

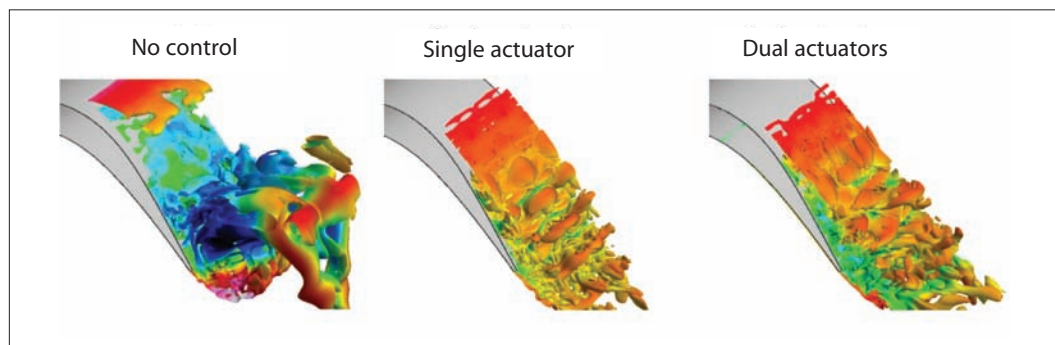
Fluid dynamics

Exciting research developments have been reported in the past year in the various subfields of fluid dynamics. A snapshot of some of these developments is provided below.

CFD methods and applications

The application of hybrid Reynolds-averaged Navier-Stokes (RANS)/large-eddy simulation (LES) methods to aerodynamic flows continued to be an active area of research in the U.S. and abroad. Symposia held in London, England, and in Kerkyra, Greece, highlighted the successes and shortcomings of these techniques. In

Isosurfaces of vorticity magnitude, which are colored by the streamwise velocity component, show the effects of plasma-based techniques to control separation on transitional, highly loaded, low-pressure turbine blades.



addition to the canonical separated-flow applications, the method is being used increasingly for wall-modeled LES and for zonal simulations.

Research continued in the development of techniques that improve the solution behavior at the interface between RANS and LES. Boeing and TTC Technologies independently improved and applied high-order-based hybrid RANS/LES procedures to accurately simulate the flow and fluctuating pressure fields required for jet noise prediction in a coupled nozzle/jet plume model.

In other developments, Stanford University researchers demonstrated remarkably accurate LES predictions of turbulent separation and its control for flow over the wall-mounted hump, first used in the 2004 NASA Langley Workshop on CFD Validation. Their results, obtained using nondissipative numerics and the dynamic subgrid-scale model, demonstrated that predictions of separation control can be achieved without resorting to direct numerical simulation, reducing computational costs by orders of magnitude.

The Direct Simulation Monte Carlo (DSMC) method is currently the most common tool used to simulate nonequilibrium flows at finite Knudsen numbers. Recently, gas-kinetic schemes based on the BGK approximation to

the Boltzmann equation have been applied by researchers at the Hong Kong University of Science and Technology, and at Old Dominion University to simulate nonequilibrium flows. By making the relaxation time parameter from the BGK approximation a function of the flow gradients, resolution of shock structures with accuracy comparable to DSMC was demonstrated at a significantly lower computational cost.

Flow control

Flow control continues to be an active area of research, with electromagnetic energy addition receiving significant attention. The computational plasma program at the University of Florida, in collaboration with the Computa-

tional Sciences Center of Excellence at the Air Force Research Laboratory (AFRL), has successfully predicted plasma-based stall control for NACA airfoils and turbine blades at high angles of attack. Also in the past year, simulations at the AFRL center explored the use of asymmetric dielectric-barrier-discharge plasma-based actuators to control the flow over blades of transitional, highly loaded low-pressure turbines, commonly employed as the propulsion systems for UAVs. The blades are susceptible to separation in high-altitude cruise, resulting in blockage of the flow passages, transition to turbulence, wake total pressure losses, and a decrease of turbine efficiency.

Various aspects of control strategies for an isolated turbine blade were investigated using high-order CFD combined with a phenomenological model to represent plasma-induced body forces imparted by the actuator on the fluid. The AFRL researchers completely eliminated separation with minimal plasma power requirements. They observed an 85% reduction in the wake total pressure loss coefficient. The flow physics by which this efficiency improvement was achieved were also identified.

Rutgers University has reported significant progress in the use of microwave energy deposition, expanding the possible regimes for flow

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control in high-speed flows. A series of experiments and theoretical analyses was performed jointly with Russian collaborators from the Institute for High Temperatures to quantitatively evaluate the effect of a laser spark precursor on the breakdown voltage required for microwave energy deposition in air, at subatmospheric to atmospheric pressure. The microwave generator employed has a maximum power of 700 kW operating at 13 GHz. The electric fields of the laser and microwave are mutually perpendicular. The results imply the potential for creating microwave discharges at arbitrary locations in the vicinity of an aerodynamic body.

Likewise, researchers at the University of Illinois Champaign-Urbana are investigating laser and microwave energy deposition methodologies and actuators with an eye toward uncovering opportunities for exploiting instabilities that can be controlled with the techniques. The experiments have resulted in the successful forcing of large-scale structures in a supersonic cavity shear layer using energy deposition. Princeton University has demonstrated nanosecond pulse, sustained high-velocity dielectric barrier discharge surface jets, and "snowplow arc"-driven separation control.

In the emerging research area of feedback flow control, a major problem has been the availability of suitable (meaning simple enough to solve) mathematical descriptions of the flow. Traditionally, low dimensional dynamic models of flow fields have been fraught with mathematical stability problems as well as a limited range of validity.

However, over the past year, several promising approaches have emerged. Trust-Region POD (CNRS, France) as well as Balanced Truncation (Princeton University) have been shown to improve the range of validity, or the numerical stability, respectively. A method combining Double POD and system identification based on neural networks (DPOD-ANN-ARX) improves stability, range of validity, and models actuation effects for both open-loop and closed-loop flow states (Air Force Academy). These developments can be expected to lead to greatly improved understanding of open-loop controlled-flow physics and practical feedback controllers in the near future.

Transition

Several exciting developments highlighted the continued pace of research in laminar-turbulent transition, especially in high-speed boundary layers.

NASA's computational analysis of the Pegasus flight experiment from 1998 provided the

first flight validation of stability-based prediction methods for crossflow-dominated transition in high-Mach-number 3D boundary layers. Specifically, the correlation of disturbance growth factors with in-flight transition locations via the e^N method indicated that the same range of N factors as found earlier for low-speed flows also correlates observed transition characteristics over both the cold wing glove and the in-board, hotter tile region of the Pegasus wing.

Extensive analysis and ground tests were performed by an AFRL-led team in preparation for flight one under the HIFiRE (Hypersonic International Flight Research and Experimentation) project. HIFiRE will use a series of flights with low-cost sounding rockets to develop and demonstrate fundamental hypersonic technologies deemed critical to the realization of next-generation aerospace weapon systems. Flight one will test high-frequency instrumentation in a flight environment, with a focus on boundary-layer transition and shock-boundary layer interaction. The preflight effort has shown that hypersonic smooth-body transition should be achievable with the proposed configuration consisting of a 7-deg half-angle cone with 2.5-mm nose radius. However, one side of the vehicle will be tripped to ensure transition and to obtain rough-wall data.

To gain fundamental insights into the dynamics of hypersonic shear flows, NASA Langley researchers have begun using the nitric oxide planar laser-induced fluorescence, or NO-PLIF, technique. In one experiment, NO was seeded into a Mach 10 laminar boundary layer that passed over discrete triangular and rectangular trips and became turbulent downstream. The shape of trip-induced flow instabilities appears to be consistent with the hairpin-shaped vortices observed in lower speed regimes.

In subsonic flow, as part of technology development for low-weight, high-efficiency airframes to allow persistent loiter capability for AFRL's SensorCraft program, Texas A&M University demonstrated the efficacy of distributed roughness elements (DRE) in extending the length of laminar flow from 30% to 60% chord on a subsonic swept wing at chord Reynolds number up to 8.1 million. The flight test of the 37-deg swept wing was accomplished on a Cessna O-2 with the test article mounted to a hard point of the Cessna's port wing. Infrared thermography was used to measure the extent of laminar flow. A surprisingly strong correlation between transition location, DRE height, and test article surface roughness was observed, which was also confirmed via nonlinear parabolized stability computations.