Design of an Electric Actuated Airbrake for Dynamic Airspeed Control of an Unmanned Aeroelastic Research UAV

Sendner, Franz-Michael[1]
Technische Universität München, Institute of Aircraft Design, Boltzmannstr. 15, Garching bei München, 85748, Germany

Stahl, Philipp[2]
Technische Universität München, Institute of Aircraft Design, Boltzmannstr. 15, Garching bei München, 85748, Germany

Rößler, Christian[3]
Technische Universität München, Institute of Aircraft Design, Boltzmannstr. 15, Garching bei München, 85748, Germany

Hornung, Mirko[4]
Technische Universität München, Institute of Aircraft Design, Boltzmannstr. 15, Garching bei München, 85748, Germany

The FLEXOP Project aims to develop new methods and tools to assist the design of aircraft with highly flexible wing structures. Aeroelastic flight testing with an unmanned flying demonstrator shall help to validate and verify these approaches. Visual line of sight operation due to German airspace regulations introduce additional challenges to the aircraft design: Since maneuvers have to be performed slightly below flutter speed a precise and fast airspeed controllability has to be ensured. Since the thrust response of the integrated jet engine is proven to be impractical for fast airspeed control, the electric actuated airbrake has to be designed for providing the required control force. In the present paper, the design of the airbrake system is shown in detail, starting from configurational studies to aerodynamic design and analysis up to structural sizing. Further, the approach to actuator selection, testing and integration is shown. Finally, a rapid prototyping, low-cost approach to system parameter verification for the flight controller design is presented.

Nomenclature

UAS	=	Unmanned Aerial System
COTS	=	Commercial Off-The-Shelf

I. Introduction

THE international FLEXOP (Flutter-free Flight Envelope Extension for Economical Performance Improvement) research project, incorporating several European universities and manufacturers, aims to develop new methods and tools to assist the design of aircraft with highly flexible wing structures. Flight and especially flutter testing with a low-cost, subscale unmanned flying demonstrator shall help to validate and verify these approaches. Three sets of interchangeable wings with different aeroelastic properties enable testing of design approaches on a comparable configuration[1] . Regulations for the operation of unmanned aerial systems (UAS) in German airspace require the

[1] Research Scientist, Technische Universität München, Institute of Aircraft Design, franz.sendner@tum.de
[2] Research Scientist, Technische Universität München, Institute of Aircraft Design, philipp.stahl@tum.de
[3] Research Associate, Technische Universität München, Institute of Aircraft Design, christian.roessler@tum.de
[4] Professor, Technische Universität München, Institute of Aircraft Design, mirko.hornung@tum.

vehicle to be operated within visual line of sight of the pilot[2]. Beside the resulting acceleration and deceleration requirements, the airspeed must be controlled within a 2% margin during aeroelastic test phases. The jet engine thrust, as well as the airbrake display controllable forces aligned with the airspeed vector. Due to the response time of the engine in the order of seconds, thrust setting is not an effective measure for short-term airspeed control. In consequence, the airbrake is designed to match the requirements of precise airspeed control. In the present paper an approach to aerodynamic design and analysis based on empirical data is presented. Based on the aerodynamic forces and moments, structural sizing and actuator selection criteria in specific are presented. To comply with the low-cost approach, electric Commercial Off-The-Shelf (COTS) actuators from Robotics and Radio Controlled Modelling applications are investigated. Implementation and testing of the selected actuator with the help of an actuator testbench and an airbrake mock-up is shown.

II. Design Approach and Current Status

In a first step, conceptual considerations for suitable integration are presented: The three pairs of interchangeable wings (each with different aeroelastic characteristics) can be considered as the scientific payload, besides the instrumentation. To avoid any aerodynamic or stiffness disturbances during the tests near flutter speed, any wing-mounted devices are not regarded. Further boundary conditions, e.g. ground clearance, a minimum pitching moment contribution, as well as a careful separation of the empennage and the airbrake wake are derived, as illustrated in Figure 1. An investigation into historical implementations is conducted to evaluate feasible configurations of the airbrake qualitatively.

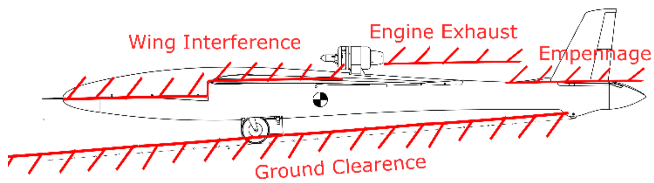

Figure 1: Restricted Areas for Airbrake Flap Integration

For the present design case two concepts of integration into the airframe are analyzed in detail: Displayed in Figure 2 is a combined landing gear door/airbrake, arranged ventrally, so that the resulting force vector points through the Center of Gravity. A second concept consists of two separate brake flaps, symmetrically arranged to the flanks of the fuselage, as shown in Figure 3.

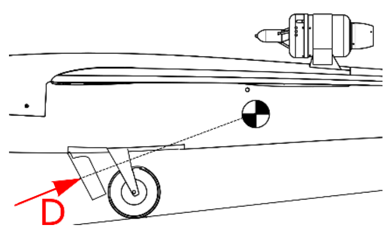

Figure 2: Ventral Configuration

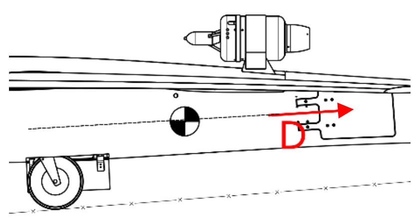

Figure 3: Side-by-Side Arrangement

With the found concepts, a more detailed aerodynamic analysis is shown: A trade-off between maximum drag coefficient of the brake flap and resulting hinge moment is made by using empirical data for flat plates of small aspect ratio[3]. In Figure 4, both maximum drag coefficient, as well as minimum hinge moment coefficient are displayed for relevant aspect ratios of airbrakes. As can be seen, higher aspect ratios reduce the hinge moment and increase the maximum coefficient of drag. Though, integrational aspects will naturally limit the maximum aspect ratio of the airbrake for most applications. Force fluctuations and decrease in maximum drag coefficient due to airbrake inflow and fuselage boundary layer interactions are approached by introducing a separating gap between airbrake flap leading edge and the fuselage. For preliminary sizing of the gap, the boundary layer thickness at the fuselage station of the airbrake flap leading edge is analyzed by classic boundary layer theory[4]. The resulting increased lever arm of the aerodynamic force adds to the hinge moment. In consequence, a minimum separation has to be found. With the results of the aerodynamic analysis and design, both preliminary actuator sizing, as well as structural mass estimation are approached. Investigated principles of actuation include linear servo actuators, single high torque servo actuators, as well as twin actuators coupled in series, all in the range of small robotics or RC Modelling applications. Feasible actuation concepts are modelled based on specifications and used with a point-mass MATLAB/Simulink Mission Simulation. Mock-up based testing, like illustrated in Figure 5, as well as actual integration of the best performing actuation solution are displayed. Verification tests for the aerodynamic design as well as flight experiments are scheduled. If data is available and processed until May 2018, a verification section will also be included in this paper.

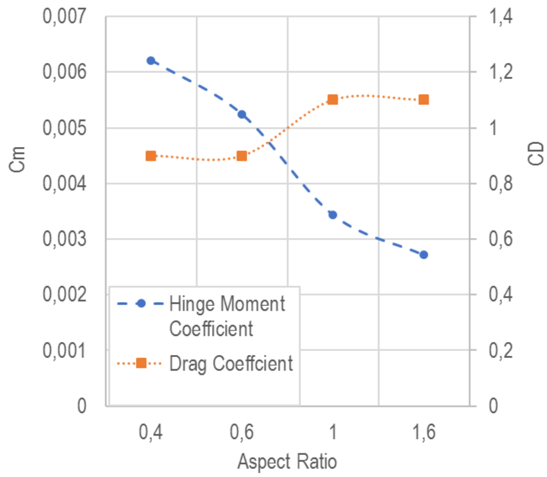

Figure 4: Airbrake Drag- and Hinge Moment Coefficient according to Ortiz et Al. (2015)

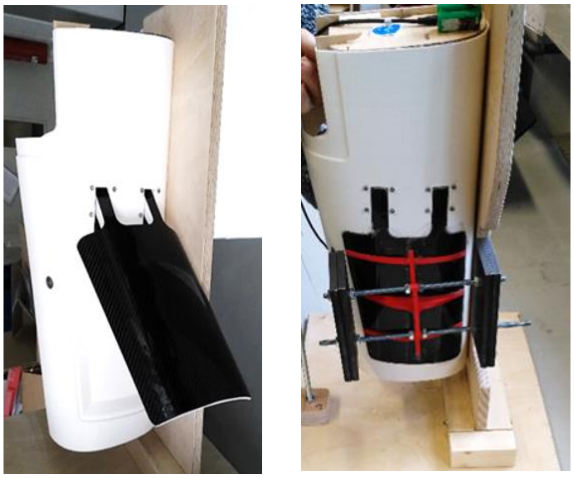

Figure 5: Rapid Prototyped Mock-Up Testing Bench

III. Acknowledgement

The research leading to these results is part of the FLEXOP project. This project has received funding from the European Unions Horizon 2020 research and innovation program under grant agreement No 636307.

References:

[1] FLEXOP Consortium, 2015. The FLEXOP project. [Online], Available at: https://flexop.eu/, [visited 10/03/2016].

[2] LuftVO, 2012. *Luftverkehrs-Ordnung vom 10. August 1963 (BGBl. I S. 652), die zuletzt durch Artikel 3 des Gesetzes vom 8. Mai 2012 (BGBl. I S. 1032) geändert worden ist* [Online], Available at: http://www.gesetze-im-internet.de, [visited 13/06/2015].

[3] Ortiz, Xavier, Rival, David, Wood, David, "Forces and Moments on Flat Plates of Small Aspect Ratio with Application to PV Wind Loads and Small Wind Turbine Blades", Basel: MDPI Energies Journal, 2015

[4] H. Schlichting, Klaus Gersten *Grenzschichttheorie*, 10th ed., Springer-Verlag, Berlin, 2013