15. MICROTEAM - SWIFT : EYES IN DISGUISE

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15.1 Introduction

When the very first sketches of flying machines where drawn by Leonardo da Vinci, the animals flying around in nature provided him with inspiration. Nowadays aircraft are being built in mass production, and yet again innovation may be sought in the flight of birds. The common swift (*apus apus*) is capable of flying up to 5 times the distance to the moon and back during its lifetime. Swifts have been observed to fly without landing for over a year. Its flight performance is not limited to endurance flight. Also, it is capable of magnificent agility, which it uses to catch insects and even mate in flight. To achieve this versatile performance, the swift morphs its wings; changing wing shape to accustom the body plan to different flight conditions makes this bird the most efficient and versatile flyer in nature.

15.2 Mission objectives

The final objective of this project is to design a bio-inspired Micro Air Vehicle (MAV) that will participate as a technology demonstrator in the First US-Asian MAV08 competition in India, 2008. The goal is to impress the contest officials by showing the feasibility and benefits of morphing wing technology. Next to morphing wing technology, the design will demonstrate multiple micro camera vision. The design has aptly been named 'RoboSwift'. The design project is executed during the Design Synthesis Exercise 2007. The mission statement of RoboSwift is the following:

"Perform ground surveillance and bird behavioural research at 1 km height, for 1 hour while looking and gliding like a common swift."

RoboSwift will be able to perform two different missions that pose similar requirements to the aircraft.

Firstly, RoboSwift is part of MicroTeam, a collaboration of 3 unmanned vehicles that as a whole forms a sensor network of micro vehicles on the ground and in the air to safely explore threats in unknown terrain. RoboSwift's task within the team is to provide live footage of the terrain, in its role of 'eye-in-the-sky'. It will achieve its stealth by mimicking the appearance, motion, and behavior of the common swift. The MicroTeam as a whole will compete in the MAV08 contest in India, performing a joint surveillance mission. A sketch of this mission can be seen in figure 15.1.

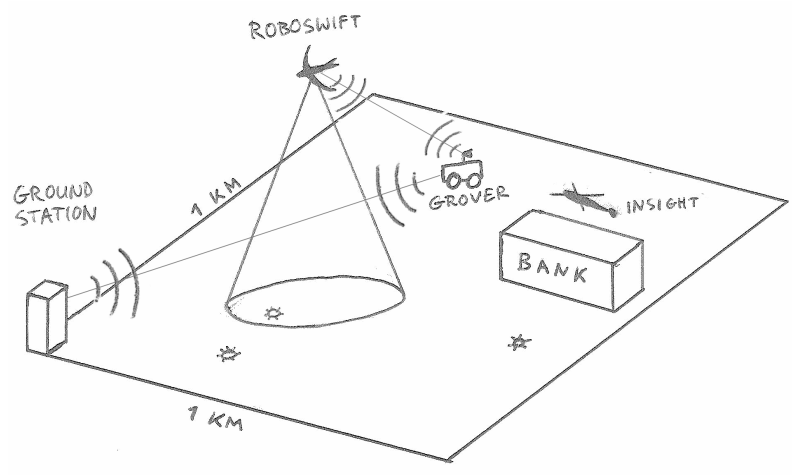

Figure 15.1: Schematic of the MicroTeam mission

Secondly, RoboSwift shall assist biologists in performing bird research. It will fly in proximity to swifts and send down the recorded camera footage. A sketch of this mission can be seen in figure 15.2. Such an aid greatly enhances the possibilities of biologists to research swift behaviour at heights up to 1 km, which up till now has only been done using radar.

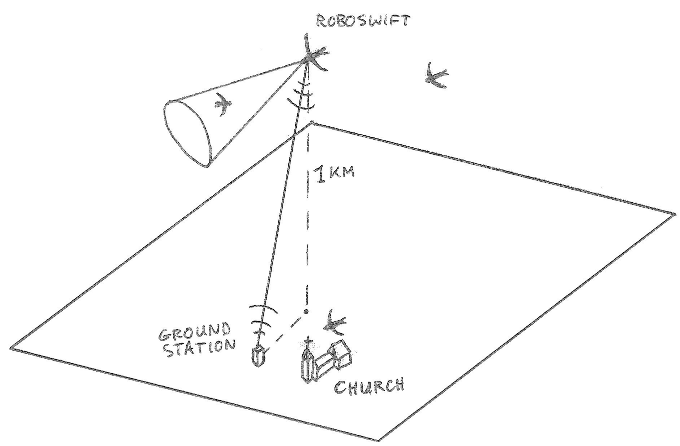

Figure 15.2: Schematic of the bioresearch mission

RoboSwift's bio-inspired morphing wing allows it to mimic the swift's impressive performance at a broad range of speeds. Just like the swift, RoboSwift adjusts its wing sweep, wing surface, aspect ratio, chord length to maximize its performance envelope.

In short, the RoboSwift team's objective has been to

"Design a bio-mimetic, morphing-wing, micro air vehicle, with inherent stability of under 70 grams, with a span of less than 50 cm that has the performance envelope of a swift, with minimal control variables and can carry a stereo-vision camera for reconnaissance to support MicroTeam and bio-research, with a group of 9 students within 10 weeks."

Additional requirements that had to be met are:

- All components (actuators, motors, batteries, controllers, etc.) must be 'off the shelf' except for the vehicle's structure, morphing mechanism and, if needed, the propeller.
- The vehicle must be fitted with stereo camera vision that can be fully teleoperated with servo's using an 'off the shelf' headset and ‘telepresence’ software.
- The design should be feasible within a budget of maximal 10.000 Euro, which must cover the costs of three RoboSwift vehicles and one base-station.
- The design should be detailed enough to start production after the DSE to enter MAV07 in France and / or the First US-Asian MAV08 competition in India.

From this mission objective description all the necessary subsystems and their relations were identified.

15.3 Concept design phase

The design process started with diverging into a multitude of feasible and non-feasible design options, and then converging towards three design concepts. A large part of the design was fixed by the strict requirements (very lightweight vehicle, use of morphing wing, use of 'off the shelf' components for most systems) and conceptual design freedom was restricted to four main fields: morphing wing design, camera positioning, propeller positioning, and design of control surfaces. The different solutions for these subsystems are listed below.

Morphing wing design and control surfaces

Different solutions were found to achieve variable sweep and wing surface reduction at the same time. These can be divided into two principal groups: bat-like wings using elastic materials supported by composite structures, and wings built up from feather-like composite structures. The bat-like elastic wings proved very promising in view of area reduction, but development of the elastomer material was found to be unfeasible within the time available. Therefore this option could not be used for the final design. To make a choice between the other two concepts, both feathered wings, the possible area reduction is evaluated. With a multiple joint mechanism, larger reductions in surface area are feasible. Next to this, unlike the single joint design, the feather-like structure with multiple joints can transport aerodynamic loads via multiple paths, making the joints less prone to fail under peak loading; the final design choice was therefore fixed on the multiple joint design. This design option can be seen in figure 15.3.

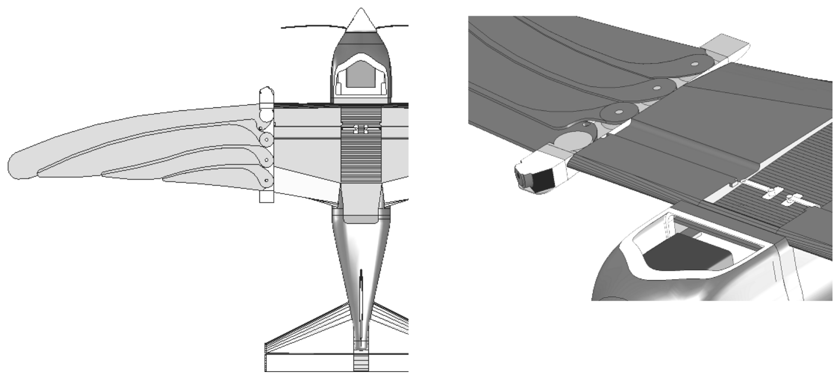

Figure 15.3: Top view and detailed view of the multiple joint feather -like morphing wings.

One of the requirements was to minimize number of control variables. RoboSwift's morphing wings provided an opportunity to do so; by morphing the wings asymmetrically, a rolling moment can be induced. In this way weight can be reduced, as the design does not need to be fitted with additional ailerons for roll control. Since micro aerial vehicles do not need to be fitted with yaw control to make steady turns, a rudder has been left out in the design.

Camera positioning

The option of actuating the camera systems to increase the field of view has been put aside early in the trade-off process to reduce mechanical complexity in the design. The main focus of the RoboSwift design is on the novel morphing wing and roll control through asymmetric morphing. Therefore the design choice was reduced to having fixed cameras mounted on the nose or positioned on the wings.

To keep the option open for having stereo-vision aboard RoboSwift (for which a considerable distance, or baseline, between the two cameras is needed), the nose cameras option was discarded. Wing-mounted cameras for forward vision were therefore considered to be the best option. This design option can be seen in figure 15.4.

Propeller positioning
There are three feasible configurations for positioning the propeller. Either a single propeller is mounted on the nose or a single push propeller is mounted on the back of the fuselage, and a third option is to use two wing-mounted propellers. Because wing-mounted cameras were considered the best option positioning of the vision systems, the option of putting propellers on the wings was discarded. A push-propeller at the back of the fuselage has the disadvantage that the tail structure must be strengthened, adding weight to the design and shifting back the centre of gravity. Also the noise produced by the push-propeller will be larger, due to the interaction with the disturbed flow coming from a deflected elevator. Therefore the choice for placing the propeller in the nose has been made. This propeller will automatically fold its blades backward when it is not rotating, to minimize the drag during gliding.

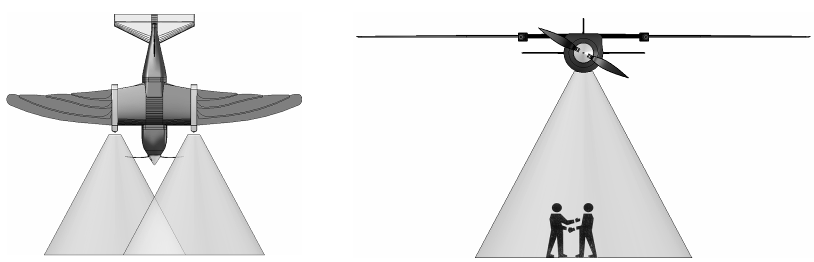

Figure 15.4: The wing-mounted cameras and the belly camera combined with the propeller in the nose (top view and front view respectively).

15.4 Detailed design phase

During the detailed design phase the configuration with a feathered morphing wing with multiple joints, wing-mounted cameras and a folding propeller on the nose was worked out. Also the off the shelf components were selected such that at the end of this phase, the RoboSwift design will be ready for production. During the Design Synthesis Exercise, models were made for the aerodynamics and stability to compare RoboSwift's flight characteristics to that of the swift. From these figures it has been possible to verify that RoboSwift has a performance that is enhanced by the morphing wing, and that it possesses inherent stability. The aerodynamics of micro aerial vehicles are dictated by the very low Reynolds numbers at which they fly. Since software prediction of the aerodynamic characteristics at these Reynolds numbers can be very inaccurate, aid was taken from wind tunnel tests, which provide the most reliable data for the thin airfoils. The aerodynamic modelling was performed using a Vortex-Lattice method. Also the structural integrity of the morphing wing has been studied by modelling the aerodynamic forces acting on the feathers using the Finite Element Method (FEM). Outcomes of both models were used to create a feasible actuation mechanism that enables the wing to morph to an optimum sweep angle at each given flight speed.

The performance envelope of RoboSwift was indeed extended to reach superior performance. Swifts fly at an average speed of 8 to 9 meter per second and can have maximum speeds of 25 m/s. This large flight envelope requires, beside the morphing wing technology, a propulsion system that is optimized to the given limits to be able to deliver the power required. Hence, models were made to simulate the motor and propeller performance. What resulted from the morphing wing models for the performance is that at low speeds the gliding ratio is optimal with unswept wings, whereas at higher velocities the swept wing gives a better performance. By using the morphing wing the flight envelope can therefore be extended and this can be seen in figure 15.5.

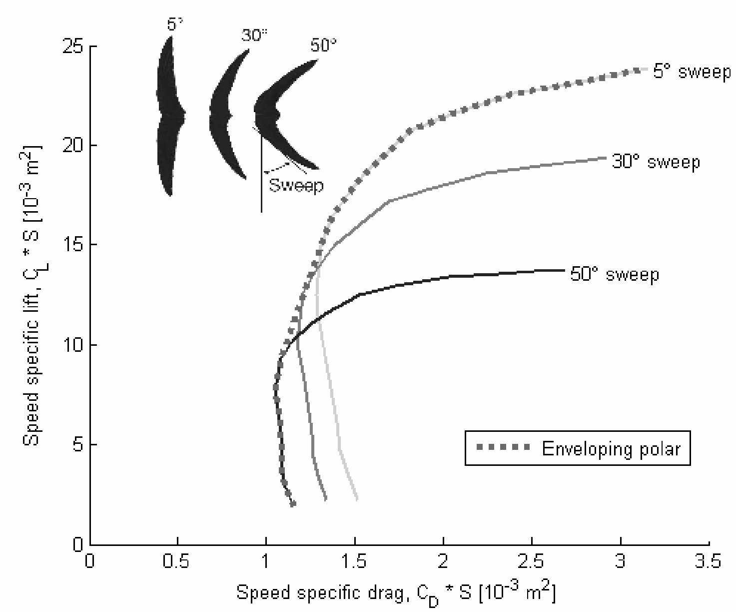

Figure 15.5: The lift drag polar of RoboSwift showing the extended flight envelope due to morphing.

Inducing roll using asymmetric morphing is realized by implementing a difference in sweep angle between the left and right wing. The induced difference in sweep and wing area results a difference in lift between the two wings. This difference creates a rolling moment. The difference in drag, which is also induced, will be counteracted by the vertical tail. Since this roll control method has never been implemented before, it needed extra attention during the design. Stability calculations have been made to ensure that this control method is reliable.

The camera system consists of three cameras; two wing cameras looking in flight direction and one belly camera looking downward for ground surveillance. This system enables switching between the three cameras and it provides live streaming videos of any two cameras at the same time. The cameras in the nose offer wide field of view up to 120 degrees. The configuration for the cameras in the wings can be adjusted to make stereo-vision possible. The pilot makes use of a head mounted display to observe the images as naturally as possible. When the ground surveillance is performed, the images from the belly camera are shown on a separate screen.

The overall swift resemblance of RoboSwift has been of great importance during the detailed design phase. Roboswift will mostly fly at high altitudes and therefore its bottom view silhouette and especially the flight behaviour are most critical. To realise swift resemblance the horizontal tail plane has been made of transparent material, so that it will blend out at large distances. RoboSwift's resemblance with a swift can be seen in figure 15.6

The budget for realising this project is also estimated during the detailed design phase to make sure that the total costs for three RoboSwift vehicles and one ground station do not exceed the budget of 10.000 Euro.

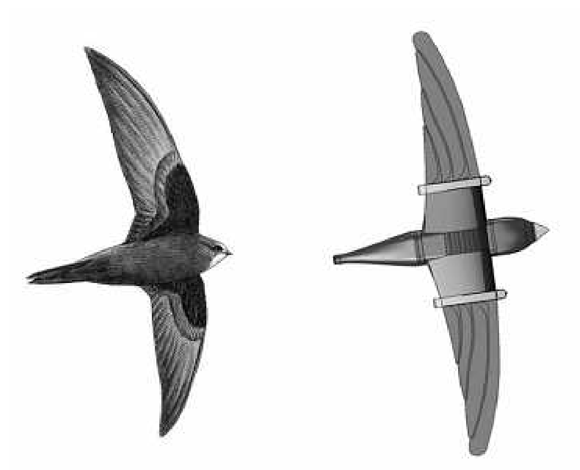

Figure 15.6: The swift resemblance of RoboSwift.

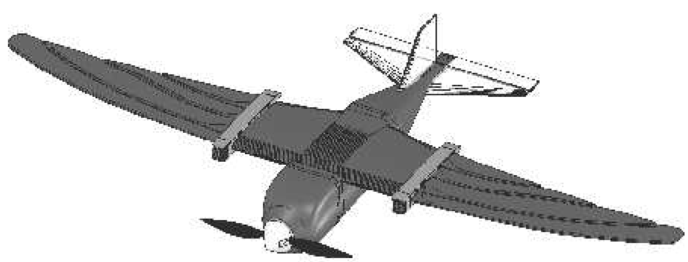

Figure 15.7: The final design concept of RoboSwift

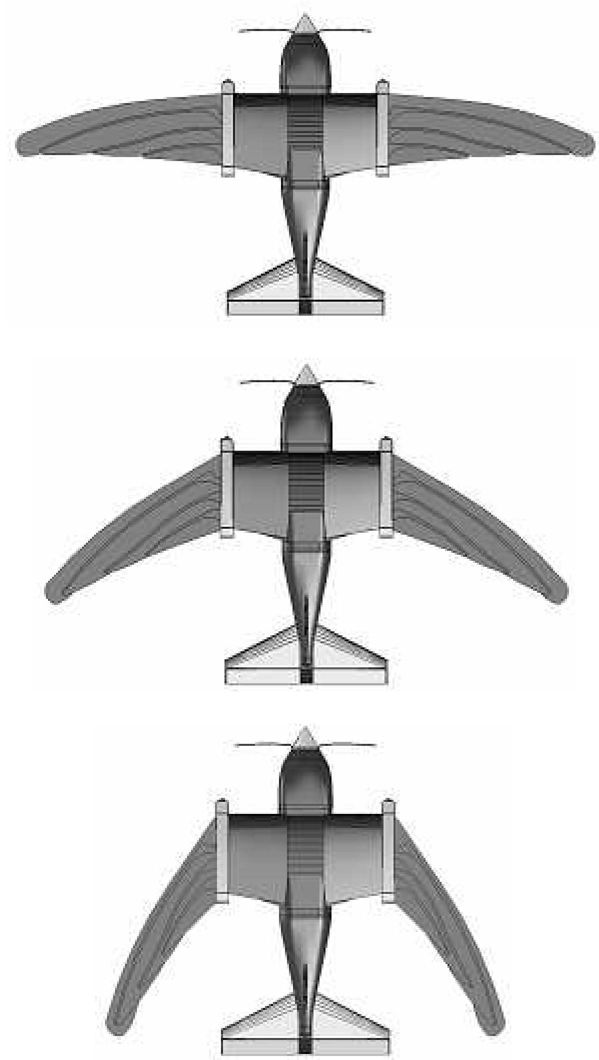

Figure 15.8: Top view of the sweeping of the morphing wing for 5°, 25° and 50° sweep

15.5 Animal welfare

Animal welfare is an essential part in RoboSwift's design. Especially during bioresearch missions animal welfare precautions play an important role. For, within this mission the interaction with live animals is inherent. Laws in animal experiments need to be taken into account, as well as the ethics involved. These issues could pose

additional constraints on the design of RoboSwift or preparation and execution of the mission.
For a professional insight into these matters contact has been made with an authority on animal experiments, affiliated with the Royal Netherlands Academy of Sciences (K.N.A.W.). In combination with his recommendations and swift behavioural articles good insight has been obtained in the animal welfare of RoboSwift's missions.

15.6 The first US-Asian MAV08 competition

The RoboSwift team has accepted the challenge to continue the project and actually build a flying RoboSwift to compete in the First US-Asian MAV08 competition in India, in March 2008. To ensure the realization of RoboSwift, an extensive production plan, timeline schedule, pilot training program and sponsor plan have been set up and worked out during the Design Synthesis Exercise. Starting immediately after completion of the exercise, the team will kick-off this phase.

15.7 Conclusions

The RoboSwift team has accomplished designing a bio-mimetic Micro Aerial Vehicle, capable of imitating the common swift in performance and appearance. The final design has become a reliable, feasible and interesting blueprint, with opportunities for the development of a fully operational RoboSwift.
During the detailed design phase the chosen configuration subparts (feathered morphing wing with multiple joints, wing-mounted cameras and the folding propeller in the nose) were combined and worked out. Also, the off the shelf components were carefully selected so that after completion of the Design Synthesis Exercise, RoboSwift's design would be ready for production.
To validate the design, extensive calculations and mathematical models have been made for the aerodynamics, performance, stability and structural strength. This made it possible to compare RoboSwift's flight performance to that of the common swift, showing it to be capable of expanding the performance envelope like a real swift. Further, it was calculated that this micro aerial vehicle is indeed inherently stable. The structural integrity of the morphing wing was

studied as well by modelling the aerodynamic forces acting on the feathers. By implementing the novel technology of asymmetric morphing in the RoboSwift's design, the control surfaces could be reduced. Although asymmetric morphing has never been implemented before, calculations showed this technique to be very promising.

The research that has been carried out by the nine students of the RoboSwift team has been performed within the 10 weeks of the DSE. Insight has been gained on the physics behind morphing wing theory and the implementation techniques. A feasible design has been produced and the next phase has been worked out leading to concrete ideas on building, testing and assembly. There now exists a fundamental basis for further elaboration of design.

The RoboSwift team is confident with the design it has produced and will enter the next phase self assured. RoboSwift shall demonstrate its unique morphing and bio-mimetic capabilities to the public at the latest during the MAV08 competition in March 2008.