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Critique of Turbulence Models for Shock-Induced Flow Separation

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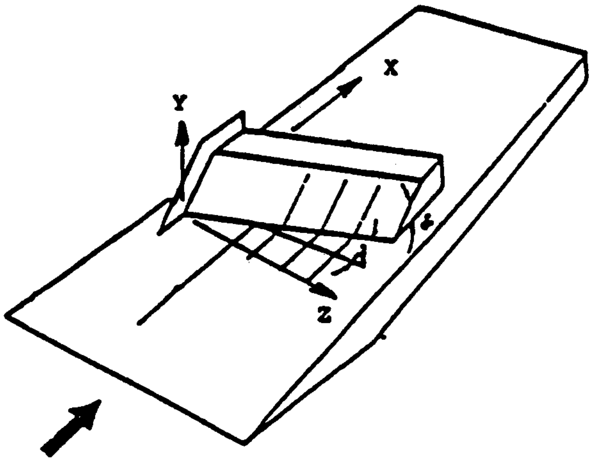
RECENT results for a 60-deg swept 24-deg ramp at $M \approx 3$ show poor agreement between Navier-Stokes computations and experiment[1] (Fig. 1). Whether the flat plate leading edge was assumed to be straight or swept 60 deg had little impact on the computations (compare cases 1 and 2 with case 3). Going from the Baldwin-Lomax to the Jones-Launder turbulence model appeared to improve prediction somewhat (compare cases 3 and 4, respectively), until the streamwise grid spacing was refined (case 5), when the comparison became as bad as for cases 1–3. As it is well known that prediction of pressures is a very mild test of a computational method, the results in Fig. 1 give cause for concern. Obviously the computations, although performed by well-recognized experts in the field, do not simulate all aspects of the physical flow phenomenon involved.

The computational flow model of Ref. 1 is shown in Fig. 2a. It contains only a primary separation with associated vortex. This contrasts with the flow picture evolving from swept-fin experiments[2] (Fig. 2b), where both secondary and tertiary flow separations with associated vortices were identified. Supersonic experimental results for a sharp-edged delta wing also show the presence of secondary flow separation[3] (Fig. 3). One asks oneself if all three types of flow separation are not very similar, and that the likely reason for the poor agreement between prediction and experiment in Fig. 1 is the failure to include correctly secondary flow separation effects in the numerical simulation.

Using a skin-friction visualization technique, Szodruch and Monson[4] have determined the positions of separation and attachment lines on a 70-deg delta wing at $M = 3$ (Fig. 4). Primary and secondary flow separation features are outlined in detail, with flow attachment (A_1, A_2, and even A_3) causing a significant increase in skin friction.



Case No.	Turb model	Leading edge	x_u/δ_∞	M_∞	δ_∞ (cm)	$Re_{\delta\infty}$	Total pressure (kPa)	Total temp. (deg K)
1	B-L	Straight	n/a	2.95	0.22	1.4×10^5	689	266
2	B-L	Straight	n/a	2.95	0.22	1.4×10^5	689	266
3	B-L	Swept	26.2	2.95	0.39	2.3×10^5	689	275
4	J-L	Swept	40.4	2.95	0.39	2.3×10^5	689	275
5	J-L	Swept	40.3	2.95	0.39	2.3×10^5	689	275

B-L Baldwin-Lomax; J-L Jones-Launder; n/a not applicable

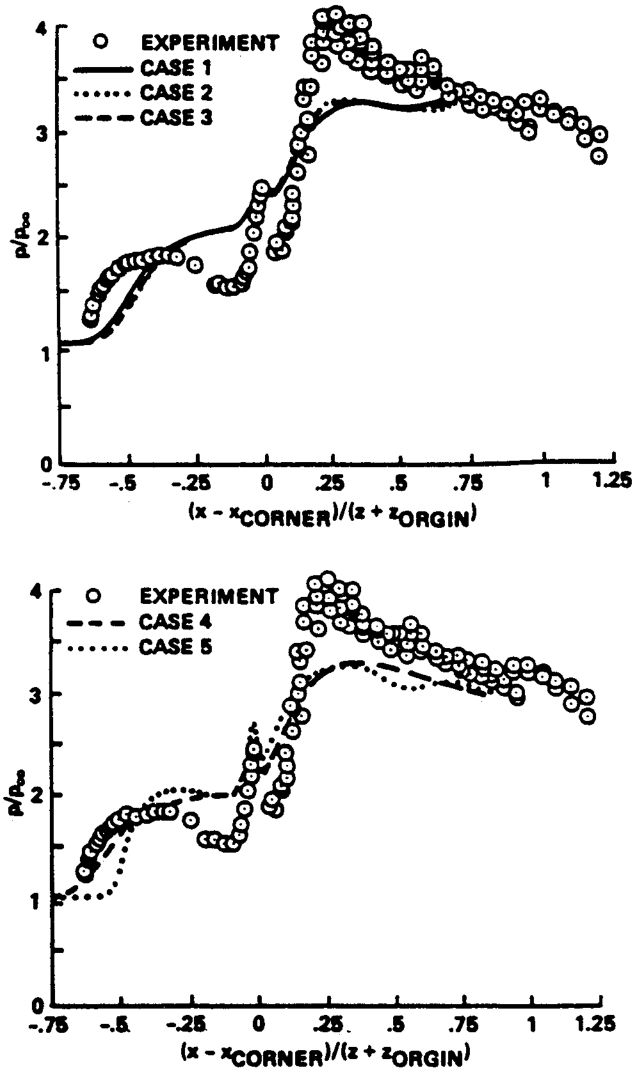


Fig. 1 Supersonic turbulent flow at Mach 3 past a 60-deg swept 23-deg compression corner.[1]

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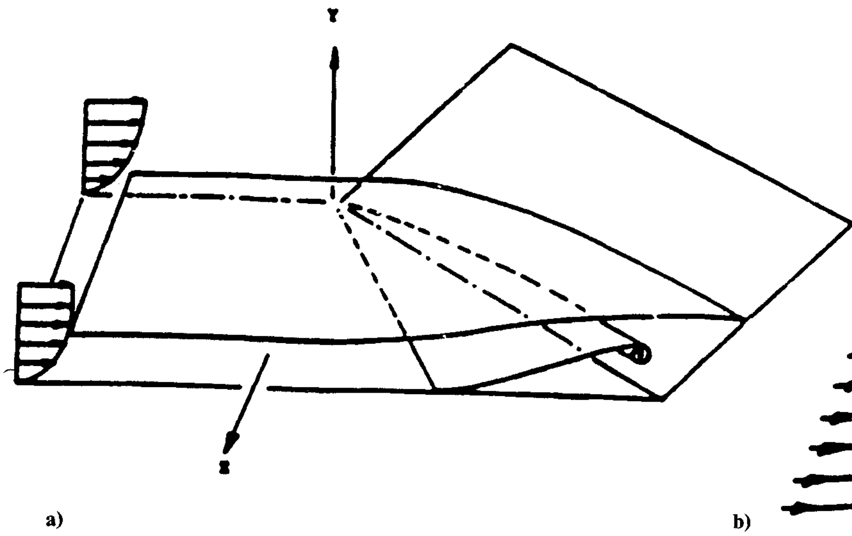

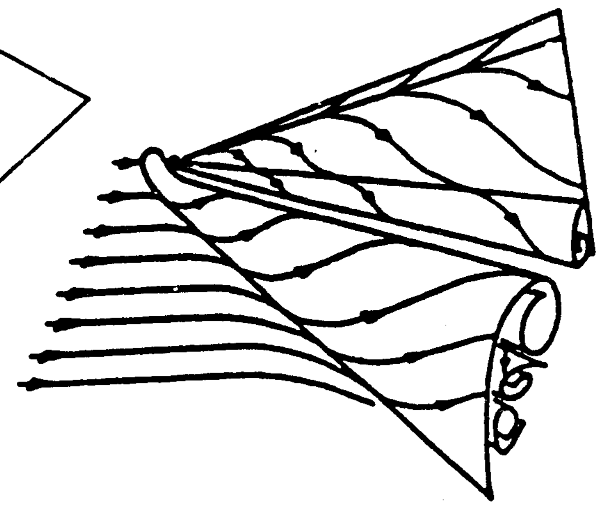

Fig. 2 Flow separation models: a) computational model of separated flow in swept compression corner[1]; b) flow separation model from experiments with a swept sharp fin.[2]

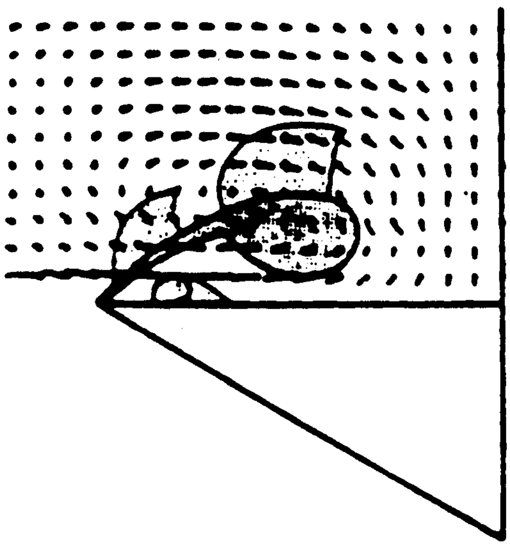

Fig. 3 Vapor screen picture of a thick 70-deg delta wing at $M=2.0$ and $\alpha=10$ deg.[3]

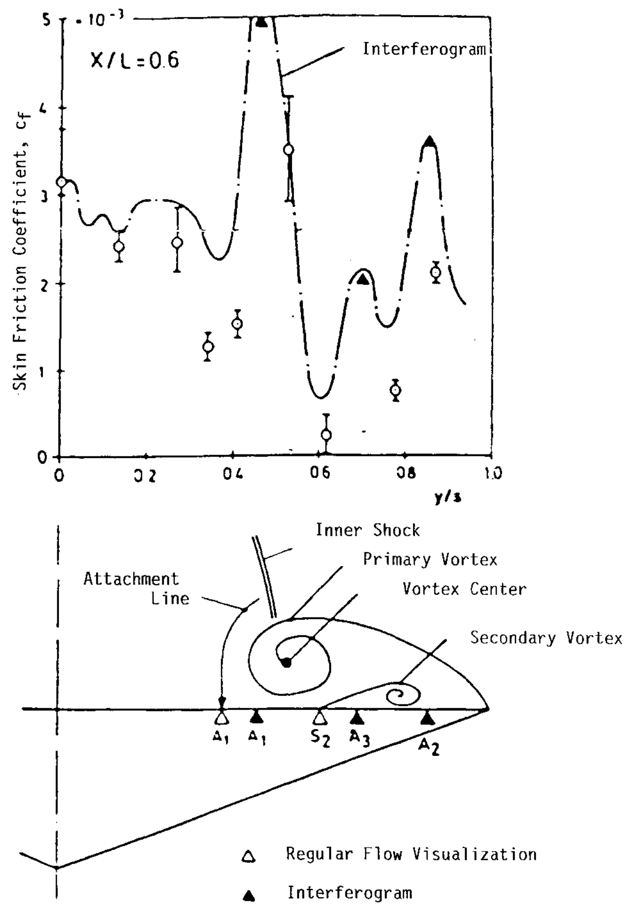

Fig. 4 Comparison between flow visualization and skin-friction measurements on a thick 70-deg delta wing at Mach 3 and 8-deg incidence.[4]

The similarity of flow separations on swept wedges or fins with that on delta wings is exemplified further by comparing the experimental results for a 40-deg swept ramp[5] (Fig. 5) with those for a 60-deg swept ramp (Fig. 1). As in the case of delta wings, it appears that 40-deg sweep cannot produce a fully developed vortical structure. Based upon delta wing experience one would expect that a sweep of 50 deg or more would be needed before a fully developed vortex structure could develop for the ramp-induced flow separation.

Combining the results[2-4] in Figs. 2-4 suggests the flow model shown in Fig. 6 for the 60-deg swept ramp.[1] Although the physical flow mechanism suggested here has to be investigated further before one can determine conclusively the reasons for the observed large discrepancies between computation and experiment, the results give cause for concern in regard to the maturity and reliability of numerical simulation of physical flow phenomena. This is especially true in view of the fact that in the case illustrated here, using 1987 state-of-the-art numerical simulation methods, the physical flow over a very simple geometry, a swept ramp, cannot be simulated. Consequently, a very effective interaction between the theoretician and the experimentalist, of the type observed in the past,[6-9] will be needed before a realistic numerical simulation can result.

There is presently a tendency to oversell numerical simulation, even suggesting it to be a useful design tool. Of particular concern are those publications in which only the numerical results are presented, with the author claiming that they repre-

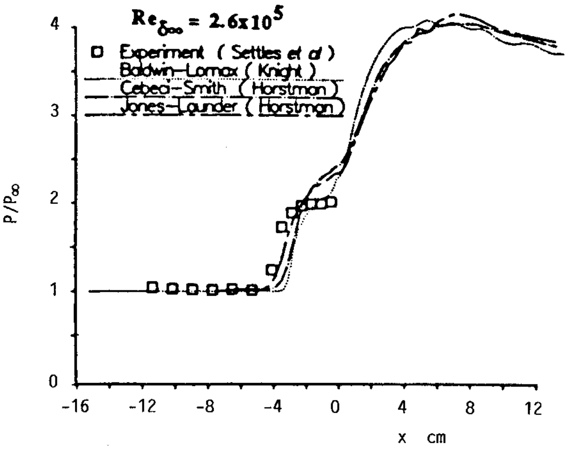

Fig. 5 Supersonic turbulent flow at Mach 3 past a 40-deg swept 23-deg compression corner.[5]

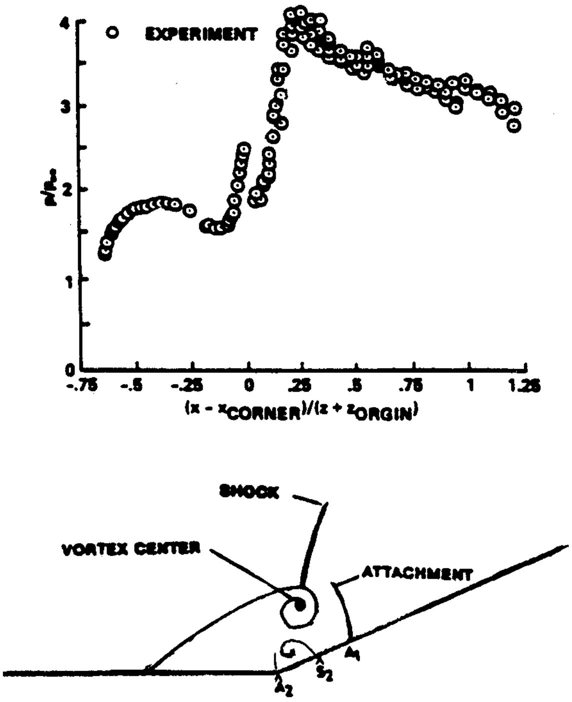

Fig. 6 Suggested flowfield characteristics at Mach 3 for a 60-deg swept 23-deg compression corner.

sent a realistic simulation of physical flow phenomena of concern. Fortunately, this danger is beginning to be recognized and demands are now being raised that with very few exceptions numerical simulation results should not be allowed to be published without the simultaneous presentation of results obtained by other means, e.g., by experiments. Only by diligent, intelligent use of physical and numerical experiments together can a realistic simulation of full-scale fluid mechanics be achieved.

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Free Rotation of a Circular Ring with an Unbalanced Mass

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Introduction

LARGE space structures are much more flexible than their terrestrial counterparts.[1] Rotation of large space structures may be desirable for stability, thermal, or artificial gravity reasons. Previous literature includes the large deformations due to the free rotation of a slender rod[2,3] and a ring about a diameter.[4]

An important model of a space station is a ring rotating about its axis of symmetry. If the ring is balanced, it will be stable and remain circular. The present Note considers the case when the ring is unbalanced by a mass attached to a point on the ring.

Formulation

Figure 1 shows the origin of the coordinate system located on the symmetry line opposite a mass of magnitude m. The system is rotating in its own plane with angular velocity Ω about the center of mass. Normalize all lengths by the natural radius R of the ring and all stresses by EI/R^3, where EI is the flexural rigidity. The governing equation for large deformations is[5]

$$\theta'\theta'''' - \theta''\theta''' + \theta''(\theta')^3 - q_n\theta'' + q_t(\theta')^2 + q_n'\theta' = 0 \qquad (1)$$

where $\theta(s)$ is the local inclination, s the arc length from the origin, and q_n and q_t the normal and tangential stresses caused by centrifugal forces. Consider an elemental length shown in Fig. 1. Let ρ be the mass per unit length of the ring. We find $q_t = -Br\sin(\theta-\psi)$ and $q_n = Br\cos(\theta-\psi)$, where $r\cos\psi = h$

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