"tail-off" c.g. margin, while c_{tp} and c_{tt} share the same sign, as before. Thus, when the pitching axis runs through the aircraft c.g., v is greater or less than unity according to whether the two c.g. margins have the same sign or not; but when the "tail-on" c.g. margin is infinite and the "tail-off" c.g. margin is finite, v is unity.

To help in the study of the conditions at and near the FDS, we differentiate Eq. (1) with respect to n, put $\nu = 1$, and, to simplify matters, assume that the wing is mass balanced ($\xi_i = 0$) and get

$$\begin{bmatrix} c_{hp} & c_{ht} & c_{hs} \\ c_{pp} & c_{pt} & 0 \\ c_{tp} & 0 & 0 \end{bmatrix} \begin{bmatrix} q_e' \\ q_t' \\ q_s' \end{bmatrix} = \begin{bmatrix} 1+b \\ \bar{\xi} \\ 0 \end{bmatrix} \tag{3}$$

where $q' = \mathrm{d}q/\mathrm{d}n$ and $\alpha_0 = Mg/(\frac{1}{2}\rho V^2 S a_1)$.

This matrix equation can be solved by inspection to get

$$q_p' = 0 \tag{4a}$$

$$q_t' \alpha_0 = \bar{\xi} / c_{pt} \tag{4b}$$

$$q_s'/\alpha_0 = 1 - \bar{\xi} c_{ht}/c_{pt} + b \tag{4c}$$

Under the same conditions, Eq. (1) gives the pitch angle itself as zero[3] and, from this and Eq. (4a), we see that the pitch angle is zero whatever the normal acceleration. All the wing incidence is due to torsion and in the present case the incidence at the wing tip is 50% greater than it would be were the wing rigid. Hence, the spanwise position of the center of action of the wing lift is further outboard than it would be on a rigid wing and the flexural and torsional moments the wing structure has to resist are increased. The maldistribution of lift over the span becomes worse as the speed is increased above the FDS, because the pitch angle becomes increasingly negative and the amount of torsion must be increased to counteract it.

Turning our attention to Eq. (4c), the trimming surface angle, per g, c_{pt}/c_{ht} is the moment arm in pitch of the lift due to torsion that, in this case, is the distance between the aerodynamic centers of the trimming surface and wing. Hence $\bar{\xi} c_{ht}/c_{pt}$ will be greater or less than unity according to whether the "tail-off" c.g. margin is negative or positive, but in either case $1 - \bar{\xi} c_{ht}/c_{pt}$ is likely to be small. b, the trimming surface pitch damping, is $\frac{1}{2}\rho s c \bar{\xi} a_1 / M$, where s is the area of the trimming surface and the other letters have their previous meanings,[4] and is also likely to be small. Thus, the trimming surface angle per g will be small at the FDS and will be zero for a particular speed near it and at this speed the aircraft will be in trim whatever the normal acceleration.

The foregoing describes an essentially static conception of divergence and the aeroelastic phenomena allied to it. The divergence speed given by the trim equations is high, but the same equations show that there might be problems due to adverse spanwise loadings at lower speeds and that, at speeds near its fixed-root divergence speed, the normal acceleration of the aircraft will be very sensitive to trimming surface angle. The example taken is simple, but there seems no reason why similar results would not be obtained from more comprehensive equations.

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Dynamic Loads on Twin Jet Exhaust Nozzles Due to Shock Noise

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Introduction

STRUCTURAL failure of the B-1 aircraft exhaust nozzle external flaps has been observed during flight tests.[1] Similar damage to some F-15 aircraft has also been noted. Since both aircraft contain twin engines with similar internozzle spacing a phenomenon resulting from the interaction between the two jets is a possible cause of this damage. This Note examines the acoustic near field generated by model single and twin jet configurations to determine if closely spaced dual nozzles generate significantly higher acoustic loading than that encountered with a single nozzle.

The major component of the noise from a jet measured in the downstream direction is due to turbulent mixing. However, for underexpanded sonic jets and imperfectly expanded supersonic jets, the sound radiated in the upstream direction is dominated by shock noise, consisting of both random and discrete components designated as broadband shock noise and jet screech, respectively.[2] Screech is a feedback process between the shock cells and the nozzle exit involving disturbances within the jet and upstream traveling sound waves. It is characterized by stages, with stage changes being marked by a frequency shift in the generated tones[3] and a spatial shift in the downstream shock structure.[4] As many as five stages have been identified, these having been labeled[5] as stages A_1, A_2, B, C, and D. The maximum amplitude of the fundamental tone of each stage is measured in the upstream direction.[4] For a given nozzle pressure ratio, increasing jet temperature raises the screech frequency due to higher velocities in the jet.[6] Flight influences which stage dominates[7] and lowers screech frequencies by increasing the feedback cycle time.[8] Screech tones have been measured in a Trident aircraft in flight[9] and have been blamed for structural damage to the empennage of a VC10 aircraft.[10]

Experiment

The experiment was conducted in the NASA Langley Quiet Flow Facility.The dual nozzles were constructed from ⅝ in. internal diameter pipe. Their external surfaces were machined to provide a thin lip at the nozzle exit and a smooth transition to the housing in which they were mounted (Fig. 1). The nozzle spacing was chosen to equal that of a scaled B-1 aircraft (approximately 1.9 nozzle diam). A ¼ in. microphone was strapped to the interfairing of the nozzles to measure the acoustic field near the nozzle exit

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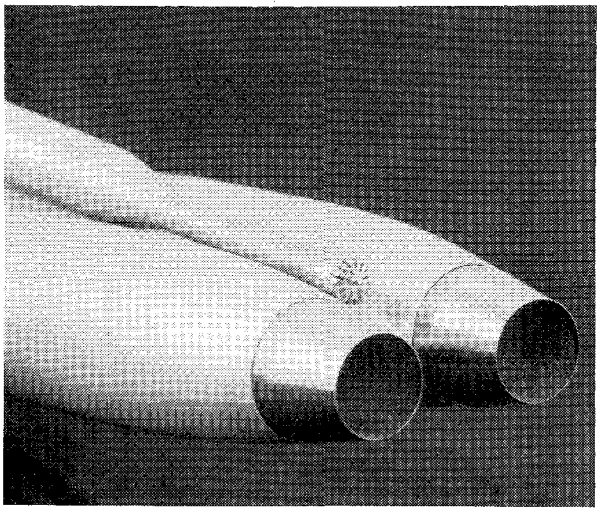

Fig. 1 Dual nozzles with microphone mounted on interfairing.

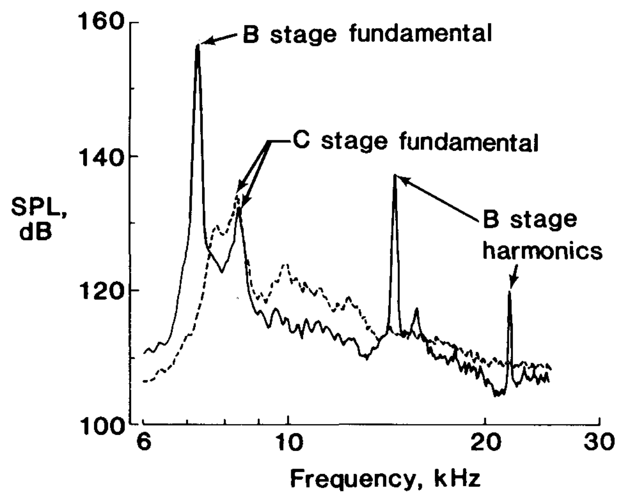

Fig. 2 Sound pressure level spectra with 60 Hz bandwidth at 1.5 fully expanded Mach number. —— twin jets, – – – – single jet.

plane. The sonic jets exhausted into stationary air at nozzle pressure ratios corresponding to fully expanded Mach numbers between 1 and 2. Single jet results were obtained by blocking off the flow through one of the pipes.

Discussion of Results

The noise spectra obtained from the empennage mounted microphone were similar for the single and twin jets at both ends of the pressure ratio range investigated. However, the results differed considerably at intermediate pressures, as typified by the spectra shown for a fully expanded Mach number of 1.5 in Fig. 2. The dominant tones in the twin jet spectrum occur at 7.3 kHz and its harmonics. This corresponds to B stage screech. A lower amplitude C stage with a fundamental frequency of 8.3 kHz is also present. For the single jet, the C stage oscillation dominates and has about the same amplitude as that of the twin jets. Although dominant at lower nozzle pressure ratios, the B stage cannot even be detected in the single jet spectrum. The difference in the maximum spectral level of the two configurations is seen to be about 22 dB.

The amplitudes of the fundamental screech tones were determined for both nozzle configurations from spectra obtained at twenty nozzle pressure ratios ranging from 2.1 to 7.5. These are shown in Fig. 3 vs the jets' fully expanded Mach number. The amplitudes are similar for both nozzle configurations for all but the B stage. The presence of the second jet greatly enhances both the B stage amplitude and the pressure ratio range over which it dominates. The enhanced resonance of the closely spaced twin jets increases the acoustic pressure impinging on the empennage by more than 20 dB over that of the single jet for fully expanded Mach numbers between 1.4 and 1.5. Its level exceeds 155 dB (0.16 psi rms) over a range of nozzle pressure ratios.

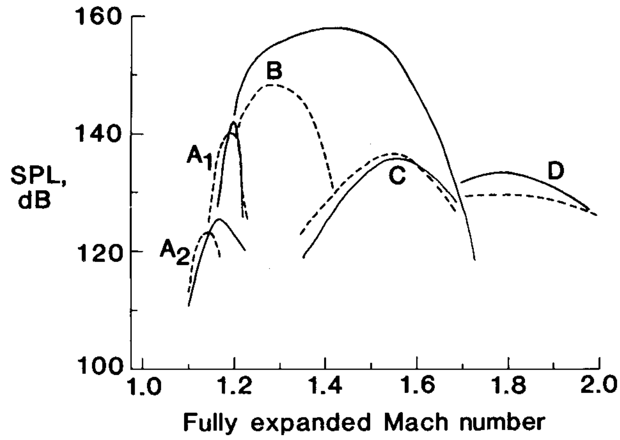

Fig. 3 Variation with fully expanded Mach number of the amplitude levels of the fundamental tone of the various stages of screech. —— twin jets, – – – – single jet.

Conclusions

Closely spaced twin jets have been found to oscillate to a much greater extent than a corresponding single jet over a wide range of nozzle pressure ratios. The twin jet acoustic levels that propagate upstream to the exhaust nozzles can exceed the single jet levels by more than 20 dB. Hence, the structural damage found in supersonic twin jet configurations may be caused by this acoustic resonance. Of course, since the existence of a given screech mode as well as its frequency and directivity are functions of the jet temperature, nozzle geometry, and flight speed, more exact simulation of these variables is necessary to confirm this.

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