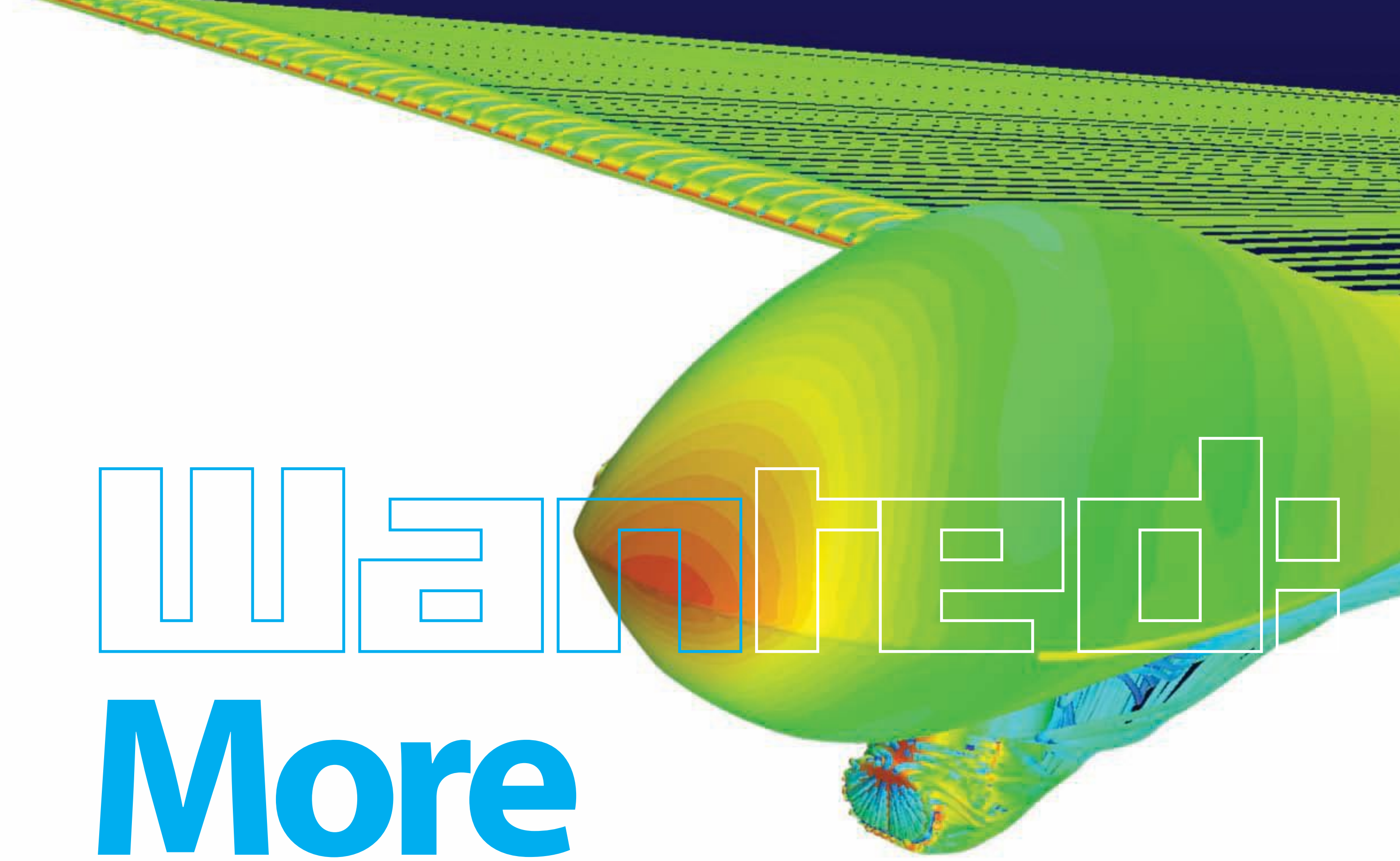


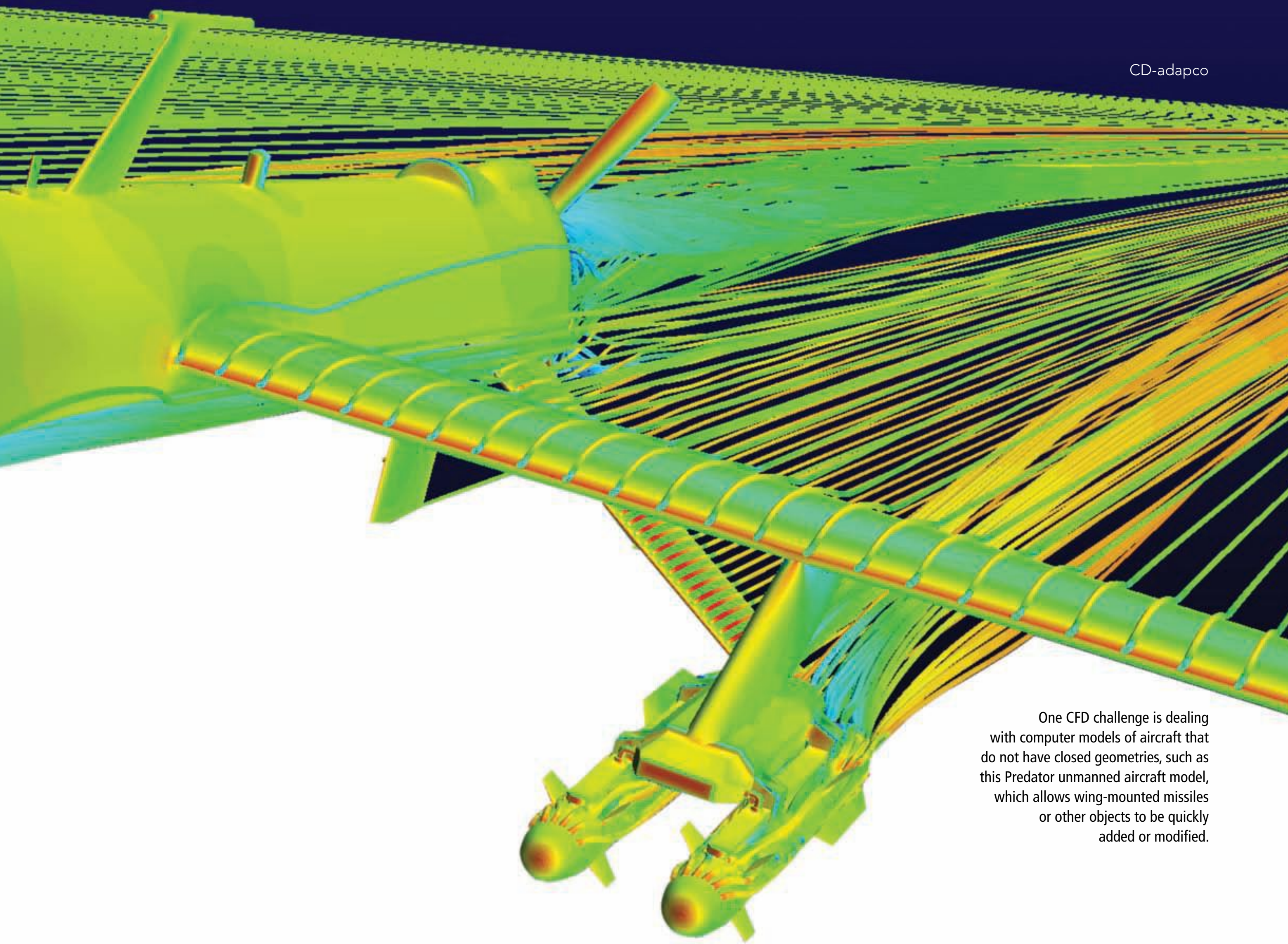
Wanted: More focus on CFD

Computational fluid dynamics has been a powerful tool for airframe designers, but American researchers are sounding an alarm about the troubles they see lurking for CFD software. Keith Button spoke to the authors of a report NASA commissioned on the topic.

By Keith Button

U.S. aircraft designers see all sorts of amazing machines in our future — airplanes with electric propulsion; with shapes that are part wing and part conventional body; with giant wingspans or with wings braced by struts and trusses.

American research is underway on some of these ideas, but aviation advocates in the U.S. are beginning to sound the alarm about a threat they see to their ability to get the best of these concepts into operation before other nations or non-U.S. corporations do. These experts warn that the U.S. does not have an adequate plan in place to improve today's computational fluid dynamics and other digital simulation tools and to get ready for exotic new computing concepts, such as circuity made from microscopic carbon nanotubes or computers that rely on quantum properties.



One CFD challenge is dealing with computer models of aircraft that do not have closed geometries, such as this Predator unmanned aircraft model, which allows wing-mounted missiles or other objects to be quickly added or modified.

Those technologies offer enormous potential because of their ability to rapidly process terabytes of data, but today's CFD algorithms and computing code would need to be rewritten for them.

There's also lots of room for improvement in the nearer term. Today's CFD products — the colorful physics-based digital simulations of aerodynamic flows — look very impressive and have assumed a larger role in aircraft development. But they are not as powerful as many designers and analysts would like.

"There's this perception in the [CFD] community and outside the community that when you see all these pretty pictures from current CFD methods that those are sufficient to design all kinds of new vehicles, but that's not the case. There are some glaring inaccuracies in many different areas," says Juan Alonso, an associate professor of aeronautics and astronautics at Stanford University.

Adapting CFD to the times will require the aerospace community to solve technical issues, win more funding and instill better collaboration among private industry, government agencies and university experts in high-performance computing, software design and applied mathematics, experts say.

"These are hard problems that cannot be solved by any one organization," says Jeffrey Slotnick, technical fellow in computational aerodynamics at Boeing in Huntington Beach, California.

Slotnick is one of the authors of a report commissioned by NASA, "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences." The report was completed in November 2013 and released in March. In the months since, the writers have publicized their findings in appearances at the Salishan Conference on High Speed Computing in Oregon, the AIAA Aviation Forum in Georgia, and at a user event in Kobe, Japan, put on by the RIKEN institute.

The report lays out a CFD development plan that has NASA taking the lead role by funding a base research program for simulation technologies, creating a formal structure for in-house simulation software development, making high performance computing available for CFD development, establishing testing and validation programs to assess CFD predictions, fostering collaboration, and attracting world-class engineers and scientists to the field of CFD.

From Slotnick's perspective, the key recommendation is to get a better collaborative effort off the ground: "We can't just rely on business as usual here. We have to do something fundamentally different to solve the problems."

Today, computational fluid dynamics is used to predict the aerodynamic characteristics and performance of airplanes before they are built. CFD does well at simulating air flows in cruising conditions, where an airplane operates 99 percent of the time. It's much less effective at predicting performance in other situations, such as takeoffs, landings and other low-speed, high-lift conditions in which flaps are deployed, or for simulating stalls or other conditions at the edges of the flight envelope, says Dimitri Mavriplis, professor of mechanical engineering at the University of Wyoming and an author of the report. Those flight conditions produce turbulence — the swirls and eddies created when air does not flow smoothly over the surface of the aircraft. Physical model tests in wind tunnels or real-world flight tests are used to judge performance in those scenarios because CFD lacks the accuracy needed to make credible design decisions, says Alonso, the Stanford professor and one of the report's authors. This weak spot in

POWER PLAYERS

High-performance computers are essential for advanced computational fluid dynamics applications. The Top500 project ranks the world's most-powerful computers based on a benchmark that measures the maximum number of floating-point operations per second, or flops, the computer has achieved. As of November, NASA's fastest computer ranks just outside of the top 10.

Rank	***Name***	***Performance (in petaflops)***	***Site***	***Country***
1	Tianhe-2	33.9	National Super Computer Center	China
2	Titan	17.6	Oak Ridge National Lab, Energy Dept.	U.S.
3	Sequoia	17.2	Lawrence Livermore National Lab, Energy Dept.	U.S.
4	—	10.5	RIKEN Advanced Institute for Computational Science	Japan
5	Mira	8.6	Argonne National Laboratory, Energy Dept.	U.S.
6	Piz Daint	6.3	Swiss National Supercomputing Centre	Switzerland
7	Stampede	5.2	Texas Advanced Computing Center, University of Texas	U.S.
8	JuQueen	5.0	Juelich Research Center	Germany
9	Vulcan	4.3	Lawrence Livermore National Lab, Energy Dept.	U.S.
10	—	3.6	Undisclosed government agency	U.S.
11	Pleiades	3.4	NASA Ames Research Center	U.S.

Source: Top500.org

current CFD simulation comes from reliance on mathematical models that are based on previous testing experience and approximations, instead of pure computations.

While some features of the air flow are as large as the aircraft, turbulent swirls can be smaller than 1/100th of an inch, very close to the surface of the plane. To calculate those flows with CFD, a mesh, or three-dimensional grid, is set up to account for each cube of space around the simulated aircraft. The mesh can include billions or trillions of cubes, or cells, each with calculations for velocity, density, temperature and other factors.

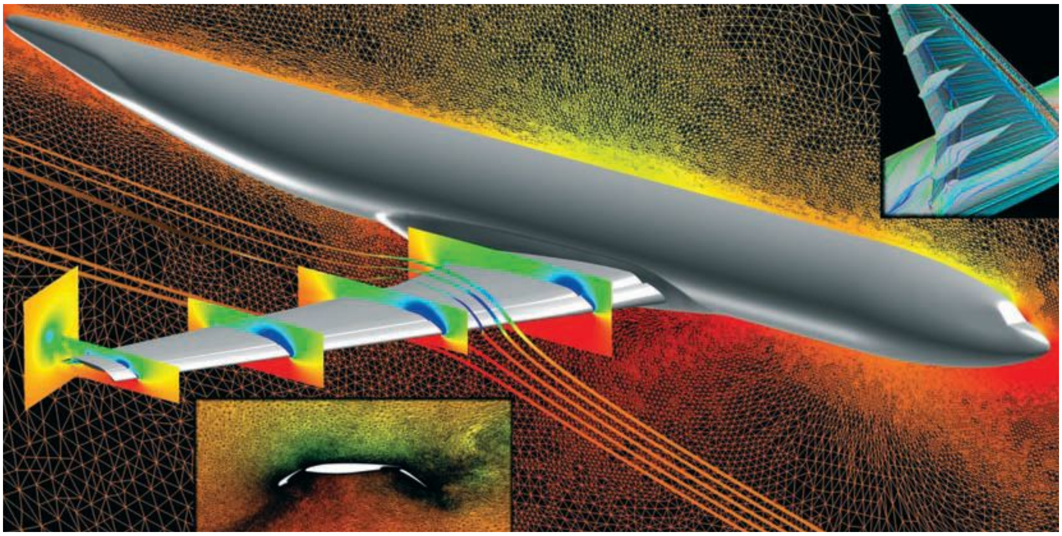
CFD calculations with today's level of computing power cannot handle the computational size of the meshes, so these mathematical models are necessary. But because the models are based on approximations, they introduce error and uncertainty into the simulation results, Alonso explains.

"We can't just rely on business as usual here. We have to do something fundamentally different to solve the problems."

— Boeing's Jeffrey Slotnick, on the future of CFD

circuitry and quantum computing bears fruit sometime after 2030. The problem, Gropp says, is that today's well-understood CFD algorithms and software will have to be rewritten or overhauled to work on massively parallel computers or quantum computers.

Some high-performance computers using massively parallel systems already have more than 1 million conventional processing cores, and within another decade some will have more than 1 billion cores, Gropp says.



The intensive calculations needed to generate this CFD visualization — a mesh adaptation simulating a transport aircraft in a high-lift configuration — were performed by a NASA high-performance computer.

NASA/Elizabeth Lee-Rausch, Michael Park

Until recently, designers of CFD tools could count on advances in computer processing cores, or chips, to run increasingly more sophisticated and larger-scale CFD models. But about eight years ago, the exponential increase in the clock speeds of computers, a measure of processing power, came to an end, explains Bill Gropp, a professor of computer science at the University of Illinois Urbana-Champaign and an author of the report.

Improvements in computing speeds in the next few years will come from massively parallel computers, in which large numbers of processing cores are combined and run in parallel. An even more revolutionary leap is expected when research on carbon-nanotube

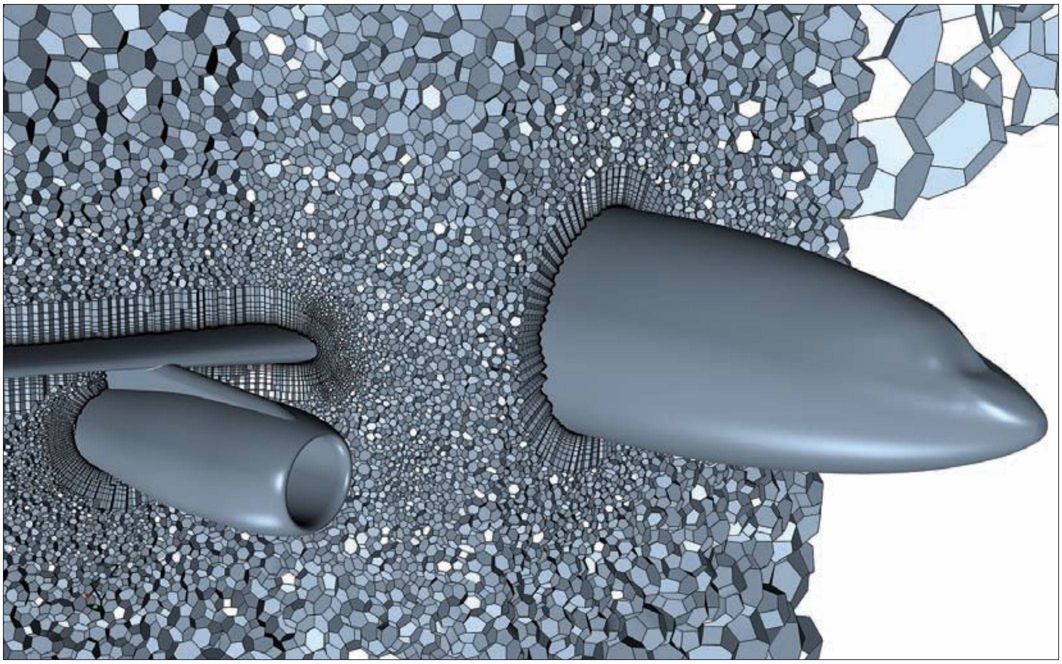
It's also not a given that the fastest computers will be available to U.S. aerodynamicists. Since 2013, China has been the home of the most powerful computer, according to the Top500 project, which ranks the world's high-performance computers. China's Tianhe-2, or Milky Way-2, can operate at a speed of 33.9 petaflops and has a theoretical peak speed of 54.9 petaflops, or roughly 550,000 times faster than a laptop computer. With recent upgrades, NASA's most powerful computer, called Pleiades, moved up the list from 21st in June to 11th in November. Pleiades has achieved 3.4 petaflops and has a theoretical peak of 4 petaflops. The only other NASA computer in the top 100 ranks 50th.

The report amounted to a figurative blowing of the whistle about the potential effect on CFD from these computing advances. "I think [the motivation for the report] was the realization within NASA that in high-performance computing, we are not doing what we should be doing," says Mujeeb Malik, technical lead for revolutionary computational aerosciences at NASA's Langley Research Center in Virginia.

Twenty years ago, NASA was a pioneer in high-performance computing. Now, the Department of Energy has the fastest U.S. computers and most of the budget — $1 billion per year — while NASA invests a tiny fraction of that in high-performance computing, Malik says. "For aviation applications, we are falling behind."

CFD and other computational simulation tools have allowed great advances since 40 years ago, when most of the analysis was done through wind-tunnel testing, Malik says. In aircraft engine development, the number of real-life tests necessary has dropped by about 75 percent. And at Langley, since 1980 NASA has closed down 20 wind tunnels, partly because of CFD advances.

CD-adapco



The rapid generation of 3-D meshes around aircraft models, a key step in the CFD process, will become even more important as more powerful computers enable higher-resolution simulations, according to a NASA report.

But even using today's best computers, simulation technologies can take a long time to work through complex problems. Malik says one of his colleagues, using 2,000 to 3,000 processing cores on Pleiades, took two to three months to run a CFD model calculating air flow around an aircraft's landing gear and the associated noise.

To improve its computing power, Malik predicts that NASA will use the capabilities of the Energy Department, but he says more investment in high-performance computing might also be needed by NASA.

Flight certification by analysis alone — meaning to accurately predict the aircraft's behavior under specific conditions — would be a key goal. "What we'd like to do, in a perfect world, is do all of the analysis up front and have that analysis be good enough for flight certification without doing any flight testing," Slotnick says. Even short of that ultimate goal, he says, improved computational modeling would mean less wind tunnel, and flight testing would be needed to earn a certification.

What really excites experts like Slotnick and Alonso is the potential of making more use of CFD in the design phase. Today, innovation is crimped by the cost and time it takes to build a physical model and test it in a wind tunnel. Designers tend to avoid getting too daring, because they don't want to have to ship the craft back to the factory for changes. The wind tunnel tests are mostly meant to confirm the design — not help designers innovate.

As Slotnick puts it, a physical wind tunnel model is supposed to be "prophetic" about the aircraft's performance. The model can't be changed — at least not easily — but CFD would give new flexibility. "If you have a computational process in place, where you can do design and morph geometry in the design process, then you can explore areas of the design that you might not have ever thought of before," he says.

Design is "a huge carrot out there, in terms of what we'll be able to do in the future," Slotnick says. "In 20 years, engineers will not simply be doing CFD analysis," he predicts. "They'll be sitting and doing high-fidelity design using computational methods and incorporating CFD into the design, almost in real time."

At stake could be NASA's ability to meet the design demands of the future. "For many, many years, we've squeezed out almost everything that is possible from the tube-and-wing configuration standard commercial aircraft," Alonso says. But developing cleaner, more fuel efficient or quieter planes will require more innovative configurations, he says.

Besides the Holy Grail of certification by CFD modeling, NASA space missions have a lot riding on CFD advancements, says Mavriplis, the University of Wyoming professor.

"A lot of those things you can't test. You basically have to do some sort of risk reduction, and then assume that the probability of something going wrong in flight is small enough," he explains. On the latest Mars mission, "the heat shield was quite a bit thicker than it needed to be, so that was extra weight/mass that could have been used for payload, if they had better confidence levels in what those rates would have been."

The U.S. commercial industry also risks falling behind Airbus and other non-U.S. competitors, Mavriplis says.

NASA/Shishir Pandya

The ability to create CFD simulations of unconventional aircraft designs, such as the D8 double bubble concept, is a challenge for aeronautical innovators.

How the collaboration will come together to make CFD advancements possible is not yet known, Slotnick says. "Informally, we're struggling with how to move forward a little bit, because the mechanism by which we can bring people together is really not in place," he says. "Trying to figure out how to build that mechanism, and what that mechanism is going to be, is the next step to address."