RQ15-23

1. **Research Title:** "Implementation of High-Fidelity Turbomachinery Analysis Capability in a Discontinuous Galerkin Solver."

2. **Individual Sponsor:**

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3. **Academic Area/Field and Education Level:** Computer Science / Aerospace Engineering, Computational Fluid Dynamics (MS or Ph.D. level)

4. **Objectives:** Implement boundary conditions and turbulence models applicable to unsteady, full annulus turbomachinery analysis with the discontinuous Galerkin formulation. Develop regression and unit tests as appropriate to ensure proper operation of the solver. Research and develop higher-order non-reflective boundary conditions for stable numerical simulation of internal flow and turbomachinery components. Compare higher order results with existing finite volume methods and perform cost-benefit analysis in using varying numerical schemes.

5. **Description:** Discontinuous Galerkin is a finite element method that has recently been extended for use as a higher order method in fluid dynamics. Having the ability to perform turbomachinery analysis using such a scheme, along with the ability to produce and implement additional numerical methods, boundary conditions, and turbulence models, is crucial in turbine engine research. The resulting toolset will have applications in system design and analysis for internal and external flows, particularly for engine installation simulations.

6. **Research Classification/Restrictions:** This research is FOUO and has ITAR restrictions.

7. **Eligible Research Institutions:** Place an X in all that apply.
   X Universities (DAGSI) ☐ AFIT (only) ☐USAFA

8. **Interest in Summer USAFA Cadet (Avg Cost for USAF Cadet for 33 days was $5000):**

   N/A

Public Release Pending

Additional Details

RQVC has been developing a discontinuous Galerkin solver for higher-order CFD analysis. The solver is flexibly written, allowing any number of equation sets to be implemented. This is amenable to multidisciplinary analysis, ultimately enabling heat transfer and fluid-structure interaction.

The solver is written in C++ and uses meta-templating and Python preprocessing to ease generation of repetitive code, symbolically expand equations, and other menial programming tasks. Details of discretization are masked using these meta-programming techniques in order to simplify the implementation of new equation sets.

The work to be performed can easily complement on-going work and the planned roadmap for the solver. Specific tasks which must be accomplished in order to perform a demonstration of coupled diffuser-fan analysis:

- Implementation of turbomachinery periodic, inlet, and outlet boundary conditions appropriate for higher order simulations
- Implementation of sliding interface boundary conditions for unsteady data transfer across blade rows
- Development of turbomachinery appropriate regression tests
- Comparison of solutions to existing finite volume solvers, existing fan solutions, and application to full annulus phenomena such as stall and distortion transfer

The output of this endeavor is of direct interest to several organizations within RQ. Although the focus of this effort is on the turbomachinery portion of the solver, full implementation thereof would still represent a significant contribution to the overall solver and the use of discontinuous Galerkin for fluid equations.

References

Marshall Galbraith, Paul Orkwis, John Benek: Discontinuous Galerkin Scheme Applied to Chimera Overset Viscous Meshes on Curved Geometries. 42nd AIAA Fluid Dynamics Conference and Exhibit, AIAA-2012-3055 (2012)

Donald A. French, Marshall C. Galbraith, Mauricio Osorio: Error analysis of a modified discontinuous Galerkin recovery scheme for diffusion problems. Applied Mathematics and Computation 218(13): 7144-7154 (2012)

Marshall Galbraith, Paul Orkwis, John Benek: Automated Quadrature-free Discontinuous Galerkin Method Applied to Viscous Flows. 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, AIAA-2011-493 (2011)