FORCED OSCILLATION TECHNIQUE: THEORY

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1. Forced-oscillatory techniques

Forced-oscillatory experiments (also known as direct forced-oscillation technique) still remain a unique way to obtain a wide range of stability parameters. The method is based on the assumption that the reaction of the system to a sinusoidal displacement of the model (primary motion) is of the same type with some phase lag. The response of the system is locally linearized by assuming that the amplitude of the spectral response is centered on the forcing frequency. This is generally true when the amplitude and the frequency of the displacement are kept small. The same assumption supports the validity of the derivative based mathematical models commonly used in aeronautics (linear superposition of effects). Higher order harmonic approximations instead of frequency-centered derivatives can be used to remove this limitation.

Forced oscillatory experiments must not be confused with aeroelastic testing on flexible wind tunnel models. The model is a rigid body and the flexibility of the support is usually an undesired feature of the system.

The inertia of the model does not affect the results but substantially changes the power of the driving system (oscillatory unit). The power required to oscillate the model is in no way correlated with the maneuver of the equivalent flying vehicle.

A review of the available experimental methods will be shortly presented to clarify the differences and the similarities with the other techniques. This outline will also help to limit confusions or misleading interpretations of wind tunnel dynamic tests. The reader is invited to remember that the flowfield surrounding the configuration in the test section may be unsteady even if the model is held in a fixed position (this is the case of separated flows in post-stall regimes). The motion of the model is eventually super-imposed to the existing flow. Another concern for a complete undestanding of the differences among the several types of wind tunnel tests is that the motion of the model must not be visualized in terms of Euler angles (pitch, roll and yaw attitudes) only: the motion of the model is also affecting the aerodynamic angles (angles of attack and sideslip). Note that Euler angles of the model may vary keeping the aerodynamic angles unchanged (whirling arm maneuver or snaking maneuver). The opposite may be also true (heave motion).

Static testing is the primary experimental source for aircraft aerodynamic data. The purpose is the determination of aircraft nondimensional static coefficients $C_i\left(\alpha,\beta,\mathrm{Re},Ma,\delta_C\right)$. The model is statically positioned according to a sequence of aerodynamic angles $\left(\alpha,\beta\right)$ during wind-on runs and the loads acting on the configuration are measured by means of a force transducer (external or internal balance). For each model position wind-off tare loads are subtracted (attitude dependent gravitational loads). The effect of voltage output drift is also corrected. Wind tunnel static corrections[1] are also included in the data reduction procedure (solid blockage, wind tunnel blockage, wake blockage, buoyancy, support interference, streamline curvature, dynamic pressure correction). The coefficients are finally given as a function of aerodynamic angles $\left(\alpha,\beta\right)$. Static stability derivatives can also be obtained by numerical differentiation of static data.

Large amplitude oscillations: this wind tunnel technique is based on a large amplitude – high frequency forced angular motion of the model that removes the restrictions of local linearization required for the small amplitude oscillatory methods (analysis of hysteresis and bifurcations). The results are provided as functions of amplitude and rate (reaction surfaces instead of conventional aerodynamic derivatives). Large power outputs are necessary to generate the forcing torque on the model. The mechanical suspension system may become massive to limit both the vibrations induced by the driving unit and the deflections of the sting during the wind on runs (large inertial and aerodynamic oscillatory loads).

[1] Pope,A., Harper,J., "Low Speed Wind Tunnel Testing", John Wiley & Sons, New York, 1966