Results from laboratory experiments - summary

We are pleased to report that our team has run a set of experiments in a supersonic wind-tunnel aimed at proving the central key concept of ASPIRE – the operation of the rotating wedges and air-fuel mixing – and that these have produced exciting results. The results indicate that the system works exactly as predicted in our models and simulations. This, in turn, indicates that the engine should work as envisaged.

The results are presented in full in our paper:

C. MacLeod and M. J. R. Smith, Air-fuel Mixing in the ASPIRE Hypersonic Engine, *Journal of the British Interplanetary Society (JBIS)*, Vol 75, No 11, 2022. pp 387 - 397.

The paper can be purchased here: Journal of the British Interplanetary Society

Unfortunately, the journal has embargoed open-access public distribution of one year after publication. So, this summary is aimed as a preview of its contents for those that cannot obtain the full paper.

We have also produced a video about the results here: Video of latest work

Experimental setup

A small supersonic wind-tunnel was set up to provide experimental test flows. The flows produced had Mach numbers ranging from Mach 1.64 to Mach 1.96 with an average of Mach 1.74. At the average speed the flow parameters were: Static pressure p = 133 kPa, temperature T = 180 K and density ρ = 2.6 kg/m^3.

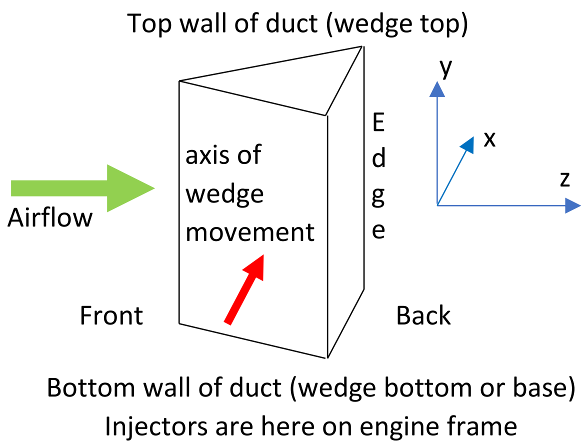
These speed and pressure figures correspond to the conditions in the mixing section of a Mach 3 to 4 free-stream engine. However, the flow temperature of an actual scramjet stream is much higher - and this results in a lower density in the flow (around 0.9 kg/m^3 in the Mach 3.5 case). In turn, this means that the mass flow rate per unit area in the tunnel system is approximately 1500 to 1700 kg/sm^2 compared to around 700 kg/sm^2 for a Mach 3.5 free-stream engine. In fact, this flow rate is higher than in any real engine.

Since pellet dynamics depend almost exclusively on fluid momentum, the experimental setup represents a more challenging environment for mixing than a real engine - with the pellets subject to almost twice the highest fluid momentum forecast.

Given this, and since flow regime in the mixing area does not change over the operating region of the engine, it is very likely that the behaviour observed in the experiments below is qualitatively similar over the range of Mach numbers representative of a real engine.

A variety of different pellets were used in the tests including solid cylindrical organic starch pellets (ρ = 470 kg/m^3) and round plastic pellets of various diameters from 0.5 to 10 mm (ρ = 910 kg/m^3). For liquid and droplet experiments, water was used (ρ = 1000 kg/m^3). These materials were chosen to be comparable to a range of likely fuels – for example, common liquid or light solid fuels like kerosene or liquid cryogenic methane and heavier solids like RDX.

In order to make the observations below clearer, directions are defined with respect to the wedges as shown below. Note that the x, y, z designations below, although they are indicated by arrowed lines, just refer to the axes - not particular directions.



x direction is across the width of the wedge (into the page and along the axis in which the wedge travels).

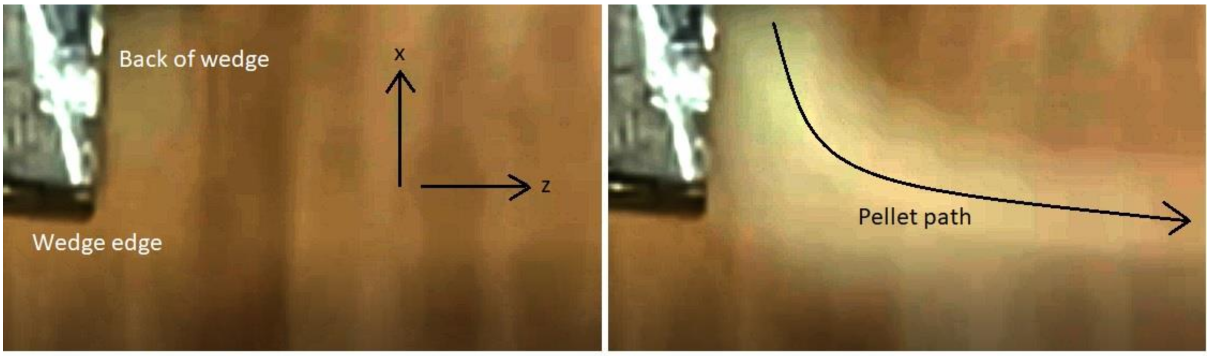
y direction is up the height of the wedge (vertical on this diagram and in the axis which runs from bottom to top of the duct).

z direction is along the direction of airflow (horizontal on this diagram).

Experimental results

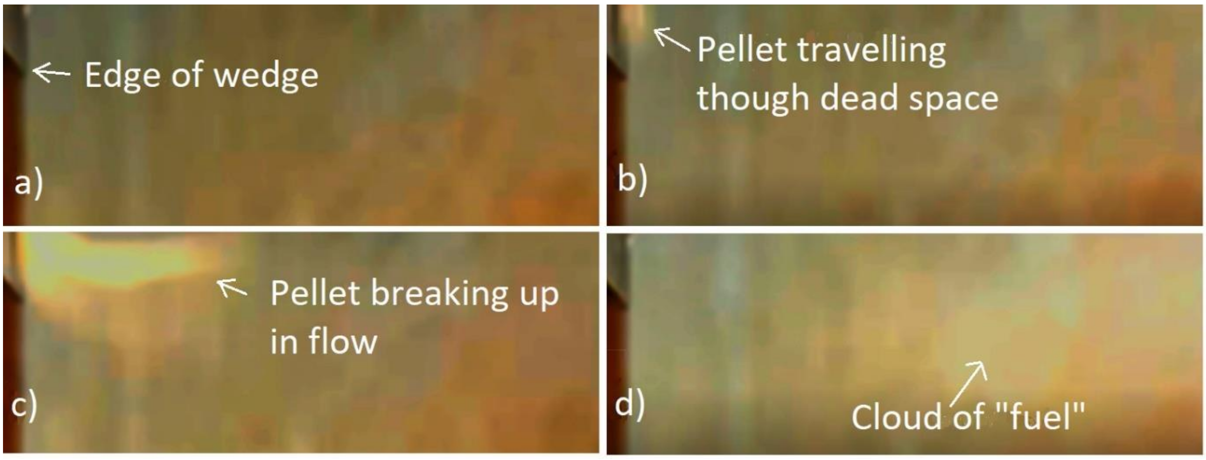
Some of the results are shown in the diagrams below.

The first shows a 0.5 mm diameter, 1 mm long starch pellet, travelling in the x direction at 10 m/s exiting the back of the wedge. The pellet appears fuzzy because the camera, filming at 240 frames per second, has blurred its motion. The wedge has a half-angle of 5^o and is 15mm long (in the z direction).

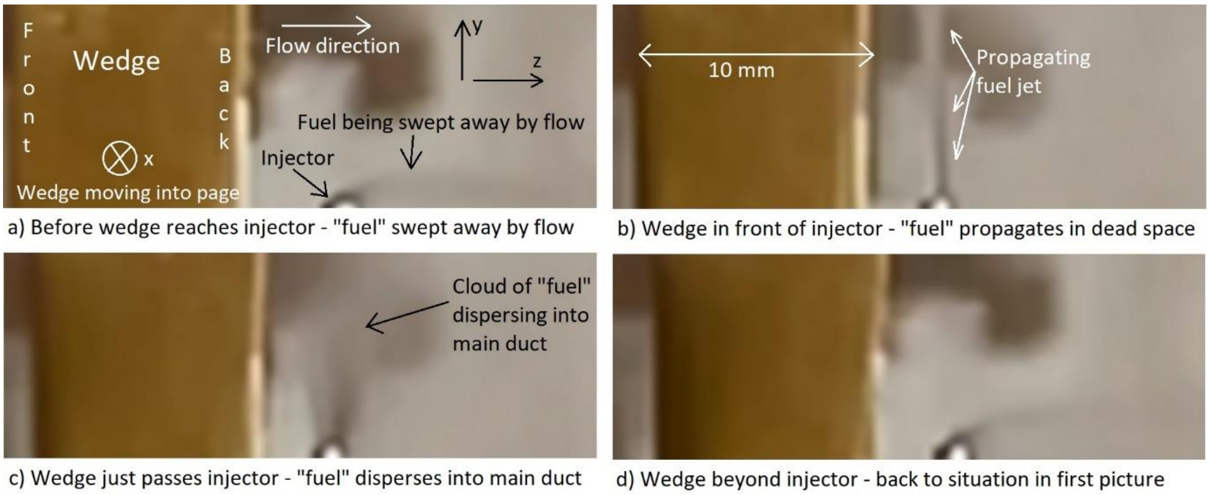


a) Wedge before pellet arrives b) Path of pellet leaving wedge

The next diagram shows a wider view of a similar event – this time illustrating the ultimate breakup of the pellet. In picture a) the pellet has not yet arrived at the edge of the wedge (which is at the top left of the image). Picture b) shows the pellet arriving through the dead space at the back of the wedge. Picture c) was taken at a similar time to that above – as the pellet leaves the wedge edge. Finally picture d) shows the cloud of “fuel” (starch in this case) vaporising and dispersing in the flow.



Finally, the diagram below shows a series of images which neatly encapsulate the whole series of experiments. These show a 10 mm long, 5° half-angle wedge, moving at 1 m/s into the page (away from the camera) and passing in front of an injector, injecting water at 1 m/s.



a) Before wedge reaches injector - "fuel" swept away by flow

b) Wedge in front of injector - "fuel" propagates in dead space

c) Wedge just passes injector - "fuel" disperses into main duct

d) Wedge beyond injector - back to situation in first picture

Pictures a) and d) clearly show the normal injector situation – with the “fuel” being swept away by the flow before it can mix. Picture b) shows what happens when the wedge moves in front of the injector – the liquid can now move through the dead space behind the wedge and covers the whole height of the duct. Picture c) shows the situation as the wedge just sweeps past the water-jet – the water disperses into the main flow at the wedge edge. This sequence of events is exactly as predicted by the previous theoretical work and simulations.

Conclusions

The experimental verification of ASPIRE’s main concept is a key milestone in its development. The results outlined above and in the full paper clearly demonstrate that the use of rotating wedges and discrete fuel injection to provide stoichiometric air-fuel mixing is a valid and productive path. They closely align with the predictions of the theoretical and simulation work, with no major surprises evident.

The full paper will be made publicly available when the embargo period is over.