



National Aeronautics and  
Space Administration



# Communications for the TechEdSat/PhoneSat Missions

## NASA Ames Research Center

Presentation to Small Satellite Pre-Conference Workshop

August 5, 2017

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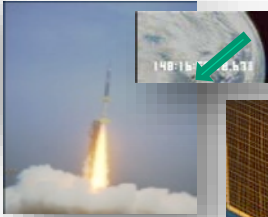
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Jon Wheless, Engineer

# SOAREX/TechEdSat/PhoneSat Teams



SOAREX-6  
(2008)



SOAREX-7  
(2009)



TES-1  
Oct 4, 2012



TES-2  
PhoneSat  
Iridium-test  
Aug 21, 2013



TES-3  
Aug 3, 2013  
(6 wk de-orbit)



TES-4  
Mar 3, 2015  
(4 wk de-orbit)



TES-5  
Mar 6, 2017  
(deorbited  
Jul 29)



TES/PS Team, 2014



SOAREX-8  
(2015)



SOAREX-9  
(2016)



TES/PS Team, Summer 2017





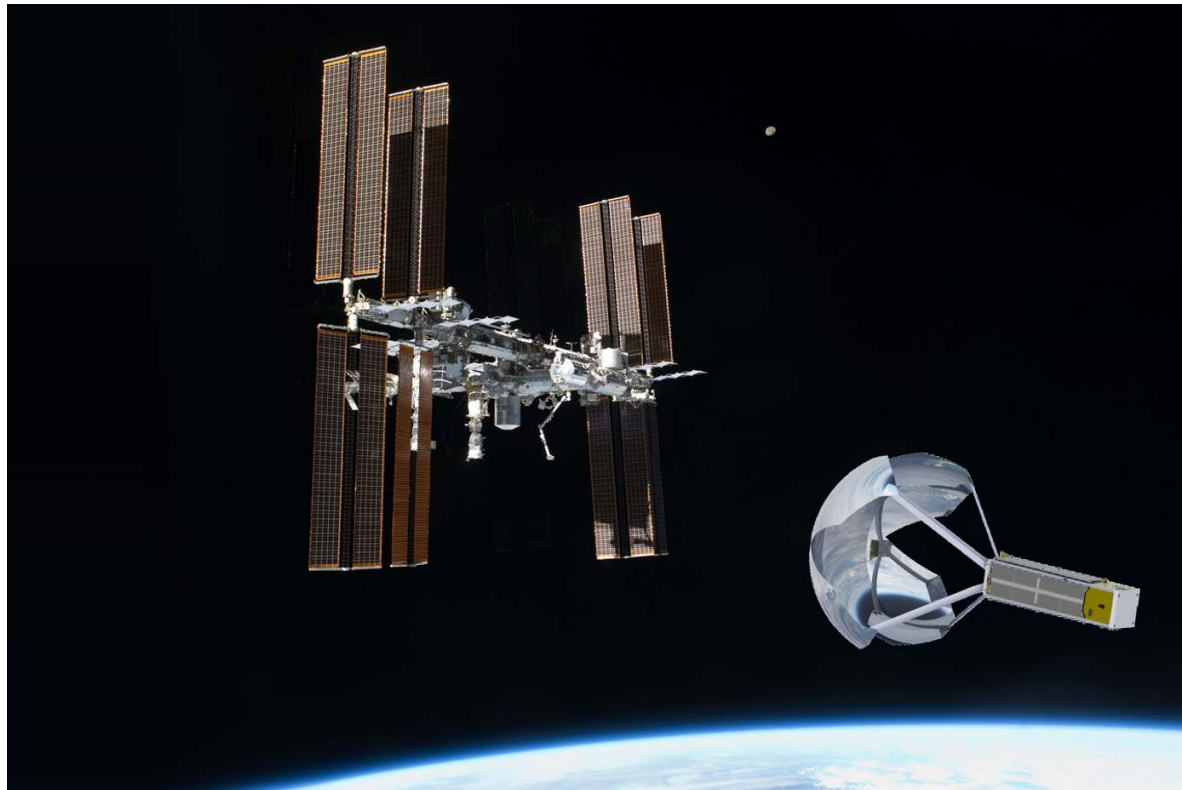
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# What is an Exo-Brake...?

Simple, drag-modulated de-orbit system based on tension elements

TechEdSat5 was deployed from ISS on March 6, 2017 by NanoRacks





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# The TechEdSat 5 Exo-Brake Experiment

- The Exo-Brake is an exo-atmospheric braking and de-orbit device which has successfully flown twice before in a fixed configuration on TechEdSat-3 and 4
- The TechEdSat rapid prototype flight series is conducted as a hands-on training environment for young professionals and university partners
- The project helps verify Entry Systems Modeling by gathering real-world data aboard sounding rockets and CubeSats
- In the future, passive Exo-Brake systems may be used for small-sat disposal and the development of technologies to permit on-demand sample return from Low Earth Orbit (LEO) scientific/manufacturing platforms

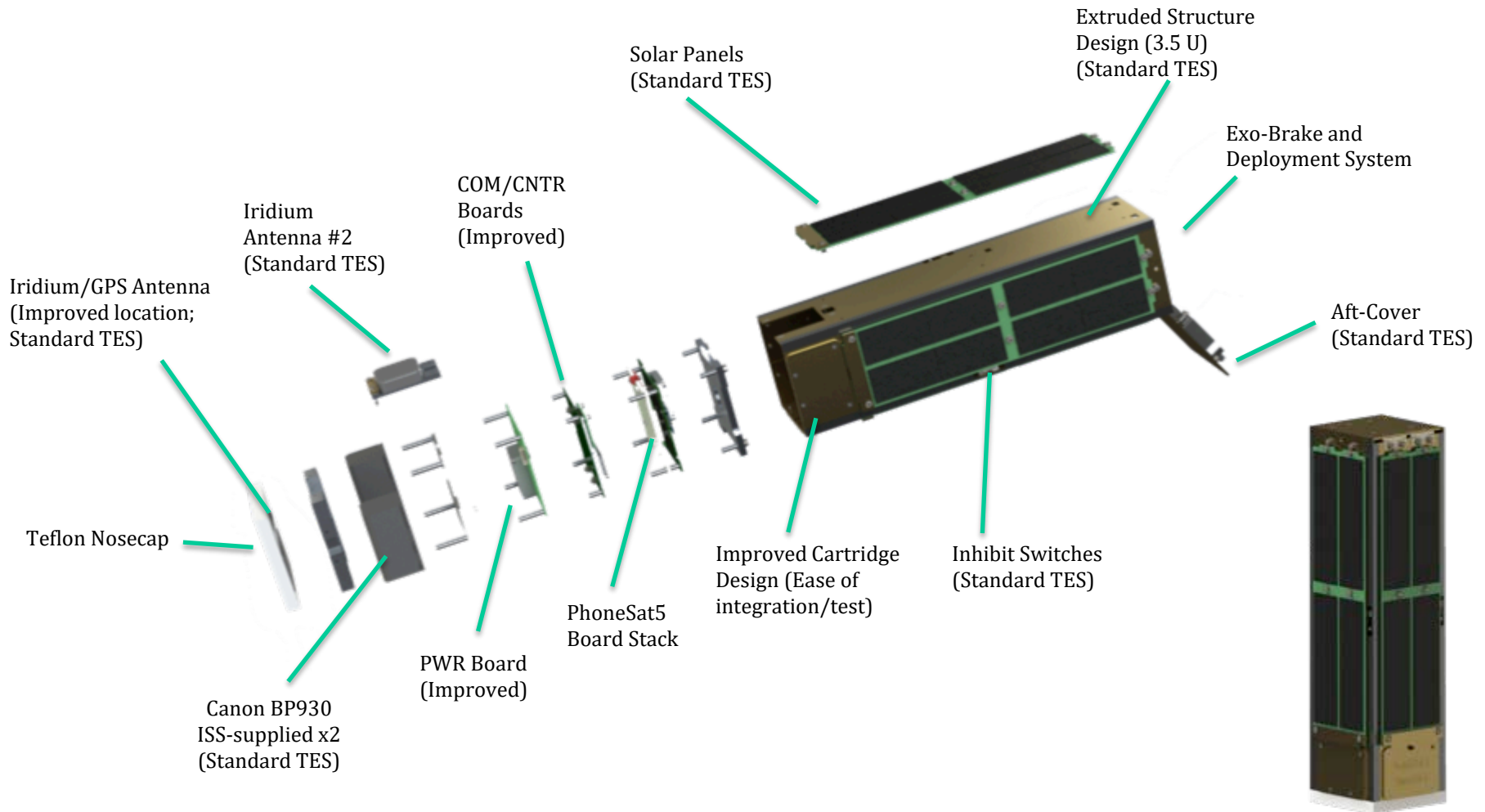


# TechEdSat 5 (TES5)

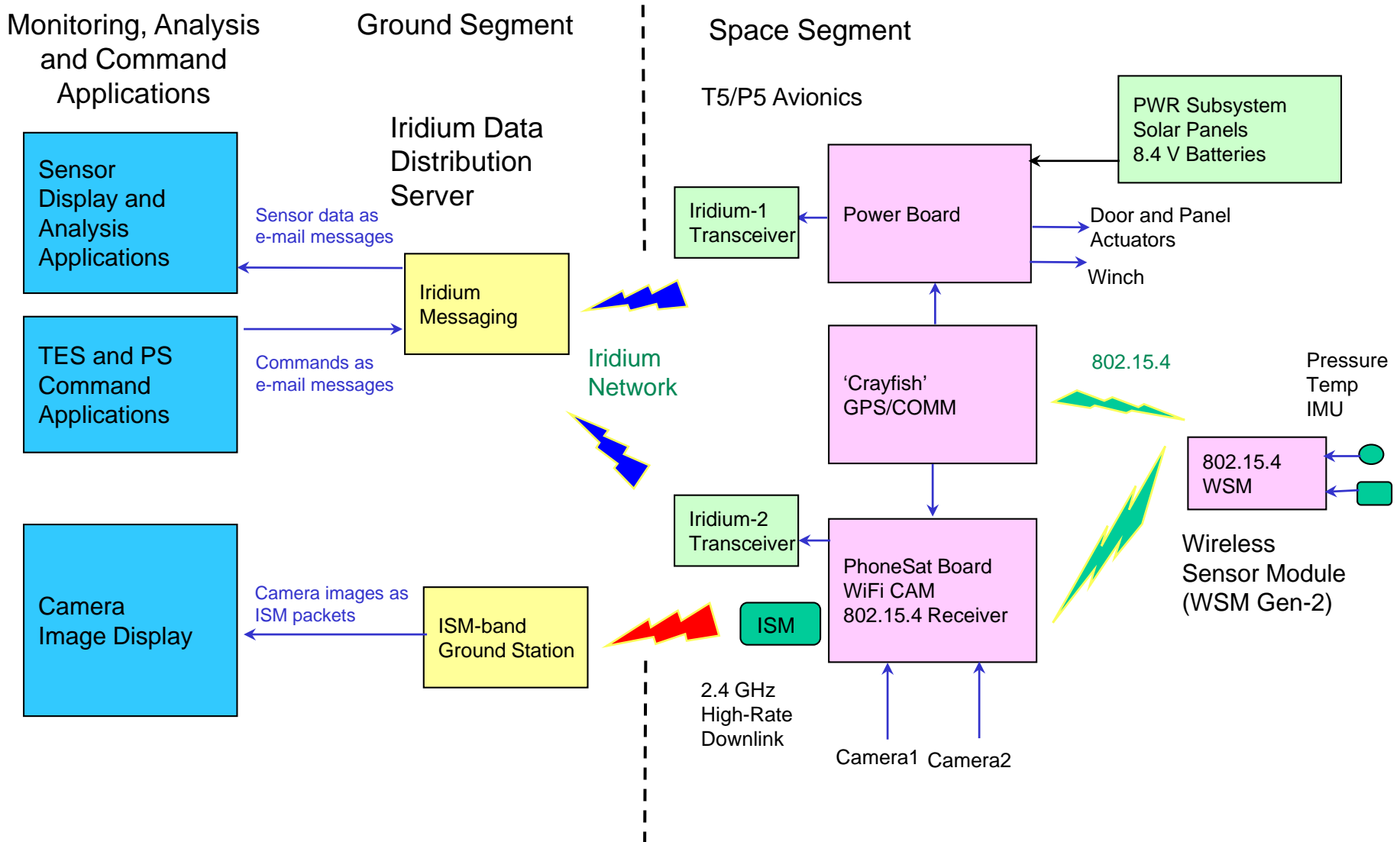
## Avionics, Software and Communications

- The 3.5 U CubeSat contains a low-level AVR microprocessor for power control and a high-level Atom processor for fast data processing
- The primary Command and Telemetry (C&T) link is provided by the Iridium constellation through on-board Short Burst Data (SBD) modems.
- A modified Wi-Fi transceiver allows scheduled downlink at 1 Mbps when over our Wallops Island ground station
- TES5 includes a Wireless Sensor Module for inertial, magnetic, air pressure and temperature sensing.
- TES5 had two cameras which downlinked images via Wi-Fi or, with heavy compression, via Iridium constellation

# TechEdSat-5 Anatomy



# T5/P5 Flight System Architecture and Dataflow

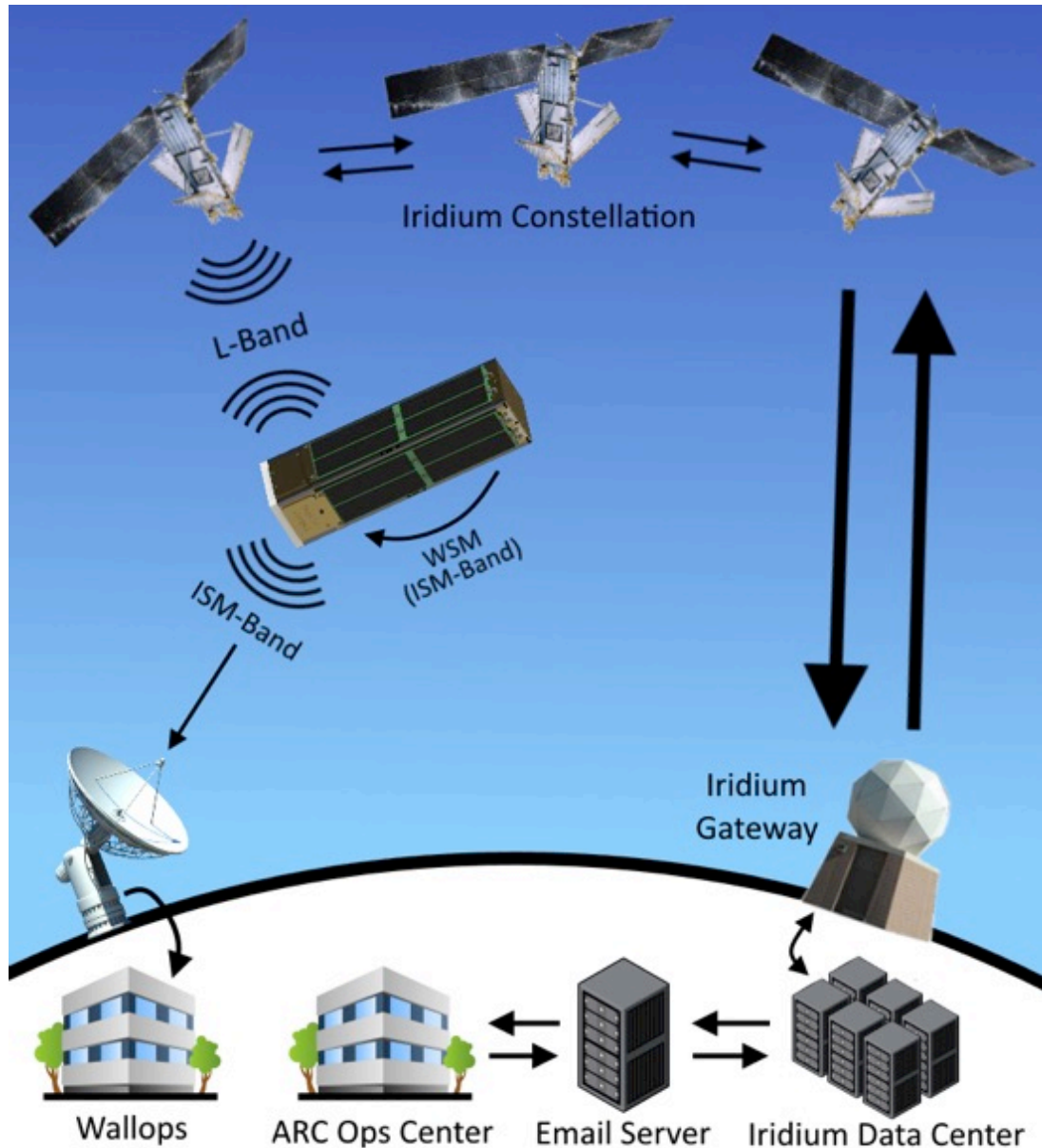




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# Ames

Discovery | Innovations | Solutions



## TechEdSat-5 Communications Overview

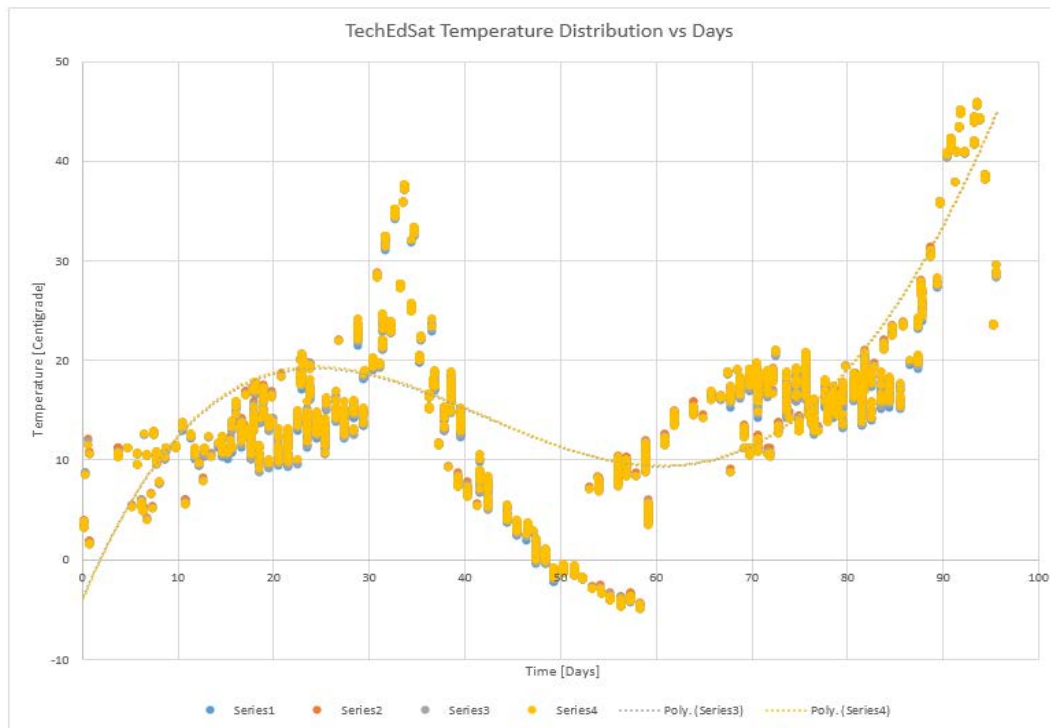
**FEATURING:**  
Iridium SBD Modems  
ISM-Band high-rate  
downlink





# Previous Experience: TES-2

First successful Iridium in-space nanosat experiment

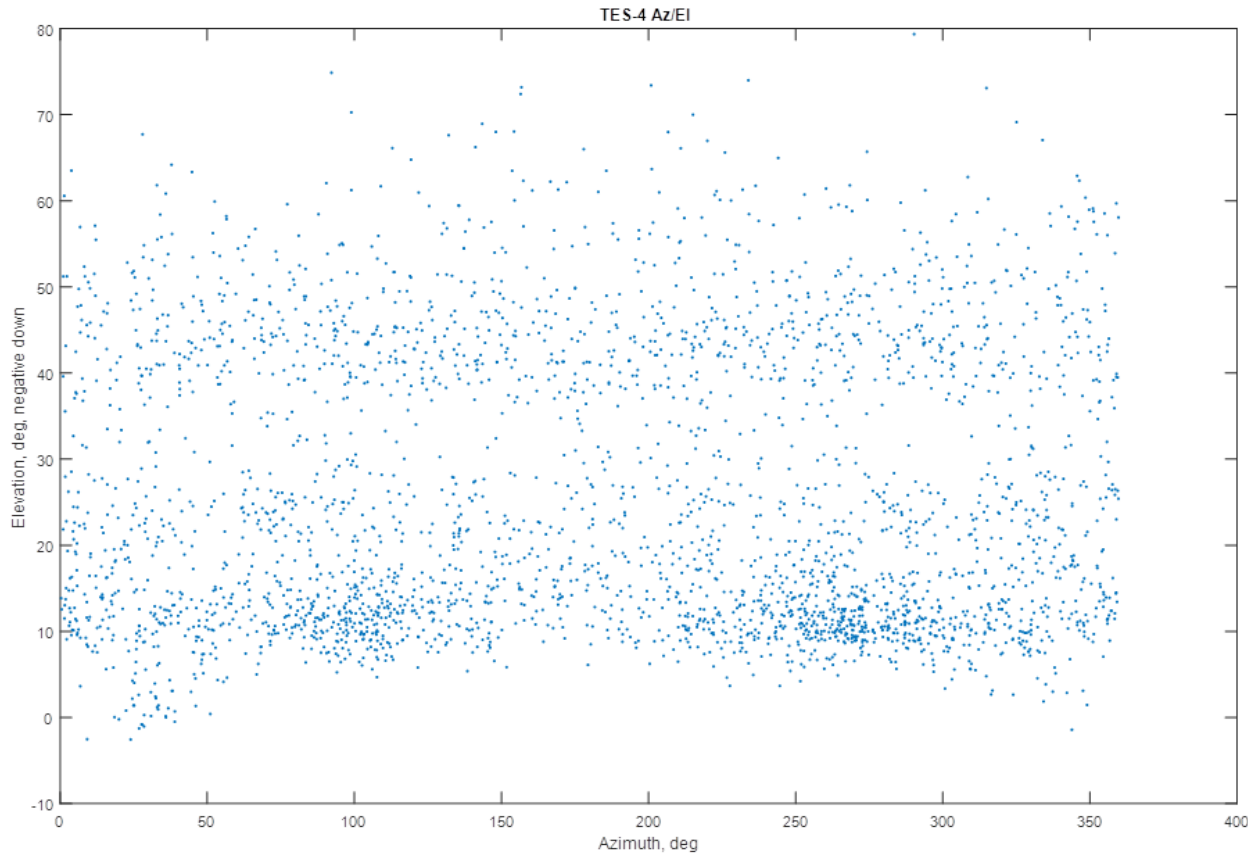


Shows distribution of handshakes over 100 hours (fwd patch; tumbling)



# Previous Experience – TES-4

## Direction from the Iridium Constellation Perspective

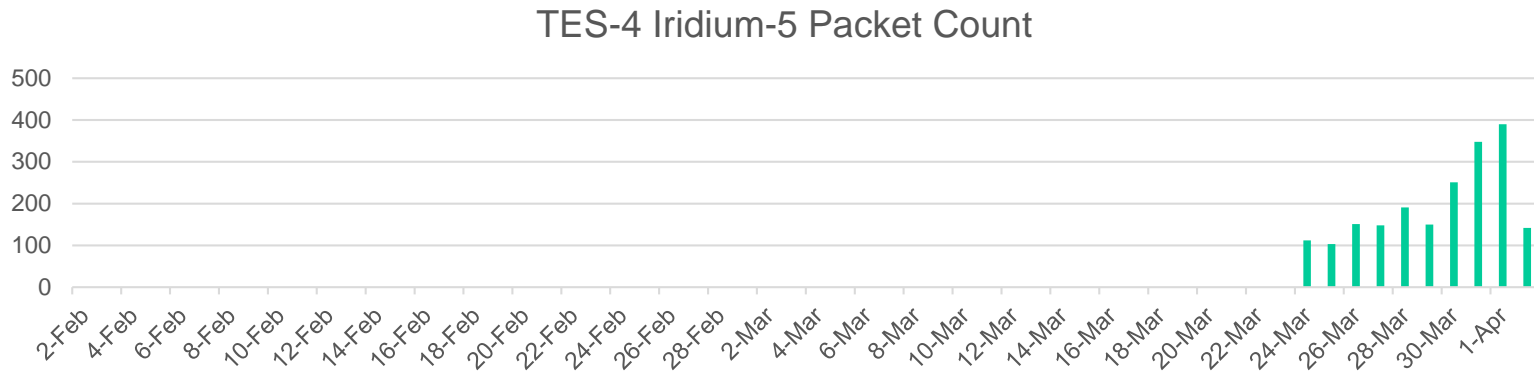


TES-4 messages vs. elevation and azimuth (from forward patch antenna)

Sent ~100 packets per day; received 25 out of 25 commands sent

# Previous Experience – TES-4 Ortho Antenna

100-400 hits/day when the 2<sup>nd</sup> level Avionics was turned on



Note: Orthogonal patch antenna orientation zenith was not known, but was expected to be slowly rotating

# Data Packets from T5/P5 via Iridium

## TES5 Health Data

Initial Data from TES/PS show “IT WORKS”

- ✓ WSM-”Cricket”
- ✓ GPS
- ✓ PhoneSat

## WSM-Cricket

MOMSN>1271

```
41 88 07 ad de ef be be ba 0f 00 52 5f 6a 00 15 07 00 00 5b 0a 2e ff 0c ff
05 ff fe ff ff 00 07 00 07 ff fc 00 16 ff bb 00 51 00 19 40 00 fc 3c 62
```

CricketID: BABE

TimeStamp (s): 5398.378

PacketNumber: 5383

Pressure (kPa): 0.091

**OnBrdTemp (° C): 26.06** Temp1 (° C): -24.4 Temp2 (° C): -25.1

Accel (G): -0.002, -0.001, 0.007 Gyro (Deg/s): 0.07, -0.04, 0.22

Mag (uT): -10.346, 12.146, 3.749 Light (lux): 0.00 Bat (V): 3.26

Temp1 is the thermocouple on the solar panel and Temp2 is the one embedded in the Teflon nose cap.

## TES5 Iridium Packet Interpreter

```
Packet:
5,1a831,21dc,3d1,404,446,495,1f,20,848,0,,1d,be6

Powerboard information:
packetNumber: 5
elapsedTime: 108593
batteryVoltage: 8.668
spVoltage1: 0.977
spVoltage2: 1.028
spVoltage3: 1.094
spVoltage4: 1.173
batteryCurrent: 0.031
safeMode: OFF
exobrakeDeployed: TRUE
deployingExobrake: FALSE
regulators: 0000
timeExobrake: 2120
timeLastCommand: 0
commandResponse:
iridiumDelay: 29
attemptedTransmits: 3046

Note: GPS string is not present.
```

## Phonesat GPS

Iridium metadata:

MOMSN>1268 MTMSN>0

session\_time>1488832376552 lat>0.07239 lon>72.99772

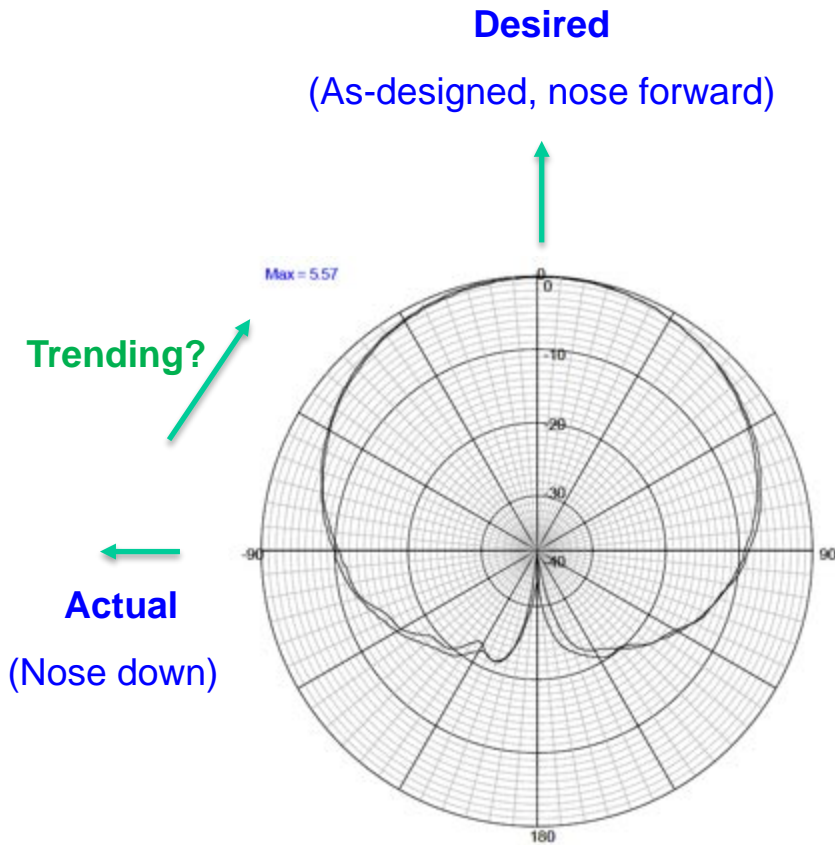
Onboard GPS data: time: 1488831732 (Mon Mar 6 12:22:12

PST 2017) px: 3736540.5672 py: 4480193.2322 pz: -

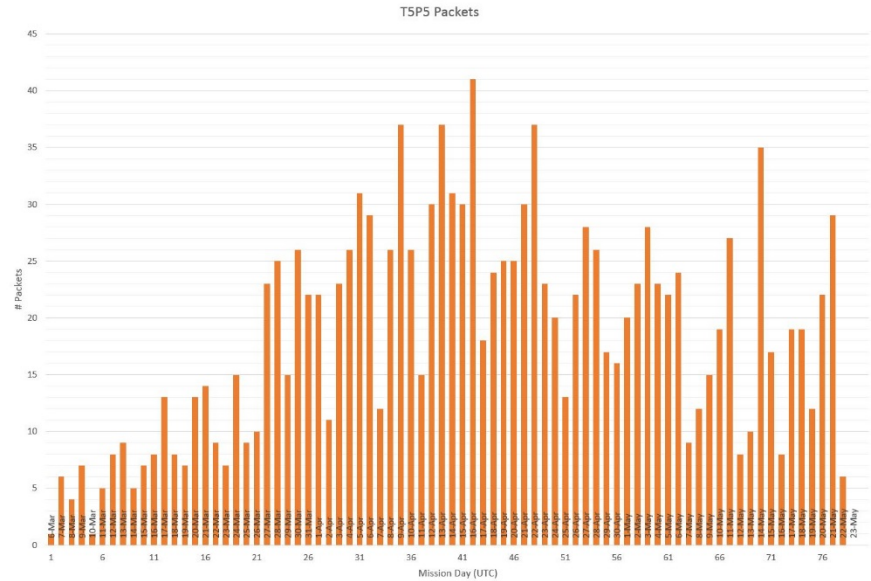
3455134.8574 vx: -

2187.0305 vy: 5348.8718 vz: 4570.3105

# TES5 Status – End of Mission



**Iridium Antenna Radiation Pattern**



**TES-5 is in a 'nose-down' orientation, Iridium antenna provides -10 dB gain at 180 degrees**

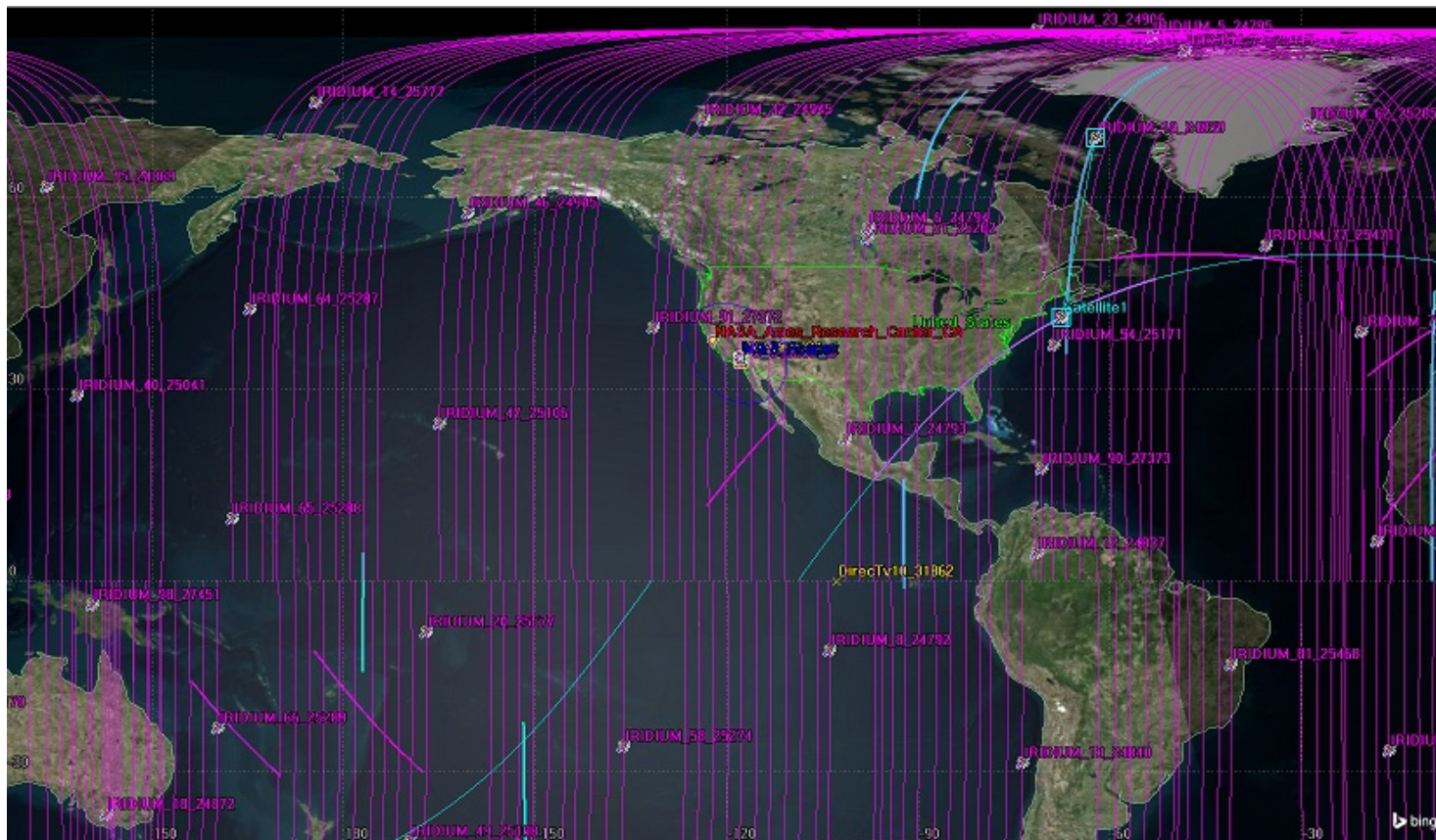
**Link margin analysis shows nose-down attitude compromises communication**

**Number of packets/day was slowly changing, perhaps due to slow changes in AoA**

# STK Iridium Comms Analysis – Coverage

## Active Iridium Satellite Constellation Ground Tracks

Six belts of eleven Iridium satellites in polar orbit

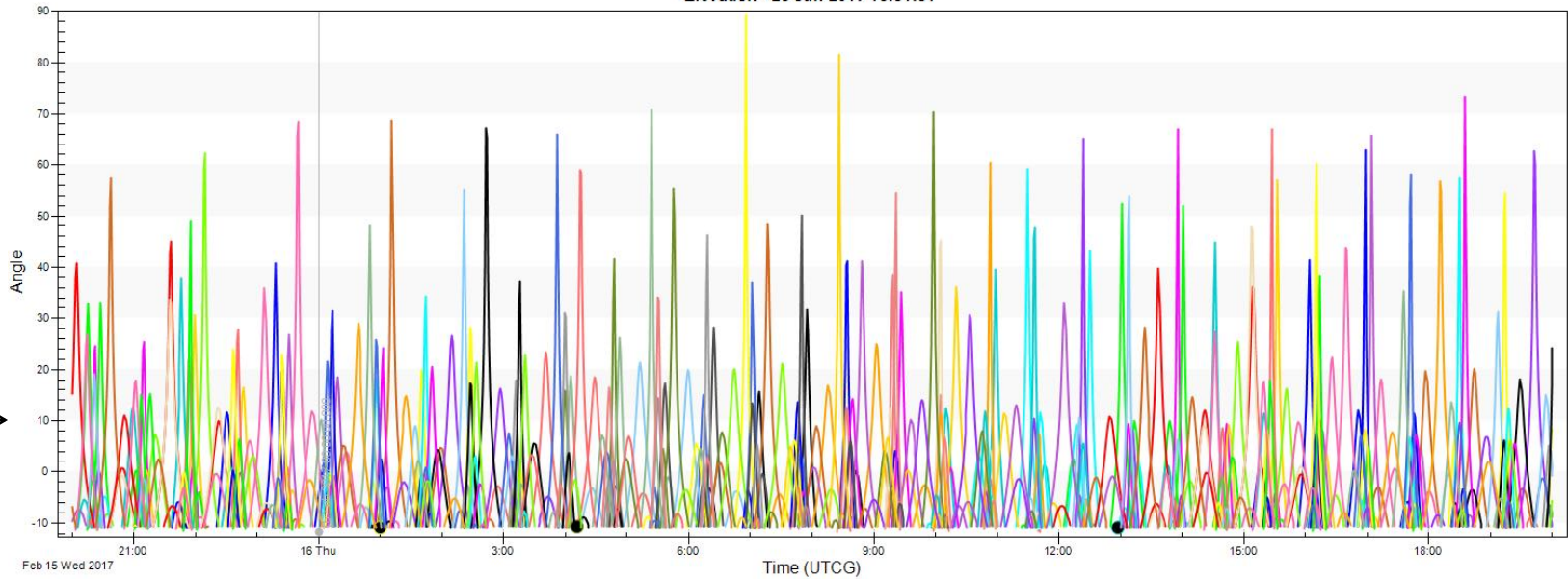


Pattern offers 100% ground coverage

# Iridium Comms Analysis – TES5 Forward

Elevation from TES5 to all Iridium satellites – 4000 Km maximum range

Elevation - 28 Jun 2017 18:31:31



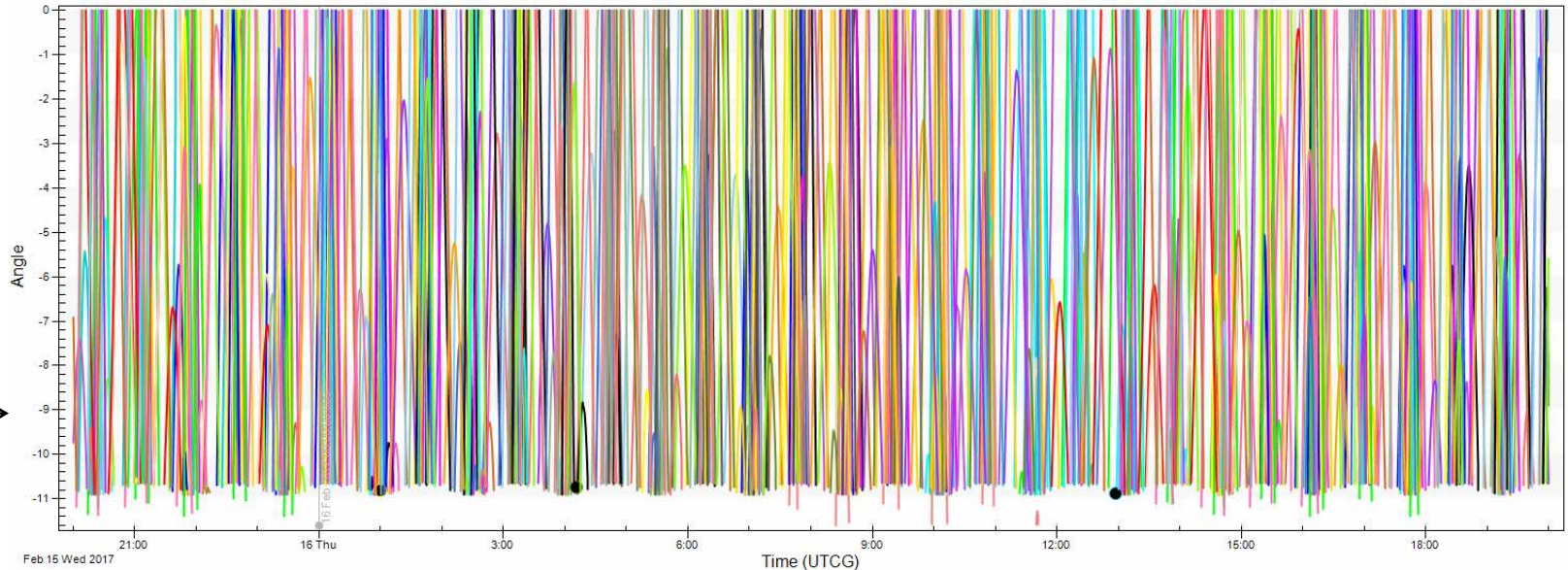
- Satellite-To-IRIDIUM\_10\_24839 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_11\_25573 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_12\_24837 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_13\_24840 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_14\_25777 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_24869 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_16\_24872 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_19\_24965 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_20\_25577 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_21\_25778 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_22\_24907 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_23\_24906 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_28\_24904 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_30\_24949 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_31\_24950 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_32\_24945 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_34\_24969 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_35\_24966 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_37\_24962 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_39\_25042 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_3\_24931 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_40\_25031 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_41\_25040 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_43\_25039 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_45\_25044 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_46\_25044 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_48\_24905 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_47\_25106 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_49\_25108 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_50\_25172 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_51\_25262 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_52\_25199 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_53\_25173 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_54\_25171 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_55\_25272 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_56\_25170 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_58\_25174 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_59\_25275 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_6\_24795 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_60\_25276 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_62\_25283 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_63\_25285 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_64\_25287 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_65\_25285 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_66\_25285 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_67\_25289 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_68\_25292 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_69\_25291 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_70\_25343 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_72\_25343 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_74\_25345 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_75\_25346 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_76\_25346 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_77\_25471 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_78\_25432 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_79\_25471 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_80\_25499 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_81\_25499 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_82\_25499 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_83\_25499 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_84\_25500 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_85\_25500 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_86\_25500 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_87\_27492 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_88\_27492 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_89\_27372 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_90\_27372 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_91\_27372 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_93\_25511 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_94\_27374 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_96\_25500 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_98\_27375 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_97\_27400 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_98\_27401 - FromElevationAngle (deg)

For FWD attitude: all possible contacts are from -12 degrees to ~80 degrees – good telemetry and command links

# Iridium Comms Analysis – TES5 Nadir

Elevation from TES5 to all Iridium satellites – 4000 Km maximum range

Elevation - 28 Jun 2017 18:34:17



- Satellite-To-IRIDIUM\_10\_24329 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_10\_24372 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_10\_24904 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_24968 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_25104 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_25199 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_25279 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_25288 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_25340 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_10\_25499 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_13\_24700 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_27480 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_11\_25578 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_19\_24965 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_30\_24949 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_39\_25242 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_16\_24905 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_25173 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_24766 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_16\_25239 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_14\_25245 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_14\_25488 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_11\_25458 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_10\_25773 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_11\_25785 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_20\_25577 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_21\_25778 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_31\_24950 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_3\_25431 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_25106 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_18\_25196 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_18\_25272 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_14\_25211 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_16\_25276 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_16\_25290 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_25345 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_25492 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_17\_25487 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_19\_25772 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_13\_24540 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_21\_25778 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_32\_24948 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_40\_25041 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_49\_25108 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_49\_25272 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_58\_25272 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_61\_25330 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_61\_25395 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_62\_25276 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_62\_25291 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_76\_25492 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_76\_25491 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_80\_25531 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_84\_25774 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_14\_26777 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_22\_24907 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_34\_24969 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_41\_25040 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_50\_25172 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_58\_25170 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_62\_25265 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_6\_24734 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_77\_25471 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_77\_25470 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_84\_25530 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_96\_27376 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_15\_24669 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_23\_24905 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_25\_24966 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_43\_25039 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_51\_25052 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_58\_25274 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_64\_25327 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_64\_25327 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_70\_25342 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_7\_24790 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_38\_25525 - FromElevationAngle (deg)
- Satellite-To-IRIDIUM\_96\_27376 - FromElevationAngle (deg)

For nose-down attitude: all contact from 0 to -11 degrees: link margin constraints show lower probability of successful handshake

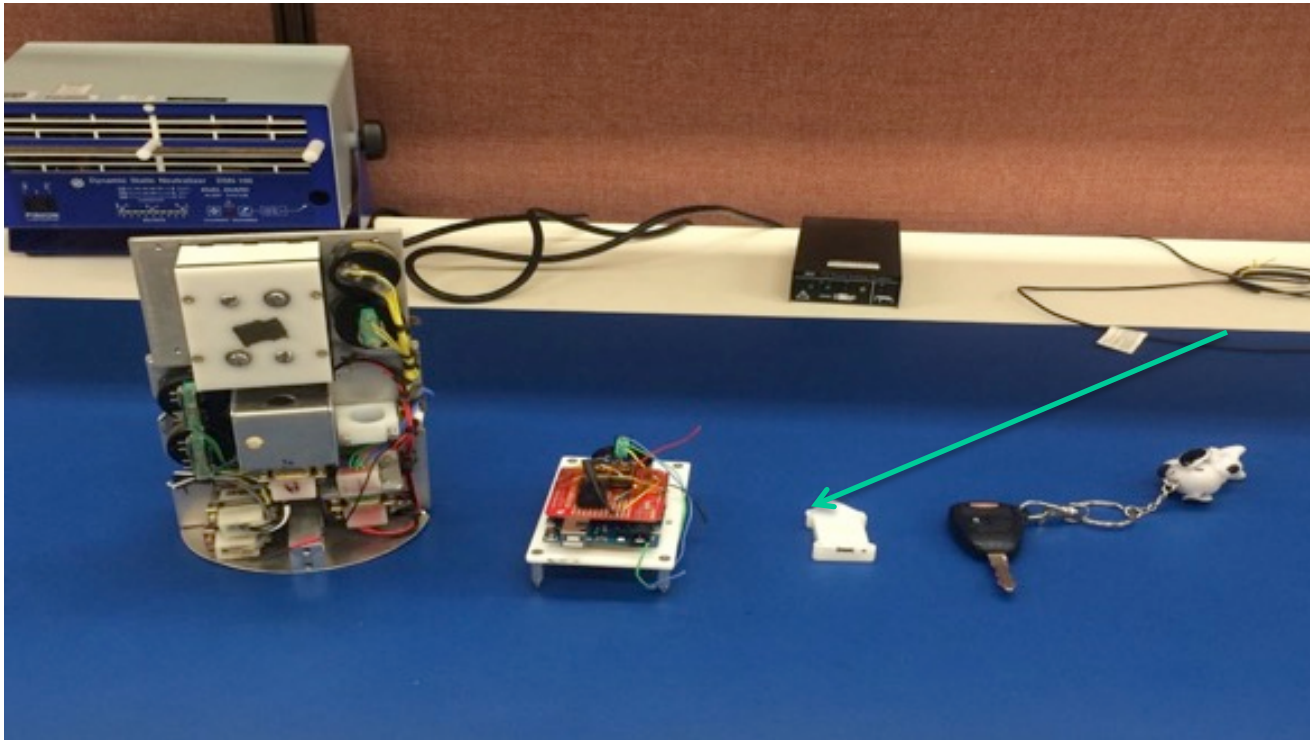




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# Wireless Sensor Module Experiment



## Evolution of Wireless Sensor Module

**Far left:** Original SOAREX-1 data acquisition module

**Second from left:** SOAREX-8 WSM concept trial version

**Third from left:** currently developed system for SOAREX9 and TES-5

**Fourth from left:** Marc's key chain

# Future Missions: TechEdSat 6, 7, 8

## TechEdSat-6 [3U]

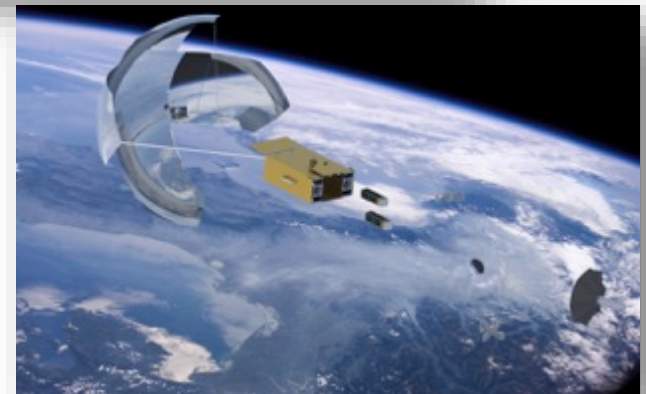
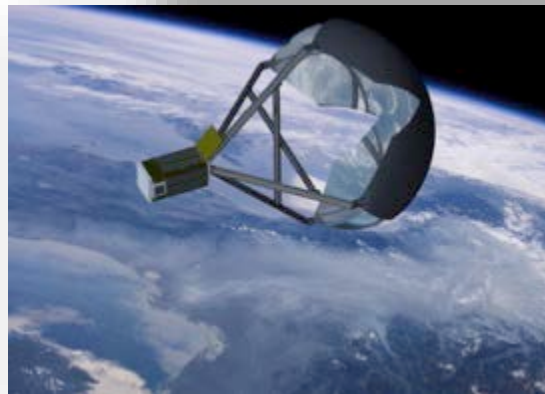
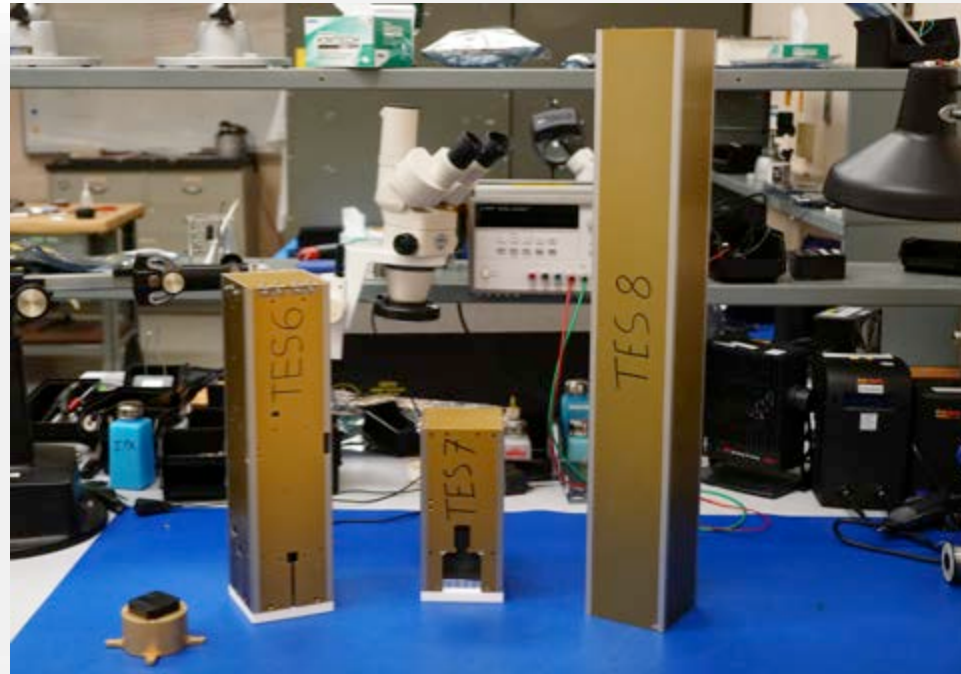
2<sup>nd</sup> Modulated Exo-Brake Test  
Improved Exo-Brake Tensioner  
New Ops/Schedule Plan  
Drag Coeff. = 5 kg/m<sup>2</sup>  
CUBIT-1 Test

## TechEdSat-7 [2U]

High Packing-Density Exo-Brake  
Novel strut design – no modulation  
Drag Coeff. = 1 kg/m<sup>2</sup>  
CUBIT-2 Test

## TechEdSat-8 [6U]

'Hot' Exo-Brake  
Modulated with beta=4 kg/m<sup>2</sup>  
'Deep Dive' into atmosphere  
Drag Coeff. = 5 kg/m<sup>2</sup>  
Novel Comm. Equipment



\* All CSLI Approved

