Aerothermodynamic Design Problems of Non-Winged Re-Entry Vehicles

The transport of payload into space, either suborbital, orbital or superorbital and its return to the Earth’s surface, is known to require the development and construction of suitable vehicles which are able to withstand the very severe thermal and mechanical (pressure and shear stress) loads encountered during such a mission. In the early days of space exploration, the designers had the feeling that the vehicle shapes should be as simple and compact as possible. So, capsules and probes as the most important types of non-winged re-entry vehicles (RV-NW) were born.

In this chapter we deal with a few major aerothermodynamic design problems of RV-NW’s. Aerothermodynamic phenomena, high Mach number and total enthalpy effects as well as particular trends in aerothermodynamics of RV-NW’s are mostly similar to those of RV-W’s, Sections 3.1 and 3.2. However, we consider also vehicles for re-entry from higher altitudes than treated in Chapter 3 and also vehicles operating in extraterrestrial atmospheres.

The lunar return of APOLLO takes place with a velocity much higher than those typical of RV-W’s. Therefore we find in this case much more severe thermochemical phenomena. Also the flight in extraterrestrial atmosphere leads to further, specific thermo-chemical description problems. We abstain from giving an overview of the special aerothermodynamic issues of such vehicles.

First, a general overview of the topics treated is given, strategies for atmospheric entry and orbital transfers are sketched, and configurational aspects are discussed. Because RV-NW’s as a rule have no aerodynamic stabilization, trim and control surfaces, we concentrate our considerations in two of the five main sections on issues of static and dynamic stability. A general treatment of static stability also of these vehicles is given in Chapter 7. The last section is dedicated to a discussion of thermal loads.

5.1 Introduction and Entry Strategies

The class of non-winged re-entry vehicles considered here comprises ballistic entry probes (Sub-Class 1), traditional capsules like APOLLO and SOYUZ (Sub-Class 2) as well as blunted cones and biconics (bicones and bent bicones) (Sub-Class 3). While, normally, the capsules do not have aerodynamic control surfaces, the sub-class of cones may have some, in particular body flaps for
longitudinal trim and, in case of multi-functional control surfaces with inclinations with respect to the lateral axis, also for roll control and lateral stability, Fig. 5.1 c).

For the capsule sub-class, the lift-to-drag ratio during atmospheric re-entry is mostly in the range of \(0.3 \lesssim L/D \lesssim 0.4\). It should be mentioned here that, in order to avoid confusion, that for capsules, a positive lift will only be obtained for negative angles of attack (if classical aerodynamic definitions are used, Fig. 7.3), because the aerodynamic lift force is caused predominantly by the front part (heat shield) of the vehicle, Fig. 5.1 a), whereas in the case of a biconic, the lift force is brought about by the whole body, Fig. 5.1 b). The explanation of this behavior is given in Section 5.3. The aerodynamic efficiency of the blunted cone sub-class is somewhat higher and lies between \(0.7 \lesssim L/D \lesssim 1.4\). In that case the contribution to the aerodynamic forces and moments is distributed over the whole body.

It is the intention of this chapter to provide the reader with detailed information about:

**Fig. 5.1.** Angle of attack for entry probe or capsule, a), and bicone, b), required for positive lift \(L\). Sketch, illustrating the role of multi-functional control surfaces on bicones for pitch, yaw and roll, c).