IUTAM Symposium on Unsteady Separated Flows and their Control, June 18-22, 2007, Corfu, Greece

WHY DO SHOCK WAVES MOVE IN SEPARATED FLOWS ?

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Introduction

It is well known that in shock/boundary layer interactions, the system of shock wave moves. The motion is moderate when there is no separation, but can be very important in presence of large separated zones, or in particular situations like in air intakes. This is not totally surprising, since turbulence is an unsteady phenomenon. The more surprising finding is that the frequencies involved by the shock oscillations are, in first analysis, much lower than those produced by the rest of the flow. In this paper, a review of such phenomena is proposed in different cases of flow interaction; different hypothesis are discussed.

1 What is known

In spite of a large amount of experimental work, there are a few things which are firmly established about shock waves and separation. Among them, we know that shock waves are in general stable, but they act as low pass filters.. On the other hand, separated zones have their own dynamics, mainly dominated by the presence of a reverse flow, producing eddies of larger scales than in boundary layers. These separations are shown to produce rather low frequencies, depending of the geometry. In particular, such separated bubbles may be organised according to three-dimensional cells or may produce tornado vortices.

2 What is discussed

Many things are still ignored. Among them, it may be remarked that the shock transfer function is in general not known, and should be determined in each flow case. As shocks are interfaces between upstream and downstream conditions, their motion should depend on upstream and downstream conditions. This problem is discussed from the measurements performed in particular in compression ramp flows and in shock reflection, among others. A possible candidate for explaining the low frequencies of the shock motions may be the very large scale eddies (VLSE) characterised in subsonic boundary layers and recently put in evidence by the Austin Group (Ganapathisubramani et al. 2006). The importance of the meandering of the VLSE in such interactions and their effect on shock motion is discussed. In particular, the influence of upstream perturbations and vorticity is considered. Recent results on the influence of periodic roughnesses (Dussauge et al. 2006) are presented and discussed. Surprisingly, it is found that shock motion, in a case of an oblique shock reflection, is rather insensitive to such upstream conditions.

The alternative would be the influence of downstream conditions. In some particular geometrical cases like the interaction with a blunt obstacle, it has been shown by Dolling (Dolling & Smith 1989) that the downstream conditions control the main frequency of the shock unsteadiness. In other configurations, things are not so clear. Detailed inspection of the wall

pressure signal close to the foot of the shock reveals contributions of various events and scales, but in general does not shows clearly the respective contributions . In order to classify these events, a compilation of the dominant frequency of the shock motion has been performed. The frequencies were normalized by the upstream velocity and by the length of interaction. The striking fact is that even if there is no real collapse of the data on a single curve, they are grouped together with some scatter. This shows that such a normalisation provides at least the right order of magnitude for the dominant frequency. This representation will be discussed, and in particular the point of the relevant length scale.
The influence of the downstream flow conditions is considered. The case of interactions producing buffeting, where some long range interaction are produced by the flow far downstream through acoustic coupling is not taken in account. It is recalled that laminar interaction studies suggest that 3-dimensional flow structure may be produced in first place by weak enough shocks, before unsteadiness. Are all turbulent interactions three-dimensional in nature and can such three dimensional structures be an efficient source of excitation (i.e. at low frequency) for the shock system? Another question is the point of possible couplings between the flow downstream and the shock. At moderate, supersonic Mach numbers, the separated bubble includes large subsonic zones, so that acoustic coupling can be produced. These points will be discussed through some experimental results, which suggest that such 3-dimensional structures may contribute to the shock motion, but are not the only source of excitation of the system.

3 Conclusions

Some simple conclusions are drawn from this review.

The 3-dimensional character of separation may be different from a flow to another one, and therefore, it seems difficult to find a universal explanation of the shock motion. Probably the partial collapse found for the dominant frequency results from a compromise between the moderately low frequencies produced by the separated zone and the response of the shocks which acts as low pass filters. Probably, we will have to consider different flow regimes to describe the diverse origins of the low frequencies motions.
The unsteadiness of the shock motion (and to some extent of the separated zone) involves frequencies which are felt in the whole interaction zone, with consequences far downstream. This suggests that global instabilities might play a major role in some interactions.
More simply, if there is some sort of coupling between shock and separation, the analysis should be focused more on the phase relationships between these parts of the flow, and not only on amplitudes and spectra, as (almost exclusively) done in the past.

References

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