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UNSTEADY SHOCK WAVE - BOUNDARY LAYER INTERACTIONS
FY 2000 AFOSR Entrepreneurial Research Task

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14. ABSTRACT
The objective of the research performed was to investigate shock – boundary layer interactions at transonic conditions in the presence of unsteady vortex flows originating upstream of the shock location. These conditions are germane to both external and internal flows: principally, flows over a geometry representative of a modern fighter wing at transonic maneuvering conditions and within transonic compressor states, respectively. Despite intentions to the contrary, these conditions were studied separately as it was determined that insufficient overlap existed for the computational tools and conditions of choice.

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unsteady aerodynamics, shock-boundary layer interactions, transonic aerodynamics, separated flows

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Final Report: Unsteady Shock Wave – Boundary Layer Interactions
FY 2000 AFOSR Entrepreneurial Research Task

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Research Objectives

The objective of the research performed was to investigate shock – boundary layer interactions at transonic conditions in the presence of unsteady vortex flows originating upstream of the shock location. These conditions are germane to both external and internal flows: principally, flows over a geometry representative of a modern fighter wing at transonic maneuvering conditions and within transonic compressor stages, respectively. Despite intensions to the contrary, these conditions were studied separately as it was determined that insufficient overlap existed for the computational tools and conditions of choice.

External Flows

Using $COBALT_{60}$[1] two types of unsteady CFD calculations were performed on a representative fighter wing geometry. The conditions investigated were consistent with transonic maneuver conditions where the main wing panel experiences gross separation while the leading-edge extension slowly builds vortex lift with increasing angle of attack.

The first type of unsteady calculation consisted of starting an unsteady calculation from a previously converged solution using the same angle of attack used in the steady state calculation. A sample graph is presented in Figure 1, which shows the pressure time history at several locations on the upper surface of the wing. For all angles of attack studied, the pressure histories exhibited no unsteady motion other than the low amplitude noise.

The second type of calculation was also started from a previously converged solution, but instead of continuing at the same angle of attack, the angle of attack was changed abruptly at the start of the unsteady calculation by an angle ranging from 0.5 to 1.5 degrees. This introduced a large perturbation into the simulation, allowing the possibility of capturing true nonlinear instabilities which require a nontrivial departure from the steady state. An example is provided to illustrate the typical behavior that has been found for this type of calculation. As seen in Figure 2, the sudden change in the angle of attack causes a transitory change in the pressure, but a steady state is soon attained. In all of the simulations performed thus far, the calculations have not exhibited the type of oscillatory behavior that has been seen in wind tunnel experiments.

One cause for this discrepancy is the fact that in the numerical simulations, there is no aerodynamic coupling between the forces on the wing and the boundary conditions, i.e., unsteady forces in surface accelerations or deformations; instead, the geometry is rigid throughout the calculation. A second possible cause is the fact that for these simulations, a moderate amount of temporal damping was required in order to use a reasonable time step. When using non-zero temporal damping coefficients, the time accuracy of the simulation is lost to some extent. Several different values of these coefficients were used in order to study their effect on the solution. In all cases, no unsteady behavior was found beyond low level noise. This damping reduces the time accuracy of the calculations, thus yielding calculations that are not strictly time accurate. Currently, more calculations are being performed at the Air Force Academy to determine if the temporal damping significantly changes the unsteady behavior in the cases of interest.

Internal Flows

The objective of this research is to numerically simulate the unsteady flow features in a transonic compressor stage consisting of an upstream wake generator and a downstream transonic rotor, with emphasis being placed on developing a fundamental understanding of the underlying unsteady interactions involved. Of particular interest are the effects of unsteady vortex shedding from the wake generator on the rotor and the losses created by the vortex shock interaction. The flow solver used for this study is an unstructured-grid Navier-Stokes solver (USM3D[2]) modified for rotating turbomachinery flows.

The ultimate objective was to obtain a three-dimensional, unsteady simulation of the compressor configuration, which consists of 24 wake generator blades and 33 rotor blades. Because both of these numbers are divisible by 3, we can simulate 1/3 of the entire machine with 8 wake generator blades and 11 rotor blades and apply periodic boundary conditions in the circumferential direction. Before performing this simulation, however, several intermediate steps were required as defined below.

After making the necessary modifications to the flow solver, a 2D unsteady simulation will be performed to validate the solver modifications. The simulation will consist of a linear cascade with 8 wake generator blades and 11 rotor blades with profiles taken from the mid-span. The rotor blades are translated to mimic the rotation in the three-dimensional case. The 3D simulation will be performed for 1/3 of the actual machine (8 wake generator blades and 11 rotor blades) with periodicity conditions in the circumferential direction.

The use of solution-adaptive gridding will be investigated to determine whether or not it can significantly improve the resolution of unsteady vortical structures shed from the wake generator and the interaction of those structures with the rotor bow shock. The authors of the flow solver and grid generator have performed some solution-adaptive simulations[3], but the necessary codes have not been released to date.

All of the required flow solver modifications, except for the rotor domain rotation, have been made and tested using simple test problems. The solver is now capable of running a 2D steady-state test of the configuration without rotor blade movement. A steady-state solution without rotor movement is necessary to provide an initial condition for the later unsteady simulation with rotor movement.

A true 2D simulation is not possible with the current 3D flow solver. Therefore, the 2D simulation is really performed in three dimensions on a thin, flat domain uniform in the spanwise direction. Single-blade-passage grids were generated for both the wake generator and rotor blades, and then stacked in the transverse direction 8 times for the wake generator and 11 times for the rotor. The 19 individual grids were then combined into a single computational grid with appropriate interface boundary conditions defined. Figure 3 shows the computational grid for the two-dimensional simulation.

The steady-state 2D simulation has been completed. Mach number contours from the resulting solution are shown in Figure 4. The separation seen on the rotor blades is due to the artificially low flow incidence due to the fact that the rotor blades are not moving. The steady-state 2D solution will serve as the initial condition for the unsteady 2D simulation with rotor movement. Flow solver modifications to include rotor movement are being made.

References

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2. Frink, N. T., "Tetrahedral Unstructured Navier-Stokes Method for Turbulent Flows," AIAA Journal, Vol. 36, No. 11, pp. 1975-1982, 1998.
3. Pirzadeh, S. Z., "An Adaptive Unstructured Grid Method by Grid Subdivision, Local Remeshing, and Grid Movement," AIAA Paper 99-3255, 1999.

Figures

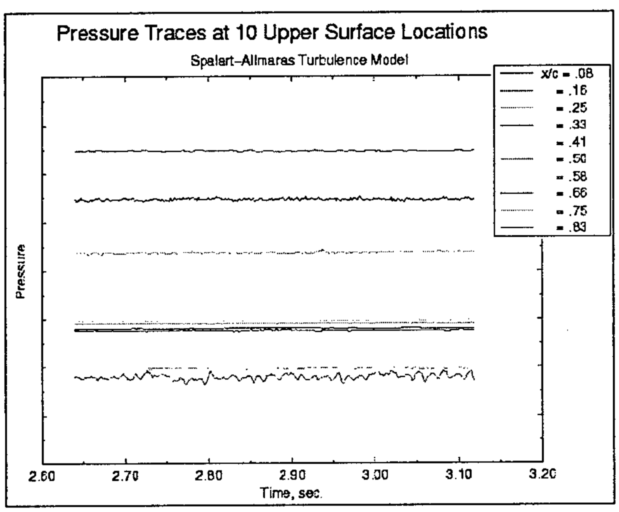

Figure 1

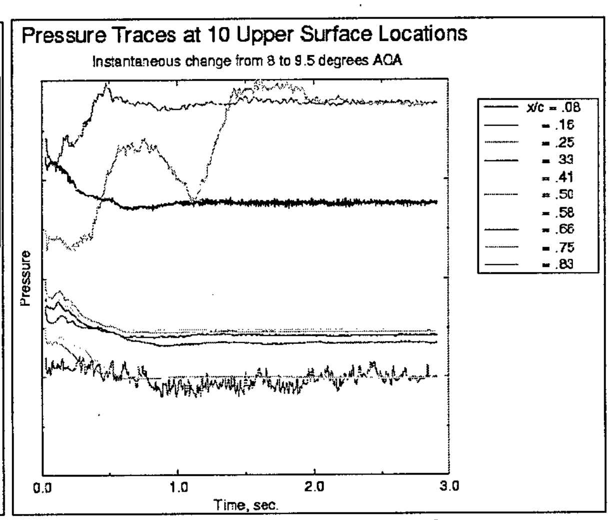

Figure 2

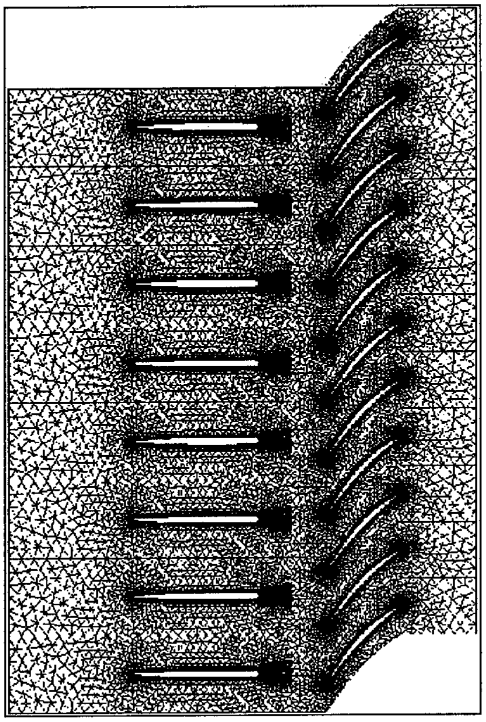

Figure 3

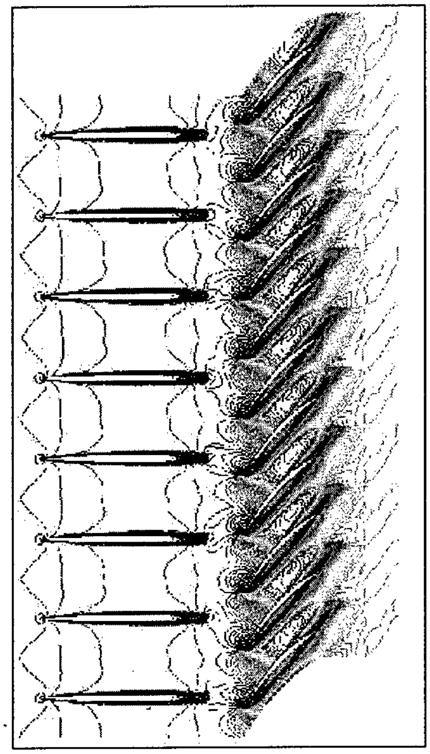

Figure 4

Use of Funds

VA

FY	In-House Labor	Capital Equipment (Computational)	Contracts/Grants	Travel	Total
00	$ 68 K	$ 30 K	$ K	$ 3 K	**$ 100 K**
01	$ 87 K	$ 7 K	$ K	$ 6 K	**$ 100 K**

PR

FY	In-House Labor	Capital Equipment (Computational)	Contracts/Grants (NASA Glenn)	Total
00	$ 22 K	$ 48 K	$ 30 K	**$ 100 K**
01	$ 50 K	$ 20 K	$ 30 K	**$ 100 K**