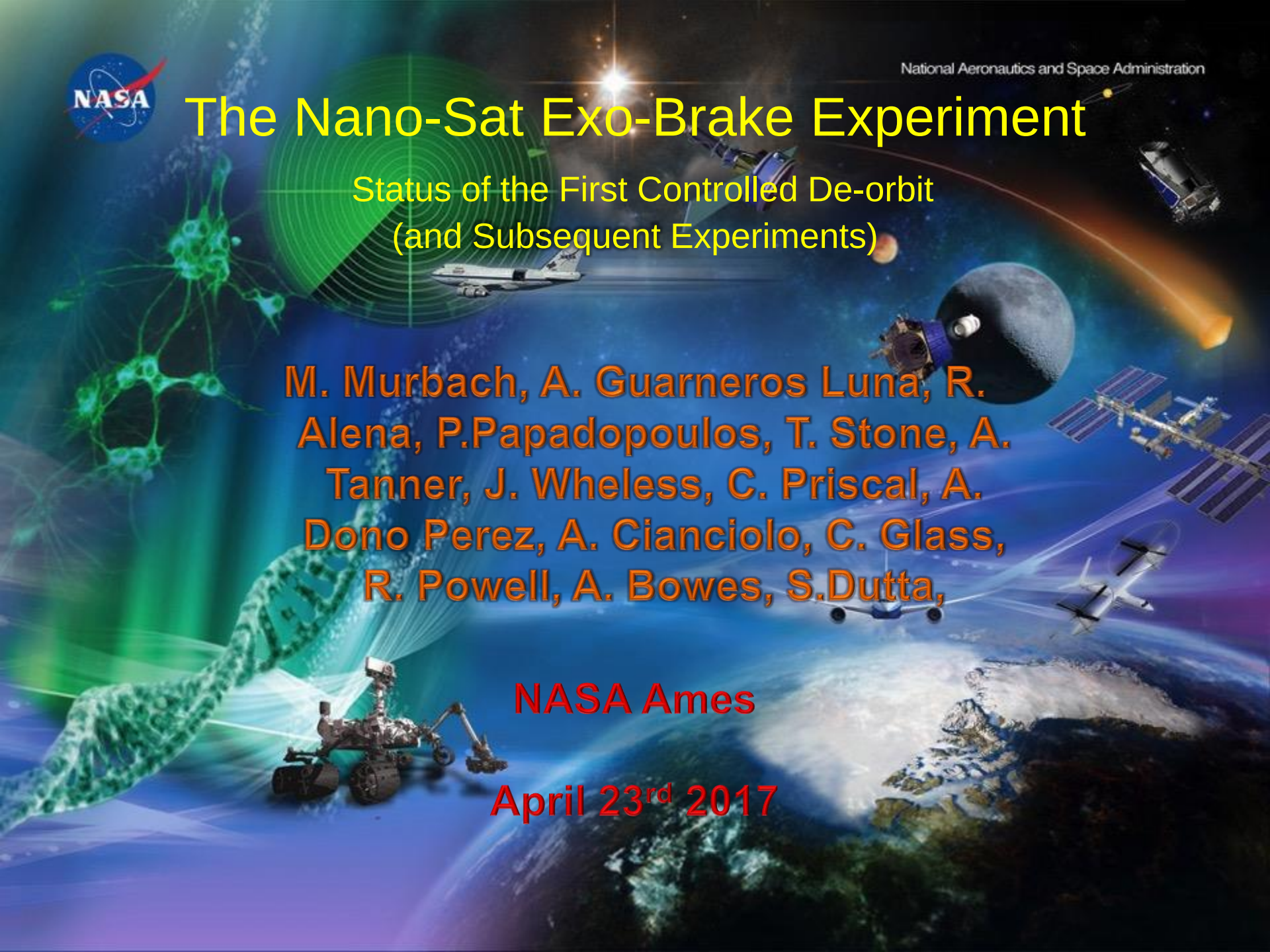


The Nano-Sat Exo-Brake Experiment

Status of the First Controlled De-orbit (and Subsequent Experiments)

M. Murbach, A. Guarneros Luna, R. Alena, P.Papadopoulos, T. Stone, A. Tanner, J. Wheless, C. Priscal, A. Dono Perez, A. Cianciolo, C. Glass, R. Powell, A. Bowes, S.Dutta,

NASA Ames

April 23rd 2017

The Nano-Sat Exo-Brake Experiment

Status of the First Controlled De-orbit (and Subsequent Experiments)

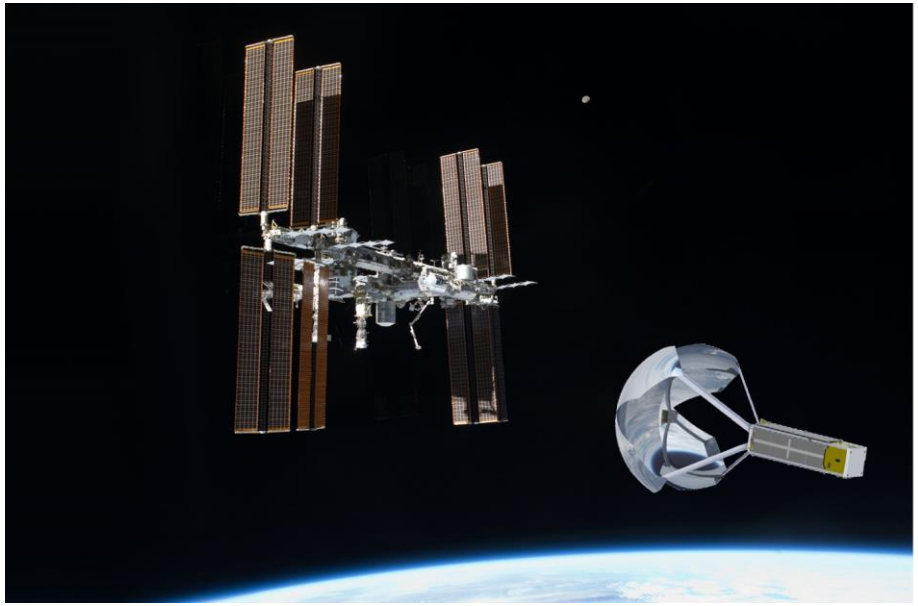
The design and operational experience with the first controlled Exo-Brake system flown during March, 2017, as conducted by the NASA Ames Research Center, is described. The Exo-Brake is an exo atmospheric braking and de-orbit device which had successfully flown twice before in a fixed-drag configuration on the nano-sat orbital platforms TechEdSat-3,4. The TechEdSat-5 flight, is intended to be the first to permit a commanded shape change which affects the drag (and, the ballistic coefficient), and thus allowed improved targeting. The use of the Iridium constellation and on-board Short Burst Data (SBD) modems, as well as Global Positioning Systems (GPS), permitted daily updates to be performed. This allows compensation for the Thermosphere density variations captured in the F10.7 variable. Current and highly detailed analysis based on Monte-Carlo techniques suggest that ~7 modulations can achieve a relatively small <200km target ellipse at the Von Karman altitude. Drag data and over-all performance of the system is provided, as well as the description of the proposed subsequent experimental flights. There are noted advantaged for this type of de-orbit procedure as compared to a more traditional propulsion based de-orbit system. Also, the comparison with solar-sail type systems is shown to be favorable. The rapid flight series, of which this is a part, is conducted as a hands-on training environment for young professionals and university partners. In the future, such Exo-Brake systems may be used for more accurate nano-sat or small-sat disposal – or the development of technologies to permit on-demand sample return from Low Earth Orbit (LEO) scientific/manufacturing platforms.

Outline

- **The Series…**
  - Relevant Flight Experiments
- **TechEdSat-5 Objectives**
- **3D Isometric View/Components**
- **Avionics Stack/Comparison**
  - Architecture
  - Avionics
  - Physical Stack
- **COM**
  - Overview
  - Wireless Sensor Modules
- **T5/P5 Current Status**
  - Data Packets
- **Entry/Target Prediction**
- **Next Up**
- **Summary**

What is an Exo-Brake…?

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



The nano-satellite…

The Exo-Brake Experiment is based on the TechEdSat-N/PhoneSat Flight Platforms

National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

Relevant Flight Experiments

SOAREX/TechEdSat-N Team

Flight Experiments of Recent Years (2008-2015): 9 Flights

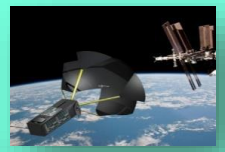
SOAREX-6
(2008)

SOAREX-7
(2009)

TES-1
Oct 4, 2012

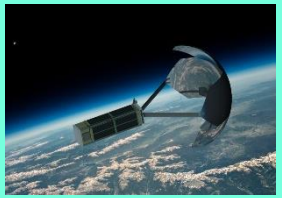
TES-2
PhoneSat
Iridium-test
Aug 21, 2013

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



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

SOAREX-9
(March 7, 2016)



T5/P5
Mar 6, 2017
(currently in orbit)

…here before

SOAREX-8
(2015)

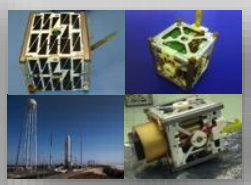
PhoneSat Team

Flight Experiments of Recent Years (2009-2015)

Balloon
June 9, 2011

Intimidator-5
July 29, 2010

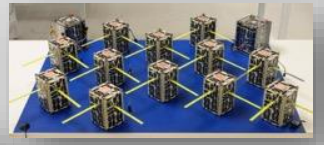
SpaceLoft-6
Apr 5, 2012



PhoneSat 1a, 1b, 2.0
Antares A-ONE
Apr 21, 2013

PhoneSat 2.4
ORS-3 Minotaur 1
Nov 20, 2013
(still in orbit)

PhoneSat 2.5
CRS-3 Falcon 9
Apr 18, 2014



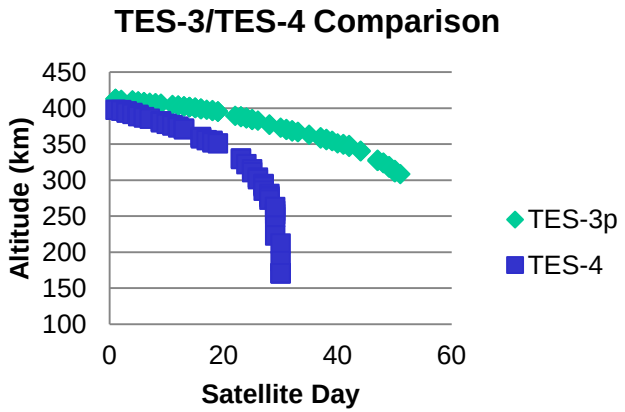
EDSN
Super Strypi
Oct 29, 2015

Nodes
Orb-4 Atlas V
Dec 3, 2015

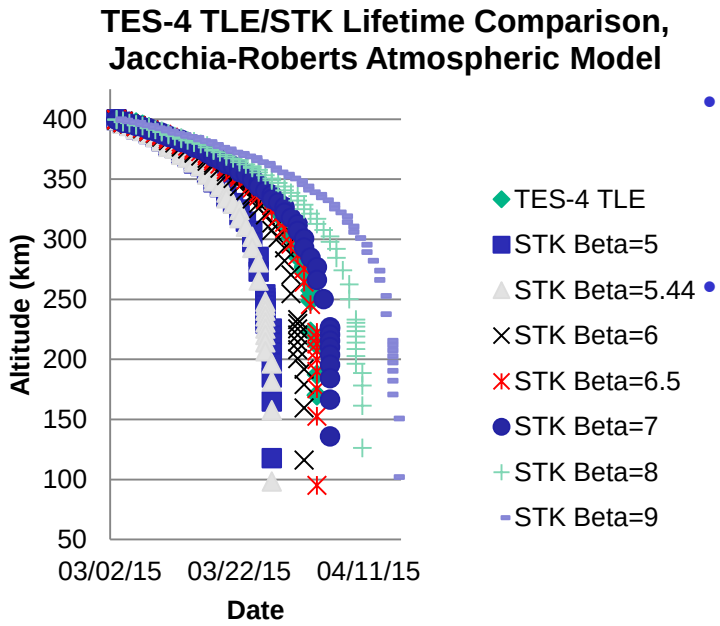
SOAREX-8
Terrier/Black Brant
July 7, 2015

Exo-Brake Science/Mission Objectives

Fixed Exo-Brake Test Flights

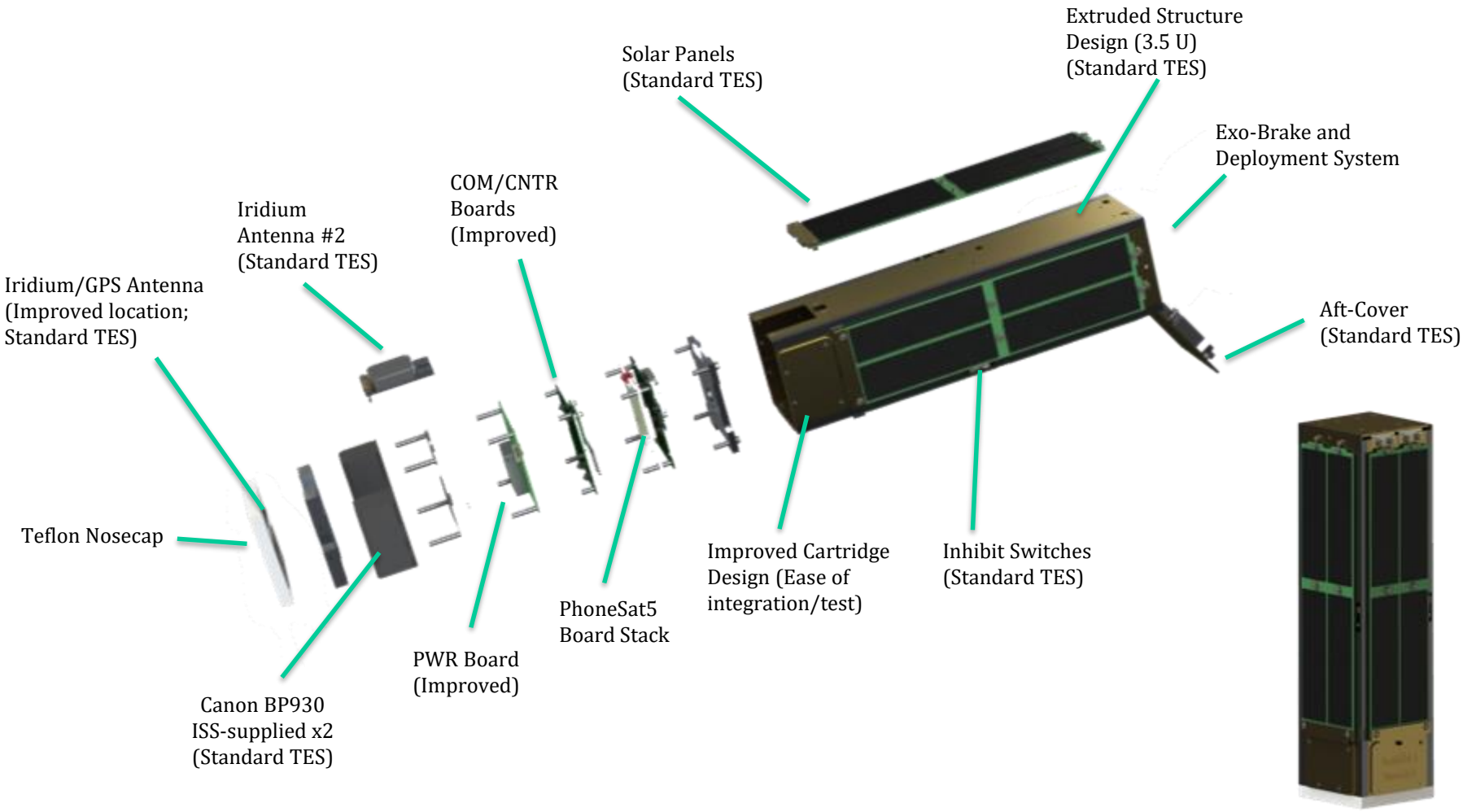


Development Risk is spread over several flights

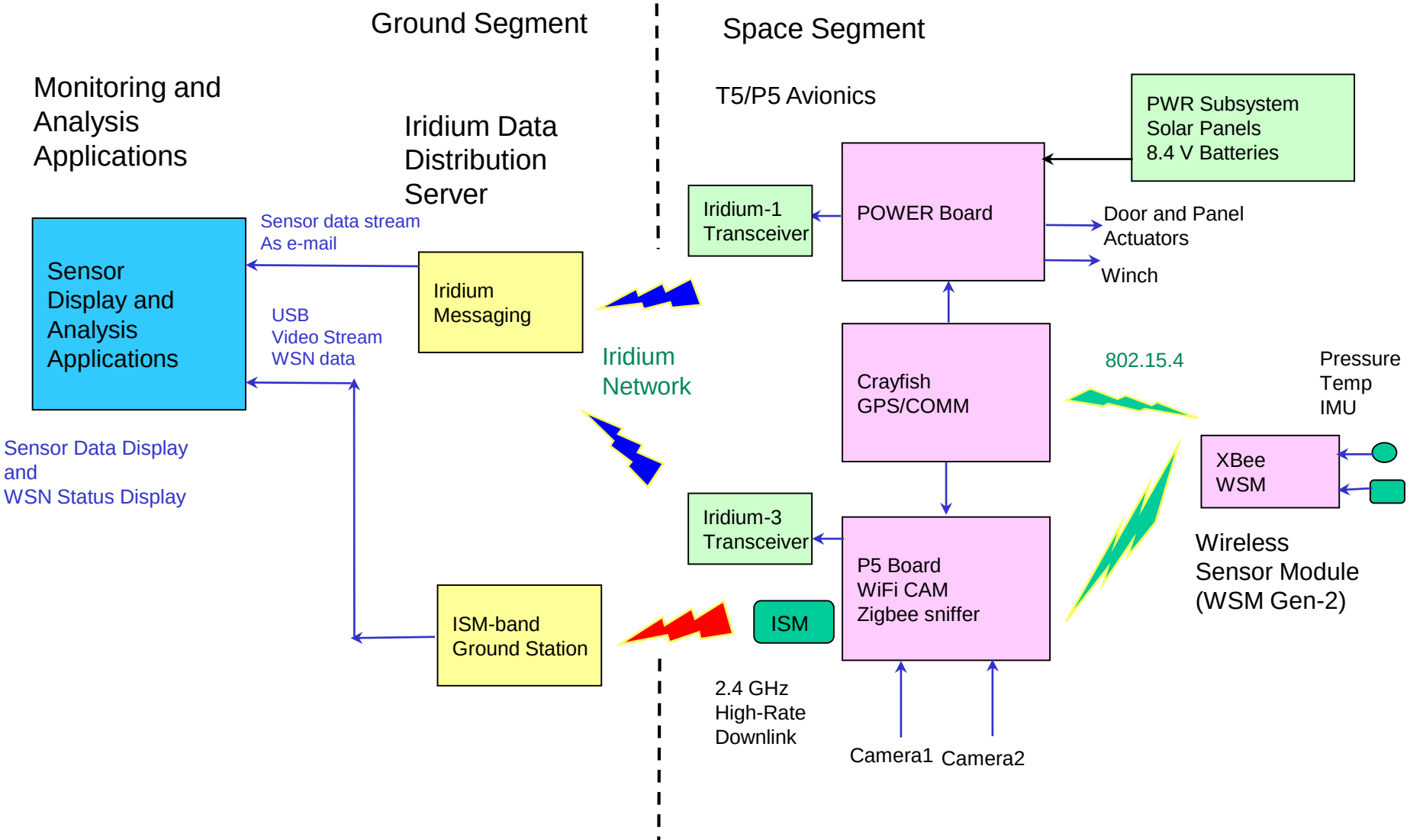


- First Modulated Exo-brake Experiment
- Improve uncertainty analysis for controlled flight through the Thermosphere (performed detailed comparison to TES-3 and TES-4 w.r.t key Thermosphere variable uncertainties).
- Improve prediction of re-entry location (100 Km) and foundation for autonomous control.
- Core technology for sample return from orbital platforms and interplanetary nanosatellite missions

TechEdSat-5 Anatomy



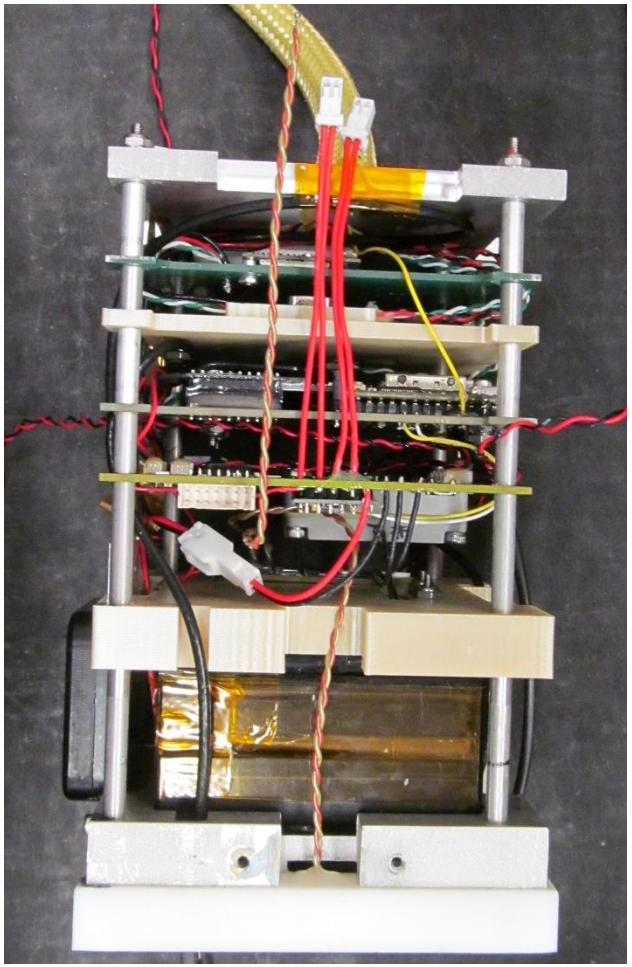
T5/P5 Flight System Architecture and Dataflow

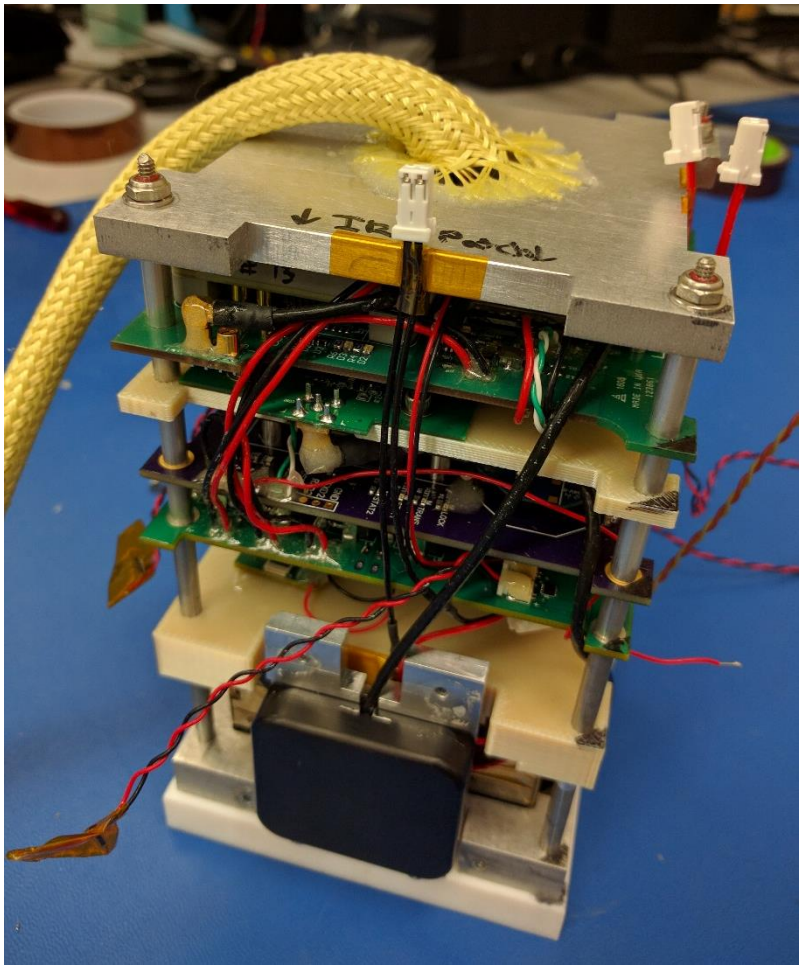


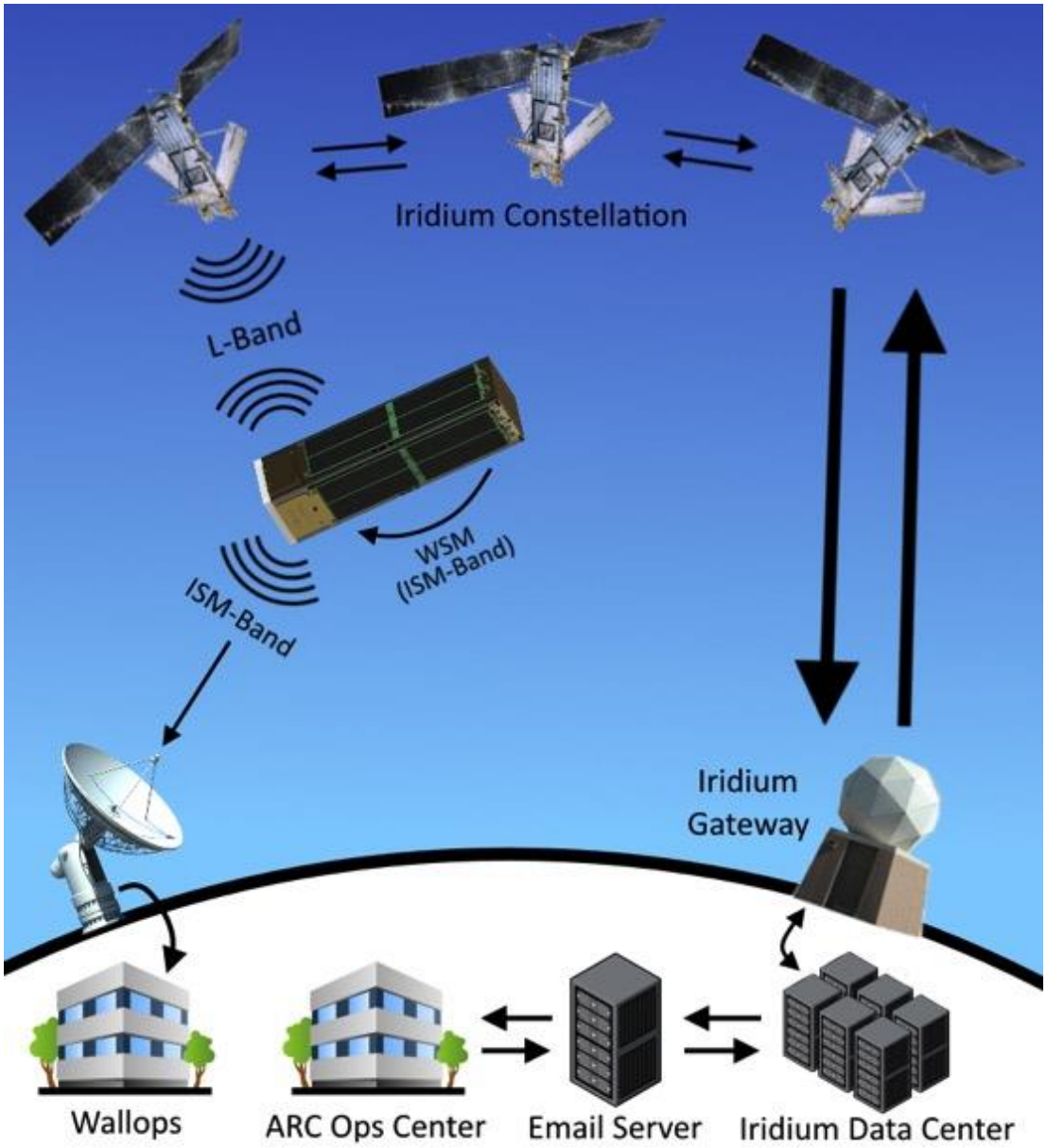
TechEdSat5 / PhoneSat5 Avionics

Purpose	Name	Processor(s)	Memory	Power Draw	I/O Pins
Power control and comms	Arduino Pro Mini	ATmega328 16MHz	32KB Flash 2KB RAM	0.10W	14
Data collection	Teensy 3.1	32-bit ARM Cortex-M4 72MHz	256KB Flash 64kB RAM	0.08W	34
High-speed ISM-band comms	Intel Edison	500MHz dual-core Atom; 100MHz Quark MCU	4GB Flash 1GB RAM	0.41W - 0.97W	30
Wireless environmental sensor	Cricket 1.2	TI CC2538 – ARM Cortex M3, 32MHz	512KB Flash, 32KB RAM	0.1mW - 0.06W	32

T5/P5 Avionics Stack







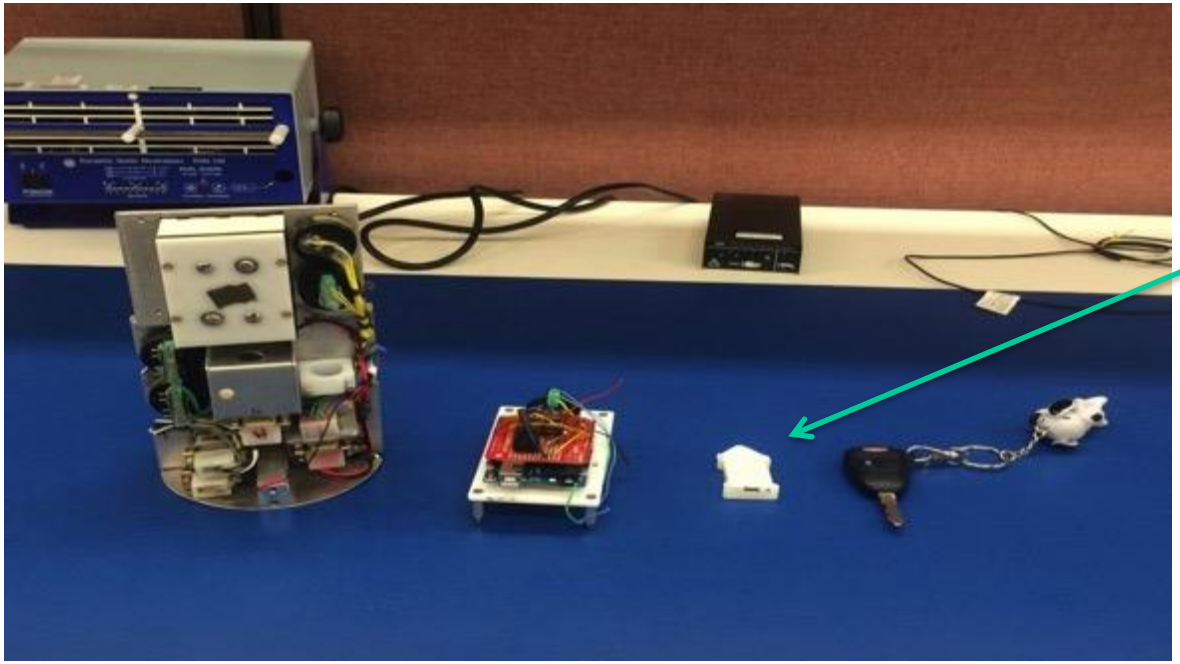
NASA TechEdSat-5 COM Overview

FEATURING:

Iridium SBD Modems /ISM-Band for higher data rate

‘TDRS for CubeSats’

WSM Experiment
(Wireless Sensor Module)



WSM 2.0 Experiment on TES-5

Evolution of unique Wireless Sensor Module

Far left: Original SOAREX-1 data acquisition module
Second from left: SOAREX-9 WSM 1.0 trial version
Third from left: currently developed system for SOAREX9 and TES-5
Fourth from left: Marc's key chain…

Data Packets from T5/P5 via Iridium

Initial Data from TES/PS show "IT WORKS"

- ✓ WSM-"Cricket"
- ✓ GPS
- ✓ Health Data

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.

TES5 Health Data

```
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

ESM/Exo-Brake Current Status

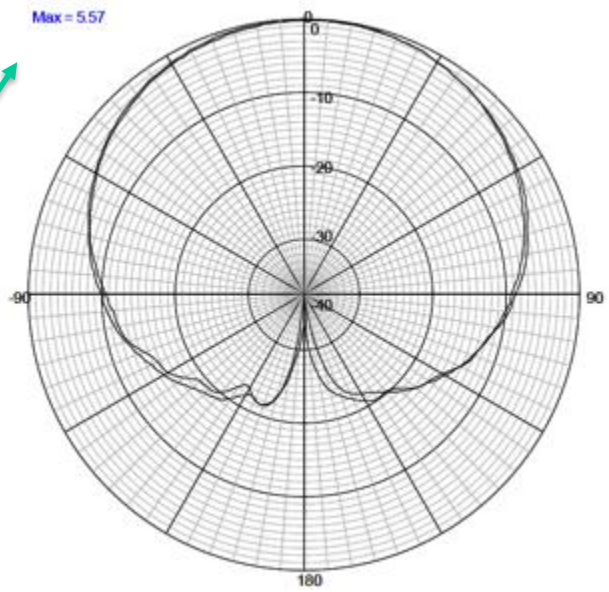
Desired

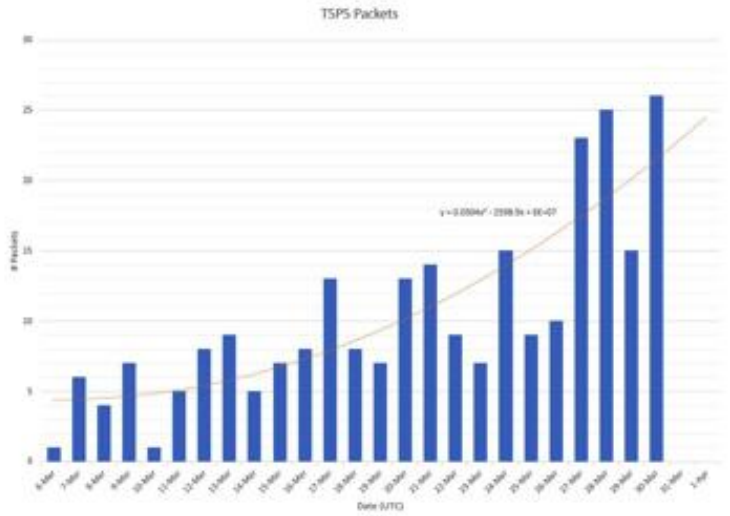
(‘design’; ‘nose-forward’)

Trending

Current

‘Nose-down’





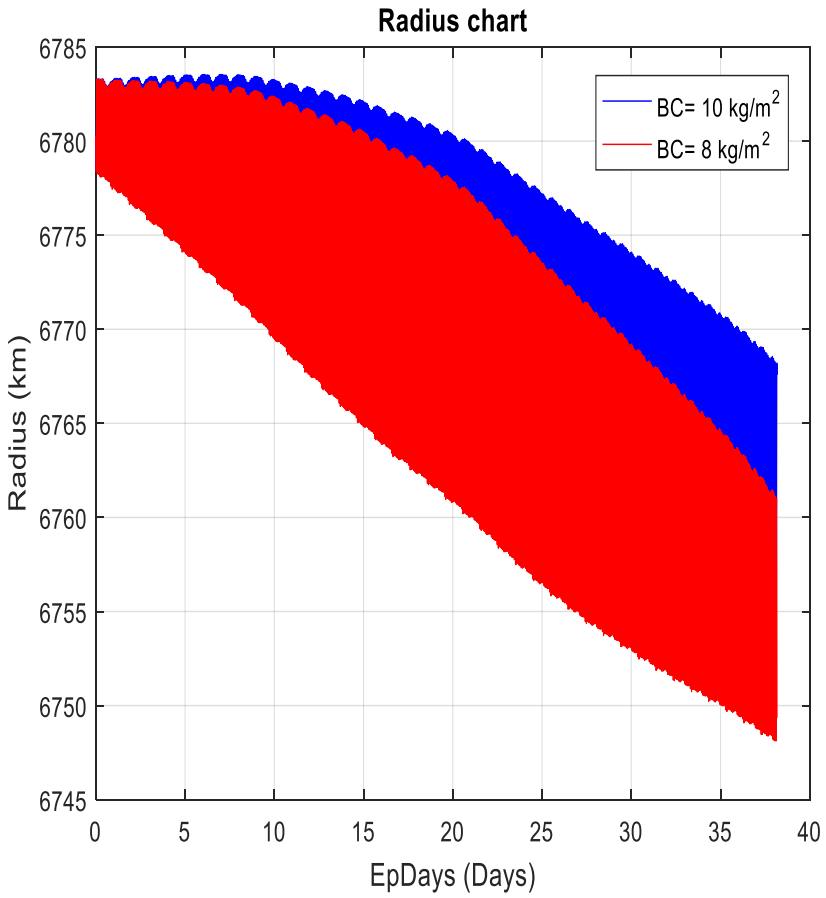
TES-5 is in a ‘nose-down’ orientation

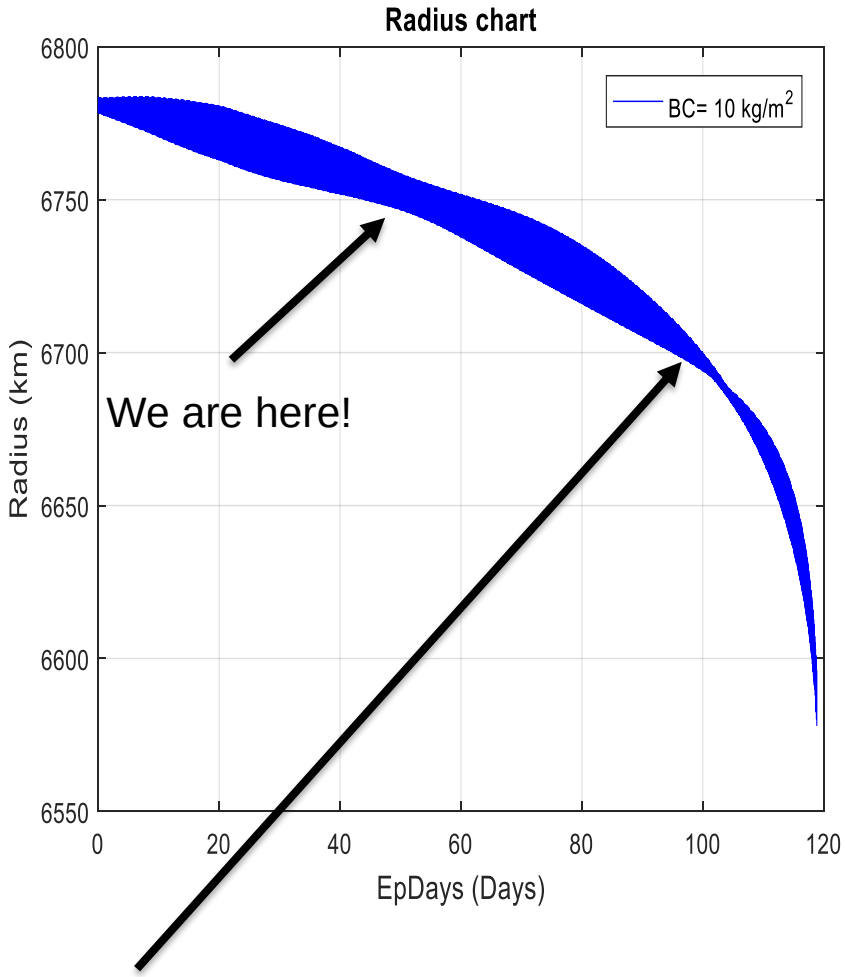
At -90deg (from ‘design’ horizontal flight 0deg), the link margin for ‘up-link is compromised a further -10dB (on top of -7dB for downlink baseline).

Number of packets/day is slowly increasing, suggesting that the link will improve – permitting a successful uplink.

Note: TES-4 had 25/25 uplink packets received (completely unique in the nano-sat community) in 28 days.

Modulation To Begin At 280-300 Km

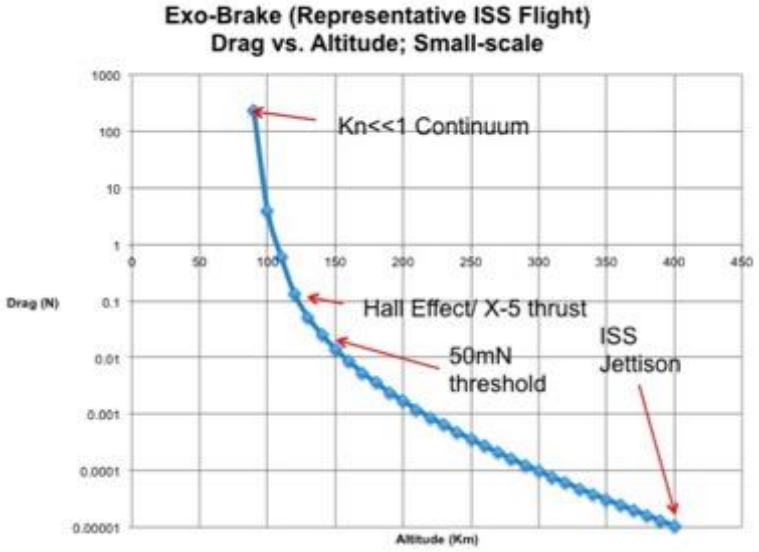




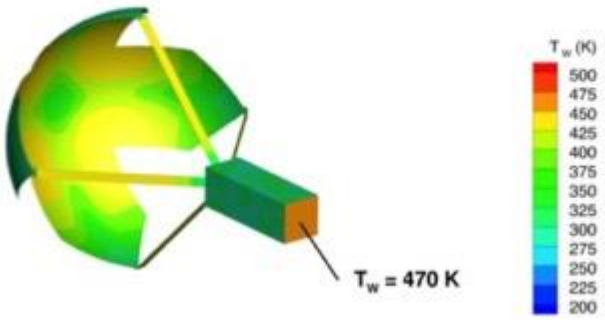
STK Results JB2006 Model A. Dono

At ~300km altitude, the modulation/target experiments are expected to commence.

Improve Targeting (Modulation)

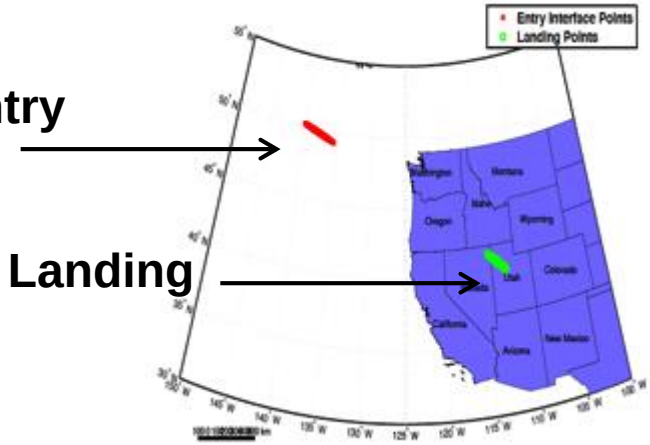


Nano-Sat and Exo-Brake Radiative Equilibrium Temperature
DSMC at $Kn_L = 10$, $\alpha = 0°$, $\varepsilon = 0.85$, 126 km Altitude



C. Glass, (LaRC)

Sample Return/Re-entry Targeting With Modulated Exo-Brake: Validation – it WORKS!



S. Dutta, A. Cianciolo, R. Powell , (LaRC)

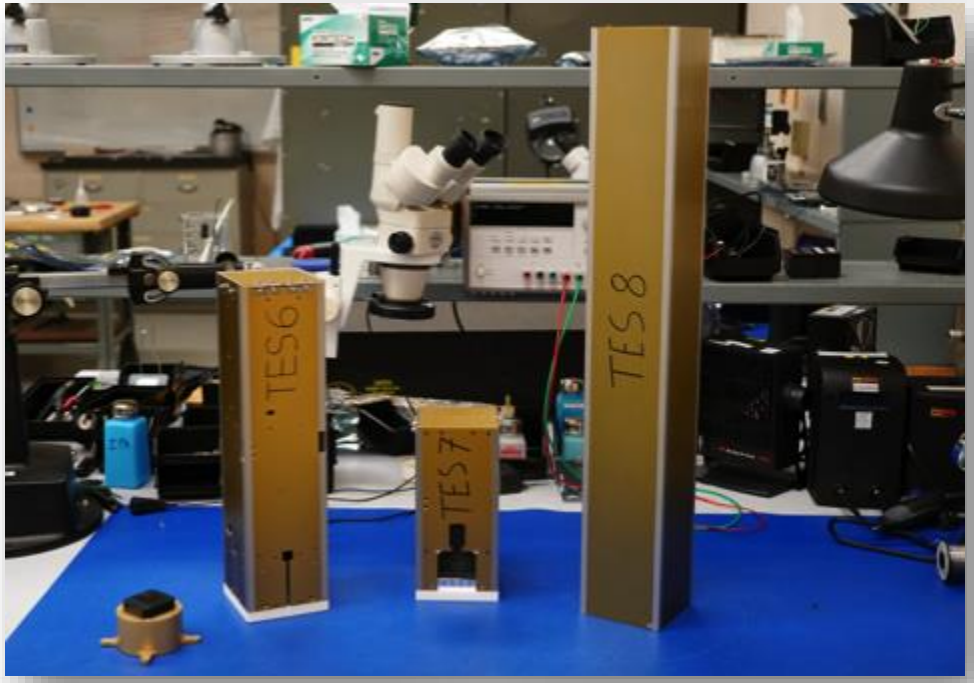
TechEdSat 6,7,8

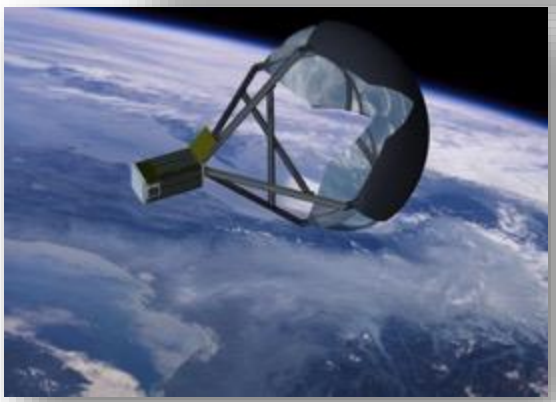
TechEdSAt-6 [*3U*]
2nd Modulated Exo-Brake Flight Test
Exo-Brake Tensioner
New OPS/Schedule
CUBIT-1

TechEdSat-7 [*2U*]
High Packing Density Exo-Brake
[Novel strut design – no modulation]
Beta= 1kg/m2
CUBIT-2

TechEdSat-8 [*6U*]
Hot Exo-Brake
Modulated with beta=4kgm2
'Deep Dive'
Novel COM

* All CSLI Approved





Summary

Exo-Brake is shown to provide a simple, safe means of de-orbiting nano/small spacecraft

- **Tension device provides more shape (drag) stability at altitudes <130km**

First Modulated (controlled) Exo-Brake flight test in progress

- **Full COM and control expected by 2nd week of June, 2017**

The TechEdSat-N/Phonesat provide the rapid experimental development platform

- **Unique COM systems permit up/downlink commands once/orbit**
- **Flexible systems provide accommodation of ancillary experiments**

Development risk is deliberately spread over multiple flights

TechEdSat 6,7,8 are in development

- **TechEdSat-6 [3U] applies experience from TechEdSat-5 for targeting 'practice' the Von Karman line [July, 2017]**
- **TechEdSAt-7 [2U] high packing density, low-beta disposal experiment [September, 2017]**
- **TechEdSat-8 [6u] combines above with high temperature Exo-Brake [March, 2018]**

Unique platform allows for SPQR-1, a small-sat system under development with $5m^2$ - class Exo-Brake

- **Based on SOAREX 8,9 sub-orbital experience**