# UAV Propulsion System Design for Increased Acceleration and Deceleration Requirements

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*

Hermanutz, Andreas[3]
*Technische Universität München, Institute of Lightweight Structures, Boltzmannstr. 15, Garching bei München, 85748, Germany*

Rößler, Christian[4]
*Technische Universität München, Institute of Aircraft Design, Boltzmannstr. 15, Garching bei München, 85748, Germany*

Hornung, Mirko[5]
*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. Flight and especially flutter testing with an unmanned flying demonstrator shall help to validate and verify these approaches. Though, regulations for the operation of UAS in German airspace introduce additional challenges to the aircraft design: The delimitation of the flight testing to visual line of sight increases significantly the demands on acceleration and deceleration of the vehicle. Following, the requirements for the propulsion and brake system of this demonstrator differ noticeably from classic aircraft design problems. Additionally, for budget and schedule reasons, only off-the-shelf solutions should be implemented for the propulsion system. In the following, an alternative evaluation and optimization approach was implemented by a variation of propulsion and deceleration principles, incorporating a dynamic simulation of the test flight mission. The optimization focused on sufficient acceleration performance while minimizing total system costs, as well as system mass (including mission fuel weight). Surprisingly, evaluating the results, a single micro turbojet engine in combination with fuselage mounted airbrakes prove to be the lightest, low-cost solution.**

## Nomenclature

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|---|---|---|
| *UAS* | = | Unmanned Aerial System |
| COTS | = | Consumable-Off-The-Shelf |

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[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 Scientist, Technische Universität München, Institute of Lightweight Structures, andreas.hermanutz@tum.de
[4] Research Associate, Technische Universität München, Institute of Aircraft Design, christian.roessler@tum.de
[5] Professor, Technische Universität München, Institute of Aircraft Design, mirko.hornung@tum.

# I. Introduction

THE international FLEXOP 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 subscale unmanned flying demonstrator shall help to validate and verify these approaches[1]. Additional to the challenging aeroelastic design task, regulations for the operation of UAS in German airspace introduce further challenges to aircraft design. Since the vehicle has to be operated within visual line of sight of the pilot[2], the demonstrator has to be accelerated to the flutter-onset regime and decelerated to maneuver airspeed within this delimited airspace. Further, a minimization of the costs and a reduction of design and integration efforts was required by the project proposal, so that COTS solutions were preferred.

From preliminary mission design and estimations, it was observed, that the available distance for acceleration and deceleration would be around 1500m. Obviously, not only aerodynamic performance and vehicle inertia are crucial parameters for meeting this requirement, but thrust and decelerating force response and characteristic over time in specific. These special demands are not covered by classic aircraft design approaches[3], which mainly focus on steady operation, so that an alternative approach had to be found. In consequence, it was decided to conduct a variation of propulsion and deceleration concepts and systems, evaluate the alternatives by a numeric flight mission simulation and eliminate solutions with insufficient performance[4]. Finally, the optimum solution could be selected by minimizing total system mass and unit costs. Surprisingly, a single turbojet engine solution has proven to meet these requirements best. This paper covers the implemented approach in detail and discusses and explains the results.

# II. Approach and Current Status

In a first step, an investigation in available principles of propulsion and deceleration was conducted. Examined engine alternatives ranged from reciprocating engines over turbojet and turboprop units to electric drives. Investigated deceleration systems included aerodynamic decelerators and thrust reversing methods. From preliminary analysis and practical considerations, some alternatives could be eliminated from the start. For the remaining solutions, detailed specifications and measurement data was gathered.

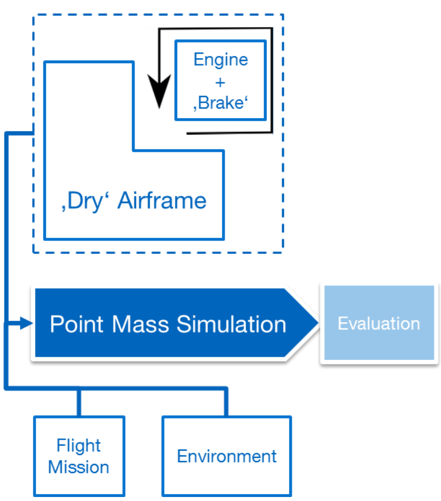


**Fig. 1: Flight Mission Decomposition**

In a next step, the design of the numeric full mission simulation was approached. At first, the flight mission decomposition into aircraft, environment and mission pattern subsystems was introduced, as illustrated in Fig. 1. For the variation, the aircraft was divided into a 'dry airframe' and the combined engine/deceleration module. Generic, dynamic thrust models were developed, including propeller modelling for power producing engines. Further, dynamic fuel consumption and flight control computer throttle input was modelled. Approximations to dynamic behavior of airbrakes and thrust reversal were derived, as well as aircraft aerodynamics and inertias modelling. The actual mission simulation is represented by a dynamic point mass modelling of a flight section with defined load case. By joining multiple of this flight sections with transferred boundary conditions (masses, control inputs, forces), the full mission can be simulated. The physical model of the flight section was implemented with the help of MATLAB/Simulink. A MATLAB script joins the individual flight sections of the full simulation and calculates the mission for all possible engine/decelerator combinations. Important parameters, including throttle, thrust, airspeed, airbrake force and fuel consumption are logged and saved. A representative evaluation of a simulated flutter test section is given in Fig. 2 and Fig. 3[5]. An automatic ranking by total system mass and unit costs of the alternative systems should help to manage the evaluation of over 200 combinations.

The simulation results approve largely the expected behavior of the respective solutions: Propeller driven solutions are superior to jet solutions in terms of response time and thrust over time. Rotary engines feature the lowest absolute fuel consumption, while turbojet engines show the least fuel efficiency in the investigated range. Also thrust reversal prove to be more effective than aerodynamic deceleration[6]. Though, surprisingly, the optimum solution regarding minimum total mass and lowest costs prove to be a single turbojet solution in combination with airbrakes[7]. In consequence, the result was verified by manual evaluation of the better performing alternatives. Various factors contribute to the superiority of the single turbojet engine which should be explained in detail in the final paper. Finally, the found optimum was selected for the further design process.

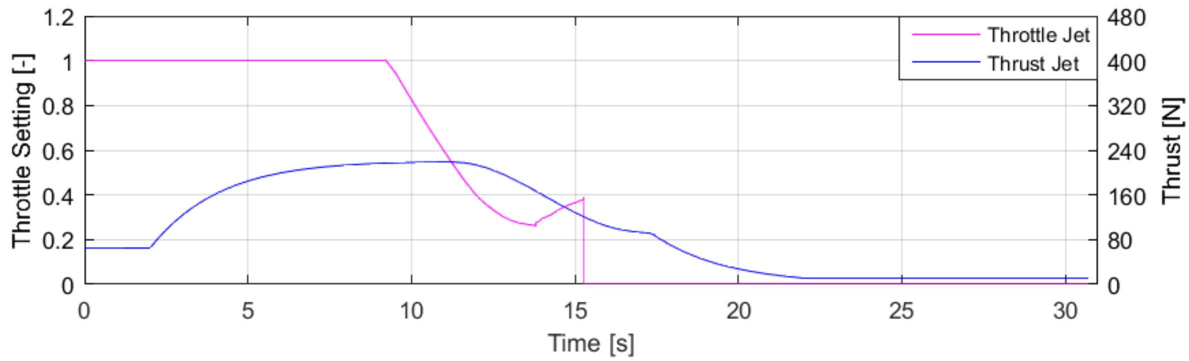


**Fig. 2: Throttle/Thrust over Time of a Flutter Test Section for the Single Jet Engine/Airbrake solution (Sendner)**

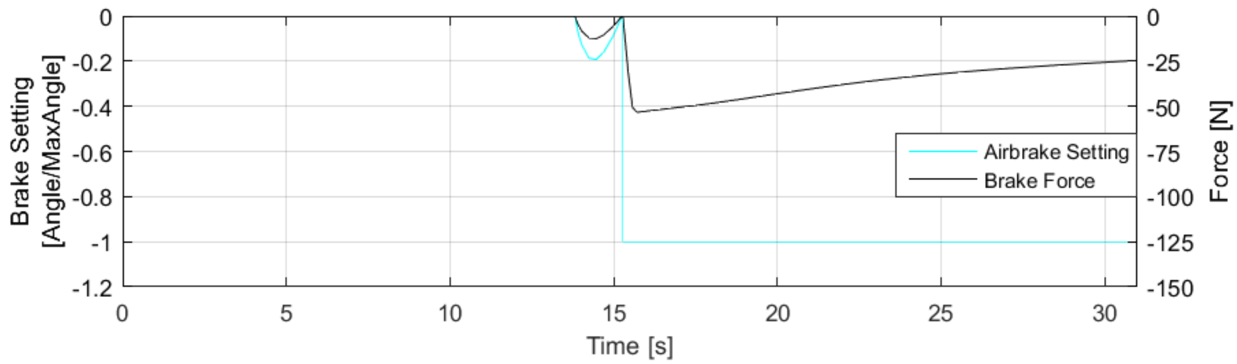


**Fig. 3: Brake Command/Air Brake Force over Time f a Flutter Test Section for the Single Jet Engine/Airbrake solution (Sendner)**

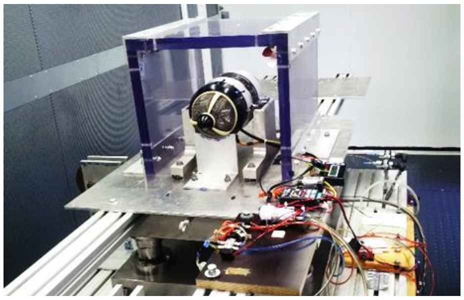

**Fig. 4: Micro Turbojet Engine on the Institute's Test Bench**

Considering the strict performance margins, the simulation results, which were based upon manufacturer specifications and analytical approximations, had to be verified as early as possible. A rapid prototyping approach was chosen for the airbrake, so that a functional mock up could be built. Further, a sample of the turbojet engine could be acquired from the manufacturer. Test bench measurements, as depicted in Fig. 4, at the facility of the Institute of Aircraft Design were conducted to derive the actual response time and thrust over time behavior. Implementation of the measurement results into the mission simulation, which was continuously updated, prove the assumptions. Finally, it is expected that validation measurements can also be provided for the response characteristic and force over time behavior of the airbrake.

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