The Perfect Glider

Martin Hromčík, Krištof Pučejdl, Stanislav Kunst, Martin Höhne

Department of Control Engineering, Faculty of Electrical
Engineering, Czech Technical University in Prague

Abstract

In this paper, we elaborate the concept of “Perfect Glider”–a tailless aircraft with a high aspect ratio wing. We propose a combined actuator consisting of a reaction wheel and a moving mass for active pitch stability and control, and develop respective control laws. We also present a small-scale demonstrator platform and report the first successful experimental flight.

1 Introduction

When high endurance is the ultimate goal of aircraft design, the recipe is well known and completely straightforward.[1] A theoretically perfect glider aircraft would feature a wing with an infinite aspect ratio. This design maximizes aerodynamic efficiency, specifically the lift-to-drag ratio (L/D), which in theory has no upper limit. This design minimizes induced drag, which is a major source of drag in real-world aircraft with finite wings. In addition, the design would eliminate any non-lifting components that add drag, such as the traditional tail, resulting in a flying wing configuration.

This configuration – high aspect ratio tailles wing – is the subject of all considerations in this paper. Flight stability and control associated with this design is an obvious concern. While the roll and yaw axes do not present a major challenge, pitch artificial stability and controllability are impossible to achieve using aerodynamic control surfaces.

---

[1] The rest of this paragraph is an adopted and shortened version of the Google AI response to the query “theoretically perfect glider”. We acknowledge Ivan Sobicka, TaktiQ.com, to coin the term “Perfect Glider” for our aircraft concept.

Roll stability can be achieved by standard stability and control augmentation systems that utilize ailerons as actuators. The roll moment of inertia is comparatively high, leading to slow response times, so there are no particular requirements related to the high bandwidth of actuators. At the same time, the authority of ailerons as actuators is clearly sufficient and their size and placement can follow standard design procedures. For active yaw axis damping and aerodynamic stiffness – note that the inherent weathercock stability and yaw damping is virtually nonexistent in our considered case – nontraditional actuators like all-moving-wingtips, differential flaps, or clamshells can be used, along with differential thrust in the case of propelled and multi-engine variants.

In contrast, pitch motion cannot be stabilized and controlled using aerodynamic surfaces due to the small distance between the Center of Mass (CoM) and the leading or trailing edges of the high aspect ratio wing. We therefore propose to use a reaction wheel propelled by an electric drive as the fast primary actuator – and moving-mass actuation as the secondary flight control mechanism to address the pitch trimming and the reaction wheel desaturation. The inherently low pitch moment of inertia of the considered aircraft is correlated favourably with the inherent high bandwidth, immediate impact, and low requirements on control authority (read resulting weight) of the reaction wheel subsystem.

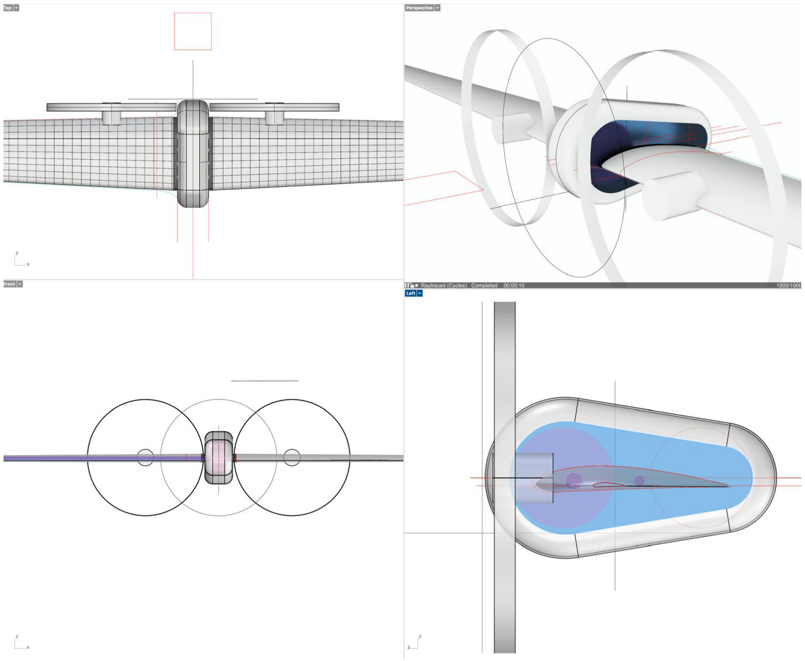

Figure 1: Artistic view of the “Perfect Glider” concept. Credits to Petr Bakos, Harddecore Creative Studio, www.petrbakos.com.

Reaction wheels (RW's) are routinely used as primary actuators in satellite Attitude Determination and Control System (ADCS). They are composed of a rotating disc attached to the satellite structure and propelled by means of (brushless-) DC or PMSM electric drives. They feature a high bandwidth and are suited for precise and continuous actuation. RW's work according to the third law of Newton (the law of action and reaction): when accelerated by its drive, they exert the reaction torque on the satellite. The main drawback of RW is their potential saturation: to attenuate persistent disturbances, they tend to accelerate beyond any limits, reaching the maximum RPM's of the electric drive and being inoperable any longer. Suitable desaturation techniques, using secondary actuators such as on/off jets in ADCS, are therefore essential.

In our case, we propose using Moving-Mass Actuation (MMA) for effective RW desaturation. Combined with RW as the primary actuator, commanding the aircraft CoM back and forth so that it implicitly decelerates RW, is a viable option. As a result, CoM slowly tracks the center of pressure, which changes with dynamical pressure and angle of attack, giving rise to a statically neutrally stable aircraft. The architecture of the complete control law is elaborated and discussed in Section 2.

Regarding the application potential, the emerging field of stratospheric drones seems to be the most promising and straightforward domain for our proposed design. Saving structural weight and aerodynamic losses associated with the tailplane is certainly tempting - although the trade-offs associated with the RW and MMA instrumentation are not for free either of course, in terms of structural complexity and increased weight. We partly address these concerns in our demonstrators: we use the RW itself as the moving mass simultaneously; and to avoid adding dead weight, we propose incorporating battery cells into the RW which are then used to power the actuators and propellers. Refer to Fig. 4, 5, 6.

2 The pitch axis stability augmentation system

As control outputs, the following signals are considered:

a) RW CURRENT CMD commanded current of the RW drive,

b) MMA VEL CMD commanded velocity of the MMA actuator.

The current fed to the RW drive is proportionally related to the torque exerted by means of the back-EMF motor constant. Current control of DC and PMSM drives is a standard functionality of many available units (the MOTEUS system is used in our flight demonstrator, see section 3. For the MMA motion, we assume that a fast velocity control servo loop is implemented. Note the PILOT INPUT line, enabling the operator to command the pitch moment (or the RW current, respectively).

As measured variables, we consider

a) PITCH RATE pitch rate of the aircraft, q [rad/s]

b) RPM revolutions per minute of the RW

The architecture of the combined SAS (Stability Augmentation System) pitch control law is depicted in Fig. 2. The symbols Kp and Ki are proportional and integral gains, respectively, 1/s blocks represent integrators.

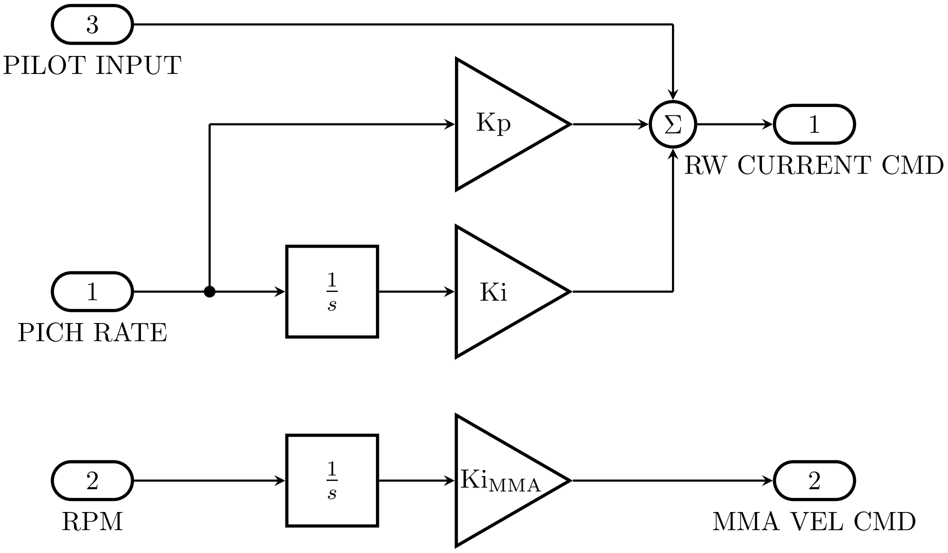

Figure 2: Architecture of the pitch axis stability augmentation control law.

3 Experimental small-scale platforms

3.1 Pitch-axis test platform

First, we built a stationary platform. RW consisting of batteries was assembled using a 3D printed frame. The brushless DC motor was engaged and for current control the MOTEUS board was selected. The reaction wheel is mounted on linear bearings and driven by a belt to also serve as the MMA secondary actuator.

The control program runs on a compact ESP32-S3-Pico board at a sampling frequency of 100 Hz, which corresponds to the maximum throughput of the BNO055 IMU used in the system. This IMU includes onboard sensor fusion, providing filtered and reliable motion data. Communication with the MOTEUS controller is handled through an SPI-to-CAN FD converter.

To reduce weight, the batteries powering the demonstrator are integrated into the RW and electrical power is transferred to the on-board electronics via slip rings and carbon brushes.

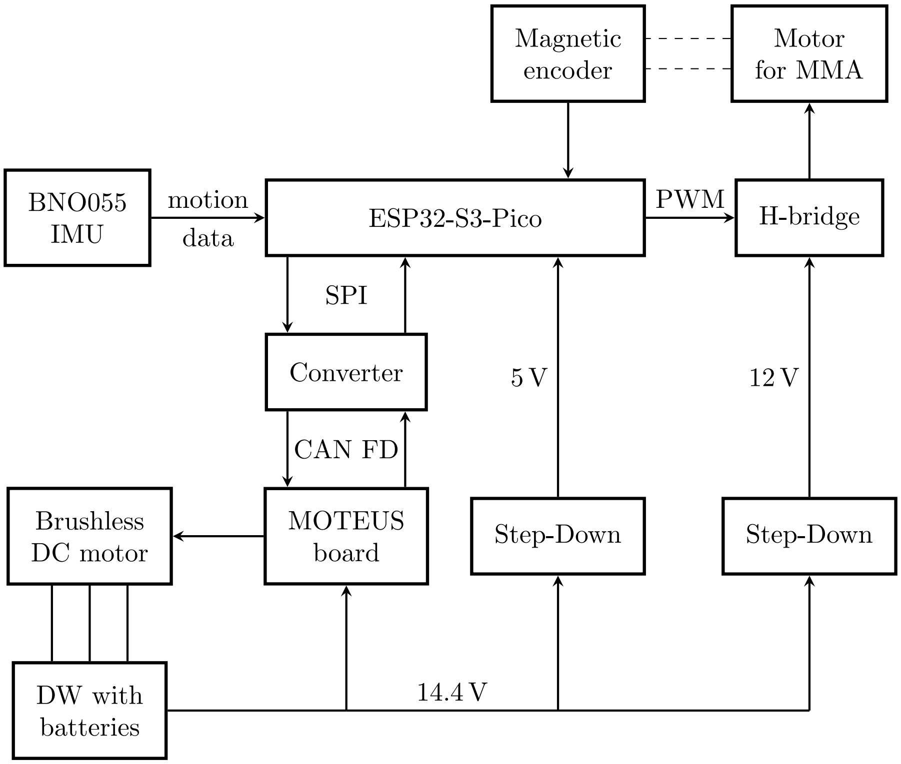

Figure 3: Architecture of on-board electronics.

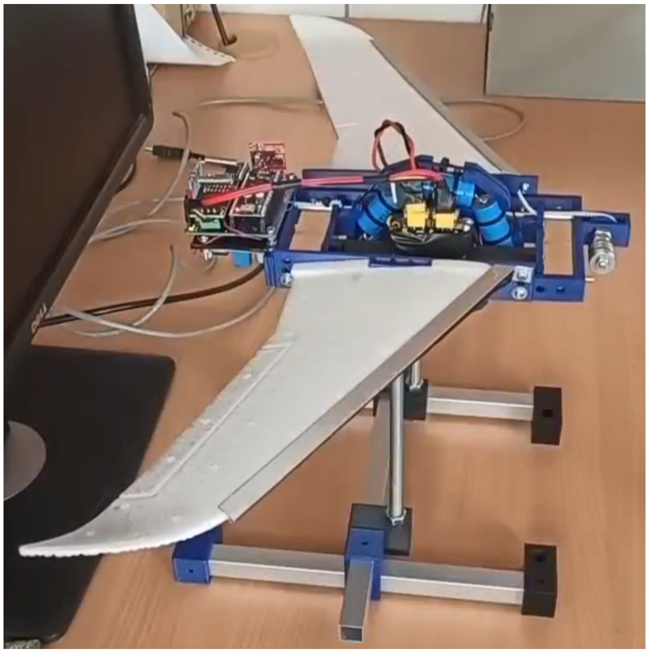

Figure 4: The ground demonstrator on a stand.

The video capturing the ground demonstrator in action can be found at

`https://drive.google.com/file/d/1HnPIxDRbH68h1mU9UVerXPcahyzF_p_L/view?usp=drive_link`

3.2 The flight demonstrator

A small scale aircraft was built around the RW assembly verified in the ground tests. The EPP wings of a standard commercial 1.7 m wingspan RC model glider were attached to the central body. For the vehicle to be launched, the vertical take-off controller was tuned and implemented. The vertical flight (take-off mode) and indication of the transients into the cruise horizontal flight are shown in the video

`https://drive.google.com/file/d/1b3z3dmqsTwKINELGMmHMwpyErM0E3Zo6/view?usp=drive_link`

Figure 5: The reaction wheel assembly.

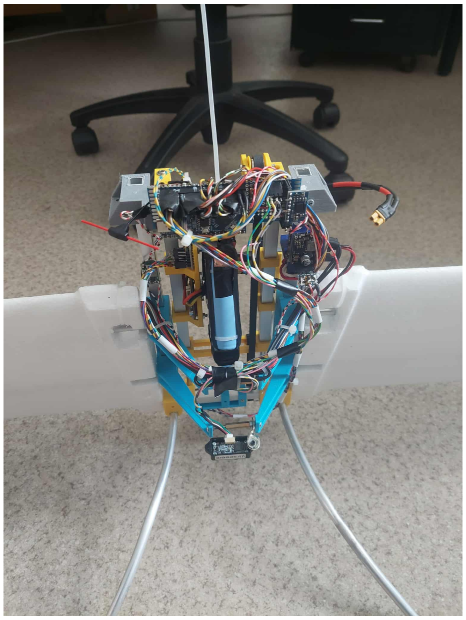

Figure 6: Complete on-board HW assembly of the flight demonstrator.

Figure 7: The flight demonstrator.

4 First flight test

The first short successful experimental flight of the small scale flight demonstrator was realized on October 7, 2025, in Prague. It is captured in the video

`https://drive.google.com/file/d/1ZyMCyXasPgVVgBsYMrSug45oDISMTQ3-/view?usp=drive_link`

Most notably, the footage 0:15-0:23 shows an eight second stable horizontal flight.

The experiment was terminated by an uncontrolled landing / soft crash. This was expected as MMA actuation was not enabled in the first experimental flight (CoM was located close to the leading edge and fixed), and RW reached saturation after several seconds, compensating for the nose-down aerodynamic pitching moment.

5 Future research

1. The proposed control concept is suitable for distributed implementation. If coupled with a distributed payload – as can be assumed for stratospheric drones (electronics, batteries, antennas) – the RW and MMA actuation could potentially lead to extremely high wingspan designs. Static wing bending is not a major issue as there is no significant central mass and the

wing loading is uniform; and the low expected inherent torsion stiffness associated with the long and thin wing would be locally controlled and actively increased by an array of RW/MMA agents distributed along the wingspan.

2. Coupling the rotation of RW with some kind of propulsion is tempting. Not only would it lead to more effective RW operation, supposedly reducing its power consumption, but it could also result in nonzero output torque even in the case of steady RW rotations. Think of a "paddlewheel" as a first approximation.

3. Most importantly, the ideas presented in this report need to be elaborated from various points of view to assess the practicality of the concept. Simulation validation on simplified aerodynamic models and quantitative evaluation is currently under development in our team, which shall give rise to specific requirements on the RW and MM actuators, and to stability margins and performance guaranties of the control laws. We also truly believe that this first conceptual paper could motivate experts in the related field of aircraft design, aerodynamics, aircraft propulsion, to further develop the Perfect Glider idea, present specific potential weight and aerodynamic savings (or not) compared to the traditional aircraft design approaches, and thus kindly contribute to the proliferation of this new high-endurance aircraft concept.

6 Conclusions

In this paper, we demonstrate the plausibility of the Perfect Glider concept, a reaction-wheel stabilized high-aspect-ratio tailless aircraft. For a small scale-experimental demonstrator, a short sustained horizontal flight is reported. We explain the idea of a combined reaction-wheel/moving mass actuator and present related control laws of a pitch-axis SAS system. Specific selected future research directions are proposed – and a broader proposal is made towards experts in related domains, to move this new high endurance aircraft concept forward.