Second generation EmDrive

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EmDrive is the worlds first propellant-free propulsion system

Concept has been developed for spacecraft propulsion, using two different theoretical methods, by independent groups in UK and China

Both groups have demonstrated experimental first generation thrusters, of different designs, with a specific thrust of 300mN/kW

UK research work funded by government grants and private investment

First generation, low thrust technology, designed for in-orbit applications, transferred to US.

Experimental second generation (2G) high thrust device, cooled by liquid Nitrogen, achieved design Q value

Theoretical study solved dynamic problem for 2G engines. Solution has led to designs for launch vehicle and terrestrial applications

Inventor's Background

11 years R&D in electrical engineering and the defence Industry

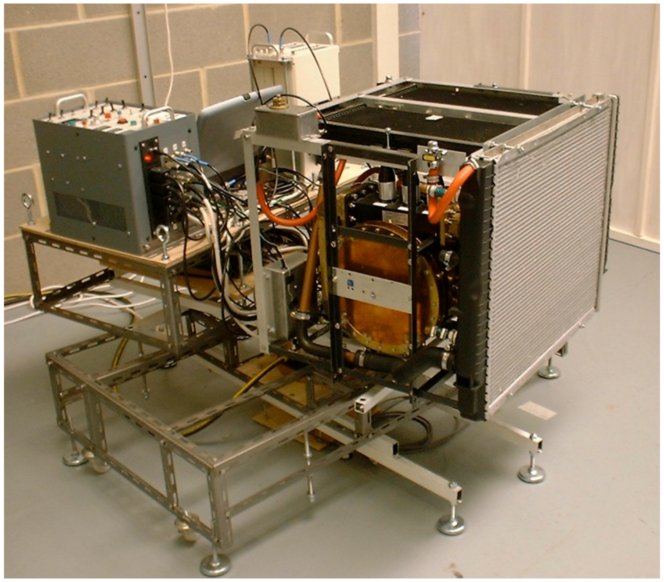
20 years engineering and project management with EADS Astrium,Europe's leading Space company

Head of Payload Engineering Dept

Project Manager for NATO 1V and Hotbird Payloads

11 years as Director of SPR Ltd, in R&D for EmDrive

EmDrive Background



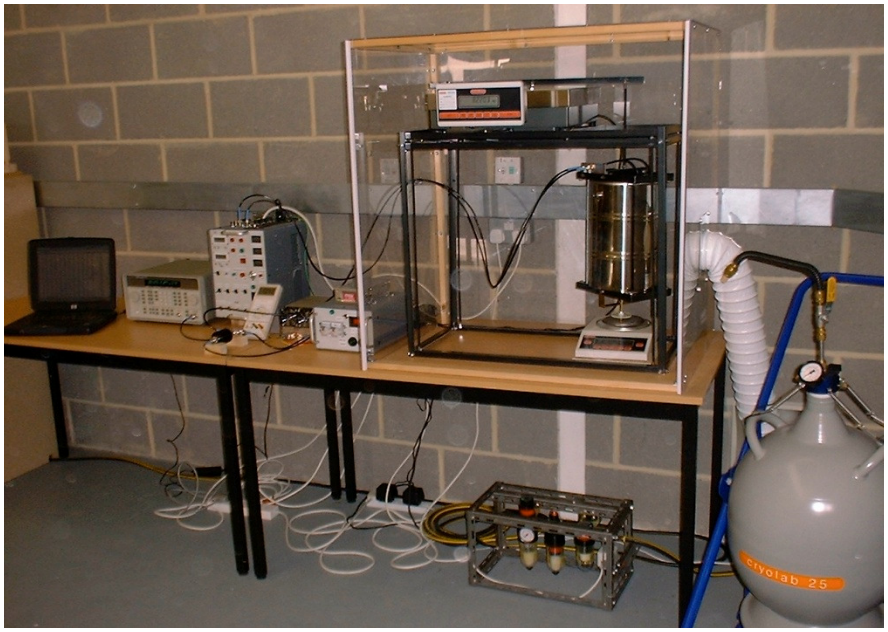
Conceived as a solution to a missile guidance problem in the 70's

Theory applied to spacecraft propulsion requirements in the 90's

- 2001 Experimental Thruster project at SPR
- 2003 Demonstrator Engine project
- 2006 Experimental 2G Superconducting Thruster project
- 2007 Dynamic test of Demonstrator Engine

2008 2G Test Data	Flight Thruster programme
2009 2G Mission studies	Boeing design contract
2010 2G Dynamic studies	Flight Thruster test data
2011 2G Test rig development	Chinese test data

2G Experimental Work

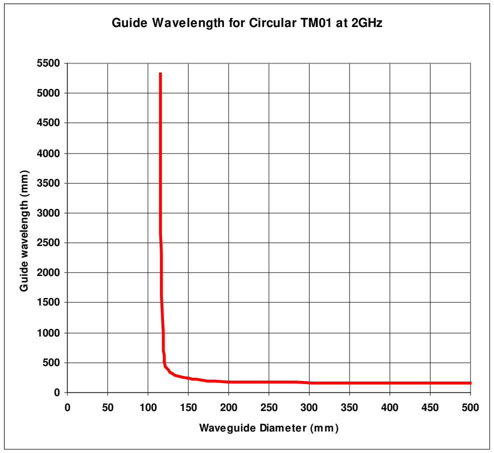


2G experimental thruster under low power tests

Hybrid Spaceplane Aerodynamic Model

Principle of operation complies with all laws of physics

- Resonant microwave cavity with truncated cone shape
- Guide velocity higher at large end
- Reflection force higher at large end

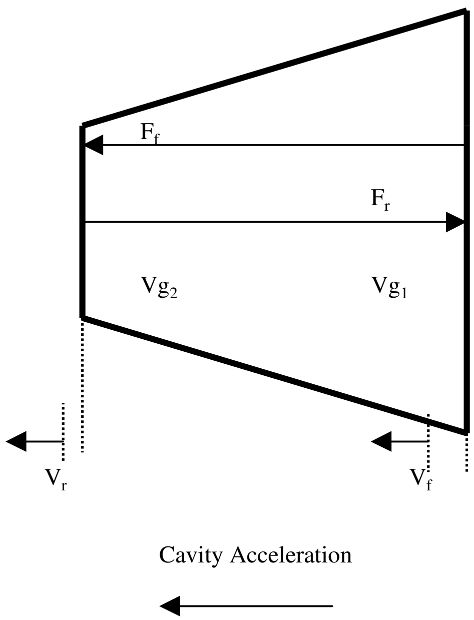


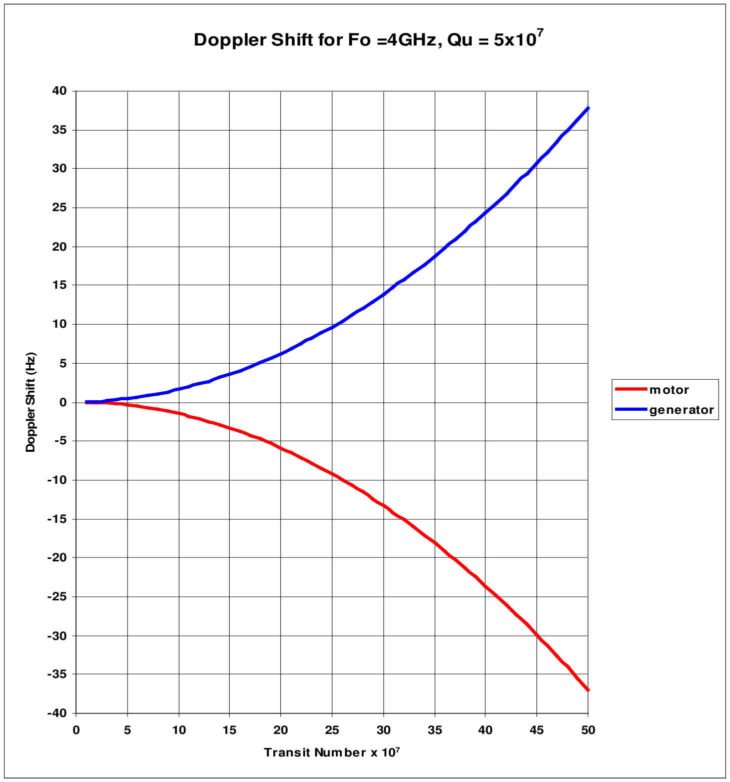
- Non linear wavelength to diameter relationship
- Negligable Axial component of wall force
- Newton's Law results in acceleration (in opposite direction to resultant force)
- Conservation of Momentum preserved
- Acceleration gives internal Doppler shift and energy loss
- Conservation of Energy preserved

- Thrust depends on cavity Q factor
- Q Factor = Stored Energy/Energy loss per cycle
- Mechanical Structure typical Q <1
- Room Temperature Microwave Cavity Q $5x10^4$

- Q depends on wall resistivity
- Superconducting 2G Cavity Q $=1x10^9$
- Requires Cooling with Liquid Hydrogen
- 2G cavity gives step change in Thrust

Conservation of Energy





Cavity acceleration produces unequal Doppler Shifts in F_f and F_r during each wavefront transit.

Mathematical model illustrates Doppler shift for both Motor and Generator modes. ie EmDrive is a classic electrical machine.

+ve acceleration gives a frequency decrease and hence an energy loss (motor)

-ve acceleration gives a frequency increase and thus an energy increase (generator)

Effects of Doppler Shifts

The Doppler shifts occuring in each transition will, under high Q and high acceleration, cause the frequency of the EM wavefront to move outside the operating bandwidth of the cavity.

This mechanism severely limits the acceleration achievable with superconducting cavities.

An engine design has been established which enables this effect to be reduced, and allows acceleration of up to 0.5m/s/s to be achieved for a specific thrust of 1 Tonne/kW .

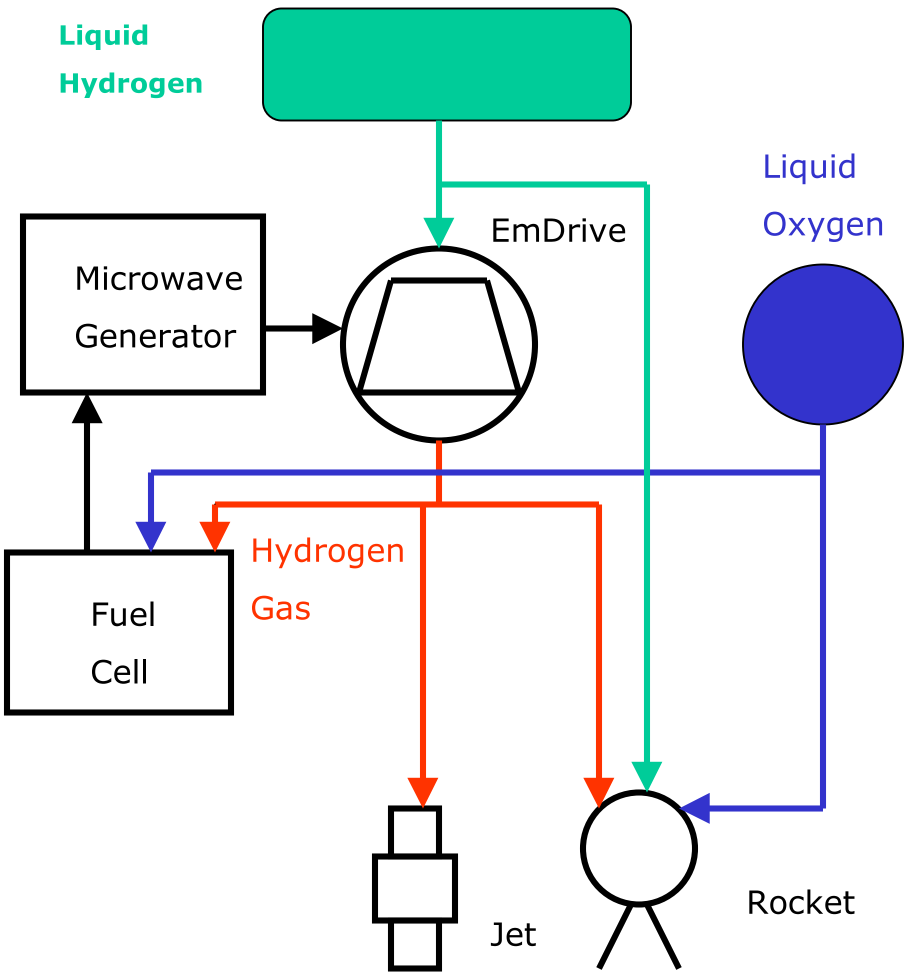
This acceleration limitation, in the vertical plane only, will allow 2G EmDrive engines to be deployed as lift engines in a number of aerospace vehicles.

An important application will be a hybrid spaceplane, giving low cost access to geostationary orbit. This will enable Solar Power Satellites to significantly undercut the cost of nuclear power stations, and will give a sustainable solution to the world energy crisis.

The launch sequence is a very slow ascent to above orbital altitude using EmDrive lift engines, followed by separation of the orbital module which then imparts orbital velocity to the payload using conventional rocket propulsion

The spaceplane flight profile gives low g and low thermal stress. This results in a conventional low cost airframe, capable of hundreds of launches.

Hybrid Spaceplane Propulsion System



Atmosphere operation

Low speed (256 mph max)

Low vertical acceleration (.05g)

EmDrive → Lift

Pitch roll & yaw

Jet → Propulsion

Space operation

High speed

Low horizontal acceleration (0.32g)

EmDrive → Lift

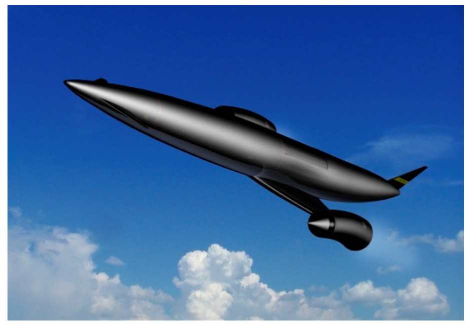
Pitch roll & yaw

Rocket → Propulsion

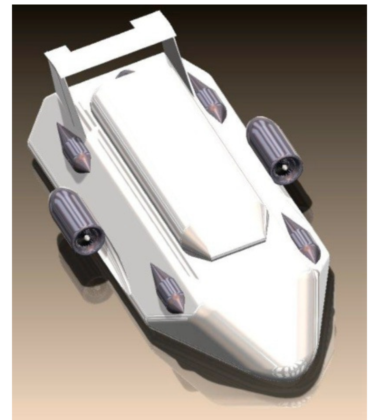
Performance Comparison

Atlas V 551

Skylon spaceplane + upper stage

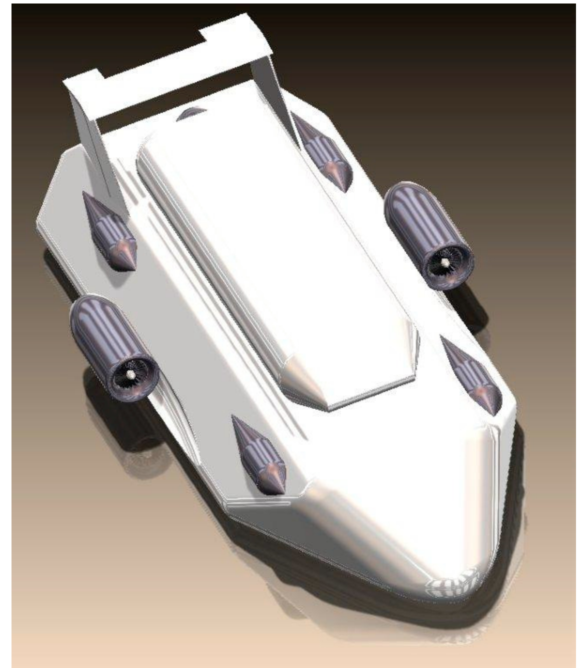


EmDrive spaceplane + orbital module



Parameter	Units	Atlas V 551	Skylon spaceplane +SUS	EmDrive spaceplane + OM
Launch Mass	Tonnes	541	345	315
GSO payload mass	Tonnes	3.8	3	49.4
LEO payload mass	Tonnes	20	16	15.9
Number of launches		1	200	500
Max vehicle acceleration	g	4.6	3	0.05
Max velocity in atmosphere	mph	1,040	3,535	256
Cost per launch	$M	110	40	11.2
Cost per kg payload to GSO	$	28,947	13,333	224

Markets for 2G EmDrive



Solar Power Satellite Launch

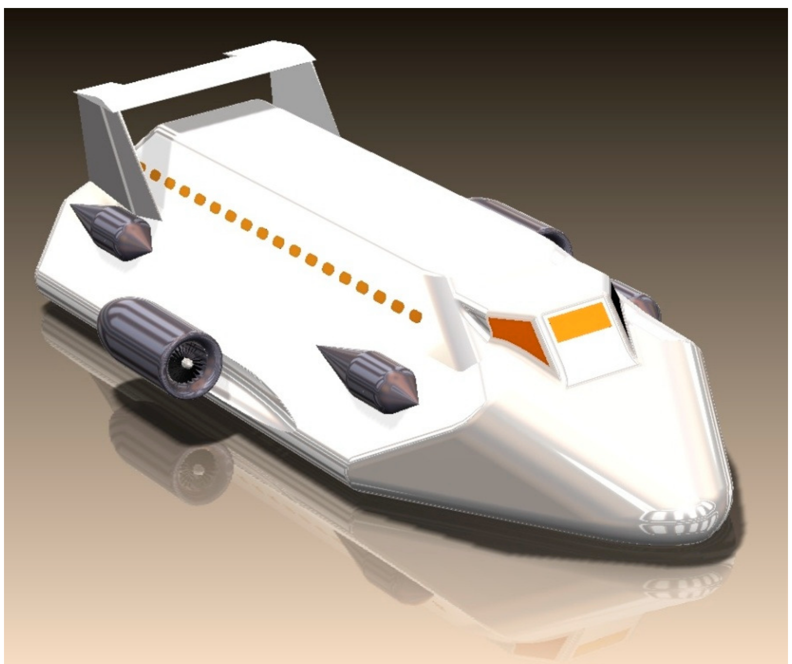
Reusable unmanned carrier spaceplane

Rocket propelled Orbital module

50 Tonnes payload to Geostationary orbit (36,00km)

Reduces launch cost by a factor of **130**

Makes Solar Power Satellites economically viable



Long Haul Transportation

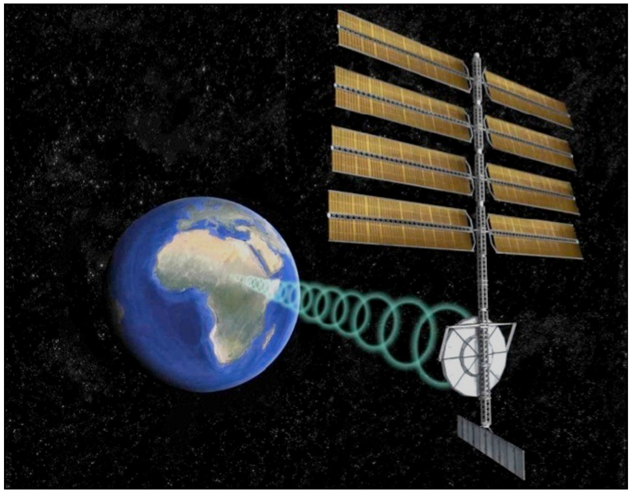
London to Sydney in 2 hours 40 mins

City centre to city centre with quiet VTOL

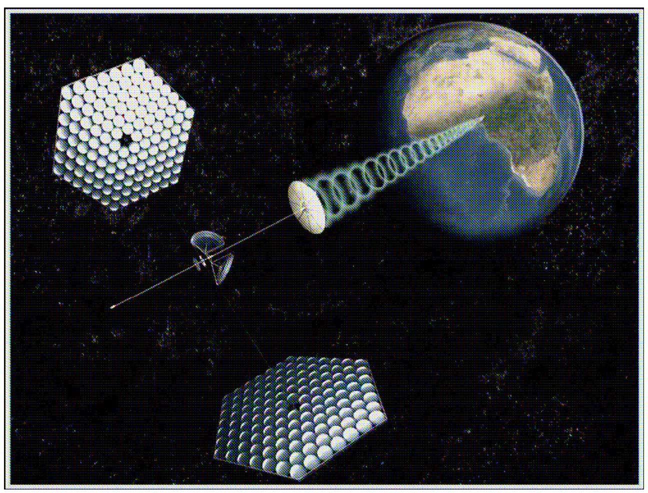
Green, liquid hydrogen fuel

Payload mass 59 Tonnes (100 passengers)

Microwave Power Transmission from Solar Power Satellite



Type 1 Classic Microwave SPS (1979)



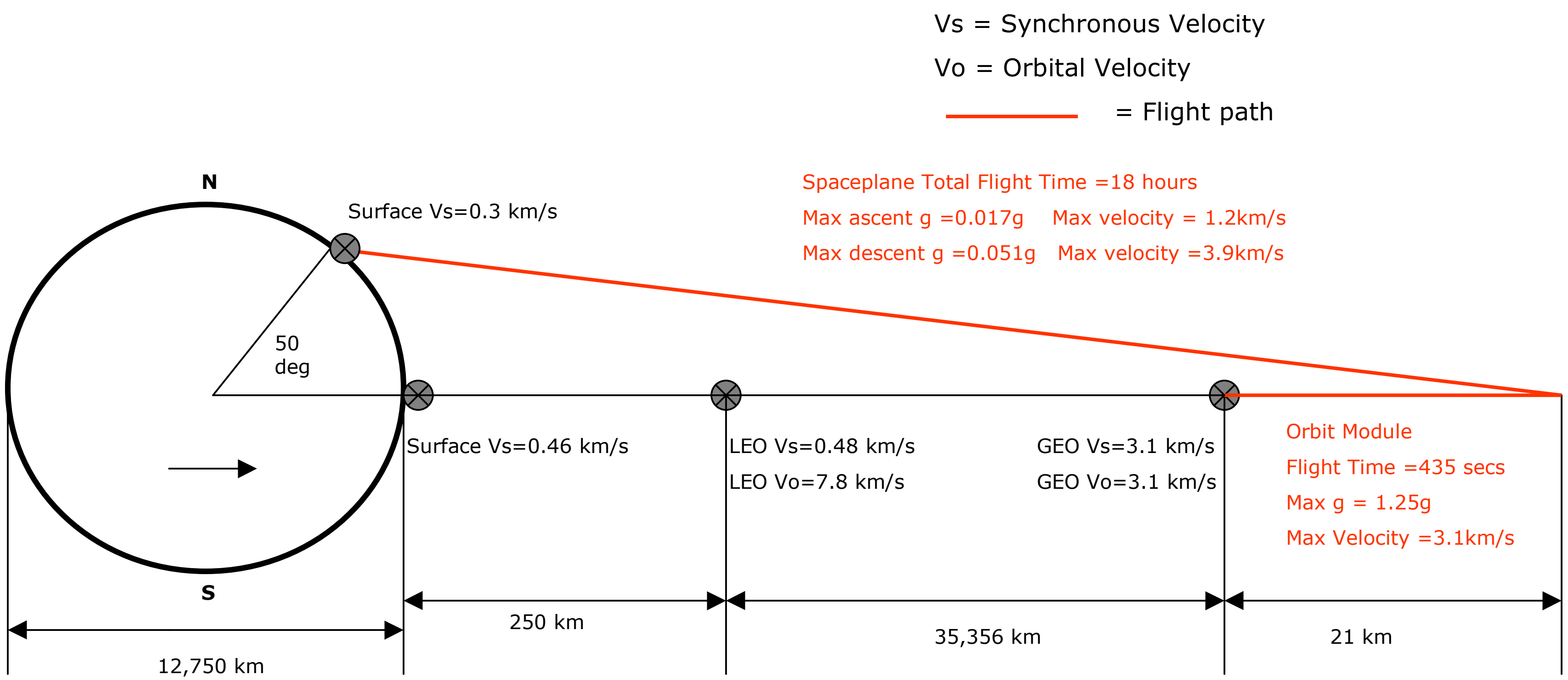
Type 111 Modular Sandwich Microwave SPS (2011)

- Typical transmission frequencies 2.45GHz or 5.8 GHz
- Low energy density (max 23mW/cm^2) Receive array dimensions 6.8kmx8.5km for 2GW delivered power
- Beam is phase locked to pilot signal, prevents beam accidentally moving off-target
- Receive sidelobe levels, outside site boundary 0.1mW/cm^2 would be well below the accepted leakage level for domestic microwave ovens(5mW/cm^2)

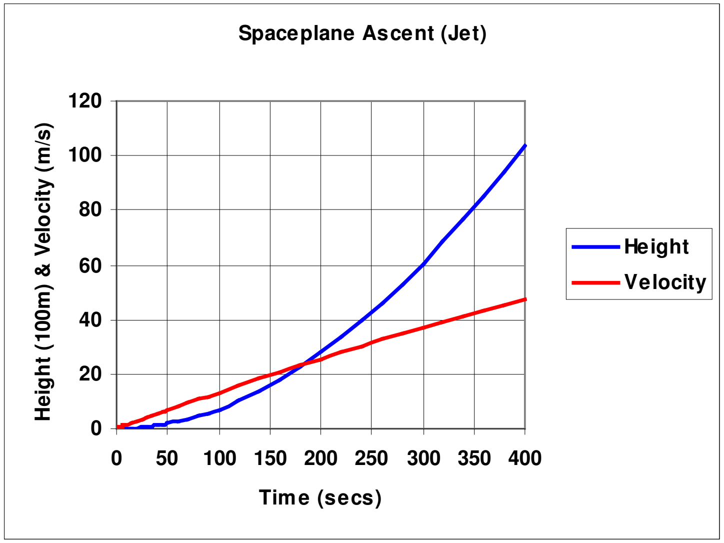
- IAA study report "Space Solar Power" Nov 2011 states there are:
- "no fundamental technical barriers that would prevent the realisation of large scale SPS platforms during the coming decades"
- however "questions remain as to the economic viability"
- and the most critical challenge is "the essential requirement for very low cost Earth to Orbit Transport."

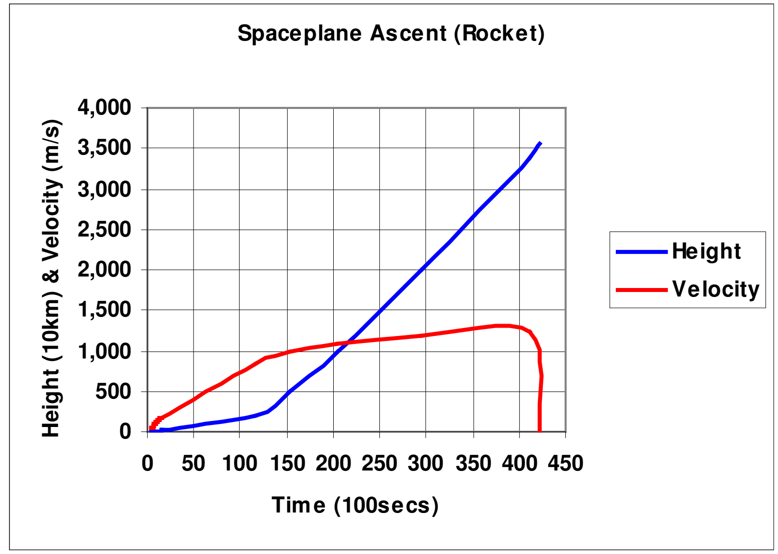
- Type 111 SPS is highly modular. Total mass 6,700Tonnes for 2 GW. Requires 134 spaceplane launches . 3 spaceplanes would take less than 1 year to build SPS, using tele-robot assembly
- Total transportation costs are:
  $194Bn existing launcher (1,700 Atlas V rockets)
  $20Bn IAA study requirement
  $1.5Bn EmDrive Spaceplane

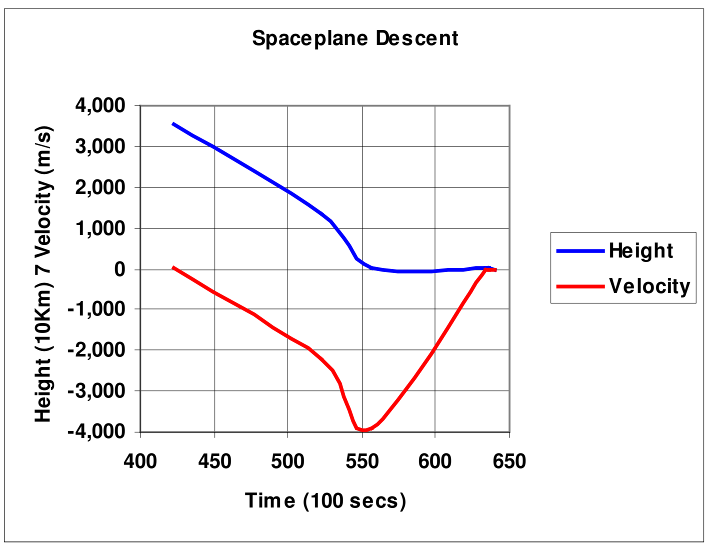
Geo Launch Dynamics

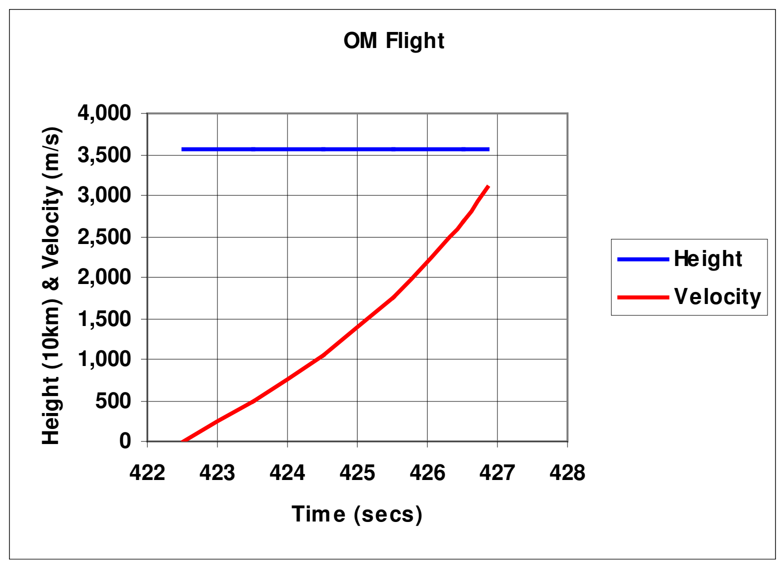


GEO Mission Flight Profile

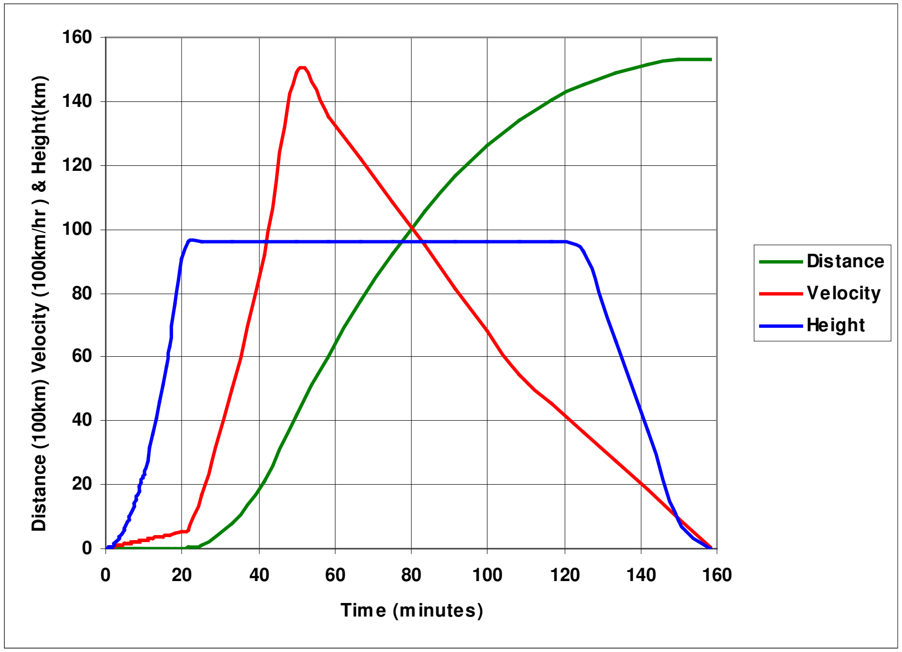


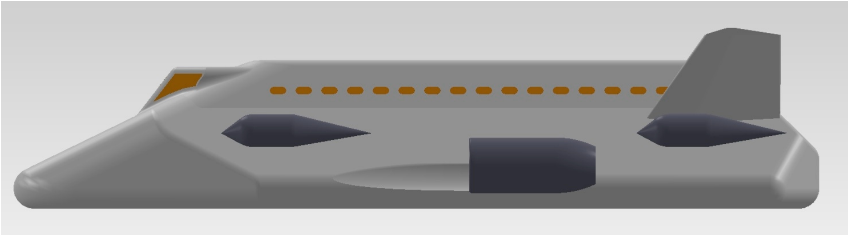






London to Sydney Flight Profile





Time (mins)	Mission Phase	Propulsion Systems active	Axial Thrust (Tonnes)
0 to 1	Vertical take-off	EmDrive	0
1 to 7	Ascent 1	Jet + EmDrive	4
7 to 20	Ascent 2	Rocket + EmDrive	4
20 to 50	Cruise	Rocket + EmDrive	40
50 to 150	Deceleration	EmDrive	-8
150 to 156	Approach	Jet + EmDrive	4
156 to 158	Vertical landing	EmDrive	0

Other Markets for 2G EmDrive

Personal Air Vehicle

Automatic passenger carrying vehicles

Clean quiet VTOL operation

Door to Door transportation

Elimination of traffic Jams

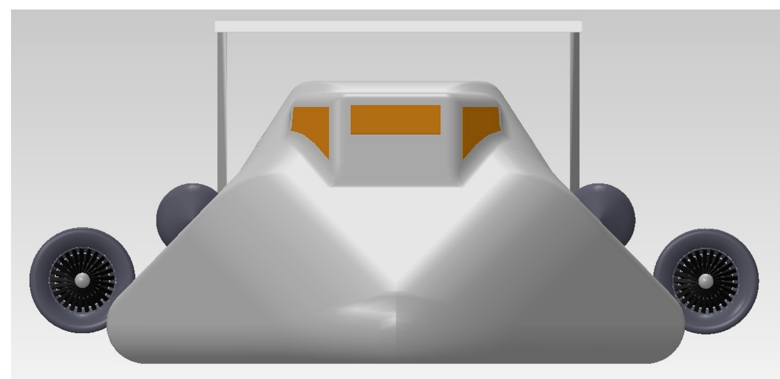
Future Space Applications

Space Tourism

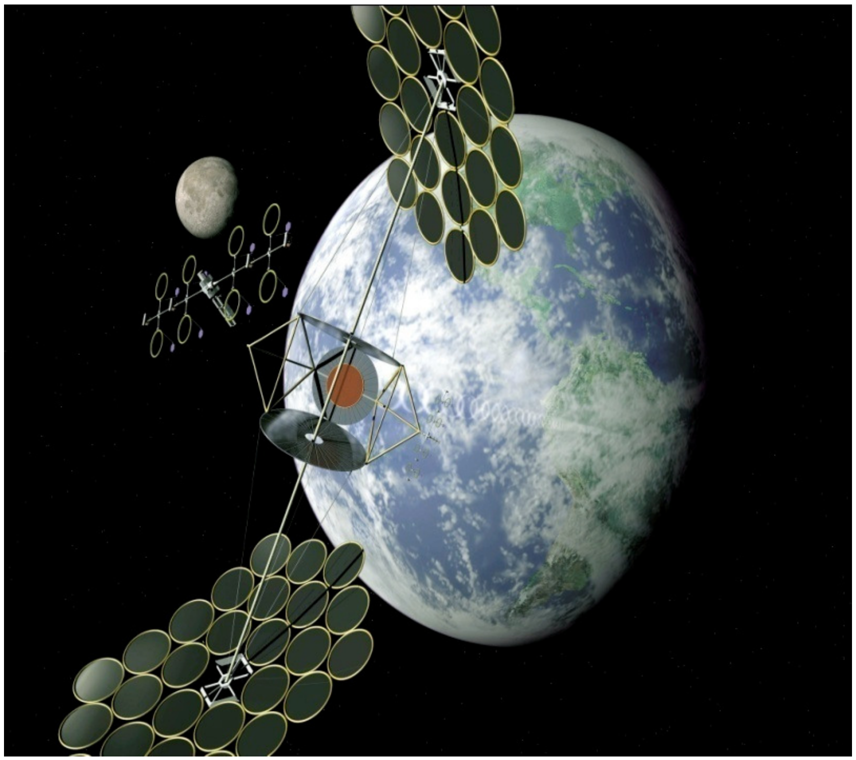
Helium 3 extraction from Moon

Solar system exploration

Asteroid mining



Global Benefits



- 2G EmDrive will give a quantum shift in Energy and Transport
- Solar Power Satellites have been acknowledged as **THE SOLUTION** to green baseload energy provision, providing launch costs can be reduced
- Carbon based fuels for future transport and energy production will be replaced by Hydrogen and Solar Satellites
- EmDrive is Highly disruptive,but will lead to a truly sustainable modern world
- EmDrive is the enabling technology for ambitious space missions