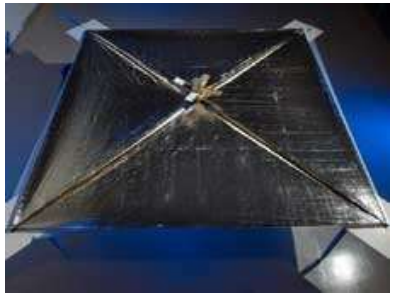
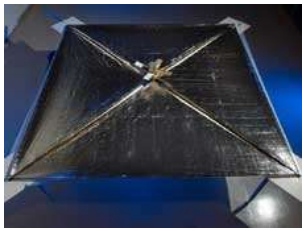


FP7: Deorbit Sail Project

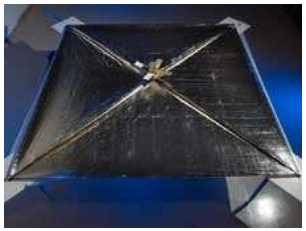
Prof WH Steyn

KNOWLEDGE



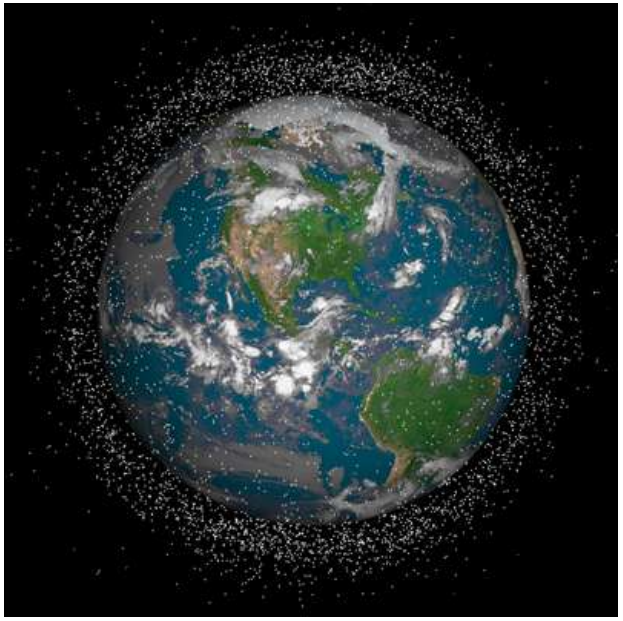
Historical Background

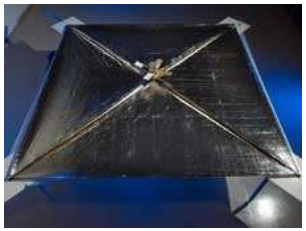
- **WHS Sabbatical: Jan – Apr 2009 at the Surrey Space Centre in the UK**
  - » South Africa – UK Science Network Grant
    - – R 12 000 air fare (NRF) & £ 3 982 subsistence (Royal Society) received
  - » Collaborated with Dr Vaios Lappas at SSC on new space missions
  - » NASA Nanosail-D mission failed during launch in Aug 2008
    - – To demonstrate first solar sail deployed in space
    - – 3U Cubesat design
    - – 10 m^2 deployed sail
    - – Supposed to be only a 4 day mission
  - » Proposal for a Cubesail-A mission
    - – Demonstrate deployment of 25 m^2 solar sail (5m x 5m)
    - – Measure solar force over a minimum 1 year period
    - – Change in inclination ≈ 3°/year in a 800 km initial Sun Synchronous orbit
  - » WHS designed the attitude control system for Cubesail-A
    - – An *Aerospace Science and Technology* journal paper was published: "Cubesat solar sail 3-axis stabilization using panel translation and magnetic torquing"
- **FP7-Space-2010 Collaborative Project proposal**
  - » Compiled by Dr Vaios Lappas in November 2009
  - » To demonstrate satellite de-orbiting manoeuvres for space debris mitigation



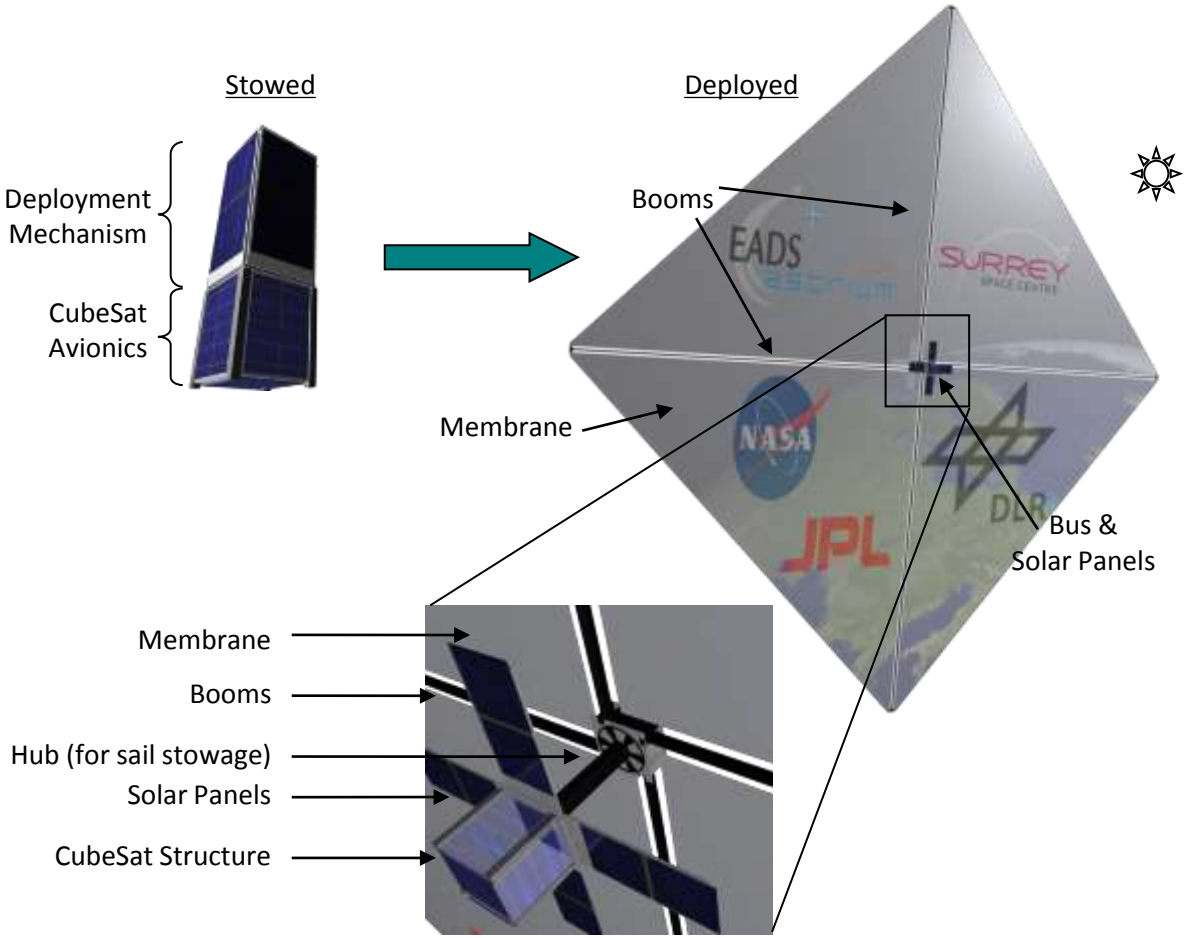
Project Objective

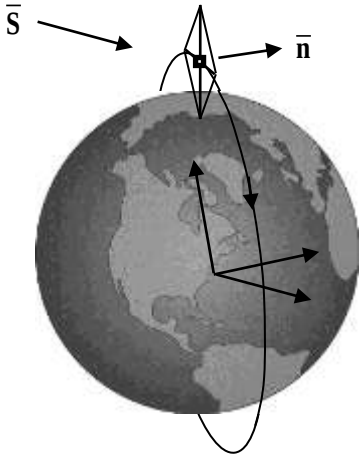
- The goal of this project is to develop and flight test a deorbiting device based on a 25-m squared Solar Sail. The approach will be to modify Solar Sail deployment technology for use as a satellite and/or rocket upper stage deorbiting system. Recent events have exasperated the growing problem that orbital debris, or "space junk," poses to spacecraft

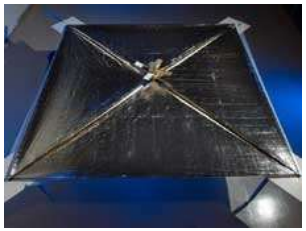




Solar Sail Deployment Concept



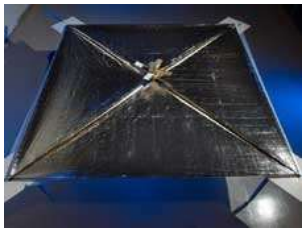




FP7 Evaluation Report

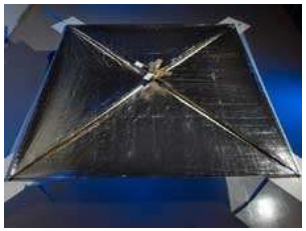
2.3-01/2 Space weather /on-orbit collisions (CP)

Rank	Proposal Acronym	Content	EU Contr. (in MEUR)	Score
1	DEORBIT SAIL	Debris removal, solar sails	1.999	15.0
2	PLASMON	Space weather – radiation belt modelling	1.972	14.5
3	SWIFF	Space weather – modelling forecasting	1.559	14.5
4	SPACECAST	Space weather – modelling forecasting	1.965	14.0
5	CLEANSPACE	Debris removal by laser illumination	1.999	13.5
6	AFFECTS	Space weather - advanced forecast	2.000	13.0
7	SIDER	Space weather - radiation shielding	1.067	13.0

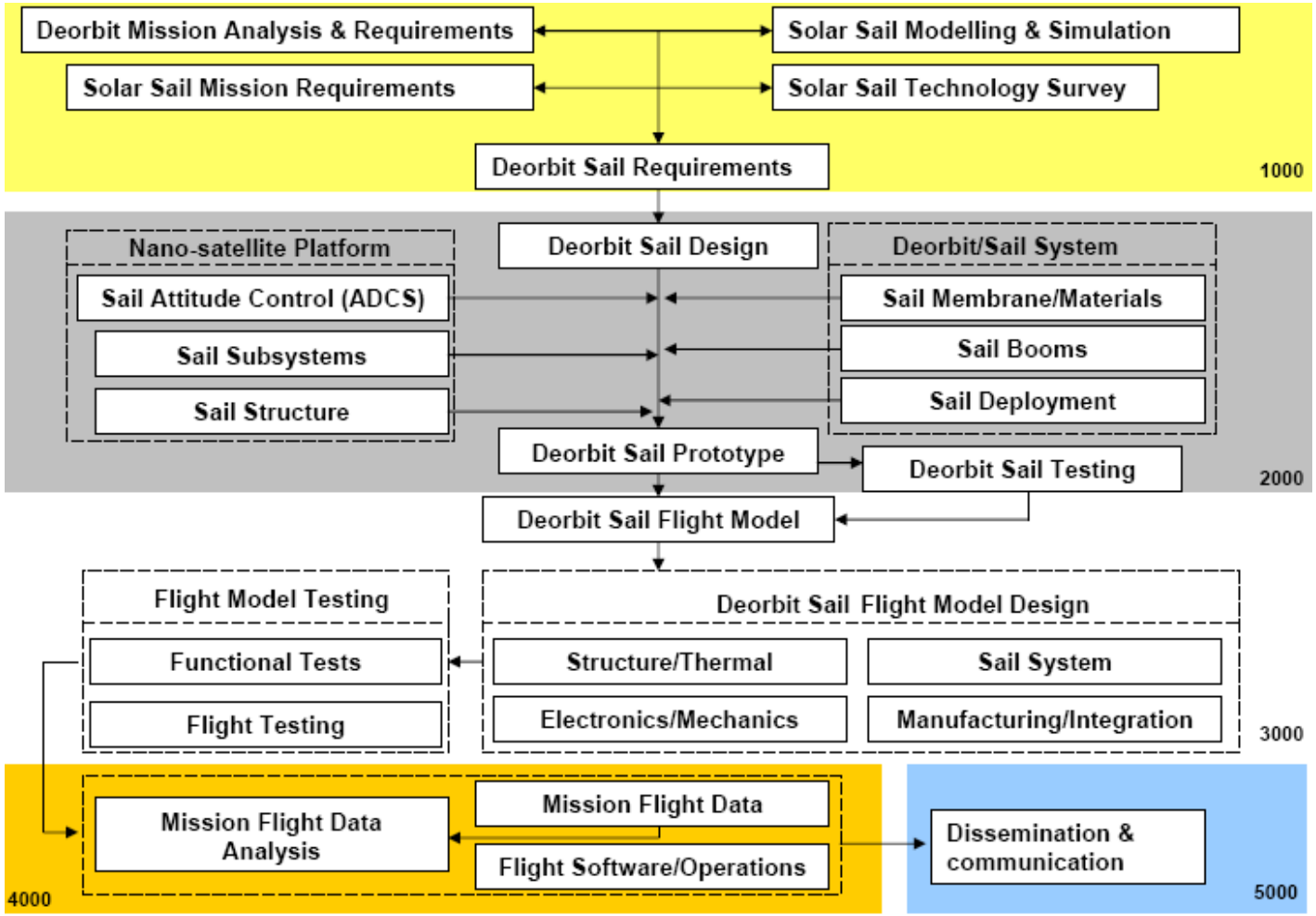


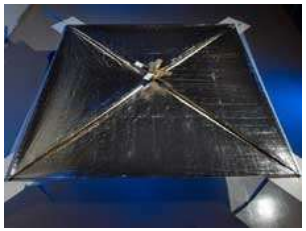
Evaluator Comments

- *"The proposed device is an innovative, well conceived system for the de-orbiting of Low Earth Orbit spacecraft. The proposal is well presented and demonstrates a good understanding of the issues involved. The objectives are challenging but realistic assuming use of CubeSat heritage and considering timelines of past CubeSat-type missions"*
- *"The consortium is appropriate and balanced and includes leading entities in their field with a good mix of small and large industry participants, agency, and universities. Inclusion of the South African Stellenbosch University, which has considerable relevant small satellite experience, is laudable as an example of African-European space cooperation"*
- *"The project will have an impact at the international level but with significant system capability centred on contributions at the European level which will translate to useable and saleable results"*
- *"In addition, while focussed on the security of space area, the project will also address part of the space transportation work programme (SPA 2010.2.1-04) as it is applicable to other future space transportation means (e.g. orbit transfer, inter-planetary transportation)"*



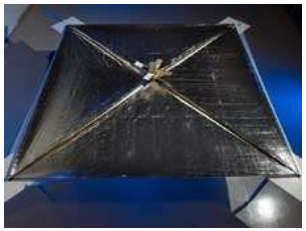
Deorbit Sail Project Plan





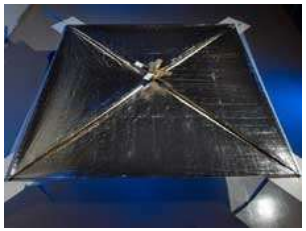
Project Participants

Participant No.	Participant organisation name	Country
1 (Coordinator)	Surrey Space Centre (SSC)	United Kingdom
2	Jet Propulsion Laboratory Caltech (JPL)	U.S.A.
3	German Aerospace Centre (DLR)	Germany
4	EADS Astrium (AST)	France
5	Stellenbosch University	South Africa
6	University of Patras	Greece
7	Athena-SPU (ATH)	Greece
8	Middle Eastern Technical University (METU)	Turkey
9	Surrey Satellite Technology Limited (SSTL)	United Kingdom
10	ISIS	Netherlands



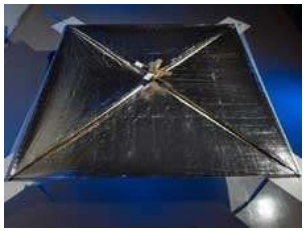
Project Participant Roles

	Short Name	Country	Business activity	Main role in the project
1	***SSC***	United Kingdom	University – Teaching and research	Coordinator; Sail Mission requirements; sail technology survey; solar sail mechanism/deployment; flight model functional testing; management
2	***NASA JPL/Caltech***	USA	University – Teaching and research	Solar Sail modelling and simulation; finite element analysis
3	***DLR***	Germany	National Research Institute and Space Agency	Development, manufacturing and test of deployable gossamer booms
4	***AST***	France	Large Systems Integrator	Solar Sail materials, Solar Sail testing
5	***STE***	South Africa	University – Teaching and research	Spacecraft attitude determination and control; orbit control
6	***UoP***	Greece	University – Teaching and research	Cubesat (satellite) CF structure, thermal analysis
7	***ATH***	Greece	University – Teaching and research	Satellite electronics, dissemination and communications
8	***METU***	Turkey	University – Teaching and research	Sail boom controls/damping
9	***SSTL***	United Kingdom	Small, Medium	Flight operations, flight data analysis, ground station support
10	***ISIS***	The Netherlands	Small, Medium	Satellite subsystems (power, RF), integration, flight campaign and launch vehicle integrator



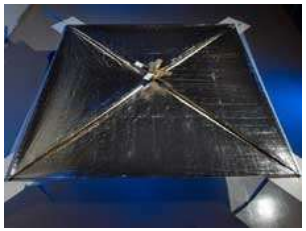
Man-month Effort

Manmonths	WP Leader	Total PMs	1-SSC	2-JPL	3-DLR	4-AST	5-STE	6-UoP	7-ATH	8-METU	9-SSTL	10-ISIS	% Overall Effo
WP1 Sail Reqs, design and simulations	SSC	10	4	1	3	0	1	0	0	1	0	0	5
T1.1: Deorbit Mission Analysis and Requirement	DLR	2	1		1								1
T1.2: Solar Sail Mission Requirements	SSC	2	1							1			1
T1.3: Solar Sail Modelling and Simulation	JPL	4	1	1	1		1						2
T1.4: Sail Technology Survey	SSC	2	1		1								1
WP2: DEOBRIT-Sail Development/Prototyping	AST	66	11	2	15	13	11	4	7	3	0	0	33
T2.1 Sail Materials	AST	4			1	3							2
T2.2: Sail Booms	DLR	10	2		8								5
T2.3: Sail Mechanism	SSC	10	4		2	3				1			5
T2.4: Sail Deployment	SSC	10	3		2	5							5
T2.5: Sail Testing	ATH	10	2		2	2	1		3				5
T2.6: Sail ADCS	STE	8					8						4
T2.7: Sail Subsystems	ATH	6					2		4				3
T2.8: Cubesat CF Structure	UoP	2						2					1
T2.9: Sail Thermal Analysis	UoP	2						2					1
T2.10: Sail FEA	JPL	2		2									1
T2.11: Boom Controls	METU	2								2			1
WP3: Deorbit Sail FM	DLR	70	6	0	19	4	2	2	14	2	0	21	35
T3.1: Sail Structure	ATH	8	2						3	1		2	4
T3.2: Sail System	DLR	12	1		5	2			2			2	6
T3.3: Electronics	ISIS	12	2				1		4			5	6
T3.4: Mechanics	DLR	10			4			2	4				5
T3.5: Manufacturing/Integration	DLR	12			5							7	6
T3.6 Functional Tests	SSC	8	1		3	1			1			2	4
T3.7: Flight Tests	DLR	8			2	1	1			1		3	4
WP4 Mission Flight Data	SSTL	30	9	0	2	0	0	2	0	2	12	3	15
T4.1: Flight Software/Operations	SSC	22	8		1			2		2	6	3	11
T4.2: Flight Data Analysis	SSTL	4			1						3		2
T4.3: Ground station	SSTL	4	1								3		2
WP5: Dissemination & Comm'n	ATH	12	5	0	1	1	0	0	3	0	0	0	6
WP6: Management	SSC	12	12	0	0	0	0	0	0	0	0	0	6
Total PM RTD		176	30	3	39	17	14	8	21	8	12	24	88
Total PM DEM		12	5		1	1		2	3				6
Total PM MGT		12	12										6
Total Overall PM		**200**	47	3	40	18	14	10	24	8	12	24	
% Overall PM			**23.5**	**1.5**	**20**	**9**	**7**	**5**	**12**	**4**	**6**	**12**	100



Project Funding

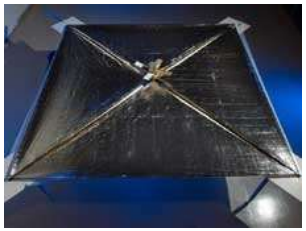
N.	Proposer name	Country	Type	Total cost (€)	%	Grant requested (€)	%
1	UNIVERSITY OF SURREY	UK		577,013.00	20.05	479,128.00	23.97
2	California Institute of Technology	US		35,833.00	1.24	30,000.00	1.50
3	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	DE		530,287.00	18.42	398,965.00	19.96
4	ASTRIUM S.A.S.	FR		460,593.00	16.00	241,546.00	12.09
5	STELLENBOSCH UNIVERSITY	ZA		180,000.00	6.25	140,000.00	7.00
6	UNIVERSITY OF PATRAS	EL		126,667.00	4.40	100,000.00	5.00
7	ATHENA RESEARCH AND INNOVATION CENTER IN INFORMATION COMMUNICATION & KNOWLEDGE TECHNOLOGIES	EL		303,881.00	10.56	234,036.00	11.71
8	MIDDLE EAST TECHNICAL UNIVERSITY	TR		103,333.00	3.59	80,000.00	4.00
9	Surrey Satellite Technology Ltd	UK		104,836.00	3.64	54,918.00	2.75
10	ISIS - Innovative Solutions In Space BV	NL		456,000.00	15.84	240,000.00	12.01
			Total :	**2,878,440.00**	**99.99**	**1,998,593.00**	**99.99**



Our Contribution

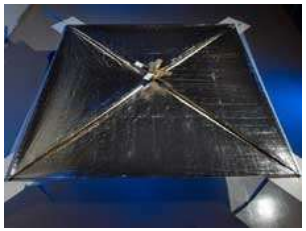
- **T2.6: Sail Attitude, Determination and Control Systems (ADCS)**
- Contributing partners (task leader in bold): **STE**

- This work package will focus on the algorithm and hardware development of the ADCs system for the sail. Sensors and actuators will be developed and tested. Specifically a novel 2-axis tilt mechanism will be developed based on a linear motor system to tilt a portion of the satellite bus about the pitch and yaw axes to a maximum length of 3 cm in order to take advantage of the centre of mass/pressure offset and use it to control the sail. Furthermore a wide angle lens will be used as a sun/horizon sensor for the determination system based on commercial off the shelf technology (COTS).



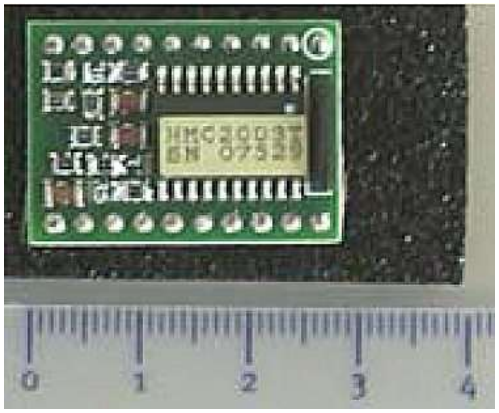
Nadir & Sun Sensor (CubeSense)

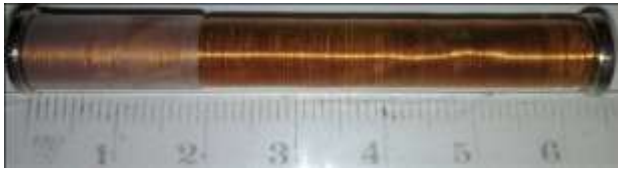
- 664 x 492 pixel CMOS camera with parallel interface
- Nadir and sun sensor heads
- 190 deg FOV fisheye lens
- Dual FPGA/SRAM system for redundancy
- PIC processing of nadir & sun centroids for ADCS OBC
- I2C interface to camera & OBC
- Measurements every 10 sec
- Accuracy expected:
  Nadir & Sun direction < 1 deg
- Total mass = 120 g for CubeSense
- Total power < 300 mW on average

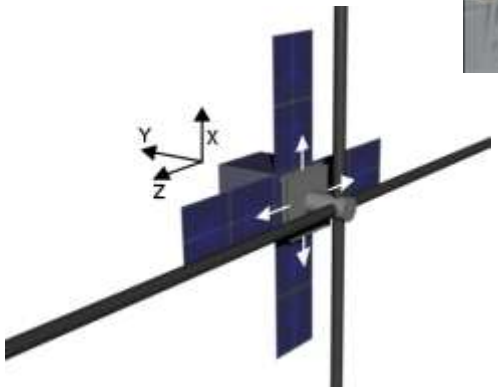


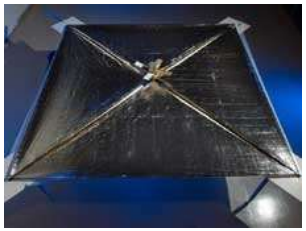
Attitude Control Actuators

- Initial detumbling & sail deployment using magnetic control
  - » 3-Axis Magneto-resistive sensor: ± 60 μT range
  - » 3-Axis torquerods: M_{max} = 0.2 Am^2
- Post-sail deployment: 3-axis stable solar sail
  - » 2-Axis X/Z Translation stage: ± 3 cm range to adjust CoP of sail
  - » Magnetic X-product controller for full attitude stability
- Total mass of sensors & actuators:
  - » Magnetic controller board = 80 g, Torquerods = 20 g each
  - » Translation stage = 120 g, CubeSense unit = 120 g
  - » ADCS Total = 380 g

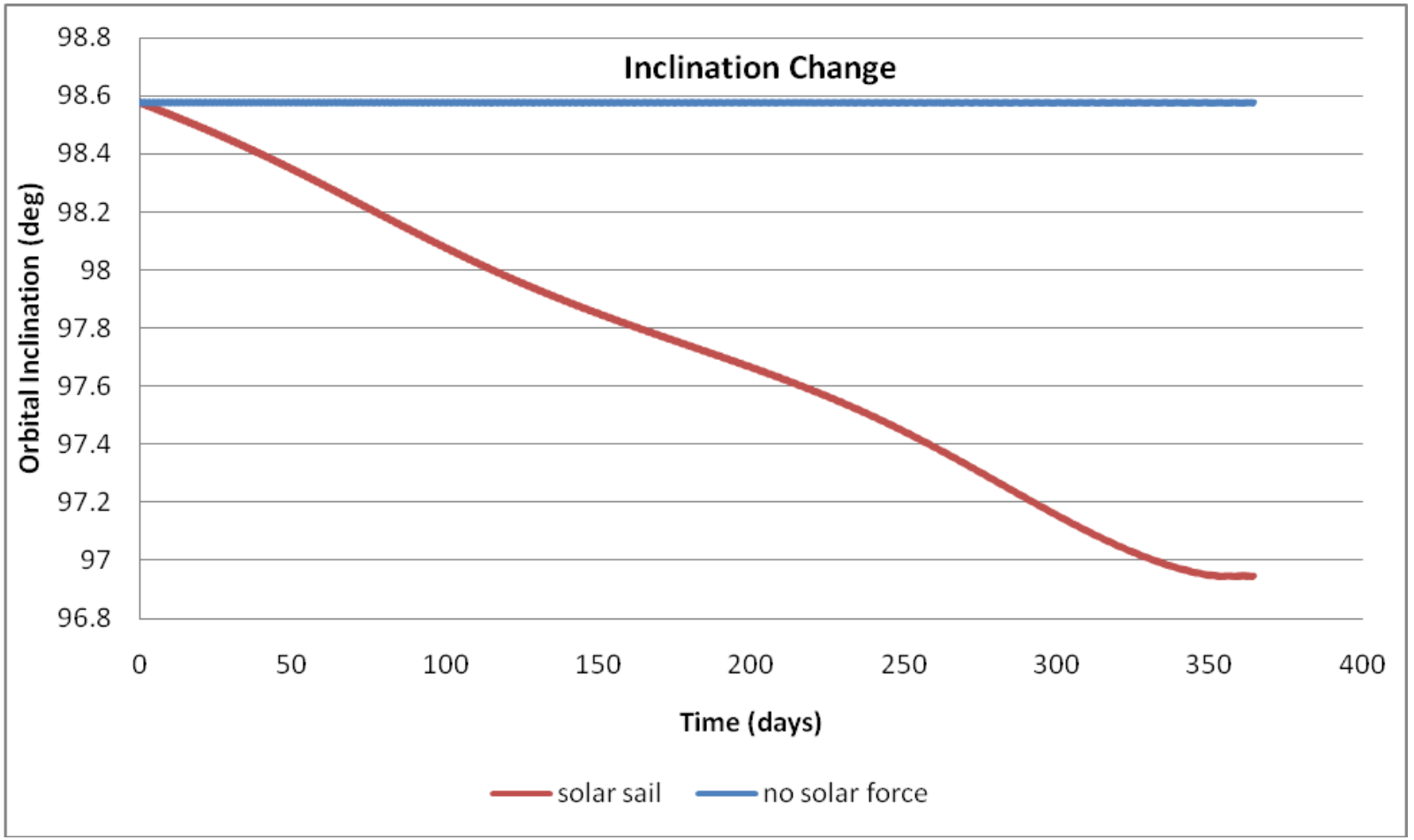


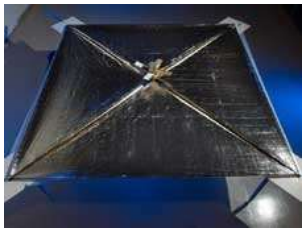






Solar Sail Expected Result





3-Axis Control Performance