The Dynamic Operation of a High Q EmDrive Microwave Thruster

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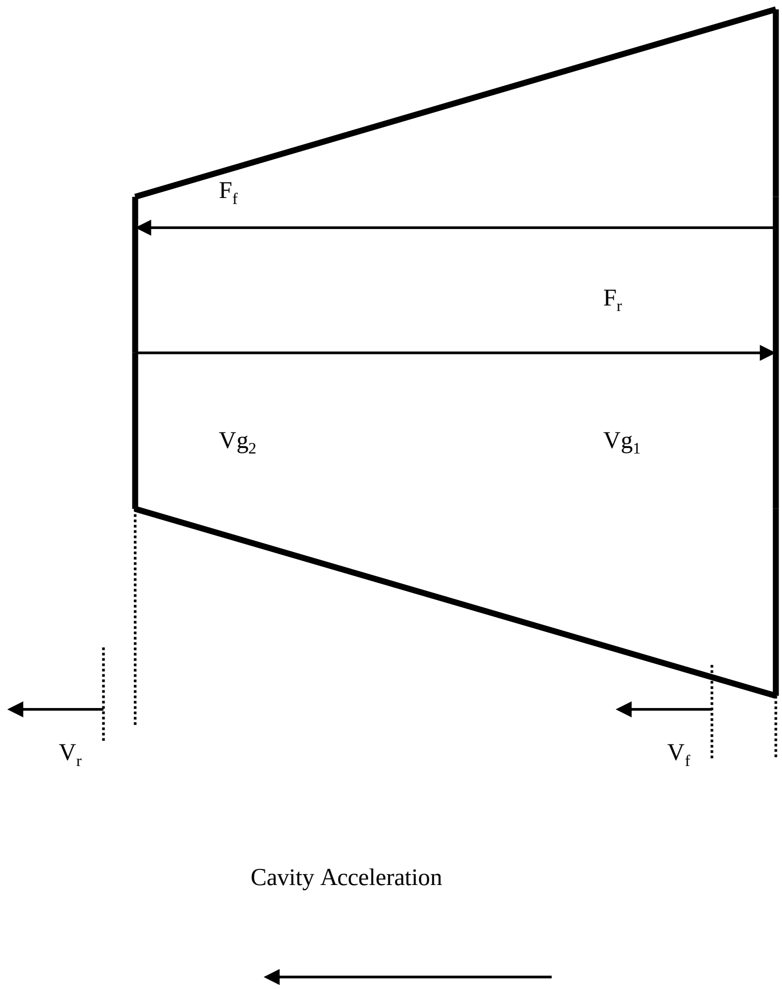
Abstract

The static operation of an EmDrive microwave thruster has once again been demonstrated by Chinese experimental work. The work repeats and enhances results obtained in earlier UK experiments, and confirms the direct relation between specific thrust and Q factor of the cavity.

This paper considers the dynamic operation of a thruster with the very high Q factors obtained when a cavity employs superconducting technology. The very high specific thrusts resulting from such second generation (2G) devices must be subject to the law of conservation of energy. It follows therefore, that there must be a mechanism which limits the acceleration of any vehicle propelled by a 2G EmDrive thruster.

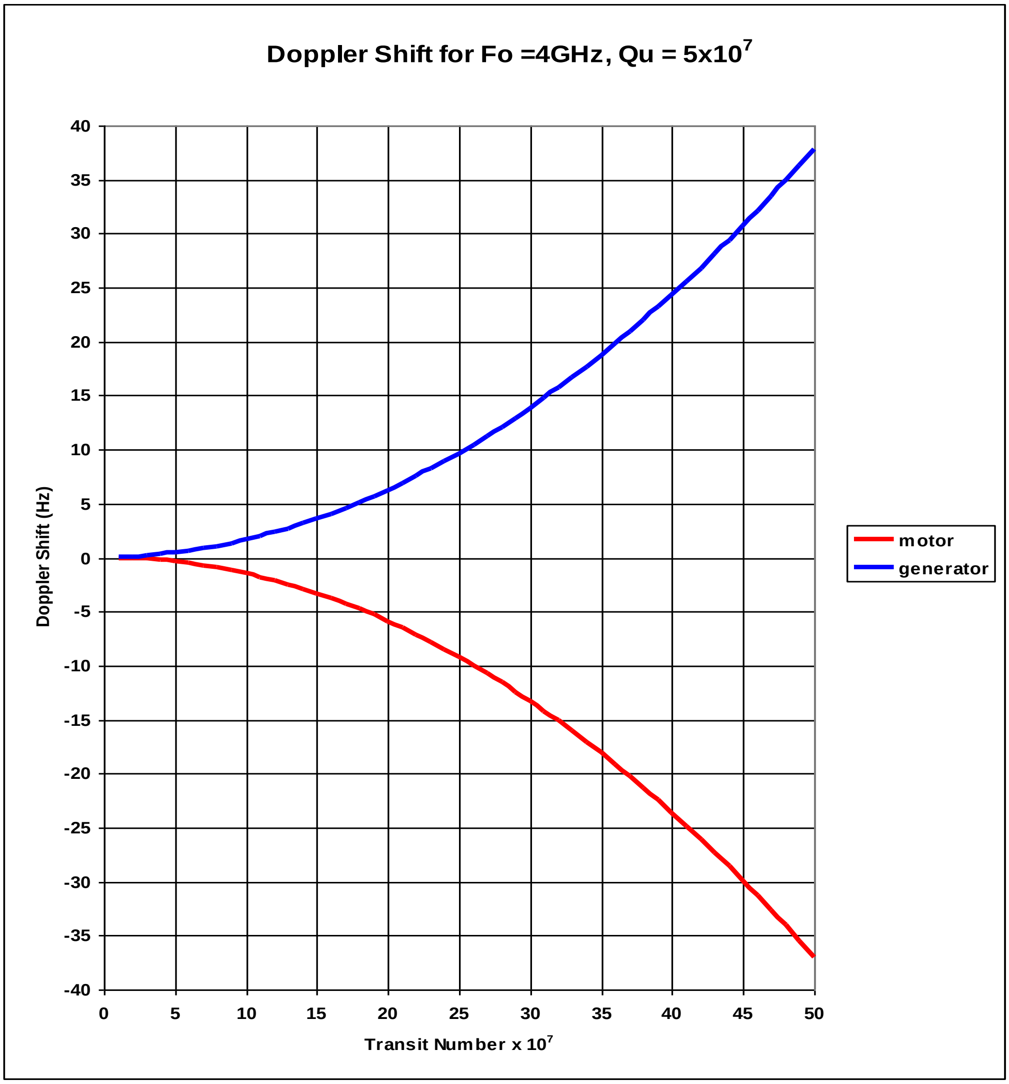
A mathematical model of a 2G thruster is described which illustrates such a mechanism. The results from the model show the Doppler changes, which occur when a thruster is subject to acceleration.

Mathematical Model



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

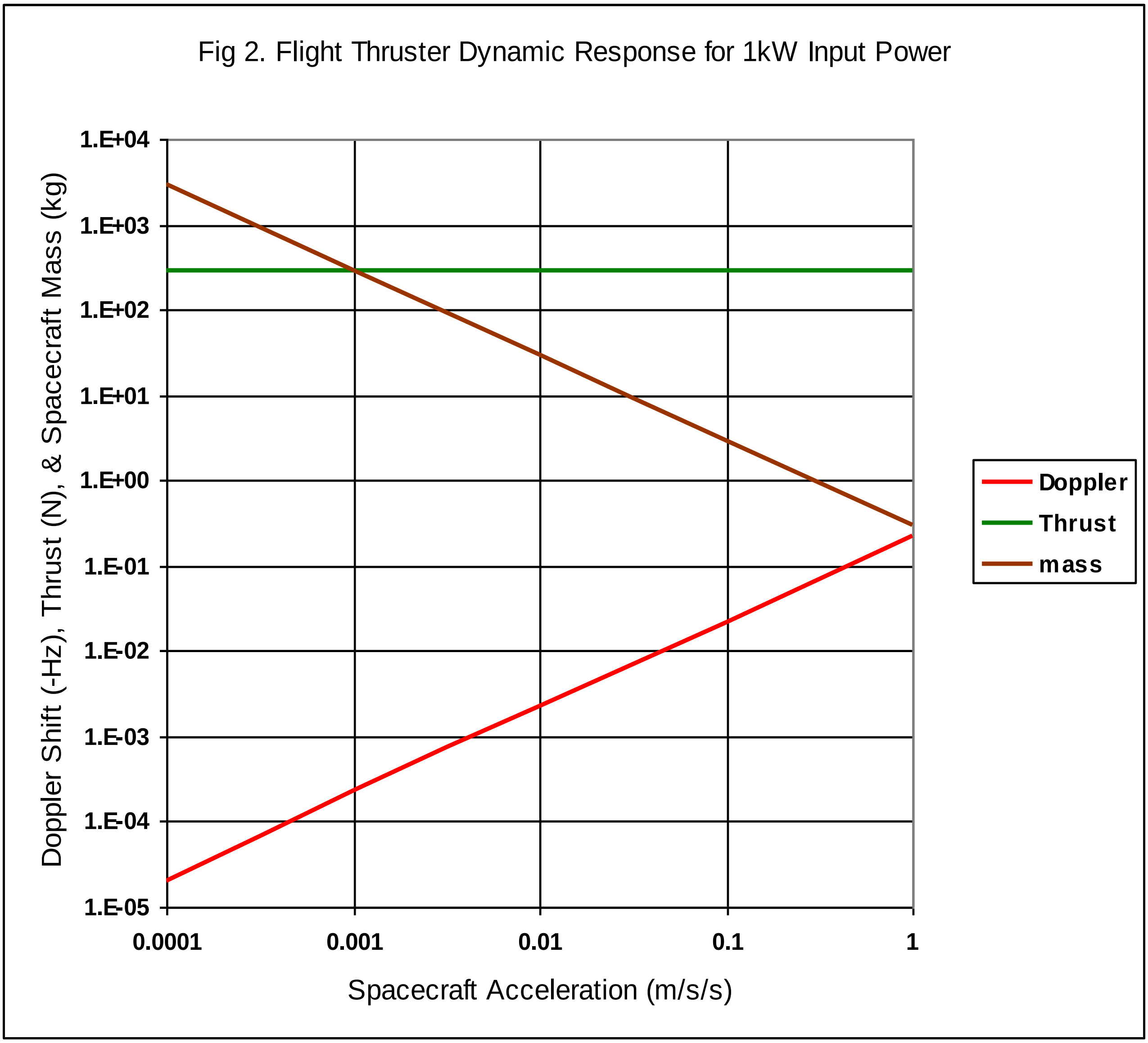
Doppler Mathematical model illustrates Doppler shift for both Motor and Generator modes.



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

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

Model Results for a First Generation Thruster

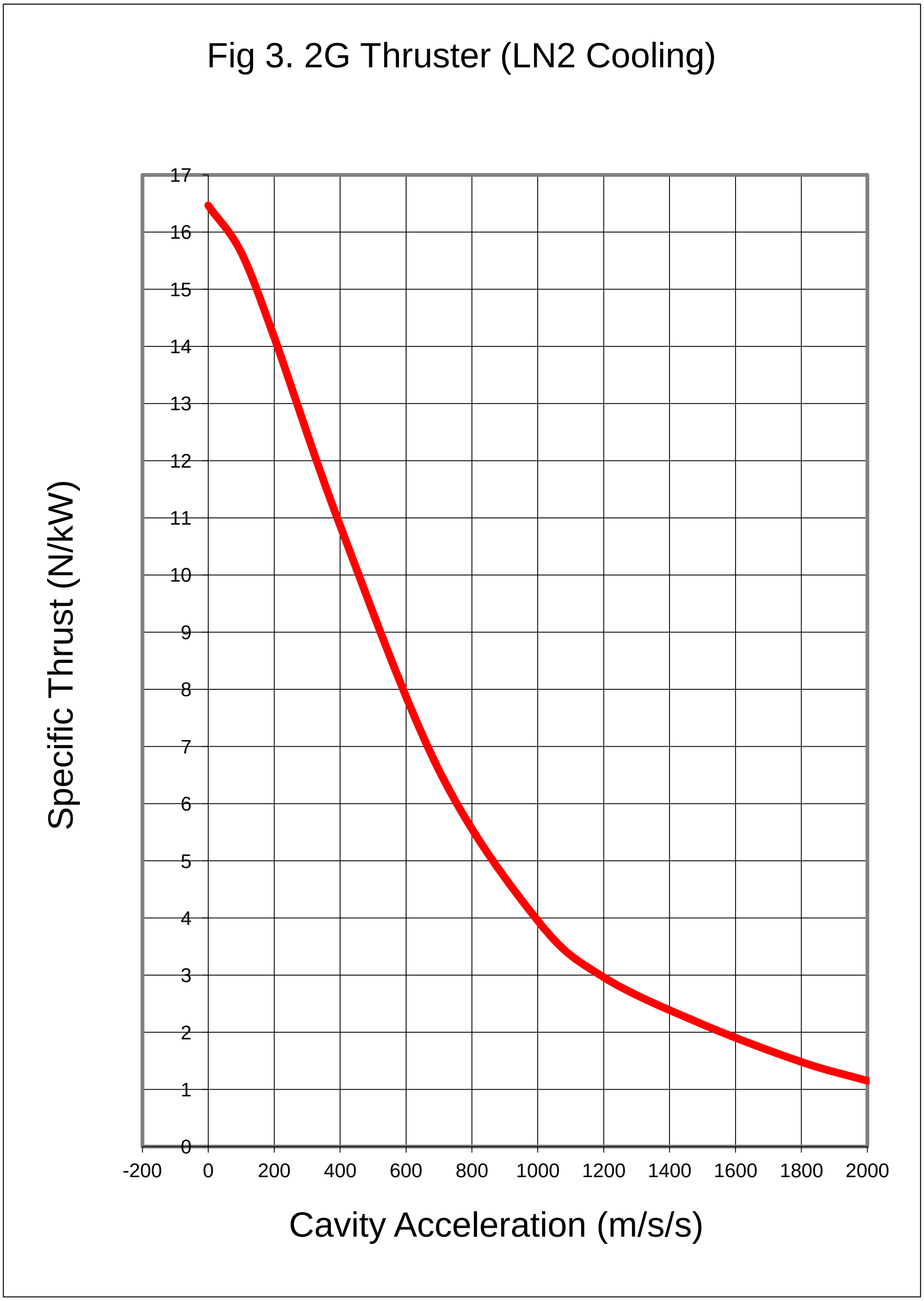


The Dynamic performance of the non superconducting Flight Test model, manufactured and tested by SPR Ltd, and described in REF 3 was modelled with a cavity *Qu* = 50,000 and F_{res}=3.85 GHz.

The results show that for such a low Q factor, spacecraft acceleration levels up to 1m/s/s causes negligable Doppler shifts (<1Hz) such that no loss of Q is experienced, and therefore the thrust remains constant.

To illustrate typical applications, the spacecraft mass is also plotted against acceleration, assuming 1kW of microwave input power to the thruster.

Model Results for a Second Generation Thruster



Superconducting second generation thrusters were then modelled, cooled first with liquid nitrogen and then with liquid hydrogen. The Thruster designs were based on the results obtained from the experimental YBCO thin film thruster. With the thruster cooled to 77deg K using liquid nitrogen, a Q of $6.8x10^6$ was measured.

Fig 3 shows the model results with the modified 2G thruster cooled with liquid nitrogen, giving a static specific thrust of 16.5 N/kW for an unloaded Q factor of $3.7x10^6$.

With this modest value of Q it requires high acceleration to cause significant reduction of specific thrust. In this case an acceleration of 1000m/s/s (100g) gives a specific thrust reduced to 4 N/kW.

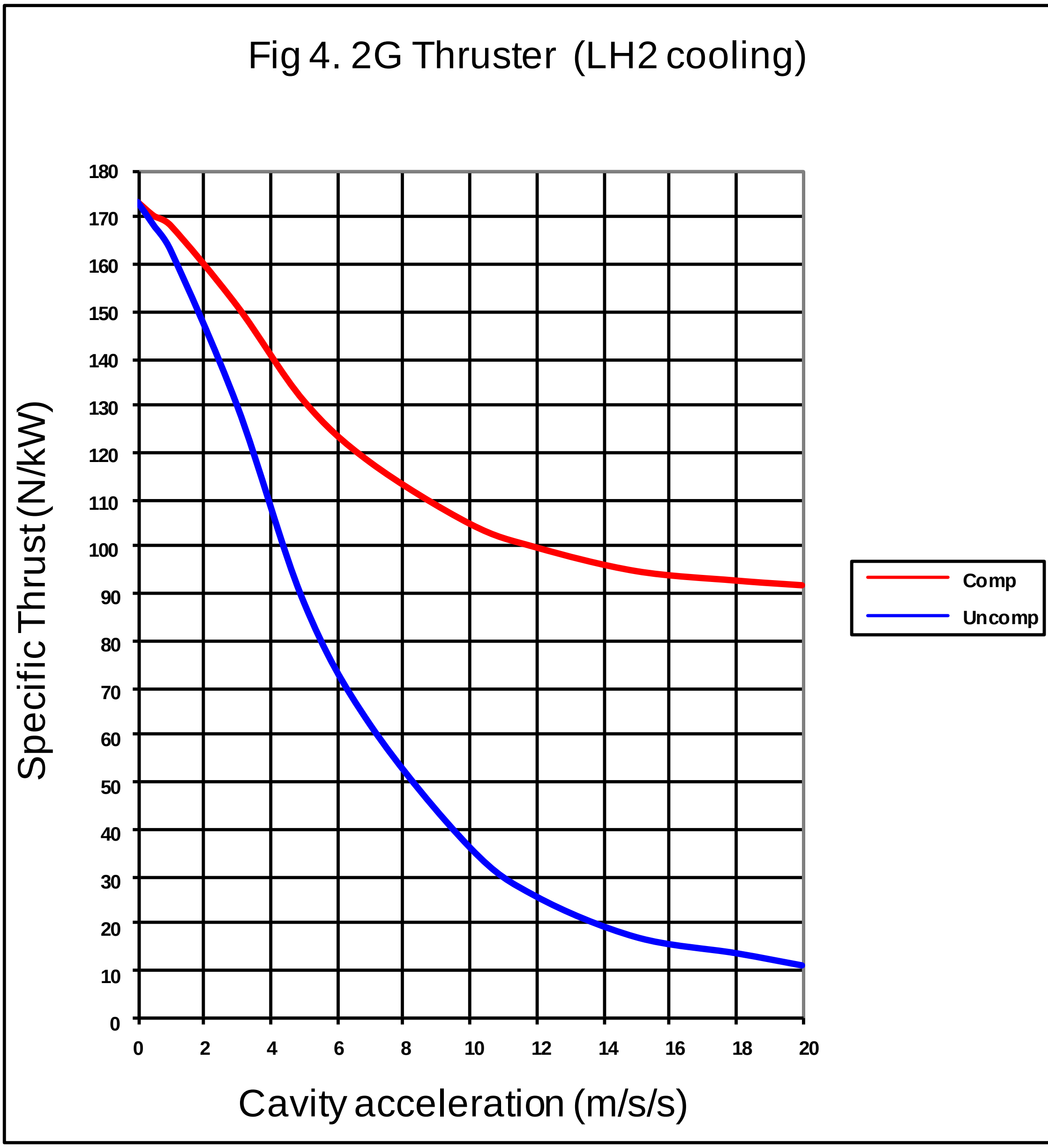


Fig 4. 2G Thruster (LH2 cooling)
Specific Thrust (N/kW)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
Cavity acceleration (m/s/s)
Comp
Uncomp

Fig 4 gives the results for a lower frequency cavity cooled by liquid Hydrogen, thus operating at a temperature of 20deg K, and achieving a static specific thrust of 173 N/kW, with an unloaded Q factor of 3.9×10^{7}.

For an uncompensated thruster, the loss of Q, and hence reduction of specific thrust with acceleration is more pronounced. The model results show a specific thrust of 11 N/kW for an acceleration of 20m/s/s (2g).

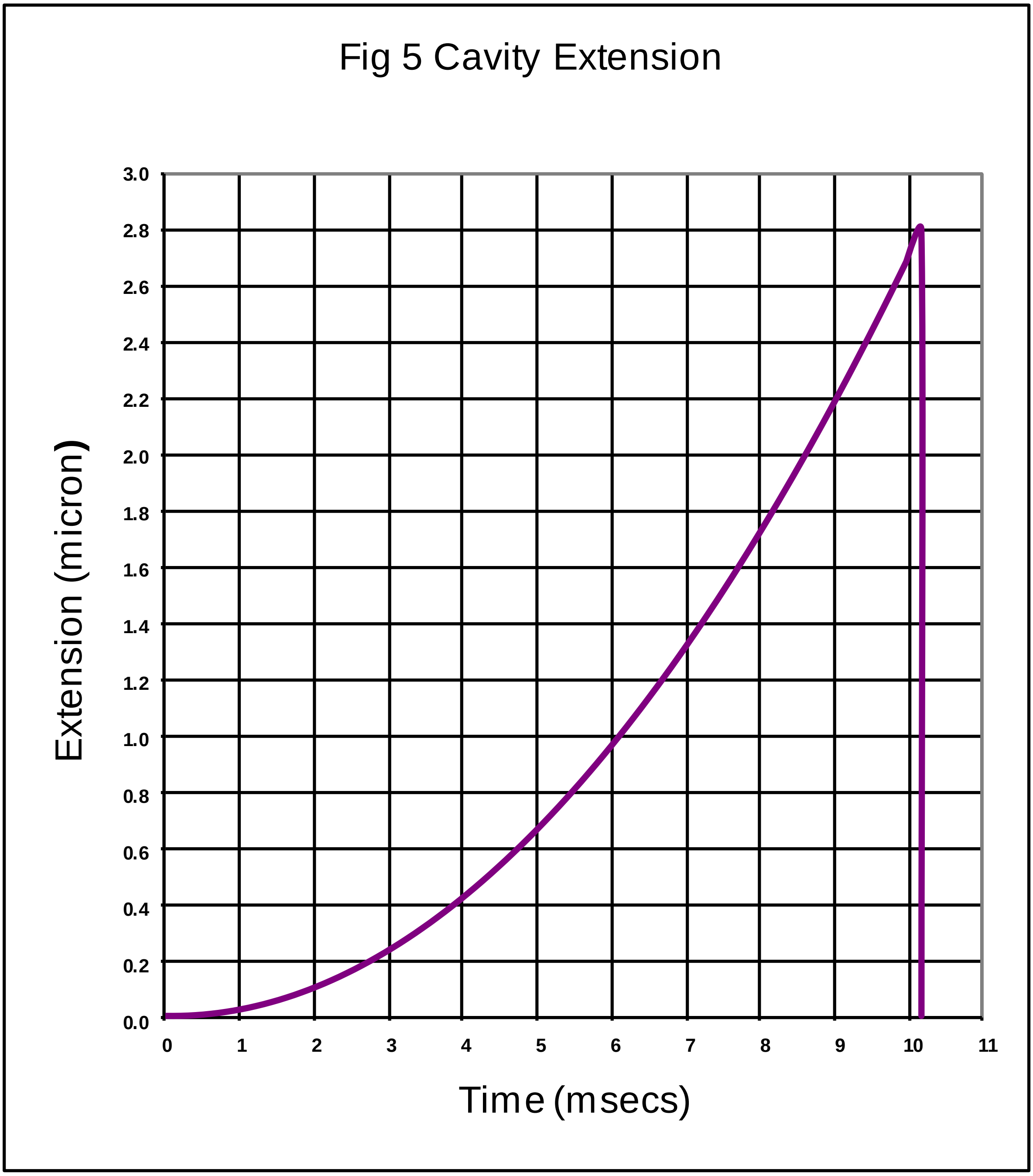


Fig 5 Cavity Extension
Extension (micron)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
Time (msecs)

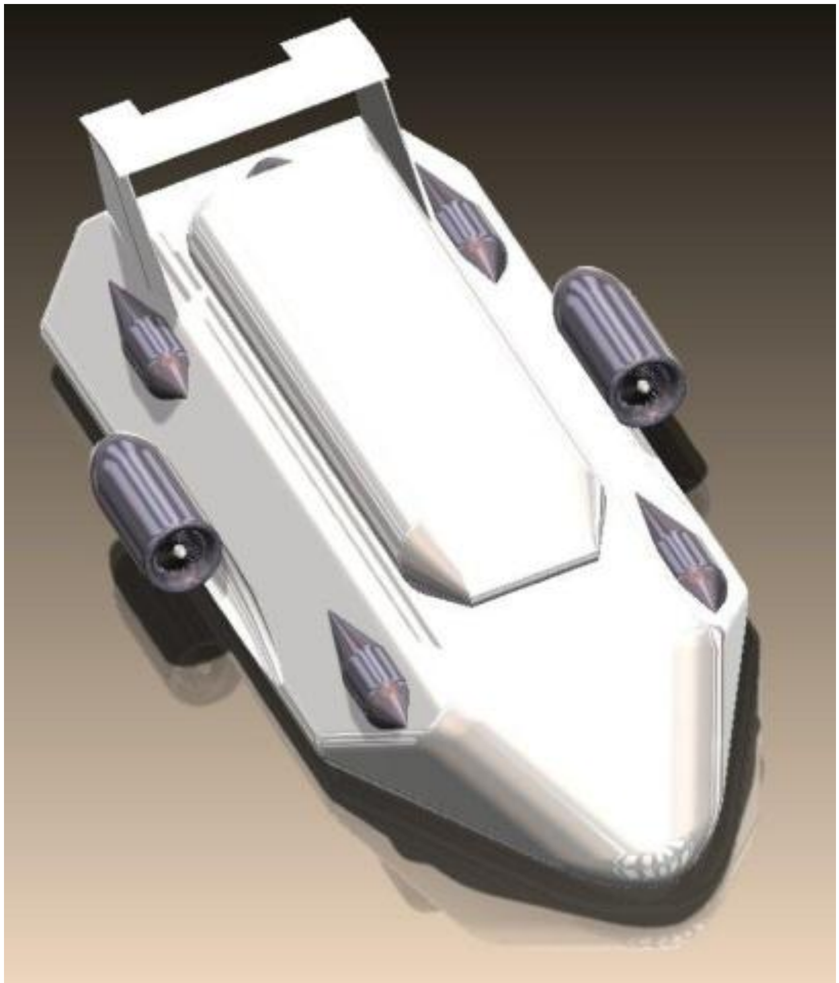
A compensated cavity was designed and modelled, where the axial length of the cavity is modified according to the acceleration experienced by the thruster. The cavity extension for a positive acceleration of 20 m/s/s is illustrated in Fig 5. The extension results from a pulsed voltage being applied to piezoelectric elements in the sidewall of the cavity. The pulse length is determined by the time constant of the resonant cavity.

Clearly this simple form of compensation cannot completely compensate for the Doppler shift throughout a full pulse cycle, but fig 4 shows that the specific thrust at 20m/s/s can be improved to 92 N/kW.

High Power L-Band Thruster

A large high power thruster was designed, operating at 900 MHz. This thruster again used a YBCO superconducting coating, and was cooled with liquid Hydrogen. The compensation technique included both cavity length extension and frequency offset. A specific thrust of 9.92 kN/kW was predicted with an acceleration limit of 0.5m/s/s.

This L-Band thruster was part of a design study for a radically new approach to launch vehicles. A Hybrid Spaceplane was proposed, using 2G L-Band EmDrive thrusters as lift engines, with conventional low thrust jet engines and rocket engines for auxilary propulsion. These secondary propulsion units are fuelled by the gaseous Hydrogen, boiled off during the cooling of the EmDrive thrusters. The fuel cells used to provide DC power to the microwave power sources would also be fuelled in the same way.



Following spaceplane mission analyses, a preliminary costing was carried out. The costs assumed the main application would be the launch to geostationary orbit of the components of a global solar power satellite (SPS) system.

The EmDrive spaceplane performance and costs were then compared to specified Atlas V and predicted Skylon spaceplane data.The results are summarised in the following table.

Parameter	Unit	Atlas V	Skylon	EmDrive
Launch Mass	T	541	345	315
GSO payload mass	T	3.8	3	49.4
LEO payload mass	T	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

Conclusions

A mechanism which limits the acceleration of very high Q, EmDrive thrusters, and thus ensures compliance with conservation of energy constraints, has been described and mathematically modelled.

For first generation in-orbit propulsion applications, thrust will be constant throughout the total thrust period, and be equal to the measured static thrust.

For second generation superconducting thrusters, compensation techniques can be employed to minimise the loss of thrust with acceleration.

A high power, superconducting, L-band thruster is proposed for a novel Hybrid Spaceplane design. This vehicle would be capable of reducing the launch cost to GEO by a factor of 130.

This cost reduction would ensure Solar Power Satellites become the preferred solution for future energy requirements and global warming problems.