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Engineering Notes

Flight Dynamics of High-Aspect-Ratio Flying Wings: Effect of Large Trim Deformation

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I. Introduction

PATIL and Hodges [1] presented an integrated model for the aeroelasticity and flight dynamics of a high-aspect-ratio flying wing. The authors conducted a nonlinear trim computation for straight and level trim flight and compared the results for a flexible configuration and the corresponding rigid configuration based on the undeformed shape before application of loads. The nonlinear model was linearized about the trim point and eigenvalues were computed to study the linear stability characteristics of the airplane at the trim point. A root-locus plot for the longitudinal flight dynamic eigenvalues was generated with the payload at the center as the variable for both the rigid body based on the undeformed shape and the flexible configuration. Results showed that the root-locus plot for the rigid body configuration did not capture the trend shown by the flexible configuration.

This paper uses the integrated model developed by Patil and Hodges [1] to understand the effect of nonlinear static aeroelastic deformation on the flight-aeroelastic stability of a flexible flying wing configuration. Additional trim cases and lateral flight dynamic characteristics not studied by Patil and Hodges [1] are also presented here. Trim results are presented for climbing flight, level turn, and climbing turn. Linear stability analysis is carried out about straight and level trim and root-locus plots for longitudinal and lateral flight dynamic modes are compared for three configurations: the flexible configuration, a rigid body configuration based on the deformed shape at trim, and a rigid body configuration based on the undeformed shape before trim.

II. Mathematical Modeling

The integrated modeling for the aeroelasticity and flight dynamics of a flexible, high-aspect-ratio flying wing has been published previously [1,2] and will not be repeated here. To trim the airplane in turning flight, a few additions were made to the control allocation and the mathematical modeling which are presented next.

As in [1], the flying wing configuration used in this paper has five engines evenly spaced along the wing span as shown in Fig. 1. The entire trailing edge is actuated and is split into two sections along the span. The two sections deflect in the same direction for pitch control and differentially for roll control. The total control surface deflection for each section is calculated by adding up these two components. As the flying wing does not have a rudder or vertical tail, yaw control is obtained by linearly redistributing thrust across the different engines. The differential thrust ΔT is chosen such that it is zero at the center and changes by integral multiples across the wingspan.

The trim state of the system is specified in terms of the flight speed V_∞, the flight path angle γ, and the rate of turn in the inertial frame r_i. Sideslip is constrained to be zero. The corresponding equations for specifying these quantities are given by

$$|\mathbf{V}^{n_g}|^2 - V_\infty^2 = 0 \tag{1}$$

$$\mathbf{\Omega}^{n_g} . (\mathbf{g}^{n_g}/g_0) - r_i = 0 \tag{2}$$

$$\mathbf{V}^{n_g} . (\mathbf{g}^{n_g}/g_0) + V_\infty \sin\gamma = 0 \tag{3}$$

$$V_1^{n_g} = 0 \tag{4}$$

where n_g refers to the reference node at the center of the wing, g_0 is the magnitude of acceleration due to gravity, $\mathbf{V}$, $\mathbf{\Omega}$, and $\mathbf{g}$ are velocity, angular velocity, and gravitational vectors, respectively, and V_1 is the velocity component along the local X axis.

The set of equations presented in [1] along with the four constraint equations given previously constitute a set of nonlinear equations in terms of the structural states, unsteady aerodynamic states, and trim control values (thrust, flap deflection, aileron deflection, differential thrust). These nonlinear equations are solved using the Newton–Raphson method to compute the trim configuration as well as the thrust T, flap δ_f, aileron deflection δ_a, and the differential thrust ΔT. Following trim computation, the equations are linearized at the trim point. Linear stability analysis is carried out by computing the eigenvalues of the linearized system. These eigenvalues indicate the stability of the system for small perturbations about the trim point.

III. Results

A. Verification

Though the mathematical modeling used in this paper is based on previously published work[1], the code used to generate these results is a new implementation that was developed as part of a closed-loop system for path following [3]. The open-loop aeroelastic code has been verified for a number of test cases against standard results. Boundary conditions are changed to simulate a cantilevered beam case by specifying the velocity, angular velocity, and pitch angle at the root. Flutter prediction results from the code are compared with results from an analytical model for the Goland wing [4,5] for which the parameters are given in Tables 1 and 2. Free-vibration bending frequencies, Euler buckling loads, divergence velocity, and control reversal velocity are compared with analytical results for a modified Goland wing, which has its sectional center of mass relocated to the

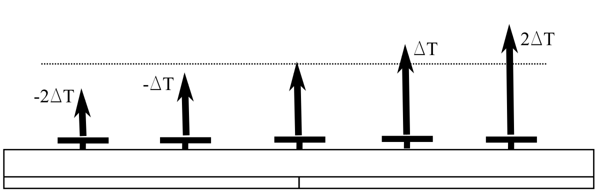

Fig. 1 Differential thrust.

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