SONIC

BOOM

Prediction, Focusing and Mitigation

BY OSAMA A. KANDIL

Can we travel from Norfolk to Los Angeles in two and a half hours? The answer is yes, if aircraft are allowed to fly over land at speeds near Mach 2, which is twice the speed of sound.

Why then are present day commercial aircraft not flying at supersonic speeds over the continental United States? The problem is the sonic boom originating from the aircraft, propagating to the ground and producing typical noise signals close to 160 decibels of sound pressure. (For comparison's purpose, a rock band can produce about 100 decibels.) The now-retired Concorde aircraft could produce a ground noise level of 135 decibels when it flew at Mach 2.

This is a harmful noise to human ears on the ground. What is needed are new aircraft designs to limit the ground noise from sonic boom to no more than 115 decibels, which is a limit imposed by the Federal Aviation Administration. To accomplish the reconfiguration of wings and other parts of aircraft that is needed to lessen sonic boom, aeronautical engineers usually find that computational and physical simulation computer codes are a cheaper means of initial research and development than are field measurements during actual flights.

A goal today of commercial aviation, with the assistance of the governments of several countries, is the development of a small, commercial airliner that can fly over land at speeds similar to those reached by the Concorde. The French-British Concorde, of course, was generally allowed to fly at supersonic speeds only over oceans because of dangers posed by its sonic boom. The next generation commercial supersonic craft must be able to fly over land as well as water at speeds close to Mach 2 (about 1,500 miles per hour) in order to tap the full demand for super-quick flights. In the research and development of a new supersonic commercial plane, computational codes are needed to predict (1) ground sonic-boom noise from various aircraft designs, (2) the occasional magnification of sonic boom called "focusing" that can happen during rapid acceleration, turns or other maneuvers, and (3) design elements for sonic-boom mitigation to meet the FAA standards of 115 decibels.

A feasibility study for small, commercial supersonic craft was ordered in 2000 by the federal Defense Advanced Research Projects Agency (DARPA) and National Aeronautics and Space Administration (NASA) Langley Research Center. Planning contracts were given to the Boeing Co., Lockheed Martin Corp. and Northrop Grumman Corp. Colleagues at the Frank Batten College of Engineering and Technology and I joined the development process by teaming up with the Virginia consulting firm of Eagle Aeronautics. We subcontracted with Lockheed Martin and Northrop Grumman and later with the NASA Langley Research Center and Northrop Grumman.

Computer Code for Predicting Sonic Boom

My research team at ODU has painstakingly developed a computer code that, indeed, does offer a very economical way to research the prediction and mitigation of ground sonic-boom noise. After initial, successful applications of our code for predicting sonic-boom ground noise of simple supersonic wings (American Institute of Aeronautics and Astronautics Conference, Breckenridge, Colo., June 17-19, 2002), we were given the opportunity to apply the code to a complex configuration of a real aircraft. By the beginning of 2003, Northrop Grumman was conducting field measurements in California on a modified F-5E aircraft. We received data from these measurements relative to our code in August 2003 and October 2004, and our biggest prediction success came in December 2004. The results showed we had successfully predicted the sonic-boom ground signature of the modified F-5E aircraft used in the Shaped Sonic Boom Experiment (SSBE) Program by Northrop Grumman. This means that the predicted computational and simulation results of our computer code were in excellent agreement with the field-measured data. Our graphic demonstrations show the predicted shock system of the modified F-5E aircraft as well as the excellent comparison of the predicted results using our computer code with those of the field-measured data. This work was reported at the Annual AIAA 34th Aerospace Science Meeting and Exhibition in Reno, Nev., Jan. 9-12, 2005.

Addressing the Superboom Problem

The next issue of this work is accurate prediction of the sonic-boom focusing, which is called "superboom." The superboom develops when an aircraft changes its speed, turns or maneuvers. With superboom conditions, the ground noise of sonic boom is magnified up to 2-3 times the original sonic-boom noise, which could propagate to the ground and severely harm human ears, as well as structures.

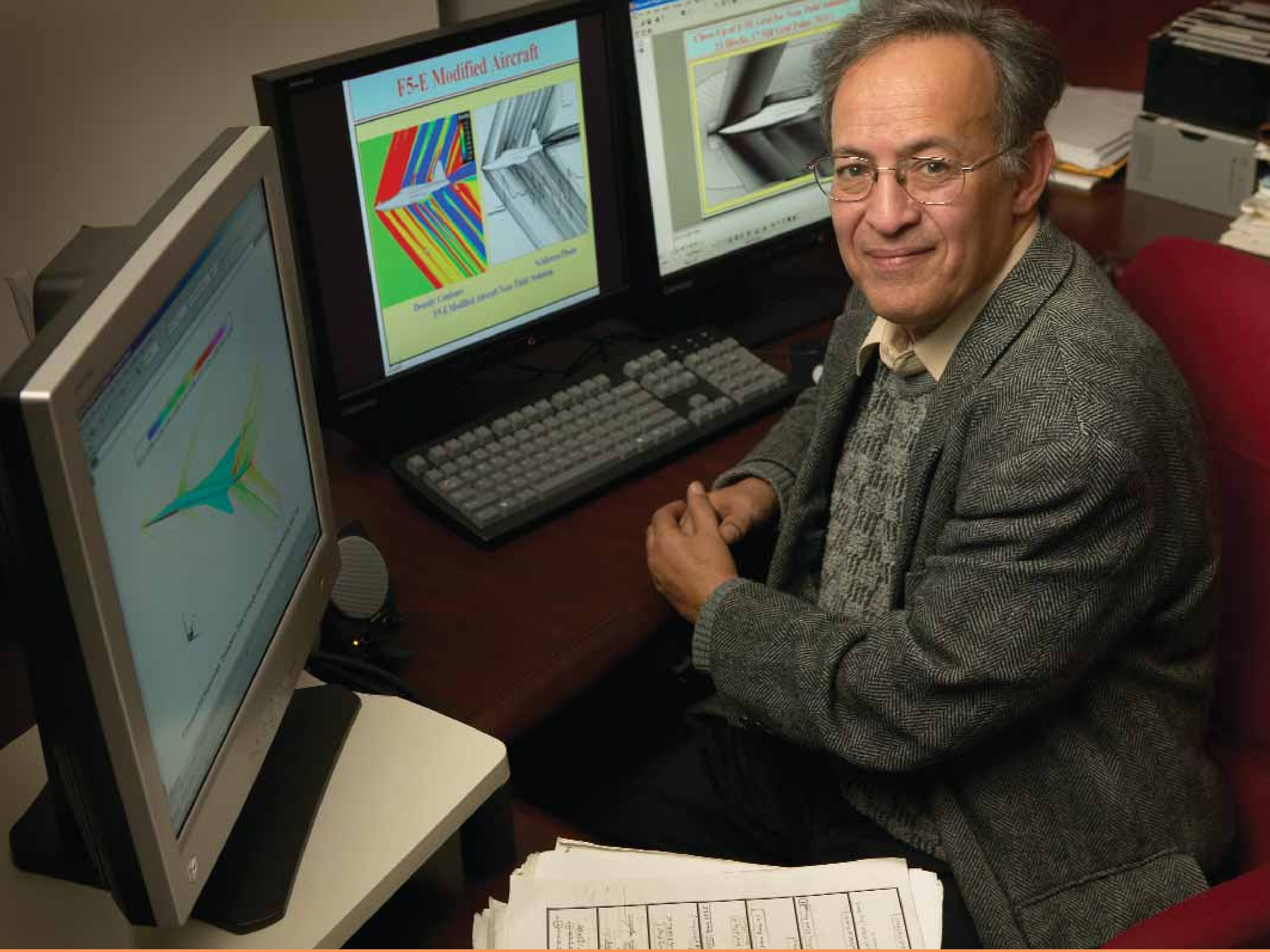
For modeling the superboom problem, certain nonlinear equations should be computationally solved. In late 2003, our ODU research team was asked to come up with a prediction method and a computer program regarding superboom. French engineers from Airbus and the University of Paris were ahead of us in the superboom prediction capability. But, by late December 2004, we at ODU had developed four computational schemes and the associated computer codes (in comparison with one computational scheme and one code for the French group) to simulate this problem.

The results of these computer codes have shown successful prediction, and the results of the different computer codes have been in good agreement with each other. Moreover, we produced animation movies for more understanding of the physics of the superboom development. This work was reported at the International Sonic Boom Conference held at Penn State University July 21-22, 2005. Members of the French group were there, and their leader, Dr. Francois Coulouvrat, congratulated me for the accomplishments. The work was also presented Aug. 15-17, 2005, at the AIAA Atmospheric Flight Mechanics Conference in San Francisco. We have developed a related graphic demonstration of predicted superboom at ground level that is three times the intensity of regular sonic-boom noise.

Turning Theory into Actual Mitigation

For sonic-boom mitigation, ODU engineers produced a study, reported at the AIAA Aeroacoustics Conference in Hilton Head in May 2003, investigating the effect of increasing the wing dihedral angle—the angle between the left wing and right wing—on the ground sonic-boom noise. The investigation was carried out on our computers utilizing our computer code. Reductions of the sonic-boom ground noise ranged from 12 percent to 14 percent. Northrop Grumman has shown another sonic-boom ground reduction of 25 percent by reshaping the lower surface of the nose portion of the F5-E aircraft. Northrop Grumman engineers used actual field tests in their research.

Research and development work conducted by our team will continue with funding from the NASA Langley Research Center to develop computational codes for design analysis with minimum human interference. The codes would be highly accurate and efficient with the use of our computer clusters in the Engineering and Computational Sciences Building. The capabilities will include prediction of both sonic-boom and superboom ground noise and mitigation of these signals through aircraft configuration redesign. The contributions of ODU engineers could help make possible the production of a "quiet" supersonic commercial aircraft that is capable of flying from coast to coast in the United States in two and a half hours.



Osama A. Kandil, Old Dominion University professor and Eminent Scholar, was the founding chair of the Department of Aerospace Engineering in 1993 and he led the department until 2002. He is an expert in computational and theoretical fluid dynamics and aerodynamics, and subsonic, transonic and supersonic flows. Government agencies and the military have awarded him more than $4 million in research grants and he has authored more than 170 refereed journal and conference proceedings papers. He is an American Institute of Aeronautics and Astronautics associate fellow and the recipient in January 2005 of a NASA "Turning Goals into Reality" award for outstanding contributions to sonic boom research. Oktay Baysal, dean of ODU's Frank Batten College of Engineering and Technology, said: "The university's aerospace engineering department has contributed to the numerous achievements of NASA Langley Research Center. Osama Kandil's accomplishments in sonic boom research are testimonials to the success of our recent emphasis on computational engineering as a peer to theory and experiment in bringing solutions to real engineering problems."