Narrative of Hafiz M. Atassi Teaching and Research

www.nd.edu/˜ atassi/research.html

Hafiz Atassi has been teaching and conducting research for 40 years. He currently holds the Viola D. Hank Chair at the University of Notre Dame. He has taught and mentored thousands of undergraduate students and has directed the research of more than 40 graduate students. His teaching emphasizes fundamental understanding, starting from first principles and then application to engineering technology. He has introduced many new undergraduate and graduate courses at Notre Dame. He founded the Center for Applied Mathematics at Notre Dame and was its director for 10 years. He has given more than 90 invited lectures and seminars at prestigious universities and institutions, in the United States, Europe, Russia and Japan.

He started his scientific and engineering career at the University of Paris working in rarefied gas dynamics with application to the re-entry problem. He carried out experiments to measure the drag and heat transfer of bluff bodies at high speed and rarefied conditions. This work was continued at Cornell University with the development of analytical methods for calculating the heat transfer and drag coefficients for various flows from the continuum to free molecular regimes (JFM 1972, I, II).

In unsteady aerodynamics he and Marvin Goldstein introduced the concept of interactive gust for a lifting airfoil and derived an elegant expression for the lift coefficient demonstrating the very significant effect of the mean flow gust distortion on the lift and sound radiation (JFM 1976, 1984, 1989). This was a breakthrough for unsteady airfoil theory whose concepts were developed by von Karman and Sears. It led to new developments in nonlinear modeling of vortical flow interaction with wings and turbomachinery blades. These ideas were extended by Professor Atassi and his students to cascade aerodynamics, aeroelasticity and acoustics (Atassi, Springer Verlag, 1993, Fung, World Scientific, 1994). Today, these ideas are implemented in all numerical models in use by industry and government laboratories.

Professor Atassi and his students have also worked on acoustic interference under NASA funding (Elsevier, 1995; AGARD-CP-571, 1995) and the inverse aeroacoustic problem under ONR funding (AlAA, 1996). They discovered a strong acoustic interference in airfoils and cascades in transonic flows, which was dubbed "acoustic blockage." This effect has been validated later by experiments in France and Sweden. The inverse acoustic problem has examined the feasibility of using acoustic signals as a non-intrusive device to get information about sound sources of a body in nonuniform flow (AlAA, 1996). Since the general problem is not unique, the main issue was to determine the accuracy of information in terms of restrictive assumptions on the source. In a way, it is to examine the question "*Under what conditions, can we hear the shape of a drum?*"

Professor Atassi and his students work on turbulence evolution and distortion in swirling flows, under NASA funding, has first focused on understanding and quantifying the effects of these phenomena, which are very important to propulsive system technologies (JSV, 1998). Their theoretical prediction of selective amplification of certain distortion modes by the centrifugal and Coriolis forces was a very significant finding with important application to marine propellers and turbofan noise prediction models. In addition, their results showed that although the centrifugal and Coriolis forces act to couple acoustics and vortical nonuniformities in swirling flows, it is still possible to identify, what they dubbed, "acoustic-dominated" modes with weak vorticity and "vorticity-dominated" modes with weak pressure variations (AlAA J., 2000). Experiments at the Johns Hopkins University, validate and support the analytical predictions made by Professor Atassi and his co-workers. These ideas were also extended under NASA Glenn sponsorship to model the scattering of high frequency disturbances in 3D geometry with swirl (JFM 2004).

Under NASA Glenn and ONR sponsorship, Professor Atassi and his co-workers have developed efficient computational methods at high frequency for application to scattering of incident turbulence in nonuniform flows by 3D annular cascades. First, they developed, 'exact' non-reflecting boundary conditions for computational aeroacoustics suitable for very high frequencies (JCP, 1995, JFM 2004). The method has been applied very successfully for very high reduced frequency flows up to 40, and led to the development of numerical codes (CAAT) relevant to to modeling noise and vibration in turbo-fan and marine propellers. CAAT is currently in use at Pratt & Whitney and Boeing. Second, under National Science Foundation funding, a Schwarz domain decomposition suitable for parallel computing was formulated (JCP, 1998). The algorithm was implemented on the Portable Extensible Toolkit for Scientific Computation (PETSc) by engineers at Argonne National Laboratory.

In the past few years Professor Atassi and his students have been working on the modeling and control of tonal and broadband interaction noise, a byproducts of the interaction of nonuniform turbulent flows with bodies such as aircraft wings, turbofan engine blades and wind turbines. Under NASA Glenn, the Ohio Aerospace Institute Aeroacoustics Consortium, and Pratt & Whitney sponsorship, they have developed a non-computationally intensive model (BB3D). The model is validated for broadband noise by comparison with NASA Source Diagnostic Test results. Comparison shows excellent agreement with data up to 15000 Hz. They have also developed a model to examine the effects of anisotropic turbulence (boundary layer) on broadband fan noise and showed that turbulence anisotropy produces spectra with hay stacks whose maxima occur at multiples of the blade-passing frequency of the rotor. Results show excellent agreement with data from Boeing and the University of Notre Dame. This work is summarized in a recent review paper presented at the IUTAM Symposium on Computational Aeroacoustics for Aircraft Noise Prediction (Procedia IUTAM, 2010) and (JSV, 2011; AIAA, 2011).

Professor Atassi most recent work is on fluid structure interaction with elastic body under ONR grant. It is an interdisciplinary study combining structural acoustics and unsteady hydrodynamics. In order to control trailing edge noise, one needs to determine how the flexural waves of a blade or a control surface interact with the turbulent flow and how this interaction affects the system impedance and the acoustic radiation. This is the first investigation that accounts for the full coupling between the flexural waves and the hydrodynamic and acoustic response of the propeller blades. Preliminary results show that blade water loading couples the flexural modes and significantly change the system impedance, leading to the formation of many peaks in the acoustic spectra at certain frequencies.

Selected Publications of Hafiz M. Atassi

"A Unified Kinetic Theory Approach to External Rarefied Gas Flows, Part 1, Derivation of Hydrodynamic Equations," co-author, S.F. Shen," *Journal of Fluid Mechanics*, **53**, pp. 417-431, 1972.

"A Unified Kinetic Theory Approach to External Rarefied Gas Flows, Part 2, Application to a Steady Low Speed Motion Past a Circular Cylinder," co-author S.F. Shen, *Journal of Fluid Mechanics*, **53**, pp. 433-499, 1972.

"A Complete Second Order Theory for the Unsteady Flow About an Airfoil Due to a Periodic Gust," co-author, M. Goldstein, *Journal of Fluid Mechanics*, **74**, pp, 741-765, 1976.

"The Sears' Problem for a Lifting Airfoil Revisited - New Results," *Journal of Fluid Mechanics*, **141**, pp. 109-122, 1984.

"Unsteady Disturbances of Streaming Motions Around Bodies," co-author, J. Grzedzinski, *Journal of Fluid Mechanics*, **209**, pp, 385-403, 1989.

"Compressible Flows With Vortical Disturbances Around a Cascade of Loaded Airfoils" co-author, J. Fang, *Unsteady Aerodynamics, Aeroacoustics and Aeroelasticity of Turbomachines and Propellers*, Editor, H.M. Atassi, Springer Verlag, pp. 149-176, 1993.

"High Frequency Gust Interaction With Single Loaded Airfoils in Subsonic Flows," with J.R. Scott, *Unsteady Aerodynamics, Aeroacoustics and Aeroelasticity of Turbomachines and Propellers*, Editor, H.M. Atassi, Springer Verlag, pp. 743-764, 1993.

"Unsteady Aerodynamics of Vortical Flows: Early and Recent Developments," Symposium on Aerodynamics & Aeroacoustics, Ed. K.-Y. Fung, pp.121-172, World Scientific, 1994.

"A Finite-Difference Frequency Domain Numerical Scheme for the Solution of the Gust Response Problem," co-author J.R. Scott, *Journal of Computational Physics*, 119(1), pp. 75-93, 1995.

"Acoustic Interference in Unsteady Transonic Nozzle and Cascade Flows" co-authors J. Fang and P. Ferrand, Unsteady Aerodynamics and Aeroelasticity in Turbomachines, Ed., Y. Tanida and M. Namba, pp. 777-794, Elsevier Science B.V., 1995.

"Inverse Aeroacoustic Problem for a Streamlined Body. Part I: Basic Formulation" co- author S. Patrick and W.K. Blake, *AIAA Journal*, 34, No. 11, pp. 2233-2240, 1996.

"Acoustic-Vorticity Waves in Swirling Flows," co-author V.V. Golubev, *Journal of Sound and Vibration*, **209**(2), pp, 203-222, 1998.

"A Domain Decomposition Method for the External Helmholtz Problem," co-author, R. Susan-Resiga, *Journal of Computational Physics*, 147(2), pp. 388-401 (December) 1998.

"Unsteady Swirling Flows in Annular Cascades. Part 1. Evolution of Vortical Disturbances," co-author V. Golubev, AIAA Journal, 38, No.7, pp. 1142-1149, 2000.

"Scattering of Incident Disturbances by an Annular Cascade in a Swirling Flow," co-authors, A.A. Ali, O.V. Atassi, and I.V. Vinogradov, *Journal of Fluid Mechanics*, **499**, pp, 111-138, 2004.

"Modeling Tonal and Broadband Interaction Noise," co-author M.M. Logue, in IUTAM Symposium on Computational Aeroacoustics for Aircraft Noise Prediction," Ed. R.J. Astley and G. Gabard, *http://www.sciencedirect.com/science/journal/22109838*, Procedia IUTAM, volume 1: pp. 214-223, 2010.

"Aerodynamics and Interaction Noise of Streamlined Bodies in Nonuniform Flows," co-author M.M. Logue, Journal of Sound and Vibration, doi:10.1016/j.jsv.2011.03.009, 2011.

"Aerodynamics and Acoustics of an Annular Cascade: Comparison with a Linear Cascade," co-authors M.M. Logue, D. A. Topol, and J. J. Gilson, to appear in AIAA Journal (2011). (Presented as paper AIAA-2010-3870).