Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

ACTIVE FLUID GURNEY FLAPS: AN EFFECTIVE SOLUTION TO PROMOTE SUSTAINABLE AIR TRANSPORTATION

Mario Lucas[1], Jorge Saavedra[1] , and Luis Cadarso [1]

[1]Aerospace Systems and Transport Research Group, European Institute for Aviation Training and Accreditation (EIATA), Rey Juan Carlos University, 28942 Fuenlabrada, Madrid, Spain

ABSTRACT

Aircraft operational weight reduction is vital to enhance aviation sustainability. Using an Active Fluid Gurney Flap (AFGF) holds promise for significant weight reduction and enhanced controlled lift augmentation. This innovative technology removes the need for actuators, deployment mechanisms, and hyper-lift surfaces such as flaps. Moreover, its working principle grants precise control over lift adjustments during operation. The AFGF mechanism involves the injection of a jet flow at constant pressure over an orifice positioned at the trailing edge of the airfoil pressure side. Its efficacy is evaluated through 2D Computational Fluid Dynamics (CFD) simulations, exploring the impacts of Reynolds numbers and air jet injection pressures.

1 INTRODUCTION

Currently, airplanes use flaps to boost lift during take-off and landing. However, employing these hyper-lift surfaces entails actuators and additional surfaces adding considerable weight. Considering the partial exploitation of these devices during specific flight phases, their installation increases both fuel consumption and emissions. To minimize the weight addition, Gurney Flap (GF) emerges as a straightforward mechanism for enhancing lift. This simple geometry can significantly boost lift, although it promotes a considerable drag penalty, making them less suitable during various flight phases. However, the underlying fluid dynamic mechanisms induced by GF offer significant potential for advancing lift enhancement applications.

To address the well-known limitations of exploiting GF while maintaining control over lift enhancement to suit flight operation requirements, the AFGF is proposed. This technology requires only the addition of an orifice on the pressure side and a compressor to facilitate the injection of pressurized air to promote the same aerodynamic mechanisms that drive lift enhancement in traditional GF (Feng, Choi, and Wang 2015). The injection deflects the flow downwards, resulting in an augmentation of the effective curvature of the airfoil profile (observe the streamlines in the AFGF simulation in Figure 1 right, contrasting with the conventional GF depicted in Figure 1 left). This modification increases circulation, suction peak, and overpressure, boosting lift force, as Traub experimentally tested (Traub, Miller, and Rediniotis 2004).

2 METHODOLOGY

Unsteady Reynolds Averaged Navier-Stokes simulations are used to assess the performance of the proposed AFGF over a 2D NREL S809 airfoil given its proven capabilities and the available data in the literature. The numerical domain is validated through a benchmark analysis, while its discretization is verified using the Grid Convergence Index. The fluid, air, is modeled as an ideal gas while the turbulence closure is achieved via the Transition SST model. High temporal resolution is required to predict the airfoil's transient performance driven by the flow discharge and its interaction with the pressure side flow. The computational approach was verified against experimental data at $Re = 1 \cdot 10^6$ and $Re = 2 \cdot 10^6$.

3 RESULTS

The aerodynamic performance of a NREL S809 airfoil featuring an AFGF using different injection pressures (P_i) is compared against the original airfoil and a conventional GF with length 5.0%c and thickness 0.4%c under operating conditions equivalent to $Re = 1 \cdot 10^6$. Figure 2 shows considerable changes in pressure distributions when the AFGF is active. Airfoil's upper surface pressure is reduced meanwhile the pressure on the lower surface is increased achieving a lift force enhancement.

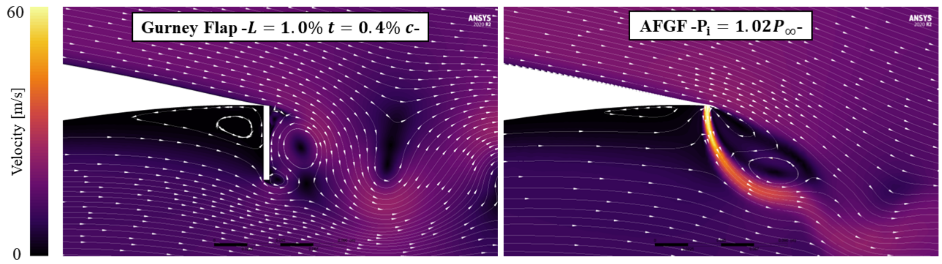

Figure 1: Velocity magnitude and streamlines at $\alpha = 0^o$ introducing lift enhancement mechanisms

GF induces a lift force increment by enhancing camber effectiveness through a pair of counter-rotating vortices downstream of GF and a recirculation bubble upstream of the GF, as depicted in Figure 1. Traditional GF increases c_{L_0} by around 530% compared to the original airfoil. In contrast, using AFGF with $P_i = 1.02P_\infty$ results in a c_{L_0} about 89% higher than the studied GF, further enhancing lift while enabling control features over its application. Additionally, when the injection pressure increases, $P_i = 1.05P_\infty$, c_{L_0} raises an additional 63%. Hence, stronger injection pressures lead to increased flow turning, enhancing effective camber and circulation over the airfoil, ultimately resulting in stronger lift enhancement.

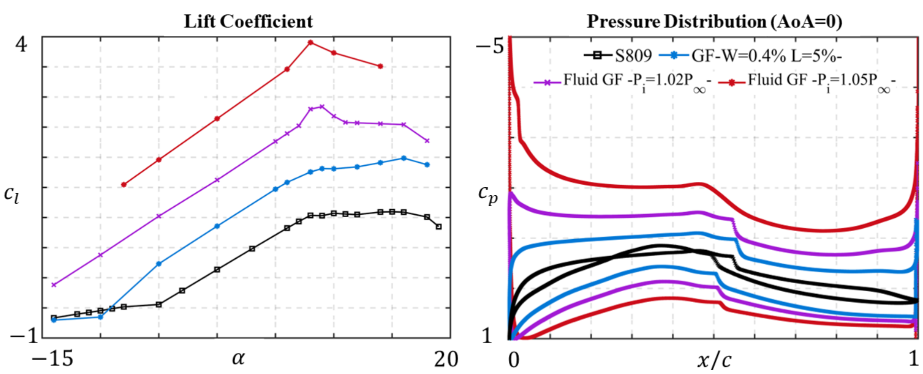

Figure 2: c_l vs. α and c_p distribution for: NREL S809, NREL S809 with GF, and NREL S809 with AFGF

These results demonstrate the significant potential of using AFGF to enhance lift during maneuvers like takeoff and landing, while also reducing weight and complexity compared to traditional hyper-lift devices. This technology, demonstrated in a 2D moderate-high curvature profile would be suitable for regional aircraft wings, airfoil profiles next to the root in wide-body aircraft wings, and wind turbine blades.

REFERENCES

Feng, L.-H., K.-S. Choi, and J.-J. Wang. 2015. "Flow control over an airfoil using virtual Gurney flaps". *Journal of Fluid Mechanics* 767:595–626 https://doi.org/10.1017/jfm.2015.22.

Traub, L., A. Miller, and O. Rediniotis. 2004, 03. "Comparisons of a Gurney and Jet-Flap for Hinge-Less Control". *Journal of Aircraft - J AIRCRAFT* 41:420–423 https://doi.org/10.2514/1.6023.