BL2 - Shock-wave/laminar boundary layer interaction

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General description

This test case considers the interaction between an incident oblique shock wave impinging a laminar boundary layer developing over a flat plate (see Figure 1). The interaction produces a separation of the flow and a subsequent recirculation bubble. This flow has been experimentally and numerically studied in [1].

Governing equations

The governing equations are the 2D Navier-Stokes equations with the ideal gas equation of state, a constant ratio of specific heats, $\gamma = 1.4$, and a Prandtl number of $Pr = 0.72$. The dynamic viscosity coefficient is given by Sutherland's law.

Geometry, flow and boundary conditions

The freestream Mach number is $M_0 = 2.15$ as retained in [1] for the numerical simulation. The Reynolds number, based on freestream quantities (see Figure 2) and the distance between the leading edge of the plate and the abscissa of impingement of the inviscid shock with the plate, is $Re = \rho_0 V_0 x_{sh}/\mu(T_0) = 10^5$. The freestream temperature is $T_0 = 288.15K$. The angle between the incident shock wave and the x-axis is $\sigma = 30.8^\circ$. In this configuration, the flow remains 2D and stationary.

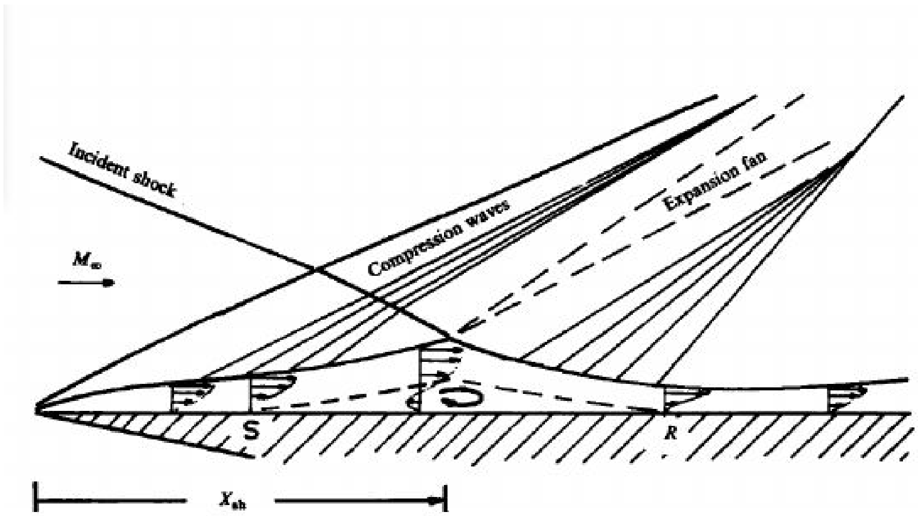

Figure 1: Schematic of the flow field (from [1]).

Figure 2 depicts the computational domain. The position of the shock wave is set through supersonic inlet conditions with a uniform state corresponding to a Mach number $M_0 = 2.15$ for $y \le y_0$ (inlet0) with $y_0 = 1.2 \tan \sigma$. The second state (inlet1) for $y > y_0$ is defined so as to satisfy the Rankine-Hugoniot relations through the shock. A non-reflecting boundary condition is imposed at the top of the domain, while a supersonic outflow is set at the outlet $x = 2$. A no-slip condition is imposed at the plate which is assumed to be adiabatic and a symmetry condition is imposed at $y = 0$ and $x \le 0$ (sym.).

Requirements

For a given discretization method or approximation order and for the full set of grids, the computation must start from a uniform flow defined by the freestream Mach number M_0 . The work unit will be defined as the limit to reach a convergence of the L2 -norm of the residuals for the mass equation of ten order of magnitude lower than the initial residuals. The error criteria are:

- the drag coefficient of the plate Cd;
- the separation and reattachment points, resp. xr and xs, evaluated from the sign reversal of the skin friction;

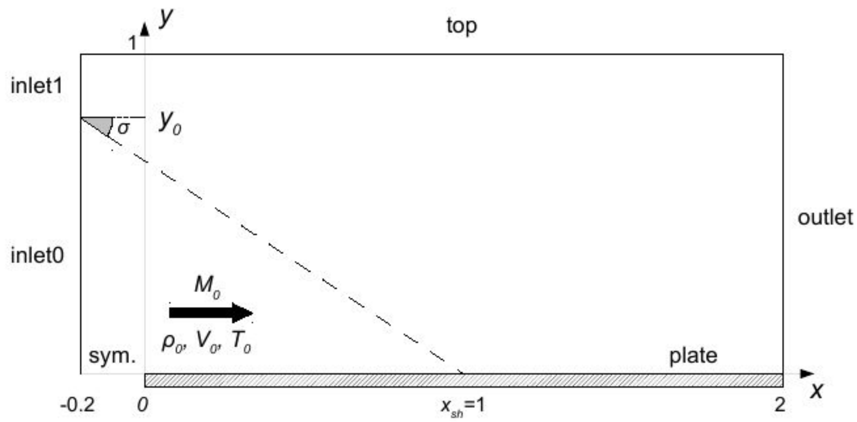

Figure 2: Computational domain and boundary conditions. The dashed line represents the inviscid shock position.

The following data are required:

- perform a convergence analysis in mesh and (if any) approximation order of the drag coefficient of the plate, Cd ;
- plot Cd, xs, xr vs. work units;
- plot Cd, xs, xr vs. h = 1/ √#DOFs where #DOFs is the number of DOFs per equation
- plot the streamwise variation of the non-dimensional wall pressure, p/p0 , with $p_0 = \rho_0 R T_0$ and R = 287.15J/kgK, and skin friction coefficient, $Cf = \tau/(\rho_0 V_0^2)$ along the plate for each computation;
- plot the streamwise variation of the non-dimensional pressure p/p_0 at a height of y = 0.1;
- plot the residuals as a function of work units and iteration number for each computation;

Meshes

Mandatory structured and unstructured grid suites, in gmsh format, will be provided on request.

References

[1] G. DEGREZ, C. H. BOCCADORO and J. F. WENDT, *The interaction of an oblique shock wave with a laminar boundary layer revisited. An experimental and numerical study*, J. Fluid Mech. 177 (1987), pp. 247–263.