Mutual Coupling of Internal Transmit/Receive Pair in Launch Vehicle Fairing Model using WIPL-D

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Abstract: Evaluating the fairing Radio Frequency (RF) Environment within the launch vehicle payload fairing cavity due to internal transmitters is an issue for the spacecraft and launch vehicle industry. This paper provides an effective approach for launch vehicle fairing evaluation of power reception and field distribution due to internal transmitters. A commercial electromagnetic computational tool, WIPL-D is applied in this study for test data comparison.

Keywords: Resonant Cavity, MoM, WIPL-D, RF Environment, Mutual Coupling

1. Introduction

A common problem in the launch vehicle industry is characterizing the radio frequency environment within the fairing cavity due to active internal transmitters [1]. Requirements for on-orbit reliability of transmitters prompts spacecraft developers to reduce the number of inhibits on the transmitter power bus. Transmitting inside the vehicle fairing, however, can lead to an RF environment for which the spacecraft has not qualified. Precisely determining this environment is essential as over-qualifying sensitive spacecraft instruments can lead to damage. Additionally, the use of computational electromagnetic software in RF environment evaluation is not yet a standard practice in the field of electromagnetic compatibility for space systems. It is then necessary to show how accurately such tools can emulate the fairing cavity environment.

To address the fairing environment uncertainties, launch vehicle providers have performed testing within the various launch vehicles. Transmission can occur at any spacecraft of vehicle frequency emitter, however, the most common sources are S band communication transmitters. As vehicle testing is expensive, it is typically desired to cover a wide frequency range so that data will be applicable for a variety of emitters. Double ridge guide horns are primarily used for such testing because of their large frequency range and availability to support standard electromagnetic test requirements [2]. In this paper, data from previous testing in a physical fairing fixture instrumented with transmit and receive horns is compared to the mutual coupling approach in WIPL-D to evaluate the tool applicability for RF cavity environment prediction [1].

2. Test Fairing Fixture

In an effort to duplicate such testing and validate computational models and test fairing fixture was developed. The fairing fixture is made of Lexan, a material similar to Plexiglas, with an external metal support frame [3]. Aluminum foil is used to line the test fixture in order to represent a typical metal launch vehicle fairing. The height and width of the fairing are 2 meters and 0.6 meters respectively. These dimensions are smaller than typical fairings, but provide a reasonable representation with laboratory setting constraints. The aluminum lined fairing fixture shown in Fig. 1 is the baseline structure model used for simulations and testing. A Double ridge guide horn was used for transmit and receive at the bottom and top of the fairing fixture respectively [4].

Fig. 1. Aluminum Lined Test Fixture [1]

3. Modeling and Simulation

Prior computational models identified obstacles in simulating the test environment such as measurement tolerance for high frequency simulations [1]. Accordingly, it is valuable to anchor additional computational tools for future model-to-model comparisons.

Although multiple electromagnetic modeling tools exist, full wave simulation tools that can accurately model very electrically large structures are not prevalent [5]. The MLFMM technique was used in [1] to extend the size and frequency capabilities of MoM. The technique used in this paper is also based on MoM, but uses higher order basis functions [6]. Hence electrically large structures can be modeled on pc platforms that have adequate memory allocations for the required unknowns. This technique requires mesh element size be on the order of a wavelength instead of 1/10 wavelength required for linear basis function algorithms [6-7]. Within cavity evaluations add to the computational complexity as the standard electric field integral equations can accentuate errors at resonance. Using combined electric and magnetic field equations adds to the complexity of the solution, but greatly improves the solution accuracy. WIPL-D has been shown to compare well with CFIE solutions [8].

The ProCad tool in WIPL-D was used to input the Pro-E CAD model of the fairing test fixture (Figure 2). Modifications to the meshing algorithm were applied to optimize the structure mesh to the frequency range of interest. Outer fairing walls were represented using a distributed impedance model. Integral accuracy was also increased for simulations due to the complexity of the structures [6].

Fig. 2. ProCad WIPL-D model of fairing structure

The difference in this simulation approach compared with the previous work presented in [1] is the use of the antenna in the model. In this simulation the antenna is used in the computational model and meshed with the fairing model instead of inserting the antenna pattern only into the model. Although more computationally expensive, manifestations of eigenmode development based on the horn structure are evident with this technique (Fig. 3). This effect would also be present in the measurement of the cavity with the horn, but not in the model where only the far field pattern is used to represent the receiver [1].

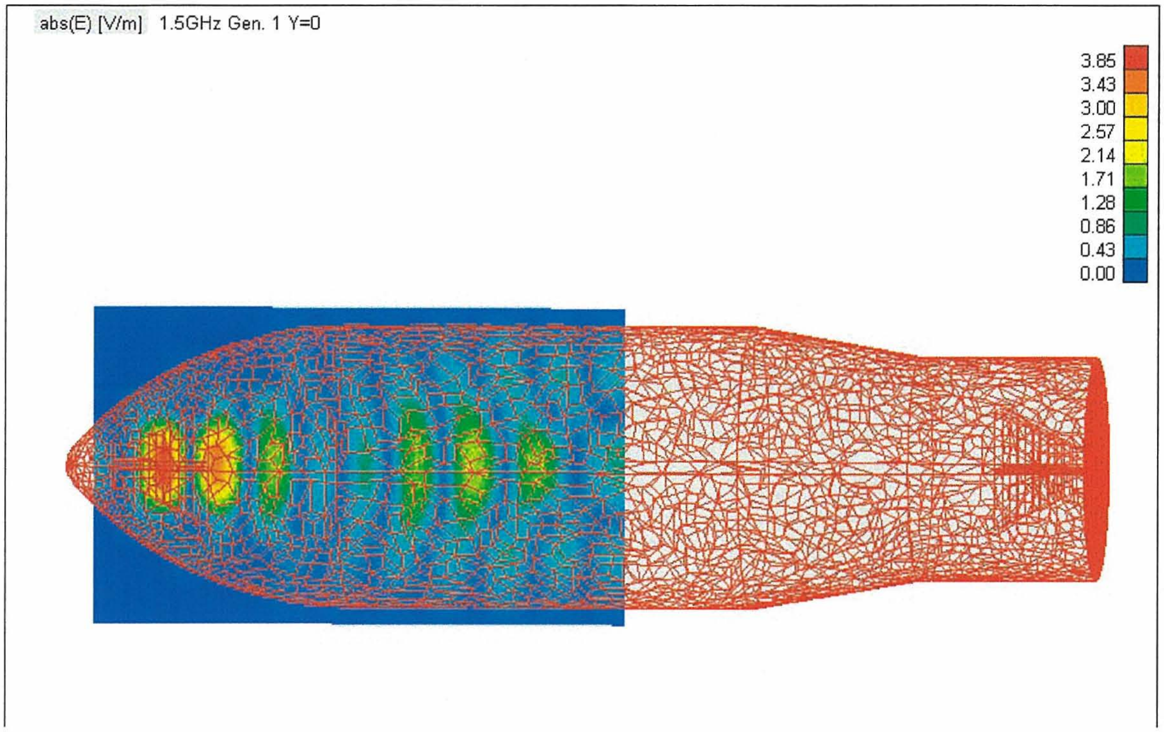

Figure 3: Fairing Cavity Model at 1.5 GHz

To emulate the test set-up, double ridge horn models were developed in WIPL-D by modifying an existing model to the EMCO 3115 dimensions [4]. Favorable gain pattern comparisons were achieved. This WIPL-D horn model was then imported into the Fairing model for simulations.

To determine the received power level, the operation setting in the edit menu was set to "one generator at a time" mode was selected[6]. S - parameter data was used to determine the mutual coupling between transmit and receive antennas in the presence of the faring cavity. The S_{21} data indicated reasonable comparisons with the fairing test fixture results as depicted in Fig. 4.

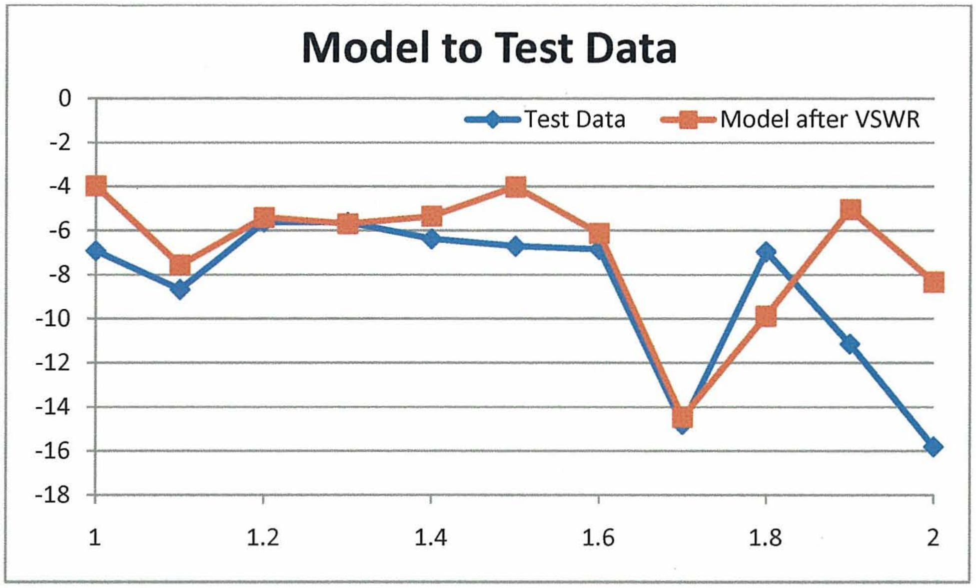

Fig. 4. Model to test comparison.

3. Conclusions and Future Work

WIPL-D has shown to be valuable in demonstrating field distributions and power reception within a fairing cavity. This tool will be used in conjunction with the MLFMM based tool to evaluate fairing internal fields in future work. As using the horn for received power affects the field distribution in the fairing cavity, future work will be based on smaller omnidirectional transmitters and smaller field probes at precision locations. Consequently, variation demonstrated in the modeled field distribution can be more precisely represented in measurement with smaller probes.

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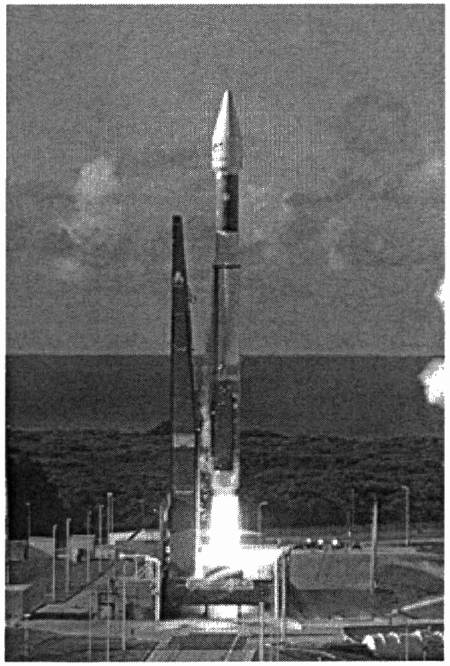
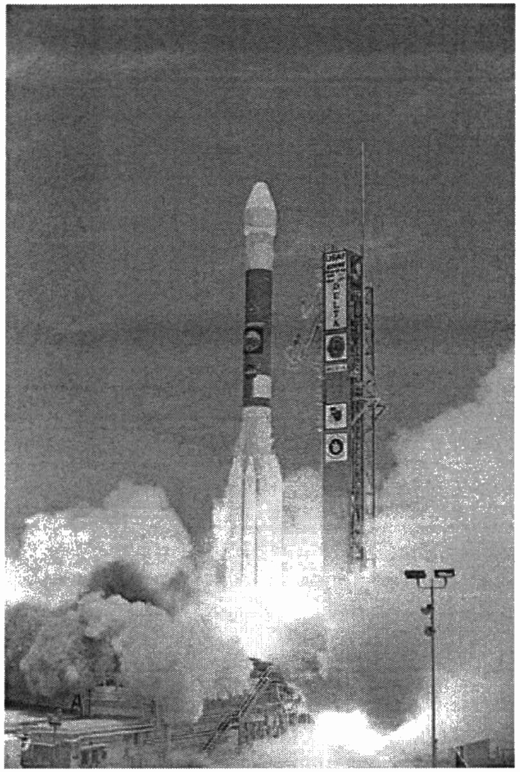
Background- Launch Vehicles

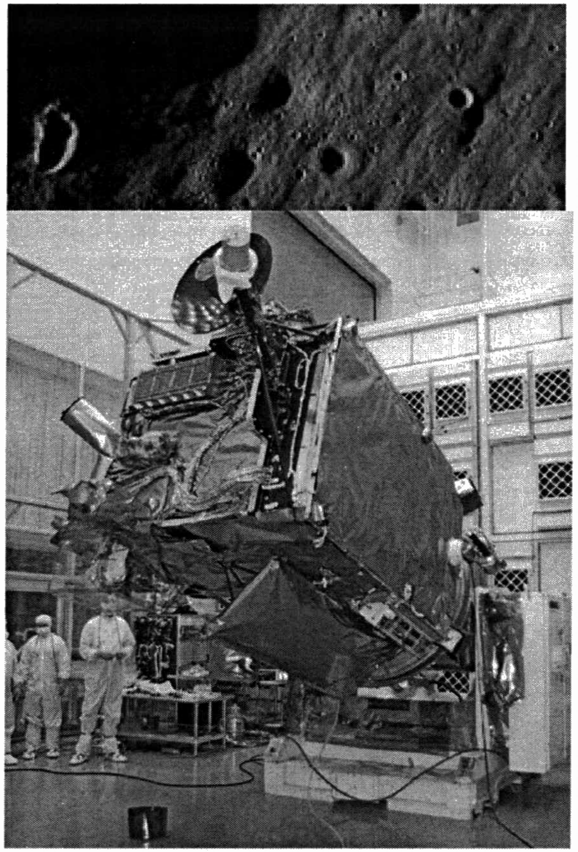
Launch Services Program launches NASA spacecraft on Commercial expendable launch vehicles.



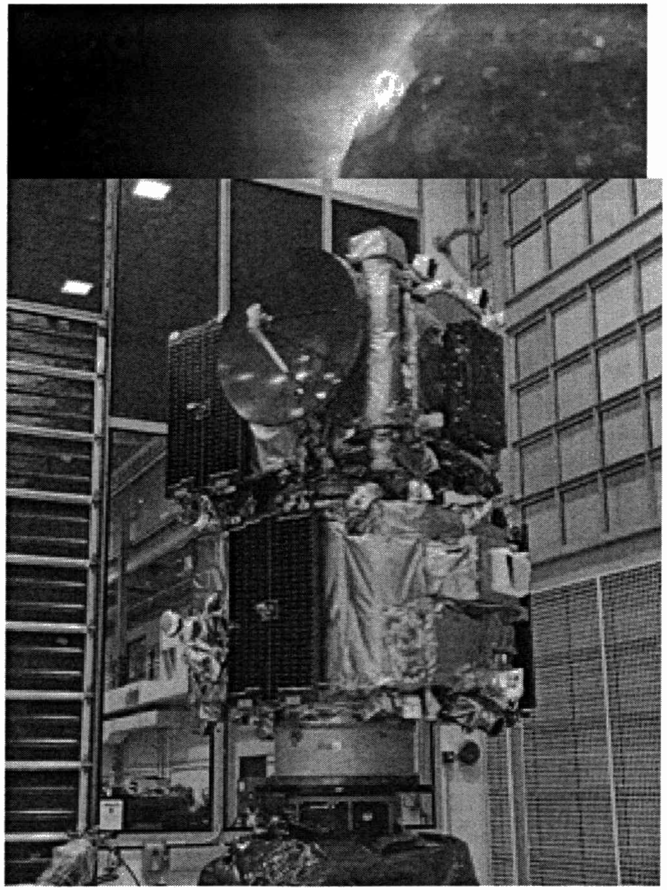


Introduction – Space Craft

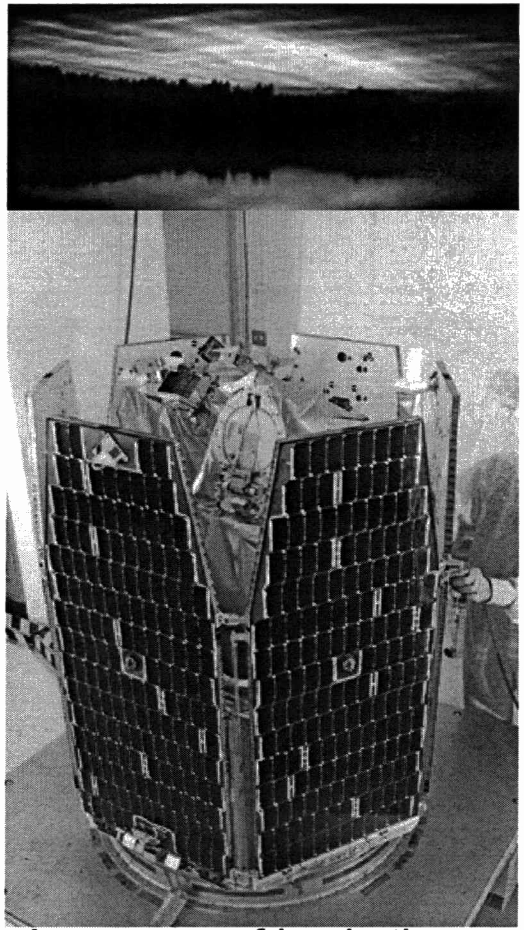
The space craft launched through LSP are widely varying in size, destination, sensitivity, and complexity.



Lunar Reconnaissance Orbiter (LRO)



Solar Terrestrial Relations Observatory (STEREO)

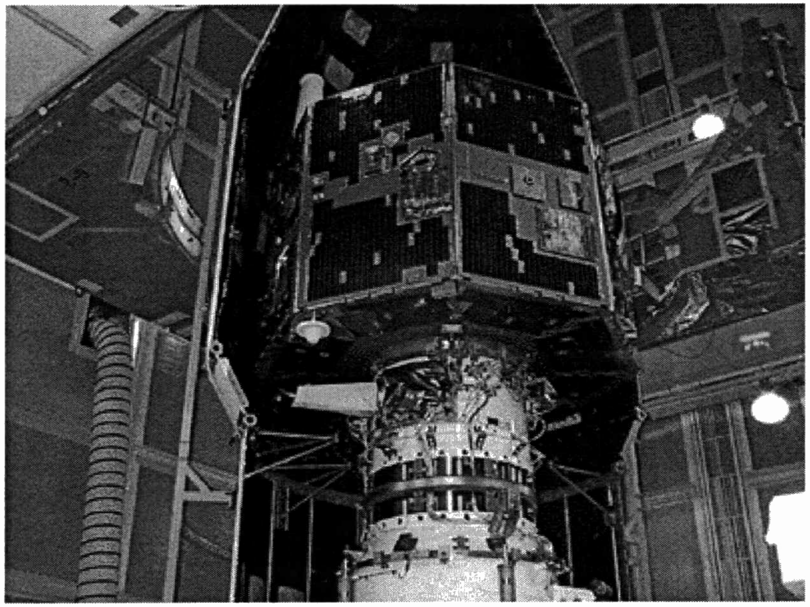


Aeronomy of Ice in the Mesosphere (AIM)

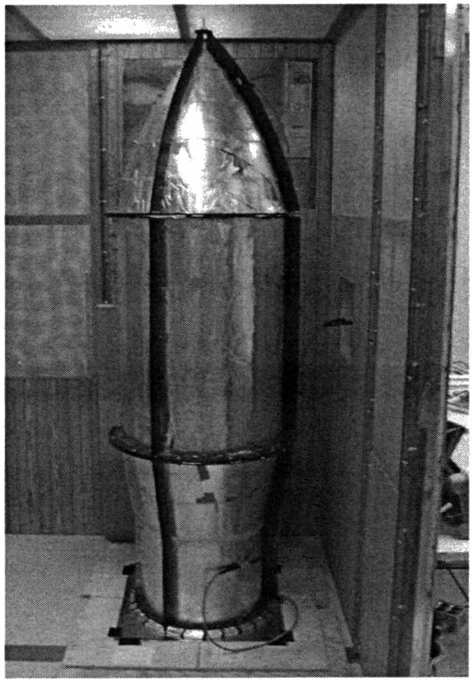
Current Issues
Fairing RF Environment

- Transmission inside Vehicle Fairing
  - Inhibits (reliability)
  - GHz frequencies
  - Computationally Intensive (large cavity and small wavelength)
  - Dielectric layers can be very thin
  - Reradiation, RF windows

- Each mission has unique parameters
  - Fairing Volume
  - Fairing Material
  - Faring Blankets
  - Payload Volume
  - Payload Materials



Scaled Fairing Fixture

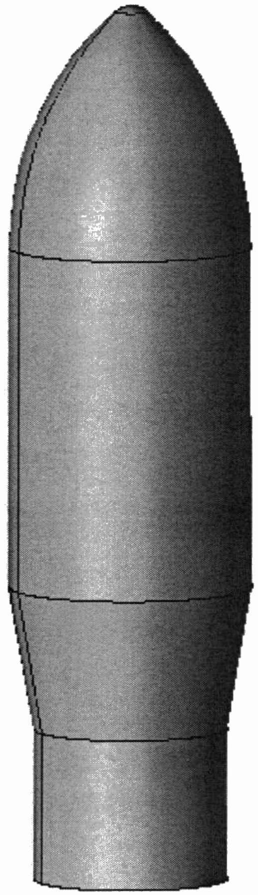


Aluminum lined test fixture [1].

- 2 m x 0.6 m fairing model
- Lexan outer shell
  - lined with aluminum foil,
  - Inner lining Kapton
- Double ridge guide horns
- Transmit Power – 1 mW

Mutual Coupling Technique

- PRO-E File for structure and horn antennas imported via WIPL-D ProCAD Tool
- Meshing constraints set for frequency S-Band
- Side Walls implemented with Distributed Impedance
- Improved Integral Accuracy.
- S-parameter data (S_{21}) between transmit and receive antennas in faring cavity in "one generator at a time" mode.



Electric Field Distribution

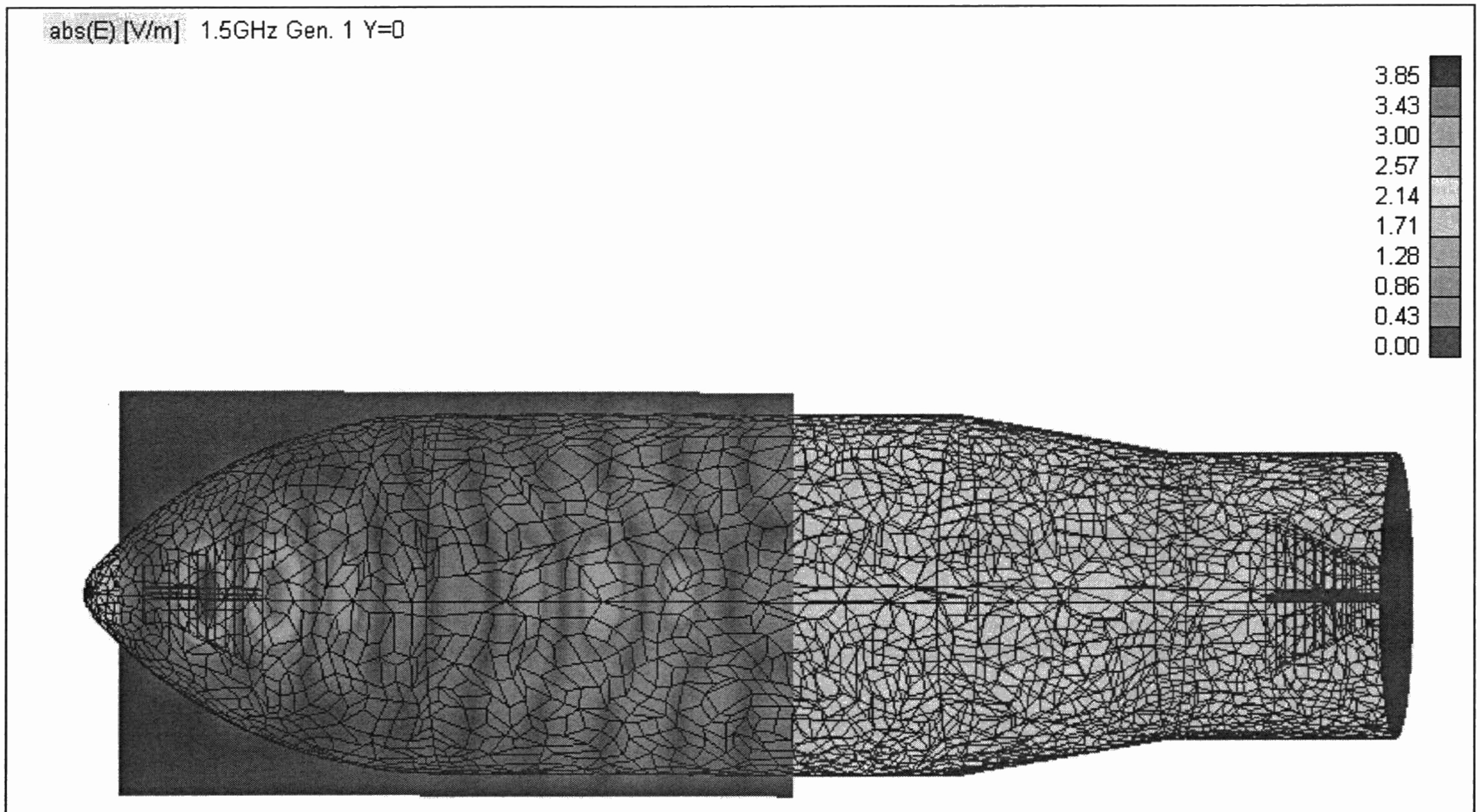


Fig. 3: Fairing cavity model at 1.5 GHz

Aluminum Lined Fairing Model to Test Data Comparison

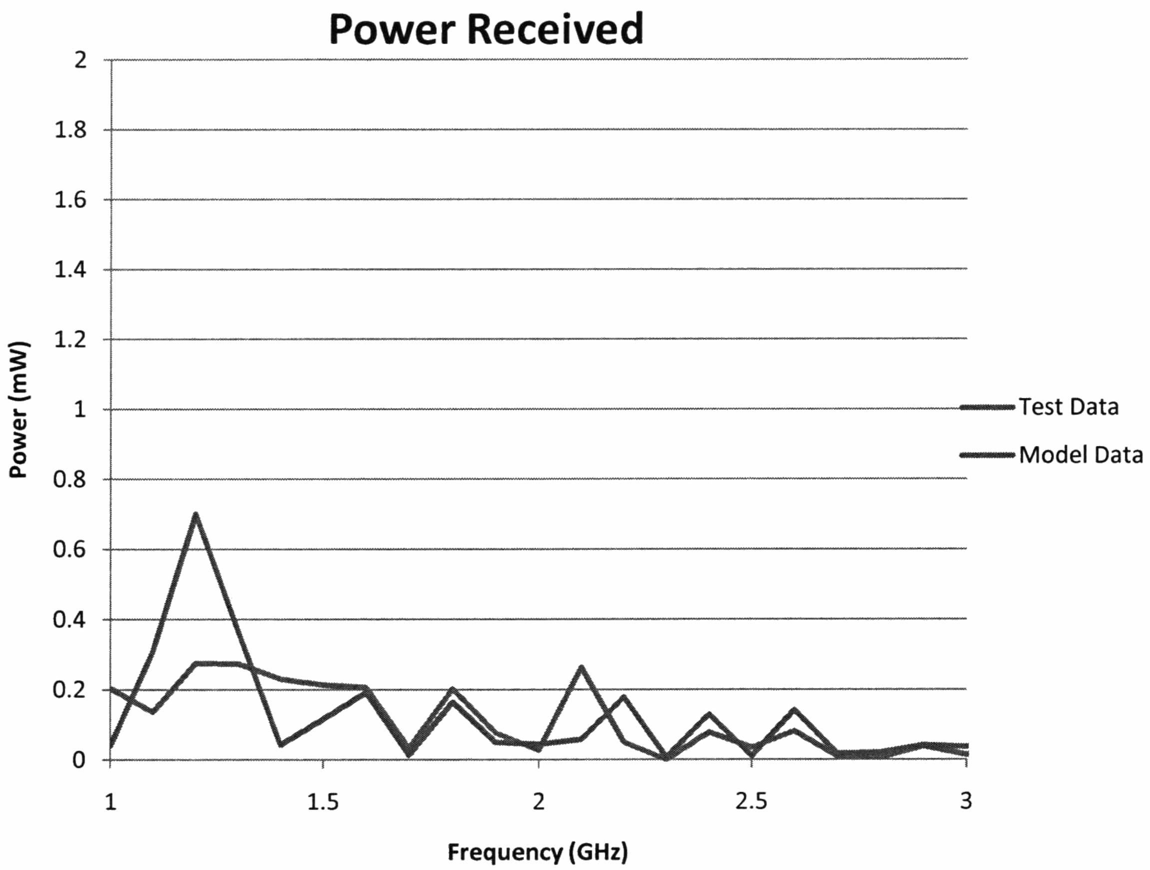
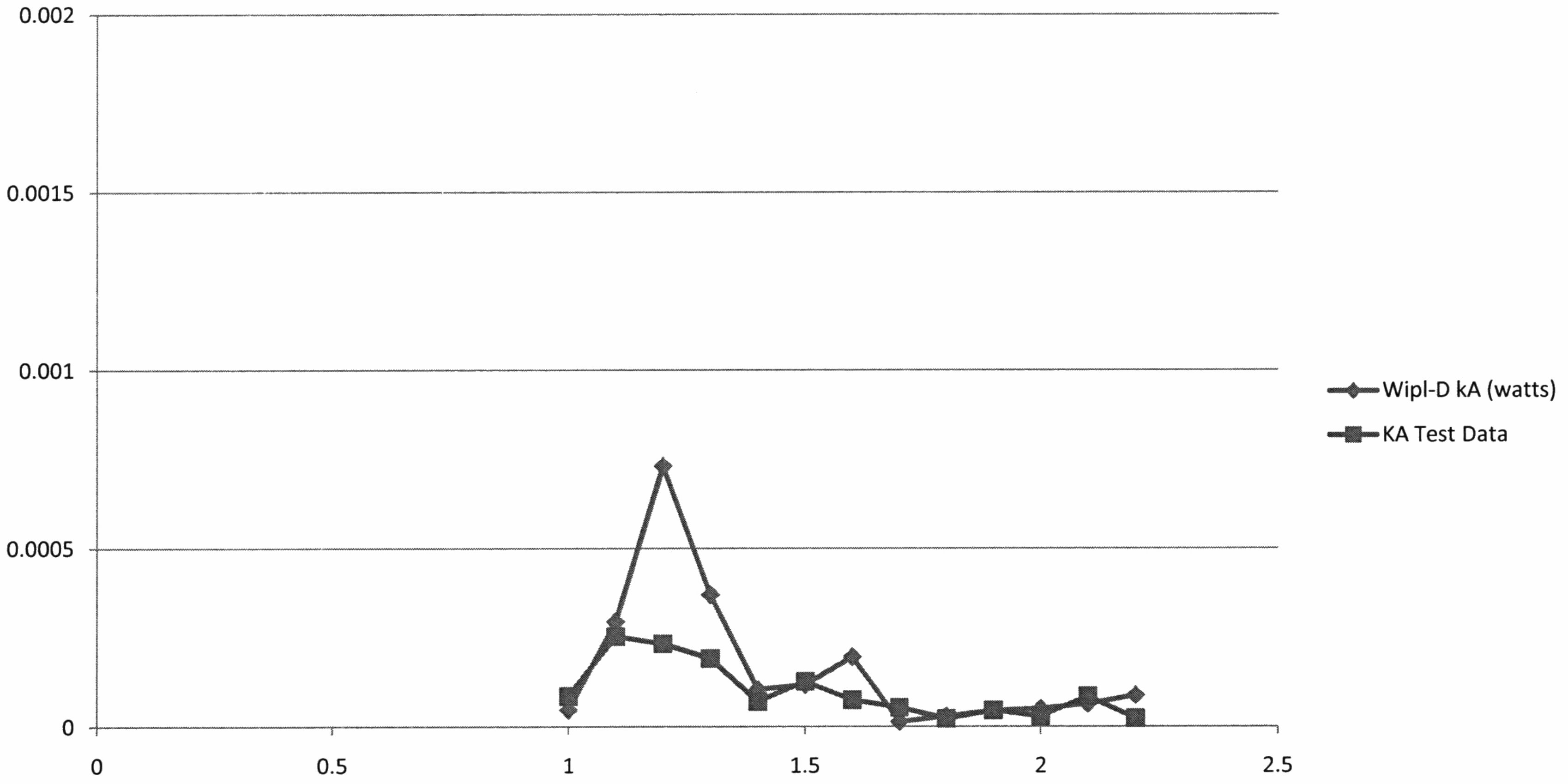


Fig. 4. Model to test comparison

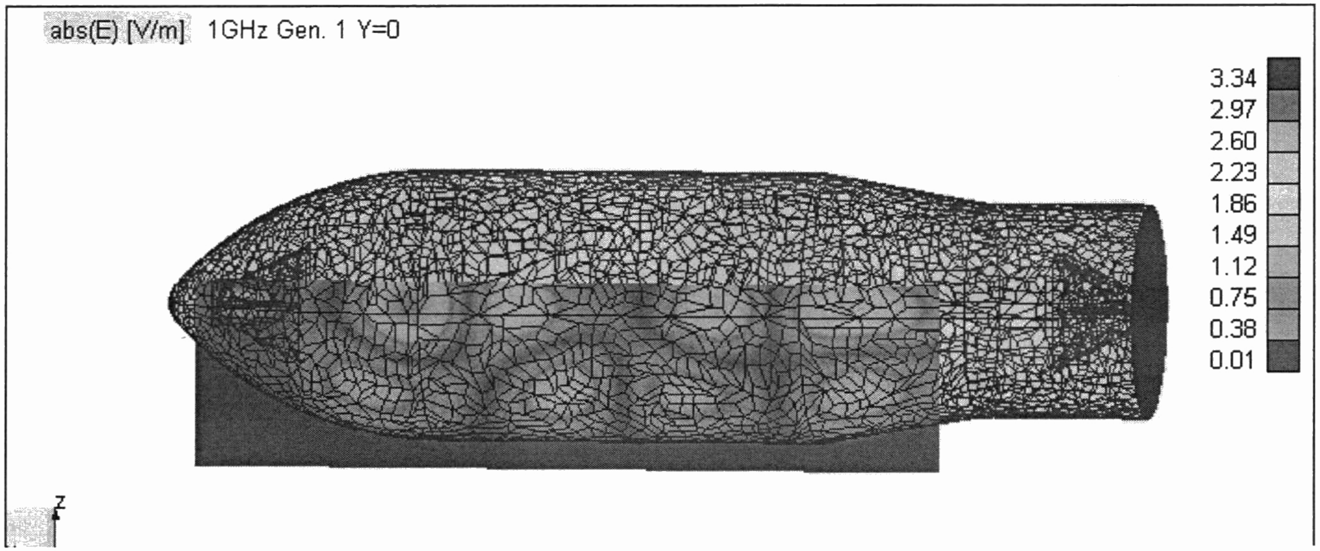
Aluminum Kapton Lining Model to Test Data Comparison

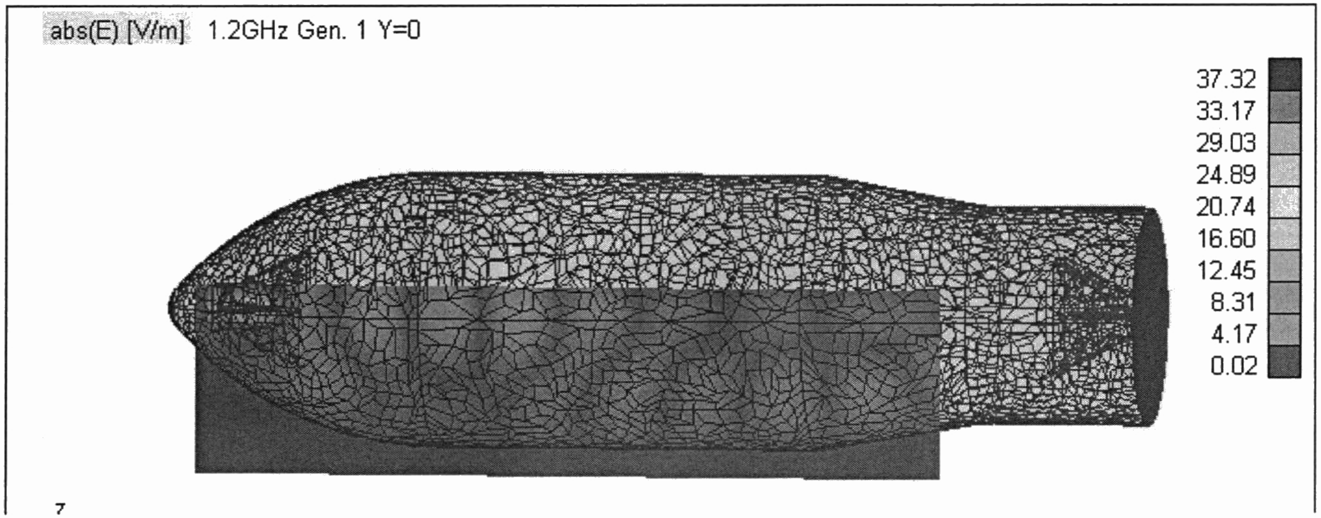


Data Discrepancies

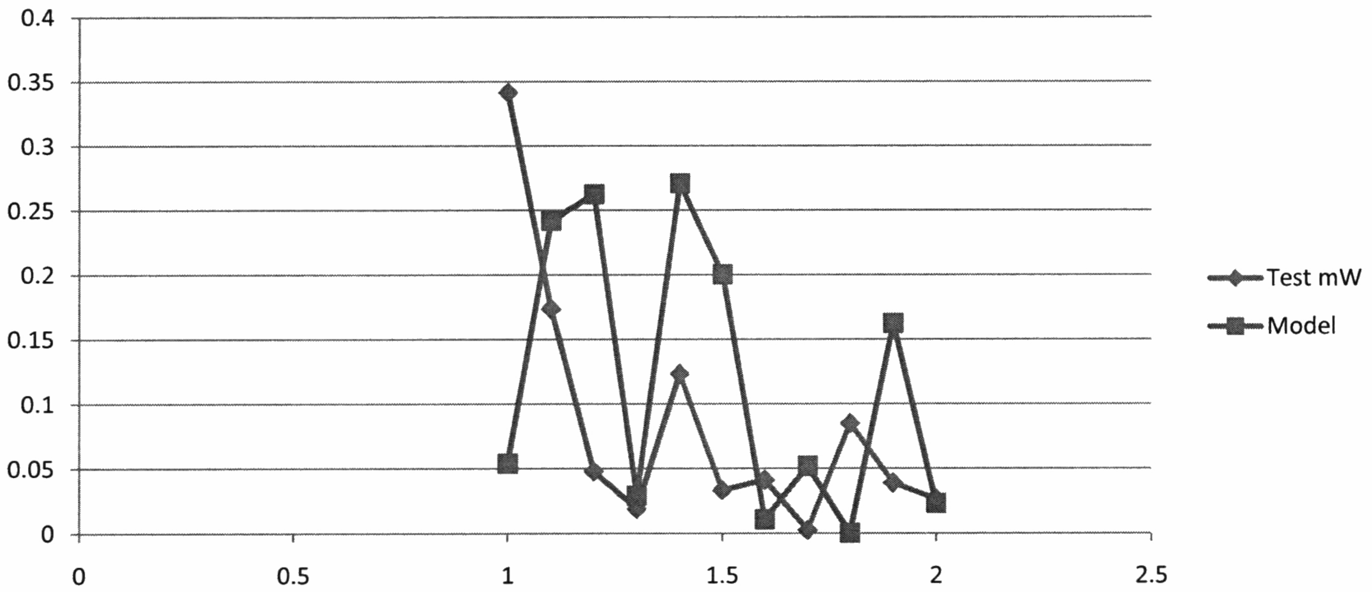
- Sensitive to small changes in Antenna location
- Fairing test model varied from CAD model slightly near the top of the fairing due to strips of lexan approximation to desired model interface.

Field Distribution in Fairing





Preliminary Loaded Cavity Comparison



Conclusions

- MoM with higher order basis function was shown to efficiently model aluminum and aluminum/kapton lined scaled fairing structures.
- Simulation times are typically less than hour/frequency with approximately 30,000 unknowns.
- WIPL-D models with composite scaled fairing structures are underway.
  - Smaller omni transmit antennas
  - Field probes in multiple locations