ARMD Transformative Aeronautics Concepts Program

# CONVERGENT AERONAUTICS SOLUTIONS PROJECT

## CLAS-ACT: Conformal, Lightweight Antennas for Aeronautical Communications Technology

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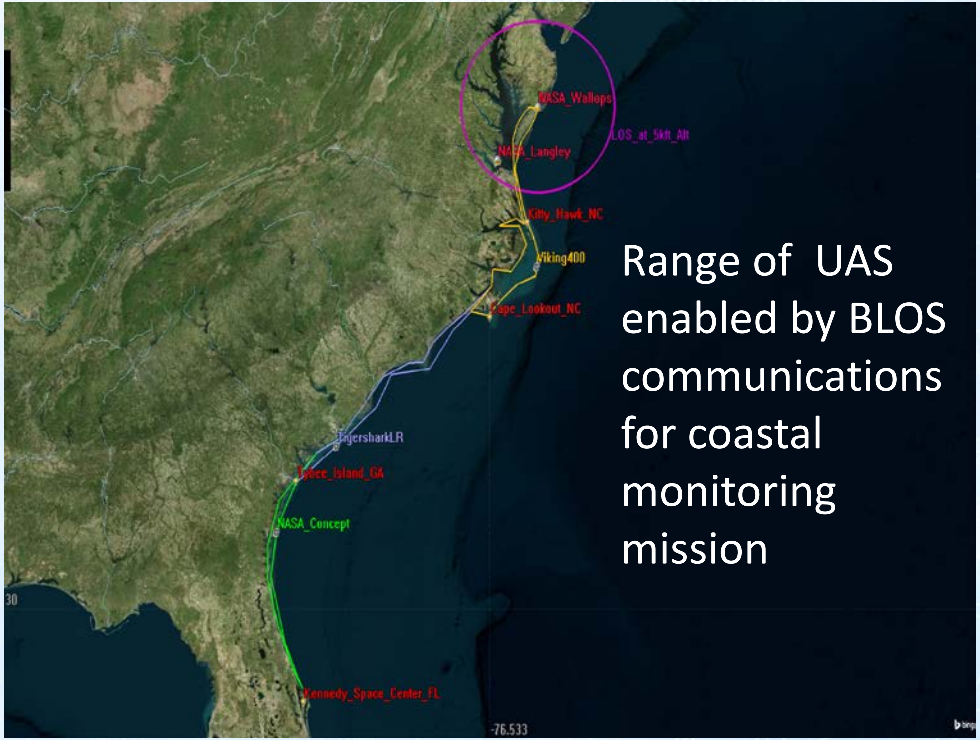
# Unmanned Air Systems (UAS) are increasing in use but range is mostly limited to line of sight

- Satellite Communication (SatCom) links would enable beyond line of sight (BLOS) coverage for UAS
- Currently only large UAS platforms can accommodate dish antennas
- Even so, they take up a lot of payload volume
- Smaller class UAS cannot accommodate SatCom Dish
- Solution: Conformal, Phased Array Antenna


Global Hawk/Northrop Grumman

ArticShark/Navmar Applied Sciences Corporation

# NASA UAS that could be BLOS enabled by CLAS-ACT antenna (445-800 lb)




L3 Viking 400

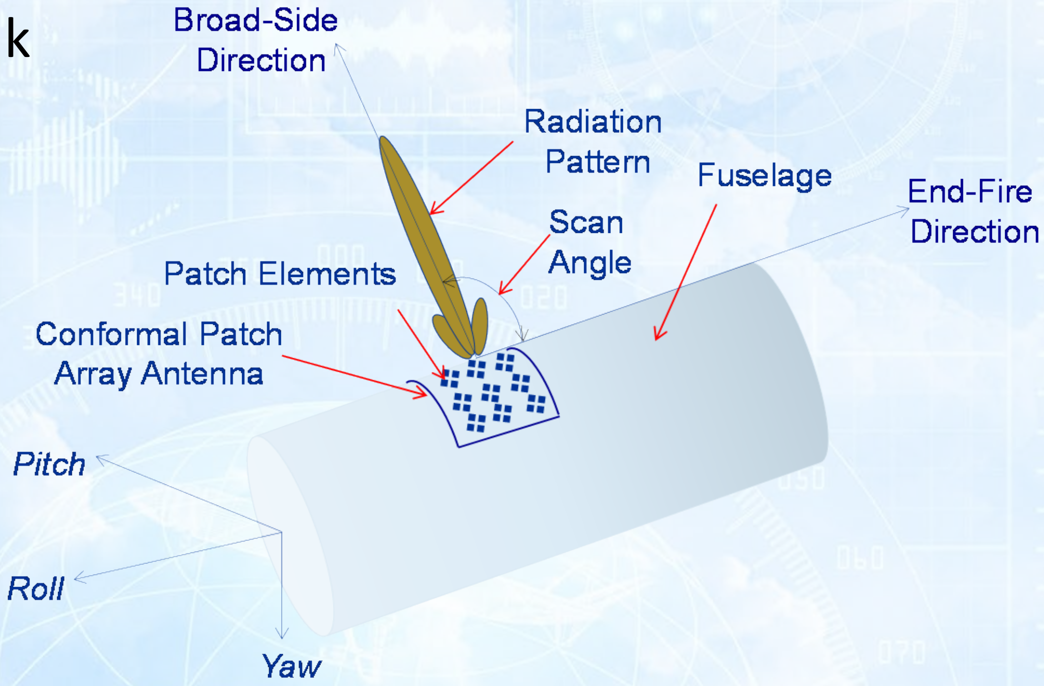
Navmar Tigershark XP

U.S. Navy/ NASA SIERRA

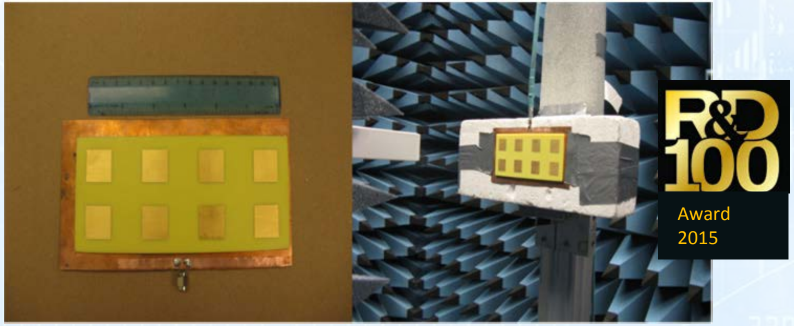
NASA (ASAB) Concept UAS

# What we are trying to do

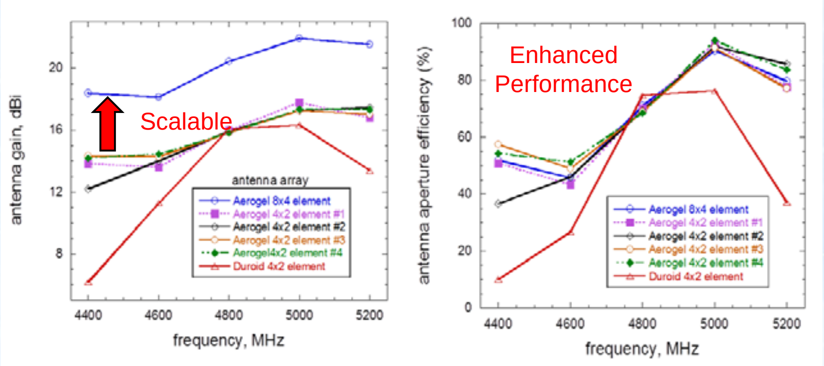
- Microwave antenna with high enough power for SatCom link
- Ultra low side lobes attenuated via electronic means to avoid interference with ground
- Built out of lightweight, low dielectric aerogels
- Conformal design to reduce drag and increase simplicity



# CLAS-ACT builds on aerogel antennas developed under Aero Seedling

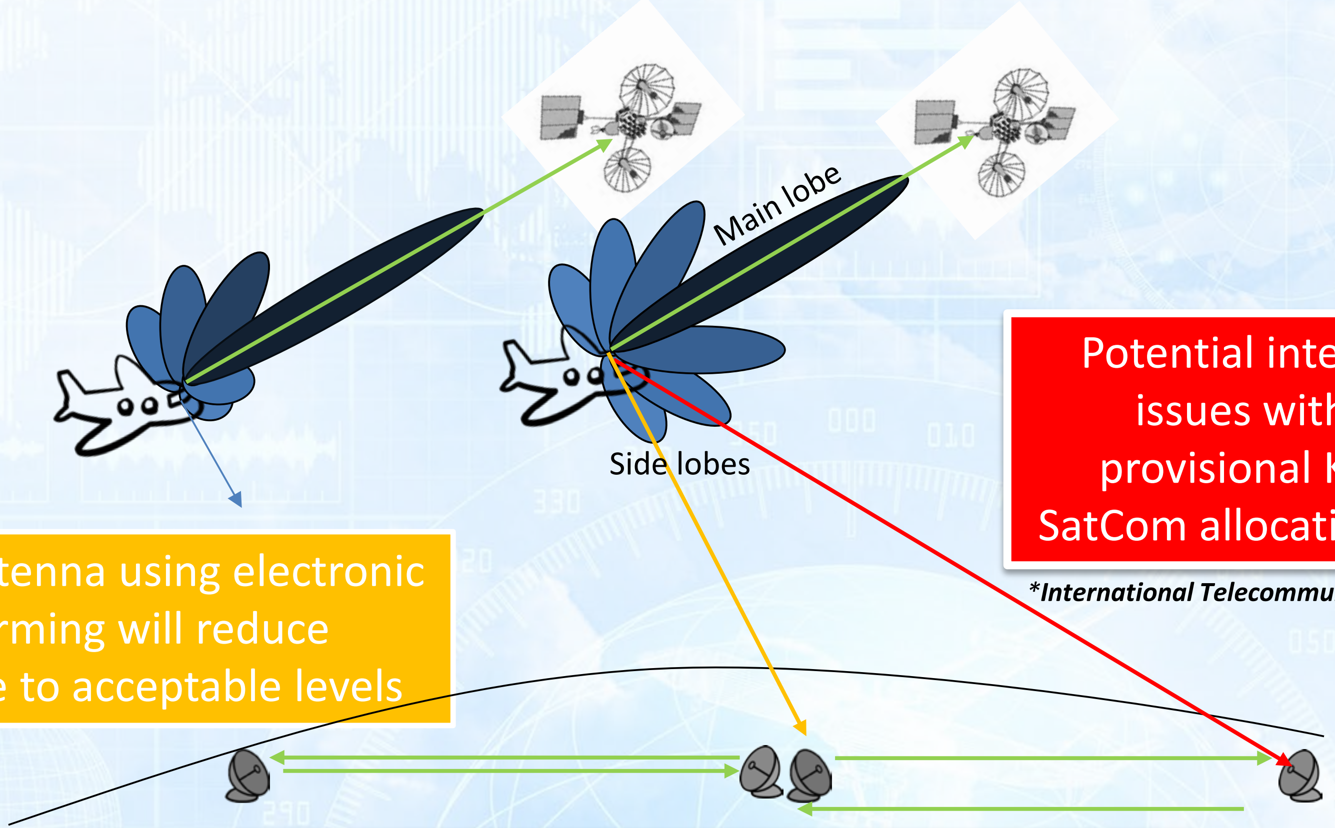



8 element array shown in far-field range




- As much as double the gain and efficiency achieved depending on frequency
- 77 % lower density than same antenna array from conventional substrates!!

# What difference will the CLAS-ACT antenna make?



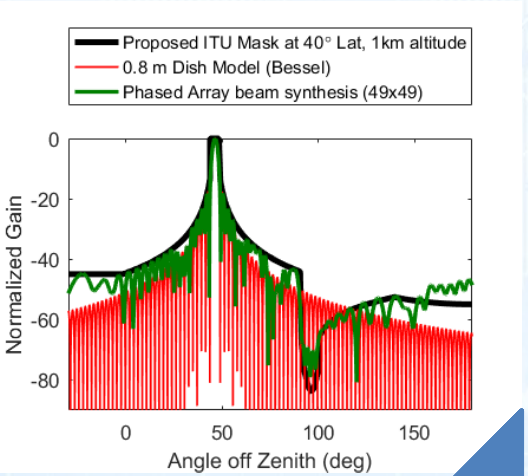

Potential interference issues with ITU* provisional Ku-band SatCom allocation for UAS

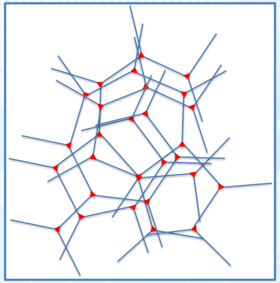
*International Telecommunication Union (ITU)

CLAS-ACT antenna using electronic beamforming will reduce interference to acceptable levels

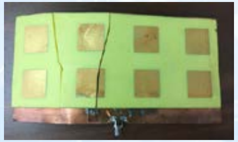
This will enable BLOS for small to medium UAS

# Goals and challenges



Rigid aerogel



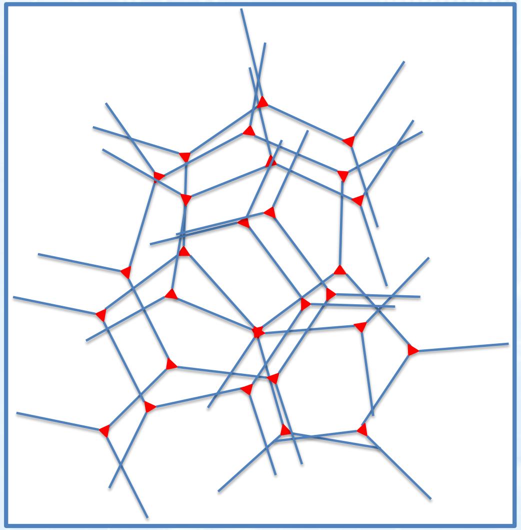
Broken antenna

Goal: Advance technologies for a Ku-band phased array antenna using an aerogel substrate to reduce SWaP (size weight and power) on UAS SatCom systems

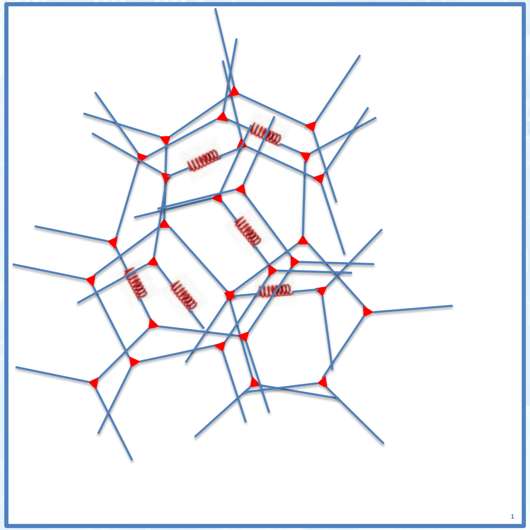
Challenge: Fabricate a tightly integrated antenna system after inventing a more flexible form of the aerogel

Challenge: Use phase array antenna beamforming to mitigate ground station interference for ITU compliance for UAS

# Where we are now:
# Making the aerogels more conformable



Rigid polymer backbone

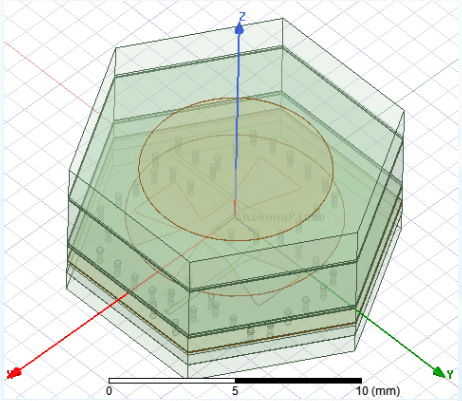


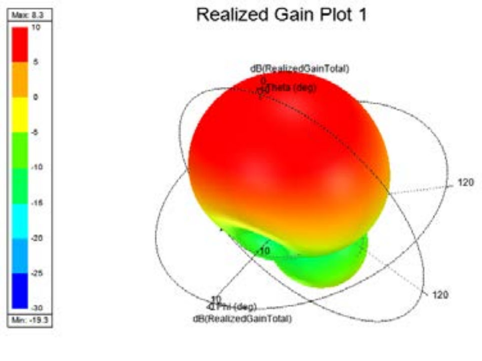
25 to 75 % flexible links included in polymer backbone

25 % of rigid links replaced by flexible links

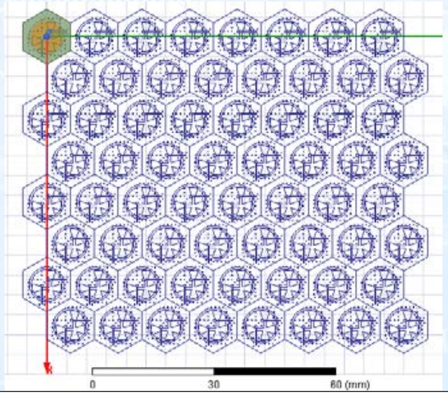
# Antenna Design Process

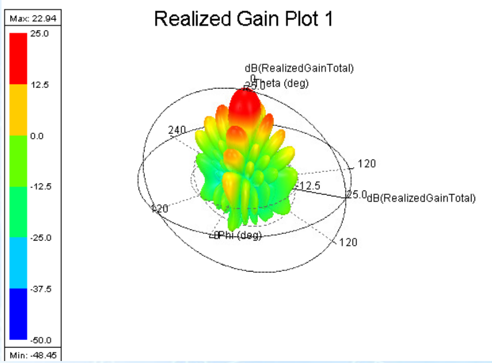
Circular Patch Element



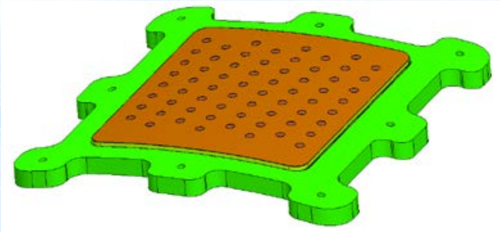



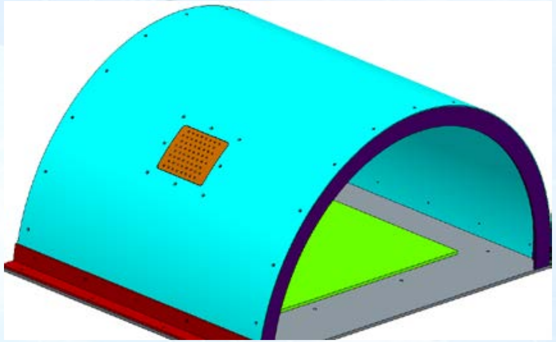

Triangular Lattice Sub-Array




Conformal Prototype Array for Flight Test

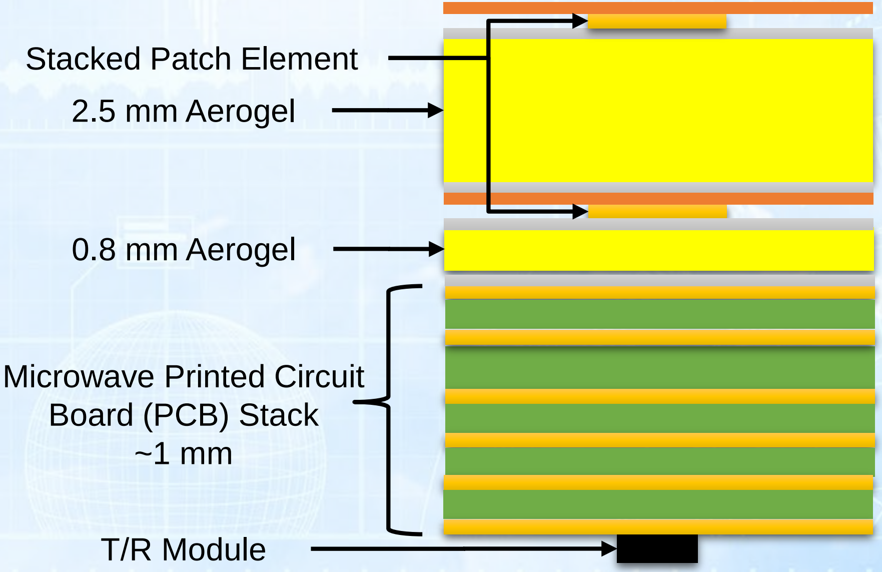


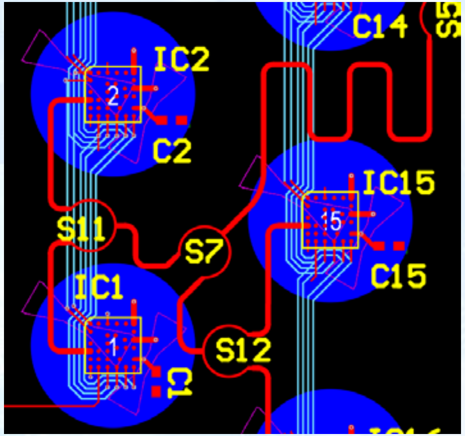


# Making an Antenna Lightweight & Conformal

**Phased array composition**

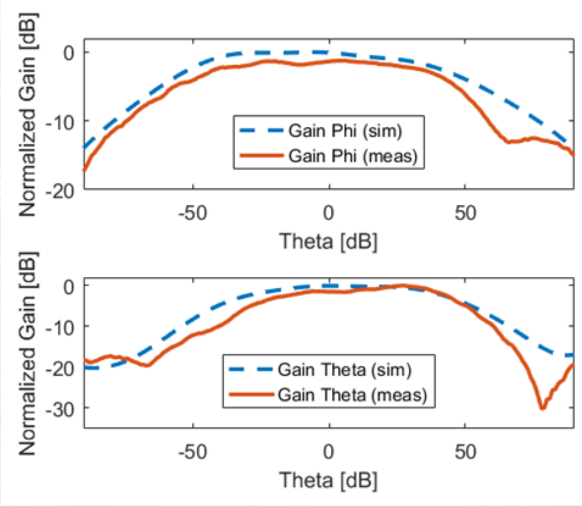
- Flexible aerogel layers (~3.3 mm) maximizes the benefits of the low dielectric constant
- Thin multi-layer stack of higher dielectric materials for the feed network
- Commercial transmit/receive (TR) chip modules provide electronic weighting of each element
- 64 element sub-array to demonstrate feasibility of 500-2500 element full scale antenna
- 50 % mass savings over conventional design

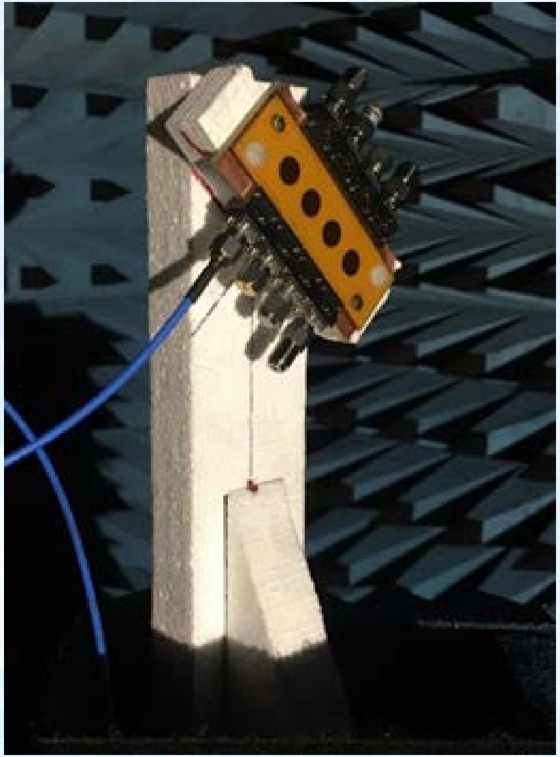


# First Antenna Array Prototype Tested

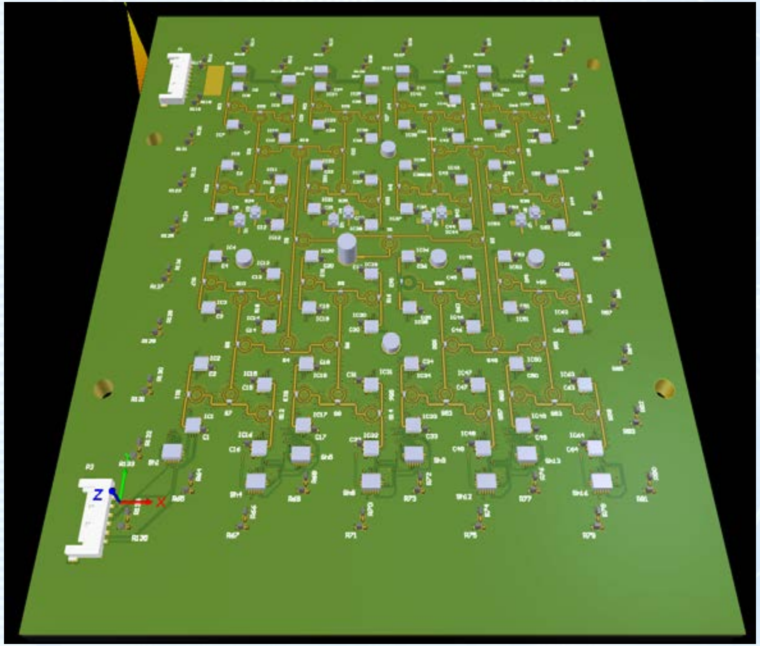
- Developed technique to align and bond the aerogel substrate with the radiating elements as well as a microstrip feed layer
- Tested in an anechoic chamber at Glenn Research Center (GRC)

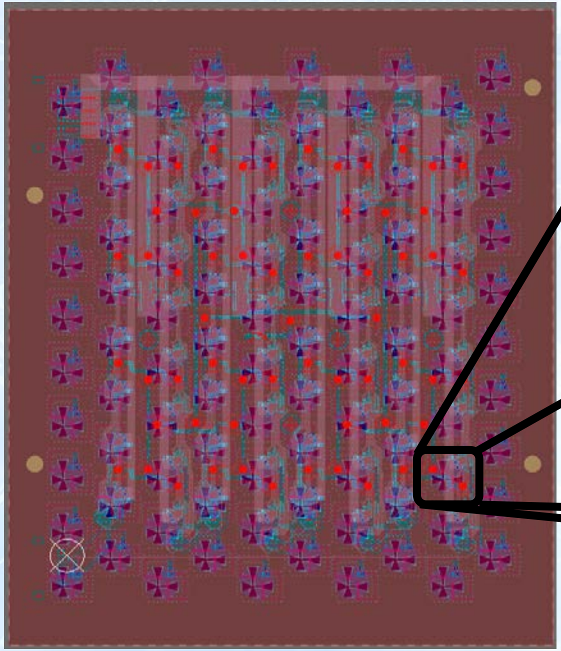


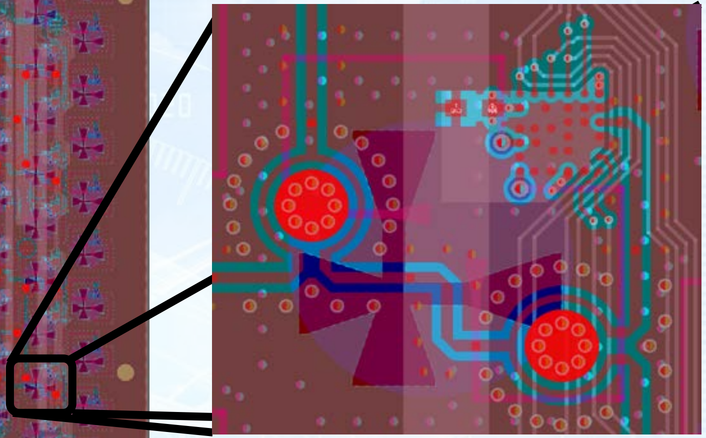



# Antenna Subarray Design for Fabrication

- Flight prototype antenna circuit board design fabrication underway.
- Anechoic chamber characterization planned late September



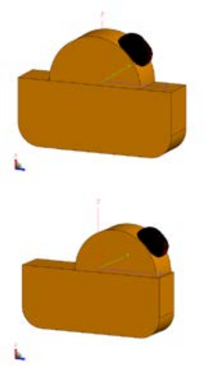


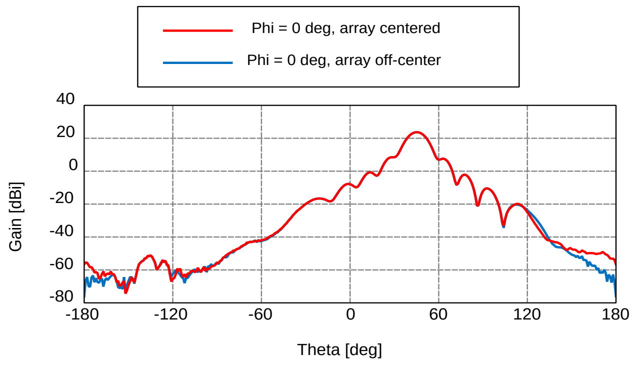


# Antenna Pattern Simulations

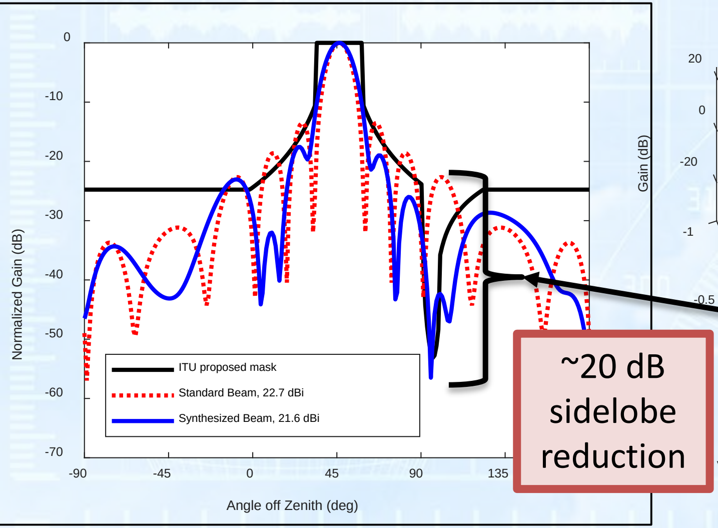
**Simulated performance of 64 element sub-array**

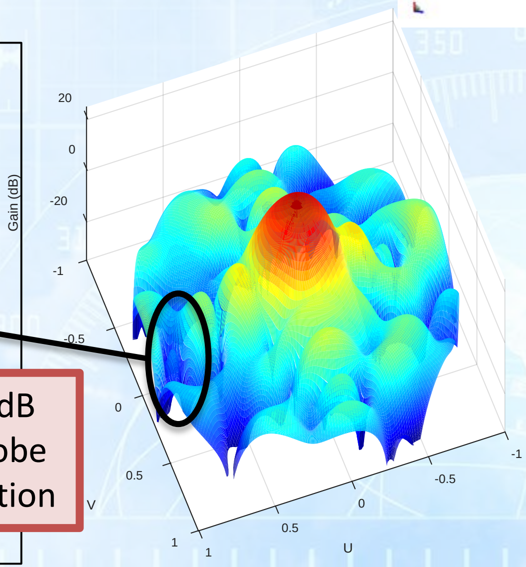
- Conformed to 16” radius
- Antenna-aircraft coupling effects
- Beam synthesis (with quantization) and null steering methods to meet ITU mask

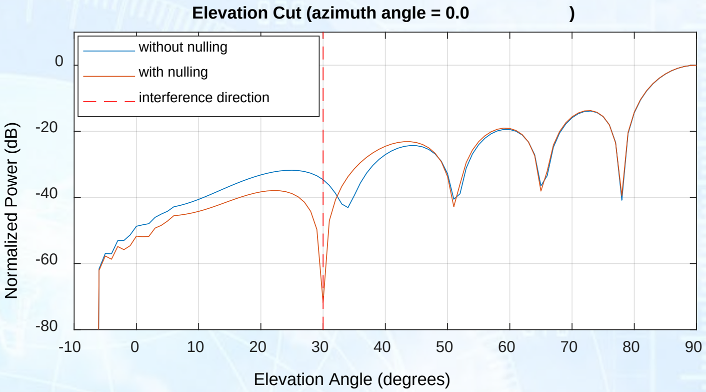





Placement of 8x8 Array on Aircraft

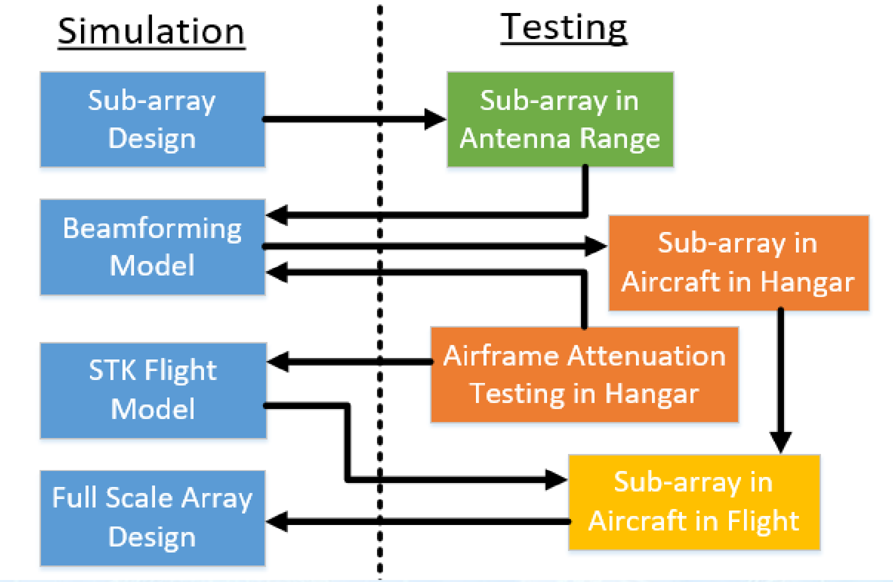



Null Steering of 8x8 Array

# Planned Testing of the CLAS-ACT Antenna




Antenna Array Simulation and Testing Flow Diagram

## Antenna Range testing – this Fall

- Capture the expected performance of the array including gain and beam steering pattern
- Validate performance after environmental testing (e.g. vibration)

## Hanger Testing on a UAS - January

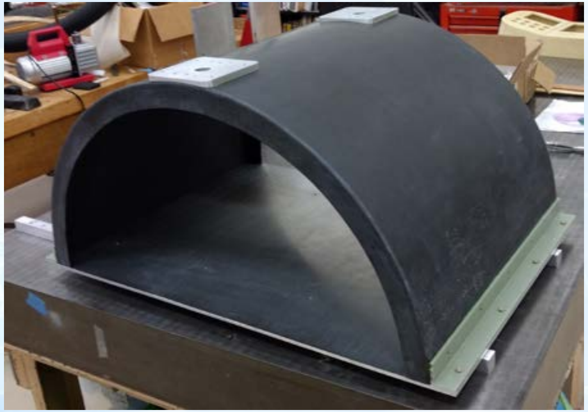
- Capture installed antenna performance, including fuselage/radome attenuation effects

## Flight testing on a UAS - February

- Capture antenna array performance and ground interference at low elevation angles (5º to 25º) during a UAS flight

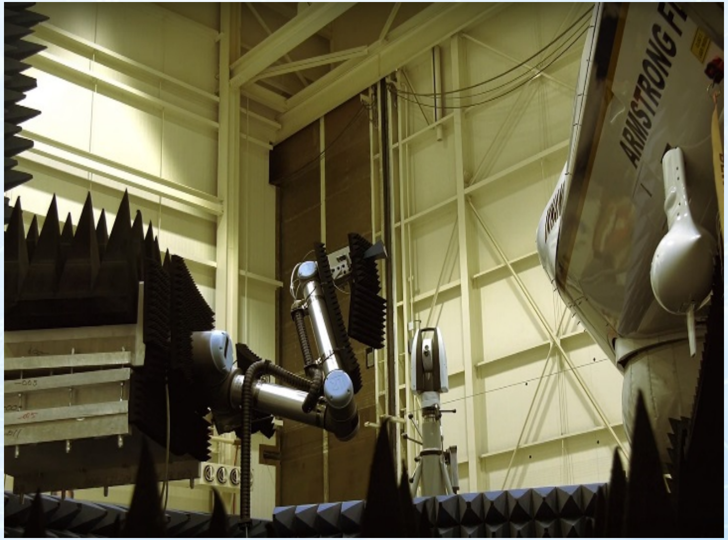
# Flight Test of CLAS-ACT Antenna on Global Hawk

- Working with Global Hawk team at Armstrong Flight Research Center (AFRC)
- Testing in restricted airspace around Edwards Air Force Base (AFB)
- Antenna will be mounted on simulated fuselage
  - Designed and built at Langley Reseach Center (LaRC)
- Mockup placed under radome inside the Global Hawk



# New Portable Antenna Metrology System

- Developed at GRC to characterize antenna in-situ
- Deployed robotic scanner to AFRC hanger
  - Brought antenna range to aircraft
  - Results on NASA's Ikhana aided ground station design
- Pre-flight testing of antenna on Global Hawk in Jan.



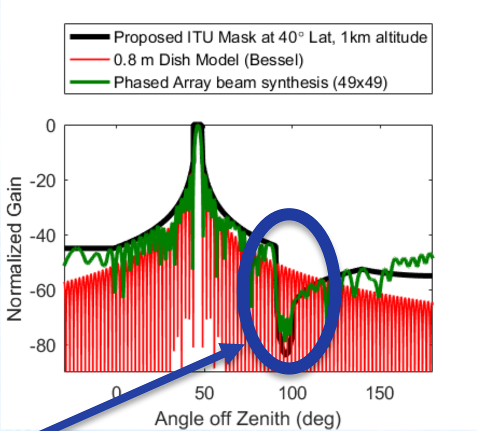
Collaborative robotic arm and laser tracker used to test antenna on UAS at AFRC

# CLAS-ACT Antenna In-Flight Characterization

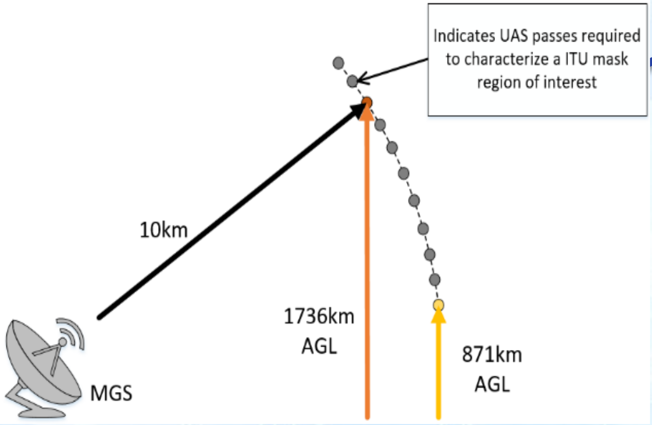
## Flight Testing on a UAS

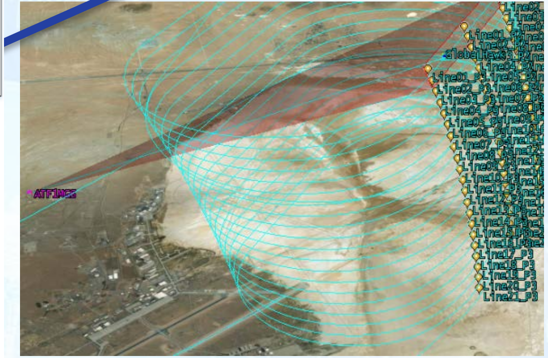
Measurement ground station (MGS) will capture antenna array performance and ground interference at low elevation angles (5º to 25º) during UAS flight

- Aircraft will fly paths of varying altitude and constant range
- Characterize installed antenna pattern
- Real world feasibility assessment of side lobe reduction




Challenge: ground stations sensitive enough to measure a signal specifically designed to be <u>very small</u>

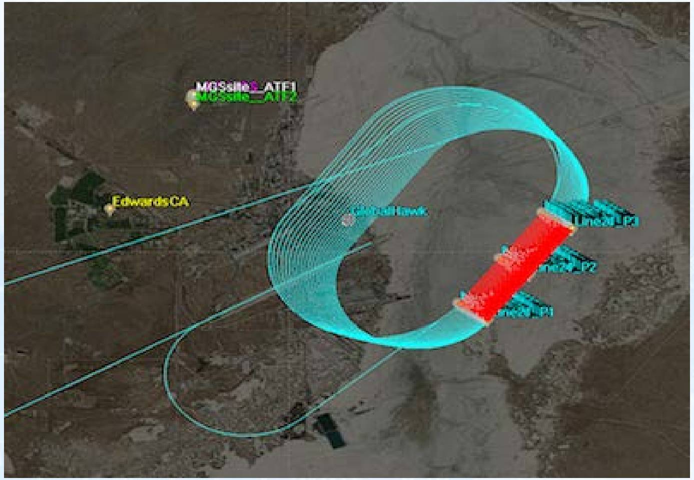


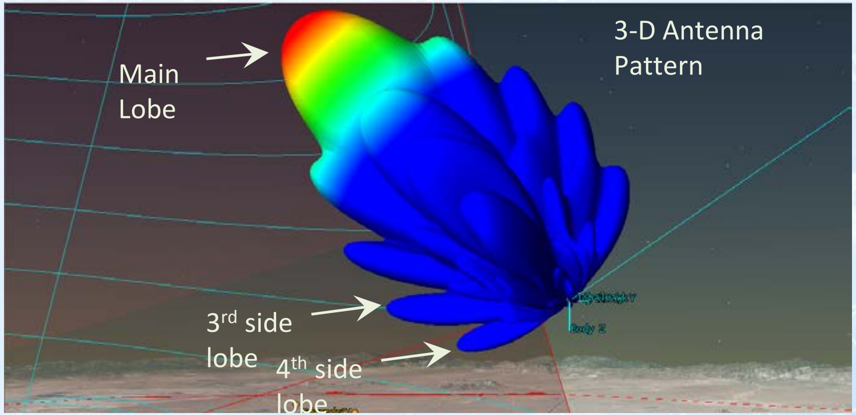



Example Flight Passes for Measuring a Region of the Antenna Pattern

# Proposed Flight Test Plan for Global Hawk

- Ames Research Center (ARC) developed realistic flight paths for low elevation passes
- -5 degree to -25 degree negative elevation wrt aircraft wing
- Input to Northrup Grumman to produce Final Mission Plan






- Sensitivity analyses
  - Wind effects on flight path and antenna measurements
  - Dynamic noise floor analysis
  - Position uncertainty effects on antenna measurements

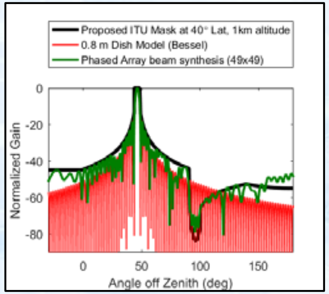
# CLAS-ACT Team

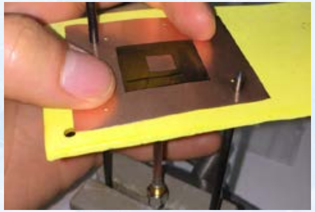
- James Downey
- Bryan Schoenholz
- Marie Piasecki
- Bushara Dosa
- Peter Slater
- Seth Waldstein
- Anne Mackenzie
- Bill Fredericks
- Scott Kenner
- Ray Rhew
- Mark Cagle
- Jeremy Smith
- Andy Gutierrez
- Patricia Martinez
- Ricardo Arteaga
- Kelly Snapp
- Rick Alena
- Aaron Cohen
- Baochau Nguyen
- Stephanie Vivod
- Haiquan Guo
- Jessica Cashman
- Rocco Viggiano
- Marcos Pantoja
- Kevin Cavicchi
- Dan Oldham

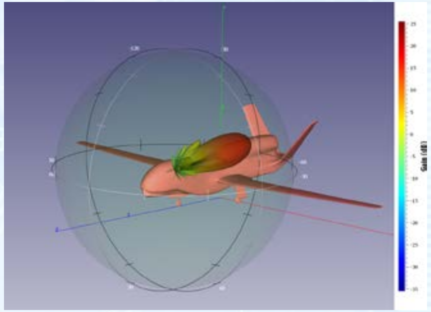
# Backup

# Conformal Lightweight Antenna Systems for Aeronautical Communication Technologies (CLAS-ACT)

- Lead Center & Partner Centers: **GRC**, LaRC, ARC, AFRC
- External Collaborators: University of Akron
- Aeronautics Barrier to Overcome: Reduce sidelobes to meet requirements for provisional Ku band use for UAS for Beyond Line of Site Communications
- ARMD Strategic Thrusts and associated Outcome(s) addressed:
  - Thrust 1: Safe, Efficient Growth in Global Operations
    - BLOS enabled conformable antennas for UAS will transform NAS through NextGen technologies
  - Thrust 3. Ultra-efficient commercial vehicles
    - Improved vehicle efficiency through reduced weight and drag
  - Thrust 6: Assured autonomy for aviation transformation
    - Enable continuous, system-wide information connectivity supporting autonomous operations
- Idea/Concept: Antennas which enable beyond line of sight (BLOS) command and control for UAS to take advantage of newly assigned provisional Ku-bands for UAS; Unique antenna designs to avoid interference with ground; Unconventional substrates to reduce weight; Conformal designs to reduce drag
- Feasibility Assessment: Demonstrate conformability of aerogel substrates and feasibility of fabrication; Demonstrate high directivity antenna with reduced sidelobes using beamforming
- Feasibility Assessment Criteria: 20 dB reduction is sidelobes; 1 m bend radius of aerogel
- Duration of Execution & total full-cost: 2.5 years & $3.5 M

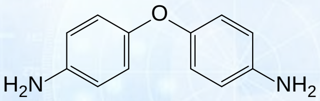


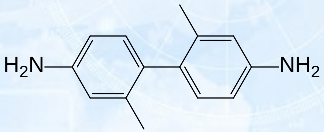


# Approach to more flexible aerogels

- Utilize aliphatic diamines to replace 25 to 75 mol % of aromatic diamine
- Goal is
  - More bendable aerogels in 2-3 mm thicknesses
  - Lowest dielectric constant
  - Best mechanical properties
  - Best moisture resistance
- Three different aliphatic diamines studied
- Modeled data from three studies to make comparison among them and come up with optimum formulation(s)

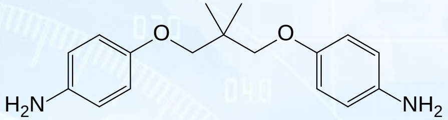


4,4'-oxydianiline (ODA)

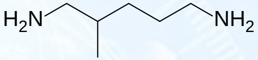


2,2'-Dimethylbenzidine (DMBZ)

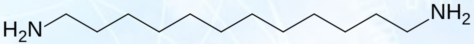
vs.



1,3-Bis(4-aminophenoxy)neopentane (BAPN)



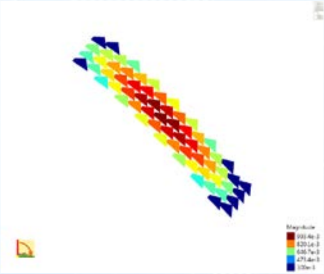
1,5-diamino-2-methylpentane (DAMP)



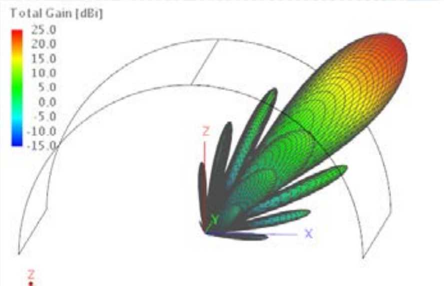
1,12-diaminododecane (DADD)

# Antenna Pattern Calculations

## Radiation Pattern for an 8x8 Array on A/C, Half Cylinder Approximation for A/C Body

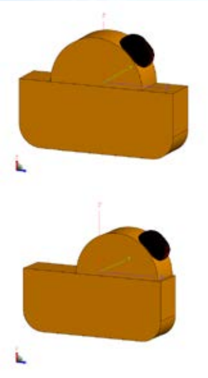


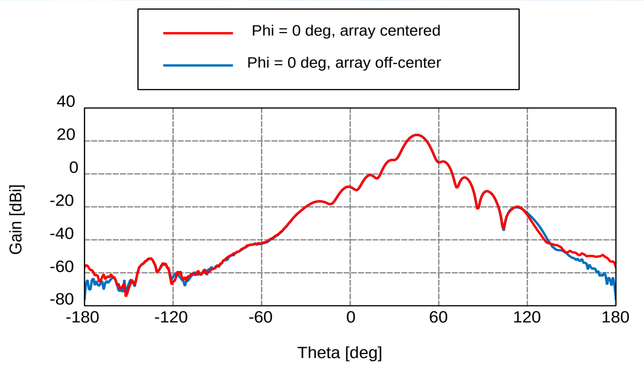
Array layout on half-cylinder platform, 16- in. radius




3-D Gain pattern

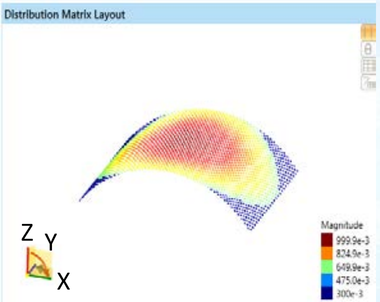
## Placement of 8x8 Array on Aircraft



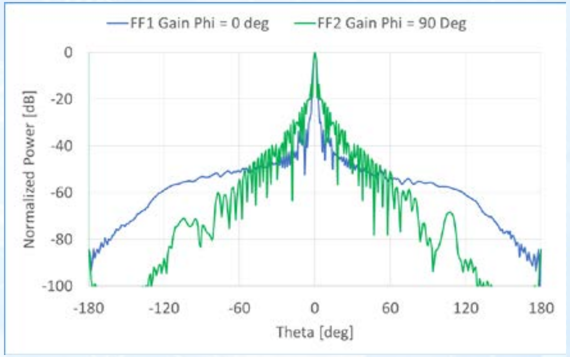



## Null Steering of 8x8 Array to Avoid Interference


## 50x50 Array Pattern With a 2° Beam Width, Cylindrical Approximation for A/C Body



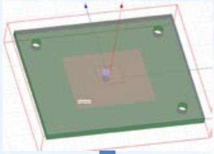

Array layout on cylindrical platform, 16- in. radius.

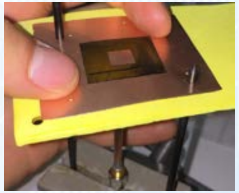



Normalized power pattern in two planes.

# Antenna Fabrication in progress

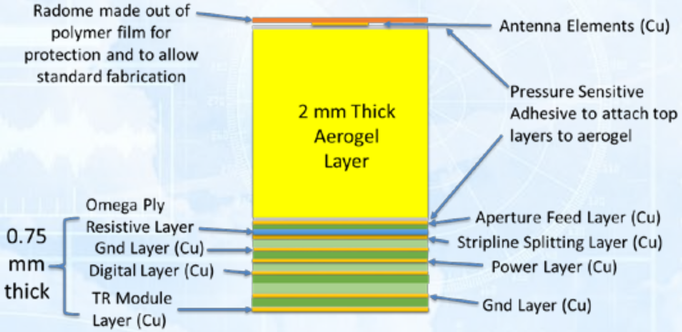
Antenna Design



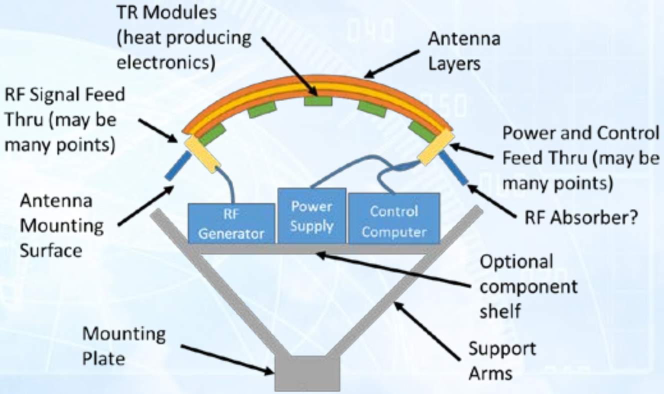


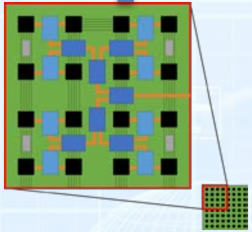
Fabrication


Multi Layer Bonding

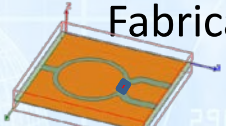

50 % weight savings over same array made with conventional substrate



Control Design

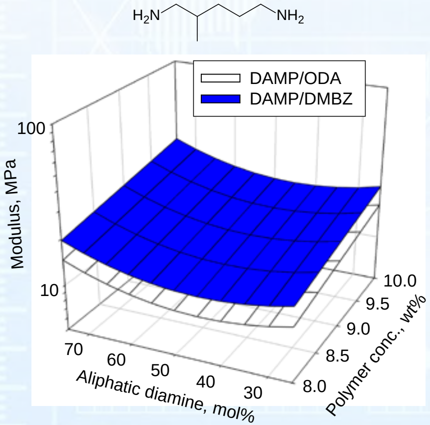
Control Circuit Fabrication

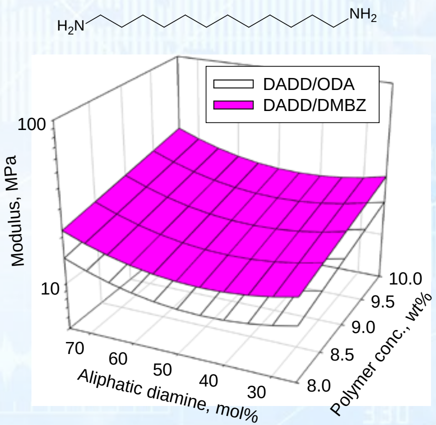


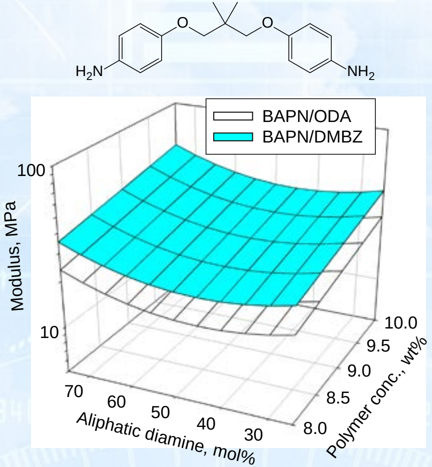
Splitting Network

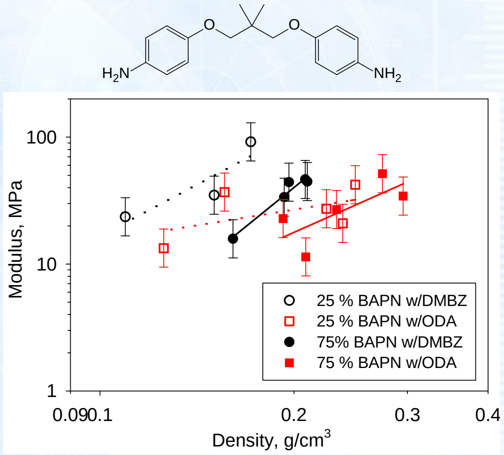
TR Module

# Effect of aliphatic diamine content on modulus




- Modulus is effected by the increase in density as aliphatic content increases
- DMBZ backbone has higher modulus than ODA even at lower density
- Picture shows DMBZ with 25% BAPN

# High Data Rate Satellite Communications for 500 lbs. MTOW Class UAS

- 500 lbs. MTOW class UAS cannot accommodate a satellite dish antenna due to system weight and volume
  - Ku band 48” dish antenna and associated communications equipment weight is 168 lbs. as fitted to Global Hawk.

- Iridium satellite systems offer global reach and are compact and light enough for Group 3 UAS
  - A single iridium channel is only 2.4. kb/s per channel; useful for command and control but generally insufficient bandwidth for most sensor data
  - Note that Iridium NEXT will support up to 1.4 Mbps

- For these reasons most Group 3 UAS are operated within line of site (LOS) of a ground station
  - LOS is 150 km for an aircraft at 5000 ft. altitude assuming a ground station antenna height of 10 m

- CLAS-ACT enables Group 3 UAS to accommodate an antenna that supports high data rate (~25 Mb/s) communications via geostationary satellites, enabling beyond line-of-site operations with real time sensor-data monitoring

Note: D.O.D. UAS Group 3 is 55 lbs. to 1320 lbs.

# UAS for CLAS-ACT

- There are very few UAS currently available in the flight regime between relatively small (10 lb. payload) and very large (1500 lb. payload)

- The lack of medium sized UAVs is likely due to restrictive regulations and because many of the potential missions can be performed with manned aircraft
  - Current FAA regulations require a Certificate of Authorization (COA) to fly UAVs over 55lbs. beyond visual range within the region of jurisdiction of the FAA
  - Currently, a COA is very unlikely to be granted for flying a large UAV over populated regions
  - It is often expedient to use a manned aircraft, rather than obtain a COA even though using a manned aircraft is potentially more expensive and restricted in endurance to a maximum of 12 hours or so
  - In the future, advanced autonomy that includes sense and avoid, plus proven very high reliability is expected to allow operation of all sizes of UAVs within the NAS

# UAVs for CLAS-ACT

L3 Viking 400

No longer in production but NASA has several available for science missions

| Dimensions | | Weights | | Performance | |
|---|---|---|---|---|---|
| Wingspan | 20 ft. | MTOW | 540 lbs. | Range | 560 nmi |
| Length | 15 ft. | Payload | 100 lbs. | Endurance | 8 h |
| Wing Area | 43.7 $ft^2$ | Sat Comm | | Airspeed | 70 kts |
| Aspect Ratio | | Empty Weight | 337 lbs. | Altitude | 15,000 ft. |
| Engine Size | 36 HP | Fuel Weight | 150 lbs. | | |

Navmar Tigershark XP Long Range

Navmar claim beyond line-of-sight capable. Variants of this UAV are widely used by the D.O.D.

| Dimensions | | Weights | | Performance | |
|---|---|---|---|---|---|
| Wingspan | 30 ft. | MTOW | 800 lbs. | Range | 1200 nmi |
| Length | | Payload | 150 lbs. | Endurance | 15 h |
| Wing Area | | Sat Comm | | Airspeed | 80 kts |
| Aspect Ratio | | Empty Weight | | Altitude | 20,000 ft. |
| Engine Size | | Fuel Weight | 180 lbs. | | |

U.S. Navy/ NASA SIERRA

Experimental aircraft, limited availability. Presumably additional aircraft could be built.

| Dimensions | | Weights | | Performance | |
|---|---|---|---|---|---|
| Wingspan | 20 ft. | MTOW | 445 lbs. | Range | 600 nmi |
| Length | 12 ft. | Payload | 100 lbs. | Endurance | 10 h |
| Wing Area | | Sat Comm | | Airspeed | 60 kts |
| Aspect Ratio | | Empty Weight | | Altitude | 12,000 ft. |
| Engine Size | | Fuel Weight | | | |

NASA (ASAB) Concept UAV

This is a conventional design powered by a small diesel engine

| Dimensions | | Weights | | Performance | |
|---|---|---|---|---|---|
| Wingspan | 30 ft. | MTOW | 500 lbs. | Range | 1530 nmi |
| Length | 16 ft. | Payload | 50 lbs. | Endurance | 28 h |
| Wing Area | 62.5 $ft^2$ | Sat Comm | 75 lbs. | Airspeed | 55 kts |
| Aspect Ratio | 15 | Empty Weight | 275 lbs. | Altitude | 20,000 ft. |
| Engine Size | 50 HP | Fuel Weight | 100 lbs. | | |

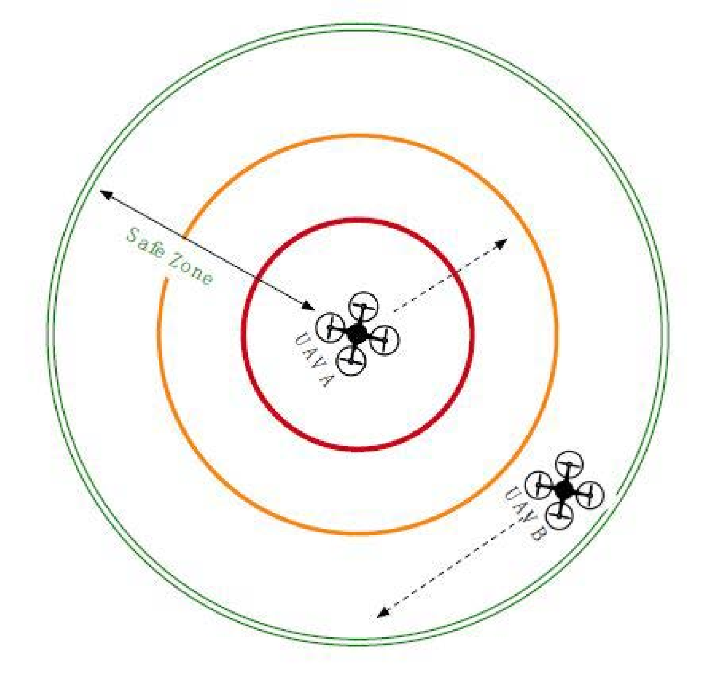
# Missions for 500 lbs. Class UAVs

- There are many potential missions for medium sized UAVs; one example is coastal monitoring
  - Harmful algae blooms
  - Turbidity
  - Water temperature (input for weather forecasting)
  - Pollution, e.g. oil spills
  - Photogrammetry, to monitor erosion over time
  - Disaster assistance, hurricanes
  - Marine life monitoring (e.g. whales, turtles)
  - Safety and security (Coastguard reconnaissance)

- Instrument package (weight < 50 lbs.)
  - Hyperspectral imager
  - High definition video and still camera
  - Thermal camera
  - Data processing computer
  - Data storage

# GT study: CLAS-ACT Benefits Summary

- Increased responsiveness: ability to quickly and effectively communicate with aircraft
- Airspace management: quickly and easily redirect UAVs to prevent accidents
- Increased efficiency, communication, and coverage in swarm applications
- Vehicle health and performance monitoring




Source: Development of Cloud-Based UAV Monitoring and Management System

# GT study: Some examples of UAV mission types and impact from CLAS-ACT antenna

| Relative Score | Mission | Examples | CLAS-ACT benefits summary |
|---|---|---|---|
|  | First Responder and Emergency Support | •Search and rescue<br>• Fire fighting<br>• Medical assistance<br>• Supplies delivery | • Recognition of situation changes<br>• Remotely providing help and support (supplies and instructions) |
|  | Disaster relief | • Rapid response<br>• Rescue assistance<br>• Disaster modeling | • Visualize and locate site and severity of disaster<br>• Instant situation updates in harmful environments<br>• Independence from ground-based systems that may be damaged |
|  | Scientific | •Volcano measurement<br>•Species monitoring<br>•Fishing and oceanic<br>•Extreme environments | • Real time data gathering<br>• Fast and accurate responder<br>• Minimal human risk and interaction |
|  | Package delivery | •Mail<br>•Commercial and private delivery | • Real-time tracking<br>• Fast and accurate redirection |

# GT study: Surface area, drag, weight of CLAS-ACT antenna

- Surface area
  - Assuming a steady 30°bank angle turn the required area increases by 15% to 0.29 m2(3.11 ft2)
  - Smallest size UAV (ThunderB) has a wing area >6x larger than this (~2 m2)
- Drag
  - Thickness of 1 cm
  - Will require a ramp to ensure lift not affected
  - Estimated drag increase <1% if applied to entire wing of smallest vehicle
- Weight
  - For required area the weight is 0.87 kg (1.9 lb)
  - Smallest UAV has a payload of ~8.8 lb

http://www.bluebird-uav.com/wp-content/uploads/2014/07/SpyLite-GDT-710x375.jpg