Finite Element Modeling of a Microwave Cavity under Resonant Conditions

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INTRODUCTION & MOTIVATION

- A tapered cylindrical microwave resonant cavity (frustum) has been reported to produce thrust without using any propellant
- Such a cavity would allow satellites to reposition in Earth's orbit by using readily available solar energy, without the need to carry additional fuel
- British electrical engineer Roger Shawyer [1] is the pioneer who investigated and developed such a device
- In 2017, NASA Eagleworks Laboratories [2] reported a thrust-to-power level of 1.2±0.1 mN/kW directed towards the small end of the frustum under resonant conditions, with no satisfactory explanation given
- The most recent experiment carried out by Tajmar *et al.* [3] at Dresden University in June 2018 suggested that the force on the frustum may be due to the interaction between cabling and Earth's magnetic field
- Whether the thrust is due to the Lorentz force via the interaction of the Earth's magnetic field and current on the side walls of the frustum is investigated here
- This requires a knowledge of current density distributions on the frustum surfaces in order to further analyse the interaction between these current densities and external Earth's magnetic field

Objective

- Using COMSOL® construct tapered microwave resonant cavity
- Reproduce and verify NASA Eagle Works model [2]
- Determine the modes using equivalent cylindrical resonant cavity definitions
- Obtain surface current density distributions
- Develop an electromagnetic model that will provide a plausible explanation of the observed phenomenon
- Adapt the developed model for laboratory tests

Theoretical Development

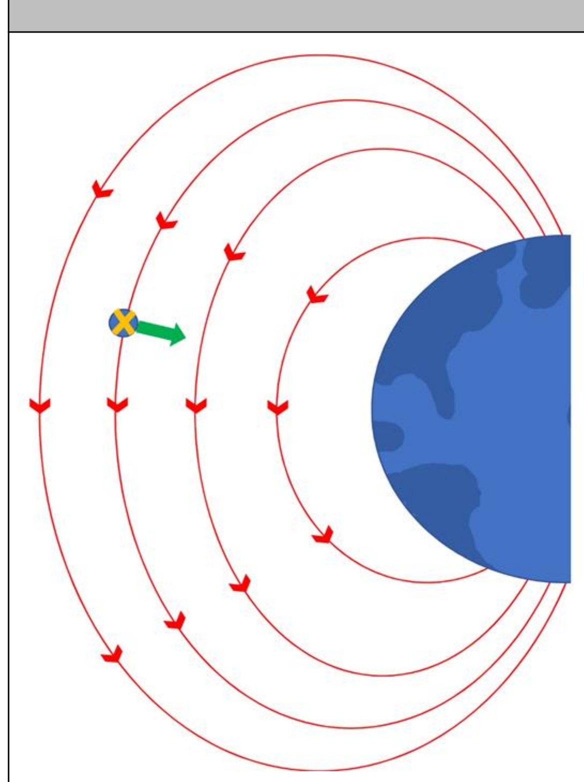

Figure 1: Sketch of the generation of Lorentz force

Induced current within the sidewalls of the frustum interact with the Earth's magnetic field resulting in a force directed into the page

Lorentz Force

$$\vec{F}_{mag} = \int (\vec{K} \times \vec{B}_E) \cdot da \quad [4]$$

*where $\vec{K}$ is the surface current density, $\vec{B}_E$ is the magnetic flux Density, $\vec{F}_{mag}$ is the Lorentz force, and da is the surface area of the frustum

Simulation Results

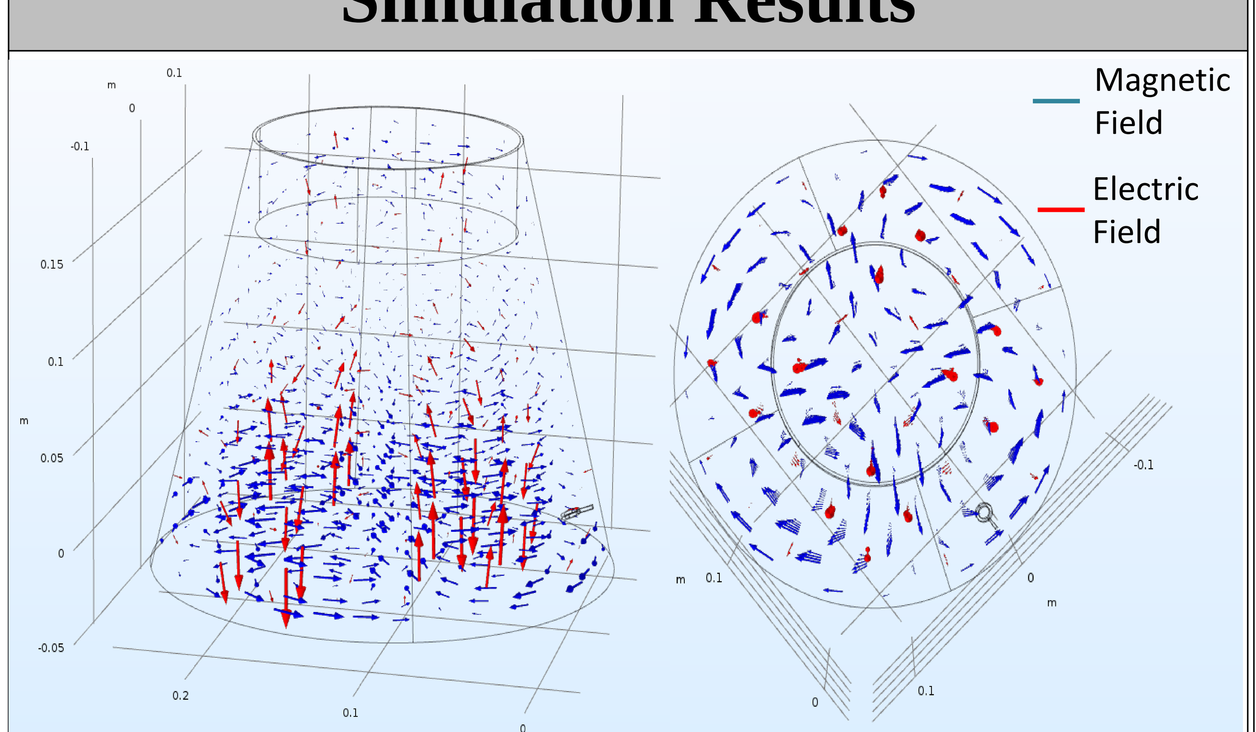

Figure 2: Side (left) and bottom (right)view of electric and magnetic field distributions of the frustum at resonant condition at 1.93GHz and Mode TM212. Models reproduce those originally published by NASA Eagleworks Laboratories [2]

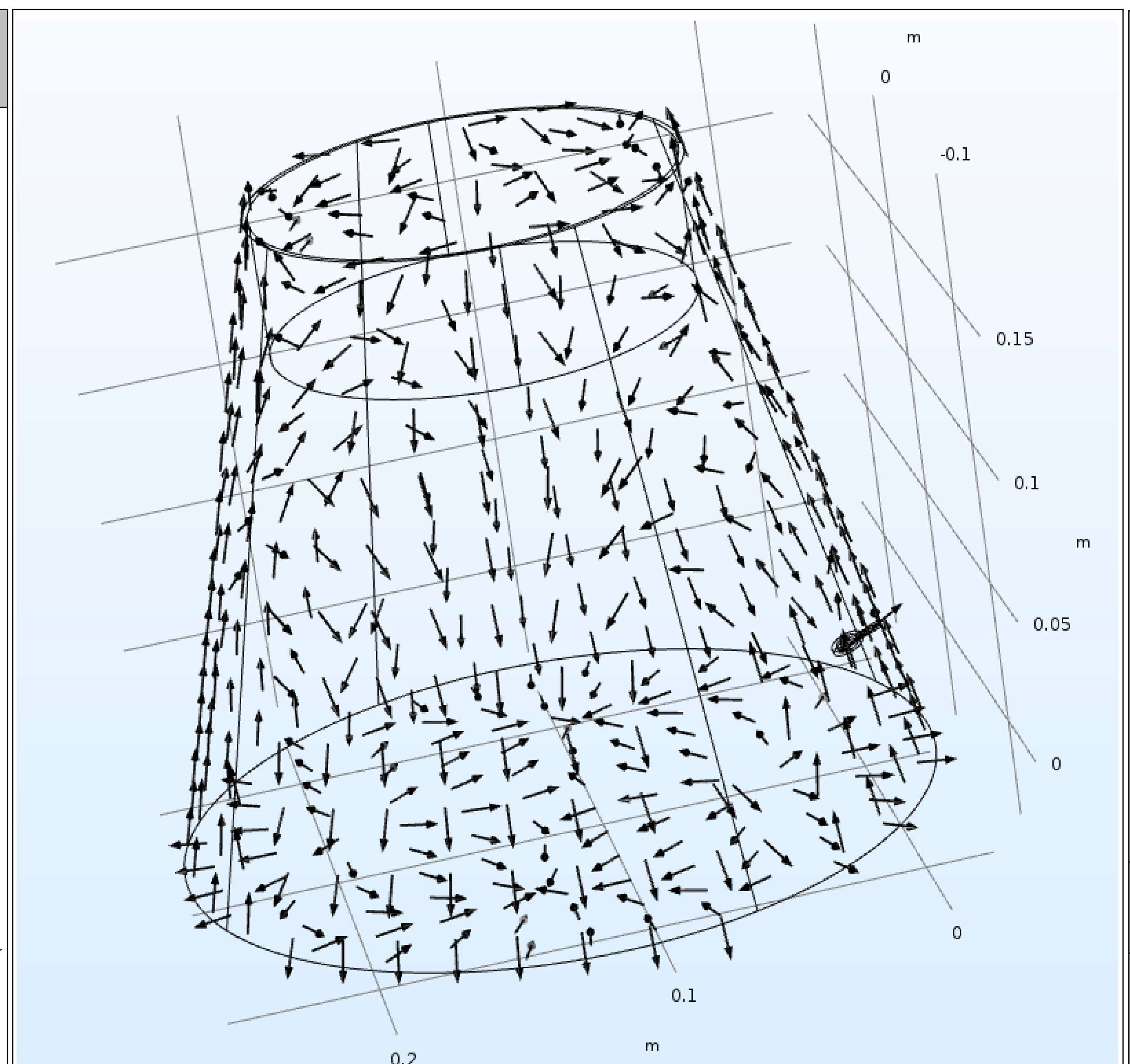

Figure 3: Surface current density distributions at resonant condition with frequency of 1.93GHz and Mode TM212

Surface Current Density Distributions

- The TM212 Mode in frustum is determined by its equivalent cylindrical counterpart that has the same height and radius as the frustum
- Surface currents are induced by the magnetic fields parallel to the boundaries of the frustum
- The non-uniform distributions of electromagnetic fields inside the frustum results in non-uniform current density vectors on the surfaces
- COMSOL generates the values of maximum current densities on software defined surfaces, and it is observed that surfaces closer to the radiating antenna tend to have the greatest maximum surface current densities, i.e. surface 3 for the frustum and surface 4 and 5 for the cylindrical cavity, however, the distribution is much more uniform in the cylindrical cavity than in the frustum, for x and y components (Table 1)

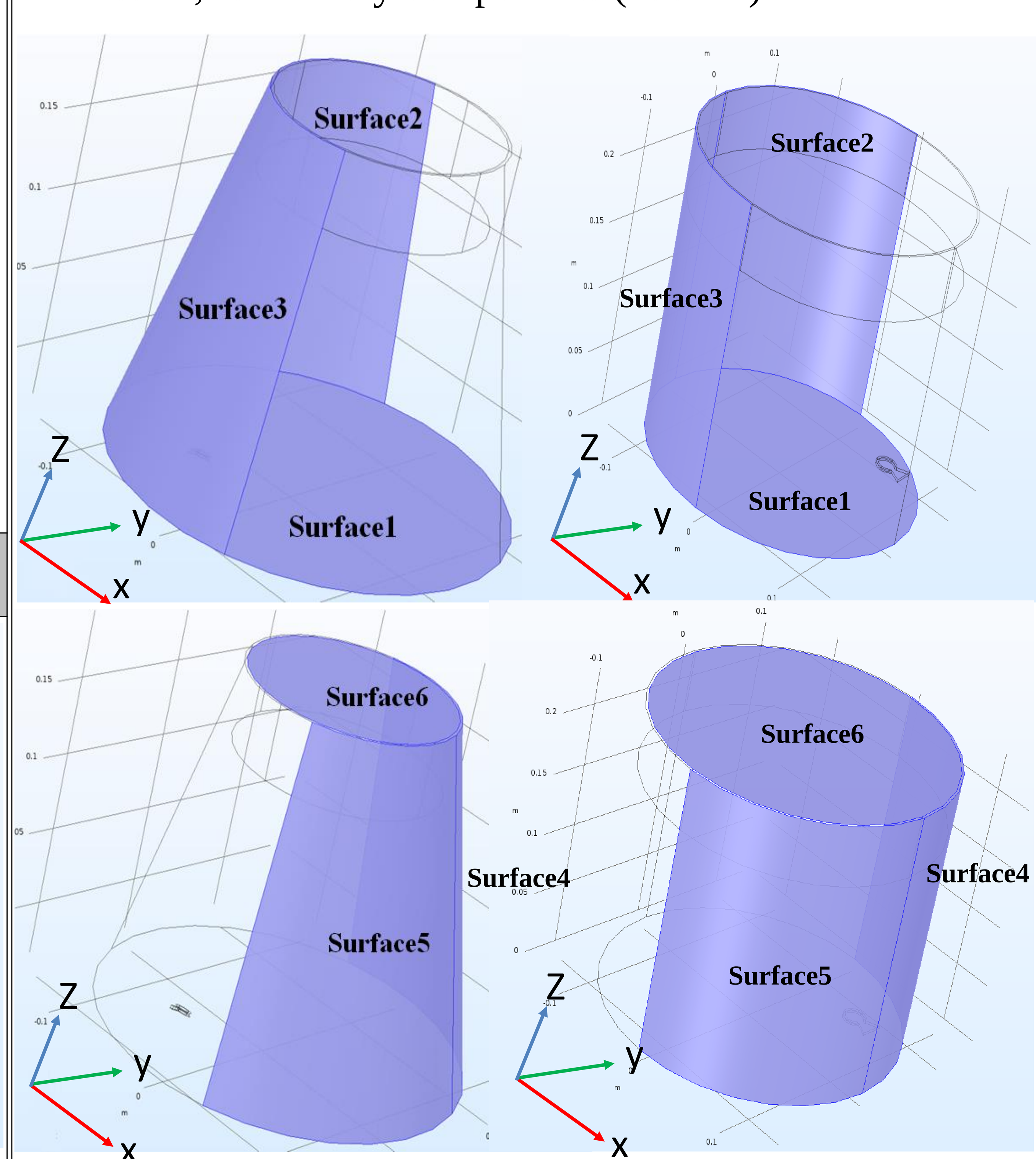

Figure 4: Surface current distributions on each surface as divided in COMSOL

Surface current densities on x, y, z components with input powers / Surface Number		1	2	3	4	5	6
X (A/M)	Frustum	0.012	0.003	0.978	0.003	0.001	0.006
	Cylinder	0.021	0.006	0.012	0.067	0.012	0.007
Y (A/M)	Frustum	0.013	0.003	0.226	0.003	0.004	0.007
	Cylinder	0.013	0.010	0.010	0.017	0.025	0.005
Z (A/M)	Frustum	0.000	0.013	0.825	0.007	0.012	0.000
	Cylinder	0.000	0.014	0.006	0.317	0.276	0.000

Table 1: Comparison of maximum surface current densities between frustum and cylinder on each surface at input power of 60w

Simulation of Earth's Magnetic Field

- A Helmholtz coil or devices similar to it can be used to generate a uniform magnetic field in COMSOL
- A Helmholtz coil is a pair of identical circular coils placed symmetrically along a common axis
- The distance of separation between the two identical coils is equal to the radius of the coil
- Each coil carries an equal electric current flowing in the same direction

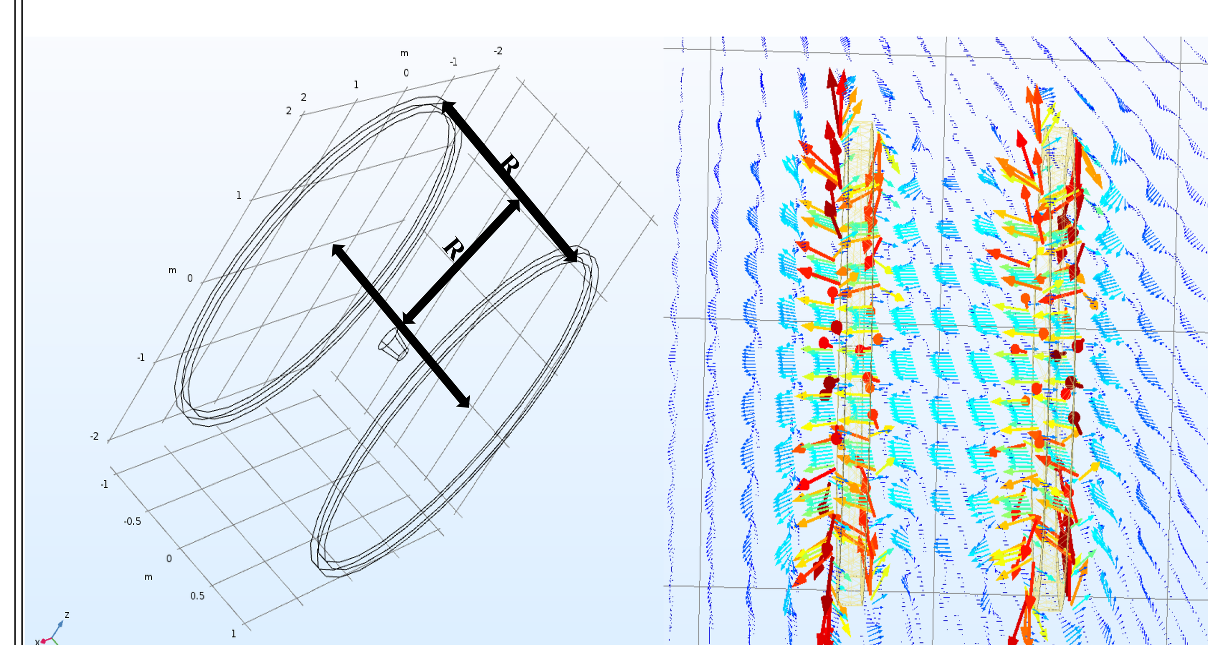

Figure 5: Helmholtz coil and uniform magnetic field generated in COMSOL

Conclusion

- A FEM Model of frustum as a microwave cavity resonator has been reproduced
- The surface to which the radiating antenna is attached has the highest maximum value of surface current densities, however, for symmetrical geometry such as the cylinder, the distribution is more uniform than in the frustum for x and y components
- Surface current densities are proportional to power input, which is in agreement with the observed thrust that is also proportional to power input [1][2]
- A Helmholtz coil will be used to simulate Earth's magnetic field, $\vec{B}_E$
- The interaction of $\vec{B}_E$ with current densities on the frustum side wall, via the Lorentz force, will be investigated in future work

References

[1] Shawyer, R., "The EMDrive Programme – Implications for the Future of the Aerospace Industry", Proceedings of the CEAS European Air and Space Conference, Manchester, 2009

[2] Harold White, Paul March, James Lawrence, Jerry Vera, Andre Sylvester, David Brady and Paul Bailey, "Measurement of of Impulsive Thrust from a Closed Radio-Frequency Cavity in Vacuum", NASA Johnson Space Center, Houston, Texas 77058 https://arc.aiaa.org/doi/10.2514/1.B36120

[3] Martin Tajmar(1), Matthias Kößling(2), Marcel Weikert(3) and Maxime Monette(4), "the SpaceDrive Project – First Results on EMDrive and Mach-Effect Thrusters", BARCELO RENACIMIENTO HOTEL, SEVILLE, SPAIN / 14 – 18 MAY 2018

[4] D.J. Griffiths, "Introduction to Electrodynamics", 4th Ed. Glenview, Person, 2013

Excerpt from the Proceedings of the 2018 COMSOL Conference in Boston