Technical Comments

Relationship between the Neutral Point, Maneuver Point, and Center of Gravity for Stability

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Introduction

IN 1965 the author presented a method he found useful in discussing certain concepts and applications of the linearized equations of motion of airplanes and missiles.[1] Inadvertently, in one of the simple examples illustrating the method, the statement was made, "On passing through air, the density, and therefore the relative mass parameter, decreases by a factor of about 1,000." Obviously, from the definition of the relative mass parameter, what was meant was that the density would decrease and the relative mass parameter would therefore increase by a factor of about 1000. This error was brought to the author's attention by Roach.[2,3] The effect on stability of a dynamically stable configuration having its c.g. forward of the neutral point, on passing from water into air, was the simple problem being discussed.

Recently, in a private communication, S. F. Hoerner questioned the author as to whether or not a vehicle could become unstable on passing from water into air. This note elaborates on the previous example showing the effect of the neutral point c.g. and maneuver point relationship on the dynamic stability.

As shown in the cited paper, the additional (or maneuver) force and moment system acting on a vehicle in a steady turn can be used to illustrate graphically the dynamic stability of the short period mode as given by the linearized equations of motion. This is summarized by Figs. 11 and 12 of Ref. 1. In the method, the aerodynamic forces and moments exclusive of the control force are transferred to the neutral point. If the sum of aerodynamic moments, other than that due to the control force, and the moment due to the centrifugal force, taken about the neutral point, is such as to increase the turning rate, then the vehicle will be unstable. If the unbalanced moment is in the direction to decrease the turning rate, then the vehicle will be dynamically stable. The moments about the neutral point are functions only of the turning rate. Before proceeding further, a few critical definitions will be reviewed for the reader.

Definition of neutral point: that point on the vehicle where the moment coefficient does not vary with angle of attack. (For a given configuration and within the range of the linearized forces, this point is fixed and depends only on the geometry of the configuration.)

Definition of maneuver point: that point on the configuration where the location of the c.g. would result in the control force required per g maneuver to be equal to zero. (The location would depend on the density of the medium through the relative mass parameter $\mu = m/\rho Sl$ where m is the mass of the vehicle, ρ is the density of the medium, S is the characteristic area on which the aerodynamic coefficients are based, and l is the characteristic length on which the aerodynamic coefficients are based).

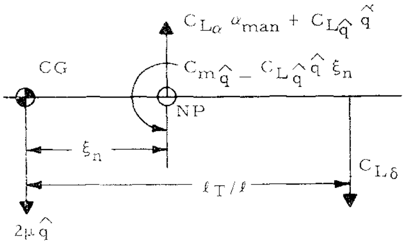

Fig. 1 Force schematic, c.g. forward of neutral point.

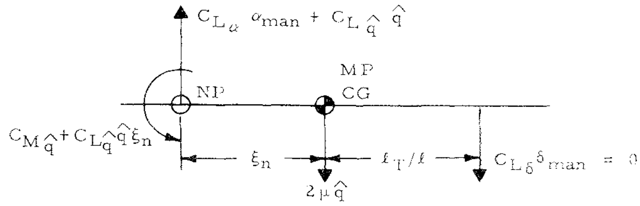

Fig. 2 Force schematic, c.g. at maneuver point.

Figure 1 is a reproduction of Fig. 12 of the initial paper, modified to include the sign of the aerodynamic moment about the neutral point. (The stabilizing surfaces normally are the largest source of the damping derivatives $C_{M_{\hat q}}$ and $C_{L_{\hat q}}$.) As discussed in the original paper, the axial force system is not shown for simplification of the sketch.

Center of Gravity Forward of Neutral Point

The configuration is dynamically stable since the unbalanced moment about the neutral point due to the rotational velocity $\hat q$ (nondimensional) is acting in the direction to reduce $\hat q$. If the configuration is stable in water, it will be more stable in air (since $\rho_{water} \simeq 1000\ \rho_{air}$).

Center of Gravity at Maneuver Point

Since the maneuver point is that point where the c.g. location will give a zero unbalanced moment due to the angular velocity $\hat q$, the maneuver point will be aft the neutral point (Fig. 2). The configuration will be neutrally stable. If the configuration is neutrally stable in water, it will become unstable in air because of the increased relative mass parameter μ on passing into air.

Center of Gravity aft Neutral Point and Forward of Maneuver Point

If the c.g. is forward of the maneuver point but aft the neutral point, then the configuration will be dynamically stable since the unbalanced moment due to the rotational velocity will be in the direction to reduce $\hat q$ (Fig. 3). If the configuration is stable in water it will be unstable in air for any significant distance of the c.g. aft the neutral point.

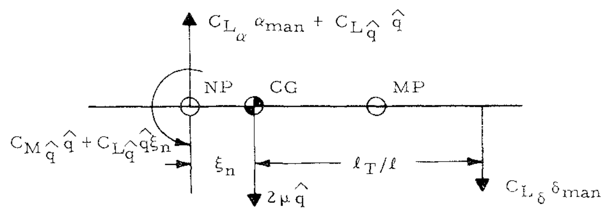

Fig. 3 Force schematic, c.g. aft neutral point and forward of maneuver point.

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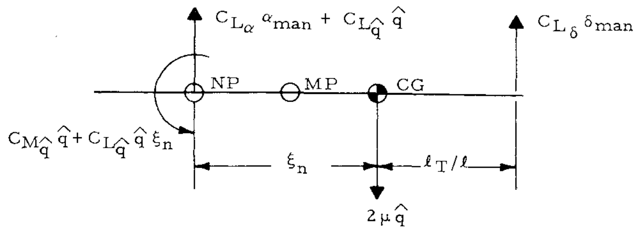

Fig. 4 Force schematic, c.g. aft neutral point and maneuver point.

Center of Gravity aft Maneuver Point

If the c.g. is aft the maneuver point, then the configuration will be dynamically unstable since the unbalanced moment due to the rotational velocity will be in the direction to increase $\hat{q}$ (Fig. 4). If the vehicle is dynamically unstable in water, it will become more unstable in air.

Summary

Application of the method presented by the author in 1965[1] to a simple stability problem results in a relationship that can be summarized as follows: 1) If the c.g. is forward of the maneuver point, the configuration will be dynamically stable; 2) a configuration that is dynamically stable in water on passing into air a) becomes unstable if its c.g. is aft the neutral point, or b) becomes more stable if the c.g. is ahead of the neutral point; 3) a configuration that is dynamically unstable in water will be more unstable on passing into air.

References

[1] Rodgers, E. J., "The neutral point in stability and control analysis," J. Aircraft **2**, 33–39 (1965).

[2] Roache, P. J., "Comment on 'The neutral point in Stability and control analysis,' " J. Aircraft **2**, 352 (1965).

[3] Rodgers, E. J., "Reply by author to P. J. Roache," J. Aircraft **2**, 352 (1965).
