UNITED STATES
AIR FORCE
ACADEMY

An Overview of Hypersonic Research Capabilities at the US Air Force Academy

Russell M. Cummings
Professor of Aeronautics
Director, DoD HPCMP HVSI

AERONAUTICS

US Air Force Academy

USAFA At A Glance

Undergraduate-only university with 4,000 students

UNITED STATES AIR FORCE ACADEMY

QUICK FACTS

66	1,164	32	27	52k
Years of Academy Tradition	Cadets Admitted to the Class of 2024	Academic Majors	Division I Athletics Teams	Commissioned Second Lieutenants

- 41 Rhodes scholars
- 10 Marshall scholars
- 13 Truman scholars
- 75 NSF fellows
- 37 Hertz fellows
- 39 Astronauts

Research at a Glance

Current as of 30 June 2020

27 Research Centers and Institutes

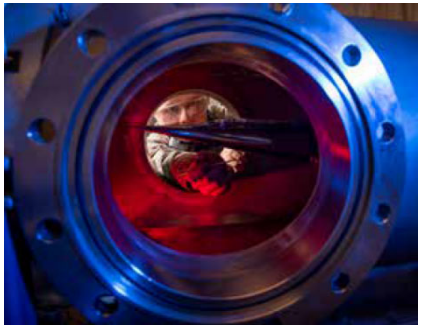
450+ cadets in Cadet Summer Research Program (CSRP)

129 active Cooperative Research and Development Agreements (CRADAs)

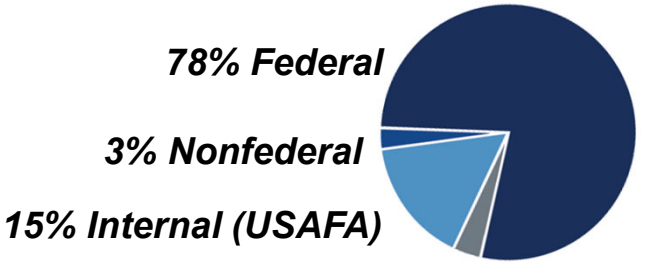
12 recent patents*

995 recent research publications*

146k PreK-12 students, **900** teachers impacted in STEM Outreach program



$40M+ Annual Budget



Our success in future conflicts relies on agile minds and creative thinking

Lt Gen Jay Silveria, USAFA Superintendent

**2018-2020*

Research Centers & Institutes

AIR
- Aeronautics Research Center (ARC)
- Center for Aircraft Structural Life Extension (CAStLE)
- Hypersonic Vehicle Simulation Institute (HVSI)

SPACE
- Astronautical Research Group & Observatory (ARGO)
- Center for Space Situation Awareness Research (CSSAR)
- Laser & Optics Research Center (LORC)
- Space Systems Research Center (SSRC)
- Space Physics & Atmospheric Research Center (SPARC)

CYBER
- Academy Center for Cyberspace Research (ACCR)
- Air Force CyberWorx – ACC*
- High Performance Computing Research Center (HPCRC)
- Institute for Information Technology Applications (IITA)

READINESS
- Center for Physics Education Research (CPER)
- Eisenhower Center for Space & Defense Studies
- Human Performance Lab
- Office of Labor Economics Analysis (OLEA) – HAF/A1*
- Scholarship of Teaching & Learning (SoTL)

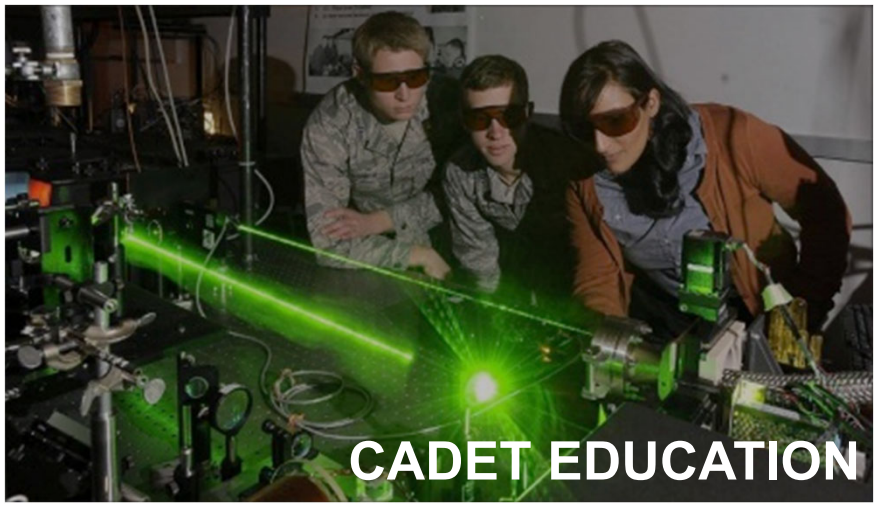
STRATEGIC STUDIES
- Center for Airpower Studies (CAPS)
- Institute for Future Conflict (IFC)
- Institute for National Security Studies (INSS)
- Nuclear Enterprise Research Center (NERC)

WARFIGHTER SUPPORT
- Academy Center for Unmanned Aerial Systems Research Center (ACUASR)
- Center for Character & Leadership Development (CCLD)
- Chemistry Research Center (CRC)
- Life Sciences Research Center (LSRC)
- Warfighter Edge (WEdge) – SOCOM*
- Warfighter Effectiveness Research Center (WERC)

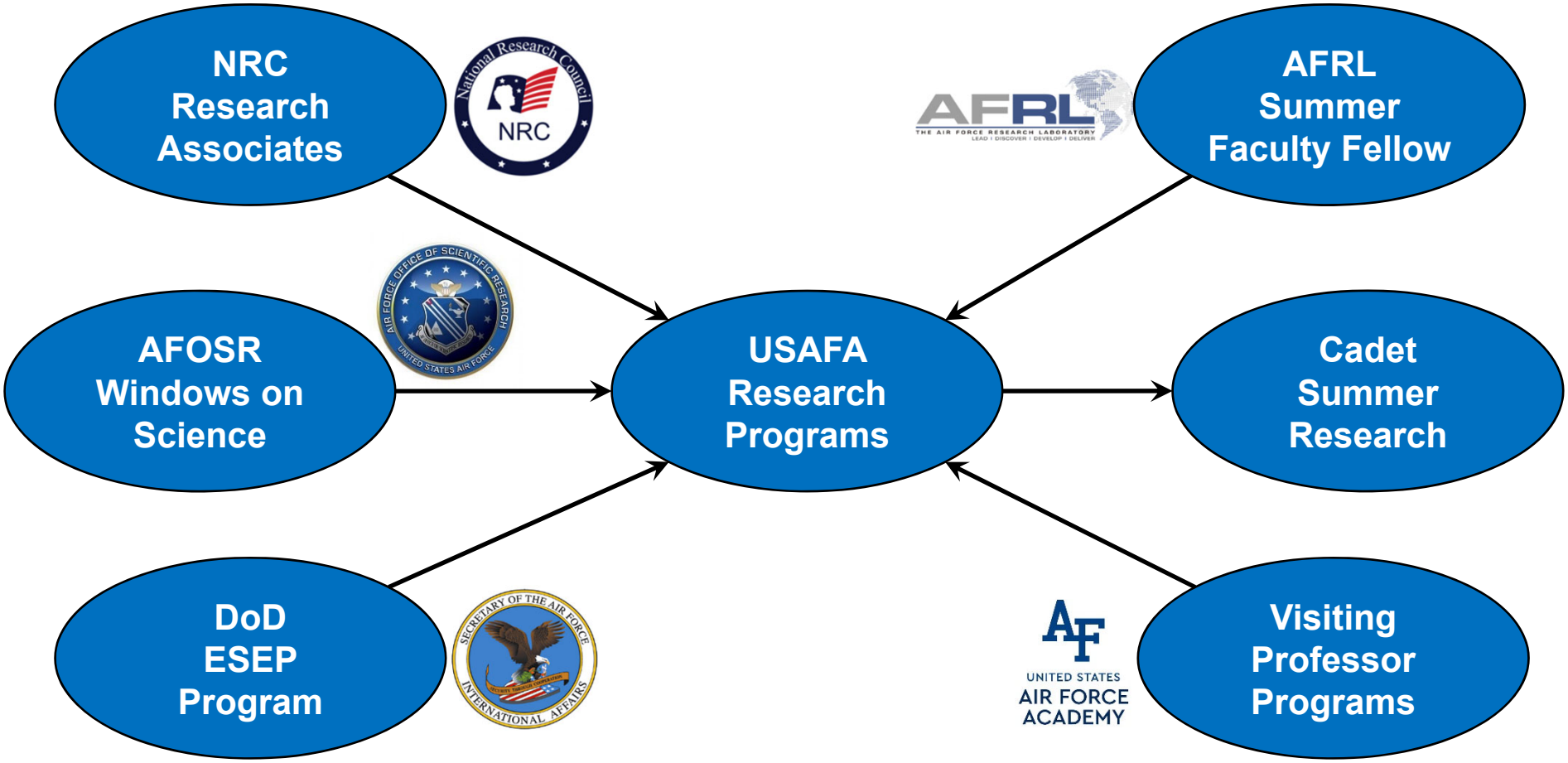
**Denotes external centers residing at USAFA – Sponsor*

AERONAUTICS

Why Research at USAFA?



How Research at USAFA?



Hypersonic Research at USAFA

- Aeronautics Research Center
- High Performance Computing Research Center
- DoD HPCMP Hypersonic Vehicle Simulation Institute
- Applied Mechanics Laboratory
- Rocket Launch Facility
- Space Physics and Atmospheric Research Center
- Microwave Measurements Laboratory
- Chemistry Research Center
- Institute for Future Conflict

Aeronautics Research Center

- **High speed facilities include:**
  - **Mach 6 Ludwieg Tube**
  - **Tri-Sonic Wind Tunnel**
  - **Combustion Shock Tube**
  - **Engine Test Cells**

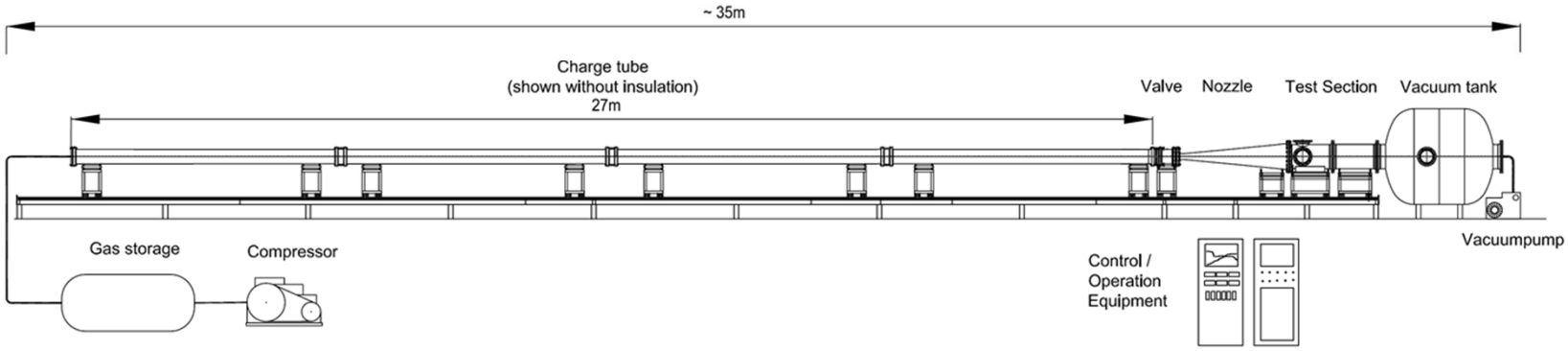
50,000 ft^2 facility including wind/water tunnels from low speed to hypersonic speeds, shock tube, engine test cells, motion-based flight simulators, fabrication shop and Cadet workshop; UAS airstrip also on base

Aeronautics Laboratory

Mach 6 Ludwieg Tube

- DURIP-funded
- Built by Hyperschall und Strömungstechnik (HST) GmbH in 2012
- Sister tunnel at TU Braunschweig

Property	Value
Mach number	Mach = 6, stable within 2%
Test gas	Air, dry
Charge tube pressure	Up to 40 bar
Temperature	Up to 400°C
Reynolds number	$Re_{max} \sim 30 \times 10^6$ m^{-1}
Run time	> 100 ms
Valve opening time	< 15 ms
Test section size	0.5 m diameter
Model size	Blunt objects with 200 mm diameter

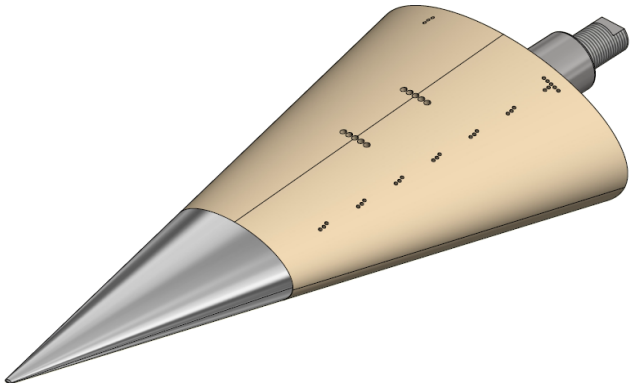


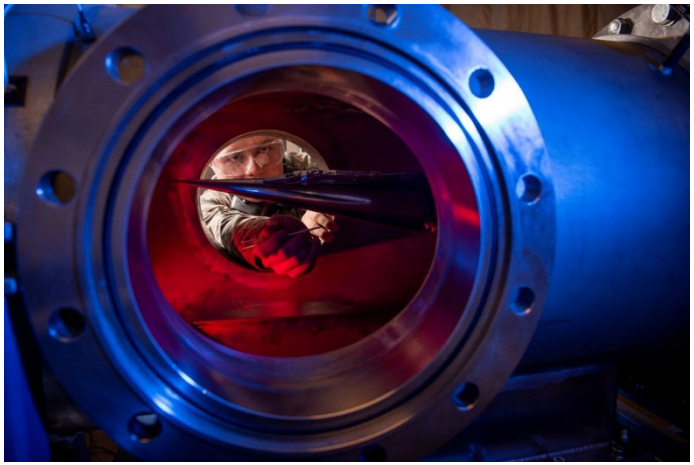
Mach 6 Ludwieg Tube

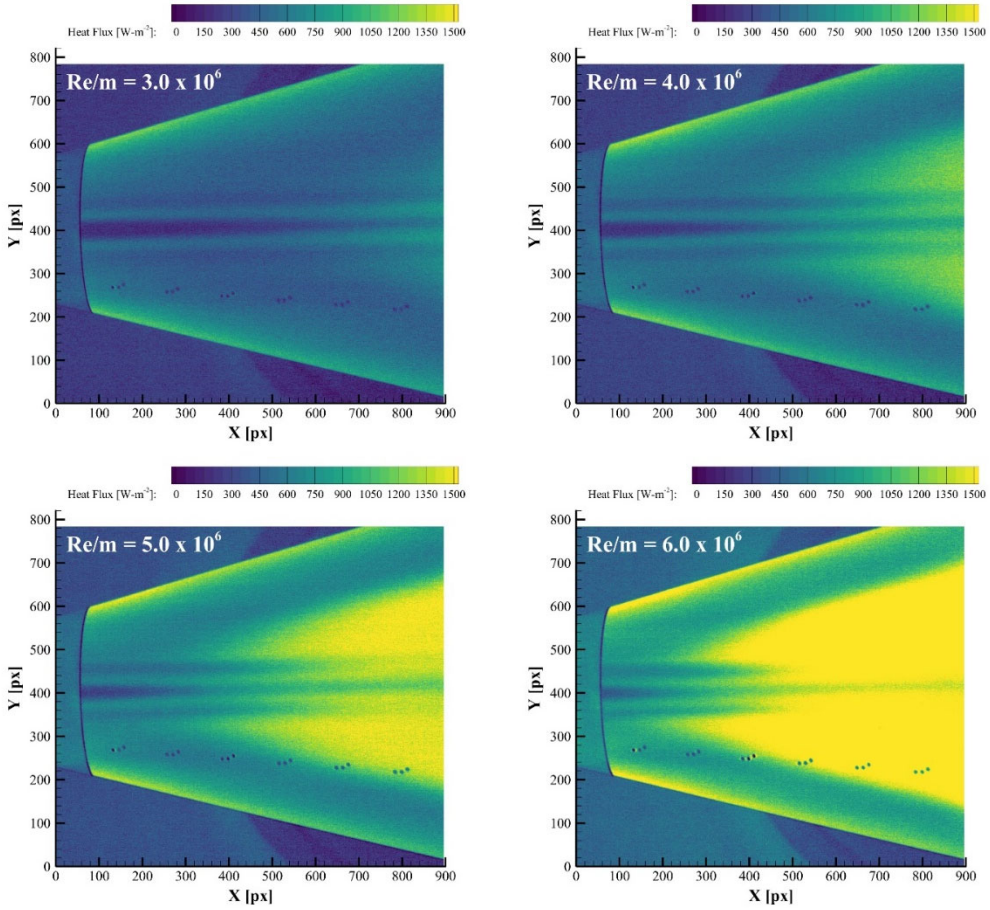
- Data acquisition includes:
  - Focused Schlieren flow visualization
  - 16 high-speed (2 MS/second) independent data acquisition channels for high speed pressure or temperature measurements
  - 16 channels of preamplifier gain ranging from ×1 to ×1000
  - FLIR SC8303 high-speed infrared camera

Mach 6 Ludwieg Tube

Heat Flux vs Unit Reynolds Number on HIFiRE-5 Model

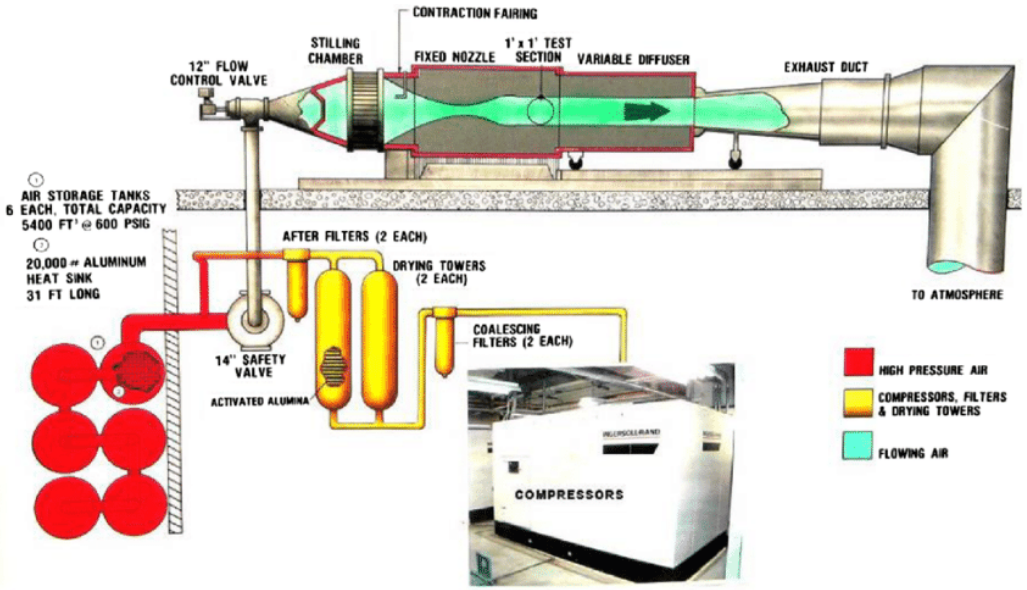






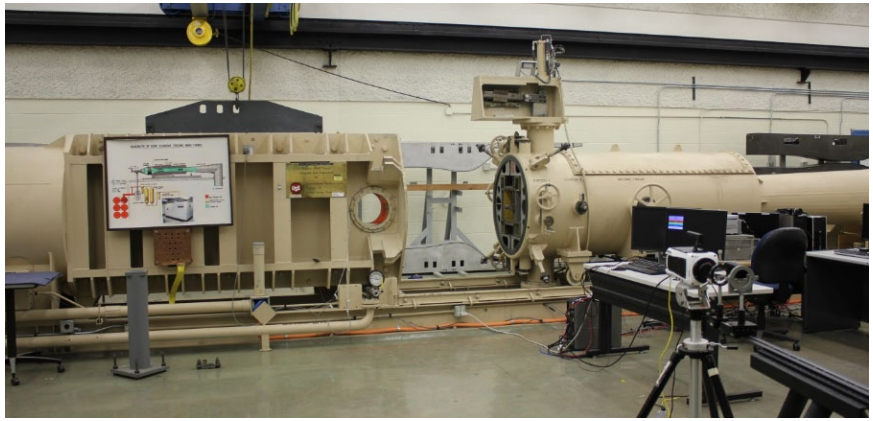
Tri-Sonic Wind Tunnel

- Blowdown wind tunnel with 1ft by 1ft test section
- Discrete supersonic Mach numbers between 1.7 and 4.5 (also subsonic and transonic conditions available)
- Test duration up to 2 minutes (depending on test conditions)



Tri-Sonic Wind Tunnel

- Data acquisition includes:
  - Schlieren flow visualization
  - force and moment measurement mounted on an automatic angle of attack sweep mechanism
  - surface pressures and temperatures
- Example projects include:
  - scale model of a United Launch Alliance (ULA) Atlas V Launch Vehicle
  - methods to control the flight of conical boost-glide vehicle

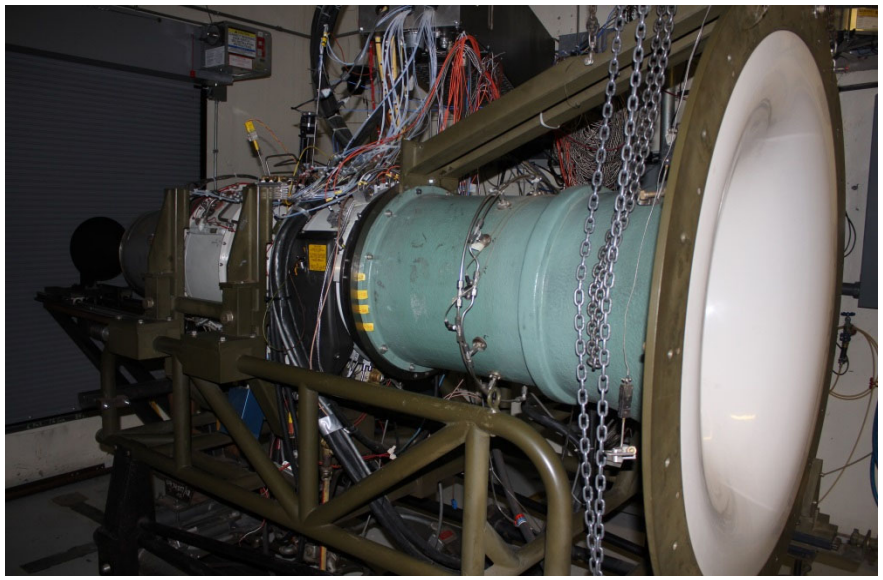


Combustion Shock Tube

- New $1M combustion shock tube with shock characterization and optical combustion diagnostics
- Capable of reaching pressures up to 60 atm
- External mixing tank and heated driven section which allows for testing liquid fuels
- Helium-Neon laser for fuel quantification, CO2 laser for ethylene quantification, photodiodes for OH* and CH* chemiluminescence sensing for ignition delay data

Engine Test Cells

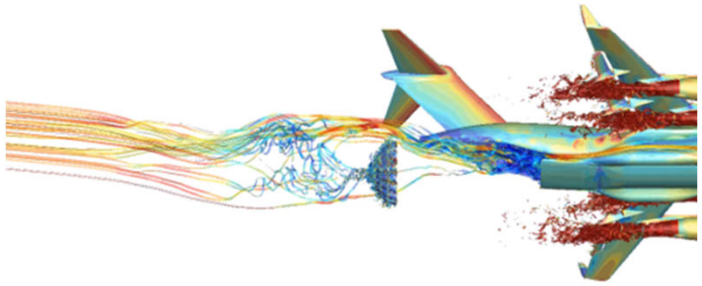
- Four hardened engine test cells
- Can handle engines with up to 8,000 pounds of thrust
- Data acquisition includes:
  - 64 thermocouples, 26 pressure transducers, fuel flow and thrust, sampled via Scanivalve DSA 3217 pressure scanners and a DTS 3250 with 64 channels of input for temperature measurements
- Example projects include:
  - Boom Technology's XB-1 engine
  - engine inlet distortion and swirl testing
  - development of hybrid propulsion system
  - development of unique propulsion concepts



F109 Turbofan Engine

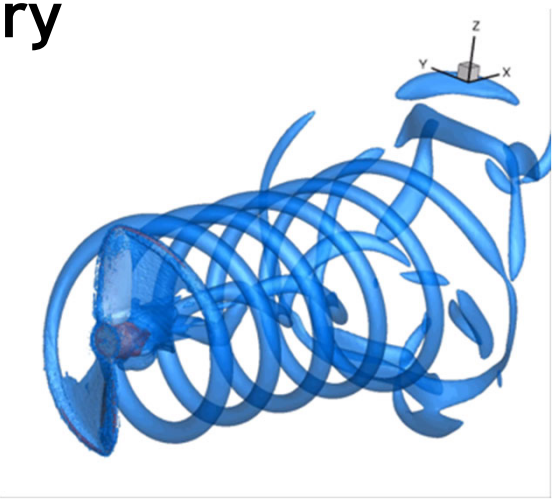
High Speed Computing Research Center

- Mission of HPCRC
  - Increase the use of HPC resources by USAFA faculty, staff, and cadets in education and research
  - Extend the use of computer-based modeling and simulation across all USAFA research centers
  - Develop methods to efficiently and effectively deliver HPC services
  - Maintain excellence in computational fluid dynamics modeling and simulations



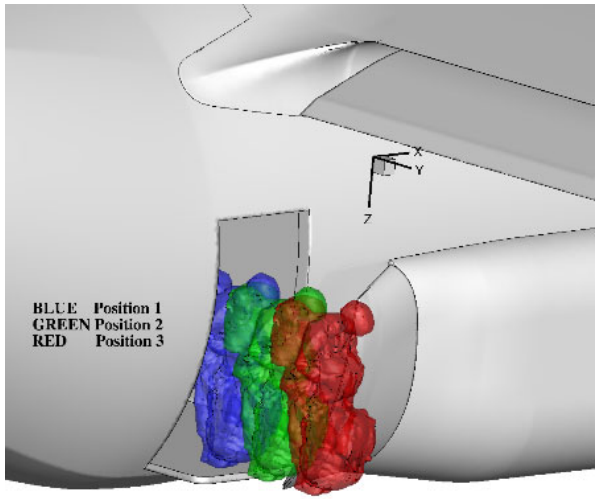
High Speed Computing Research Center

- Systems and networking
  - Defense Engineering Research Network (DREN) CORE access
  - Collaboration with other universities, service academies, and resources within DoD, DoE, and NASA
  - DoD HPCMP innovation initiatives
  - Local HPC clusters
- Computational fluid dynamics laboratory
  - Simulation capabilities
    - Fluid-structure interaction
    - Complex unsteady flows
    - High-speed gas dynamics
    - Reduced-order modeling (ROM) and physics based digital engineering (PBDE)
    - Mesh generation



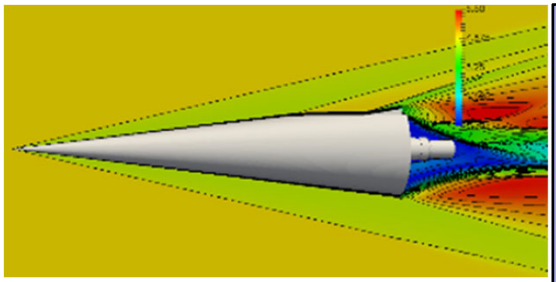
High Speed Computing Research Center

- Computational fluid dynamics laboratory, contd.
  - Development capabilities
    - Collaborator status with HPCMP CREATE™-AV/*Kestrel*
      - DoD fixed wing aircraft code
      - Source code access
      - Evaluate turbulence models for hypersonic flows
      - Feedback flow control implementation
    - Loci/CHEM
      - Mississippi State University
      - Source code access
      - Fluid-structure interaction implementation
      - Fluid-thermo-structure interaction
  - Reduced order modeling—physics based digital engineering
    - Surrogate modeling for aircraft stability and control



Aero-Thermo-Elastic Study of Hypersonic Flow Around Cone

Description



High supersonic and hypersonic flow around cone with elastic flap tested at Sandia National Laboratory

Mach number M=5 and M=8
Elastic and thermo-elastic problem

Objectives

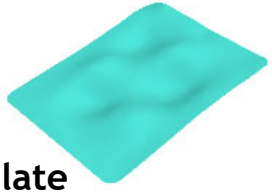
- Development and validation of computational aero-elastic and aero-thermo-elastic capabilities for hypersonic flows
- Assess capability of state-of-the-art coupling methods
- Compare to experimental data

Approach

- Use aero-elastic and aero-thermo-elastic coupling in CFD simulations
- Extract unsteady pressures and unsteady temperatures for comparison to wind tunnel data
- Compare modal coordinates and heat transfer to wind tunnel data

Outcomes

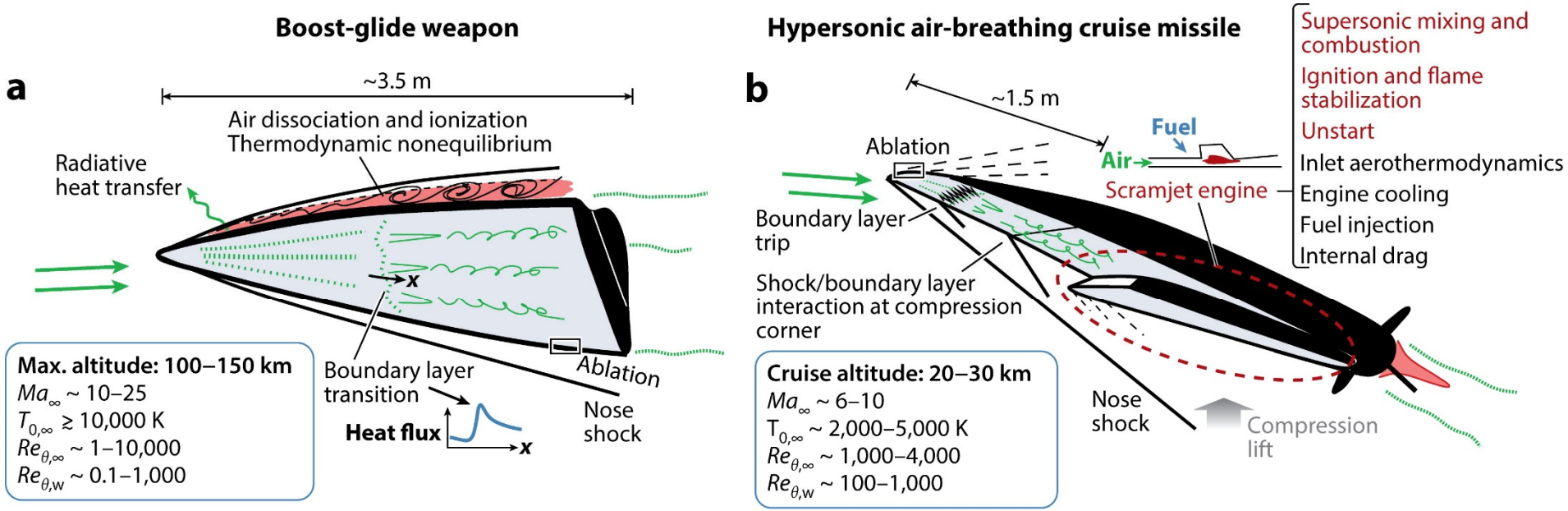
- Create meshes
- Extract and project elastic modes onto CFD surface mesh
- Run steady rigid analysis
- Run unsteady rigid analysis
- Preliminary runs with elastic plate



Structural mode projected onto CFD surface

DoD HPCMP Hypersonic Vehicle Simulation Institute (HVSI)

HVSI Mission: To measurably improve the simulation of hypersonic vehicles



Urzay J. 2018.
Annu. Rev. Fluid Mech. 50:593–627

DoD High Performance Computing Modernization Program (HPCMP)

A DoD-wide program and national asset providing high performance computing capabilities and expertise to solve DoD's most critical

DoD Services & Agencies

- Army
- Navy
- Air Force
- DTRA
- MDA
- DARPA

Major Functions

- Science and Technology
- Test and Evaluation
- Acquisition Engineering

Hardware + Network + Software

DoD Supercomputing Resource Centers (DSRCs)

- U.S. Air Force Research Laboratory DSRC
- U.S. Army Research Laboratory DSRC
- U.S. Army Engineer Research and Development Center DSRC
- Maui High Performance Computing Center DSRC
- U.S. Navy DSRC

Networking and Security

Defense Research & Engineering Network (DREN)

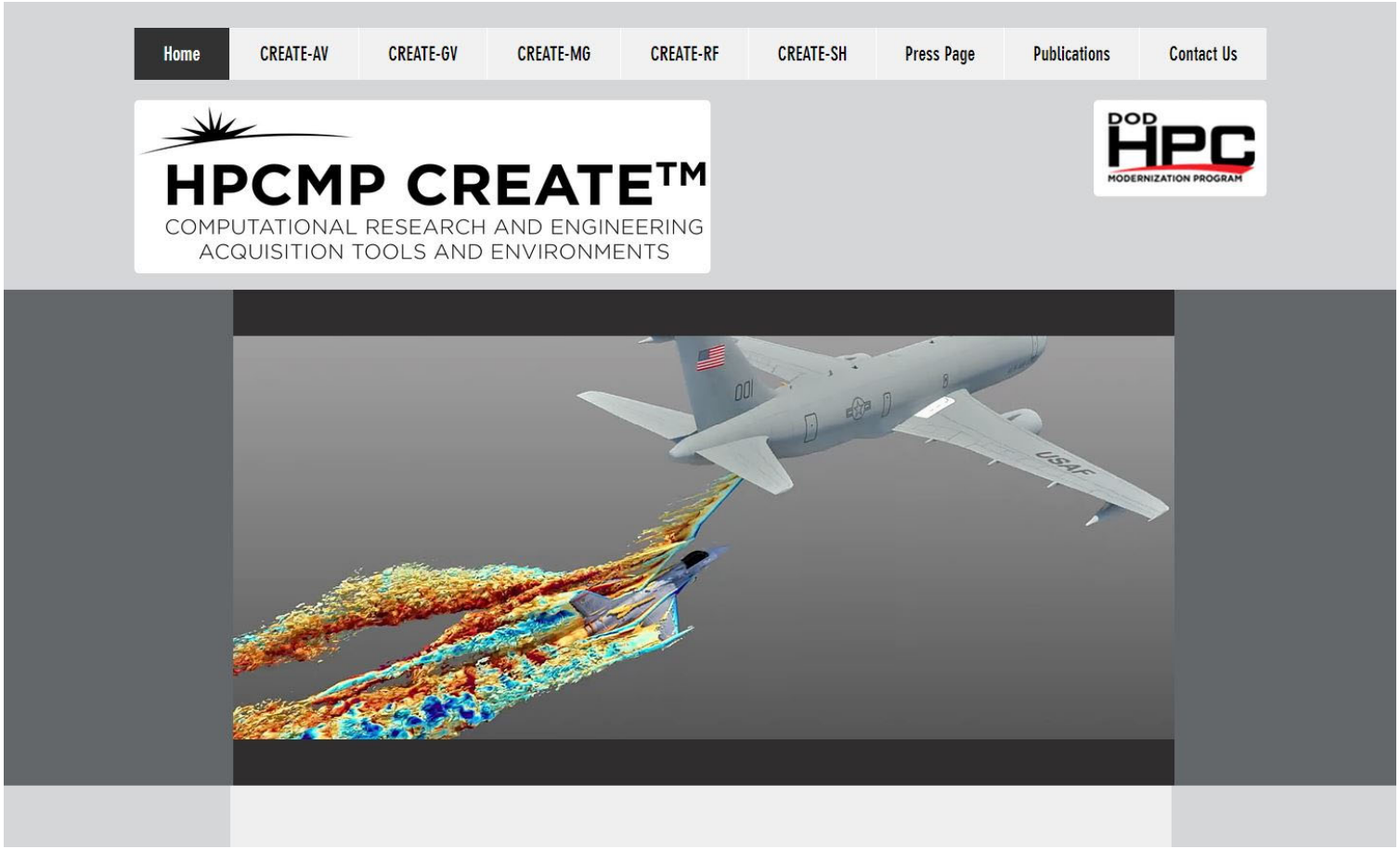
Computer Network Defense, Security R&D, and Security Integration

Software Applications

- CREATE: Software Engineering
- Institutes Cross-service software capabilities teams
- PETTT: Training and Computational Expert Support
- Frontier: Computationally Intensive Projects

Partners — DoD/Federal Agencies + PEO's/PM's + Academia + Industry

Current CREATE Software Areas



AV-Air Vehicles, GV-Ground Vehicles, MG-Meshing & Geometry, RF-RF Antennas, SH-Ships
https://www.hpcmpcreate.org

HVSI Background

- HPCMP CREATE™-AV Board of Directors saw the need for production hypersonic software tools
- Most hypersonic physics are not modeled by current production aerodynamic codes
  - gaps exist between current codes and required capability
- HVSI has been established by HPCMP for the purposes of filling those gaps
- HPCMP named Russ Cummings as the Managing Director of HVSI in Summer 2018
- HVSI is a national institute being hosted at the US Air Force Academy

DoD HPCMP HVSI

- "Hypersonic Turbulence Model" Projects started in 2019:
  - Received 60 White Papers:
    - 55 from Civilian Universities and Small Businesses
    - 5 from USG Organizations
  - External Projects Awarded:
    - Rodney Bowersox (Texas A&M), "Turbulent Energy Flux Modeling for Improved Wall Heat Transfer Prediction in Hypersonic Flows" (co-funded by ONR)
    - Datta Gaitonde (Ohio State U.) & Graham Candler (U. Minnesota), "Reynolds-Averaged Navier-Stokes Based Turbulence Modeling for High-Speed Configurations"
    - Jack R. Edwards (NCSU) & Douglas L. Stefanski (U. Tennessee), "Development of Improved RANS and Hybrid LES/RANS Turbulence Models for Hypersonic Flow Applications"
    - Graham Candler (U. Minnesota), "Development of Physics-Based Turbulence Models for Hypersonic Flows"
    - Christoph Brehm (U. Kentucky) & Neil Ashton (Oxford U.), "Development of a RANS-Based Wall-Modeled LES Approach for Hypersonic Flows"

DoD HPCMP HVSI

- "Hypersonic Transition Model" Projects starting in 2020:
  - Received 40 White Papers:
    - 38 from Civilian Universities and Small Businesses
    - 2 from USG Organizations
  - External Projects Awarded:
    - James Coder (Tennessee), "Hypersonic Transition Modeling Using an Amplification Factor Transport Equation" (co-funded by AFRL)
    - Hermann Fasel (Arizona), "Development and Testing of RANS Transition Models for Hypersonic Boundary Layers"
    - Sean O'Byrne (UNSW), "Measuring the Influence of Wall-temperature Ratio Distribution on Transition Using Optical Diagnostics"
    - Steve Schneider (Purdue), "Critical Reviews of Historical Experimental Data for Hypersonic Boundary Layer Transition Towards New Computational Comparisons"
- Future projects currently being planned

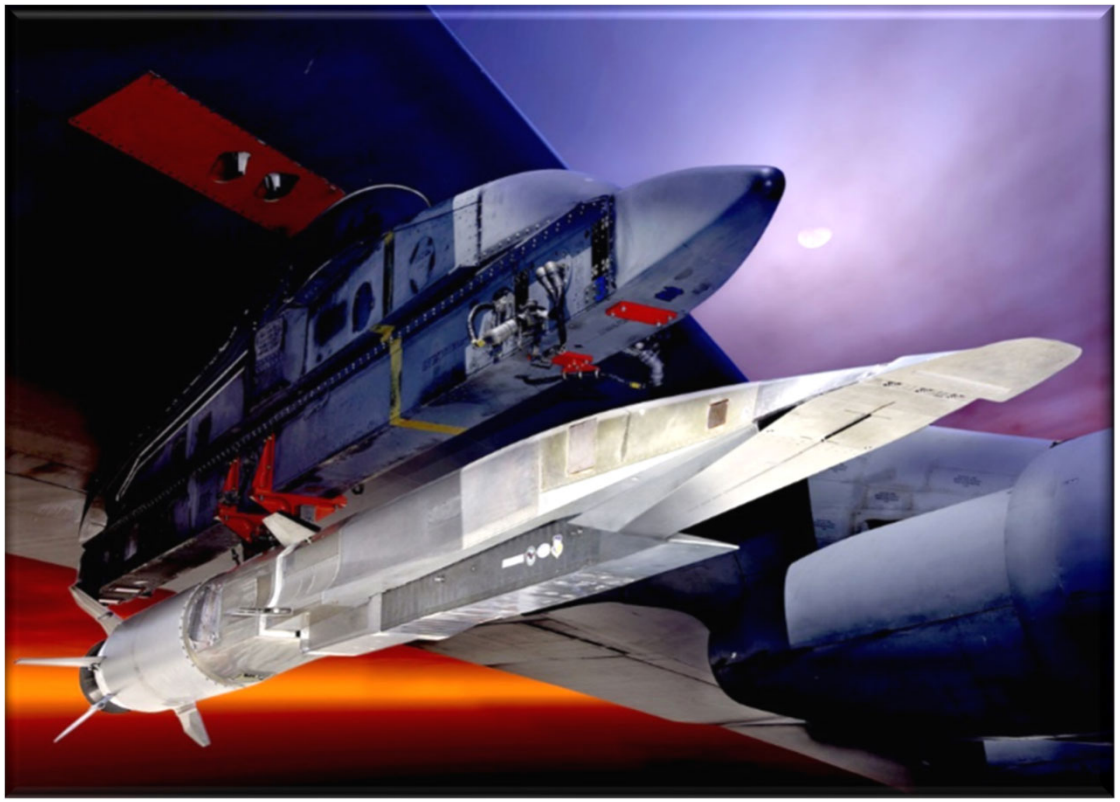
Institute for Future Conflict

- Institute for Future Conflict will focus on research and education that examines the changing character and technologies of armed conflict
- Researchers and faculty will emphasize deterrence and competitive advantage when conflict becomes necessary

Summary

- US Air Force Academy is a small, undergraduate-only university with a strong research environment
- 27 research centers and institutes enrich undergraduate experience, provide faculty development, and serve the DoD
- NRC Post-doctoral researchers, visiting scientist programs, visiting graduate students, and collaborative projects with other universities expand research
- A number of the research centers and institutes have capabilities related to hypersonics that make the Academy a good place to conduct high speed research and collaborate on important projects

Questions?



Russell M. Cummings
russ.cummings@usafa.edu

AERONAUTICS

UNITED STATES
AIR FORCE ACADEMY

Integrity - Service - Excellence