Comparison of Aerodynamic Dynamic Stability Data Sources

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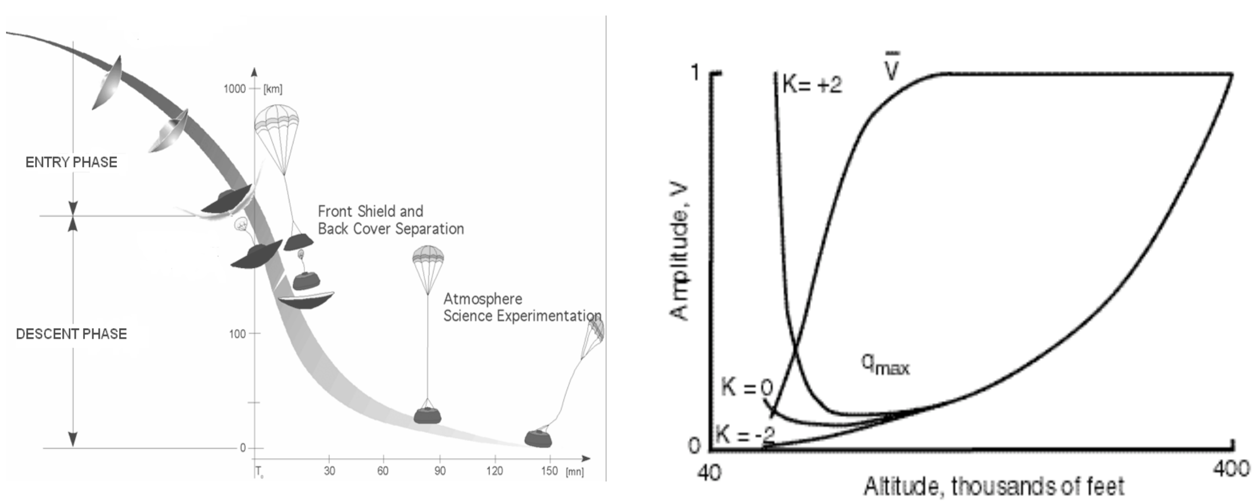
Introduction

The determination of stability coefficients has had a very long history dating back to the early history of aviation, e.g., Ref. 1. Attempts were made as early as the 1940's to separate effects due to pitching and plunging with little success. Fortunately this is normally not required for reasons that will be touched on in the section on basics. In addition dynamic stability coefficients due to pitching and plunging were found to be dominated by the tail and the effect could be estimated using tail on and tail off static pitching moment data from wind tunnel tests, as a result the measurement of dynamic stability coefficients was largely dropped for a long period of time. With the importance of high angle of attack performance by military fighter aircraft the need for dynamic stability information came to the fore again. This led to the development of rotary test apparatuses that could measure dynamic stability coefficient in a rotating system about the velocity vector in the late 1960s early 1970s (Ref. 2).

With the advent of the space age it was soon discovered that the dynamic stability coefficients were much smaller for planetary probes than for aircraft and to a large extent they were not important because the angular motion is controlled strongly by the increase in dynamic pressure as the spacecraft enter an atmosphere. With the increased effort for exploration of planets like Mars and the requirement for more precision for landing and the need to deploy parachutes to provide safe landings on the surface the need for better estimates of the dynamic stability coefficients became important. Fig. 1a shows at typical entry trajectory. Fig. 1b shows an example of the expected behavior of the amplitude of the angle of attack, Ref. 3. After maximum dynamic pressure the amplitude begins to increase and can result in problems for parachute deployment. Because of the small values of the dynamic stability coefficients significant effort has gone into overcoming some of the shortcomings of the earlier attempts.



a) Schematic of typical entry. **b) Velocity and amplitude behavior with altitude.**

Figure 1. A typical entry schematic and behavior.

This paper will concentrate on the determination of dynamic stability coefficients for blunt planetary probes. There is little data for cross comparison of the various techniques so this paper will concentrate on basic concepts and the major issues involved. The paper will start with a discussion of some basic aerodynamic concepts that need to be kept in mind when one is obtaining or using dynamic stability coefficients. Then the major issues will be considered. These can be considered in three groups, data sources and test procedures, data types and analysis procedures, and unexpected and/or unmodeled fluid physics.

Basic Concepts and Definitions

There are several basic concepts that must be kept in mind when dealing with dynamic stability coefficients. These are, flight regimes and parameters, the functional nature of aerodynamics, dimensional analysis, definitions of dynamic stability terms and axis transfers.

Flight regimes and parameters

The flight regimes and parameters will be touch on briefly for reference. The flight regimes are the very high velocities where there will be rarified gas effects at the very high altitude as well as chemistry effect in the gas flow about the body. There is also the classical hypersonic Mach number range between 4 and 8 where chemistry is not important, the supersonic, transonic and subsonic speed ranges.

The flight parameters of importance are the orientation relative to the velocity vector, for example the angle of attack, α, Mach number, M, Reynolds number, Re, center of gravity location, x_{cg}/d, and gas composition, γ. There is some indication that γ may be important even at conditions where there are no chemistry effects present, e.g., Ref. 4.

Dimensional analysis

The primary function of dimensional analysis is to reduce the number of variables. The process of doing that does not lead to unique variable groupings. For example drag $D = D(\rho, V, L, a, \mu, \alpha)$ becomes $C_D = \frac{D}{\rho V^2 L^2}(M, \mathrm{Re}, \alpha)$ but we never see it in this form we normally use $C_D = \frac{D}{0.5 \rho V^2 A}(M, \mathrm{Re}, \alpha)$. The 0.5 and A are historical. In the early days of ballistics the factor 0.5 was not used. One needs to be careful when using old data. If we are considering moments we need an extra length dimension and hence we get for pitching moment $C_m = \frac{D}{0.5 \rho V^2 A d}(M, \mathrm{Re}, \alpha)$. For blunt bodies the reference area, A, is normally the base area and the scale length is the diameter, d.

The normalized angular rates take the form $\bar{\dot{\alpha}} = \frac{\alpha d}{2V}$ and $\bar{q} = \frac{qd}{2V}$. Here again for blunt bodies the scale length is normally take as the diameter, d. The factor 2 is a historical artifact that I believe came from the aircraft community when considering roll rates. There the reference length was the span, b, and used with the factor of 2 the normalized roll rate was the ratio of the wing tips rotational velocity normalized by the free stream velocity and hence gave the helix angle of the tip as an aircraft rolled. There are some theoretical developments as well as data in the literature that do not include the factor of 2. One must be careful in using data from various sources to check to be sure how the quantities were normalized. Therefore it is good practice when writing up reports on dynamic stability parameters to write out the definitions of the coefficients used.