National Aeronautics and Space Administration

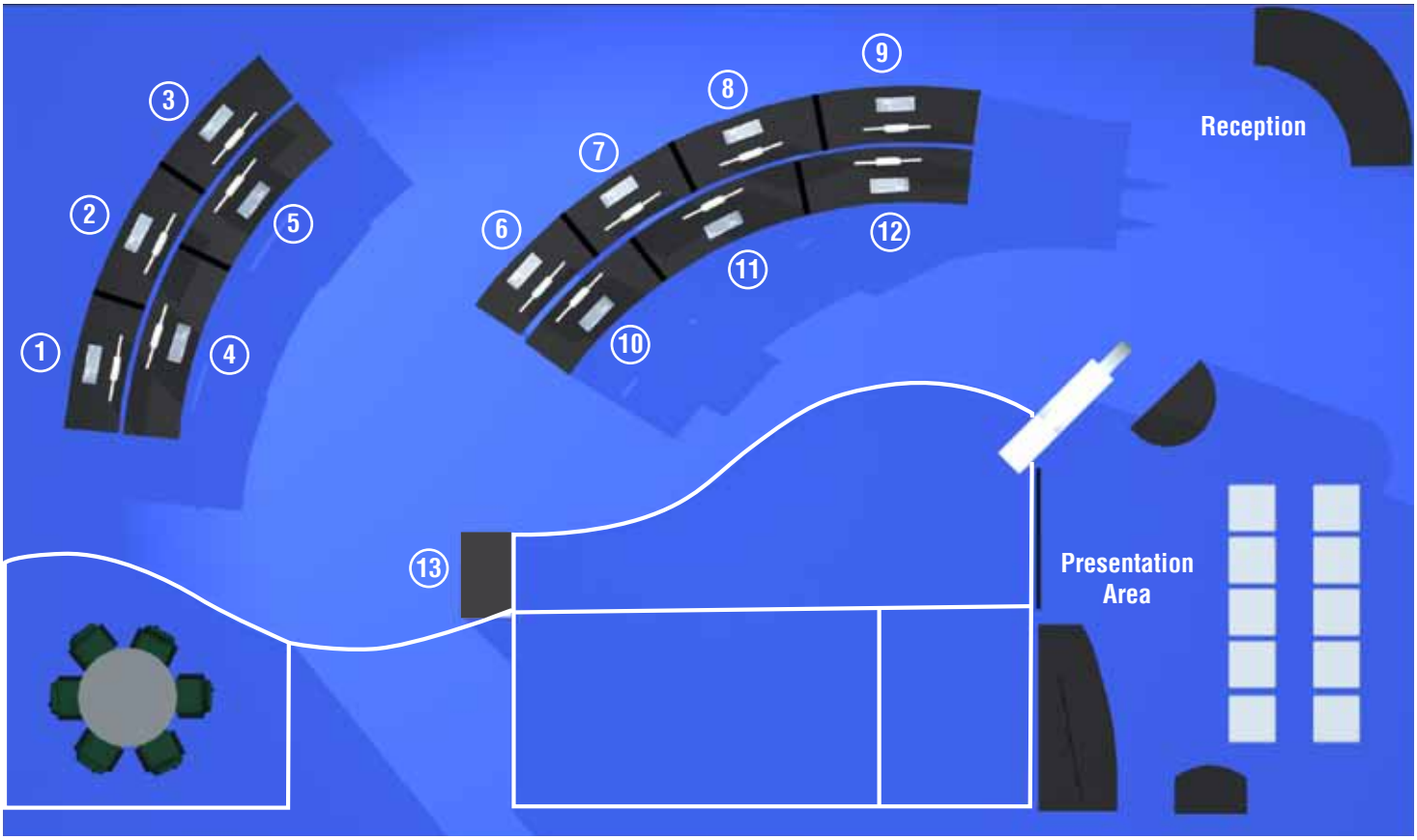


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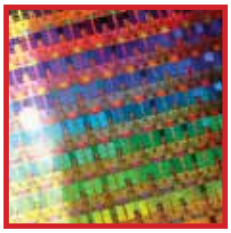
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FEATURED DEMO

Kepler: NASA's Search for Habitable Earth-Size Planets

Kepler is NASA's first mission capable of finding Earth-size and smaller planets around other stars. Launched in March 2009, the Kepler spacecraft has been continuously monitoring over 150,000 stars in the constellations of Cygnus and Lyra, watching for the periodic dimming that may indicate the presence of an exoplanet passing in front of a star.

Kepler's sole instrument is a specially designed photometer with a 0.95-meter aperture telescope. It has a very large field of view for an astronomical telescope—105 square degrees, which is comparable to the area of your hand held at arm's length. Such a large a field is needed in order to observe the enormous number of stars being monitored.

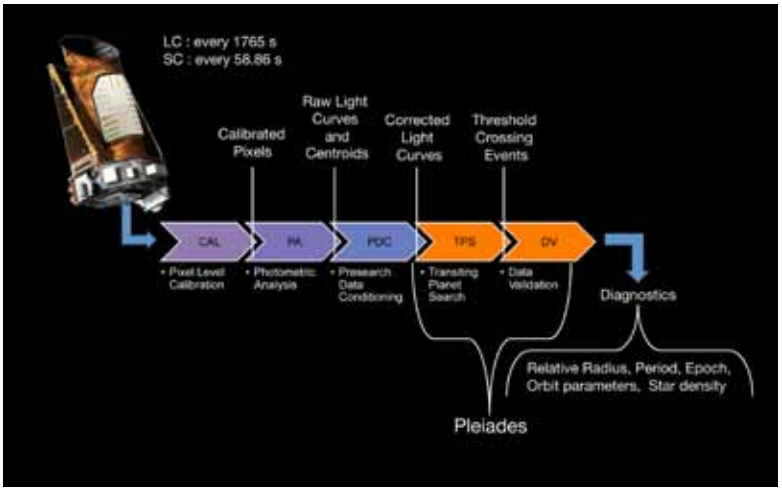


Diagram of Kepler's science data processing pipeline.

Kepler's photometer contains the largest digital camera to ever fly in space, consisting of 42 charge-coupled devices, with a total of nearly 95 megapixels. Pixels of interest are downlinked once a month and transferred to the Kepler Science Operations Center (SOC) at NASA Ames Research Center. The pixels are then calibrated, combined to form light curves, corrected for systematic errors introduced by the instrument, and then searched for the signatures of transiting planets.

As of February 2011, the Kepler team has found 1,235 planetary candidates circling 997 host stars—more than twice the number of currently known exoplanets. These results imply that some stars have more than one candidate planet. The Kepler results also included 68 planetary candidates of Earth-like size and 54 candidates in the habitable zone of their stars, leading the science team to estimate that 5.4% of stars host Earth-size planet candidates. As the mission continues, additional candidates with longer orbital periods will be found.

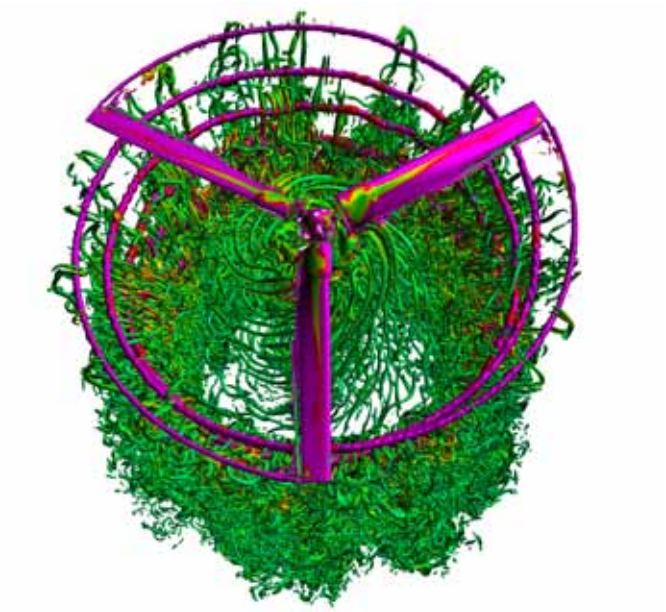
We have successfully ported the most computationally expensive portions of the Kepler "pipeline" (the transiting planet search and data validation modules) to the Pleiades supercomputer, and have demonstrated near-linear scaling up to 75,000 processors. We have also developed software that automatically copies data between the Kepler SOC and Pleiades so that we can run the less expensive computations at the SOC, while running the most expensive parts on Pleiades, in a manner that is transparent to the operators.

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FEATURED DEMO

High-Fidelity Navier-Stokes Simulation of Rotor Wakes

Helicopters and rotorcraft provide many useful civil and military functions without the need for airports and runways. However, accurately predicting aeromechanic performance and noise production for these vehicles is very challenging and requires a multi-disciplinary approach to account for rotor blade aerodynamics, blade flexibility, and blade motion for trimmed flight. Moreover, rotor blades encounter the tip vortices of other rotor blades, resulting in very complex blade-vortex interactions and vortex wake structures. NASA's Subsonic Rotary Wing Project is developing physics-based computational tools to more accurately predict these flowfields. To accomplish this, the OVERFLOW 2 Navier-Stokes computational fluid dynamics (CFD) code is loosely coupled with the CAMRAD II comprehensive code.



Navier-Stokes simulation of a V-22 Osprey rotor in hover.

Traditional comprehensive codes integrate the multi-disciplinary analyses of aerodynamics, structural response, and blade motion needed for rotorcraft simulations. However, these codes utilize a simplified, inviscid, linear aerodynamics model. CFD codes such as OVERFLOW, on the other hand, provide a higher-fidelity approach for predicting rotorcraft aerodynamics by solving the viscous, nonlinear Navier-Stokes equations. Loosely coupling the OVERFLOW 2 code with the CAMRAD II comprehensive code enables improved accuracy by replacing the linear aerodynamics model with the nonlinear Navier-Stokes equations.

The Navier-Stokes CFD approach is more accurate, but requires significantly more computational resources. Consequently, poor grid resolution, low-order spatial accuracy, and limitations of turbulence models often result in rotor vortex predictions that are weaker and more diffused than the actual physical flows. To address these challenges, several CFD improvements have been examined to improve the predictive accuracy of rotor aeromechanics. These improvements include the use of high-order spatial accuracy, adaptive mesh refinement (AMR) to efficiently improve the grid resolution of the rotor wake region, and an advanced version of the Spalart-Allmaras turbulence model based on detached eddy simulation methods.

This work enabled the figure of merit (a measure of rotor efficiency) for a hovering V-22 Osprey rotor to be accurately predicted within experimental error over a range of collective blade pitch angles for the first time, and revealed complex turbulent structures and interactions that were previously unknown. CFD simulations of the UH-60 Blackhawk helicopter rotor in forward flight provided a 50% improvement in the prediction of rotor normal forces and pitching moments. These improvements advance the state-of-the art in engineering prediction accuracy and provide new insight into rotor wakes.

These studies used 1,536 cores on NASA's Pleiades supercomputer, which enabled the completion of baseline grid solutions in less than a day and completion of AMR solutions in one week. These advancements would not have been possible without access to such high-end supercomputing resources.

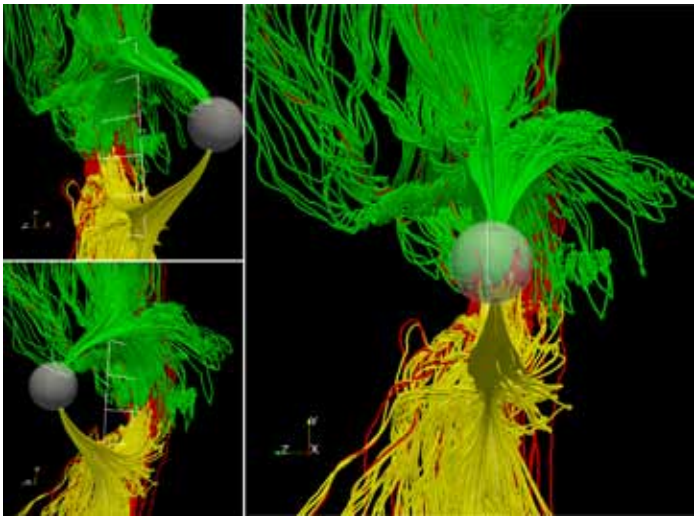
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FEATURED DEMO

Understanding the 'Crack' in Earth's Magnetosphere

Earth and other planets are engulfed in the Sun's atmosphere, which extends outward about 10 billion miles. The Earth's dipole magnetic field shields us from most of the Sun's effects and its frequent storms. However, the shielding is not perfect and, through a process called magnetic reconnection, the solar wind is able to penetrate, or "crack," Earth's magnetosphere.

This cracking, called "space weather," can affect the Earth and its technological systems, and has caused over $4 billion in satellite losses alone. Our goal is to use petascale kinetic simulations to develop a more complete understanding of the causes and conditions leading to the development of this crack in the magnetosphere.



Images from a 3D global hybrid simulation of the Earth's magnetosphere, showing the formation of large-scale magnetic flux ropes.

Modeling the kinetic magnetosphere poses a difficult computational challenge because processes occurring on the smallest (electron) scales affect the global dynamics of the magnetosphere. To address this challenge, we are pioneering the development and use of state-of the-art kinetic simulations running on massively parallel computers.

Using these simulations, we have obtained the first glimpse into the complex processes initiated on electron scales, which in turn give rise to the development of large-scale structures observed in spacecraft data. Our kinetic particle simulations are critical to understanding the space weather that results from the complex interaction between the solar wind and Earth's magnetic field. The figure above shows the discovery of electron-scale vortices that are generated under certain conditions in the magnetosphere. These vortices lead to the formation of flux ropes and play a role in transporting plasma from the solar wind into the magnetosphere.

These simulations are being used both to help guide the analysis of data from existing NASA missions, and to plan NASA's upcoming Magnetospheric Multiscale (MMS) mission. The primary goal of the MMS mission is to detect and make detailed measurements of electron-scale features in the magnetosphere that are thought to have global consequences.

NASA supercomputing resources such as Pleiades have enabled us to leapfrog existing state-of-the-art magnetospheric models. In the process, we have achieved closure on several longstanding issues related to kinetic processes operating in the magnetosphere, such as the role of certain types of waves in reconnection and the discovery of electron-scale vortices that affect the crack in the magnetosphere.

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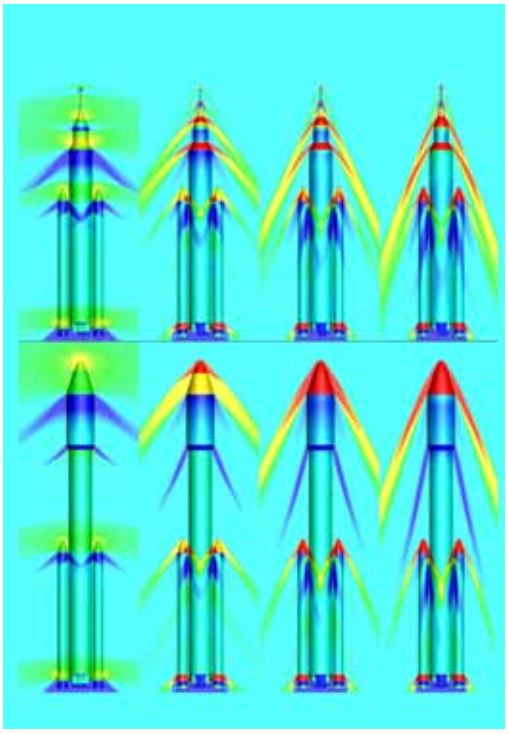
FEATURED DEMO

Modeling and Simulation Support for NASA's Space Launch System

Computational fluid dynamics (CFD) simulations are supporting the design of NASA's next generation, heavy-lift Space Launch System (SLS), which is being developed to carry large payloads for crewed exploration beyond low Earth orbit. CFD simulations of SLS ascent aerodynamics are performed to characterize the aerodynamic performance of various designs, provide aerodynamic loads for structural analysis, and estimate surface pressure signatures for acoustic analysis. Results from these analyses enable designers and engineers to optimize the vehicle's shape for better performance, and to assess the structural and acoustic loads that the vehicle will encounter during ascent.

Modeling and simulation experts are performing CFD simulations of the SLS at select points throughout the ascent trajectory. Results of the simulations are used to predict and compare the aerodynamic performance and loads of different vehicle designs. These comparisons enable the SLS design team to optimize the vehicle's shape for better performance.

CFD analyses also provide line loads and pressure signatures that engineers use to assess the structural loads and acoustics that the vehicle will encounter during ascent. CFD-generated databases of aerodynamic forces and moments also assist in the development of ascent trajectories for various mission requirements.

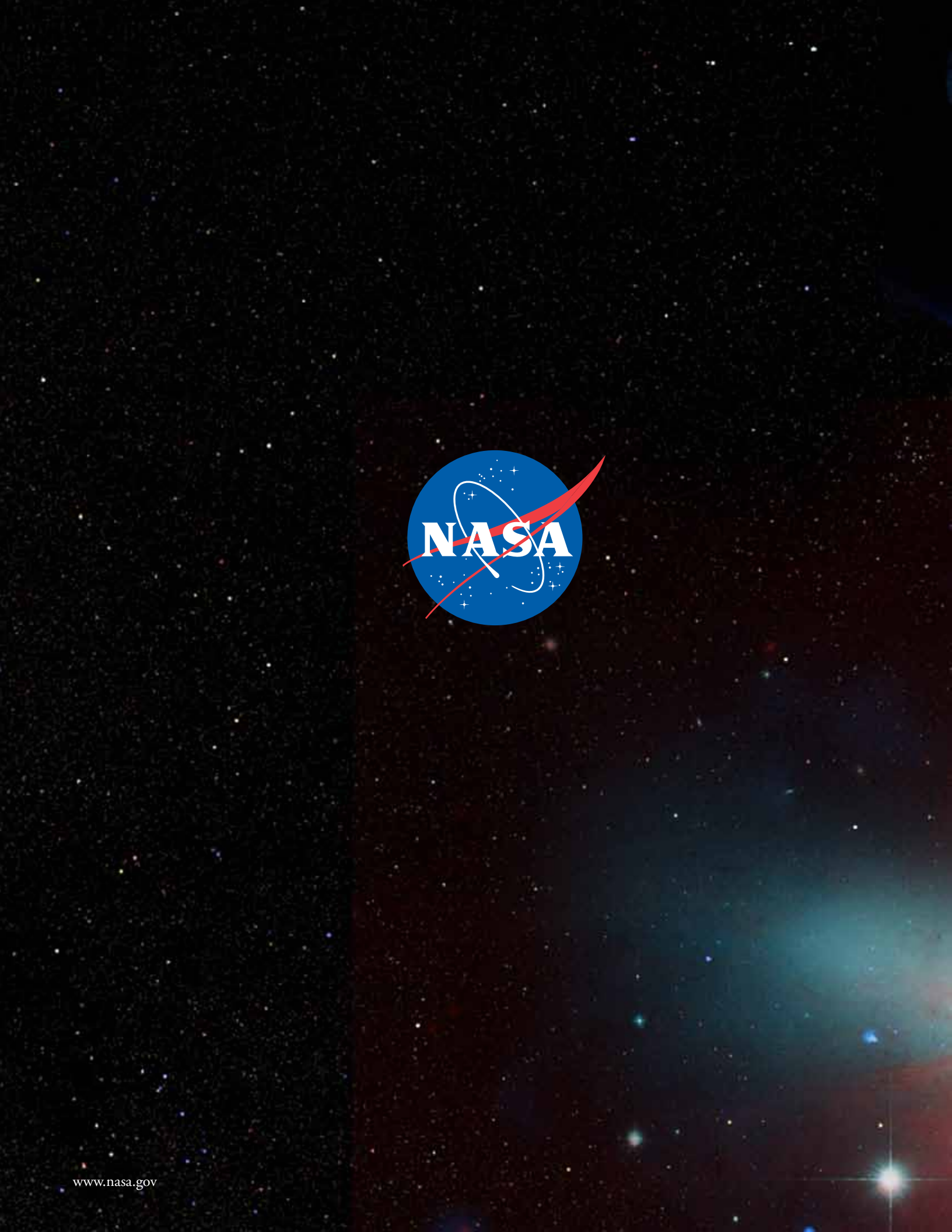


Simulations of early candidate crew and cargo launch vehicle designs at different Mach numbers during ascent.

Results from ongoing CFD simulation have been used to make critical, early design decisions for the SLS before experimental or flight data could be obtained. CFD support for SLS development will continue to advance as the vehicle design matures. Key design areas that CFD results will impact include: the outer mold line (exterior shape) of the vehicle; the type, number, and layout of rocket engine motors; and the amount of thermal protection material needed.

The NASA Advanced Supercomputing facility's high-end computing resources enable fast and efficient turnaround time for CFD simulations of the SLS. The Pleiades supercomputer allows viscous aerodynamic databases—comprised of hundreds of simulations—to be completed in under a week using 256 cores per simulation. Databases of more than 1,000 inviscid simulations, which are slightly less computationally intensive than viscous solutions, have been completed in approximately 3 days using 12 cores per simulation.

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