STAD-1 Aerodynamic Design – Summary

The following is a summary of all the work concerning the aerodynamics design of the STAD-1 Kestrel.

In this work, the preliminary aerodynamic design for the STAD-1 Kestrel aircraft is presented. Starting from data and objectives set in the design done in both the courses of Aircraft Design, the aerodynamic sizing is conducted up to a preliminary level using semi-empirical tools and numerical tools, starting with low fidelity VLM methods, up to mid and high-fidelity methods like DUST and Euler simulations.

The sizing considers firstly the introduction of the design points and objectives of the design, namely the flight conditions in terms of altitude, Mach and load conditions and the minimum required global $L/_D$ in loitering condition which is 14.

Subsequently, the wing planform design is started. The wing planform is a lambda wing, which is an optimal wing in terms of both aerodynamic performance and RCS. The planform is designed before the airfoil choice due to the medium aspect ratio and the high sweep. The design is done by setting the main parameters required for a planform using theoretical considerations and the OpenVSP design tool. The airfoils chosen for this first design are basilar NACA 64A airfoils, as close as possible to symmetrical ones. The output planform's global characteristics are presented in the following table:

Leading edge sweep	40°
Reference surface	26.56 m^2
Mean chord	2.65 m
Wingspan	10.56 m
Aspect ratio	4.198

Table 1 - Wing Data.

With the wing planform fixed, the tail is designed as well, using sizing criteria from design books adapted for a V-tail configurations. The tail and an approximated fuselage are inserted in OpenVSP. This allows to evaluate the coefficients of the aircraft, which lead to a lower $L/_D$ with respect to the wing only, but still a satisfactory result.

High-lift devices are also designed for the STAD-1. These are needed to reach the target maximum lift coefficient. Their peculiarity is that they are the control surfaces as well. Two design stages are considered for these surfaces to better refine the design, subsequently outputting the flapped polar for the whole aircraft.

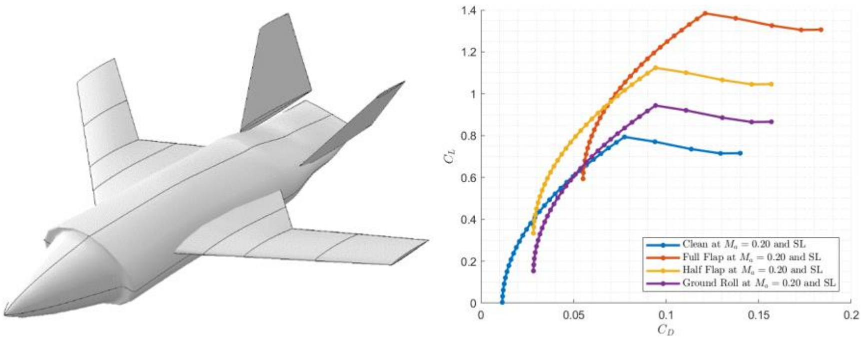

Figure 1 - Full aircraft configuration (Left) and flapped polar (Right) done with OpenVSP.

Due to more design points being in the transonic region, and due to the need to design Leading Edge Extensions which can be problematic in OpenVSP, higher order methods are used. Said methods are mid fidelity methods like Dust, as well as high fidelity methods like Euler and RANS. Their considerations are well described in the report.

Firstly, Euler simulations are used to execute the airfoil choice. Euler solver is used to consider the shockwaves in the sustained turn condition. The baseline case is tested, which was chosen with semi-empirical methods and suggestions by design books. Then more test cases are generated by varying the thickness distribution at first and by changing to 65A instead of 64A after observations, which also leads to the creation of a wing tip. Finally, supercritical airfoils test cases are generated and tested, but they do not give satisfactory results. The results are checked and compared with a RANS simulation.

Consequently, the configuration is tested by considering the fuselage and tail as well, which allows to vary the design of both fuselage and tail for better performance. The tail section of the fuselage is changed, and the airfoils of the tail are reduced in thickness. This analysis also proves that the fuselage is partially lifting.

Then, a sizing of the LEX must be done. This is done by generating different geometries where varying the chord and sweep of said extensions and carrying out a sensitivity analysis. Said analysis is done with DUST, which allows to consider the interactional behavior of the addition of the LEX and allows for a fast-prototyping approach due to the reduced simulation and geometry generation time of DUST. Subsequently, the more promising designs are tested with Euler analysis on the complete aircraft (including LEX) to better understand the phenomena and introduce the transonic effects. A final run is done with a RANS solver by considering a simplified fuselage, which allows to understand the behavior of the LEX at higher angles of attack.

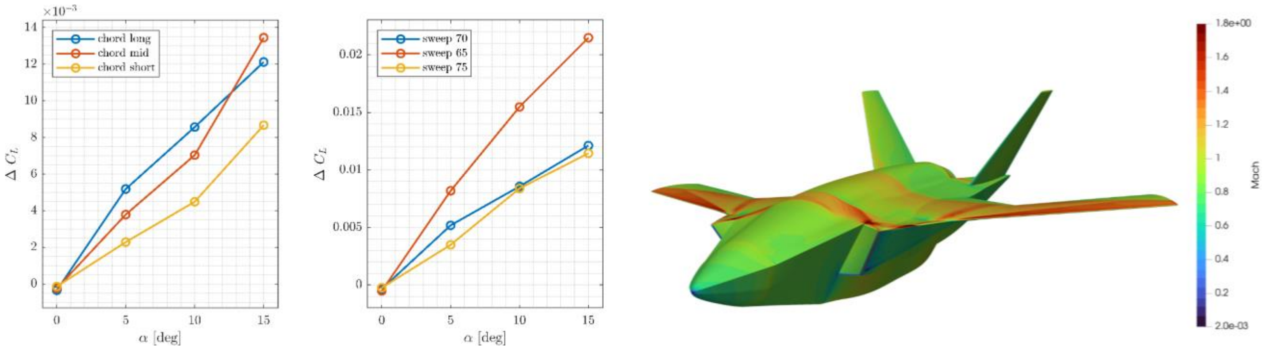

Figure 2 - LEX sensitivity from DUST and CFD analysis.

Finally, an adjoint optimization is carried out on the wing. Starting from the optimal airfoil geometry case defined previously, a control box is generated around the wing and the optimization is done using an Euler solver with the objective of minimizing wave drag in sustained turn. The constraints are set to change only the airfoils' shape and not the planform. This yields very optimal results which cannot be tested with the complete aircraft due to the inability of extracting the geometry from the deformed mesh. Nevertheless, the isolated wing is tested to verify the performance of the wing at different angles and flight conditions.

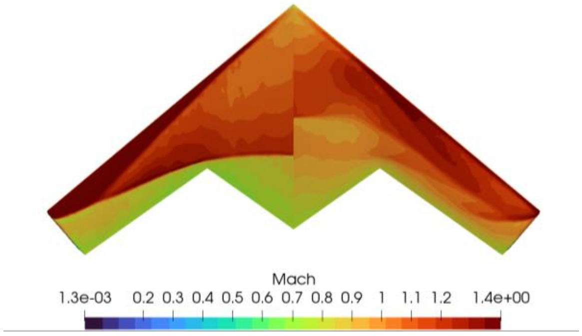

Figure 3 - Isolated wing results at M_a = 0.85 before optimization (left) and after (right).

In conclusion, this work allows to demonstrate a fast and hybrid workflow for the preliminary aerodynamic design of the aircraft, considering the different nature of all the aerodynamic phenomena and thus optimizing the development cost depending on the required accuracy. Further analysis should follow to better verify the obtained results, which are briefly presented in the report.