National Aeronautics and Space Administration

Modulated Exo-Brake Flight Testing

Modelling and Test Results

Successes With Exo-Brake Development and Targeting for Future Sample Return Capability: TES-6,7,8 Flight Experiments

NASA Ames

June 9, 2019

Team List

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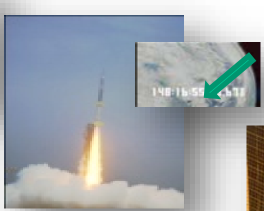
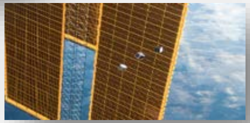
Relevant Flight Experiments (How We Got Here!)

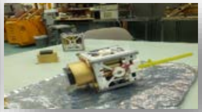

SOAREX-6
(2008)


SOAREX-7
(2009)

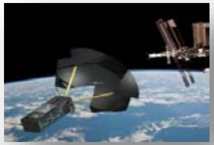

TES-1
Oct 4, 2012

SOAREX/TechEdSat-N Team

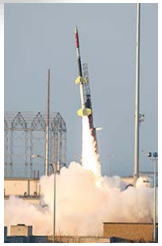
Flight Experiments of Recent Years
(2008-2015):
9 Flights


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)


T5/P5
Mar 6, 2017
(19 wk de-orbit)


SOAREX-9
(March 7, 2016)

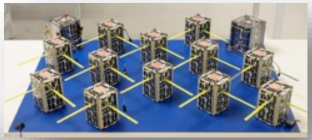

...here before


SOAREX-8
(2015)

PhoneSat Team

Flight Experiments of Recent Years
(2009-2015)


Nodes
Orb-4 Atlas V
Dec 3, 2015

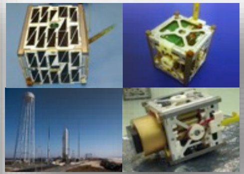

EDSN
Super Strypi
Oct 29, 2015

Balloon
June 9, 2011

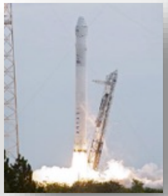
Intimidator-5
July 29, 2010

SpaceLoft-6
Apr 5, 2012

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



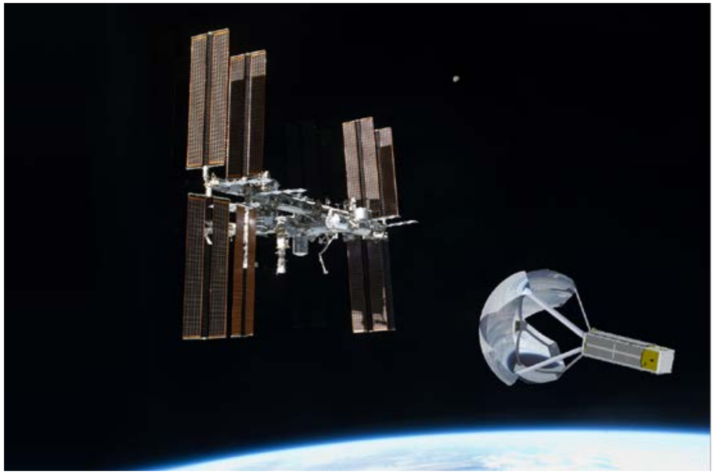

PhoneSat 2.4
ORS-3 Minotaur 1
Nov 20, 2013
(still in orbit)


PhoneSat 2.5
CRS-3 Falcon 9
Apr 18, 2014


SOAREX-8
Terrier/Black Brant
July 7, 2015

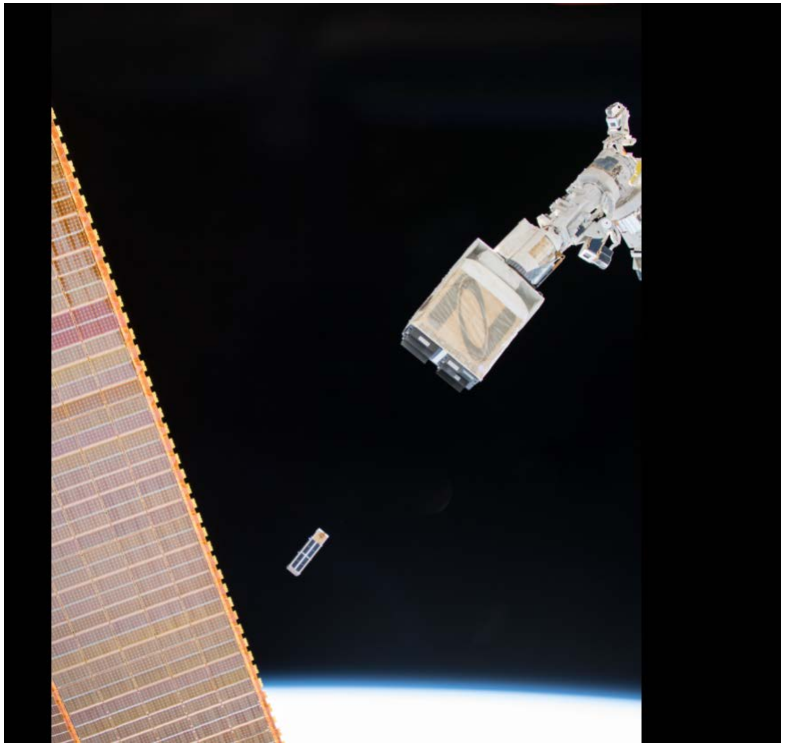
What is an Exo-Brake…?

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



vs. CORONA-type system with SRM and complex subsystems/OPS!

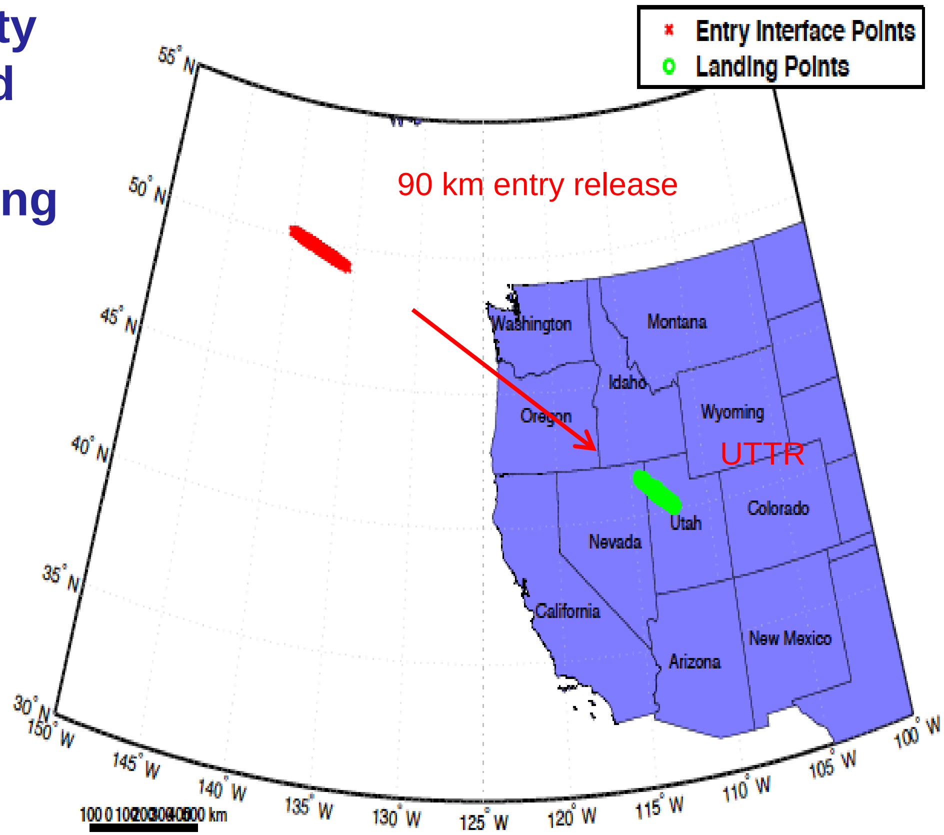
TES-6 and Exo-Brake Deployment (Nov 23, 2017)



TES6/PS6

Sample Targeting Results - UTTR

Previous work indicated the feasibility of targeting small areas – for payload recovery (2nd stage assumed DS-2 shape as representative self-stabilizing body)



Notes:

-ISS Orbit to UTTR
Exo-brake deploys re-entry system at 90km
(DS-2 NSC capsule)

-Monte Carlo dispersions
860 cases
JB2000; Earth GRAM +/-3 σ
(none on Exo-brake)

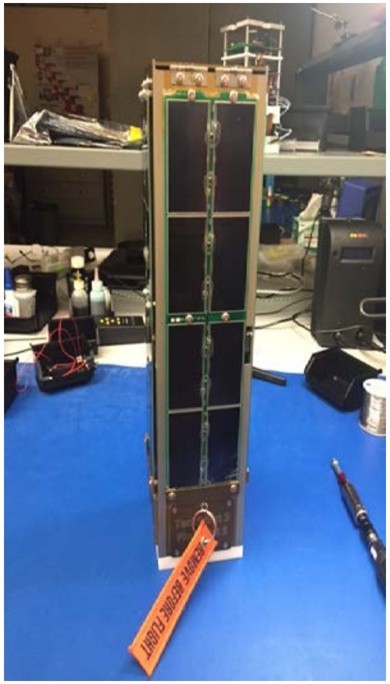
-POST2 selects 7 drag/modulation
Combinations

* Landing in 150km with capsule
appears feasible (though UTTR not
a good place to practice..)

Can we validate this experimentally?

S. Dutta, A. Dwyer Cianciolo, R.W. Powell , (LaRC) [Exo-Brake Development/Analysis Team/ARC-LaRC]

TES-6 Spacecraft Description

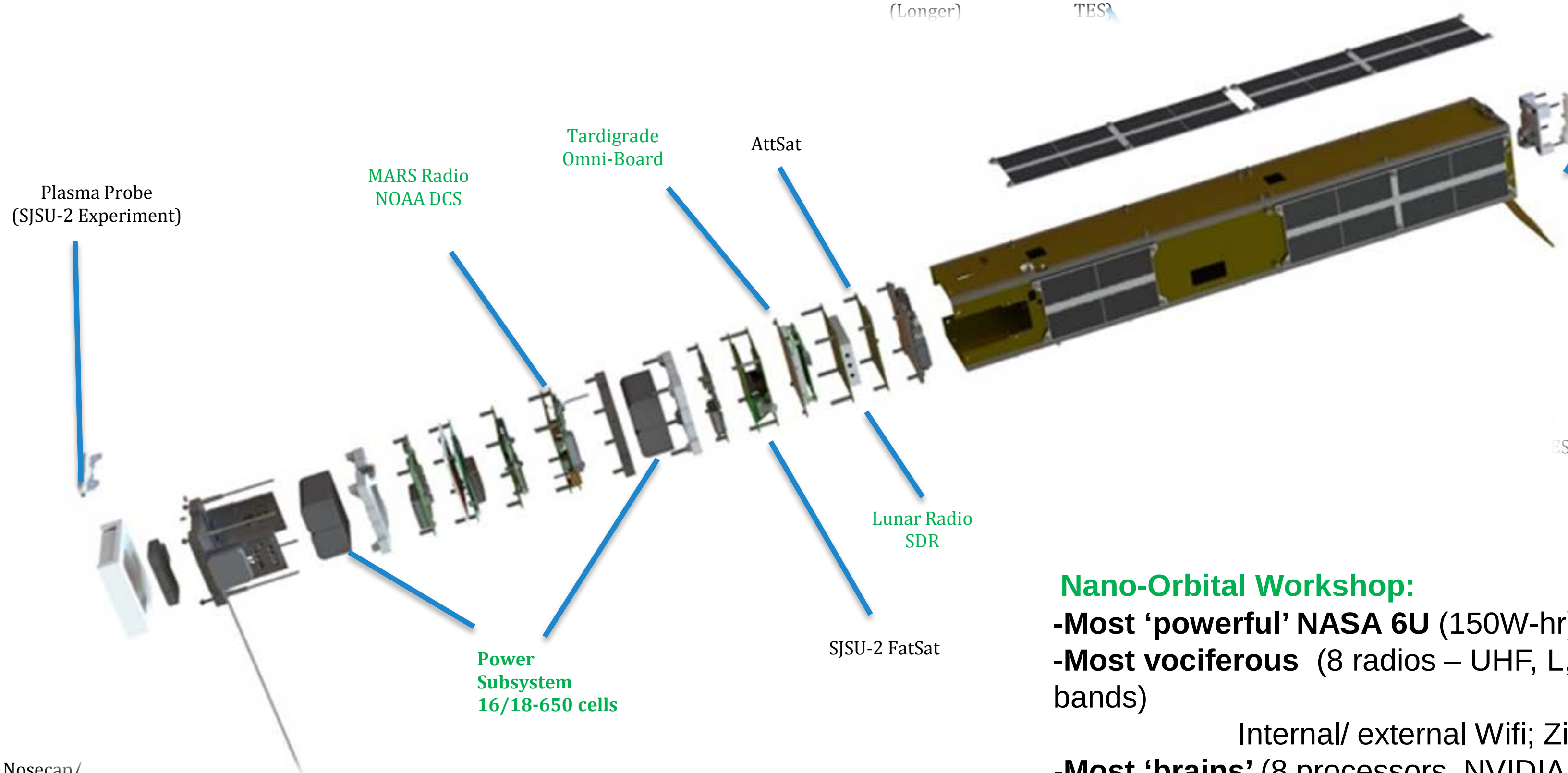


Notes:

- 3U Nano-sat with aft-door allowing Exo-Brake deployment
- Avionics stack comprised of 6 micro-processors
- Wireless Sensor Modules ('Cricket') located on interior and Exo-Brake apex (Standard Communication 802.15.4 IEEE)
- COM system comprised of 2 Iridium SBD, one 2457MHz 'WiFi' transmitter
- Orthogonal Iridium antennas permit redundant command/control capability
- Interior wireless command capability between 2 major avionics stack sections (TES and PhoneSat)
- GPS permitted a minimum of one track/orbit

* 'Record' set for WiFi long distance link

TES-8: A Nano-Orbital Workshop (NOW) Currently De-Orbiting…



Nano-Orbital Workshop:

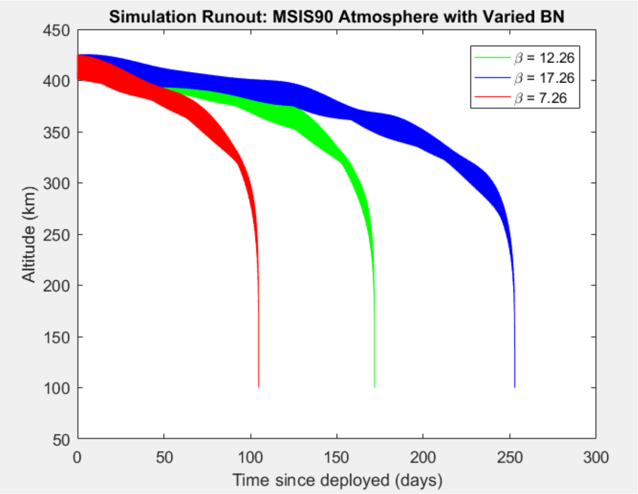
- **-Most 'powerful' NASA 6U** (150W-hr)
- **-Most vociferous** (8 radios – UHF, L, S, ISM bands)
  Internal/ external Wifi; Zigbee
- -**Most 'brains'** (8 processors, NVIDIA TX2 GPU)
- -**Most cameras** (4 including VR experiment)
- **-Most Exo-Brake** (largest one to-date; targeting)

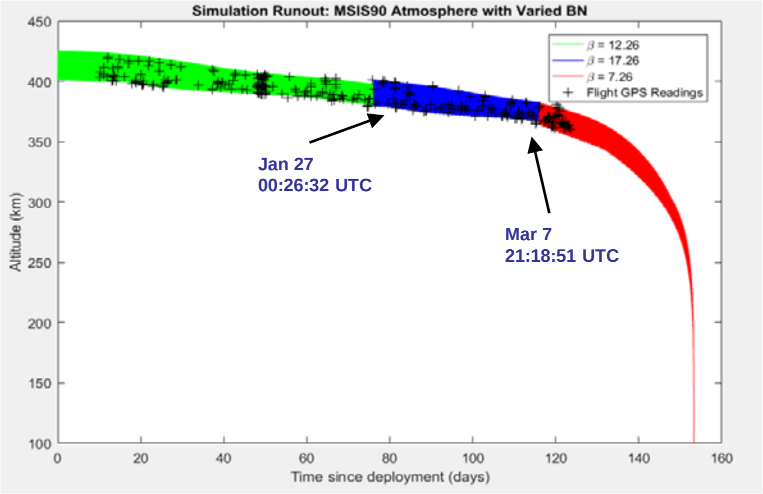
De-Orbit Targeting

Use Exo-Brake modulations to guide TES-6 over Wallops prior to re-entry

Manually command modulation times via Iridium

STK, POST2, and GMAT are used to determine modulation times on a day-to-day basis





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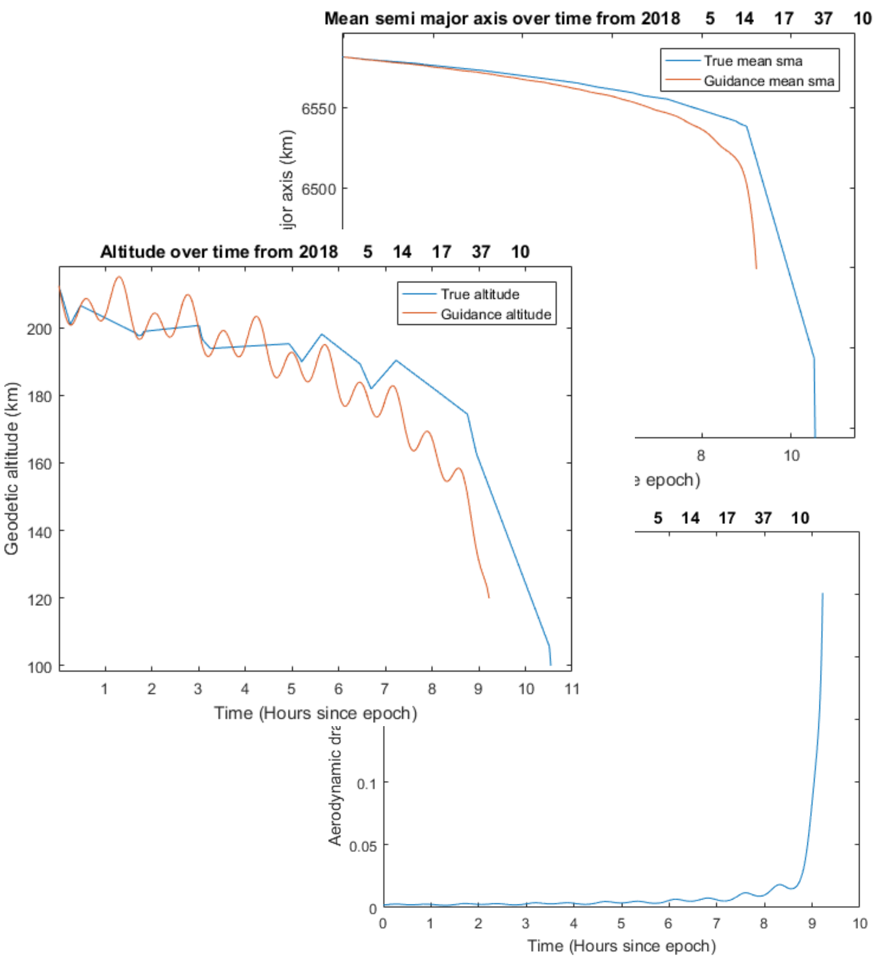
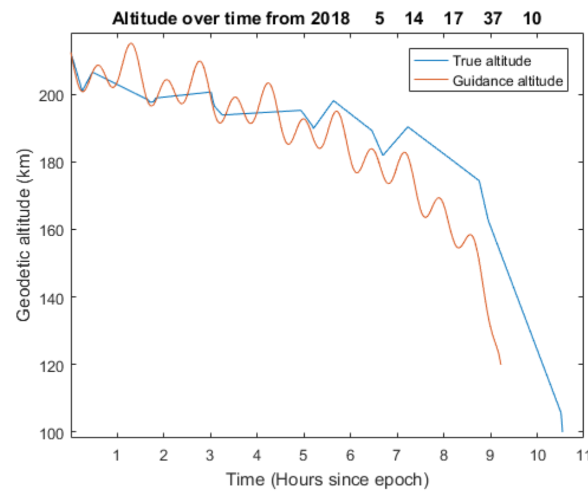
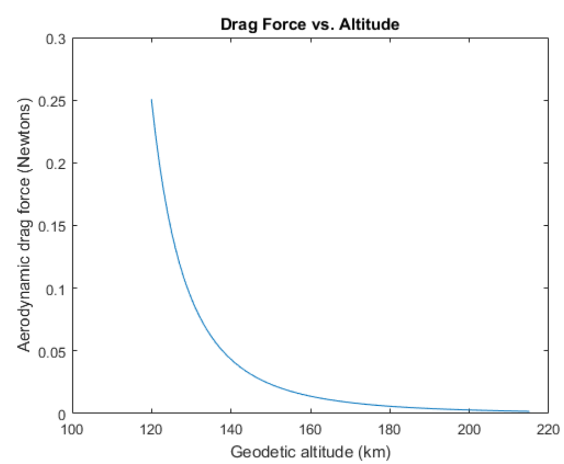
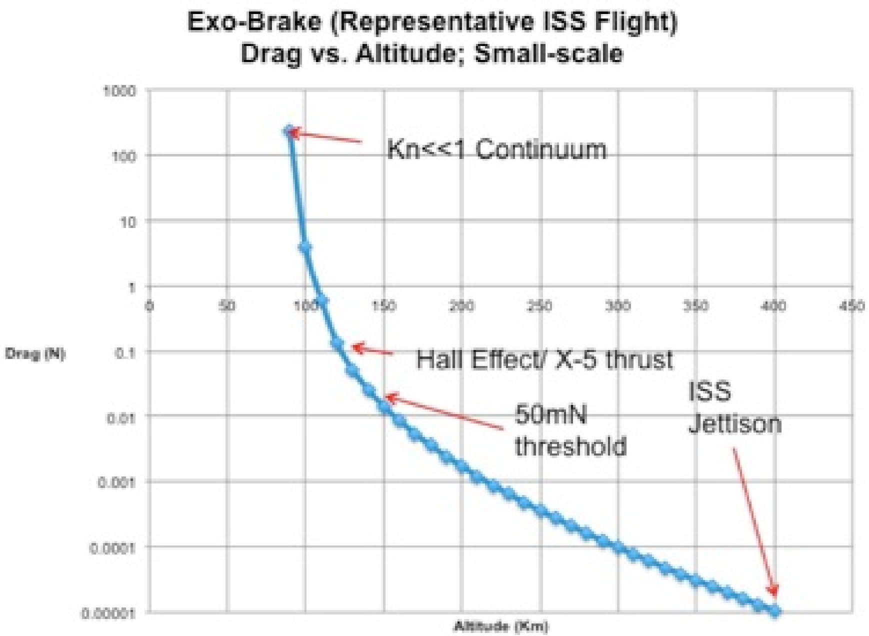
Final Guidance and Tracking



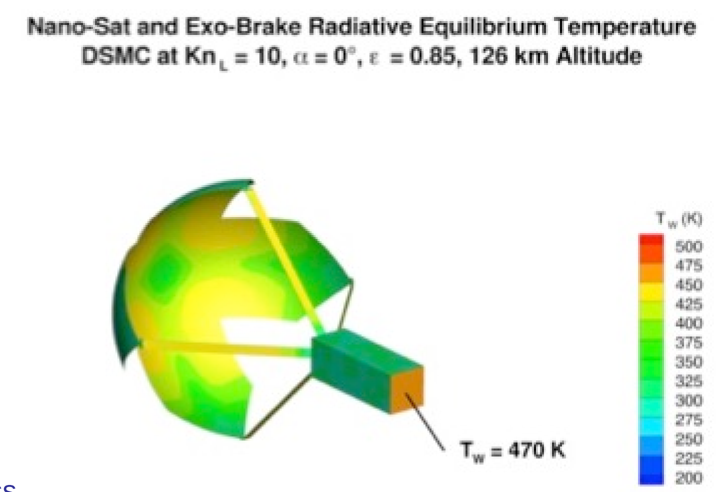




Improve Targeting (Modulation)



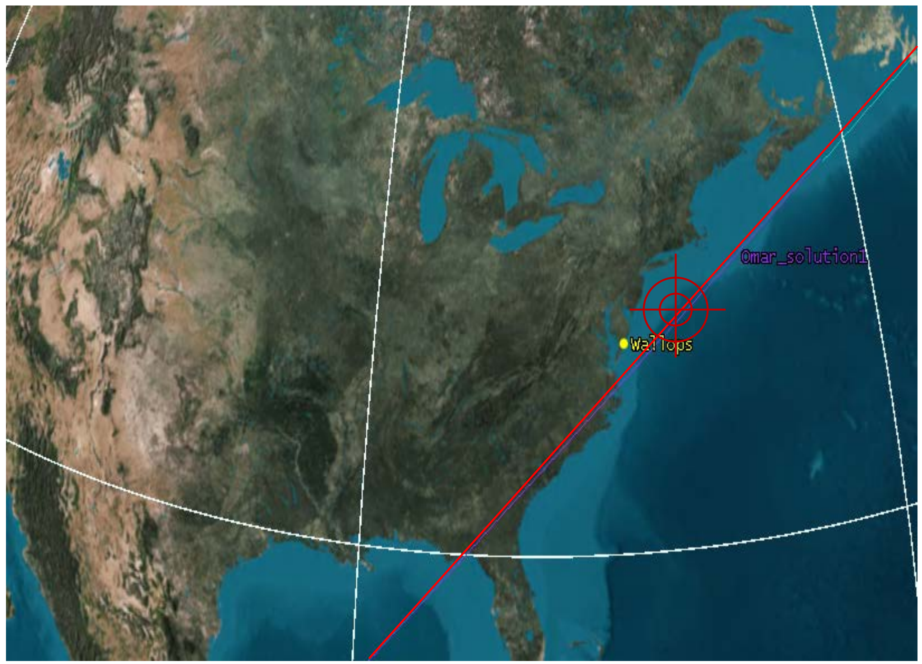
How much drag is represented?



Equilibrium Temperature at various altitudes are calculated

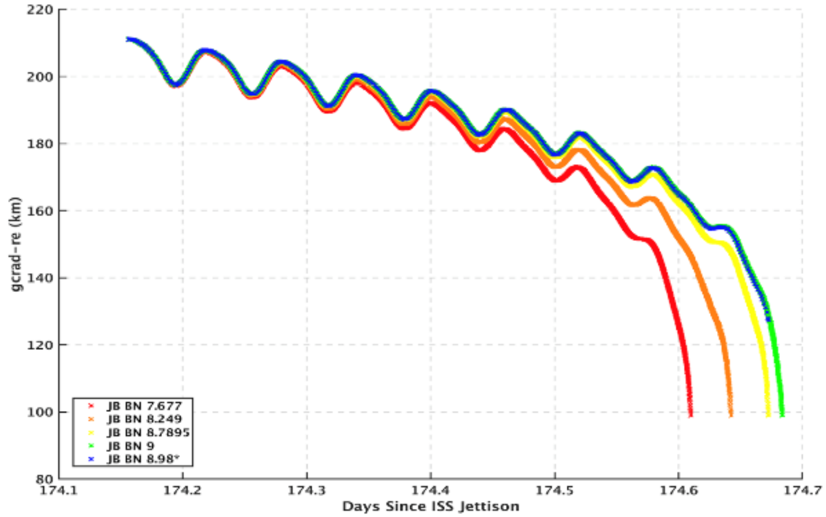
C.Glass

Track of ‘Terminal Approach’

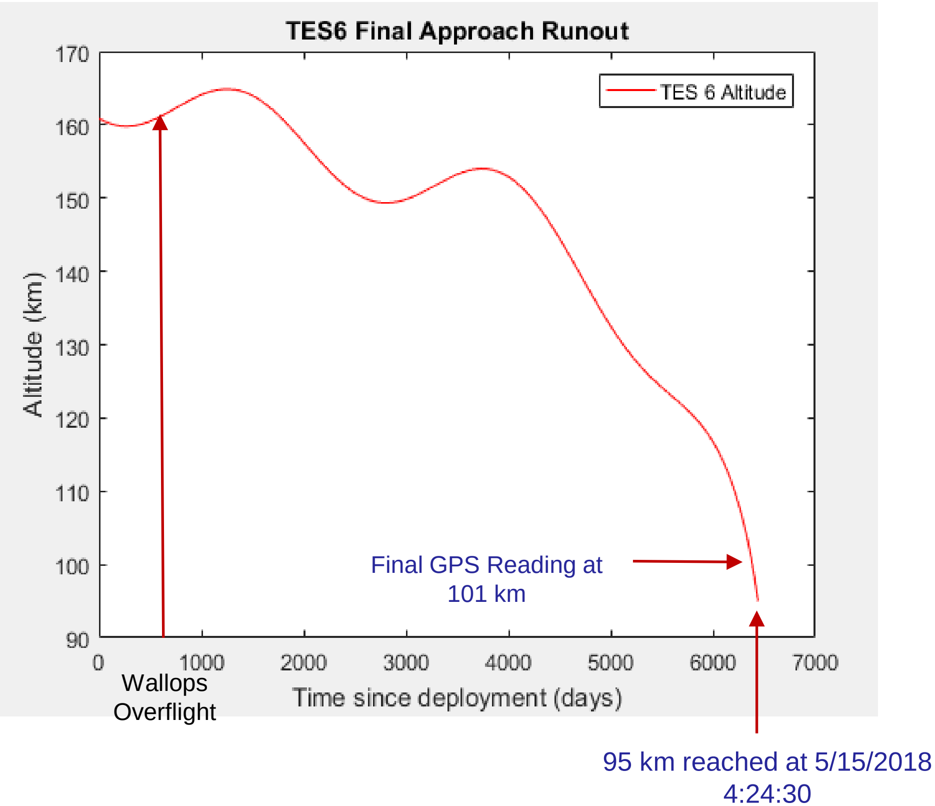


Target point (In the future, a flare maneuver to prevent overflight)

Track of 'Terminal Approach'



Track of 'Terminal Approach'



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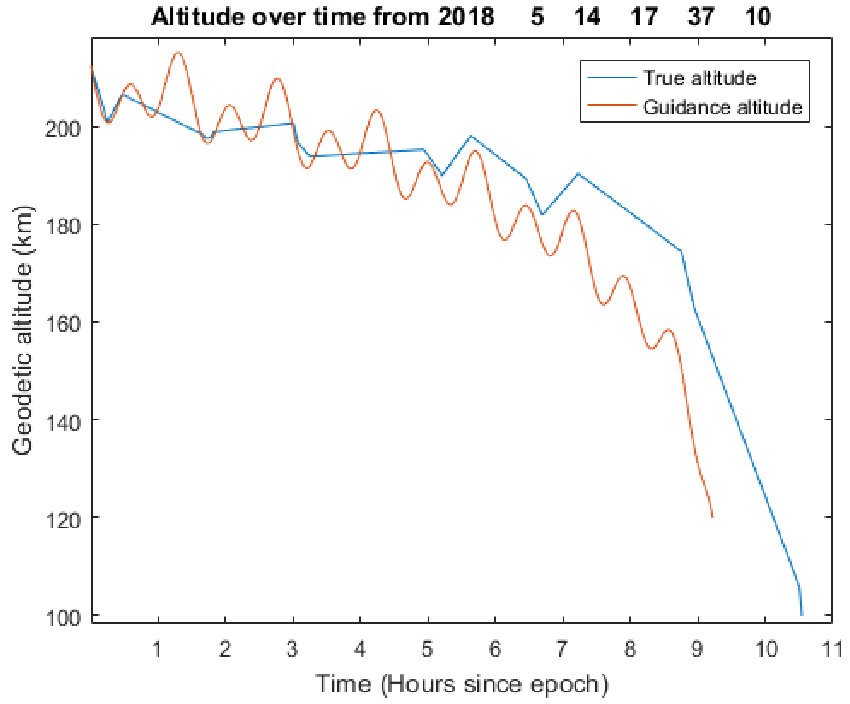

Future Flight/Opportunity Sequence

TechEdSat 9,7,8,10

TechEdSat-9 [3U]
Exp automated de-orbit

TechEdSat-7 [*2U*]
High Packing Density Exo-Brake
[Novel strut design – no modulation]
β = 1kg/m2; 450 km
CUBIT-2
2nd Virgin Orbit Flight Sept, 2018

TechEdSat-8 [*6U*]
Hot Exo-Brake
Modulated with β =4kgm2
NOAA DCS UHF (~Mars Radio)
2nd Tier SAA Experiments
Novel COM
ISS/NRCSD Nov, 2018
CURRENTLY de-orbit

TechEdSat-10 [6U]
Flight scheduled Jan, 2020

SPQR ('SmallSat') as EDL Experiment Platform

DS-2 Entry Body

TDRV

Requires dedicated ISS/JEM airlock cycle

Evolved capability enables unique EDL experiments – particularly when deployed over re-entry target close to range with TM assets (e.g., WFF or Kwajalein)

Summary

TES6 Exo-Brake Flight Test was concluded successfully on May 15, 2018

First SUCCESSFUL demonstration of controlled/targeted de-orbit via Exo-Brake Modulation

All s/c functions operated throughout (basic avionics stack, COM, Exo-Brake commands)

'Final approach' operations started at 300km (purported altitude whereby target areas could be hit <150km within latitude bands)

'Terminal approach' operations started at 200km (x orbits) with Exo-Brake 'state change' permitted final pass to align over WFF

Final 'flare' was insufficient to cause rapid descend after WFF target area [problem solved for next flight]. TES6 landed fractional orbit after.

Next 2-3 targeting flights being prepared with TES 8,10,11. TES-8 is the first of the larger 6U set (

TES 11 includes an experimental autonomous control system to be in place for final 10-18 orbits

**Progress shows that 'fine' de-orbit targeting is possible with a) sufficient Exo-Brake drag variability, b) on-board control system remove command latency due to COM system