I. Introduction

Current interest in the development of hypersonic air-breathing cruise vehicles has led to a renewal in the study of supersonic combustion Ramjets engines (Scramjet). In the classical Ramjet engine, (cf. figure 1), the flow is slowed down between the air intake and the

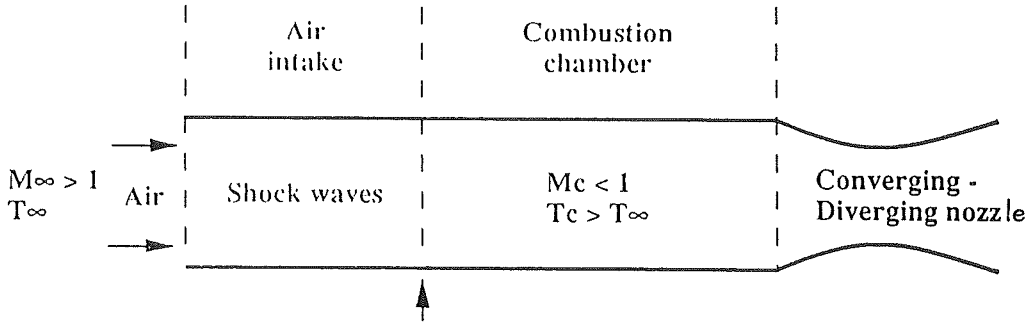

Figure 1

combustion chamber, provoking a fast decrease of performances as the flight Mach number becomes larger than 6. This decrease is illustrated in fig. 2 that gives the change of the specific impulse for different types of propulsion engines as a function of the flight Mach number. This

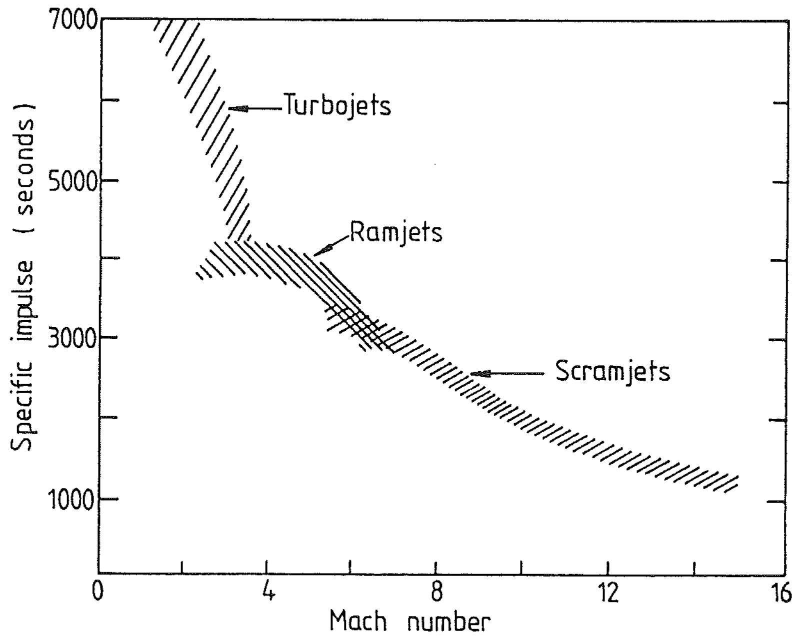

Figure 2

curve summarizes classical results given in litterature and based on "global" initial-final states calculations. It is clear that the part of the curve corresponding to Scramjet engines presumes the possible existence of stabilized combustion in a supersonic flow. This decrease is due to the irreversible transformations through shock waves which are located between the air intake and the combustion chamber, causing : (i) An important decrease in the velocity difference between the air intake and the nozzle exit, incompatible with the thrust required for propulsion ; (ii) A strong increase in the static temperature of the flow, accompanied by an increased species dissociation rate reducing the global exothermicity of the combustion process ; at the limit of large Mach numbers the whole chemical process may be become endothermic. In addition to this performance decrease, the deceleration of the flow to subsonic speeds may lead to pressure and temperature levels beyond those allowed by materials presently available. Finally, in the case of combustion in subsonic flow, the intake mass flow rate in the combustion chamber is limited by thermal choking : for mass flows rates larger than a critical value, oscilatory phenomena start to occur which, through acoustic coupling with the system, may eventually damage the engine.

One way to avoid the constraints quoted above is to maintain supersonic flow from the air intake all the way to the combustion chamber exit (cf. fig. 3). However, on a physical point of view, in addition to the fluid mechanics problems connected to the air intakes, fuel injection and mixing, ignition and control of combustion in supersonic flow give rise to a number of problems related to the coupling between a strongly exothermic chemistry and compressible, high temperature, fluid dynamics.

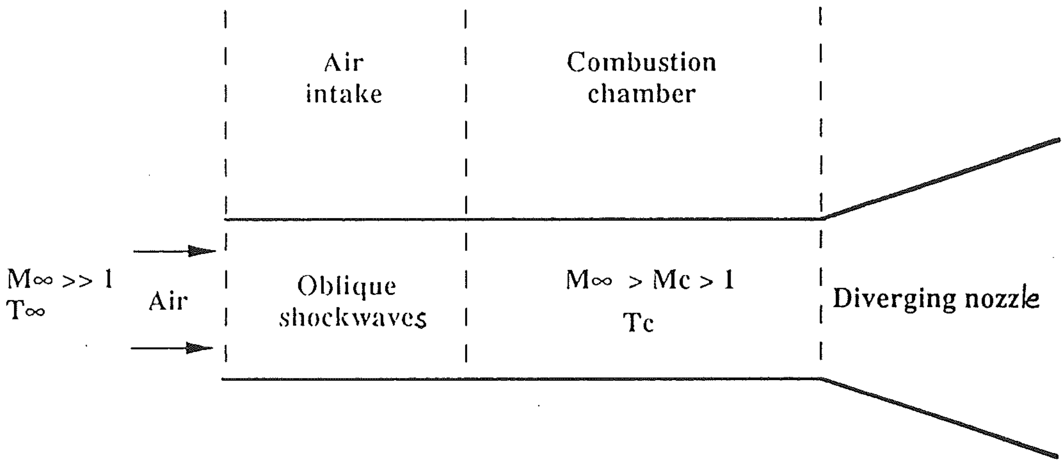

Figure 3

The objectives of the course are not to provide an exhaustive analysis of the existing litterature on the subject matter. Such an analysis can be found in Billig.

More precisely the present course is limited to the main physical aspects of some basic simple 1.D and 2.D stationnary problems, related to ignition and development of combustion in supersonic flows, and which are expected to be relevant as generic subsystems in practical cases. As shown in fig. 4, simple characteristic situations involving combustion and supersonic flow can be defined.

1 : 1.D compressible flow of premixed reactants in a channel of varying cross section
2 : Ignition and spread of combustion behind an oblique shock wave
3 : Ignition and combustion within 2-D boundary layers
4 : Ignition and Spread of combustion within mixing layer of oxydizer and combustible

Here, we shall restrict ourselves to stationnary laminar systems. Related stability and turbulence problems which remain unsolved in a large amount but are very important indeed to deal with practical geometries are out of the scope of the present course.