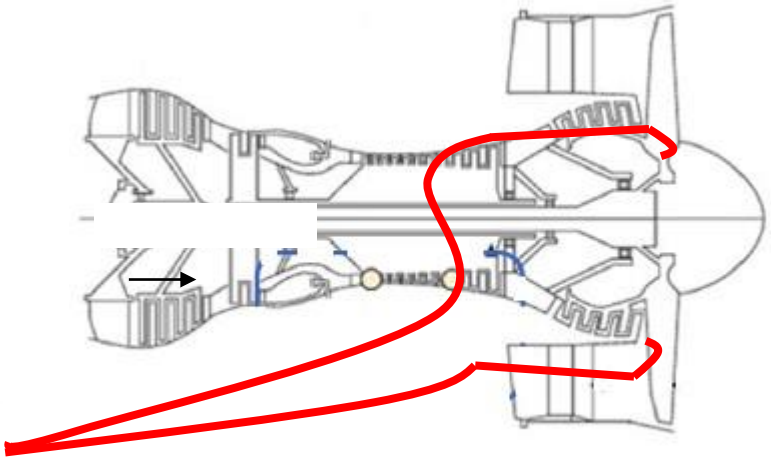
Early Considerations VIPR – Fan Face Low Pressure Compressor Injection



KSU fan face concept (included ash in the bypass)

- Core loading uncertain
- Possible damage to nacelle and aircraft
- Decoupled engine rig/engine motion
- Possible distortion and stall recovery issues



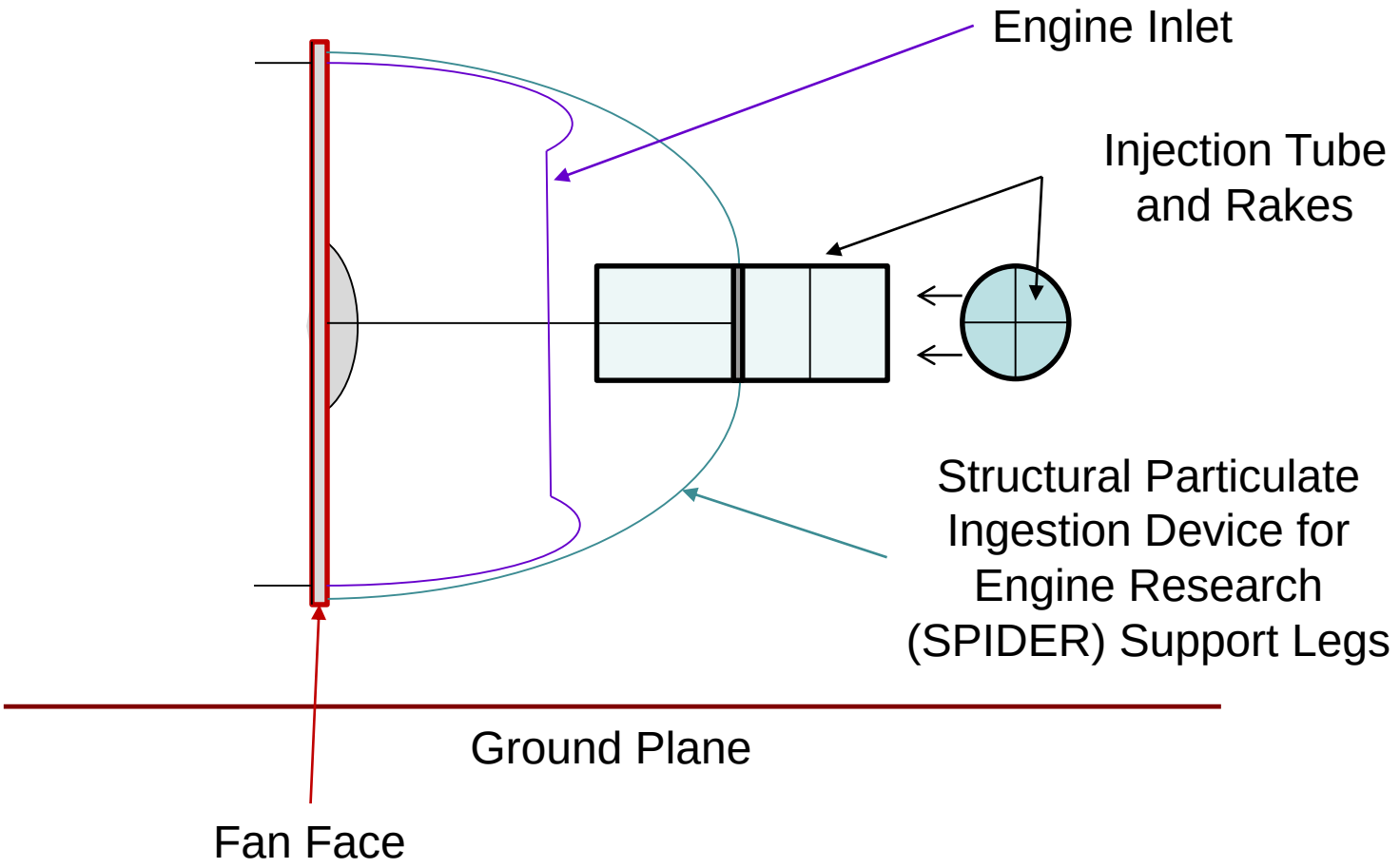
Booster injection

- Core loading known
- Undesired circumferential variation in ash induced damage
- Difficult to integrate into nacelle

Comments

- Previous concepts more along the lines of what might be accommodated in test cell environments
- Arnold Engineering Development Center (AEDC) was considered but too costly for single test with all other VIPR research
- Impacts to AEDC and clean up may have been too cumbersome
- VIPR team met at National Museum of the Air Force in late 2013 to discuss possible options for core only controlled ingestion
- ***Pathway*** was needed for OEMs and NASA to work seamlessly on VADR components and integration

Chicken Scratch Concept



This would allow for P&W to analyze fan case support structure, NASA to design and build support collar and legs and GE to integrate VADR injection mechanism into SPIDER

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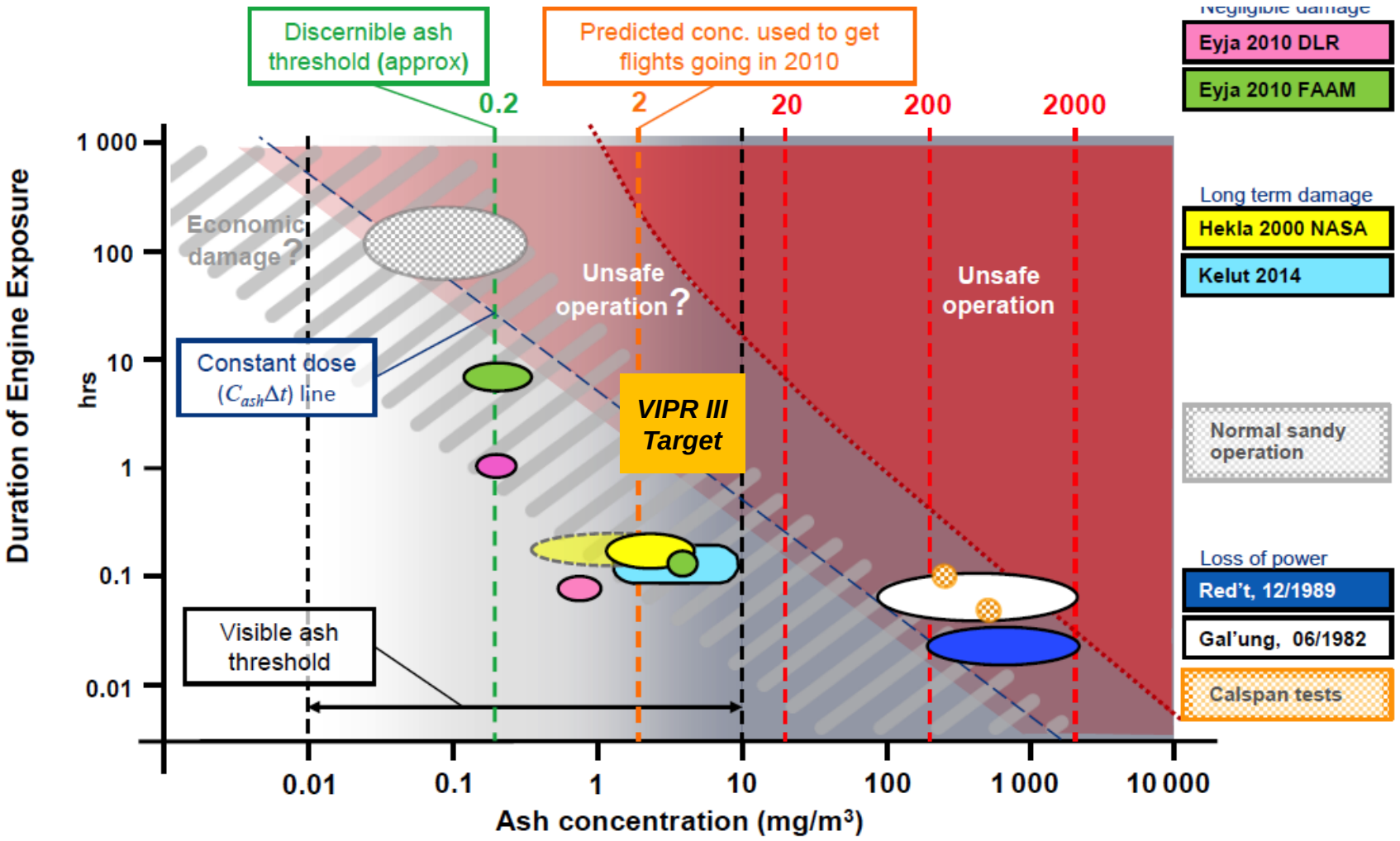
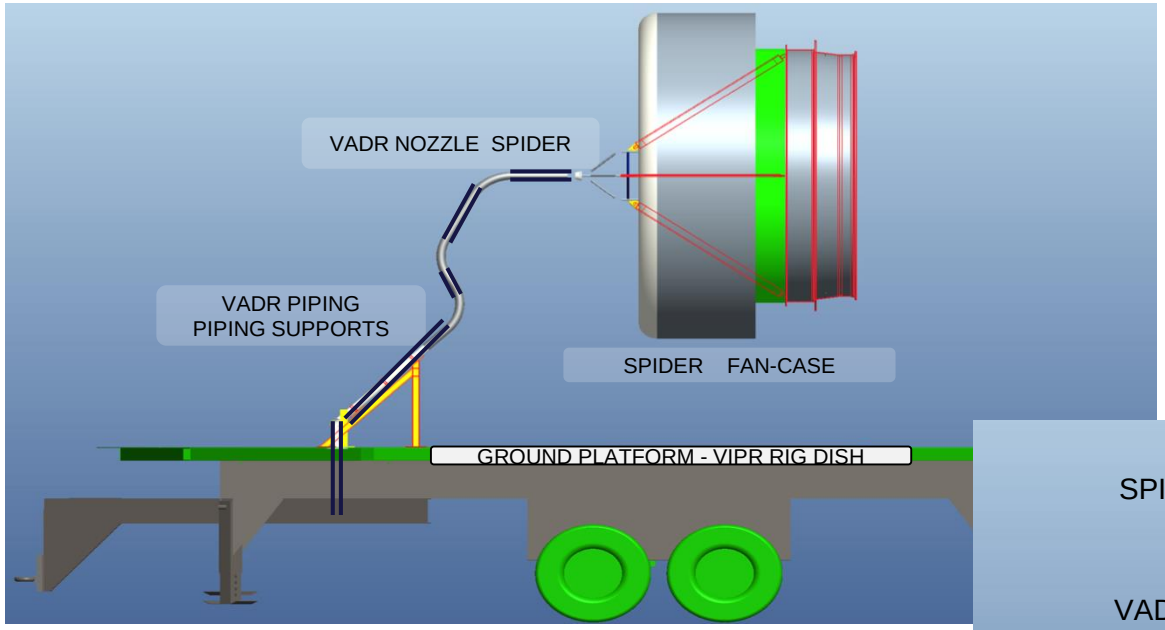
Clarkson Chart

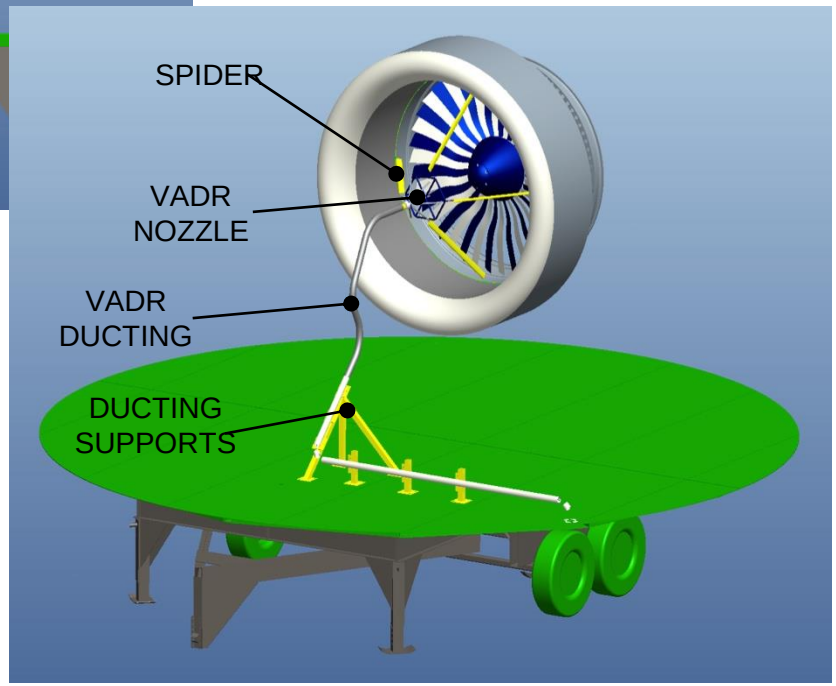


Courtesy of Rolls-Royce, plc.

VADR to SPIDER Integration V1.0



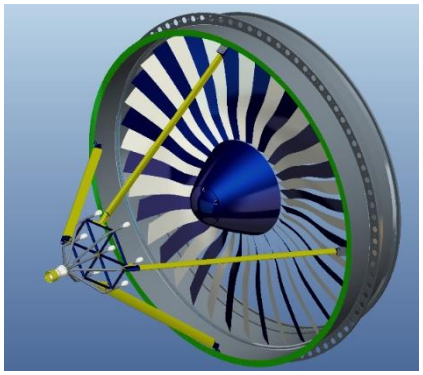
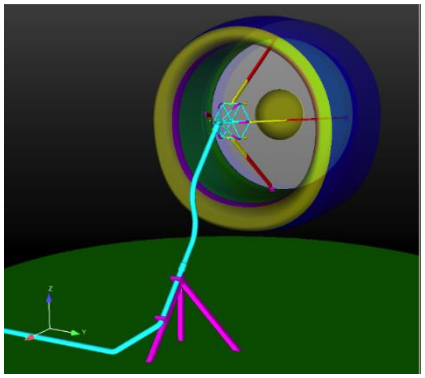
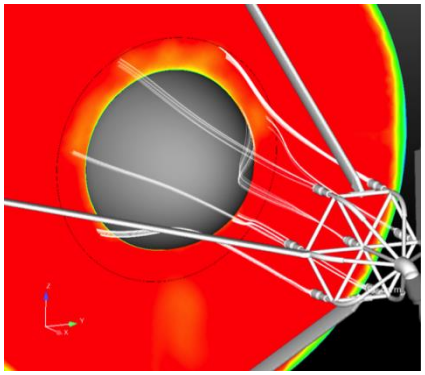
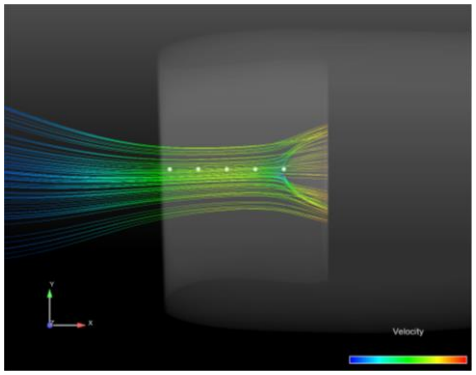
- ***Objective: VAE-1.0***
  Introduce the volcanic ash such that the rate and overall quantities entering the engine are both measurable and controllable



Conceptual Drawings Developed

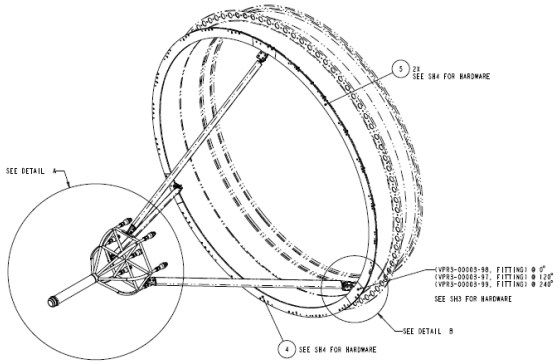
- 4 Legged SPIDER
- Attached to inner fan case as opposed to outer as first considered
- Plumbing routing considered for integration off platform to VADR control unit

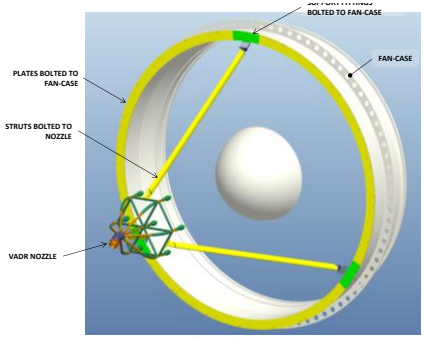
Modeling and Preliminary Analysis Confirm Controlled Flow into the Core Stream

- Good news
  - ✓ The ash will flow into the core stream
  - ✓ Ash flow is controllable
  - ✓ The engine will run unabated by the SPIDER/VADR installed in the inlet
- Not so good news
  - ✓ Found a few structural bumps but overall the concept indicated the idea will work
  - ✓ SPIDER legs went from 4 to 3 legs to ensure upsets in airflow were minimized

Integration of the VADR and SPIDER to the ground platform V2.0





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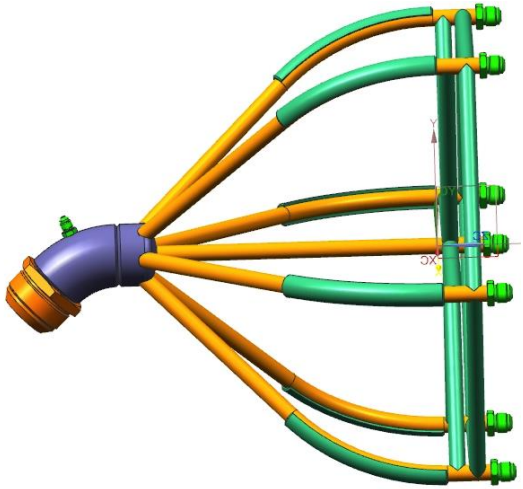
Hardware Plumbing & Nozzle Array – V1.0/2.0



Nozzle Array

- Originally considered 45° angle entering the array
- Spaced to provide ash into engine core only
- Uniformity within 25% (center nozzle has highest flow rate)
- During testing at PTO team discovered extension on array inlet was required for better uniformity

VADR Feed and Control – V1.0/2.0

- Electrical Panel & Control - Pretty much unchanged throughout
- Auger – Several bit designs evaluated to ensure steady feed rate and reduced wear
- Motor – Upgraded/modified to reduce variations in feed rate
- Shakers – Added from first version to ensure uniform flow into auger system
- Hopper – Had to be lengthened to support the longer run times
- Flow Piping - Unchanged

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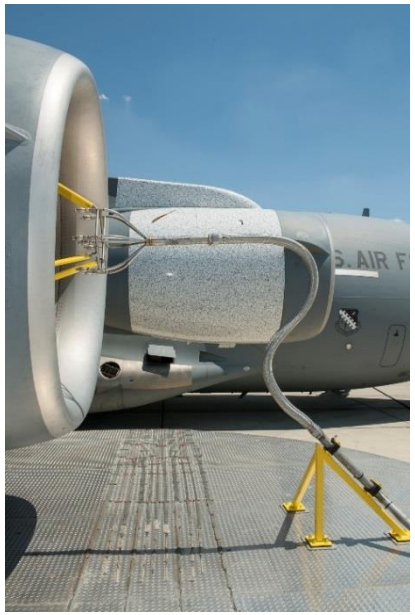
On Engine Installation & Testing



General Comments - Technical

- Higher velocity feed rates require stabilization in plumbing prior to entering nozzles
- Ash is a far more abrasive component than first realized
  - Must understand wear and tear on the system prior to use
- Uniformity is achievable across all nozzles to within 25%
- No issues identified with respect to ash clogging in tubes
  - Provided ash is dry prior to use
  - Run system calibration daily prior to use
- Auger RPM control is crucial
  - Lower flow rates can be difficult to control
- Ash hopper cannot be run dry
  - Caking and cavitation can be problematic
  - Have planned reserve in system prior to refill

General Comments - Programmatic

- Communication is key
  - Upfront requirements need to be fully understood
  - Comprehension of cultural and business environments of each partner is paramount

- Solid working agreements in place prior to commencing work
  - VIPR III was a huge research effort, the large number of partners working together across multiple time zones and activities was a challenge

Acknowledgements

Ms. CJ Bixby – NASA AFRC
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