PI Masters Forum #8

CYGNSS
(Cyclone Global Navigation Satellite System)
Lessons Learned

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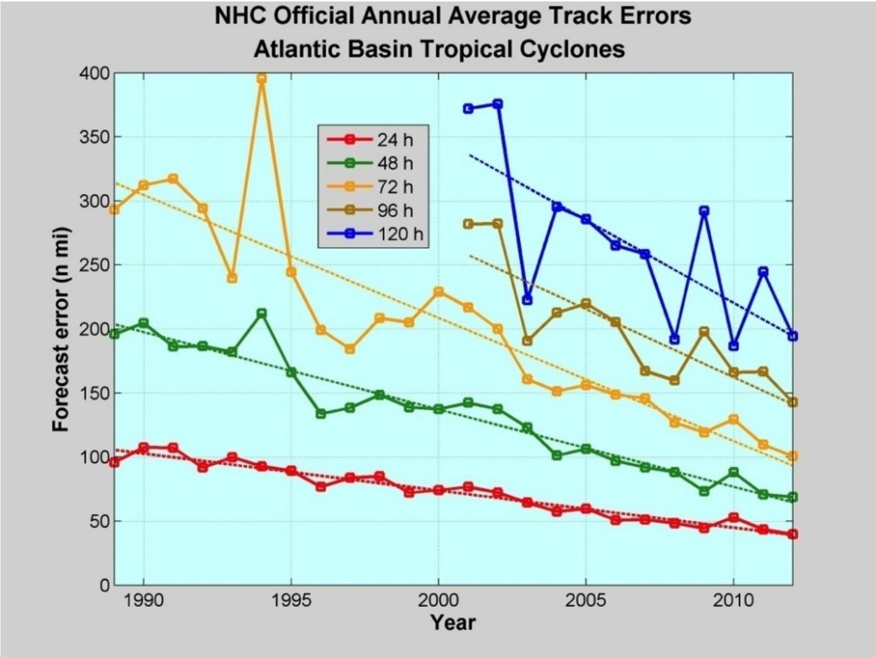
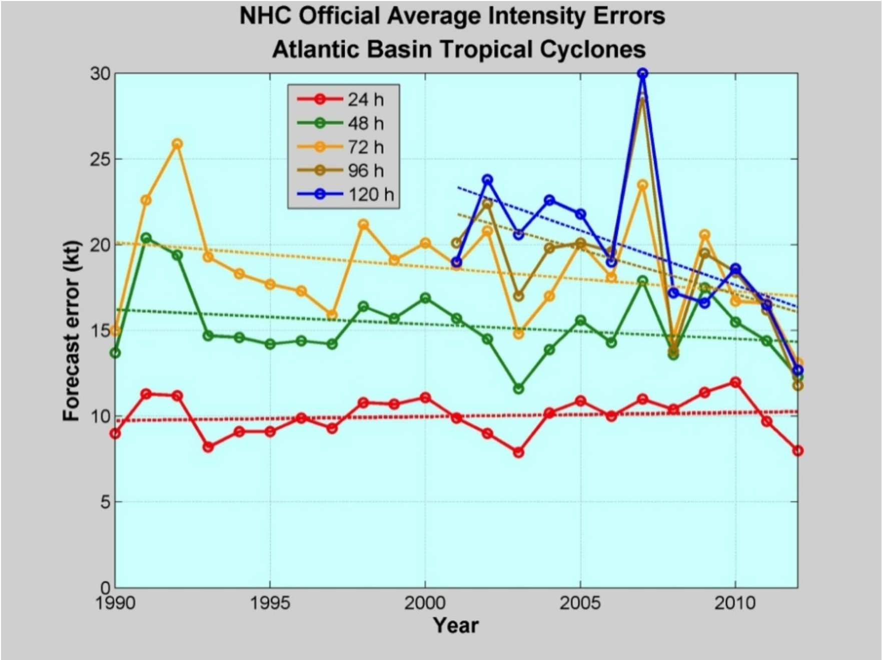
Science Motivation

- Tropical cyclone track forecasts have improved in accuracy by ~50% since 1990, largely as a result of improved mesoscale and synoptic modeling and data assimilation. In that same period, there has been essentially no improvement in the accuracy of intensity forecasts.





National Hurricane Center, http://www.nhc.noaa.gov/verification/verify5.shtml

CYGNSS Objectives and Mission Design

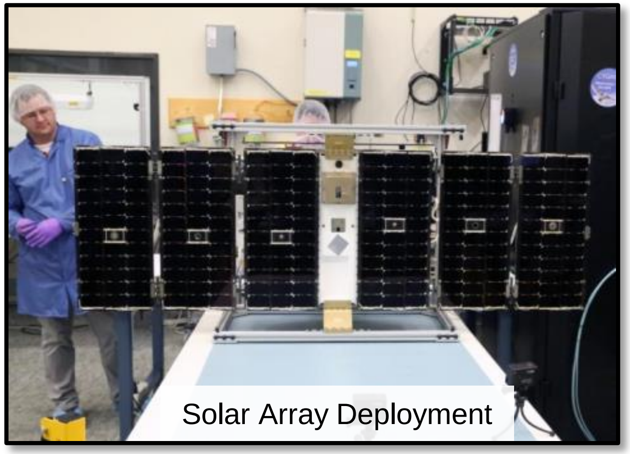
- CYGNSS Objectives
  - Measure ocean surface wind speed in ***all precipitating conditions***, including those experienced in the tropical cyclone (TC) eyewall ←*Drove the measurement technique*
  - Measure ocean surface wind speed in the TC inner core with ***sufficient frequency*** to resolve genesis and rapid intensification ←Drove the mission to be a constellation
- CYGNSS Mission Design
  - Eight satellites in low earth orbit at 35^o inclination, each carrying a four-channel modified GPS receiver capable of bistatic radar measurements of GPS signals reflected by the ocean surface

Implementation

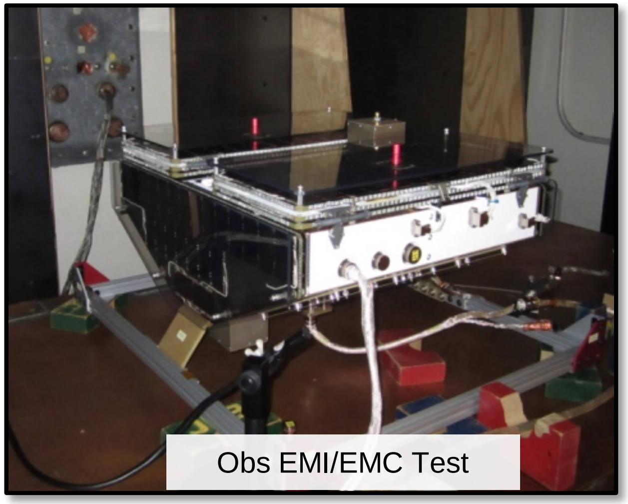
- Team:
  - Univ. of Michigan (PI C. Ruff)
    - Lead, thermal, SOC
  - SwRI
    - Mission PM, SE, SMA, Spacecraft, I&T, MOC
  - Surrey
    - Payload (FFP procurement)
  - SNC
    - Solar Arrays and Deployment Module
- Overview
  - First ESSP Earth Venture Mission
  - Cost cap: $100M not incl. GFE LV
  - Non-competitive Phase A
  - 48 months from start of Phase A to launch (with 2 months of launch delay ironically caused by Hurricane Mathew)

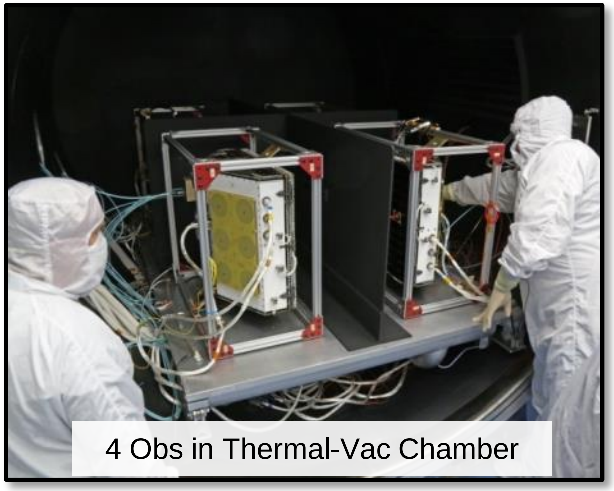
Observatory Photo Gallery


Microsat Integration


Solar Array Deployment

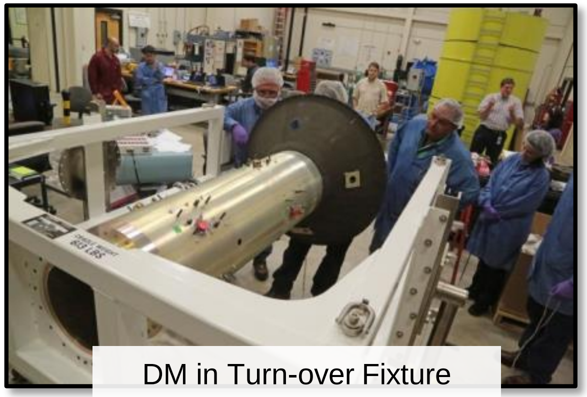

FM2 Random Vibe


Obs EMI/EMC Test


4 Obs in Thermal-Vac Chamber

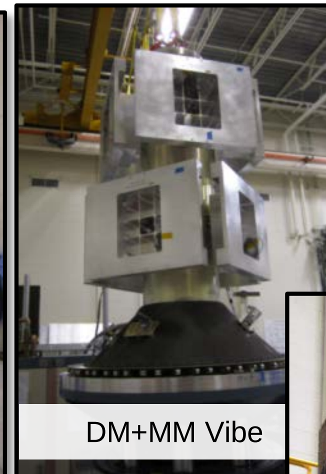

L-Band NFT in RF Chamber

Flight Segment Photo Gallery

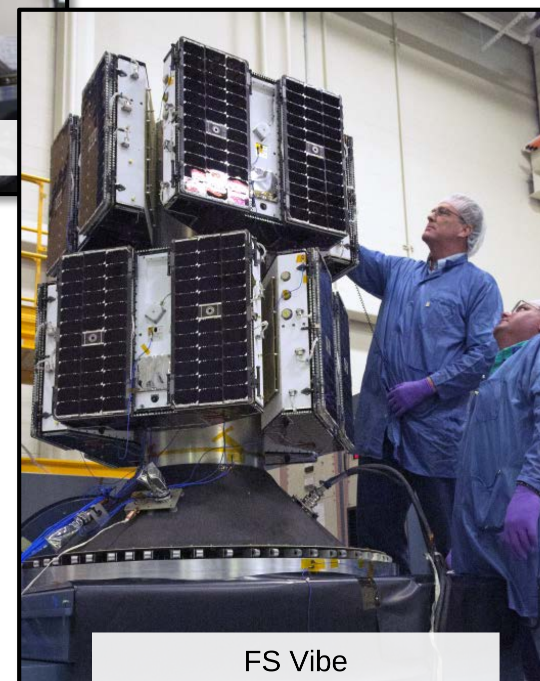


DM in Turn-over Fixture

MM install on DM



DM+MM Vibe



FS Vibe

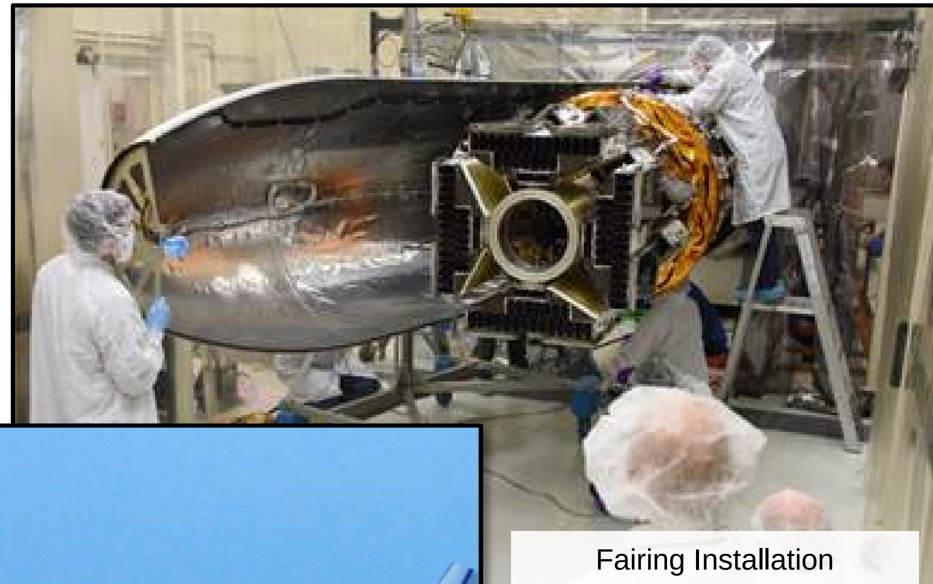
Obs install on DM

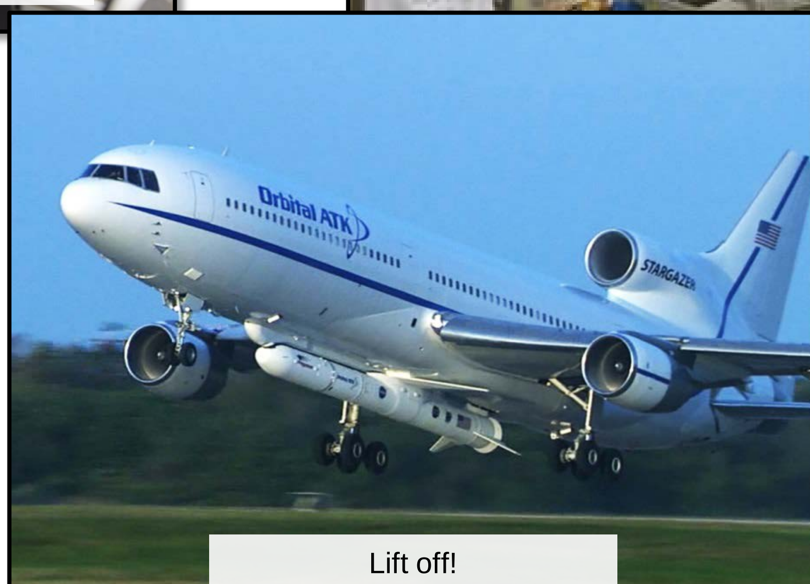
FS Shock Test

FS Horizontal Lift Dry-Run

VAFB, Ferry and Launch


Incoming Inspection at VAFB


Fairing Installation



Lift off!

Lessons Learned
Round 2

Systems Engineering Staffing

Consistent with a Class D mission budget, CYGNSS had a very lean systems engineering team that consisted of one Project Systems Engineer (PSE) plus discipline-specific SEs that served double-duty as subsystem leads, with minimal SE support staff.

- In Theory
  - Fewer staff = fewer lines of communication = more efficient
  - A Class D mission would be a good training ground for up and coming engineering staff
- In Reality
  - SE team was too lean
  - PSE was often pulled away from the rest of the team for meetings with outside stakeholders and mandatory NASA reviews
  - With no spacecraft SE to look inward and cover, PSE was over taxed and communication suffered
  - The low-budget small-team arrangement does not provide enough mentoring support for inexperienced staff

- In Hindsight
  - Don't underestimate the level of SE staffing and experience needed to be successful
  - Cross-training of staff can be invaluable, but it's a double-edged sword: it can mitigate deficiencies of a small-team in a crunch, but training itself takes time and covering for someone else is time lost on your primary responsibilities

Cubesat Vendors

CubeSat component capabilities are rapidly increasing, they fit within small class D missions, physically and budget-wise, but they also bring risks that typical/larger NASA missions face less often

- Range of CYGNSS vendor experiences:
  - Minimal issues, procurement through flight
  - Hardware not meeting spec'ed performance or spec'ed performance changing during development cycle
  - Vendor going out of business when delivery of 27 flight units is expected in 6 months
- Does not apply to all, but common themes:
  - "Interface Suggestion Documents" vs. ICD, lack of CM, slow response to issues
  - On orbit issues due to lack of rigor in design process (lack of fault detection, materials/process issues)

- In hindsight
  - More oversight and insight, figure out early which vendors need more attention and scrutiny
  - Higher-level FDC logic in s/c FSW can help mitigate problems on-orbit ← this has been a key CYGNSS driver since launch
  - More thorough component in the loop testing, and end-to-end testing
  - ***CubeSat component price tag is not the total price***

Impact of NASA Standard Processes on Small Missions

Requirements for margins/reserves, EVM, and mandatory mission reviews are proven to enhance the likelihood of success, but are largely agnostic to mission class. For small, fast-paced missions, some standard processes may actually add risk. A few examples:

- Overly conservative mass margin can preclude addition of redundancy and result in unnecessary complexity
  - CYGNSS ended up flying 4 kg ballast mass (14% of Observatory mass)
  - If maturity allows, mass could be used to reduce risk in other areas, particularly those that can only be implemented in the design phase
- Required funding reserve can drive decisions away from a direction that would reduce technical risk
  - CYGNSS should have flown dual star trackers
  - Early decisions in the design phase have lasting impacts; spending money early may afford technical robustness and reduced risk later in the project
- Do not take the wrong message
  - Standard processes exist for good reason
  - Tailoring requirements is a possible avenue, but takes time and can be tough to get all stakeholders on board
  - Spending reserves early is NOT a slam dunk; reserves WILL be needed late in the project
  - Look for early “investments” that will yield greatest returns
  - Identify cost/benefit disconnects and work through them with mission management ASAP

Thorough Testing Cannot be Stressed Enough

Despite all competing forces associated with a small mission, it is absolutely essential that end-to-end test strategy be planned, from project inception, as an integral part of the development process. This requires support from each group contributing to the mission from subsystem engineers, to AI&T, to the operations team.

- A few major CYGNSS issues
  - "Closing the loop" between ADCS sensors and effectors in a way realistic enough to thoroughly test the HW, SW, and algorithms
  - Not running long enough duration tests that would have exposed obvious problems pre-launch
  - Not sticking to the test-as-you-fly fly-as-you-test manta best as possible in all situations
- CYGNSS Saving Grace: The most flight-critical functions were designed to be as simple as possible, involving the minimum set of components, were thoroughly and independently reviewed, and thoroughly tested, repeatedly
- Accuracy and fidelity of test environments can be large cost driver, but the critical importance of those factors was repeatedly demonstrated on CYGNSS
- The operations team brings invaluable perspective to the test process and their early involvement is key
- **The value of running a test is not fully realized until all of the data from that test have been thoroughly examined, not only for what is expected from the test, but for what is not expected in the test**

Good Luck!