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SELF-EXCITED OSCILLATIONS IN DUCT FLOW WITH OBLIQUE SHOCK WAVES

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Introduction

It has been shown previously that self-excited oscillations may occur in a rectangular duct when sonic flow from a convergent nozzle expands abruptly into the duct which has a cross-sectional area greater than that of the nozzle.(1) The flow in the duct is initially supersonic, terminating in a normal shock if the driving pressure difference across the nozzle and duct is not too high. When the pressure difference is high, however, a series of reflected oblique shock waves is formed. Both flow regimes are potentially unstable; with the normal shock wave present in the duct base pressure oscillations may occur.(2) The oscillations which occur when oblique shock waves exist in the duct will be described in this paper.

Experimental Arrangement

A schematic diagram of the duct is shown in Figure 1 which also indicates the main dimensions and pressures. A wind tunnel was used in which atmospheric air at a pressure p_a was induced into a plenum at a pressure p_e by means of a vacuum downstream. Flow visualisation was possible by means of a Mach-Zehnder interferometer. A drum camera and spark light source could provide high speed films.

Flow Patterns with Oblique Shock Waves

Figure 2 shows how the base pressure p_w varies with exit pressure p_e for a typical duct in which h = 6 mm, H = 15 mm and L = 80 mm. There is a range of low values of p_e for which the value of p_w is constant, and it is in this range that the oblique shock waves occur in the duct.

Various interferograms at different values of the pressure ratio p_e/p_a are shown in Figure 3. With $p_e/p_a = 0.173$ (Figure 3a) there are three oblique shock wave reflections from the duct walls, but the third reflection is close to the duct exit. Just before the exit the flow separates from the duct walls and the static pressure quickly increases to that of the exit. The interferogram in 3a is a photograph taken at one instant in a cycle in which the separation points move upstream and downstream through a small distance.

As the pressure ratio p_e/p_a increases the mean position of the separation point moves upstream (see Figure 3b) until at a certain pressure ratio there is a sudden jump in the position of the separation points which now become associated with the area of the second oblique shock wave reflection (see Figure 3c); the flow remains unstable. With a further increase in the value of p_e the flow separation points jump again to the midstream region where the first oblique shock wave reflection occurs. Figure 3d shows one instant during a cycle, and here the entire flow downstream of the separation points is unstable. As p_e/p_a increases to 0.361 the value of p_w starts to increase and a new type of very strong oscillation exists. In this final type of instability not only do the

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points at which the flow separates oscillate, but also the shock wave structure alternates between a normal and an oblique shock wave. The frequency of the oscillation is typically 150 Hz and the peak to peak pressure fluctuation can be as high as 0.25 bars.

The various oscillations are illustrated schematically in Figure 4. In the downstream and midstream types of separation oscillations the extreme flow positions are indicated in Figures 4a and 4b, respectively. For the shock-pattern oscillation in 4c the normal shock regime is marked by the number 1, and the oblique shock regime by 2.

Conclusions

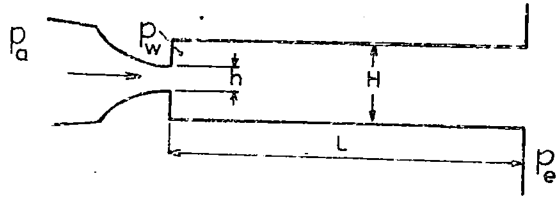
Large amplitude, low frequency self-excited oscillations exist in duct flows with oblique shock waves. The oscillations are associated with a shock-wave boundary-layer interaction.

References

(1) J.S. ANDERSON, W.M. JUNGOWSKI, W.J. HILLER and G.E.A. MEIER 1977 Journal of Fluid Mechanics 79, 769-784. Flow oscillations in a duct with a rectangular cross-section.

(2) J.S. ANDERSON, G. GRABITZ, W.M. JUNGOWSKI and G.E.A. MEIER 1977 The City University Memorandum No. ML 97. Base pressure oscillations in a rectangular duct with a sudden enlargement. (Also presented at the Ninth International Congress on Acoustics, Madrid, July 1977.)

Figure 1. Schematic diagram of the duct.



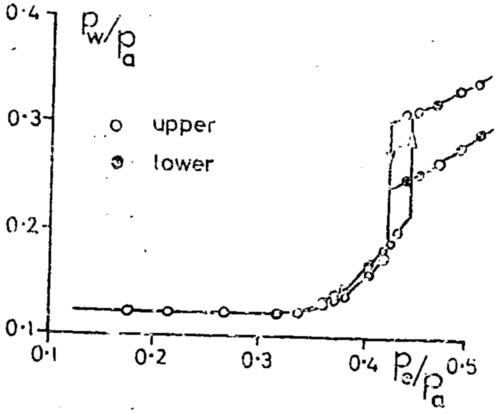


Figure 2. Variation of base pressure p_w with receiver pressure p_e.

h = 6 mm, H = 15 mm, L = 80 mm

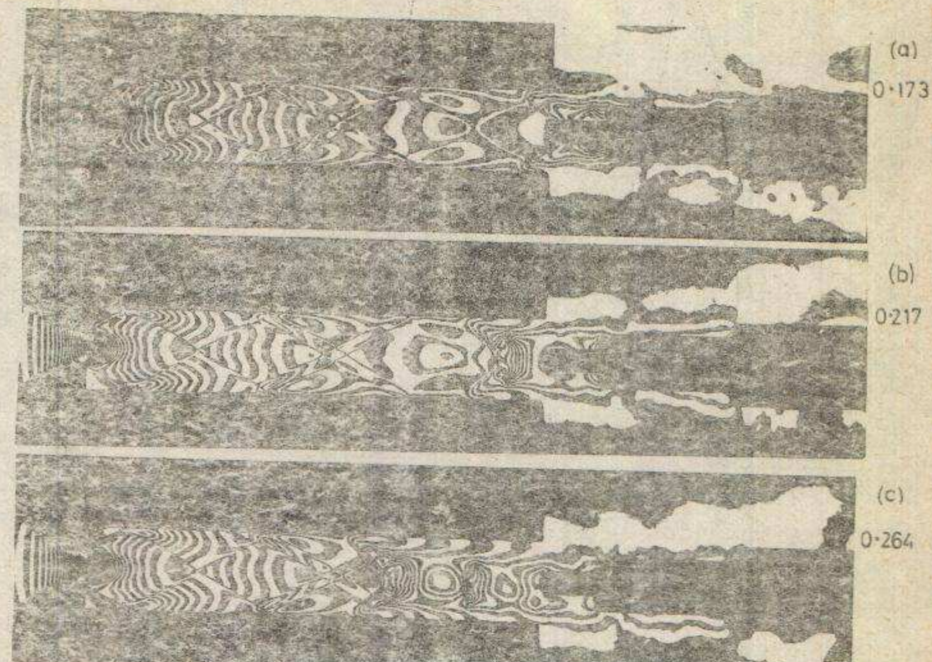


Figure 3. Interferograms of oscillation flow regimes.

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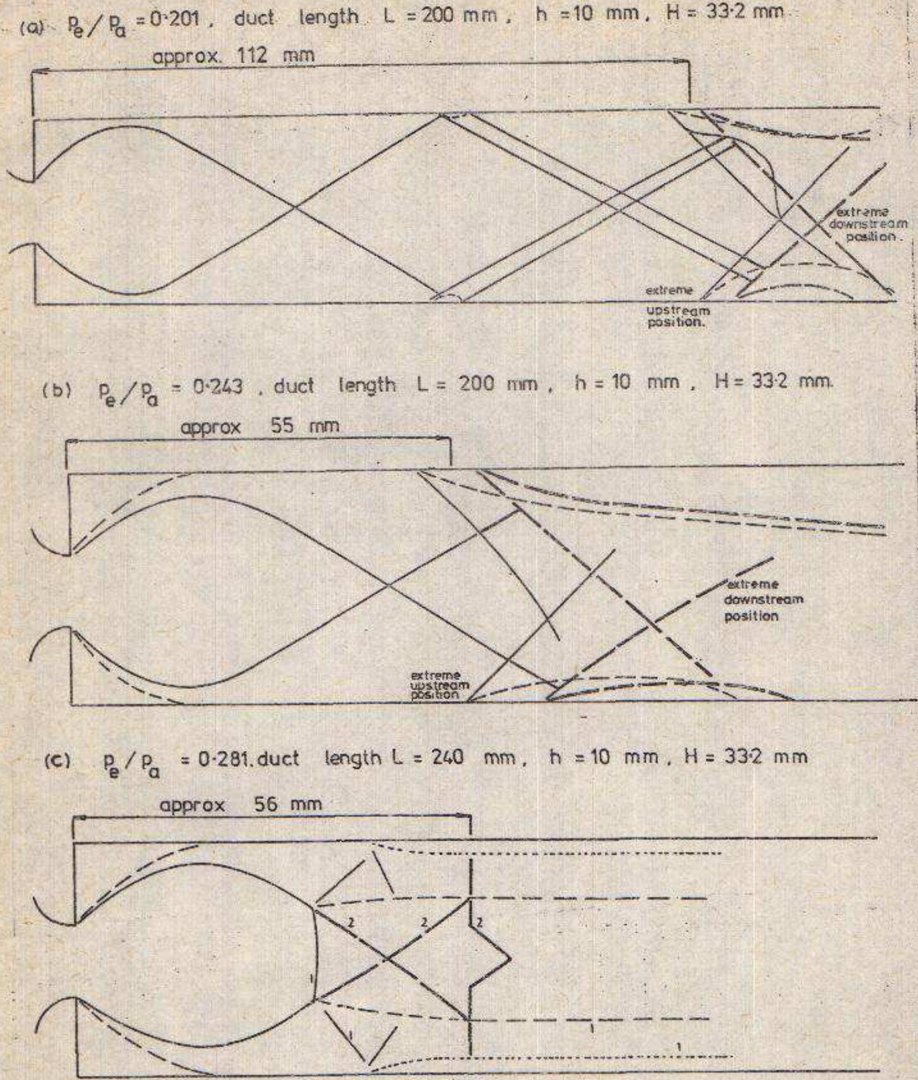

Figure 4.
Schematic outlines of downstream, midstream and shock-pattern oscillations