

HAP-ALPHA: DEVELOPMENT OF SYSTEM IDENTIFICATION MANOEUVRES FOR LOW-ALTITUDE FLIGHT TESTING OF A FLEXIBLE HIGH-ALTITUDE PLATFORM

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ABSTRACT

The work presented in this paper is conducted within the framework of the project *HAP-alpha*, in which the German Aerospace Center (DLR) is developing a High-Altitude Platform (HAP) system. The underlying air vehicle is a flexible, solar-powered, fixed-wing aircraft designed for sustained operation in the lower stratosphere. The project is nearing the Flight Readiness Review, followed by an extensive low-altitude flight test campaign. The campaign will include dedicated test manoeuvres aimed at validating the baseline models and enhancing their accuracy via system identification.

HAP aircraft are designed to operate in the lower stratosphere for a prolonged duration, often including multiple days or weeks of flight. This makes them suitable candidates for missions that typically lie in the field of satellite applications. General Earth observation missions in the civil and military field, as well as telecommunications, are just two examples of their possible manifold use cases.

However, high-altitude long-endurance missions bring several challenges. The underlying aircraft needs a very high aerodynamic efficiency, ultralight structural weight and an extremely slow operating speed. Consequently, HAP aircraft are highly flexible and suffer from a significant susceptibility to wind disturbances. This is reflected by a number of mishaps involving HAP aircraft both at higher altitudes and at sea level. Hence, these aircraft are, at present, primarily used as demonstration aircraft in the experimental context.

In order to pave the way for the operation of HAP aircraft on an ordinary and regular basis, a profound knowledge about their flight physics is indispensable. However, these aircraft operate on the verge of physical feasibility. Therefore, the applicability of common modelling approaches and assumptions are not always guaranteed and must be ascertained first. The most sophisticated approach to tackle this issue is to perform flight testing. Using the recorded flight data, the underlying models are validated and can, if they are parameter-based, be improved via system identification. The resulting higher-accuracy models can subsequently be used for more significant analyses, the generation of improved flight control systems and for pilot-in-the-loop studies.

The typical flight envelope of HAP aircraft comprises a rather narrow airspeed band. At the same time, the altitude range is considerable, starting at sea level and extending to values surpassing 20 km. The associated flight dynamics change significantly. While at very high altitudes, the aircraft behaviour resembles, to a limited extent, those of conventional aircraft, this is by no means true for flight at low altitudes. Here, the rigid-body modes and even lower-order aeroelastic modes are overcritically, or at least strongly, damped.

Aircraft system identification requires the availability of flight test data of performed manoeuvres that adequately excite the aircraft rigid-body and structural modes to a sufficient extent. Here, it is crucial that different influences can be subdivided to estimate the parameters correctly. The low-altitude flight

physics of HAP aircraft pose a remarkable challenge here. As an example, a rudder doublet is typically used to excite the Dutch roll mode. After having stopped the control inputs, the aircraft continues to oscillate for a couple of seconds. Thereupon, it can be distinguished to which extent a generated yawing moment stems from rudder input, yaw rate, roll rate, angle of sideslip, etc. In case of flexible HAP aircraft at low altitudes this behaves differently. As soon as the control input is reduced, the aircraft returns relatively fast to a rather steady flight condition. As a result, distinguishing between different influencing factors becomes significantly more challenging. Therefore, a larger amount of rudder input would be desirable. However, at the same time, it must be ensured that the associated limiting load cases are not exceeded. In addition, the small allowable airspeed band must not be left either. Both of these safety-related aspects limit the allowable amount of control inputs again. Finally, such aircraft are not capable of reaching larger steady-state roll rates. Therefore, typical bank-to-bank manoeuvres are not feasible.

Altogether, the use of classical system identification manoeuvres only has a limited feasibility. Instead, such manoeuvres must be specifically tailored to the aircraft's particularities accounting for the above-listed limits and challenges. This paper deals with this topic. It investigates which flight manoeuvres are adequate to perform system identification for flexible HAP aircraft. In doing so, it develops novel manoeuvres and assesses to which extent rigid-body and flexible parameters can be identified.

The final paper will be structured as follows: It is subdivided into two parts. The first part presents the flight dynamics model of the flexible HAP aircraft used in this work. It contains influences of the flight shape-dependent aerodynamic changes and the structural dynamics. Coupling between rigid-body motion and structural dynamics is realized via the aerodynamic forces. This model assumes quasi-steady aerodynamics. The second part deals with system identification. First, different system identification manoeuvres are designed using the flight dynamics model described before. Second, a dynamic aeroelasticity analysis including unsteady aerodynamics is performed to assess the associated loads and to limit control inputs. Third, surrogate flight test data are generated by simulating the manoeuvres using the flight dynamics model including sensor models and general low-magnitude wind disturbances. Finally, system identification is performed to identify parameters from the surrogate flight test data using the flight dynamics model with modified initial parameters.

The results show that classical doublet manoeuvres are applicable when the time units are increased and comparatively strong control inputs are applied. A 13211-pitch manoeuvre is necessary instead of a 3211 to limit airspeed excursions and a 121-bank input is used in lieu of a bank-to-bank manoeuvre. Frequency sweeps using aileron, elevator or rudder yield sufficient excitations of the structural modes and rudder doublets are the most critical with respect to loads. The final system identification process shows the general feasibility of the manoeuvres for obtaining adequate aircraft parameters.