Topic I. Serving the International Space Station

The Royal Society

Phil. Trans. R. Soc. Lond. A 1999 **357**, 2151-2155
doi: 10.1098/rsta.1999.0425

Topic I
Serving the International Space Station

Space Station ambulance.

The first items of Space Station hardware were launched in 1998 and the Station should be complete by 2006. In order to avoid reliance on SOYUZ for the return of crew members, the Shuttle and vehicles derived from the X-38 will provide for scheduled and emergency returns, but neither is ideal as an ambulance, since both will subject their occupants to significant g-forces during re-entry. Injured personnel then risk further damage, especially if they have internal injuries and/or blood clots. Thus, any Space Station ambulance must re-enter at very low rates of deceleration.

In addition, the injured must not be subjected to delay in orbit. The 're-entry window' must be wide, and the need is then for a space-based vehicle that offers low-g re-entry and a significant crossrange (that is, the ability to turn gently out of the plane of orbit and fly to selected airports). In terms of aerodynamics, these three requirements dictate a high value of hypersonic L/D and a slender vehicle.† We have called this vehicle the slender lifting entry emergency craft (SLEEC).

The origins of SLEEC can be found in the search for satisfactory configurations for winged re-entry vehicles, which started before World War II and was greatly extended in the 1950s. Among research results, Love (1964) pointed out that, with an L/D of 3.6, a re-entry vehicle could reach any point on Earth from any orbit. It was also clear from the equations that a high L/D would automatically endow the vehicle with low re-entry deceleration, but it was the extreme range which drew attention at that time. Forty years later, the Space Station provides a project for which low-g re-entry for injured astronauts leads to the observation that a re-entry vehicle shaped to give an L/D of about 3 would allow the carriage of injured astronauts with g-forces no worse than they would experience on Earth.

APECS results suggest that suitable vehicle design will permit maximum deceleration in re-entry at or below a medically acceptable $1.1g$, compared with $2g$ to $3g$ for semi-ballistic capsules and maybe $1.4g$ for the Shuttle. These studies also show that the vehicle can offer accessibility to a wide choice of airports/hospitals, and at vehicle temperatures no higher than the Shuttle already withstands. SLEEC needs to be no longer than 30 ft (9 m, say) and can be carried into orbit (four at a time) by the Shuttle; tankage and propulsion are thereby minimized, and structural design is eased by the absence of airloads during launch.

In the two opening papers of Topic I, Nonweiler and East assess SLEEC designs in two specific forms. These offer different crossranges but both provide the essential feature that g-force is maintained at $1.1g$ or below. Nonweiler selects a high crossrange configuration SLEEC22 and bases its shape on his own original approach to waverider design (Nonweiler 1959). In the hands of its originator and in its original context (which was lifting re-entry rather than cruise), the Nonweiler wing effectively avoids all the conventional criticisms to which waveriders have been routinely subjected. East describes a design that closely resembles the Dynasoar X-20. It uses a heat shield of more orthodox design than SLEEC22, and a higher wing loading which, at *ca.* 350 $\mathrm{kg\,m^{-2}}$, permits a somewhat restricted crossrange but demands a less innovative implementation.

Between these two vehicles, it seems likely that most realistic designs will be found, in other words, a basically delta planform, some 30 ft in length and (in order to fit into the Shuttle orbiter) some 14.5 ft from wing tip to wing tip, no propulsion (other than small thrusters for attitude control in space and during re-entry), and a long-

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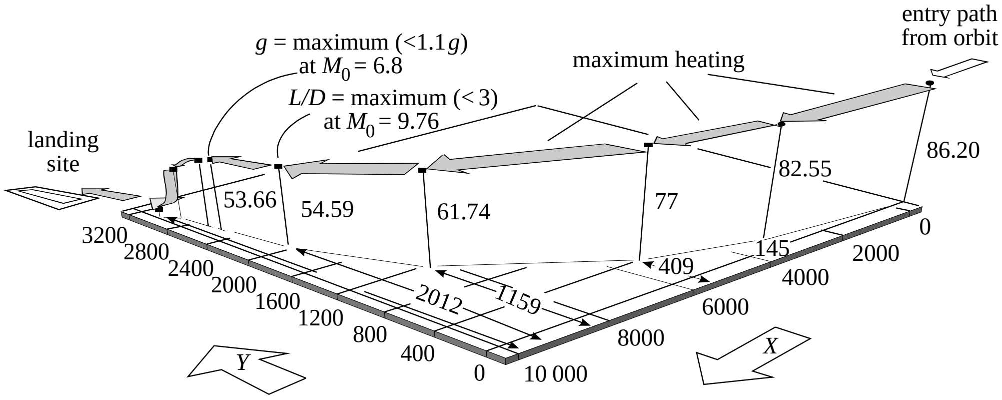
† L/D is the ratio of vehicle lift to vehicle drag.



Typical SLEEC re-entry trajectory (downrange, 10 000 km; crossrange, 3000 km)

t (s)	altitude (km)	M_0	*X* (km)	*Y* (km)	*L/D*	*g*
0	86.20	28	0	0	1.19	0.205
450	82.55	25.13	3264	143	1.29	0.299
800	77	21.6	5543	409	1.35	0.531
1350	61.74	14.06	8335	1159	2.47	1.046
1700	54.59	9.76	9329	2012	2.96*	1.046
1900	53.66	6.83	9597	2490	1.72	1.085*
1950	50.90	6	9640	2587	1.86	1.077
2150	40.81	3.64	9721	2885	2.41	1.054
	0	0	10 000	3000		

*Maxima in *L*/*D* and *g*.

Figure 1. SLEEC22 re-entry trajectory.

stroke, actively controlled undercarriage to preserve low *g*-forces at touchdown. A typical re-entry trajectory for SLEEC22 is shown in figure 1.

In his second paper, Nonweiler explores the ways in which innovative techniques can be used for heat-shield design. Nonweiler presents an updated and greatly extended analysis of thermally conductive leading edges by which to avoid the bluntness that is a feature of conventional hypersonic leading edges. Nonweiler's early work on this topic was undertaken in the 1950s and 1960s (see Nonweiler *et al.* 1971). Work on waveriders in the 1980s took some account of Nonweiler's conductive leading edges (Bowcutt 1986) and recent results in Germany, published by the AIAA (Strohmeyer *et al.* 1998) reach conclusions that are consistent with those of Capey and Nonweiler (see Townend 1978). The analysis presented here allows Nonweiler to indicate the potential, especially at higher Mach numbers, which is offered by conductive cooling, and gives the theoretical foundation for further work, both for re-entry and launch.

With regard to the choice of materials, these were exhaustively studied in the 1960s and 1970s (see Bauer & Kumer 1970), and an alloy of columbium (i.e. of niobium) was shown to retain its strength at exceptionally high temperatures and to accept protective coatings by which to delay the process of oxidation. Coated columbium alloy can be reliably used up to 1800 K (and to some extent reused subject to eventual problems with creep deformation). Even with the coating removed from areas of over 1/4 inch diameter, the material would survive several additional re-entry flights before any hole in the skin would develop (and many more before the panel would fail). For a vehicle such as SLEEC, the possibility may exist that, if the leading edges are routinely removed (and the metal recycled) after every re-entry, unalloyed columbium edges will offer both the high thermal conductivity of the pure metal and sufficient tolerance of the oxidation and erosion of a single flight; in which case, the conditions considered by Nonweiler are both realistic and potentially profitable. In all probability, a 21st century SLEEC designer would consider using more modern materials, but the importance of Nonweiler's work is that sharp leading edges do not need carbon–carbon derivatives even at re-entry conditions. With theoretical adjustments, his analysis can also assess the performance of slender injectors which (with fuel cooling on their inner surfaces) are critically important to the scramjet designer (see Topic II) and, for their own survival, are critically dependent on conductivity.

In the two remaining papers of Topic I, Vennemann, Muylaert and Walpot address the exacting process of ground testing the aerodynamics, thermodynamics and structural heating that hypersonic vehicles will experience. Very substantial investment in wind tunnels has been made over the last decade, both in uprating tunnels that already existed and in building brand new facilities. In Europe, new facilities such as the HEG in Göttingen first ran in the mid-1990s and SCIROCCO in Capua will be commissioned during 1999. Vennemann emphasizes the differences between tunnels for R & D, and those intended to subject samples of full-scale hardware to proving tests. He also outlines some of the intrinsic difficulties that wind-tunnel testing poses and indicates the need for elaborate fluid dynamic computations to evaluate performance at flight conditions that wind tunnels cannot reproduce even for short run times. Accordingly, Muylaert, Walpot and Vennemann introduce computational results that have been obtained not only for flight vehicles, but for the wind tunnels themselves, and they conclude that both computational fluid dynamics and wind-tunnel testing will remain essential in the progression from design to full-scale flight.

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