National Aeronautics and Space Administration

Supercomputing @ NASA: A Brief Overview

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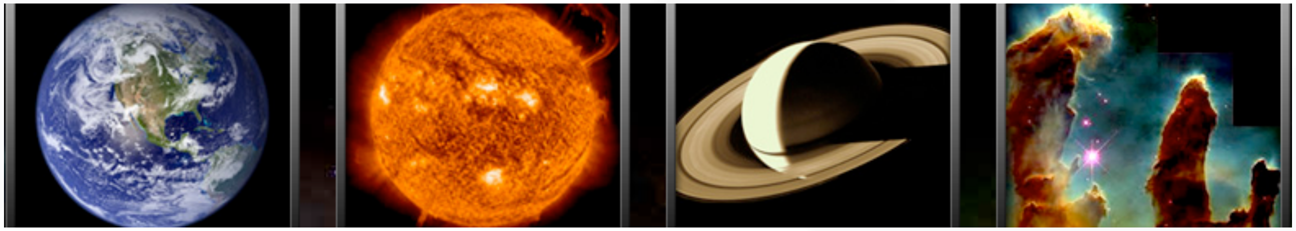
NASA Overview: Mission Directorates

- **Vision:** *To reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind*
- **Mission:** *To pioneer the future in space exploration, scientific discovery, and aeronautics research*
- **Aeronautics Research (ARMD):** Pioneer and prove new flight technologies for safer, more secure, efficient, and environmentally friendly air transportation
- **Human Exploration and Operations (HEOMD):** Focus on ISS operations; and develop new spacecraft and other capabilities for affordable, sustainable human exploration beyond low Earth orbit
- **Science (SMD):** Explore the Earth, solar system, and universe beyond; chart best route for discovery; and reap the benefits of Earth and space exploration for society



M&S Imperative for NASA R&D

Why NASA needs high-fidelity modeling & simulation

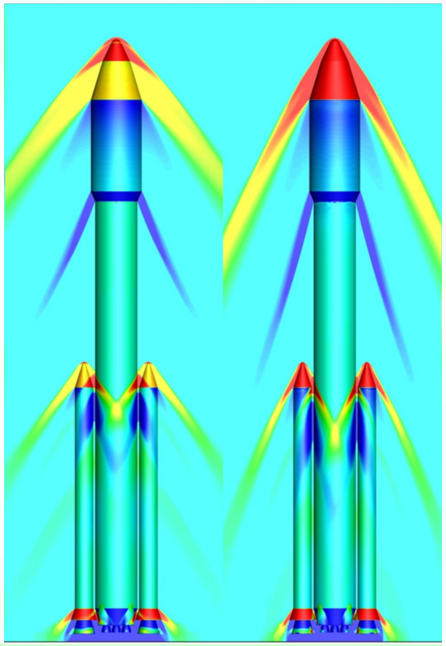
- M&S (digital experiments) and physical experiments are tradable
- Physical systems and experiments are generally expensive & dangerous (e.g., extreme environments), require long wait times, offer limited sensor data
- Decades of exponentially advancing supercomputing technology enabled dramatic improvements in cost, speed, accuracy of M&S – and provide predictive capability
- Numerous studies conclude that simulation is key to progress in science & engineering, and level of complexity is unattainable by strictly theoretical or experimental methods
- M&S provides advantage in economic competitiveness, education, health, security, science and technology, energy and environment, transportation, etc.
- Aeronautics, Earth and Space Sciences, and Space Transportation and Exploration all require orders-of-magnitude increase in M&S capability to enhance accuracy, reduce cost, mitigate risk, and accelerate R&D

M&S essential to rapidly and cost-effectively advance Agency goals

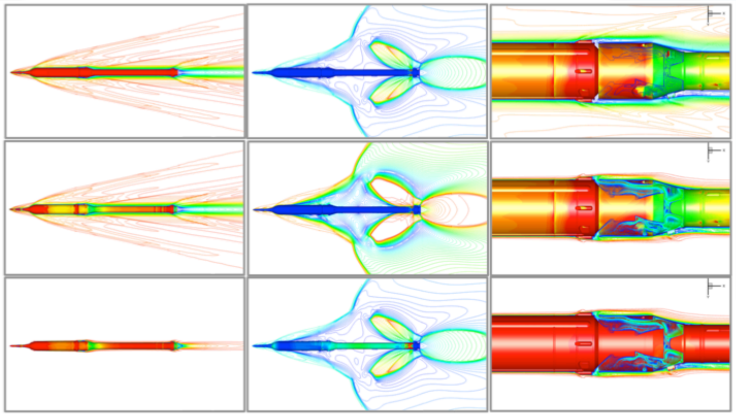
- Enabled by supercomputing technologies (hardware, software, services)

NASA's HPC Requirements: High Throughput (Capacity)

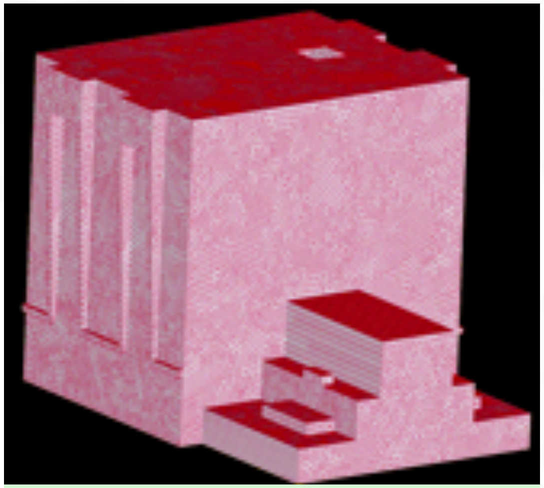
Human Exploration and Operations Mission Directorate (engineering work) usually requires HPC resources that can rapidly process large ensembles of moderate-scale computations (~2,000 cores) to explore design space



Space Launch Systems (SLS) cargo simulations



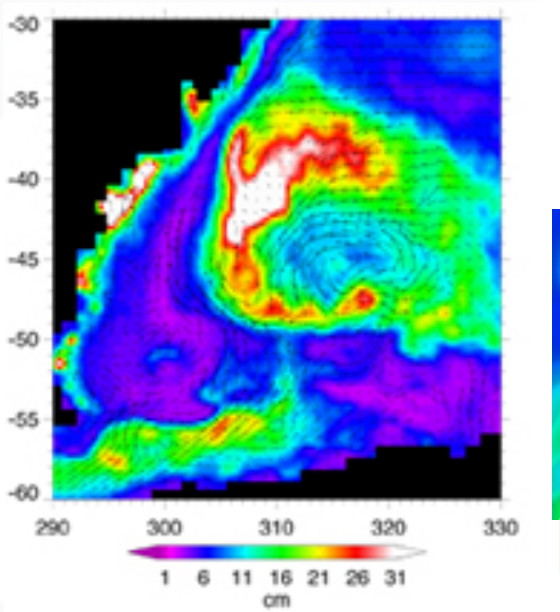
Aerodynamic and Aerothermal database generation



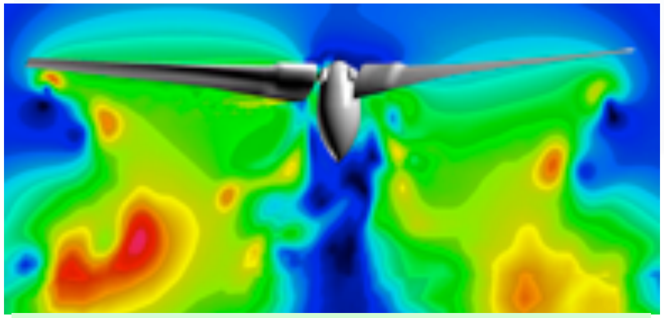
Vehicle Assembly Building (VAB) safety assessment

NASA's HPC Requirements: Leadership Scale (Capability)

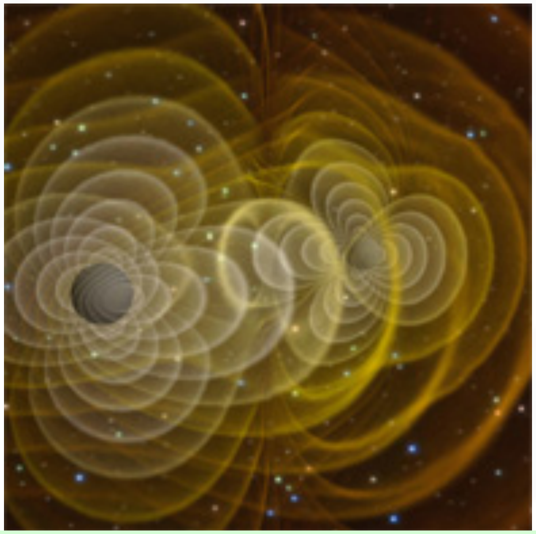
Aeronautics Research and Science Mission Directorates (scientific research) usually require HPC resources that can handle high-fidelity large-scale computations (~100,000 cores) to advance theoretical understanding



High-resolution global ocean and sea-ice data synthesis



Rotary wing aerodynamics

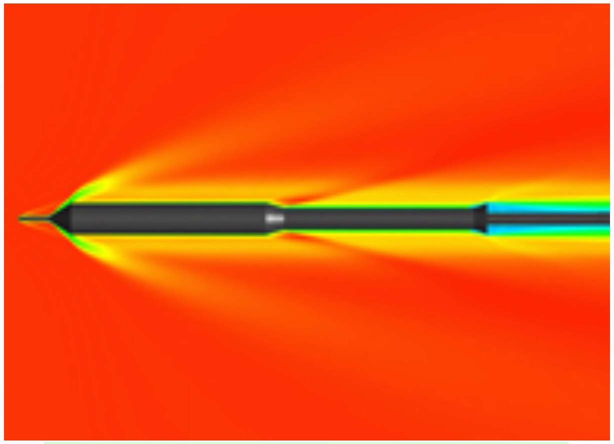


Simulating merging black holes and predicting their gravitational wave signatures

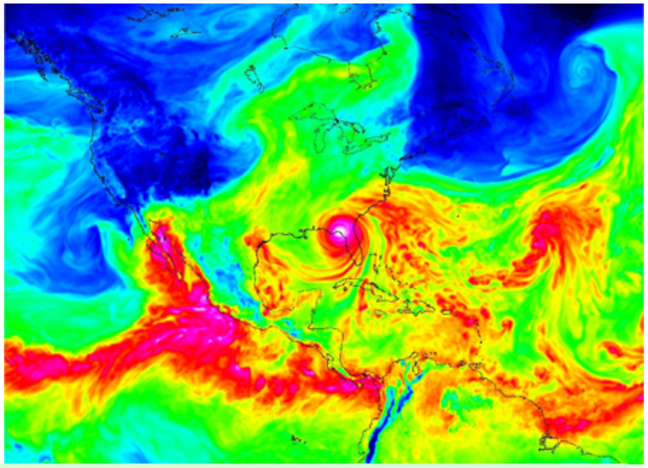
NASA's HPC Requirements: High Availability (Mission-Critical)

NASA also has significant and (sometimes) immediate need for HPC resources to solve time-sensitive mission-critical applications on demand (i.e. maintain readiness)

Protecting International Space Station (ISS) from space debris



Crew safety and risk assessment on mission abort



High-fidelity simulations for real-time hurricane prediction

High End Computing Capability

NASA HECC Project conducts work in four major technical areas

Supercomputing Systems

Provide computational power, mass storage, and user-friendly runtime environment through continuous development and deployment of management tools and systems engineering technologies

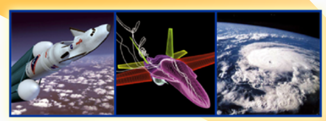
Application Performance and Productivity

Facilitate advances in science and engineering for NASA programs by enhancing user productivity and code performance of high-end computing applications of interest

HECC

Data Analysis and Visualization

Create functional data analysis and visualization software to enhance engineering decision support and scientific discovery by incorporating advanced visualization technologies and graphics displays



Networking

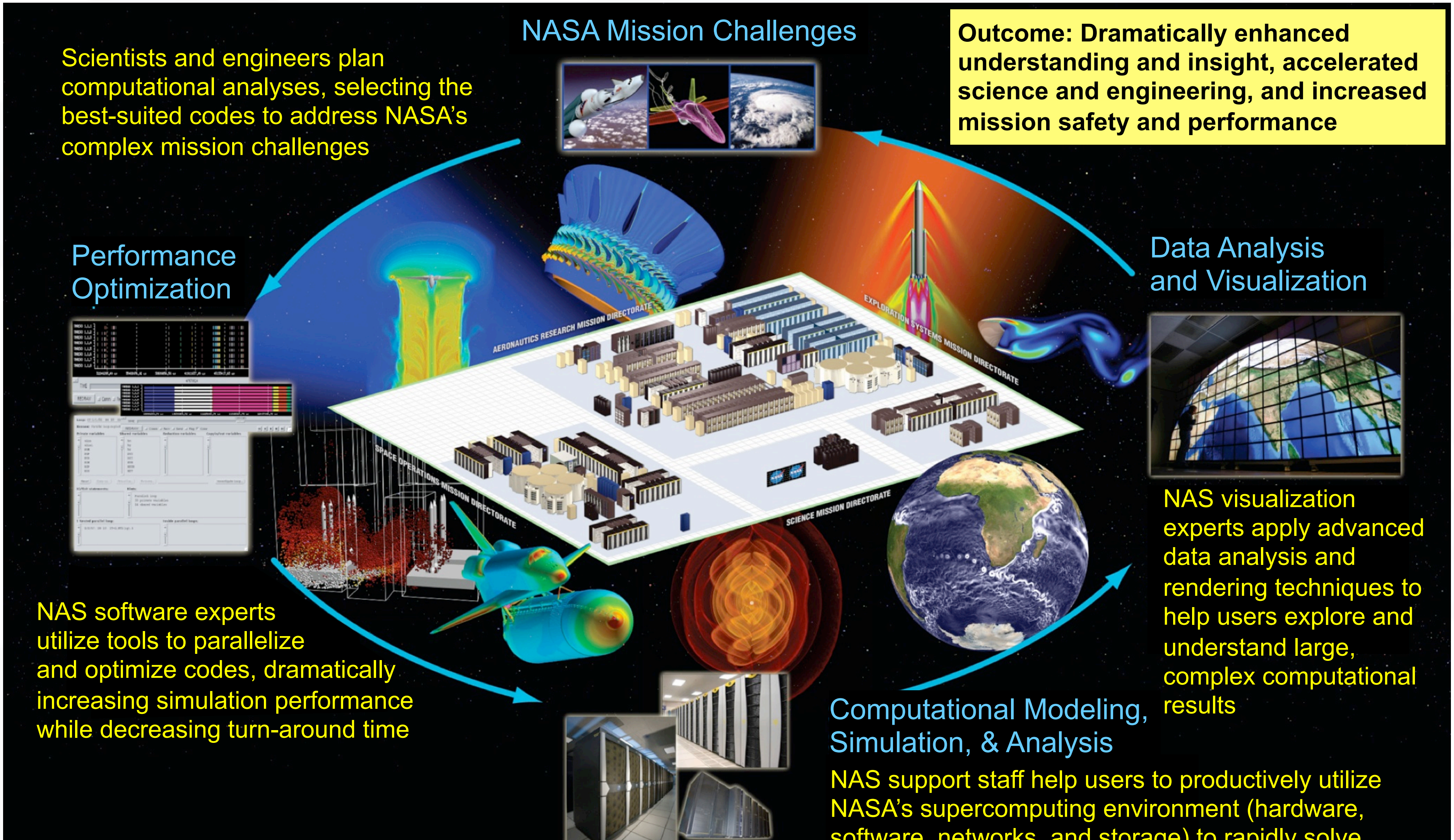
Provide end-to-end high-performance networking to meet massive modeling and simulation data distribution and access requirements of geographically dispersed users

Supporting Tasks

- Facility, Plant Engineering, and Operations: Necessary engineering and facility support to ensure the safety of HECC assets and staff
- Information Technology Security: Provide management, operation, monitoring, and safeguards to protect information and IT assets
- User Services: Account management and reporting, system monitoring and operations, first-tier 24x7 support
- Internal Operations: NAS Division activities that support and enhance the HECC Project areas

Integrated Spiral Support for M&S

Develop and deliver the most productive integrated supercomputing environment in the world, enabling NASA to extend technology, expand knowledge, and explore the universe



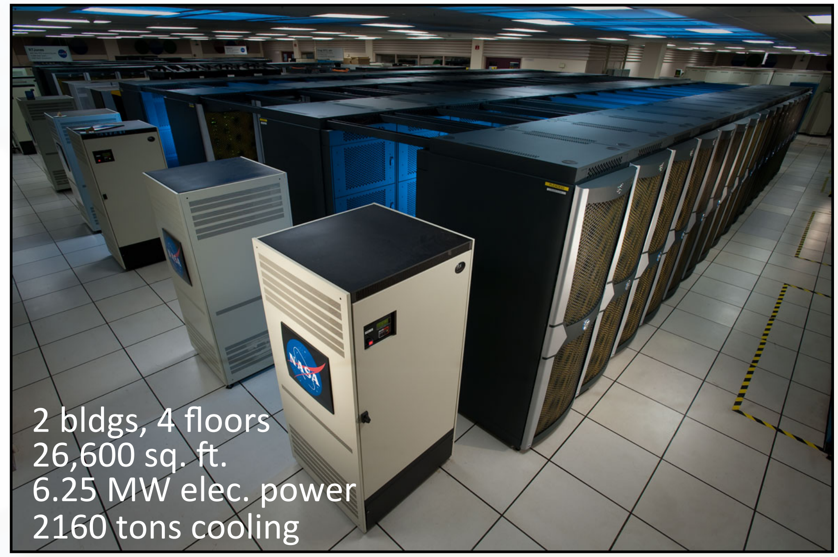
Supercomputing to Enable NASA Science and Engineering

Computing Systems

- Pleiades – 1.342 PF peak
  - 113,408-core SGI Altix ICE
  - 3 generations of Intel Xeon processors: Harpertown (4c), Nehalem (4c), Westmere (6c)
  - 186 racks, 210 TB of memory
  - Debuted as #3 on TOP500 in 11/08; now #7
  - 2 of the racks contain 64 Nvidia M2090 GPUs (41 TF, 1.5 TB)
- Columbia – 29 TF peak
  - 4,608-processor SGI Altix (Itanium2)
  - Debuted as #2 on TOP500 in 11/04
- hyperwall-2 – 146 TF peak
  - 1,024-core (Opteron), 136-node GPU cluster
  - Large-scale rendering, concurrent visualization

Balanced Environment

- Storage: 10 PB disk; 50 PB tape
  - Archiving ~1 PB/month
  - Usage growth ~1.9X/yr since 2000
- WAN: 10 Gb/s to some Centers and high-bandwidth external peering
  - Transferring 150 TB/month to distributed users

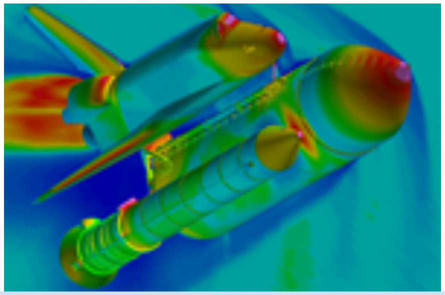


- Resources enable broad mission impact
  - MDs select projects, determine allocations
  - More than 500 science & engineering projects
  - Over 1,200 user accounts
  - Typically 300 to 500 jobs running at any instant
  - Demand for computing cycles extremely high
  - ~90 million core-hours delivered each month
- HEC demand & resources growing rapidly
  - NASA computational requirements projected to multiply by at least 4X every 3 years
  - Capacity growth ~1.8X/year since 1988

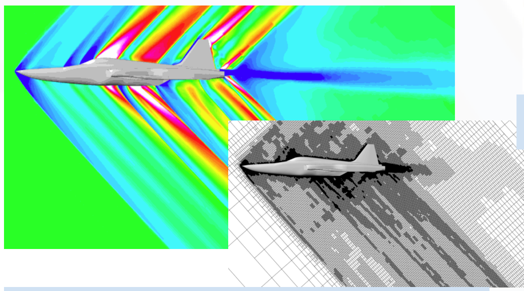
Advanced Visualization

- Supercomputer-scale visualization system to handle massive size of simulation results and increasing complexity of data analysis needs
  - 8x16 LCD tiled panel display (23 ft x 10 ft)
  - 245 million pixels
  - Debuted as #1 resolution system in world
  - In-depth data analysis and software
- Two primary modes
  - Single large high-definition image
  - Sets of related images (e.g., a parameter space of simulation results)
- High-bandwidth to HEC resources
  - *Concurrent Visualization:* Runtime data streaming allows visualization of every simulation timestep – ultimate insight into simulation code and results with no disk i/o
  - *Traditional Post-processing:* Direct read/ write access to Pleiades filesystems eliminates need for copying large datasets
- GPU-based computational acceleration R&D for appropriate NASA codes

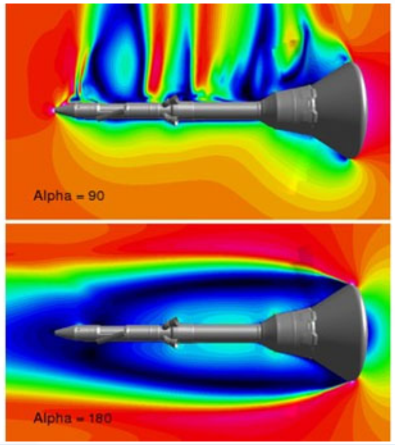
Strategic Support for NASA Programs



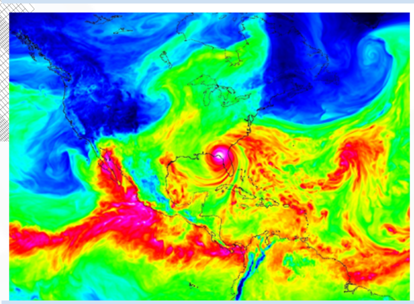
External tank redesign



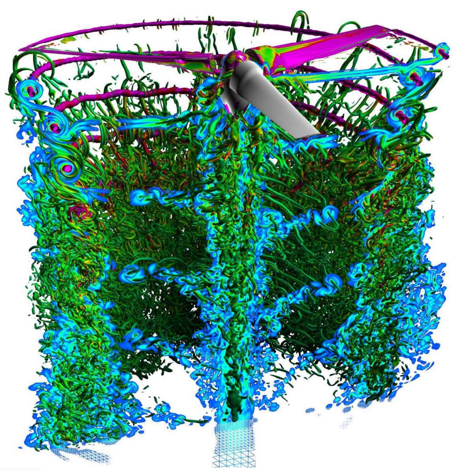
Sonic boom optimization



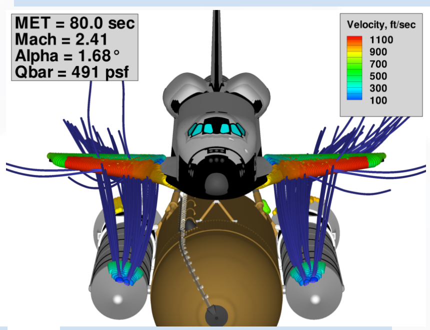
Launch abort system



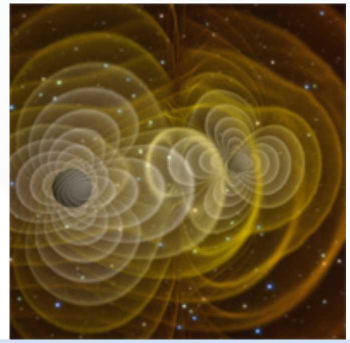
Hurricane prediction



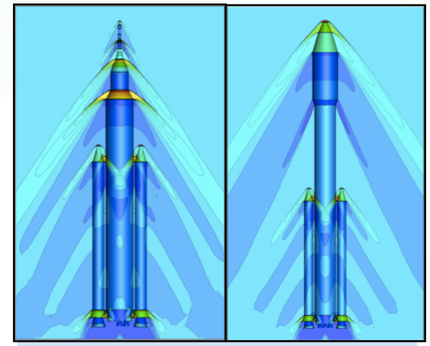
Rotary wing aerodynamics



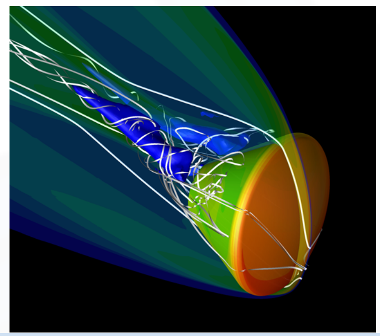
Debris transport



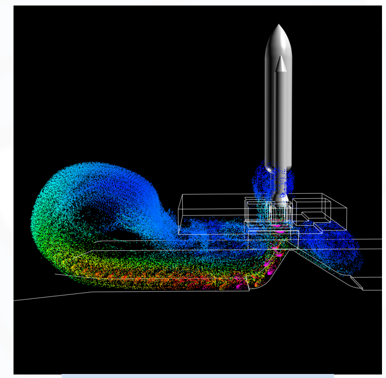
Merging black holes



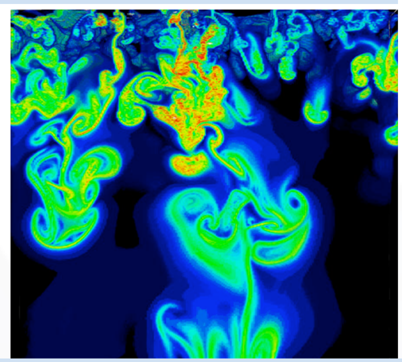
SLS vehicle designs



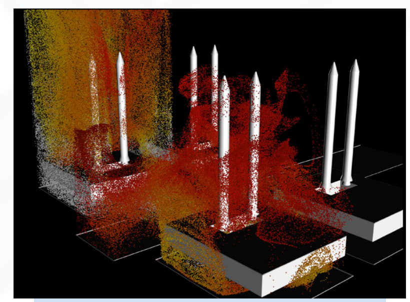
Orion/MPCV reentry



Flame trench



Solar magnetodynamics



SRB burn in VAB

Launch Pad Environment Analysis

Evaluate Shuttle Mobile Launch Platform (MLP) for next-generation launch vehicles

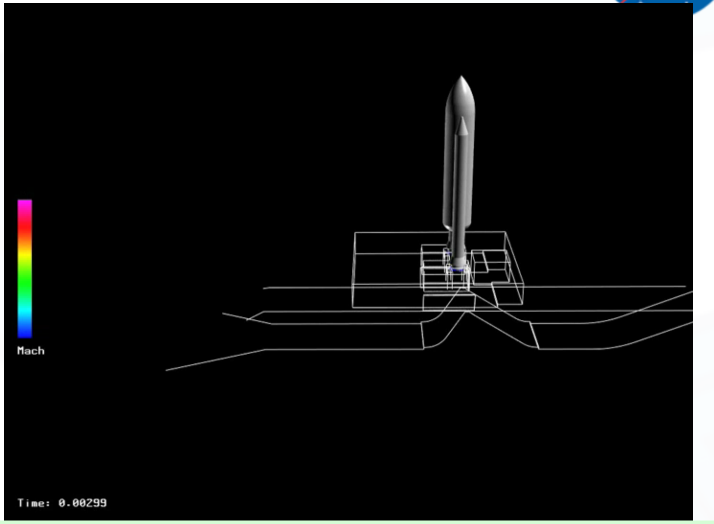
- Characterize effects of exhaust plumes and Ignition Overpressure (IOP) phenomenon of existing and new launch vehicles during liftoff
- Developed framework and demonstrated applicability (accuracy, efficiency, cost-effectiveness) of high-fidelity CFD simulation tools for launch environment and ground operations
- Generated IOP trend analyses to compare different launch pad configurations

Applications to date

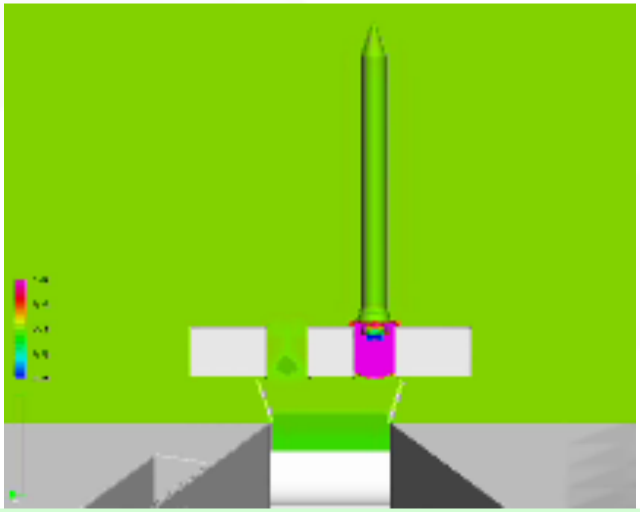
- Initial STS-1 (first Shuttle flight ever conducted) IOP analysis (no water – worst case scenario)
- Ares 1-X vehicle IOP analysis for various MLP modifications (effect on vehicle stability)
- Assessed whether Shuttle configuration needs to be modified for single-booster launch vehicle
- Results indicated that current Shuttle MLP adequate for Ares I-X flight test vehicle without expensive mods
- Accurate IOP predictions will contribute to safer missions in the future

Computational challenges

- Large-scale, complex computational grids required to model the entire launch pad infrastructure
- Time-accurate simulations to model exhaust plumes and IOP waves



Unsteady flowfield in flame trench showing particle traces colored by Mach #



Pressure contours on cutting plane through SRB and MLP in Shuttle configuration

Orion LAS Aerodynamic Database

Launch Abort System (LAS) attached to Orion to pull Crew Module away from Space Launch System during mission abort

- Simulations of LAS functionality and aerodynamics for multiple abort scenarios
- Generation of aerodynamic performance database for each major design iteration

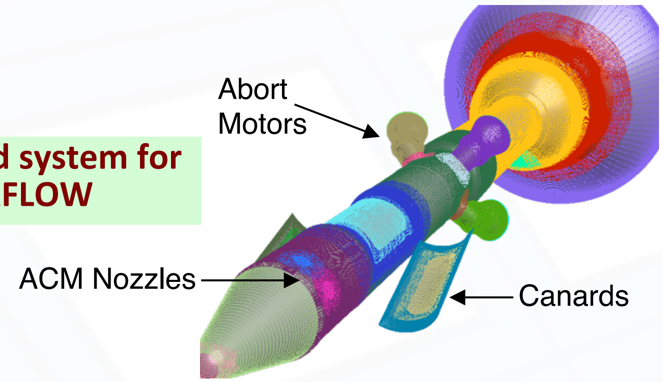
Multi-fidelity simulations of Attitude Control Motor (ACM) performance

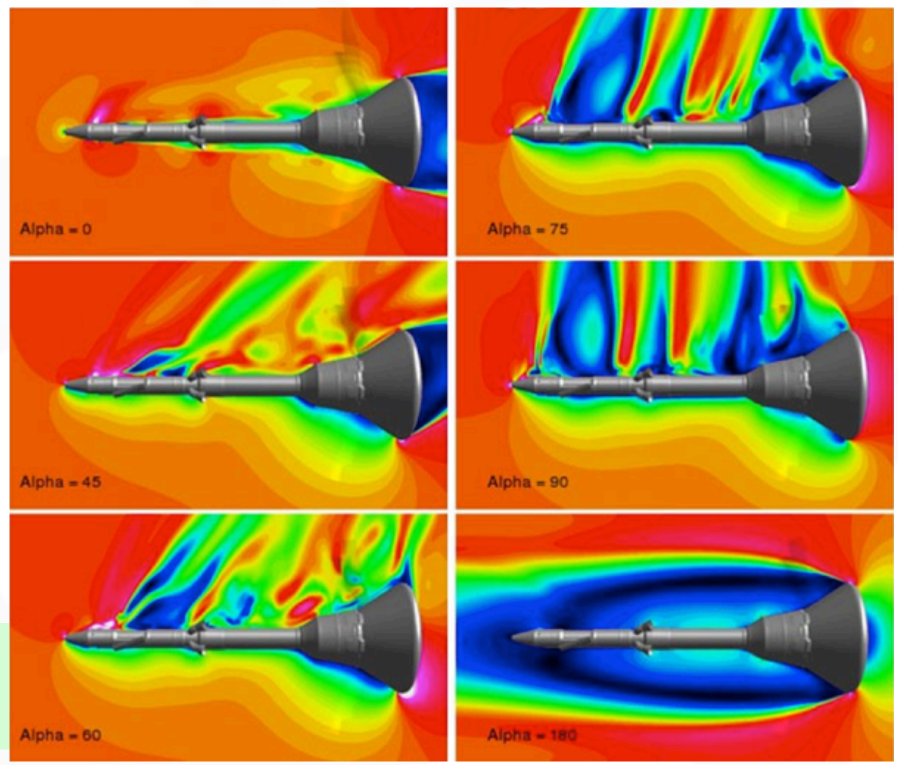
- Analysis of ACM pitch-control and jet-interaction effects for range of settings and flight configurations
- OVERFLOW (22M grid points; 1000 CPU-hours); Cart3D (7M cells; 15 CPU-hours)

High-fidelity simulations with canards deployed

- With and without ACMs firing, compute aerodynamic forces and loading during pad abort
- 35M to 46M grid points; 2000 CPU-hours

Surface grid system for OVERFLOW





Mach contours with maximum ACM power at 0-180 angles-of-attack

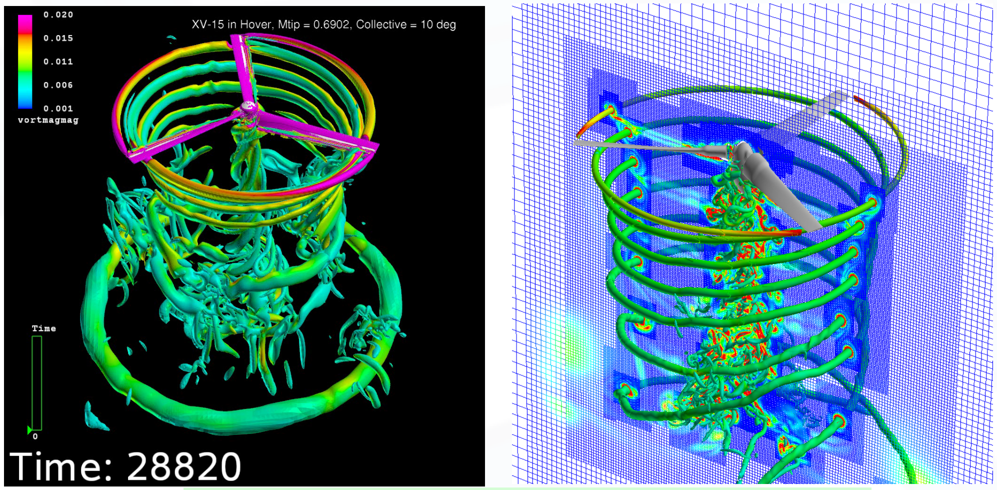
Rotorcraft Simulations

Helicopters and Tiltrotor aircraft provide many crucial services
- Emergency medical & rescue evacuation
- Heavy-lift capability
- Off-shore oil platform access
- Security patrols, military operations

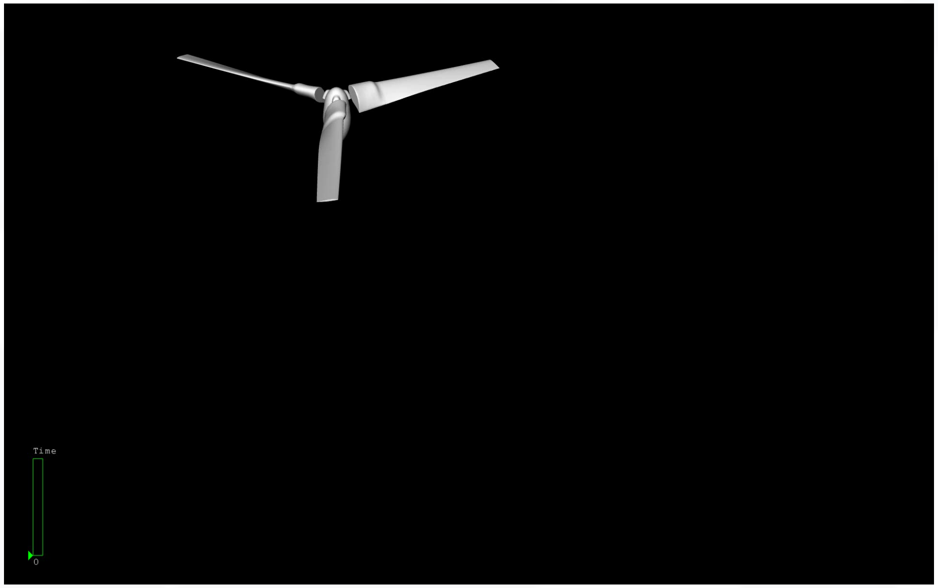
Key challenges
- Aerodynamic performance, noise
- Rotor wake, blade-vortex interactions
- Rotor blade aeroelasticity, vibration

HPC objectives
- Reduce problem set-up time via automated generation of grids and other input files
- Enhance accuracy, reduce TTS through high-order methods and automatic grid adaptation
- Improve computational performance via memory efficient scalable algorithms
- Enable scientists to "see results live" by integrating visualization software directly into CFD / CSD codes

One of the largest-ever RANS aeronautics computation to date
- 3.09B grid-point result produced using OVERFLOW-2 running on 16,384 cores



XV15 wake vortex structure in hover

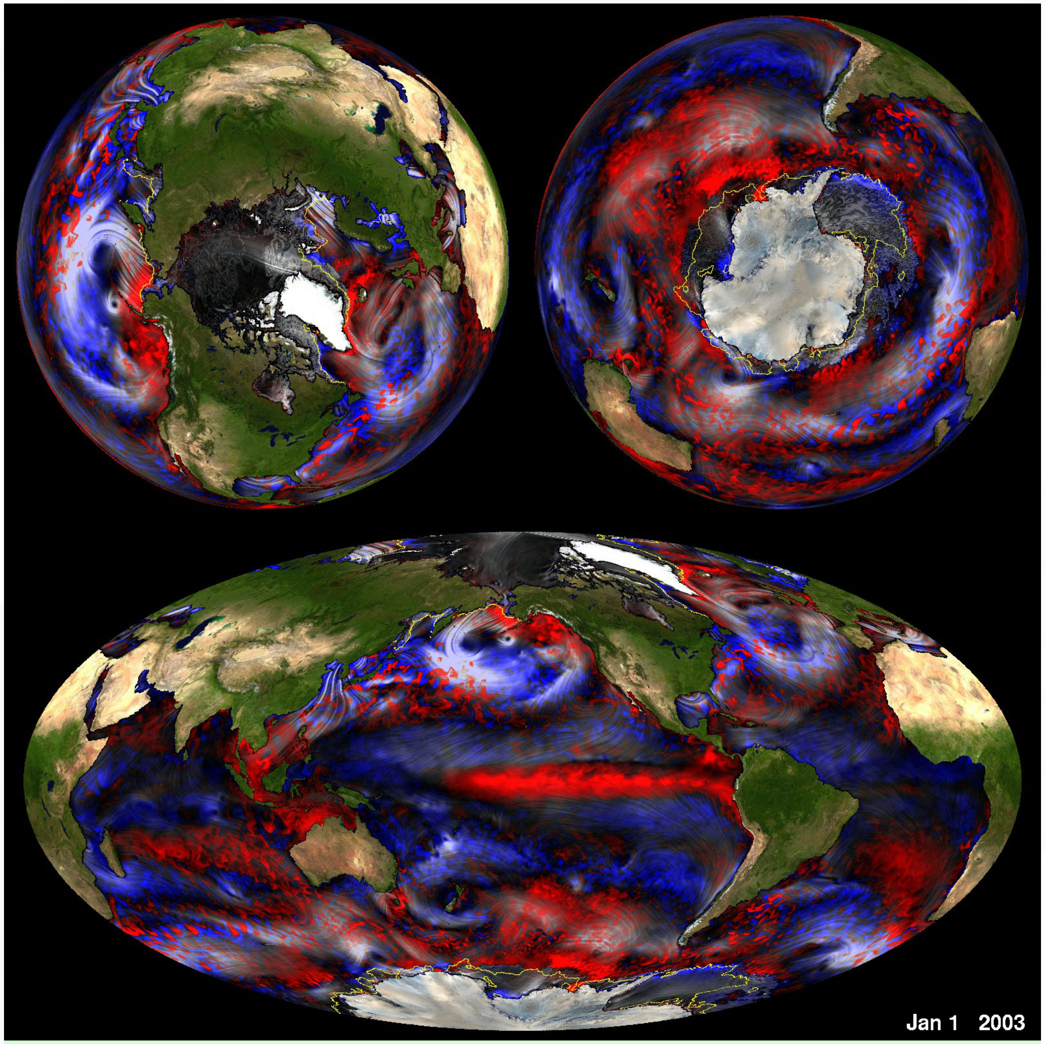


V22 in forward flight

Climate Modeling

Accurately monitoring evolving state of ocean & sea-ice establishes better understanding of the future climate of our planet

- More energy in top few meters of ocean than in entire atmosphere
- Ultra-high-resolution numerical simulation using MITgcm code
- Non-hydrostatic formulation enables code to simulate phenomena over range of scales
- Fluid isomorphism allows one hydrodynamical kernel to simulate flow in atmosphere & ocean
- Coupling models (atmosphere, ocean, land, ice, biosphere) are key to full understanding
- Advanced algorithms and powerful supercomputers enable coupled global models at high resolution, enabling discovery and insight



Deviation of ocean temperature over a 5-year period using observed wind field as forcing function

Kepler Mission Data Analysis

Kepler space telescope

– Designed to find Earth-size planets in the habitable zone of sun-like stars, it has already discovered five new exoplanets

Current HECC effort

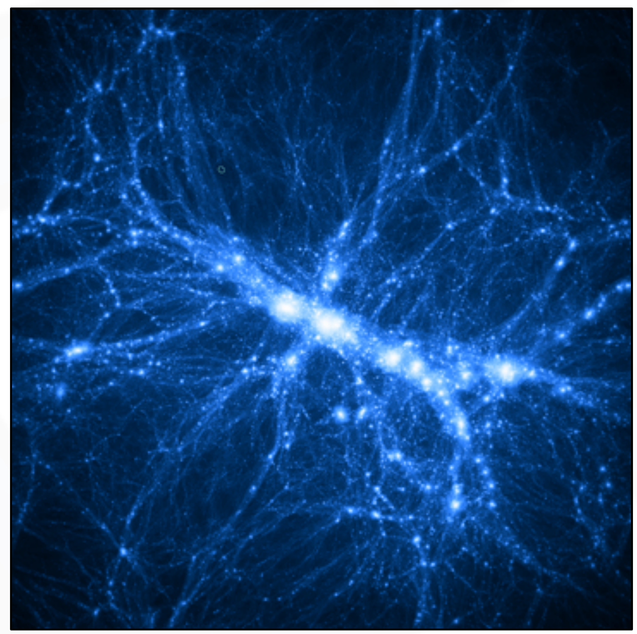
– Ran two complex Transiting Planet Search (TPS) analyses of full sky-group (83 out of 84 CCD channels) multi-quarter Kepler data, ~180K stars on 74,272 Pleiades cores in under 40 mins

– Achieved the first fully-automated end-to-end run of the Data Validation (DV) analysis module

– Enabled Kepler team to calculate large datasets that were previously infeasible and impacting specific mission milestones

– Optimizing Blender code (part of the Kepler Science Operations Center used to confirm planet candidates) to run on Pleiades and improve I/O performance

– Created custom software tools for data analysis and visualization



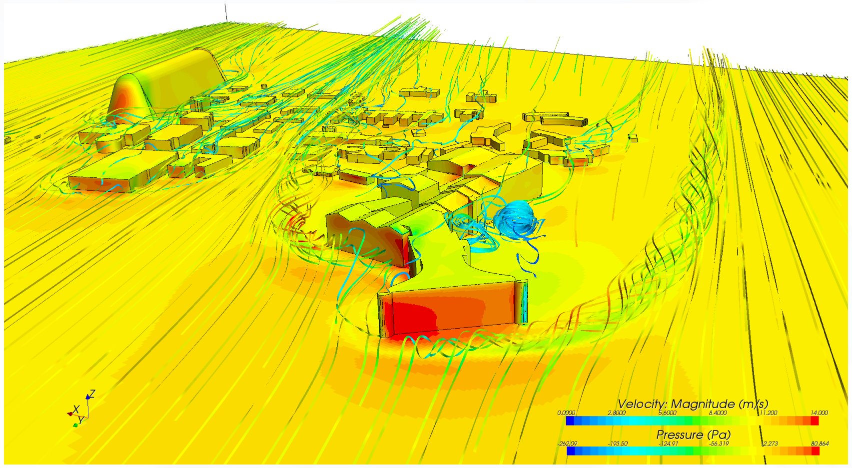
NASA Sustainability Base

"Greenest" Federal building ever

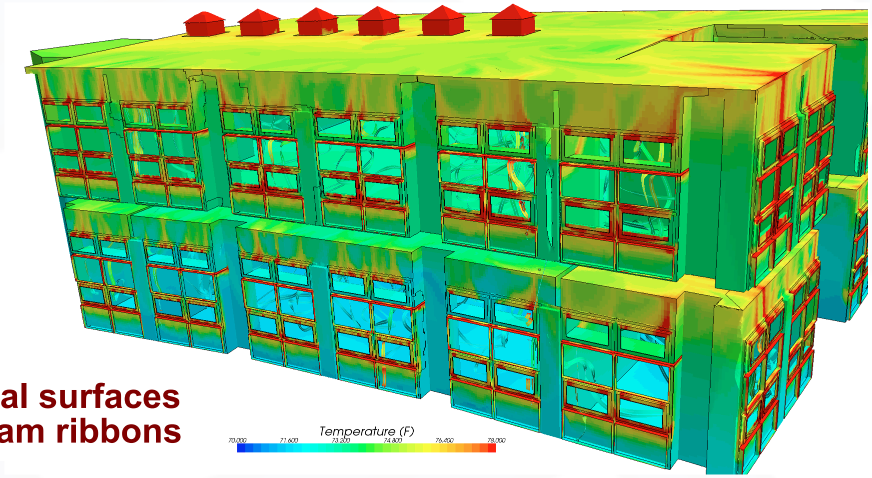
- Dynamic experimental high-performance building designed to incorporate new energy-efficient technologies as they evolve
- Anticipates and reacts to environmental and usage changes, and optimizes performance

CFD simulations

- Model seasonal wind fields in vicinity by considering all major Ames structures
- CFD results coupled with active controls database will correlate conditions at specific building locations to weather measurements and determine how to properly heat & cool
- Simulations show complex flows at Sustainability Base, mostly caused by sheltering from upstream buildings
- Inside-building simulations show expected circulation patterns: hot air rises next to windows, propagates into interior along ceiling, plunges to floor due to cooling panels, and returns to windows near floor



Stream ribbons colored by velocity magnitude; building & ground colored by relative pressure



Temperature on internal surfaces including internal stream ribbons

Thank you!

Questions?