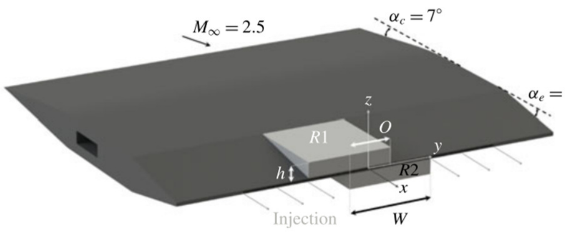
QUB - Mechanical and Aerospace Engineering
PhD Project Description

Title: **Numerical analysis of supersonic streamwise mixing to enable SCRAM jet combustion.**

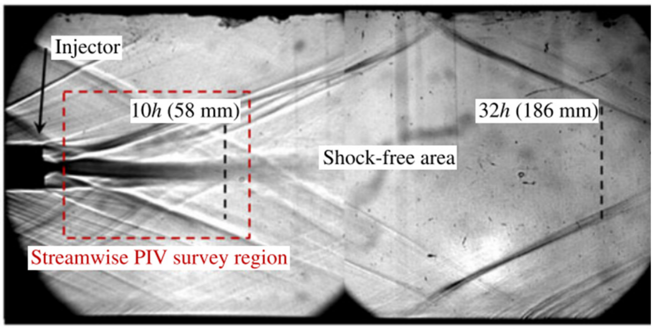
Theme: **Future Aircraft**

Project description:
One of the goals of **hypersonic vehicles research** is the development of efficient combustion engines. Supersonic combustion is challenging, to say the least, and it is hindered by three main challenges: 1) obtaining efficient fuel/air mixing in the extremely short residency times, typically on the order of 10^{-3} s; 2) the difficulty in reaching sufficient plume spreading for a uniform distribution of fuel across wide combustor cross sections; and 3) keeping the inevitable total pressure losses in the engine as low as possible.

One potential solution to the first two of these challenges is to enhance mixing between air and fuel by increasing the vorticity content in the flow field through free shear flows. This cannot be achieved with planar mixing as for subsonic combustion due to the slow growth of compressible shear layers. An alternative method to improve mixing could be the generation of streamwise vortices generated through cross stream jets or physical devices such as ramps as for example shown in Figure 1.[1]



a) Strut injector equipped with expansion ramps



b) Schlieren of the test section

Both images are courtesy of Vergine *et al.* [1]

Figure 1: Experimental set up and Schlieren test section images

Therefore, the focus of this PhD is twofold: i) To develop a fundamental understanding of the streamwise vortex dynamics for highly compressible flows which will guide the design of hypersonic combustion chambers; and ii) to analyse and demonstrate the effectiveness of different numerical modelling approaches for the prediction of streamwise vortex dynamics in high supersonic flow. The PhD will contribute to both better physical understanding and to the development of numerical methods. Specific aims and objectives for this PhD are described in the following paragraph.

Aims and Objectives:
As previously stated, the aim of this PhD is twofold: i) an understanding of the fluid dynamics; and ii) an understanding of modelling approaches. However, the development of a fundamental understanding of the streamwise vortex dynamics in supersonic flow (M≈2.5) can only be properly achieved after the strengths and limitations of different numerical modelling approaches are evaluated and established.

For these reasons, the first objectives of the PhD are related to the numerical modelling – and will focus on developing the most suitable framework for the study of this type of flow. It is foreseen that the analysis will focus on effects of turbulence modelling approaches, considering:

- Limitations of (U)RANS turbulence modelling for the development of streamwise vortices development in supersonic flows:
    - Boussinesq eddy viscosity approximation, Non-Linear Eddy Viscosity Models (NLEVM), Algebraic Stress Models (ASM), *etc.*
- Effectiveness of turbulence resolving approaches:
    - LES, VLES, DES, or Hybrid RANS/LES strategies, *etc.*

The analysis will also focus on modelling techniques utilised to reduce artificial numerical dissipation – key in correctly resolving unsteady vortices. An in-house state of the art numerical code developed by Dr Watson will be utilised for this phase.

Validation of the numerical simulations carried out during this first part is of paramount importance, and this will be carried out utilising the experimental work developed and published by Vergine. Dr Vergine will be part of the supervisory team, and the possibility of collaboration interaction here is seen as a major advantage. A short placement with Dr Vergine at the San Jose University is a strong possibility.

The development of a desirable framework from the previous objective will lead to the second objective of the project: the understanding and characterisation of the vortex dynamic in supersonic jets. Objective of the second phase is to develop a fundamental understanding of the flow features which characterise this flow, their development in space and time and their characteristics (in terms of energy content, mixing and so forth) in order to infer optimal mixing for the design of supersonic combustions chambers.

[1] Vergine, F., Ground, C. & Maddalena, L. Turbulent kinetic energy decay in supersonic streamwise interacting vortices. Journal of Fluid Mechanics 807, November 2016, pp. 353-385, doi:10.1017/jfm.2016.611

Key skills required for the post: Sound knowledge of fluid dynamics (both theoretical and computational) and a keen interest in compressible fluids and hypersonic applications

Key transferable skills that will be developed during the PhD: Advanced understanding of fluid dynamics, high performance computing, and mathematical modelling

Lead supervisor:	Dr Marco Geron
Other supervisor(s):	Dr Fabrizio Vergine (San Jose State University, Ca, USA), Dr Rob Watson
Funding mechanism:	Yet to be secured
Application closing date:	Until suitable candidate appointed.
Guaranteed stipend:	N.B. Stipend for 20-21 is not yet confirmed. Base stipend for 19/20 is £15,009.
Conditional top-up available:	To be confirmed

PhD students in the School may have the opportunity to apply to be demonstrators on undergraduate modules. Compensation for this can amount to in excess of £2,400 per year.