4.3 SOYUZ (Russia)

The SOYUZ spacecraft was developed in the 1960s in the frame of the Soviet Union's space program. Its mission profile was in the past to carry people to and from the Soviet space stations SALYUT and MIR. It is still in these days the crew carrier for the International Space Station ISS. Further, the original planing had foreseen SOYUZ to be a part of the Soviet Union's Manned Lunar program, which never came true. The first successful manned flight has taken place in Oct. 1968, subsequent to a manned flight in 1967, which ended with a crash-landing and the death of the cosmonauts. Since then the SOYUZ capsule has conducted the re-entry missions of persons from low Earth orbit flights and the ISS very reliably.

The mass of the SOYUZ capsule is approximately 3000 kg. All the launches of the SOYUZ spacecrafts are carried out with SOYUZ rockets. The transport capability and launch security of these rockets are continuously advanced since the 1960s.

4.3.1 Configurational Aspects

Fig. 4.11 shows some images of the SOYUZ capsule as part of the SOYUZ spacecraft. In Fig. 4.12 three-dimensional versions of the SOYUZ capsule shape are presented whereas in Fig. 4.13 the geometrical relations are drawn, [11]. The SOYUZ spacecraft is composed of three parts, the orbital module, the re-entry module (SOYUZ capsule) and the service module. The shape of the SOYUZ capsule consists of a front part, which is built as a spherical segment, and an aft body in the form of a blunted circular cone, Fig. 4.12. The last part of the descent of the SOYUZ capsule after re-entry in the atmosphere is performed with the help of a parachute system and the subsequent landing always takes place in the desert of Kazakhstan. This is in contrast to the procedure for APOLLO, which was designed for a water landing.

Fig. 4.11. SOYUZ spacecraft with the re-entry module in the middle of the spacecraft structure (left); SOYUZ spacecraft mock-up (middle); SOYUZ capsule after landing in the desert of Kazakhstan (right). Pictures from NASA and ESA galleries.

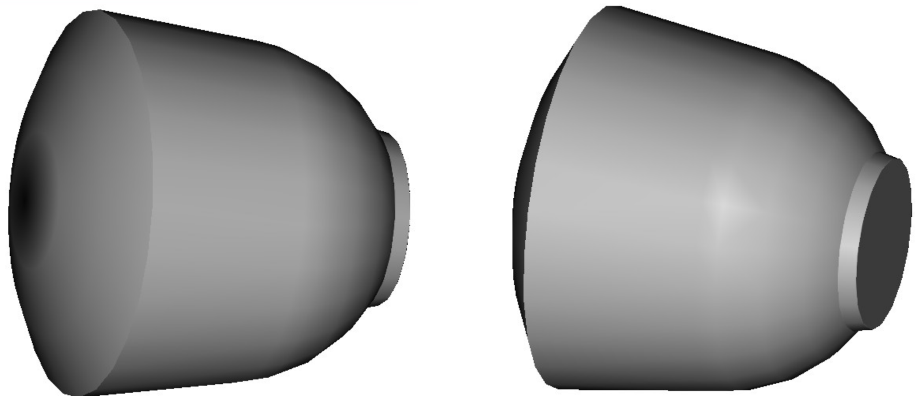

Fig. 4.12. 3D shape presentation of the SOYUZ capsule

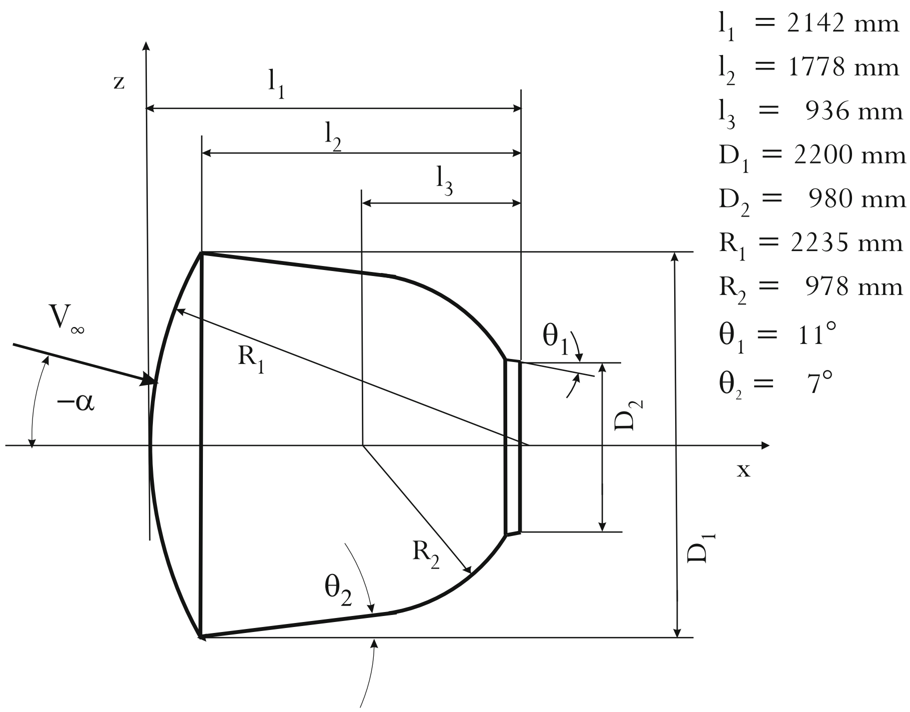

Fig. 4.13. Shape definition of the SOYUZ capsule, [11]

4.3.2 Aerodynamic Data of Steady Motion

Most of the aerodynamic performance data were obtained by experiments in the wind tunnels of TSNIIMASH and TSAGI. Both institutions are located near Moscow, Russia. Certainly some data were measured using a free flying large scale model with a diameter of 1 m.

Longitudinal Motion

The aerodynamic coefficients C_X, C_Z, C_m and L/D are given for the Mach numbers $M_\infty = 0.60, 0.95, 1.10, 1.78, 2.52, 5.96$, Figs. 4.14 - 4.17. The design goal was to attain in the hypersonic flight regime for the given trim angle $\alpha_{trim} \approx -25°$ an aerodynamic performance value of $L/D = 0.3$, which indeed was met, see Figs. 4.16 and 4.17. The vehicle behaves statically stable in the whole Mach number range presented here and the angle of attack regime $-30° \leqq \alpha \leqq 0°$. It is conspicuous that the axial force coefficient C_X has for all plotted Mach numbers its maximum at $\alpha = 0°$ and decreases with increasing negative angle of attack. This behavior is different from that of APOLLO, where the maximum of the force coefficients are Mach number dependent, with the highest negative α value for the lowest Mach number ($M_\infty = 0.5 \Rightarrow C_{Xmax}(\alpha \approx -15°)$, see Fig. 4.4). The trim angle of attack course as function of the Mach number is exhibited in Fig. 4.18 and indicates the same characteristics as the APOLLO one (see Fig. 4.8), namely to increase from subsonic Mach numbers to a local maximum at $M_\infty \approx 1.8 - 2$, followed by a moderate decrease up to Mach numbers $M_\infty \approx 4$ and a slight growing when the Mach number approaches the hypersonic regime.

Lateral Motion

The SOYUZ capsule is an axisymmetric configuration. Because of that no lateral aerodynamic characteristics exist.

4.3.3 Aerodynamic Data of Unsteady Motion

Pitch Motion

The dynamic derivative of pitch motion[1] $m_z^{\bar{\omega}_z}$ as function of the angle of attack $(-180° \lessapprox \alpha \lessapprox 0°)$ is plotted in Fig. 4.19. Generally for $-83° \lessapprox \alpha \lessapprox -3°$ dynamic stability is given, but there exists a mall sector $(-23° \lessapprox \alpha \lessapprox -17°)$ where this stability is suspended and that is just the range where the SOYUZ capsule for $M_\infty = 0.9$ conducts its trimmed flight ($\alpha_{trim}^{M_\infty=0.9} \approx -18.1°$).

Other Motions

[1] In the Russian literature the dynamic derivative of pitch motion is indicated by $m_z^{\bar{\omega}_z}$ which is proportional to $C_{mq} + C_{m\dot{\alpha}}$.

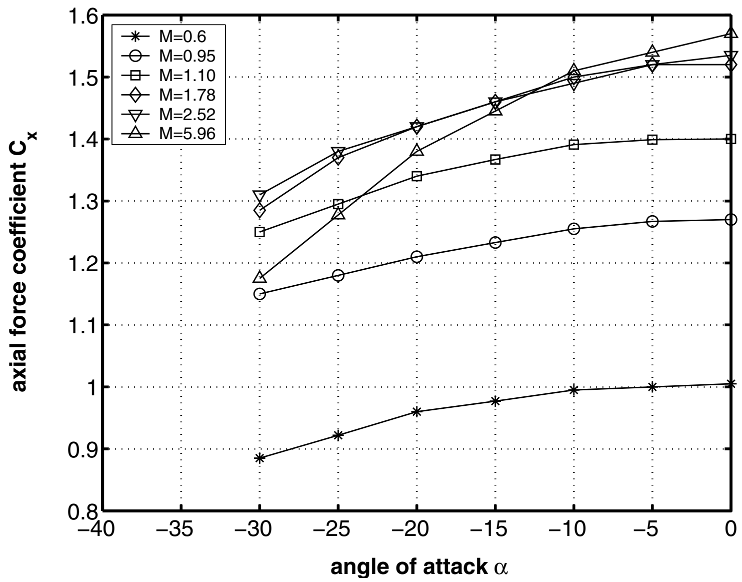

Fig. 4.14. Axial force coefficient C_x as function of the angle of attack α, [11]

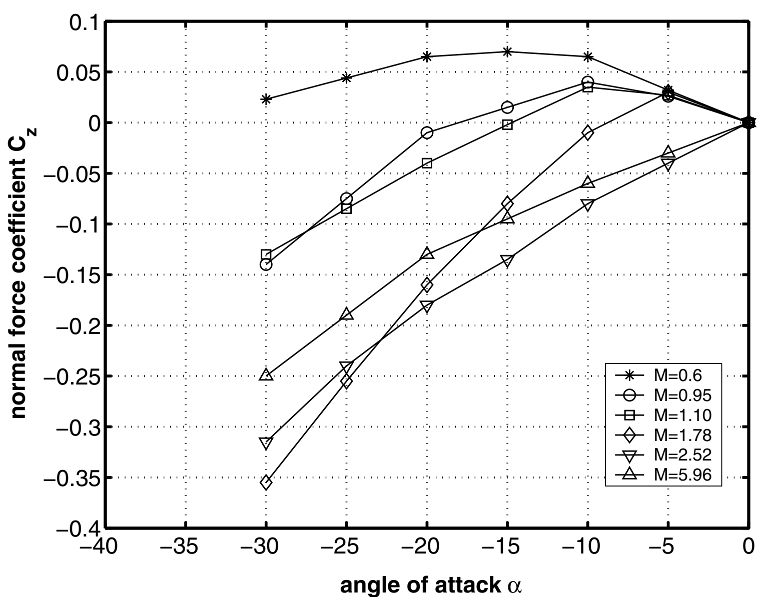

Fig. 4.15. Normal force coefficient C_z as function of the angle of attack α, [11]

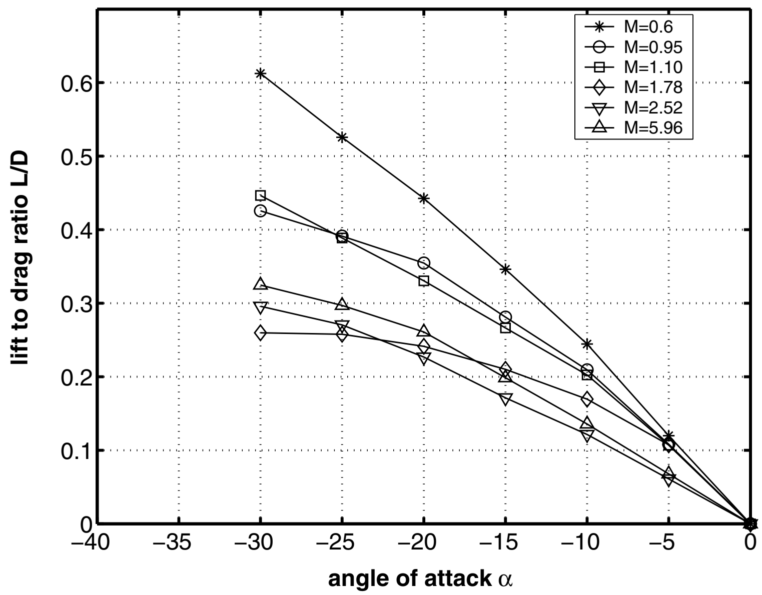

Fig. 4.16. Aerodynamic performance L/D as function of the angle of attack α, [11]

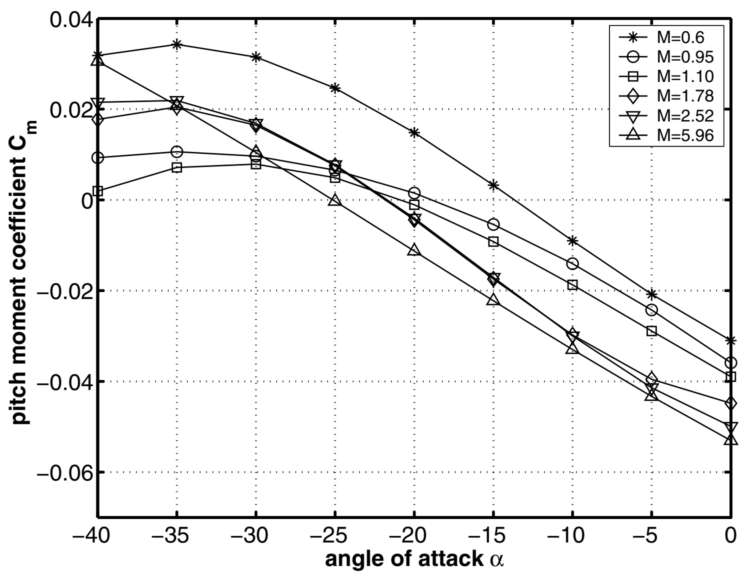

Fig. 4.17. Pitching moment coefficient C_m as function of the angle of attack α, [11]. Moment reference point: $x_{ref} = 0.37\,D_1$, $z_{ref} = 0.039\,D_1$.

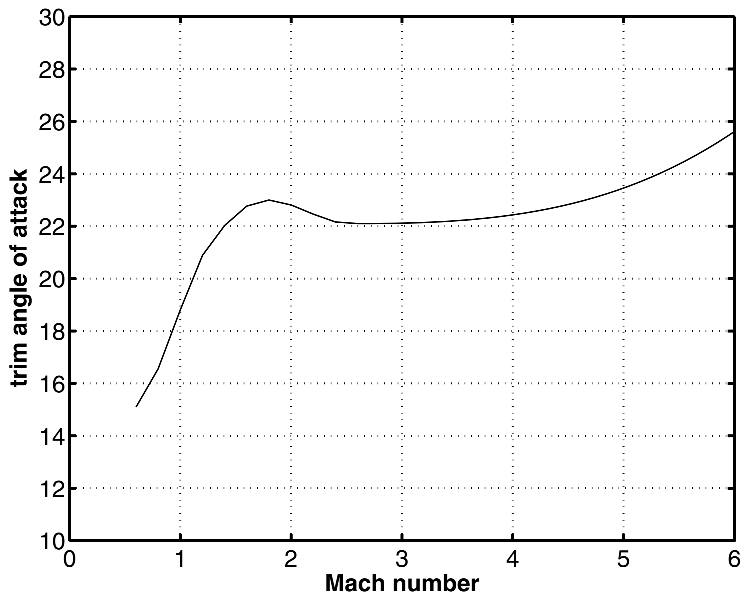

Fig. 4.18. Trim angle of attack α_{trim} as function of the freestream Mach number

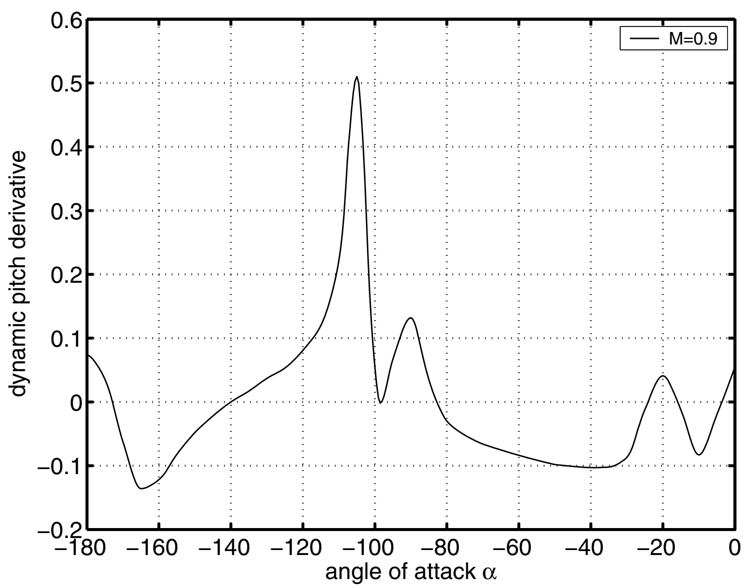

Fig. 4.19. Dynamic derivative of pitch motion $m_z^{\bar{\omega}_z}$ as function of the angle of attack α for freestream Mach number $M_\infty = 0.9$, [11]

The SOYUZ capsule is an axisymmetric configuration. Because of that only the dynamic derivative of pitch motion is relevant.

4.3.4 Peculiarities

In the following we describe the determination of a trim line in the way mentioned in Section 4.1. For a given trajectory point the coordinates x_{cp}, z_{cp} can be computed from a numerical solution[2] of the governing equations by the set of equations, which describes the general formulation of the center of pressure and which can be found in [1]. Then trimmed flight for a prescribed trajectory point is feasible for all the center-of-gravity positions which meet eq. (4.3).

As an example we extract for hypersonic flight ($M_\infty = 5.96$) from Figs. 4.14 and 4.15 for $\alpha_{trim} = -25°$ the axial and normal force coefficients $C_{X,trim} = 1.28$ and $C_{Z,trim} = 0.20$. Further we take over the center of pressure coordinates reported in [11], which are set to $x_{cp} = 0.60 D_1$ and $z_{cp} = 0.0 D_1$. For these values the evaluation of eq. (4.3) is plotted in Fig. 4.20.

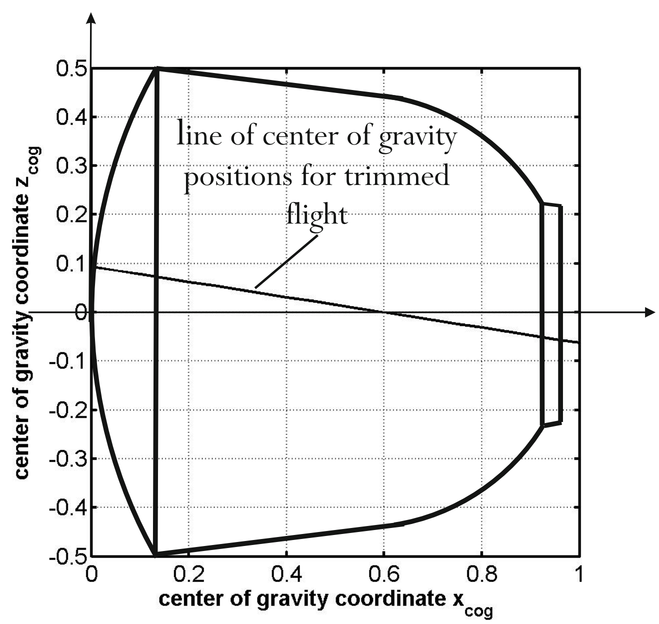

Fig. 4.20. Center-of-gravity locations for trimmed flight in the hypersonic Mach number regime. Data taken from Figs. 4.14 and 4.15 for $\alpha_{trim} = -25°$ and $M_\infty = 5.96$.

[2] Of course, the center of pressure is also subject of measurements.