NASA SBIR 2022 Phase I Solicitation

A1.05  Computational Tools and Methods

Lead Center: LaRC

Participating Center(s): ARC, GRC

Scope Title

Unstructured Meshes for Scale-Resolving Simulations

Scope Description

Computational fluid dynamics (CFD) plays an important role in the design and development of a vast array of aerospace vehicles, from commercial transports to space systems. With the ever-increasing computational power, usage of higher fidelity, fast CFD tools and processes will significantly improve the aerodynamic performance of airframe and propulsion systems, as well as greatly reduce nonrecurring costs associated with ground-based and flight testing. Historically, the growth of CFD accuracy has allowed NASA and other organizations, including commercial companies, to reduce wind tunnel and single engine component tests. Going forward, increased CFD fidelity for complete vehicle or engine configurations holds the promise of significantly reducing development costs, by enabling certification by analysis (CbA). Confidence in fast, accurate CFD and multidisciplinary analysis tools allow engineers to reach out of their existing design space and accelerate technology maturation schedules. Uncertainty quantification is a key technology in enhancing confidence in the prediction capability of the computational tools. NASA’s CFD Vision 2030 Study (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf) highlighted the many shortcomings in the existing computational technologies used for conducting high-fidelity simulations, including multidisciplinary analysis and optimization, and made specific recommendations for investments necessary to overcome these challenges. A more recent study provided a long-term vision and a technology development roadmap to enable CbA for aircraft and engine certification (see https://ntrs.nasa.gov/citations/20210015404).

During the current cycle, proposals are solicited in the following mesh generation area for CFD simulations:

Unstructured Meshes for Scale-Resolving Simulations: Mesh generation for high-fidelity simulations is a critical area of research. The focused grid-related area for which proposals are being solicited is automated and scalable mesh generation for wall-modeled large eddy simulations (WMLES). Unstructured approaches can be used to discretize highly complex flow configurations but, in addition to automation, there is need to generate the mesh robustly and efficiently regardless of geometric complexity. The mesh quality aspect is especially critical for scale-resolving simulations where numerical methods benefit significantly from element regularity and alignment for accuracy considerations, while maintaining an optimal number of cells for solver efficiency. Isotropic meshing is preferred and a combination of hex grid (near solid boundaries) and tetrahedral (further away) may provide the best compromise between solution accuracy and solver efficiency. The goal of the solicited work is to encourage development of such mesh generation software that can be interfaced and integrated with NASA CFD solvers. The requirements for the solicited mesh software include: (1) it should be able to efficiently handle arbitrarily complex geometries; (2) the software should be Message Passing Interface (MPI) parallel, scalable to billion+ cell meshes
as are typical for NASA applications; (3) the mesh generation process needs to take a water-tight bounding volume definition as input, where the surface of the bounding volume can be marked with prescribed mesh resolution(s), in addition to any user-prescribed volume refinement metrics (such as adjoint-based error metrics, prescribed volumes, etc.). Such mesh technology has the potential to drastically improve turnaround time for scale-resolving simulations for complex configurations and enabling wider use of high-fidelity CFD analysis for challenging turbulent flow problems. This research effort is expected to enable NASA solvers to interface with the resulting tool. The meshing tool should be designed to perform well on the emerging high-performance computing hardware. An additional area of research may include adaptive mesh refinement while a WMLES is progressing. Demonstration of mesh generation coupled with NASA CFD solvers (e.g., the unstructured grid code FUN3D) is considered essential for the solicited research.

**Expected TRL or TRL Range at completion of the Project**

3 to 6

**Primary Technology Taxonomy**

Level 1

TX 15 Flight Vehicle Systems

Level 2

TX 15.1 Aerosciences

**Desired Deliverables of Phase I and Phase II**

- Software
- Research
- Analysis

**Desired Deliverables Description**

**Phase I:**

1. Demonstrate fully automated unstructured mesh generation for canonical geometries as proof of concept.
2. Demonstrate accuracy and efficiency of the developed capability, using a NASA CFD solver (e.g., FUN3D).
3. Provide an executable of the mesh generation code and an Application Programming Interface (API to interface with NASA solvers for independent testing.

**Phase II:**

1. Further develop the mesh generation capability for WMLES and demonstrate on more complex topologies (e.g., NASA Common Research High-Lift Model (HLPW-4 configuration), NASA juncture flow model, multistream chevron nozzle (TMP17)).
2. Demonstrate solution accuracy.
3. Demonstrate weak and strong scaling of the mesh generation software pushing the capability limits.
5. Deliver executable of mesh generation solver along with the API to NASA for its internal use.

**State of the Art and Critical Gaps**

NASA’s CFD Vision 2030 Study identified several impediments in computational technologies and this solicitation addresses one of those related to application of scale-resolving simulations needed for expanding the scope of application of CFD across the aircraft flight envelope, particularly in the prediction of maximum lift. This solicitation also addresses meshing needs to enable such computations.
Relevance / Science Traceability

Various programs and projects of NASA missions use CFD for advanced aircraft concepts, launch vehicle design, and planetary entry vehicles. The developed technology will enable design decisions by Aeronautics Research Mission Directorate (ARMD) and Human Exploration and Operations Mission Directorate (HEOMD).

References

- https://www.nasa.gov/aeroresearch/programs/aavp
- https://www.nasa.gov/aeroresearch/programs/tacp
- NASA’s CFD Vision 2030 Study: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf
- NASA's A Guide for Aircraft Certification by Analysis Study: https://ntrs.nasa.gov/citations/202100154
- FUN3D: https://software.nasa.gov/software/LAR-19638-1

Scope Title

Unstructured Mesh Generation for Icing

Scope Description

Computational fluid dynamics (CFD) plays an important role in the design and development of a vast array of aerospace vehicles, from commercial transports to space systems. With the ever-increasing computational power, usage of higher fidelity, fast CFD tools and processes will significantly improve the aerodynamic performance of airframe and propulsion systems, as well as greatly reduce nonrecurring costs associated with ground-based and flight testing. Historically, the growth of CFD accuracy has allowed NASA and other organizations, including commercial companies, to reduce wind tunnel and single-engine component tests. Going forward, increased CFD fidelity for complete vehicle or engine configurations holds the promise of significantly reducing development costs, by enabling certification by analysis (CbA). Confidence in fast, accurate CFD and multidisciplinary analysis tools allow engineers to reach out of their existing design space and accelerate technology maturation schedules. Uncertainty quantification is a key technology in enhancing confidence in the prediction capability of the computational tools. NASA’s CFD Vision 2030 Study (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf) highlighted the many shortcomings in the existing computational technologies used for conducting high-fidelity simulations, including multidisciplinary analysis and optimization, and made specific recommendations for investments necessary to overcome these challenges. A more recent study provided a long-term vision and a technology development roadmap to enable CbA for aircraft and engine certification (see https://ntrs.nasa.gov/citations/20210015404).

During the current cycle, proposals are solicited in mesh generation for the following CFD application.

Unstructured Mesh Generation for Icing: Another topic for which proposals are solicited is the study of icing effect on aircraft performance. Icing plays an important role in aircraft design and the certification process and, therefore, modeling and quantification of icing effects on aerodynamic performance (e.g., aircraft CLmax) is required, as pointed out in the CbA report referred to previously. This solicitation invites proposals for grid generation with imposed icing shapes to enable high-fidelity CFD analysis of relevant configurations. The objective is to use the developed capability with NASA unstructured grid CFD solvers and, therefore, the proposer will address such coupling along with the capability demonstration. The proposer will collect available icing data and use it to demonstrate the unstructured grid capability as well as simulate icing effect on aerodynamic performance particularly during high-lift flight configuration. Breakdown of the proposed work, including the strategy for capability demonstration, will be a critical factor in the evaluation process. The goal of this research is to provide an automated, efficient, and accurate tool for the intended purpose. Deliverables must include an Application Programming Interface (API) to interface the meshing tool with NASA CFD solvers, in particular FUN3D.

Expected TRL or TRL Range at completion of the Project

3 to 6
Desired Deliverables of Phase I and Phase II

- Analysis
- Research
- Software

Desired Deliverables Description

Phase I:

1. Demonstrate fully automated unstructured mesh generation for canonical wing geometries as proof of concept.
2. Demonstrate accuracy and efficiency of the developed capability, using a NASA CFD solver (e.g., FUN3D), for prediction of icing effect.
3. Provide an executable of the mesh generation code and an API to interface with NASA solvers for independent testing.

Phase II:

1. Further develop the mesh generation capability including icing and demonstrate on more complex topologies (high-lift applications are of particular interest).
2. Demonstrate solution accuracy.
3. Deliver executable of mesh generation tool, including icing effect, along with the API to couple with NASA unstructured grid solvers.

State of the Art and Critical Gaps

NASA's CFD Vision 2030 Study identified several impediments in computational technologies and this solicitation addresses one of those related to application of scale-resolving simulations needed for expanding the scope of application of CFD across the aircraft flight envelope, particularly in the prediction of maximum lift. NASA's more recent study "A Guide for Aircraft Certification by Analysis" identified the need for computation of icing effects on aerodynamic performance. This solicitation also addresses meshing needs to enable such computations.

Relevance / Science Traceability

Various programs and projects of NASA missions use CFD for advanced aircraft concepts, launch vehicle design, and planetary entry vehicles. The developed technology will enable design decisions by Aeronautics Research Mission Directorate (ARMD) and Human Exploration and Operations Mission Directorate (HEOMD).

References

- https://www.nasa.gov/aeroresearch/programs/aavp
- https://www.nasa.gov/aeroresearch/programs/tacp
- NASA's CFD Vision 2030 Study: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf
- NASA's Aircraft Certification by Analysis Study: https://ntrs.nasa.gov/citations/20210015404