## 1.1 Piezo-Actuators for Gurney flap concept

### 1.1.1 *Technology Review by the University of Twente*

**Review Summary:**

References:


[1]: Consortium Projectleader, I. CleanSky/Green Rotorcraft I.T.D. Description of Work, *Agusta Westland*, 2008.

This document describes the Naca blade considered, details the requirements for the blade and contains data on the dynamic behaviour of the blade and its aerodynamic performance.

[2]: A. Paternoster, P. de Jong, R. Loedersloot, A. de Boer, R. Akkerman, Initial Technology Review, IGOR - Actuator and Control System for Green Rotorcraft I.T.D., *University of Twente, Engineering Technology*, 2009.

In this report details the various technologies available for piezoelectric actuators which ranges from stack and patch actuators to linear ultrasonic actuators. It details the methods to solve analytically the piezoelectric equations for standard piezoelectric actuators to have their characteristics. Finally, it presents in an applications part the commercial solutions available and their performances relative to each others.

[3]: A. Paternoster, Assessment of mechanical constrains on a Gurney flap with CFD computation for IGOR project, *University of Twente, Engineering Technology*, 2009.

Here are presented the CFD computations realised to investigate the mechanical energy required for the gurney flap actuations. The computations are made in steady-state. The objective was to determine a higher bound for the mechanical work the actuator needed to perform.

[4]: J.J. Wang, Y.C. Li, K.-S. Choi, Gurney flap-Lift enhancement, mechanisms and applications, *Progress in Aerospace Sciences*, Volume 44, Issue 1, January 2008, Pages 22-47

This article reviews the Gurney flap among other lift improvement mechanisms. It explains the aerodynamic phenomenon behind the lift improvement achieved by Gurney flaps. It displays also lift and drag measurements for various angles and positions of the Gurney flaps over a wide range of angles of attack. The authors conclude the Gurney flap improves the lift coefficient for subsonic and transonic speeds and that its effect is maximised when placed at the trailing edge.

[5]: Yee, K., Joo, W., Lee, D.-H., Aerodynamic performance analysis of a gurney flap for rotorcraft application, (2007) *Journal of Aircraft*, 44 (3), pp. 1003-1014.

This article focuses more on the application of Gurney flaps for rotorcrafts. It presents a CFD computation of the Gurney flap on a Naca 0012 airfoil. Yee concludes that the Gurney flap should not be longer than 2% of the chord length to avoid an increase in drag. He states that the Gurney flap improves the airfoil behaviour in light stall conditions but could not conclude for high angles of attack and deep stall conditions.

[6]: Yung H. Yu, Bernd Gmelin, Wolf Splettstoesser, Jean J. Philippe, Jean Prieur, Thomas F. Brooks, Reduction of helicopter blade-vortex interaction noise by active rotor control technology, *Progress in Aerospace Sciences*, Volume 33, Issues 9-10, 1997, Pages 647-687.

The bases for active noise reduction are stated in this detailed review of the blade dynamic behaviour and its interaction with vortexes. Active control of vibrations requires excitation at frequencies equal to 4/rev.

[7]: Altmikus A., Dummel A., Heger R., Schimke D., Actively controlled rotor: aerodynamic and acoustic benefit for the helicopter today and tomorrow, *34th European Rotorcraft Forum Liverpool*,

*UK*, September 2008.

This conference paper presents research made at Eurocopter on active trailing flaps driven. It focuses on the acoustic improvement over multiple active control techniques and displays a demonstrator with active trailing edge flaps driven by piezoelectric stacks.

## Concept

Gurney flaps are small flaps which dimensions are usually less than 2% of the chord length of the blade onto which it is installed. The aim is to be able to actuate such a flap as the rotor blade goes around the helicopter to improve the lift on the retrieving side while not affecting the characteristics of the blade on the advancing side. This will enhance the lift and maximum performance of the rotorcraft [4, 5].

## Requirements:

- The mechanical energy developed needs to be sufficient to actuate the flap in the worst aerodynamic case.
- The actuator needs to be sufficiently fast to execute one full cycle within one blade revolution.
- The weight and space taken by the actuators must be as small as possible.
- The actuators need to be embedded within the rotor blades and therefore need to sustain the high *g*-forces generated.
- The reliability should be as high as possible to meet the time between maintenance checks.

This review presents an actuator selection for actuating Gurney flaps according to these requirements.

## Investigation of the energy needed to deploy a Gurney flap:

A computation is made using the CFD capabilities of ANSYS. The Naca 23012 profile is modelled for various angles of attacks and various positions of the Gurney flap (cf. Figure 1). The airflow speed chosen for the modelling is the maximum speed the blade can encounter: 214 m/s. Having the pressure distribution around the airfoil, it was possible to compute the force needed to counter the airflow for various angles of attack (cf. Figure 2) [3].

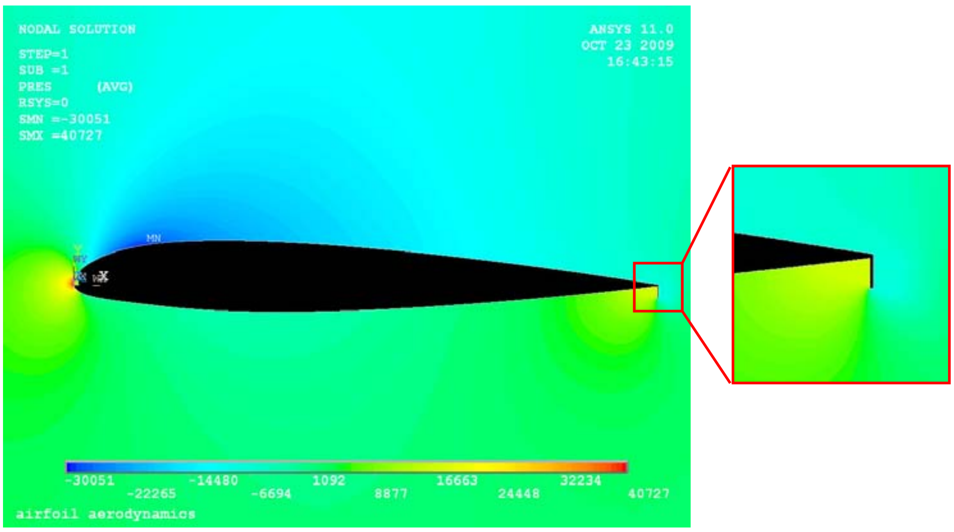



**Figure 1: Pressure distribution for a steady state computation of the Naca 23012 profile with 2% chord length Gurney flap at the trailing edge at 214 m/s.**

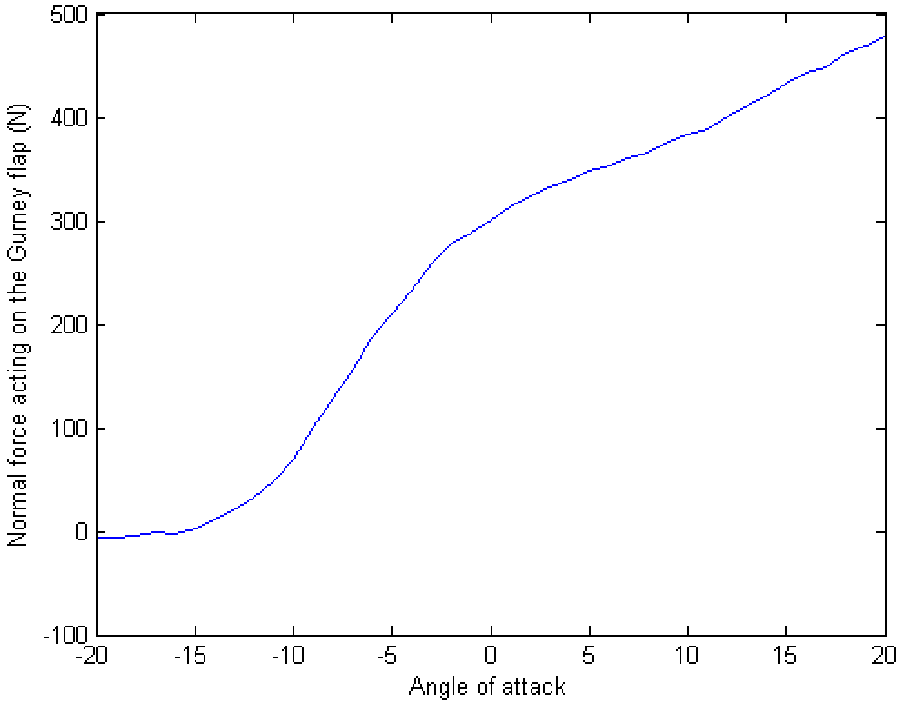
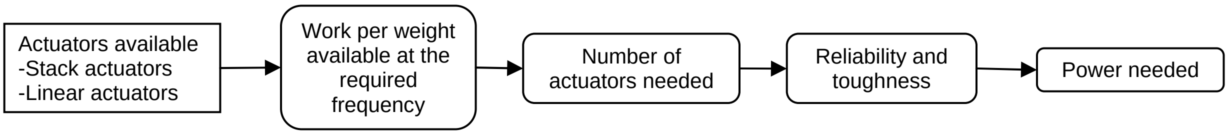



**Figure 2: Normal force acting on the Gurney flap for various and angles of attack.**

From these results, it is possible to estimate a maximum bound for the energy needed to deploy the flap per meter of wingspan. The result is that the actuator, should be able to deliver a maximum energy of 4 Joules per meter of wingspan.

## General Actuation selection:

The actuator selection is proceeded according to the following diagram.




The actuator selection is considered for the Gurney flap within two very different concepts: the active control concept where the speed is the critical parameter. The second concept is the dual-speed concept. For this one many actuators are able to deliver the required mechanical energy at a low cost in weight. The selection is mainly made on the realism of integrating these in a rotor blade.

This selection process can be applied to many other shape morphing problems that need an optimisation of the mechanical energy over the weight for a defined actuation speed.

## Active control

Deployment time:

The objective is to deploy and fold back the flap within one rotor blade revolution. The actuator should be able to deliver the 4 J/m two times per revolution and achieve a full cycle. The rotor angular velocity is 26.26 rad/s, thus the actuator should operate at 4.2 Hz [1].

Piezo-stack actuators are the most efficient piezoelectric actuators due to the high strain constants in the direction of the applied voltage and various types are commercially available. Their bandwidth is very wide and much larger than 4Hz. The figure that is going to be compared is the mechanical work that they can achieve within one cycle divided by the actuator weight. However, linear actuator cannot achieve a full stroke at 4Hz. In order to have a relevant figure, the stroke that is possible to achieve within ¼ second is taken to calculate the work per weight coefficient [2].

## Suitable actuators

Piezoelectric actuator

The best stack actuator according to these requirements is the PICA stack actuator P-025.200 from Physik Instrumente.

- Dimensions: 25 mm diameter and 244 mm length
- Work developed: 2.25 J
- Weight: 934 g
- Maximum Power @ 4.2Hz: 56 W
- Life time @ 4.2Hz: 66 000 hours
- Temperature range: -20 to +85 °C

Piezoelectric linear actuator

The best linear actuator that delivers the most mechanical energy within the given type is the ultrasonic actuator M-674.164 PILine from Physik Instrumente.

- Dimensions: 38 mm width and length, 8mm thick with a 54 mm long rod
- Work developed: 0.375 J
- Weight: 100 g
- Maximum Power @ 4.2Hz: 15 W
- Minimum Time Between Failure (MTBF): 20 000 hours (similar technology)
- Temperature range: -20 to +50 °C

## Results

The weight and power required are calculated per meter of wingspan and for the full blade. The blade length onto which Gurney flap can be mounted is 6.55 m.

| Actuator | Number of actuators | Weight (kg) | Max power (W) |
|---|---|---|---|
| Stack (1 m) | 2 | 1.9 | 112 |
| Linear actuator (1 m) | 11 | 1.1 | 165 |
| Stack (full blade) | 12 | 11.2 | 672 |
| Linear actuator (full blade) | 70 | 7 | 1050 |

The linear actuator solution is much lighter than the stack actuator alternative, but the devices are already at its maximum capabilities in terms of speed, whereas the stack actuators bandwidth would allow not only to deploy the Gurney flaps as the blade goes around but also to perform active vibration reduction at frequencies that are at least four times the revolution frequency (4/rev) [6].

**Dual-Speed rotorblade:**

The dual speed rotorblade concept principle is to have two configurations for two distinctive flight conditions. Once the Gurney flap is deployed, it provided the wing with more lift and therefore the rotation speed of the blade could be decreased. This configuration would be suited for low altitude flight with a low noise signature as opposed to a high altitude cruise flight where noise is not important anymore and where the rotorblade can recover its initial profile. The actuators to achieve that configuration change do not need to be fast and should not have high power consumption while holding the configuration (i.e the flap down).

For this problem, applying the actuator selection give the Nexact stepped actuator from Physik Instrumente as one of the best solution.

- Dimensions: 50 mm width and high, 80 mm long with 20 mm of travel range
- Work developed: 8 J
- Holding force: 600 N with no power consumption
- Weight: 1150 g
- Maximum Power: 48 W
- Time to achieve one cycle: 20 s
- Minimum Time Between Failure (MTBF): space certification (100 000 hours)
- Temperature range: -40 to +80 °C

| Actuator | Number of actuators | Weight (kg) | Max power (W) |
|---|---|---|---|
| One meter of blade | 0.5 | 0.6 | 24 |
| Full blade | 3 | 3.5 | 144 |

For this problem, other solutions could have appeared as relevant in terms of power per weight like the Squiggle actuator, but 100 actuators are needed to actuate one meter of wing.

**Limitations:**

The previous results need to be considered carefully. The figures shown do not take into account the mechanical part that will be needed to transfer the force and stoke to the Gurney flap and the electronics needed to drive the actuators that will also consumed some power. Regarding the number of actuators, it could also be interesting to have the flap divided into multiple sections individually actuated which would allow more control of the blade behaviour but would made the driving more complex.

**Conclusion:**

Gurney flap from the actuator point of view seem to be a feasible and mature solution. The technologies discussed are commercially available solutions. They are able to deliver the mechanical energy required at a low weight penalty. The energy required for the active blade is comparable to the energy needed for de-icing the blade (around 1kW). The stack actuator solution presents some interesting possible multi-purpose usage. As in this control scheme, the flap is divided into multiple sections and the operating frequencies can be much more important, it would allow to modify quickly the envelope of the helicopter not only to increase the lift for the retrieving blade, but also for damping high frequency vibrations and twisting the blade. Furthermore, stack actuators have already been successfully integrated into demonstrators for active vibration damping [7].