Conclusions

In cost-conscious times, it is tempting to say that hypersonic applications will be restricted to various forms of military weapon. However, the Space Shuttle has carried many civilian and scientific payloads, and has provided the first and only demonstrations of lifting re-entry and controlled landings on a routine basis. If constructive cynicism restricts immediate interest to projects that are smaller and cheaper than the full-scale SSTO reusable space launcher, then there are two main contenders. The first is the small but technologically exploratory aerospaceplane, intended to provide hypersonic cruise missions and to permit access-to-orbit as a small SSTO or perhaps as a TSTO second stage. The second contender is smaller still and, being simpler, is already achievable, namely an ambulance re-entry craft for the International Space Station.

Since Space Station schedules called for the orbiting of initial components in late 1998 and aim at completion in 2005–06, there is still time to design and build SLEEC as a worthy complement to the X-38 and as a much-needed Space Station support vehicle for the injured. In studying vehicle configurations for low-g, high-crossrange applications, Nonweiler and East have shown two variants of the delta-winged glider, for which flight performance has been summarized by using Pike's similarity parameters (see figure 1, p. 2140). These define C_{L} and C_{D} combinations for medium- and high-crossrange flight between Mach numbers 5 and 25 (see also Pike's figure 7, p. 2148, and figure 1, p. 2154). Wind-tunnel tests and computational aerodynamics can be guided by these and, given realistic wing loadings, heating investigations can then be specified (Nonweiler and East having assessed both conductive and conventional approaches to heat shield design). Leading edges and flat heat shield panels can be proof-tested in European wind-tunnels such as SCIROCCO as detailed by Vennemann, and the computational techniques he describes with Muylaert and Walpot will ease extrapolation of data to flight conditions. This combination of wind-tunnel and computer will form a foundation for practical design for the next few decades. It would be adequate for SLEEC, and SLEEC may well be compatible with proposals within the European Space Agency for experiments using winged atmospheric re-entry craft; in the longer term, the technologies of SLEEC and external combustion (as analysed by Broadbent) may combine to allow a 21st-century elaboration of the X-20 Dynasoar offering missions of much greater endurance.

The matters addressed under Topic II (Airbreathing propulsion) are more complex, and full-scale applications are longer term and more expensive. Part of the complexity results from the lack of decision so far on the engine cycles to be used but, in addition, the fundamental choice of propellants (for example, hydrogen, hydrogen plus additives, or hydrocarbons such as kerosene) has become an open question. Earlier insistence that only hydrogen could qualify (on considerations of airbreathing specific impulse) has now given way in certain applications to the appeal of denser fuels and smaller vehicles; and the undoubted capacity of hydrogen to cool the hottest parts of a high-speed structure seems less crucial if airbreathing Mach numbers no longer extend much beyond 10.

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It has been recorded already (see introductory comments to Topic II, pp. 2279–2283, and the ISABE Billig Lecture by Townend, pp. 2317–2334 of this issue) that for vehicles with significant payload-to-orbit, an airbreathing TSTO second stage (using kerosene for the scramjet and hydrogen for the rocket) can be much smaller than an equivalent hydrogen-fuelled vehicle (or even than a vehicle using hydrogen plus neon), where both vehicles are launched at the same initial mass and the same initial Mach number. It has additionally been shown that, for an SSTO using horizontal take-off and offering a hypersonic cruise capacity (or access to orbit) with a very small payload, a vehicle using kerosene for both airbreathing and rocket power is far heavier at take-off than an equivalent vehicle using hydrogen for the rocket stage only, or hydrogen throughout; but the kerosene-fuelled vehicle is no heavier at take-off than a large modern airliner, and it offers the logistic appeal of using only a standard fuel. The vehicle lengths of all three variants lie between those of the U-2S and the SR-71 (the vehicles they may complement or replace), and it is clear that the all-hydrogen vehicle is the largest (see figure 1, p. 2282).

There is a real need to examine the relative merits of hydrogen and hydrocarbons (for example, see Pike's paper in Topic II), especially since a fuel such as kerosene can avoid both the large bulk of liquid hydrogen and the constraints on packaging and configuration design that fuels stored under pressure (such as liquid hydrogen and liquid methane) impose on the tankage and airframe.

The foregoing has made little mention of the hypersonic transport aeroplane, because the airlines seem unlikely to regard it as a commercial necessity until China has become a driving force in the development of trans-Pacific civil transport. It is also true that hypersonic weapons have only briefly been considered. Their needs in terms of research topics and test conditions reflect special features in propulsion and trajectory design. For example, the Gulf War demonstrated the vulnerability of land forces to attacks by modest ballistic missiles such as Scud and the hairs-breadth defence offered by short-range systems such as Patriot. By comparison, an anti-ballistic missile (ABM) that intercepts a Scud within a minute or two of launch will call for characteristic features such as scramjet acceleration at very high kinetic pressures and unusually small scales. They should thus be considered separately in defining research required and conditions to be provided, but both the hypersonic transport and the long-range ABM will increase the interest in scramjets. This is because in the one case, a very extended cruise is essential, and because in the other the scramjet offers a unique combination of basically simple and cheaply expendable hardware, flexibility and fuel economy over a wide airbreathing hypersonic speed range, and a proven readiness to burn hydrocarbon or hybrid fuels. These allow the compactness on which the designer will be crucially dependent.

1. Recommendations

The aims of this Theme Issue have been

(i) to identify the projects most likely to attract funding in the next decade or two, and

(ii) to illustrate scientific research and test conditions that will need to be funded in pursuit of these projects.

The projects selected are those described opposite.

Project 1. A small-payload airbreathing aerospaceplane (offering hypersonic cruise and access to orbit as an SSTO or TSTO) whose rationale is not only that it will perform valuable reconnaissance and peace-keeping missions but that it can be physically quite small (much less than 100 ft in length).

Project 2. A two-person Space Station ambulance, which will offer the injured both a significant crossrange and re-entry at very low g, but to the funding authorities will seem relatively uncomplicated and very small (less than 30 ft in length); a vehicle such as SLEEC22 would complement rather than compete with vehicles resembling the X-38.

It is realistic to say that a Project 2 vehicle could serve the designers of other types of craft. The need for SLEEC itself is humanitarian and immediate but, in a research capacity, SLEEC would provide invaluable data on heat-shield design. A Project 1 vehicle would benefit both from SLEEC data and from the demonstrator proposed by Czysz; indeed, one strength of the Czysz proposal is that, with engine decisions once made, his demonstrator can readily evolve into the vehicle of Project 1. This underlines the importance of a demonstrator vehicle 'to fly at hypersonic speeds and altitudes consistent with airbreathing propulsion' and yet to retain 'a high performance level as a hypersonic glider'; but it offers the possibility that the demonstrator should concentrate not only on cycle design for accelerating flight but on propellant assessment, while leaving re-entry to SLEEC.

Finally, Project 1 may prove too exacting if pursued as an SSTO. It may therefore take the form of a TSTO with the scramjet on the second stage, which (subject to Nonweiler's precooling) could be launched at a moderate supersonic Mach number. This will not only relax the constraints on total system mass and demands on the first stage, but will offer the scramjet its simplest task—to propel a small super/hypersonic vehicle, without the need to accommodate the demands of subsonic and transonic acceleration.

In responding to realistic operational demands rather than by pursuing the ultimate technologies, a project and its implied costs become less daunting. SLEEC in particular would incur a marginal percentage of the tens of billions of dollars already committed to the Space Station, and yet could save Mission Control from difficult decisions on who would survive re-entry and who would not. For those selected for re-entry, even an X-38 could not return injured astronauts to the most appropriate hospitals if these are thousands of miles apart; two or three SLEECs would offer that ability with ease. The simplicity of SLEEC may also enhance the prospects that the scientist will accomplish research in time to influence the design and effectiveness of a much-needed vehicle; but a part of its simplicity lies in the fact that SLEEC would draw on much that is already known.

L. H. Townend