INFLUENCE OF THE ENTROPY LAYER ON TRIPLE DECK STRUCTURE IN HYPERSONIC RÉGIME.

by
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Inviscid- viscous interaction on a flat blunted plate in weak hypersonic régime (*i.e.* when wall perfect fluid pressure non dimensionalized by free stream pressure, say ω, is much greater than the classical hypersonic viscous interaction parameter χ_∞) is studied on the triple deck scales (Stewartson (1974), Neiland (1970)). We seek to delineate the influence of an asymptotically small nose bluntness (which create a thin layer of perfect fluid called entropy layer: Guiraud, Vallée & Zolver (1965)) on the flow structure near a laminar separation.

We outline some cases depending on the relative sizes of the upper deck and the entropy layer.

1. THE ENTROPY LAYER IS SMALLER THAN THE UPPER DECK.

In this case (Lagrée (1991)) we must introduce a fourth deck, lying between the main and the upper deck, which is the entropy layer itself (it is characterised by its small density , say gauged by $r\rho_\infty{}^*$ where r is small, and by its small thickness, gauged in Von Mises transverse variable by $d^*\rho_\infty{}^*U_\infty{}^*$, we note $d=d^*/L^*$ the ratio of tip bluntness versus the longitudinal scale).

As a result, we obtain a new fundamental equation of the triple deck written in standard scales. The reduced lower deck equations are identical to those of classical theory:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0,\; u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{dp}{dx} + \frac{\partial^2 u}{\partial x^2}. \qquad (1)$$

As boundary conditions, as usual, we have the no slip velocity condition and:

$$u(x) \to y + A(x) \qquad \text{as} \qquad y \to \infty \qquad (2)$$

However, the pressure displacement relation is different:

$$p(x) + \eta\frac{dp(x)}{dx} = -\frac{dA(x)}{dx}. \qquad (3)$$

The infinitely small parameter η (directly proportional to the nose blunting by the thickness of the entropy layer, and inversely proportional to the upper deck's scale) gauges the departure from classical theory as given below, here Fp denotes the finite part of the integral which is performed trough the entropy layer:

$$\eta = (d/\Psi)Fp\left\{\int_0^\infty \frac{1}{r\,\hat\rho(\hat\psi)}d\hat\psi\right\},\ \text{and}\, O(\eta) = O(d\,r^{-1}\chi_\infty^{3/4}\,\omega^{-1/2}). \qquad (4)$$

This may be compared with an other entropy effect in Sokolov (1983), and to the wall temperature effect in Neiland 86 and in Brown, Cheng & Lee (1990).

2 THICKER ENTROPY LAYER

If the parameter η is of order one, then the complete perturbed equation have to be solved in the upper deck:

$$\frac{\partial v}{\partial \xi} = -\frac{\partial p}{\partial \psi}, \qquad \frac{\partial v}{\partial \psi} = -\frac{1}{R_0(\psi)}\frac{\partial p}{\partial \xi}, \quad v(x,0) = -\frac{dA}{dx}. \qquad (5)$$

Where the density $R_0(\psi)$ is comming from an Euler calculs.

3. MORE THICKER ENTROPY LAYER, TWO PARTICULAR CASES:

3.1 Entropy layer and upper deck are the same

When the upper deck *is* the entropy layer the complete equations of perturbation have to be solved in the upper deck, the density is given by the density profile $R_0(\psi)$ of the entropy layer (Guiraud et al. (1965)), the equations are the same but not the gauges: the longitudinal gauge is imposed by the size of the upper deck.

3.2 Entropy layer is thicker than upper deck

When the upper deck is smaller than the entropy layer we find again the classical case with but different scales (Lagrée (1990) because the propagation takes place in a layer of very small constant density (r), for example, the longitudinal gauge is ($\omega = M_\infty^2 d^{2/3}$):

$$x_3 = \lambda^{-5/4}(\gamma - 1)^{3/2} s_w^{3/2} (\chi_\infty / \omega)^{3/4} r^{3/8}. \tag{6}$$

3 NUMERICAL RESOLUTION

Those problems have to be solved numerically, and to this end, we choose an iterative method based on standard inverse Keller Box method for Prandt'l equations, plus numerical resolution of the perfect fluid by integration of (3) or by a MacCormack scheme (case of complete relations (5)), plus revisited Le Balleur (1978) "semi- inverse" relaxation method. This permits strong coupling.

Results for η small (first case relation (3)) are close to those of Cheng et al. (1990). The linear solution predicts that the Lighthill eigenvalue k increases with η: so the curve toe stiffens with η. The separation bubble size appears to increase with η. Results for second case (complete resolution of (5)) show firmly that increasing the entropy layer diminish the bulb, and that decreasing it increases the bulb (confirming qualitatively the relation (3)).

4 CONCLUSION

To summarise, a rough sketch of small nose bluntness influence may be drawn. For $\eta \ll 1$ the study of section 1 (eq. (3)) may apply: raising η increases separation (numerically, see figure 1). For η of order one, this study fails and complete calculation of inviscid perturbation (eq. (5)) trough a thick entropy layer has been performed (see figure 2). It seems that the good trends are qualitatively obtained for thin and thick entropy layer. For larger bluntness (but always d very small) section 3.2 suggests new scales. So increasing η first promotes growth of separated region, reduces k and diminish apparent interaction region, a further increasing lowers the scale of separated region. This is qualitatively comparable with the experimental data of Holden (1971). The incipient angle separation is correlated with:

$$M_\infty \alpha (M_\infty^3 d)/\chi_\infty^2 \propto (\chi_\infty / ((M_\infty^3 d)^{3/2}))^a (d)^b. \tag{7}$$

Holden (1971), with combination of parameters and experiment, found a=-7/5 and b=0. We propose, deduced from triple deck scales, a=-3/2 and b=-1/6γ, those coefficients reflect the locality of the interaction.

5 . ACKNOWLEDGMENTS

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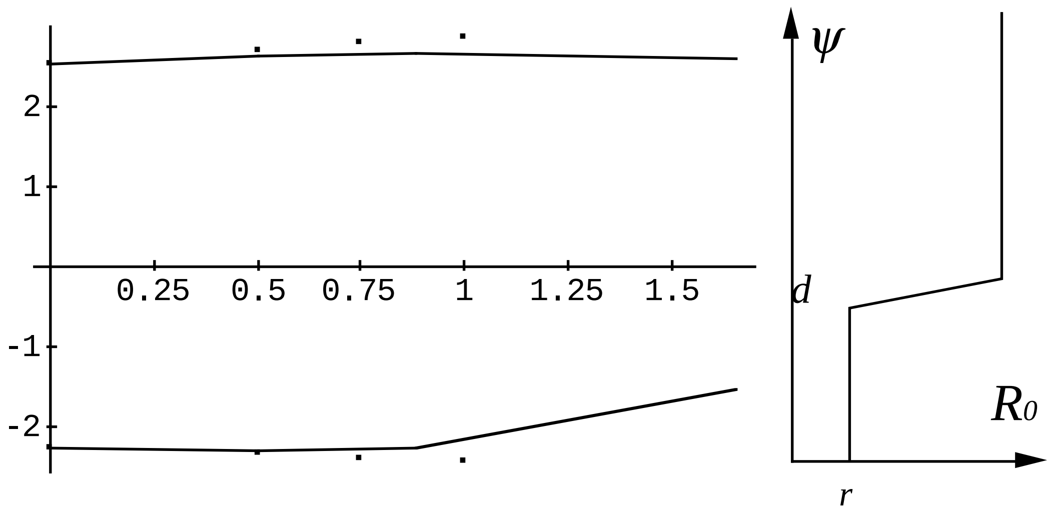

Figure 1: evolution of the abscissae of detachement and reattachement versus η, plain: resolution of (5) at *r=0.4* fixed *d* increasing, *ad hoc* "step" density profile, dots: resolution of (3)

Figure 1: exemple of pressure and skin friction distribution for relation (3).