by Rowe,[17] where the independent variable employed in the extrapolation process is the inverse of the number of panels along the chord. The $M = 1.2$ results were obtained using 40×8 and 45×9 grids, and it must be pointed out that both discretizations present the same panel aspect ratio. Although the overall agreement is very good between all methods studied, the present calculations are very close to those using the integrated-downwash model due to Stark.[7] One can also see from Table 1 that the agreement among results remains good for $M = 1.05$. Because in this case $1.5 < K < 3.1$, more refined discretizations along the chord are employed, that is, 45×6 and 60×8. Here the chordwise pressure distribution is very wavy, at least for $k_r = 0.3$.

Final Remarks

It has been shown that the present formulation gives excellent agreement both with analytical results (bidimensional region at the symmetry line) and numerical results (generalized aerodynamic coefficients) from other references. In the latter case, the authors consider that the extrapolation process to an "infinite" grid is necessary to guarantee converged values of the coefficients.

Another important point is that the generalized supersonic vortex-lattice method is an extension of the method in the case of subsonic regime. This is possible due to the use of a constant density doublet distribution over the wing (and wake, if necessary). For the aerodynamicist this is useful because this singularity is familiar and well known.

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A. Plotkin
Associate Editor

Effect of Yaw on Pressure Oscillation Frequency Within Rectangular Cavity at Mach 2

Peter J. Disimile* and Paul D. Orkwis†
University of Cincinnati,
Cincinnati, Ohio 45221-00070

Nomenclature

D	= cavity depth, cm
f_D, f_L, f_W	= fundamental acoustic modes based on cavity depth, length, and width, Hz
$f_{e,m}$	= Rossiter's edgetone frequency for mode m equal to 1, 2, 3, ..., Hz
f_v	= vortex shedding frequency, Hz
L	= cavity dimension along the minor axis, cm
M_∞	= freestream Mach number
Re_θ	= Reynolds number based on the boundary layer momentum thickness
Sr_θ	= Strouhal number based on momentum thickness, $f_v\theta/U_\infty$
U_∞	= freestream velocity, m/s
W	= cavity dimension along the major axis, cm
θ	= momentum thickness of the approaching boundary layer, mm
ψ	= yaw, the angle between U_∞ and cavity minor axis L, deg

Introduction

THE presence of a cavity in a surface bounding a fluid flow can cause large pressure, velocity, and density fluctuations in its vicinity as well as strong propagating acoustic waves. In addition, the drag on the surface can be altered, sensitive instrumentation can be damaged, and structural failure due to resonance can occur. Such flows are of interest in many different areas of engineering. Landing-gear wells, surface-mounted optical instrumentation, and bomb bays on aircraft are common examples of cavities in which reduction of pressure fluctuations, vibration, noise generation, and sonic fatigue are of prime concern.

Supersonic cavity flowfields contain a mixture of unsteady flow regimes that may include unstable shear layers that shed vortices in coherent patterns, unsteady weak shock or pressure waves, and resident vortices oriented in the transverse direction. This interaction is the result of an extremely complicated flow pattern that appears to depend on the shape of the cavity, freestream Mach number, Reynolds number, and the characteristics of the approaching boundary layer. Many prior investigations[1–4] have been conducted to gain insight into the underlying physical behavior of cavity flows. These studies, including that of Rossiter,[5] have made it possible to predict some features of the observed phenomena. Unfortunately,

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*Associate Professor, Department of Aerospace Engineering. Member AIAA.

†Assistant Professor, Department of Aerospace Engineering. Member AIAA.

this is limited to situations where the cavity spans the flow, i.e., the cavity is oriented at zero yaw. Although limited information is available for yaw angles other than 0 deg (Refs. 6–9), studies have examined cavities at 15 and 45 deg. The goal of the present work is to examine the effect of yaw on the frequency of oscillations in an open cavity when placed in a supersonic flow.

Experimental Tests

To accomplish this task, a cavity model with a length to depth ratio L/D of 2 and an aspect ratio W/L of 11.83 was fabricated. This model represents an open cavity configuration when positioned at 0-deg yaw. Figure 1 is a sketch of the cavity, which designates the locations of the high-speed pressure transducers used to monitor the pressure oscillations. Pressure transducers were mounted along the cavity centerline at the following locations: 1) $0.27L$ upstream from the separation lip, 2) $0.67L$ along the cavity floor, and 3) $0.33L$ past the aft lip of the model.

The cavity model was located in the sidewall of a 15.24×16.54 cm test section. Test conditions for the present study were $M_\infty = 2$ and $Re_\theta = 7.3 \times 10^4$. Several Mach number profiles acquired across the test section and the approaching wall boundary layer were documented prior to the acquisition of cavity data. The average M_∞ within the test section core was estimated at 1.98 ± 0.05. The calculated θ was nominally 1.92 mm, whereas boundary-layer thickness was estimated to be 12.7 mm, thereby confirming the assumption that the test section corner boundary layers were sufficiently far from the cavity side wall. The worst-case velocity deviation throughout the turbulent boundary layer was 7%. Data also showed good agreement when plotted in law of the wall coordinates between $250 < y^+ < 25{,}000$ (Ref. 10).

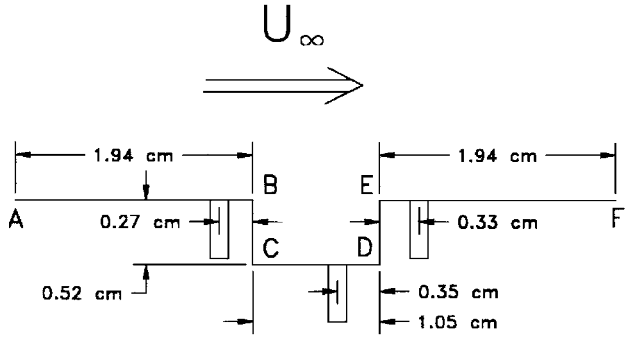

Fig. 1 Schematic of cavity.

The sound pressure level ($\overline{SPL}$) (in decibels) and frequency content of the upstream boundary layer were recorded to determine the effect of the cavity on the upstream flowfield. In case 1, the cavity floor was set such that $L/D = 2$, whereas in case 2, the cavity was eliminated. It was determined that the presence of the cavity produced no significant difference in the pressure signals received from the upstream transducer. Inspection of the fast Fourier transforms (FFTs) generated from the signals produced by the upstream transducer indicated a broad spectrum containing low-level noise without any dominate peaks. Integrating this signal, an $\overline{SPL}$ of 146.42 dB was determined. Likewise, the signal obtained from the cavity transducer showed a pressure oscillation at approximately 22.75 kHz. The amplitude of this peak was almost 10 times greater than the background noise. A comparison of the $\overline{SPL}$ determined from both the upstream and cavity transducers showed a 15 dB difference.

Results and Discussion

Variations in the dominant cavity frequency as a function of ψ (Fig. 2) have lead to the following observations. First, a dominant pressure oscillation at 22.75 kHz was visible up to 35 deg. Within this ψ range, the dominate mode remains constant to within 500 Hz. Tracy and Plentovich[6] also reported no significant difference in the frequency content of their pressure signals. Second, at $\psi = 45$ deg there is no certain dominant mode. After several runs, it was noted that although most tests produced a dominate peak at 7.75 kHz, the dominant mode switched between 23 and 7.75 kHz. The authors are not certain of the cause, but it appears that slight misalignment in the cavity ψ may have been responsible for this variation. Similar events were also noted by Plentovich[11] when very small changes in cavity length to depth ratio caused the cavity flow to switch modes. Third, a second and third mode was noted between 0 and 37.5 deg. Last, beyond $\psi = 45$ deg, the frequency of the dominant mode increased from 7.75 to 12.5 kHz at 65-deg yaw. No secondary peaks, i.e., higher modes, were identified within this range of ψ.

Using Rossiter's[5] empirical approach, the frequency of the cavity oscillations at 0-deg yaw was evaluated. The resulting correlation related the frequency of the dominate modes ($m = 1, 2, 3, \ldots,$) produced by vortex shedding within the cavity to a modified Strouhal number. This resulted in edgetone frequencies of $f_{e,m=1} = 9{,}916$ Hz, $f_{e,m=2} = 23{,}138$ Hz, and $f_{e,m=3} = 36{,}360$ Hz corresponding to each mode. In addition, the fundamental frequencies of the acoustic modes based on L, W, and D were also determined and found to be equal to 11.55 kHz, 986 Hz, and 23.24 kHz, respectively. Comparisons were also made with the vortex shedding frequency f_v determined from the Sr_θ. The Sr_θ for a separating

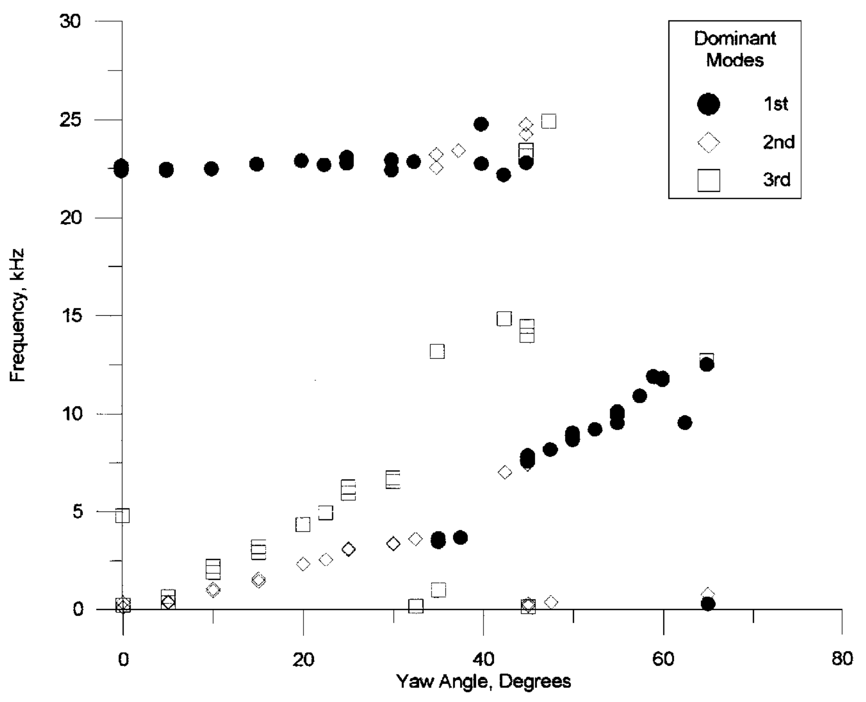

Fig. 2 Frequency of the dominant modes as a function of yaw angle ψ.

subsonic turbulent boundary layer is typically 0.021. This produced an $f_v = 5.34$ kHz, which is within 53.8% of Rossiter's predicted edgetones for the $m = 1$ mode.

As previously noted, an examination of the present frequency spectra at 0-deg yaw clearly indicated 22.75 kHz as the fundamental mode, with secondary peaks between 120 and 350 Hz. Because the fundamental mode matches the acoustic mode f_D within 2%, it may be suggested that the dominant oscillation was the result of a transverse mode. Therefore, the transverse acoustic mode based on the cavity depth would appear to be the mechanism producing the pressure oscillations recorded along the cavity floor and not the mode corresponding to vortex shedding. Yet, Rossiter's[5] second mode also agrees with the present measurements to within 1.7%, suggesting a fluid dynamic mechanism. In addition, the second mode is in good agreement with the computations of Tam et al.,[10] who determined this frequency numerically via an FFT of the pressure history at the wall centerline. Their computed frequency was approximately 26 kHz. Further, a recent work by the Ref. 12 authors provided flowfield simulations that contained a pressure wave that reflected off the floor of the cavity. This pressure wave may represent the transverse acoustic mode.

Although a combined fluid resonant flow may be the logical conclusion, it is suggested that the acoustic mode, which produced a self-sustaining oscillation in spite of small geometric changes, may be the dominant driving mechanism in the present study, at least until ψ of 35 deg. This result is similar to the flow transition reported by Zhang and Edwards[13] in which the flow switched modes from a transverse oscillation to a longitudinal oscillation as the cavity length was increased. In the present study, mode switching between 35 and 45 deg was observed to produce oscillations with frequencies of either 23 or 3.5 kHz. Beyond 45 deg, a permanent mode switch was observed. The resultant dominant frequency was 7.7 kHz at 45 deg, which increased linearly to 12.5 kHz at 65 deg yaw.

Summary

An investigation into the effect of yaw angle variations in a two-dimensional open cavity placed within a supersonic freestream was performed. The effect of yaw angle changes on the frequency of the dominant pressure oscillation was noted. Specifically, there appeared to be little change in the frequency of the oscillation up to 37.5 deg. Comparison of the measured dominant mode to the fundamental acoustic mode based on cavity depth, i.e., the transverse mode, were found to be in excellent agreement. This suggests that the dominant mechanism for the present configuration was acoustic in nature and not fluid dynamic. However, a variation in the secondary mode, probably fluid dynamic in nature, showed an increased importance as the yaw angle was increased.

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P. R. Bandyopadhyay
Associate Editor

Computations of Unsteady Separating Flows over an Oscillating Airfoil

Sungho Ko* and W. J. McCroskey†
NASA Ames Research Center, Moffett Field, California 94035-1000

Introduction

UNSTEADY separating flows over oscillating airfoils occur in many important engineering applications, such as airplanes, helicopter rotors in forward flight, and turbine blades. There are some distinct features of the unsteady separating flows (dynamic stall) over a rapidly oscillating airfoil that draw the special attention of many scientists. These features include large amounts of force and moment hysteresis and oscillatory pressure fluctuations. In most situations, these features of dynamic stall significantly limit the performance of the device.

The primary objective of the present study is to identify the most accurate, robust, and economic turbulence model for dynamic stall computations. However, testing all of the turbulence models available is simply impractical. Alternatively, only a few popular and representative models are selected after surveying papers and reports on separated flows. The Baldwin–Lomax (B–L) model[1] is selected because of its popularity as a zero-equation model. The Spalart–Allmaras (S–A) model[2] is chosen among one-equation models because of its excellent performance. Finally, the k–ϵ model[3] is selected because it is the most popular two-equation model.

Numerical Methods

The governing equations are the time-averaged, two-dimensional, compressible thin-layer Navier–Stokes equations. These governing equations are solved by the TURNS (Transonic Unsteady Rotor Navier–Stokes) code.[4] The inviscid convective fluxes $\hat{\boldsymbol{E}}$ and $\hat{\boldsymbol{G}}$ are differenced by the Roe's upwind-biased flux-difference splitting scheme.[5]

The time-marching integration of the governing equations is done by using the lower–upper symmetric Gauss–Seidel (LU-SGS) implicit scheme.[6] Whereas the LU-SGS scheme is unconditionally

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*Research Scientist, Sterling Federal Systems, Inc.; currently Assistant Professor, Department of Mechanical Design Engineering, Chungnam National University, Taejon 305-764, Korea. Member AIAA.

†Senior Research Scientist, U.S. Army Aeroflightdynamics Directorate–Aviation and Troop Command. Fellow AIAA.