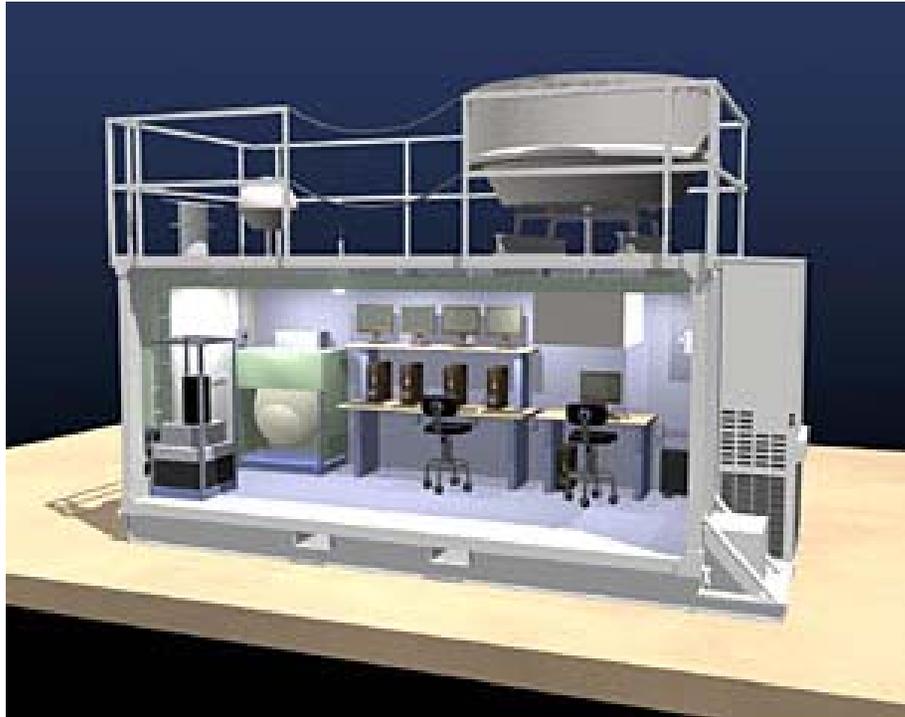


The ARM Mobile Facility (AMF) and UAV Program

Jeff Gaffney- Rick Petty (DOE, OBER)



Spring 1999 - Kauai, Hawaii
Science flights over 55,000 feet

<http://www.arm.gov/sites/amf.stm>

<http://armuav.ca.sandia.gov/armuav.html>



Operational Experience with ARM-UAV Payloads for Climate Research Applications

**Will Bolton
Sandia National Laboratories
Livermore, California**

Topics for this presentation

- **Review of ARM-UAV Program**
- **Payload and operational experience**
 - **Moving toward modularity and “commercial off the shelf”**
 - **Multiple, reasonable-cost communication options**
 - **Mission monitoring and control displays**
 - **What worked**

ARM-UAV Program objectives

The ARM-UAV Program was established by DOE to...

- Address the largest source of uncertainty in global warming: the interaction of clouds and solar/thermal energy
- Support the climate change community with valuable data sets
- Develop measurement techniques and instruments suitable for use with the new class of high altitude, long endurance UAVs
- Demonstrate these instruments and measurement techniques in field measurement campaigns

Aircraft and payload requirements are based on measurement needs:

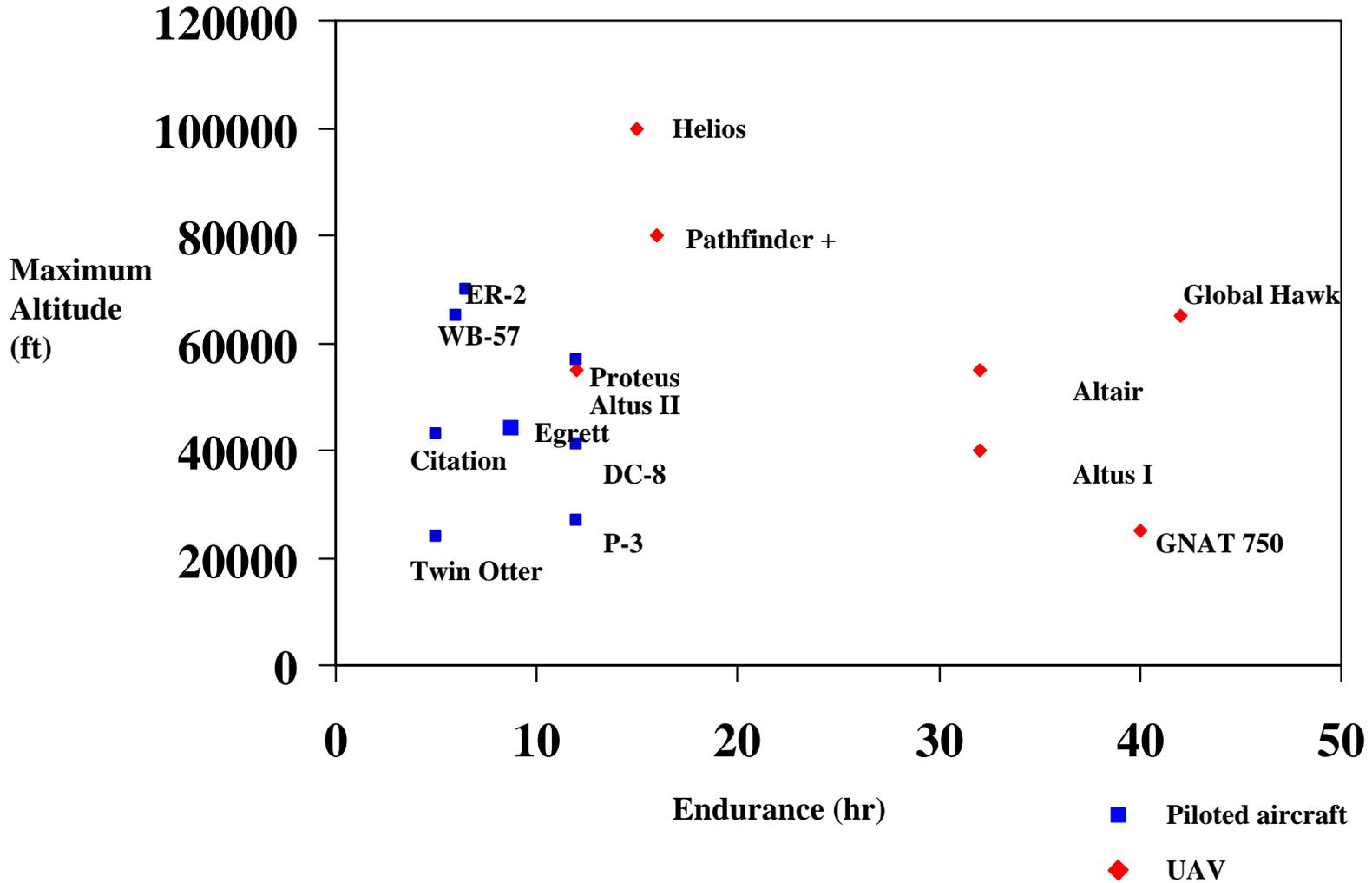
Altitude - ~ 60,000+ ft (above tropical cirrus clouds)

Endurance - \pm 2-3 hours from solar noon = 8 hours (radiometric measurements)

Payload weight - 175+ kg (adequate for radiometric and in situ instruments)

Electrical power - ~ 50+ amps @ 28 v (highly variable depending on instruments)

High altitude, long endurance aircraft options





ARM-UAV has conducted ten major field campaigns

Field Campaigns to date:

- Fall 1993, Edwards AFB, CA
- Spring 1994, Northern OK
- Fall 1995, Northern OK
- Spring 1996, Northern OK
- Fall 1996, Northern OK
- Fall 1997, Northern OK
- Spring 1999, PMRF Kauai, HI
- Summer 1999, Monterey, CA
- Winter 2000, Northern OK
- Fall 2002, Northern OK

Proteus (F02)



**Grob "Egrett"
(F95, S96)**



**GA-ASI "Altus II"
(Su99)**

**GA-ASI "GNAT 750"
(F93, S94)**



GA-ASI "Altus I" (F96, F97)



**Twin Otter
(F93, S94, F95, S96, F96,
F97, Sp99, Su99, W00)**



Proteus performance characteristics



Altitude record (10/25/00):	62,786 feet (peak) 61,919 feet (sustained) 55,786 feet (w/1000 kg payload)
Ceiling w/ARM-UAV payload:	Approx. 52,000 feet
Stall speed:	65 knots
Top speed:	250 knots/M=0.6
Mission duration:	Approx. 12 hours
Payload electrical power:	30 kW; demonstrated 600 A @ 60 kft

Current ARM-UAV payload instruments

The payload consists of 12 major instruments:

Remote sensing -

Cloud Detection Lidar

Compact Millimeter wave Radar

Spectral Radiance Package (SRP)

Scanning-High-resolution Interferometer Sounder (S-HIS)

Solar Spectral Flux Radiometer (SSFR)

Modified CM-22 and CG-4 Kipp & Zonen radiometers

Diffuse Field Camera (DFC)

In situ -

Nevzorov Probe

Cloud, Aerosol, and Precipitation Spectrometer (CAPS)

Video Ice Particle Sampler (VIPS)

Cloud Integrating Nephelometer (CIN)

Dew- and frost-point hygrometers

These instruments place a variety of constraints on payload design

Recent additions to ARM-UAV payload instruments

Instrument	Description	Lead organization
Compact millimeter-wave radar (CMR)	95 GHz cloud radar	University of Massachusetts-Amherst
Cloud, Aerosol, and, Precipitation Spectrometer (CAPS)	Cloud particle size measurement, 0.3 μm to over 1.5 mm	Droplet Measurement Technologies
Cloud Integrating Nephelometer (CIN)	Cloud optical extinction characteristics	Geber Scientific, Inc.
Nevzorov Probe	Cloud liquid/total water content	Sky Tech Research, Inc.
Video Ice Particle Sampler (VIPS)	Cloud ice particle morphology, 5 to 150 μm	NCAR

CMR



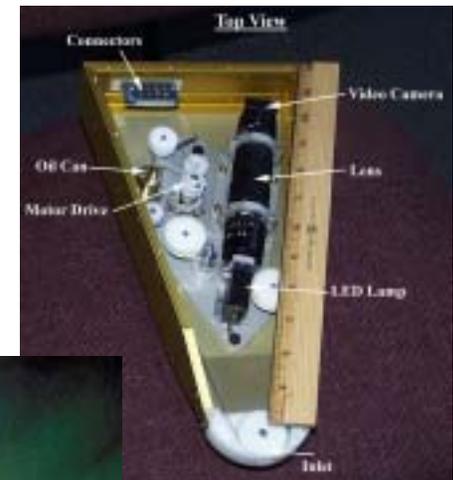
CAPS



CIN



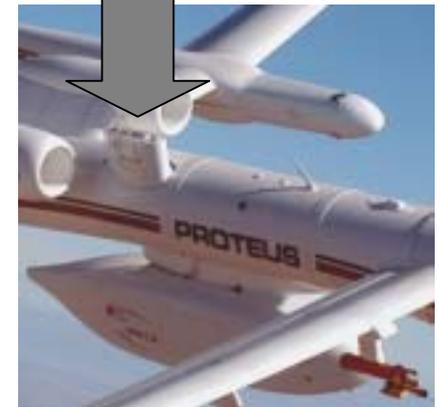
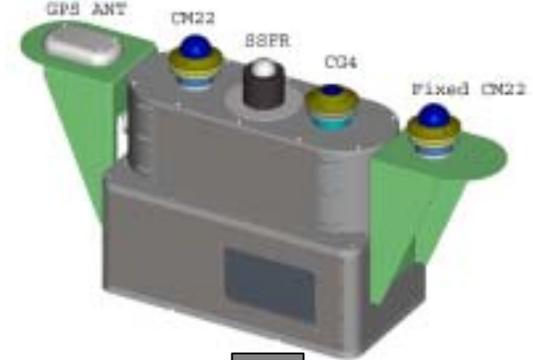
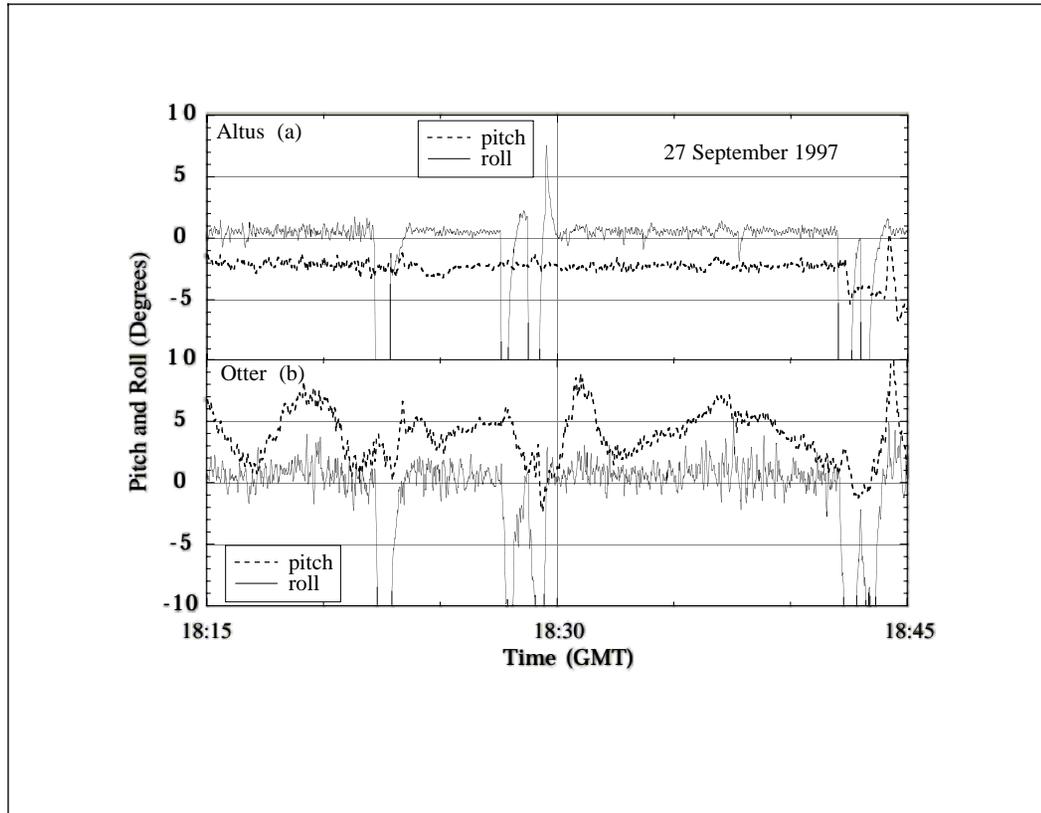
Nevzorov



VIPS

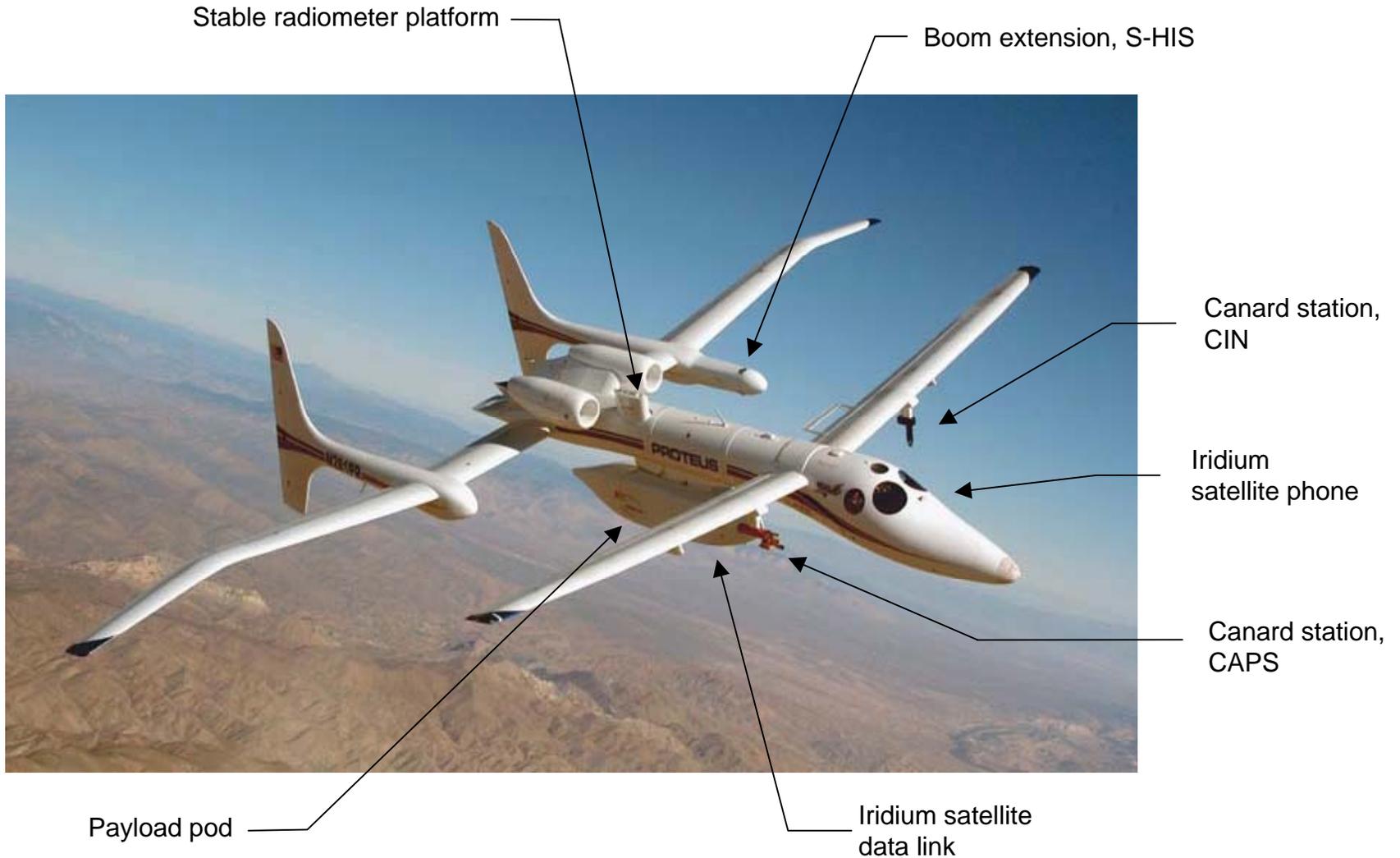
Stabilized radiometer platform improves measurements

Stabilized radiometer platform prevents small-scale angular motion

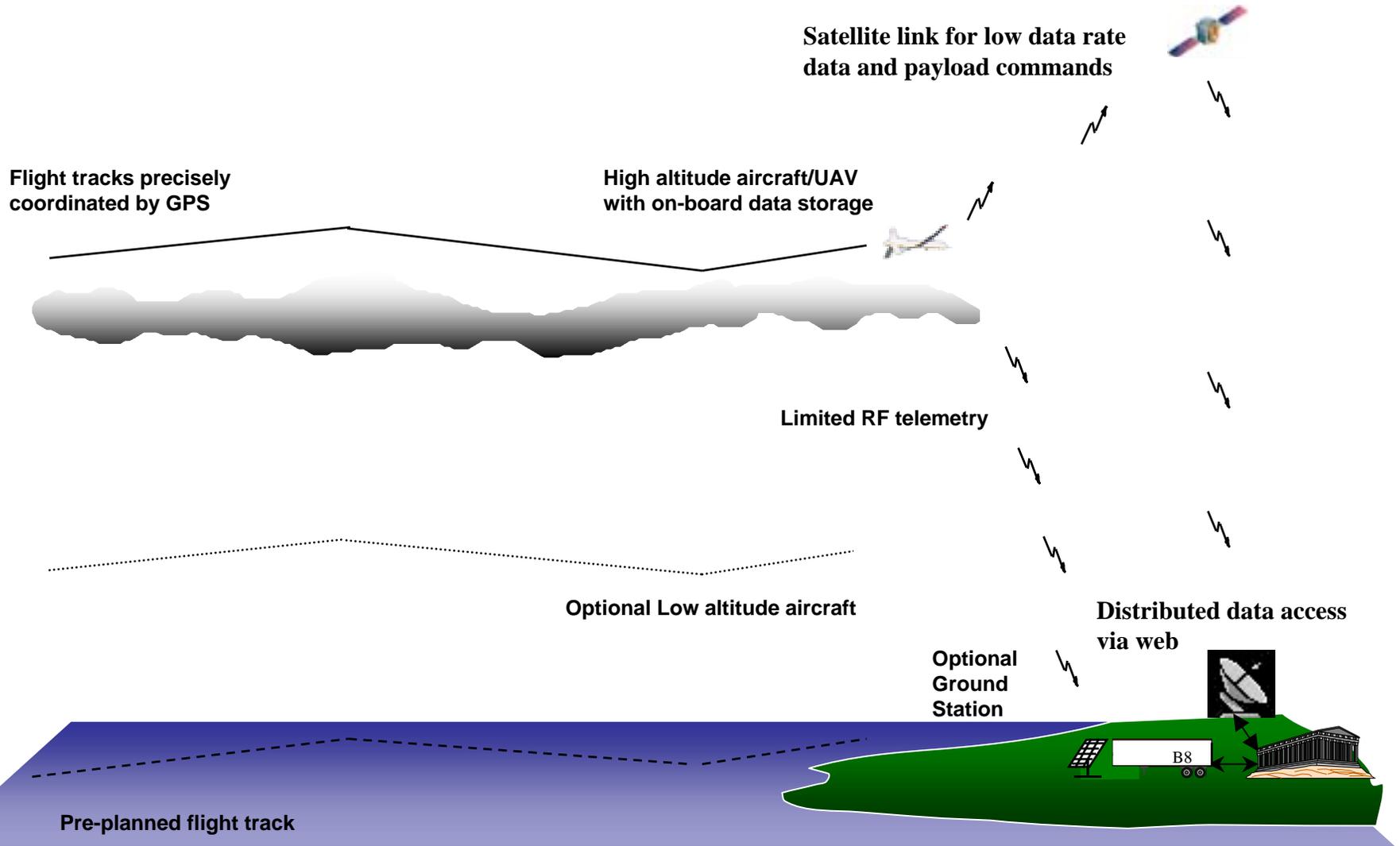


Angular stability is important for radiometric measurements

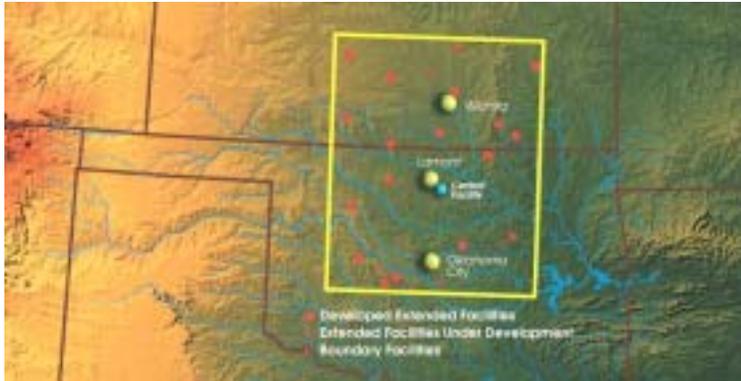
ARM-UAV/Proteus payload arrangement



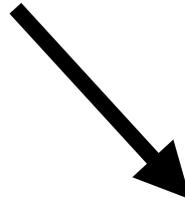
Arrangements for recent and future ARM-UAV deployments



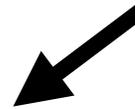
The ARM-UAV “Grand Tour”



Southern Great Plains - Oct/Nov 2002
Cirrus cloud tops
Microphysical properties



North Slope of Alaska - October 2004
Arctic cirrus properties
Surface melt radiation budget



Darwin, Australia - February 2006
Tropical cirrus clouds

ARM-UAV mission control and display capabilities

Mission Controller monitors and controls payload by three means:

- Ethernet direct connection (hangar/ramp only)
- RF modem (line-of-sight, \leq about 30 miles from base)
- Low data rate/low cost satellite data link (Iridium)

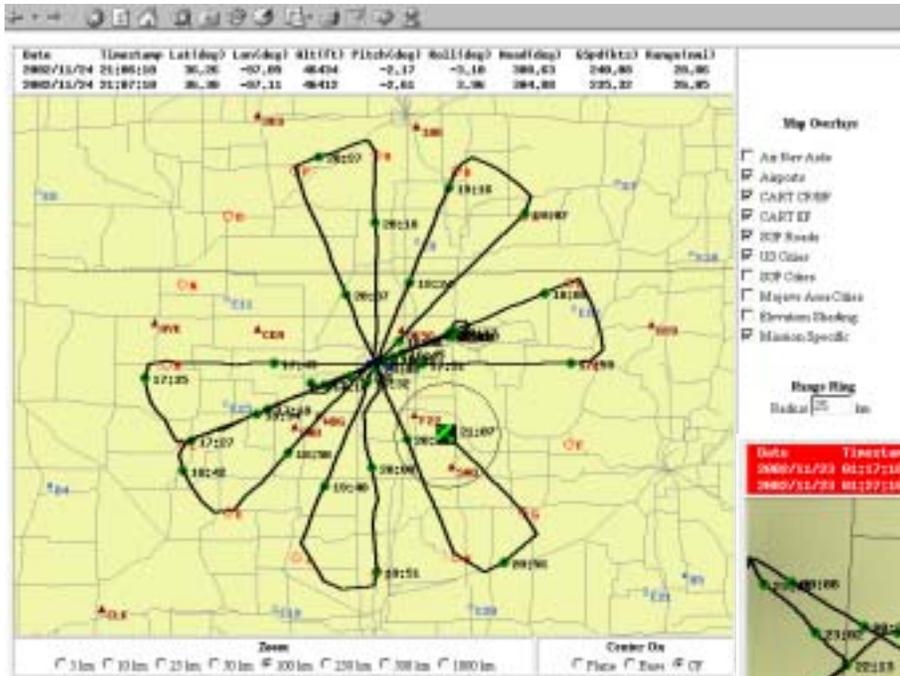
Payload senses connected links and automatically selects fastest available

During flight:

- Uplink commands and downlinked data during flight via Iridium satellite data link or line-of-sight RF from Mission Ground Station computer
- “Housekeeping” instrument and aircraft data displays aid mission planning and monitoring
- Scientific “quick look” data accessible to scientists during flight from anywhere with internet access
- Instrument and payload power uplink commands allow the re-configuration of payload during flight
- Voice communication with flight crew via VHS radio (line-of-sight) or Iridium satellite phone (over-the-horizon voice link to pilots via



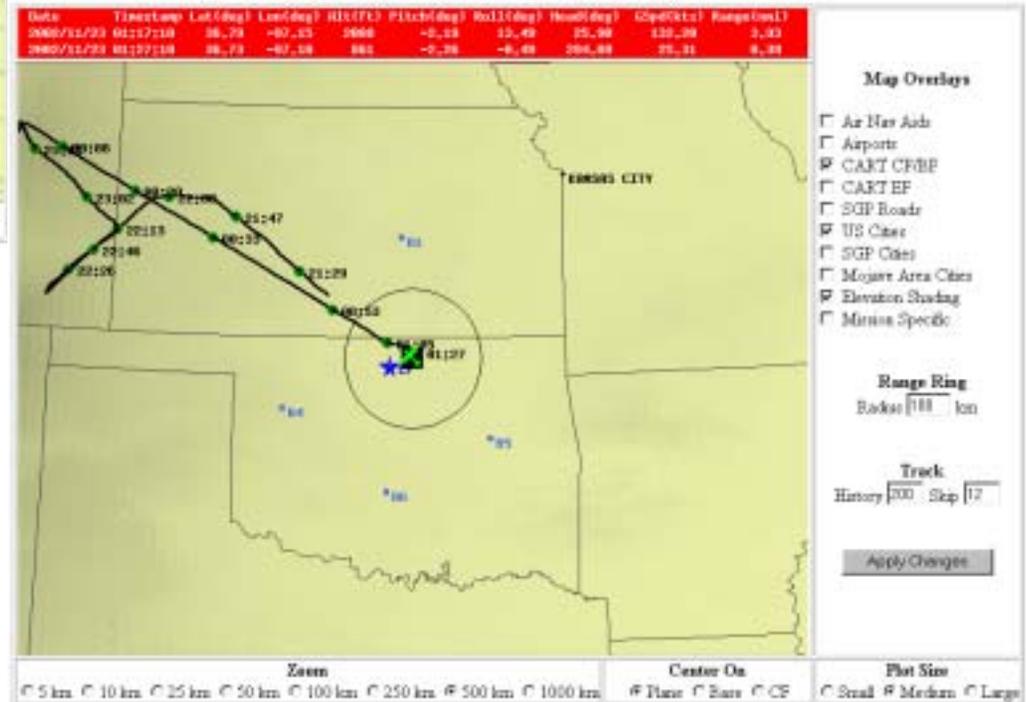
ARM-UAV mission control and display capabilities



100 km range

Map display allows monitoring flight path in near real time

500 km range



Mission control and display capabilities

State of health displays monitor instrument and payload at various levels of detail

Health and Status Summary for Active Flight

Payload Communication Link: [LINK OK](#)

New: 2002/11/24 20:59:24 Last File: 2002/11/24 20:59:00 (Delta 1 min)

AGS	InstaMaster	InstaConfEter	InstaSubEter	InstaDef
135	0	432	40	
HRP-CM1	flex_val	flex_err	flex_min	flex_max
430.2	538.3	-1395.9	-4513.3	
HRP-CM3	flex_val	flex_err	flex_min	flex_max
445.3	582.9	-1382.3	-4657.9	
HRP-CM2	flex_val	flex_err	flex_min	flex_max
393.9	54.1	-1848.0	5225.0	
HRP-CM7	flex_val	flex_err	flex_min	flex_max
-36.9	-33.5	-1128.9	2.5	
HRP-CG1	flex_val	flex_err	temp_val	temp_err
342.6	173.8	225.2	248.7	
HRP-CG4	flex_val	flex_err	temp_val	temp_err
-8.6	33.7	225.2	248.9	
HRP-CG6	flex_val	flex_err	temp_val	temp_err
388.3	283.7	225.2	234.7	
CARD	Ensl	Overd		
Overd				
CBL	sub45	sub46	sub47	
34.94	38.05	37.38		
CEM	Ensl	err	error/denom	
err		960748		
CMR	UPLINK	TX Mode	QVA_VolReg	RAMonCPU
152	55.04	40.46	42.35	
DFC-DF1	DAT File Count	Cam Temp	Remaining Disk	
585	-22.95 degrees C	0044055003 Bytes		
DFC-DF1	DAT File Count	FEA Temp	Remaining Disk	
586	-4.68152	0044055003 Bytes		
MET-PTA	MAGI Temp	magi accuracy	magi error	altitude error
-59.3	134.3	140.4	1403.3	-0.1
MET-DEM	altitude	altitude_err		
1317.08080	-73.120813			
MET-CR1	altitude	altitude_err		
-2094.08080	-78.379997			
NAV	latitude_degrees	longitude_degrees	altitude_meters	pitch_degrees
35.759132	-96.388215	14191.859375	-1.736812	-2.2244887
DEV	dev_sls	dev_err	dev_ag	dev_rfd
2.3	2.7	3.7	3.3	
PAE	low_spr_ratio	CI_SPIERR	IR_SPIERR	OL_SPIERR
24.8	-23.2	49.3	5.62	1.7.0
SDG	latitude_degrees	longitude_degrees	altitude_meters	sp_speed
35.357403	-96.337145	14191.272461	(ACTIVE)	
SHD	earthstation_name	EarthStationLength	InstaComm	InstaComm
no data file	no data file	no data file	no data file	no data file
SLP	Ensl	Overd	err	err
Overd	err	err	err	err
SWH	sw_hemp	sw_rsk file	sw_rsk file	
no rsk file	no rsk file			
SWR	SOH File Count	DAT File Count	Remaining Disk	
70	9647	0075811449 Bytes		

Health and Status for Active Flight, Cube DFC

MGS: 2002/11/24 21:28:17 Last SOH: 2002/11/24 21:24:00 (Delta 4 minutes)

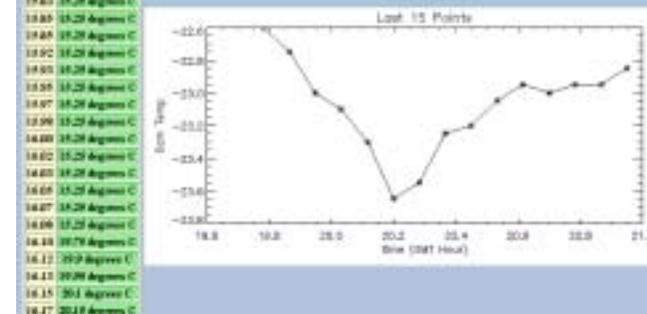
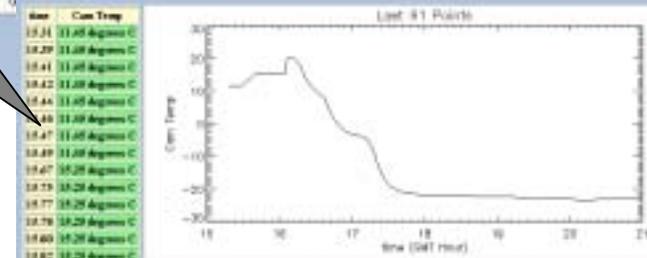
Click on a variable name to view plots and time history

DFC internal time: 2002/11/24 21:21:57

Cam Exp	Cam Gain	Cam HRes	Cam Info	Cam LL Mean
95	3.12924e-007 dB	1300 pixels	1312AM DVC6.1	0
Cam LL Std Dev	Cam LR Mean	Cam LR Std Dev	Cam Mode	Cam Offs
0	0	0	IDL	2.06169 %
Cam Temp	Cam UL Mean	Cam UL Std Dev	Cam UR Mean	Cam UR Std Dev
-22.95 degrees C	0	0	0	0
Cam VRes	Cap Count	Cap Error	DAT File Count	Instrument
1030 pixels	234	0	636	DFC
Remaining Disk	SOH File Count			
0451821568 Bytes	92			

Plots and Time History for Active Flight, Cube DFC, variable: Cam Temp

[Summary Page](#) [MGS User Page](#)



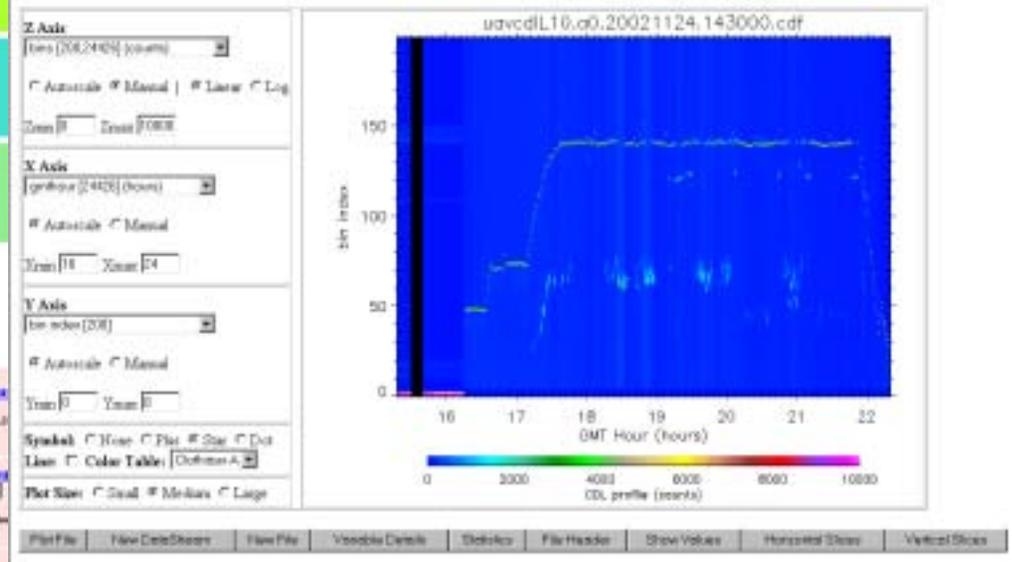
Mission control and display capabilities

Uplink controls instruments

Instruments



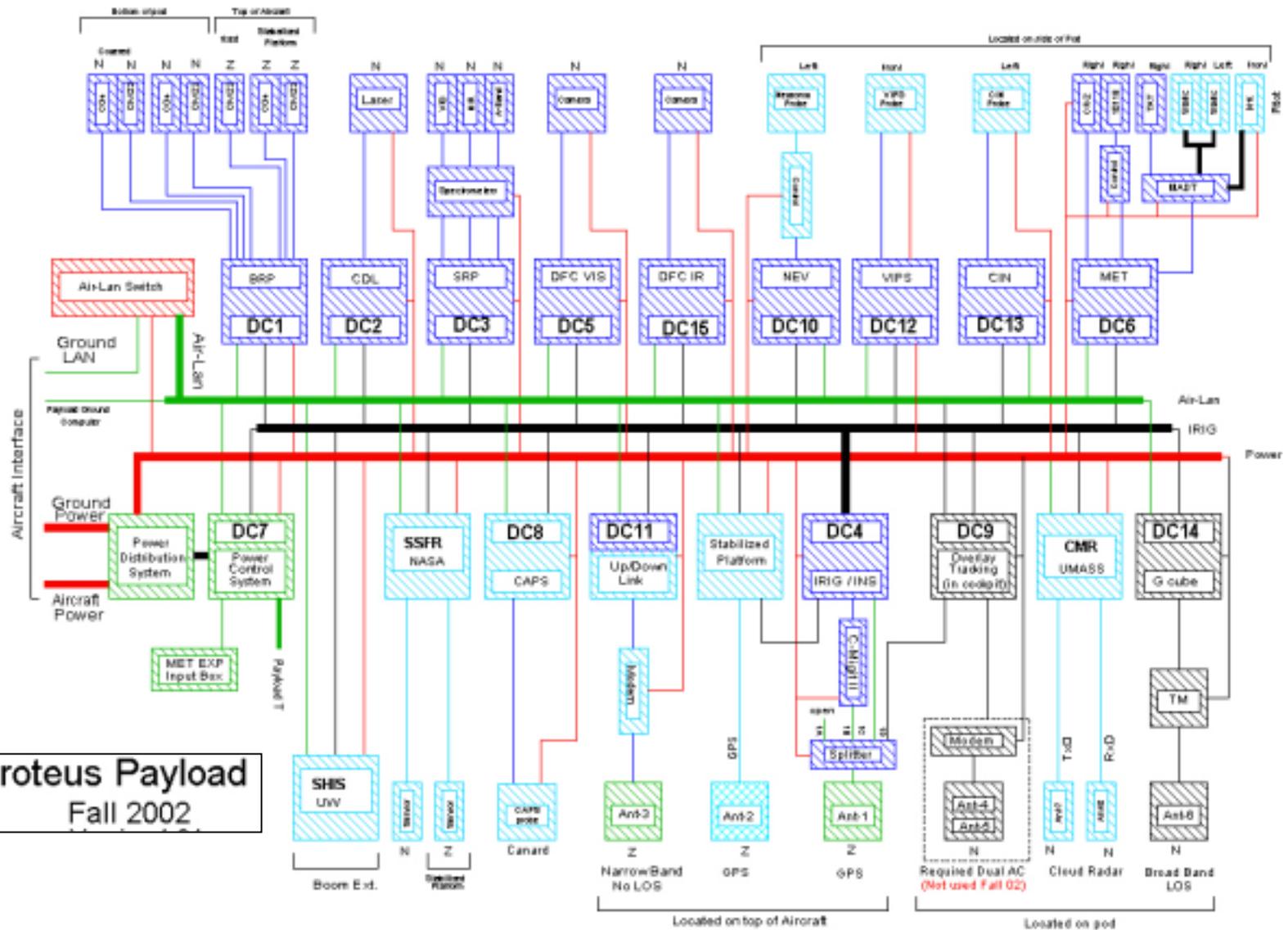
Interactive plotting allows data access



Uplink Commands for CDL

LIDAR Disable CDL 0	Standby Off STANDBY 00	Standby On STANDBY 01	Detector Gate Delay DETDRG (0-100)	Debug Command DEBUG (0-255)
LIDAR Enable CDL 1	Mode Standby MODE0	Set Time TIME	Counter Bias Delay CTYBIAS (0-200)	WFOV Control WFOV (0-255)
Laser Disable LASER 00	Background MODE1	Set Data File Interval (min) DATA_INT (0-60)	Bin Width BINW (0-1000)	
Laser Enable LASER 01	Single Shot MODE2	Set SD01 File Interval (min) SD01_INT (0-60)	Measurement Duration DURATION (0-1000)	
Heater HEATER (0-100)	Free Run MODE3	Neutral Density Filter PDF (0-7)	Laser Shot Rate SHOTRATE (0-7)	

Payload electrical and data configuration



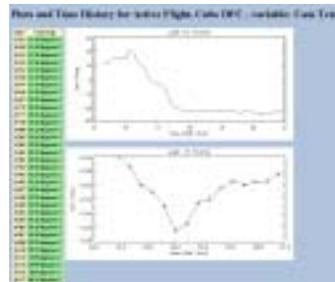
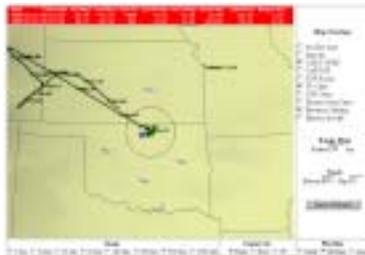
Many elements of the payload approach were notable

On board storage in dedicated PC-104-based “data cubes”

Modular instrument/data cube

Commercial cables and components

Low-cost, over-the-horizon data communication



Summary

- **ARM-UAV has...**
 - **developed equipment and operational capabilities for scientific use of UAVs**
 - **utilized UAVs in a number of major flight campaigns, acquiring valuable scientific data in over 430 hours of scientific flight**
- **Conclusion:**
 - **UAVs offer unique capabilities for important scientific applications**
 - **UAV cost, reliability/maintenance, availability, and airspace access need to improve**
 - **Payload approaches using commercial elements appear satisfactory (satellite phones/data transmission, COTS cables/connectors/components)**

For more information about ARM-UAV, please see:
<http://armuav.ca.sandia.gov/armuav.html>



*U.S. Department of Energy's
Office of Science*

NOAA/NASA/DOE

UAV

Interagency Collaboration

Rickey Petty

March 24, 2004

Proposed NASA/NOAA/DOE Collaboration for Climate Change Research

- There are needs in global climate change observations to augment satellite observations and extend to under-represented regions (e.g, oceans)
- The proposed collaboration between NASA, NOAA, and DOE is intended to address the challenges of an international Earth Observation System using UAVs as an integrated piece of the global system

CCSP Strategic Plan

- Observations:
 - Goal 1; Design, develop, deploy, integrate, and sustain observation components into a comprehensive system.
 - Goal 2; Accelerate the development and deployment of observing and monitoring elements needed for decision support.
 - Goal 3; Provide stewardship of the observing system.

CCSP Strategic Plan

(2nd cont)

- Goal 4; Integrate modeling activities with the observing system.
- Goal 5; Foster international cooperation to develop a complete global observing system.
- Goal 6; Manage the observing system with an effective interagency structure.

CCSP Core Science Elements

- Atmospheric Composition
- Climate Variability and Change
- Water Cycle
- Land-Use/Land Cover Change
- Carbon Cycle
- Ecosystems
- Human Contributions & Responses to Environmental Change

CCSP Core Approaches

- Modeling Strategy
- Decision Support Resources Development
- Observing and Monitoring the Climate System
- Data Management and Information

Just an added comment

NACP Science could be a customer with regards to its mission of ascertaining sources and sinks of CO₂.

Addressing Science Issues

Potential scientific issues that could be addressed by this collaboration using UAVs have been identified*:

- Scaling Issues
- Statistics of Cloud and Radiative Properties at Multiple Levels and Locations
- Analysis of Life Cycles of Clouds not Currently Possible

* Greg McFarquhar, “Scientific Rationale for Use of UAVs in Global Unified Profiler Network”, draft working paper, September 2003.

Addressing Science Issues

2nd (cont)

- Statistical Analysis of Atmospheric Behavior in a Large Phase Space than Previously Possible
- Atmospheric Statistics in Sparse Regimes
- Critically Needed Data for Large-Scale Model Simulations
- Long Transects for Parameterization Development
- Tropospheric/Stratospheric Exchange

Addressing Science Issues

3rd (cont)

- Aerosol/Cloud Interactions and Indirect Effects
- Indirect Effects in Ice Clouds

The Collaboration Process

The process for establishing the proposed collaboration is now being developed:

- Agreement in principle between the Agencies
- Workshop to establish a well-articulated scientific basis for the collaboration
- Informal collaboration on planned activities
- Develop MOA and establish formal collaboration

Timeline for Collaboration

Possible timeline for establishing the proposed collaboration:

- **Agency coordination teleconference - April 2004**
- **Science Workshop (@ Scripps) - July 2004**
- **Informal collaboration opportunities - 2004-2006**
- **Formal collaboration - 2007 and beyond**

Conclusion

This is an exciting possibility with great potential

There are many issues to be addressed before the collaboration can be considered likely

Many will be asked to contribute to the development of the scientific basis and objectives of the proposed collaboration

Please stay tuned for more information