REVIEW OF

"TECHNICAL REPORT ON THE DEVELOPMENT OF A MICROWAVE ENGINE FOR SATELLITE PROPULSION"

ROGER SHAWYER JULY 2006

Document Number: JWS-SPR-TN-018
Project: EM Drive

This document contains – Proprietary Data

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27-Aug-06

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Company Ltd

CHANGE RECORD

Issue	Date	Change Details	Origin
Draft 1	27-Aug-06	First Issue	JWS

DISTRIBUTION LIST

Internal	External
J Spiller	R Shawyer - SPR

Date this copy was printed - 27-Aug-16

CONTENTS

1 INTRODUCTION

The EmDrive is a new concept in electric propulsion for spacecraft which directly converts electrical energy to thrust. The theoretical principles have been developed, an experimental model has been constructed and experimental testing, to verify the performance, undertaken. This work was performed by Roger Shawyer of Satellite Propulsion Research Ltd under a DTI SMART award. It is described in Technical Report on the Experimental Microwave Thruster and reviewed by this author in Review of "Technical Report on the Experimental Microwave Thruster Roger Shawyer September 2002".

Work has been continued by Roger Shawyer at SPR and a demonstration engine built and tested. This work was funded by a DTI Research and Development grant and is described in Technical Report on the Development of a Microwave Engine for Satellite Propulsion. Patents have been granted for this invention.

2 APPLICABLE DOCUMENTATION

2.1 Applicable Documents

Technical Report on the Experimental Microwave Thruster - Roger Shawyer - September 2002

Review of "Technical Report on the Experimental Microwave Thruster Roger Shawyer September 2002", JWS-SPR-TN-005 – John Spiller – October 2002

Technical Report on the Development of a Microwave Engine for Satellite Propulsion – Roger Shawyer – July 2006

2.2 Reference Documents

The EmDrive 'Microwave Propulsion for the Space Industry' - Roger Shawyer - July 2002

A Theory of Microwave Propulsion for Spacecraft – Roger Shawyer – 2004

3 DOCUMENT SCOPE

This document covers a review of a report entitled "Technical Report on the Development of a Microwave Engine for Satellite Propulsion" by Roger Shawyer of Satellite Propulsion Research Ltd dated July 2006. The work was authorised by Satellite Propulsion Research Ltd on 2-Jun-06. Much of the data is proprietary and is covered by an NDA signed on the 5-Oct-02. Thus the information contained in this report must not be disclosed to a third party without the approval of both Satellite Propulsion Research Ltd and J.W. Spiller.

4 THE REVIEW

4.1 Review Approach

The report is divided into three main sections - Theory, Design, Test Programme plus conclusions and further work. As with my last review, I have followed this layout in the review. I have reviewed the report's conclusions and future work before adding a final section on my conclusions from the review.

The theory of operation is now well established and a comprehensive paper has been written.

The design of the engine is well documented and follows from rigorous detailed design calculations. The author has viewed the experimental assembly first hand and can confirm that the standard of construction is consistent with the objectives of this phase. Foreseen difficulties in the conversion of the design for use in space were discussed in the review of the experimental thruster and are still relevant.

The test of the engine is much more straight forward than for the experimental thruster and the performance is easy understand. There is a marked reduction of interfering effects except for thermal effects.

Future work is discussed and should be preceded by a feasibility study for the major items of development.

The sections and figures quoted in this section of the review refer to those of the report reviewed.

Questions and points of clarification arose during the review process and have in general been clarified by telephone or email. These clarifications have then been discussed in the relevant sections of the review.

4.2 Theoretical Review and Comment

The report suggests a new theoretical approach which is helpful in the understanding the principles of operation and should be compared to the approach described in "A Theory of Microwave Propulsion for Spacecraft". This section is a little thin on detail and it would be useful if this approach was carried through to the derivation of the thrust equation as in the above. Some further justification of the assumptions made is needed to establish that "the whole assembly will move"

It would also be interesting to explain what happens to the speed of movement as this approaches the speed of light.

4.3 Design Review and Comment

It would be useful to have a section describing the work that was done on mission sizing and the reasons for choosing the size of engine to demonstrate. This should also cover the performance predictions for that engine.

The rest of the section is well covered except that it was difficult to follow the layout of

the microwave components and a schematic would be useful.

The design of the input matching could be improved with further work, which would improve the efficiency of the engine, but is not at this stage in the development a serious problem.

The thermal problems associated with continuous operation proved to be demanding and the design of the liquid cooling must have been a challenge. It would be expected that for space operation it will be even more of a challenge.

4.4 Test Review and Comment

The test program is well thought out and based on the previous work on the experimental thruster.

The small signal microwave tests are well described and the results much as expected.

The high power tests appear to show that the thermal performance is as expected, although it is not stated. It is not clear why the temperatures continue to rise after the power is turned off. After how long does it start to fall? In order to understand Figure 3.2.1 better it would have been useful to know exactly location of the temperature monitors (the preheat is a mystery).

Did the thermal design compensation work satisfactorily?

The main part of the test program is concerned with the thrust tests. These are much clearer than those of the first experimental engine now that the thruster can be operated in the steady state condition.

The thrust vector positive direction on page 20 viz page 6 appear different.

Figure 3.3.4 would indicate a tuning accuracy of 0.05mm was required not 0.5mm as stated. This appears consistent with the small signal tests.

I assume that the input tuner is the same as the matching tuner and the swept tuner is the same as the resonance tuner. Are both tuners fitted with stepper motors?

There appears to be a big difference between the up thrust and the down thrust values in Figure 3.3.4.

It would be useful to show an example of the calculations made during the data processing to give an idea of the corrections needed. I assume that the thermal effects in the cooling system are the largest correction.

There is a significant lag between the power being applied and the thrust reaching a steady value. Figure 3.3.6 indicates this lag is more than 30 seconds. This is stated to be due to the integration time of the balance arrangement, 30 seconds seems too long for this. This is not so marked in Figures 3.3.7 or 3.3.8 but the up and down times different. In the horizontal tests, Figure 3.4.5, this lag is apparently absent. So what is different?

Figure 3.4.2 does not clearly explain what is happening in the horizontal test rig.

4.5 Conclusions Review and Comment

There is no justification for (a) in the main text, see Section 4.3.

The thermal test results are not quite as clear as implied by (e), see Section 4.4.

The results quoted in (j) and (m) are not supported by predictions, see Section 4.3. In Section 4.4 I also point out some apparent anomalies in the thrust measurements which are not explained n the text.

There is no justification for (n), which should have its own section in the main text describing a possible flight engine design and its expected performance. There is likely to be significant further development required on a suitable space qualified microwave source.

4.6 Further Work Review and Comment

The development of a dynamic test rig will be very valuable as it will allow the measurement of the engine thrust using a different physical principle that that used in a balance. This could mean improvements to air bearings to reduce their friction beyond the present state of the art. This work should be pursued. As should the work to improve the efficiency of the engine.

The potential performance that could be achieved with a superconducting engine is most exciting and should be pursued for its own sake. It is likely that the engineering problems which will arise will be very challenging. However there is a good deal of technology available already and an experimental engine feasible but not without problems along the way. It will also be interesting from a theoretical point of view to start to push the boundaries of the physics and see some of the limiting effects on performance, such as conservation of energy, coming in to play.

The section does not describe the work necessary to design, build, test and qualify a space engine.

5 CONCLUSIONS AND RECOMMENDATIONS

The new approach to a theory of operation is welcome and could be developed into an alternative explanation of operation and derivation of the performance predictions.

Work on the design has progressed well and the development model constructed is much more practical and robust than the experimental model. This has allowed a much more rigorous test program to be undertaken.

This more extensive test program allows a more direct measurement of performance but in doing so it has raised a few more detailed questions on the operation of the thruster and the test rig. As I mentioned in my report on the experimental engine an independent test to verify the measurements is an essential par of the review. This has still not been carried out. The development of an alternative test method was started but was not successfully completed. This should be pursued. I would recommend that this question of independent test verification should be addressed before further design work is undertaken.

There are two possible next steps in the design program which could be taken in parallel. These are the development of an experimental supeconducting engine and the development of a space qualification engine with a view to an in orbit demonstration. It is recommended that before either of these steps is undertaken a feasibility study is made. The cost of development, qualification and production of a space qualified engine should also be estimated.