Technical Evaluation Report

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INTRODUCTION

In the past five to ten years computational aero- and hydro-acoustics (CAA and CHA) have emerged as fields with tremendous potential for physical understanding and prediction of the noise generated by unsteady flows. Many of these advances have been due to the extraordinary increases in computational power that have occurred. In addition, new algorithms, specifically designed for acoustics problems, have been developed.

The NATO/AVT Symposium, held in the Manchester Town Hall, on October 8-11, 2001, provided an opportunity for the assessment of the most promising approaches for the prediction of noise from air and sea vehicles. The program committee, chaired by Prof. Ir. Joop Slooff of the National Aerospace Laboratory/NLR, recognized that the acoustic characteristics of both air and sea vehicles are important in both wartime as well as peacetime operations. In particular, they noted the following four areas of importance:

- "Acoustic fatigue loads and their consequences for structural integrity are important factors in the design and operation of vehicles, air vehicles in particular.
- The acoustic signature of sea and air vehicles is of great importance for military operations in wartime.
- For air vehicles the contribution to community noise during peacetime operations is of growing concern.
- For sea and air as well as land vehicles the inboard noise level and, for air vehicles, the near field acoustic environment is important for the effective and efficient operation of the vehicle and its systems."

The papers presented at the Symposium all contributed in some way to one or more components of the theme. The papers were grouped into sessions focused in the following areas:

- Propulsion and Power Noise
- Fluid Flow Noise
- Noise Propagation
- Structural Response and Acoustic Loads Suppression.

In addition, there were three invited lectures:

- An overview of CAA by Professor Christopher K. W. Tam, Florida State University, USA
- A description of emerging computational tools by Dr. William Blake, U. S. Navy, USA
- A discussion of physiological and psychological effects of low frequency noise by Dr. N. A. A. Castelbranco, Center for Human Performance, Portugal.

The Symposium schedule originally included 29 technical presentations and 3 invited lectures. Prior to the meeting 11 papers were withdrawn or the authors failed to attend. Some of this significant reduction in the number of presented papers was clearly due to the tragic events of September 11, 2001 that put constraints on travel: particularly for government employees or military personnel. However, not all the withdrawals could be obviously blamed on these events and this was very disappointing for the Symposium organizers. In any event, the quality and relevance of the remaining papers provided a sound basis for discussions and conclusions.

In this evaluation it is not intended to provide a detailed summary of the presentations or questions and responses, though some comments are made on each paper presented at the Symposium. Rather, an emphasis will be placed on those areas where further progress is necessary or where particular advances have been made. The evaluation begins with a review of the invited lectures. This is followed by a discussion of the presentations grouped by the first three technical areas listed above. There were no presentations in the last area: Structural Response and Acoustic Loads. An attempt is made to identify areas in need of study that were not addressed directly in the Symposium. Finally, some suggestions are made for future research directions.

INVITED LECTURES

Appropriately, Christopher K. W. Tam of Florida State University delivered the first invited lecture. He has developed specialized algorithms that minimize dissipation and dispersion. He has also provided several non-reflecting boundary conditions for zero flow, uniform flow and nonuniform flow at outflow boundaries. All these techniques are widely used in the CAA community. The techniques were outlined and the rationale behind their development was explained. An example that demonstrated the use of these methods was given in the form of the simulation of jet screech. In this study, Tam used a multi-size-mesh, multi-time-step strategy to reduce computation time. The Cartesian grid in the vicinity of the jet nozzle was very fine and coarser grids, by a factor of two, extended out to the far field. The grid size of the coarsest grid was 2^n times coarser than the finest mesh. In this way the time steps for each region may be synchronized and only the finest grid used the smallest time step. In addition, the Navier Stokes equations were used on the finest grid domains near the jet flow. The Euler equations were used in the coarser domains. No problem was encountered at the interface between the two regions. The agreement between experiment and simulation in terms of modal content, frequencies and absolute levels was impressive.

Even though the simulation considered a three-dimensional phenomenon, a quasi three-dimensional approach was used with only 5 azimuthal modes being considered. Though this is appropriate for the very organized resonant phenomenon under consideration, it avoids the computational complexity associated with truly three-dimensional, broadband, unsteady phenomena. The true broadband component of the measured noise was not resolved and any suggestion of broadband behavior was due to the finite time sampling.

In response to questions concerning the use of high-order schemes in shock-containing flows, Tam noted that he used a selective artificial damping scheme to eliminate high wavenumber components and that the method was not akin to a TVD scheme. Tam also noted that he used the artificial damping throughout the computational domain. Also, with the use of a multi-size- mesh, multi-time-step strategy there was no need for a non-uniform grid. This technique required the least CPU time for the problem under consideration. However, this would not be the case for problems with a more complex geometry. A question was raised as to whether the use of the use of the k-ε turbulence model might cause the loss of physical significance. Tam replied that the turbulence model simulated the cumulative effects of the small-scale turbulence. Since the wavelengths of the large-scale instabilities are so much greater than the fine scale turbulence, the scale disparity allows the neglect of the effect of each individual fine scale eddy. Only their cumulative effect needs to be modeled.

William Blake described various computational and experimental methods that are under development for the prediction of fan or propulsor noise with a particular emphasis on low Mach number or hydrodynamic applications. The tools are in a modular form with different aspects of the problem being treated separately. For example, LES or DNS may be used to describe the details of the flow field near the blade. For engineering purposes, on complex geometries, a combination of RANS and embedded LES methods are used. The fluid loading and noise sources may be described in terms of a surface dipole for acoustically compact sources. Blake argued that the essential difference between aeroacoustic and hydroacoustic applications is the lack of quadrupole source mechanisms. In addition, bubbly flows and cavitation are also not present in aeroacoustic applications. Examples were given for several applications. In the case of the response of rotors to inlet turbulence it was shown how an inversion of the predicted noise, based on simple strip theory, could be used to extract information on the incoming turbulence. Cascade effects and rotor/stator interaction were also described. The distortion of wakes by a swirling flow, which is important in the determination of the interaction of the wake with a downstream stator, was discussed. It was noted that the stability of the wake flows follow Rayleigh's criterion for rotating flows. In addition, Blake indicated that full three-dimensional effects were under investigation. Finally, various approaches to the prediction of trailing edge noise were described. Blake stressed the importance of the use of a combination of computational methods when near term engineering applications are under study. He also emphasized the importance of experimental verification of each step in the development of prediction schemes. In response to questions concerning the universality of the predicted inflow turbulence spectrum, Blake indicated that there could be significant differences between different applications and geometries.

Dr. Nuno A. A. Castelo Branco of the Center for Human performance, Alverca, Portugal, delivered the final invited lecture. The topic of his lecture, the risk factors associated with exposure to low frequency noise (LFN), was not central to the Symposium theme of computational methods. However, the presentation provided an enlightening and sobering introduction to the damaging physiological and psychological consequences of exposure to LFN. It was explained how repeated exposure can result in decreased capacity for cognitive functions, the sudden onset of respiratory problems, and mood alterations. These effects are not captured in the usual psychoacoustic metrics, as they cannot be heard: being at frequencies below that of human hearing. However, exposure can result in physiological changes such as thickening of the pericardium and cardiovascular thickening. Dr. Castelo Branco was asked what regulations were under consideration to protect military personnel or civilians from the effects of LFN. He responded that no changes to current legislation were planned or underway with two exceptions: Puerto Rico and Mozambique. In the former case a January 2001 law limits the emission of LFN and in Mozambique preparations for a new law include LFN. He noted that permissible exposure levels for LFN, the necessary recovery times for each type of exposure period and dose-response data are unknown. These are necessary for human exposure legislation. Individual susceptibility indicators are under study in Dr. Castelo Branco's group: but as yet, there is insufficient data. Dr. Castelo Branco's lecture provided a startling exposure of the attendees to the importance of another aspect of aeroacoustics that appears to have been almost overlooked.

Propulsion and Power Noise

The first papers in this area focused on fan noise and its prediction. Yin and Delfs described calculations of the noise radiated by ducted and unducted fans. The fan was represented by spatially distributed rotating dipoles. They used a multi-domain strategy similar to that discussed by Tam. Their predictions showed that in the absence of flow the ducted fan radiated no noise as the modes were cut off. In the presence of flow, a mode generated by the fan was cut on according to theory and this was shown by the numerical solution. In addition, the inclusion of a shear flow outside the uniform parallel stream representing the parallel duct flow was shown to change the radiated noise directivity: presumably due to refraction. It was surprising that the shear layer only seemed to generate an instability wave when excited by the transient sound radiation. One might expect a thin shear layer to support a wide range of unstable frequencies. It would be easy to check using a parallel flow stability analysis whether this is the case. Also, it would be instructive to include the shear layer generated by the duct boundary layer in the calculations. In response to questions the authors indicated that swirling flow could be included in the calculations and that the imposed shear was only external to the duct wall.

Wilson submitted a paper that introduced a different perspective to the analysis of numerical simulations. Faced with the likelihood that discrete boundary conditions for internal flows are imperfect, a method was presented to extract the "real" acoustics from numerical reflections. This is an intriguing approach that may be very helpful when a traditional CFD code is being used to analyze aeroacoustic behavior. The paper indicated the conditions and regions where the wave-splitting technique would fail to work. These include the fan exit region owing to the presence of swirl and lined ducts. Also, the method does not work well near the cut-on/cut-off boundary. To some extent, the paper begs the question as to whether the technique could not be employed to improve the existing nonreflecting boundary conditions.

de la Calzada, Quintana and Burgos described the application of a traditional nonlinear CFD code for the simulation of acoustic propagation. Few details of the code were provided. In addition, the examples did not make use of standard benchmark problems that would have allowed a better assessment of the accuracy of the method. The importance of nonreflecting boundary conditions and grid resolution were highlighted. The paper raises the interesting question of the balance between the use of an existing and well-tested (for CFD purposes) code for acoustics problems and the development of a specialized high order code. In the long term, the latter choice is likely to be appropriate: but in the short term, especially if complex geometries are to be analyzed, the continued use of a low-order accurate existing codes with a very refined grid may be the logical choice. The authors emphasized this point in response to questions. It was their intention to minimize the number of different codes used in the simulation of unsteady aero-thermal behavior of turbine stages and they were concentrating on only having one code. They also argued that the typical acoustic wavelengths considered were already much longer than the typical scale of the viscous regions in the flow. Thus a fine mesh was already necessary to resolve the viscous effects. Of course, this is balanced by the need for additional grid points in potential flow regions. In terms of execution time the authors indicated that the nonlinear code took only twice as long as the linear code: the nonlinear code requiring one day to run the flat plate cases presented in the paper.

Huttl, Kahl, Kennepohl and Heinig described the use of a linearized Euler solver for the study of acoustic propagation and the interaction of sound waves with a cascade. The code used a finite-volume discretization and a three-step Runge-Kutta time integration. The authors demonstrated the effect of propagation angle relative to coordinate directions on a very skewed Cartesian grid. The details of the boundary conditions were not provided. Though, in answer to questions, it appears that the boundary conditions were prescribed on the basis the analytical solution. This would seem to overspecify the problem. The authors gave some criteria for accuracy in amplitude and phase for plane waves. It is not clear how this would help for broadband acoustic phenomena with significant variations in propagation angle. The authors' comparisons with an analytic solution for sound propagation through a cascade of plates were impressive though the boundary conditions were again unspecified. Though this is a good starting point, the performance of the code for realistic blade geometries and loading and broadband disturbances is unknown.

Djaffar, Alexandre and Hany described a fan noise generation and propagation code developed by Pratt & Whitney Canada. An important component of this work was the integration of a CFD solver for the fan pressure distribution and its coupling with an acoustic radiation code. The numerical method was based on a spectral element technique and the grid generation was achieved with a CAD based approach. The test cases considered were sufficiently realistic to indicate the potential for CAA methods to make a real contribution in the near term to fan aeroacoustic design.

Jayatunga, Kroeff, Carrotte, McGuirk and Petersen authored the one paper in the area of Power Systems. This was a combined experimental and computational study of the flow and noise in the diffuser of an industrial gas turbine engine. A steady RANS CFD calculation and experiments were used to identify the gross features of the flow and the potential noise producing regions. Once the diffuser was identified as a primary noise source, a geometrically simplified model was examined using LES. On the basis of preliminary results from the LES the acoustic analogy was used to predict the radiated noise power. The source was modeled as a ring of dipoles. However, since the LES provides the wavenumber/frequency characteristics of the wall pressure fluctuations, (once a long enough time sample has been obtained), this information could be used to describe the noise source.

In the area of Jet Noise, Page, McGuirk, Behrouzi and Hossain described a combined experimental computational study. As in the previous paper the averaged flow properties were determined by a RANS CFD solution. The information on turbulent kinetic energy and length and time scales were then used in a "four source model" for the noise from a coaxial jet. The agreement between the CFD and experiments was reasonable in the early stages of the jet development though it deteriorated further downstream. This could have been associated with experimental errors in seeding the ambient flow. No noise predictions were provided. In response to questions the authors argued that RANS CFD would be more effective than LES or Detached Eddy Simulation (DES) for jets with complex exit geometries. However, it is difficult to see how the inherently isotropic k-ε turbulence model could capture the subtle mixing effects of serrations or chevrons. Also, the authors indicated that they were not yet modifying the "four source model" on the basis of the CFD but were determining the equivalent coplanar exit conditions presently required by the model.

Harper-Bourne described his prediction scheme for the near-field noise of combat aircraft. This paper could have fallen into the category of Acoustic Loads, as it dealt with both hydrodynamic and acoustic loads in the jet near field. Prediction models for both the jet mixing noise and shock-associated noise were presented. The predictions were based on the Lighthill acoustic analogy with the turbulent source statistics described in a fixed reference frame. Predictions of both Sound Pressure Level (SPL) and spatial coherence of the near field were made. The agreement between the predictions and measurements was quite good: though the method is semi-empirical and uses some of the measured data within the prediction scheme. However, it did show the effectiveness of the acoustic analogy formulation - even in the jet near field. In response to questions the author indicated that the assumptions about the form of the source cross correlations do affect the convective amplification factors. Details are contained in the AIAA paper (AIAA 99-1838) referenced in the written version of the paper.

Bogey, Bailly and Juvé presented an impressive LES study of a Mach 0.9 jet. The agreement achieved between predictions and experiment for both the flow and noise properties and available experiments was excellent. The authors chose a relatively low Reynolds in order to be able to capture as many turbulent scales as possible within the framework of the LES. They also described their interrogation of the instantaneous flow and noise fields to identify regions of apparent strong noise production. They concluded that the flow properties at the end of the potential core correlated well with the largest excursions in the acoustic pressure signal at small angles to the jet downstream axis. It appears that the frequency of the noise radiation is set by the fundamental stability properties of the jet flow: but that the breakdown of the large turbulent structures at the end of the potential core scatters energy into the low wavenumbers required for noise radiation. The highest resolved frequency, approximately a Strouhal number of unity, was set by the grid resolution in the near and mid acoustic fields where the linearized Euler equations were used to propagate the sound. The frequency resolution in the flow field was higher and a broader frequency range of the radiated noise could be predicted.

FLUID FLOW NOISE

In the area of shear layers and vortex shedding/interaction, Michael Howe presented the first paper. This paper described a methodology for the determination of the Green's function in the presence of either stationary or vibrating boundaries. The technique used the Kirchhoff vectors for the body in the definition of the compact Green's function. The Kirchhoff vector components are the velocity potentials of incompressible flow past the body having unit speed in the component direction at a large distance from the body. I had not encountered the use of these vectors before and they appear to be a powerful analytic tool. Several cases were examined including a source in the vicinity of a surface irregularity, sound from a vortex interacting with a sphere, parallel blade vortex interactions, edge noise, and a projectile entering a duct. This last case, that could represent a high-speed train entering a tunnel with an entry hood, gave impressive agreement with experiment. In every case the unsteady flow was deterministic. In the last case of the projectile entering the duct the noise contribution from the vortex sheets shed from the discontinuities in the duct cross section were small. Thus, although these solutions serve as excellent benchmark cases to validate CAA codes, it is not clear that the paper represents either CAA or CHA (at least as far as I understand their definition).

Golanski, Fortune and Lamballais presented a low Mach number DNS of a temporally evolving shear layer. They compared this low Mach number approximation with a full DNS and showed good agreement. The purpose of the study was to examine noise scaling for nonisothermal turbulent shear flows. For an isothermal shear they showed that the scaling with Mach number could be deduced from Lighthill's acoustic analogy assuming a "quadrupole" source. However, for the nonisothermal case the scaling was better approximated by assuming that the nonisentropic, "dipole" source term was dominant. This has implications for source modeling in heated turbulent flows. However, the results are only formally valid at very low Mach number, which may be of limited practical importance.

Lummer, Grogger and Delfs described the use of mean flow fields calculated using a steady RANS CFD code in CAA simulations. The paper was focused on the development of efficient and accurate interpolation methods to map the RANS flow field onto a CAA grid. The largest errors were observed where the CFD grid had kinks or was very coarse: but in the latter case these are regions where the mean flow gradients are small. An example of the solution of the linearized Euler equations was provided for the interaction of an acoustic pulse with an airfoil. This paper provided an example of the numerical algorithms that must be carefully developed when the acoustics of nonuniform men flows are examined. It is also possible to converge the mean flow to a steady state on the CAA grid prior to the introduction of unsteadiness. Local time stepping and multigrid methods are useful in this approach. In response to questions the author agreed that the mass and momentum balances for the interpolated mean flow on the CAA grid were not checked. However, the linearized Euler equations were solved in non-conservative form so artificial fluxes will always be present. It was assumed that the modeling error in the RANS calculation was at least one order of magnitude larger than that introduced by interpolation.

Ewert, Meinke and Schröder described several formulations of hybrid CFD/CAA methods. These included a compressible extension of the viscous/acoustic splitting technique of Hardin and Pope, the linearized Euler equations with momentum sources, and the "acoustic perturbation equations." The last represent an attempt to separate acoustic and non-acoustic sources within the framework of an acoustic analogy. An example problem of the noise radiated by a cylinder in a laminar flow at low Reynolds number was given. The general methodologies all depended on a separate compressible CFD solution for the flow field and the use of linearized Euler equations for sound propagation. Since the compressible near field solution is available, the radiated noise could presumably also be obtained using an acoustic analogy, wave extrapolation method such as the Ffowcs Williams Hawkings equation.

Manoha, Delahay, Redonnet, Ben Khcli, Guillen, Sagaut and Mary described a similar set of approaches. Here, the near field flow solution was extended to the far field using either the Ffowcs Williams Hawkings acoustic analogy, applied on the surface, a Kirchhoff integral method or the discretized Euler equations. The porous surface Ffowcs Williams Hawkings integral method (also referred to as a wave extrapolation method) was not used. This might have improved the matching between the extrapolated solution and the direct computation as evidenced by the discontinuity observed when the Kirchhoff integral method was used. The authors applied their numerical approach to the noise radiated by a lifting airfoil. The focus was on the noise generated and scattered near the trailing edge. In results not given in the written version of the paper they showed how upstream and downstream propagating waves in the airfoil boundary layer could be distinguished using the wavenumber frequency transform of the LES solution. This indicated that some scattering occurred at the leading edge as well. This is a very effective way of interpreting the unsteady data.

Two papers were presented in the area of cavity noise. The first, by Soemarwoto and Kok used two different sets of equations to describe the flow. The first was based on a RANS solution with the k-ω turbulence model throughout the entire domain. The second only applied this model in the boundary layer regions. The Euler equations were used in the reminder of the domain. This choice was made as the RANS solution was too diffusive for the separated shear layer flow and suppressed the broadband behavior. Also, the apparent resonant third and fourth resonant modes were found to be harmonics of the lower modes and did not conform to Rossiter's formula. The results were stated to show good agreement with experiment for the amplitude of the resonant modes when the latter model was used. The effect of a ramp at the cavity trailing edge was shown to suppress the resonant feedback effects. The authors indicated that the flow/acoustic code was fully coupled with a structural dynamics code for aeroelastic calculations. They also stated that the discretization errors of their code had been assessed separately. Also, they argued that the initial conditions played no role in the results as sufficient time had been allowed for transients to exit the computational domain before sampling was performed. The authors also responded that a Detached Eddy Simulation was under consideration to overcome the diffusive nature of the RANS model.

Gloerfelt, Bailly and Juvé described a two-dimensional DNS of a cavity with length to depth ratio of 2. They used their simulation to evaluate different methods to extrapolate the near flow field solution to the far field. In particular the porous Ffowcs Williams Hawkings acoustic analogy was considered. Examples where the volume integral was included or omitted were given. The porous Ffowcs Williams Hawkings acoustic analogy method was compared with a Kirchhoff method for different integration surfaces above the cavity. Since the additional nonlinear terms given by the former method are small in the case considered, there was little difference between the two wave extrapolation techniques. There was a difference in the radiated noise field when only the surface integral was included in the acoustic analogy. This was because the volume term contained significant information on the noise sources.

However, it is more expensive to implement (even in two-dimensions). The authors concluded that for the problem under investigation the wave extrapolation methods provided the most efficient method for obtaining the radiated noise field.

NOISE PROPAGATION

The technical presentations concluded with two presentations on noise propagation. Kirkup described several applications of the Boundary Element Method (BEM). He noted that for both exterior and interior acoustic problems in uniform media the BEM has considerable advantages over either Finite Element or Finite Difference methods. This is because the problem may be transformed into a surface integral form. Examples were given of applications of the method and a suite of Fortran routines available to potential users were introduced. The author noted that the method was very efficient for sound propagation in uniform media (calculations taking only seconds or minutes on a modern PC) but was unable to describe propagation in nonuniform media. The order of accuracy depended on the elements used. The examples given by the author used piecewise constant elements as these are the simplest and most efficient to implement.

Blom, Hagmeijer and Védy described the development of the Discontinuous Galerkin (DG) method for the solution of the linearized Euler equations. This method has the advantage that it can be high-order accurate on an unstructured grid with only local dependencies. This makes the method efficient for parallel implementation. The authors gave an example of the use of their three-dimensional code in the solution of a two-dimensional sound propagation benchmark problem. They also provided some information on the parallel performance of the method. A grid dependence study was performed to assess the convergence of the scheme. They noted that a formal order of accuracy had only been established for a one-dimensional problem on a uniform grid. The authors also indicated that, for structured grids, finite difference methods would be more efficient: however, the DG method is more suitable for unstructured grid calculations.

SUMMARY AND CONCLUSIONS

The technical presentations at the Symposium showed how far computational methods for the prediction of noise from unsteady flow have advanced in only a few years. However, the papers also indicated that considerable progress is still to be made. Perhaps the clearest distinction between the different approaches that were presented was between methods that focused on the understanding of the physics of sound generation and radiation and those that attempted to solve problems of immediate practical importance. The distinguishing characteristic between these two classes mostly lay in the complexity of the geometry considered. For the most part, methods that have been developed and applied successfully to CAA problems have been based on high-order accurate algorithms. Methods developed for problems involving complex geometries have typically been low-order accurate. The exceptions to this are spectral element methods, such as those described by Djaffar *et al.* that inherently involve the use of structured grids, and the Discontinuous Galerkin method. The latter may be applied on unstructured grids but suffers computational costs when high-order basis functions are used for the nonlinear Euler or Navier-Stokes equations. Thus, it would appear that the directions for future work will involve:

- Detailed studies of fundamental aeroacoustic phenomena for simple geometric cases, and
- Hybrid schemes, where a detailed near field flow solution is coupled with an acoustic analogy or wave extrapolation method to obtain the radiated noise.

In the latter case, a trade must be made between the order of accuracy of the method, with the resulting decrease in the grid resolution requirements, and the applicability of the method to problems with complex geometry. In addition, the availability of existing unsteady flow solvers must be considered, especially if the aeroacoustic calculations are part of a larger suite of programs that might include aerodynamic performance and aeroelastic behavior. The compatibility of the codes is certainly an issue.

In terms of algorithmic development, a basic set of CAA algorithms is now available. Further development may be necessary for strong shock-containing flows: but the example given by Tam for the screech simulation suggests that this is not a problem if selective artificial damping is used. A caveat would be that this example did not involve the interaction of a broad range of turbulent scales with the shocks. Thus, it would appear that the door is open for attacks on problems that are generated by "real world" geometries. This is where further algorithmic development appears to be needed. If a reliance on low-order, traditional unsteady CFD methods, with a very fine grid, is to be avoided, then much remains to be done to develop *efficient* high-order schemes for complex geometries. Until such methods appear, complex geometric aeroacoustic problems will continue to only be amenable to detailed flow field simulations, with low-order schemes on a very fine grid, coupled with extrapolation methods for the radiated noise.

Though the field of CAA has much to accomplish, the high-order methods that have been developed so far hold tremendous potential for applications in other areas of fluid dynamics. It should be recognized that these methods are a considerable improvement over traditional CFD methods for unsteady flow problems. Thus, applications to problems in areas such as transition, turbulence simulation, thermoacoustics, nonlinear wave propagation, to name but a few, are ripe for attack by the CAA community.

As a final comment, it is interesting to note that none of the papers addressed the issue of noise reduction. At the same time as we gain an increased understanding of the physics of noise generation, our focus should be on how this information could be used to reduce noise. That is at least as great a challenge as the "simple" simulation or prediction of noise generation and radiation.

Reference # of Paper: Technical Evaluation Report
Discusser's Name: Dr. Bastiaan Oskam
Author's Name: Prof. Philip Morris
Question:

You concluded that there is no need for new algorithms. How about shock noise due to shock/turbulence interaction? Do we not need higher-order accurate algorithms that can also represent shock waves without spurious oscillations?

Answer:

The point I was trying to make was that there are many high-order accurate algorithms now available for wave propagation on structured grids. Further effort in this area would appear to be a waste of effort. In addition, the results presented by Professor Tam indicated that a careful combination of high-order methods and artificial damping do result in the accurate simulation of shock-containing flows. However, in that area, I would agree that the broadband interaction problem has yet to be tackled and I would withhold any conclusions until that problem is attempted. The main point I was trying to make was that a great deal of effort should be expended to develop robust and efficient methods for aeroacoustic problems on unstructured. Then CAA can be applied to geometries of practical interest.