Flutter analysis of a hose-drogue system with aerodynamic grid fins for aerial refueling

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Aerial refueling significantly improves the range, endurance, and operational flexibility of military aircraft by allowing mid-flight fuel transfer from a tanker to a receiver aircraft. Among the available configurations, the hose–drogue system remains one of the most widely employed solutions. It consists of a flexible hose stabilized by a drogue, which provides aerodynamic guidance during engagement. However, this configuration is inherently susceptible to aerodynamic instabilities, particularly under turbulent or high-speed conditions, which may lead to severe oscillations, increasing the risk of structural failure and potentially jeopardizing the refueling operation.

This work presents a comprehensive mathematical framework for the analysis of the dynamic and aeroelastic behavior of hose–drogue refueling systems with a new passive stabilization device based on grid fins located at the hose–drogue junction. While the identification of flutter boundaries constitutes a fundamental element of the analysis, the primary contribution of the present study lies in the development and aeroelastic assessment of this novel grid-fin–equipped configuration. Grid fins, composed of a lattice of aerodynamic surfaces arranged within a box-like structure, offer several advantages over conventional planar fins and are introduced to improve system stability.

The modeling approach is based on a formulation capable of predicting both the static equilibrium configuration and the linearized dynamic response of the hose–drogue system. This framework enables an aeroelastic analysis to determine flutter conditions (speeds, frequencies, and modal shapes) across a range of flight conditions and hose configurations.

To quantify the stabilizing effect of the grid fins, in the proposed work a new aerodynamic model is developed to account for both steady and unsteady aerodynamic loads, using the Doublet-Lattice Method combined with a Unit Grid Fin approach. Wind tunnel measurements are used to validate the steady aerodynamic predictions. The grid fins prototype is integrated into the hose–drogue model, allowing for a direct comparison between configurations with and without grid fins. The results demonstrate that the proposed grid-fin configuration leads to a significant increase in stability margins and a noticeable shift of the flutter boundaries toward higher speeds, confirming the effectiveness of grid fins as a passive stabilization solution for hose–drogue aerial refueling systems.