Extreme Fidelity Computational Electromagnetic Analysis in the Supercomputing Era

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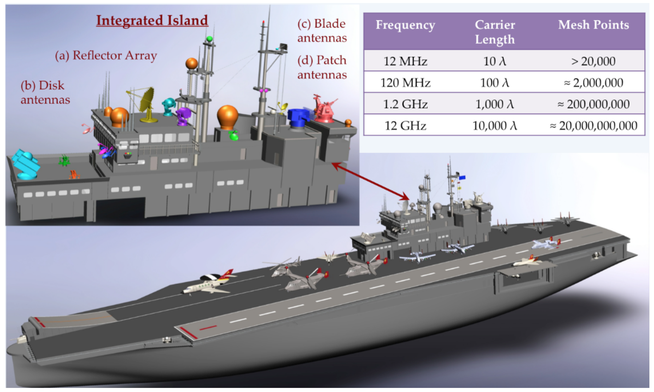
Introduction

Computer simulation of electromagnetic phenomena is an indispensable tool for engineering applications. The solution of many high-fidelity, large-scale, real-world problems is beyond the capabilities of conventional methods. The evolution of high-performance computing provides a natural set of tools with which to solve many physical problems.

In this work, we address the solution of real-world electromagnetic problems that face three unique challenges: geometrical complexity for high-fidelity modeling, computational complexity in multi-scale simulation, and time complexity for extreme-scale computing.



Frequency	Carrier Length	Mesh Points
12 MHz	10 λ	> 20,000
120 MHz	100 λ	≈ 2,000,000
1.2 GHz	1,000 λ	≈ 200,000,000
12 GHz	10,000 λ	≈ 20,000,000,000

Fig. 1) Aircraft carrier model

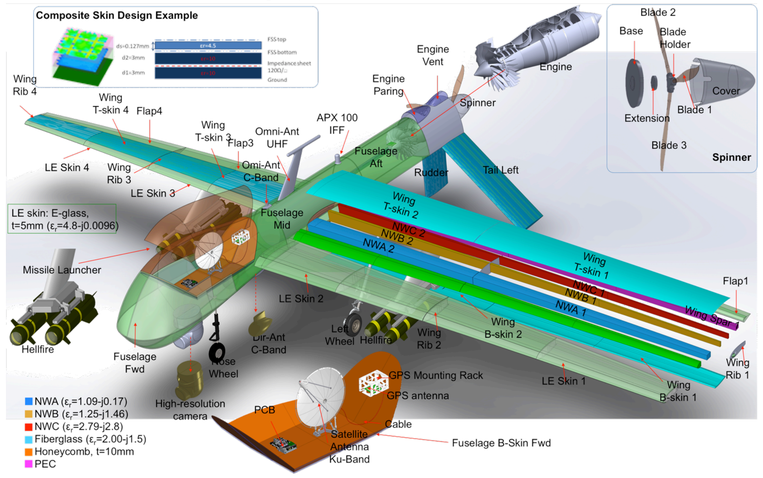


Fig. 2) UAV model

Technical Contributions

Primary Ingredients:

1. Geometry-aware discontinuous Galerkin BEM
2. Geometry-based IE domain decomposition method
3. Optimized matrix compression
4. Local direct solver
5. Adaptive, paralel IE algorithms

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Methods

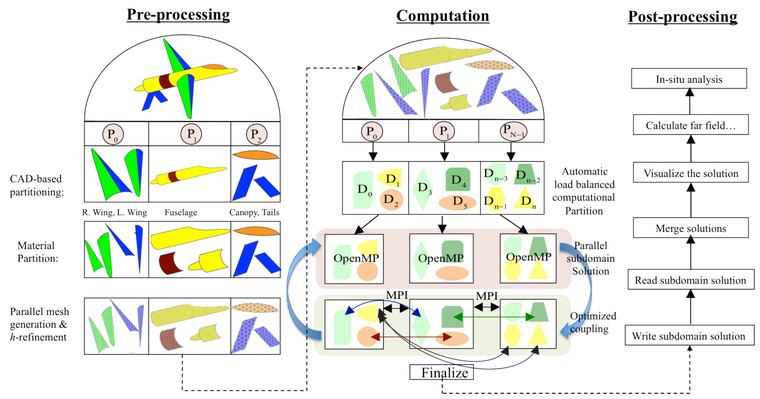
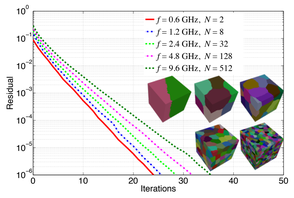


Fig. 3) Parallel Framework



MT-CFIE:

$$\alpha \boldsymbol{e}_m + (1-\alpha)\bar{\eta}_m \boldsymbol{j}_m - \bar{\eta}_m \mathcal{C}_{\alpha}^{k_m}(\boldsymbol{j}_m; \partial\Omega_m) - \hat{\boldsymbol{n}}_m \times \mathcal{C}_{(1-\alpha)}^{k_m}(\boldsymbol{e}_m \times \hat{\boldsymbol{n}}_m; \partial\Omega_m) = \boldsymbol{y}_m^{inc} \text{ on } \partial\Omega_m$$

IP-DDM:

$$\frac{1}{4\iota k_0} \sum_{\mathcal{C}_{mn} \in \mathcal{C}} \langle [\![\mathbf{j}]\!]_{mn}, \sum_{n=1}^{2} \Psi_F(\nabla_\tau \cdot \boldsymbol{v}_n; S_n) \rangle_{\mathcal{C}_{mn}} + \frac{\beta}{2k_0} \sum_{\mathcal{C}_{mn} \in \mathcal{C}} \langle [\![\mathbf{j}]\!]_{mn}, [\![\mathbf{v}]\!]_{mn} \rangle_{\mathcal{C}_{mn}} = 0$$

UAV – Materials Problem

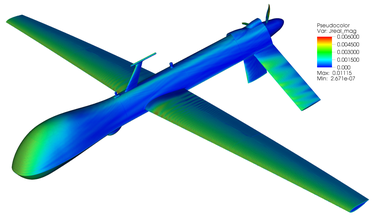


Fig. 4a. UAV surface current

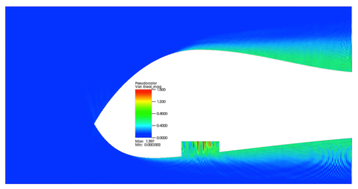


Fig. 4b. Composite wing

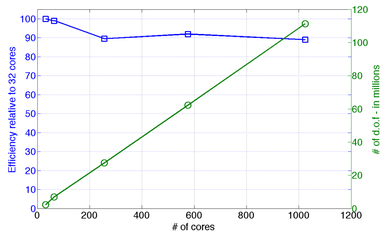


Fig. 4c. Weak Scaling Test

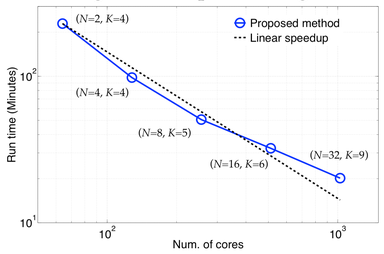


Fig. 4d. Strong Scaling Test

Carrier – Large-Scale Problem

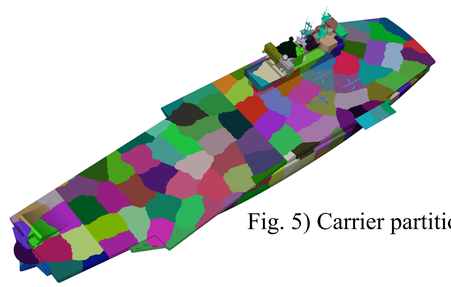


Fig. 5) Carrier partitioning

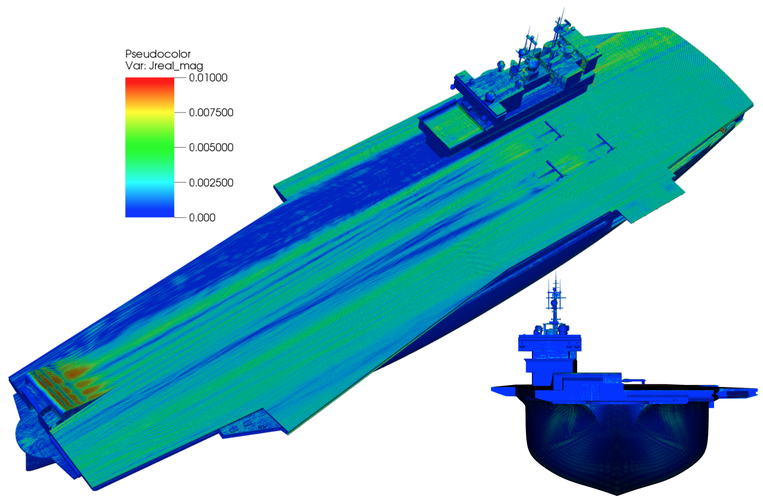
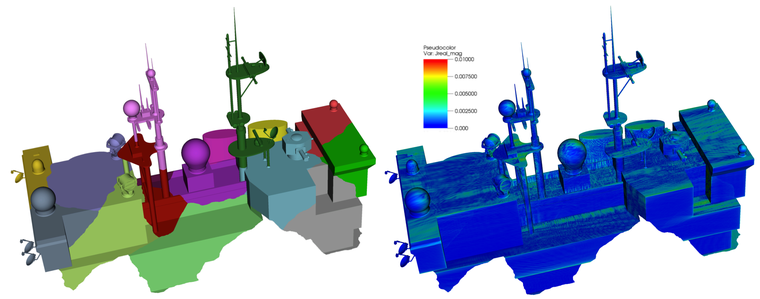


Fig. 6) Carrier surface current at f = 2 GHz



a. Subdomain partitioning b. Surface current

Fig. 7) Antenna deck

Conclusions & Future Work

We have presented a scalable, convergent geometry-aware domain decomposition method for real-world electromagnetic problems. This method is capable of solving complex, from a materials, multi-, and extreme-scale standpoints, real-world engineering problems.

Furthermore, the framework presented has been designed from start to finish with parallelism in mind. Future work will involve the following items:

- In-situ load balancing
- Cloud computing
- Real-world engineering problem with 4 billion DOFs

References

[1] W. C. Chew, M. S. Tong, and B. Hu, *Integral equation methods for electromagnetic and elastic waves.* Morgan & Claypool Publishers, 2008.

[2] Zhen Peng, Ralf Hiptmair, Yang Shao and Brian MacKie-Mason, "Domain decomposition preconditioning for surface integral equations in solving challenging electromagnetic scattering problems," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 1, pp. 210-223, Jan. 2016..

[3] Brian MacKie-Mason, Andrew Greenwood and Zhen Peng, "An adaptive, parallel surface integral equation solver for very large-scale electromagnetic modeling and simulation," *Progress In Electromagnetics Research, Invited paper for the Commemorative Collection on the 150-Year Anniversary of Maxwell's Equations*, vol. 154, pp. 143-162, 2015. .