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RAPID PROTOTYPING IN AIRCRAFT DESIGN USING CFD, WIND TUNNEL AND FLIGHT TESTING

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Abstract

The demand for testing new technologies using flying demonstrators in a cost-effective and risk-mitigating way is increasing. This paper describes the process and methods used for rapid prototyping, sub-scale flight-testing and analysis of an aircraft design. New wings have been designed and manufactured for a radio-controlled flying demonstrator in a collaboration between Industry and academia. The results can be used in education and research to further enhance and explore the field of aeronautical engineering.

Keywords: Aircraft design, Rapid prototyping, Flight mechanics, Modelling and simulation

1. Introduction

In this paper, we describe the process and methods used in an industry – academia collaboration project using rapid prototyping, sub-scale flight-testing and analysis of an aircraft. The project follows the whole development process: preliminary design of several configurations, detailed design with the choice of configuration using computational fluid dynamics (CFD) as well as wind tunnel testing, with additive manufacturing in the form of 3D-printing, and finally flight testing followed by the analysis and reporting of the results. The project idea is based on an existing radio-controlled aircraft and is shown in Figure 1.

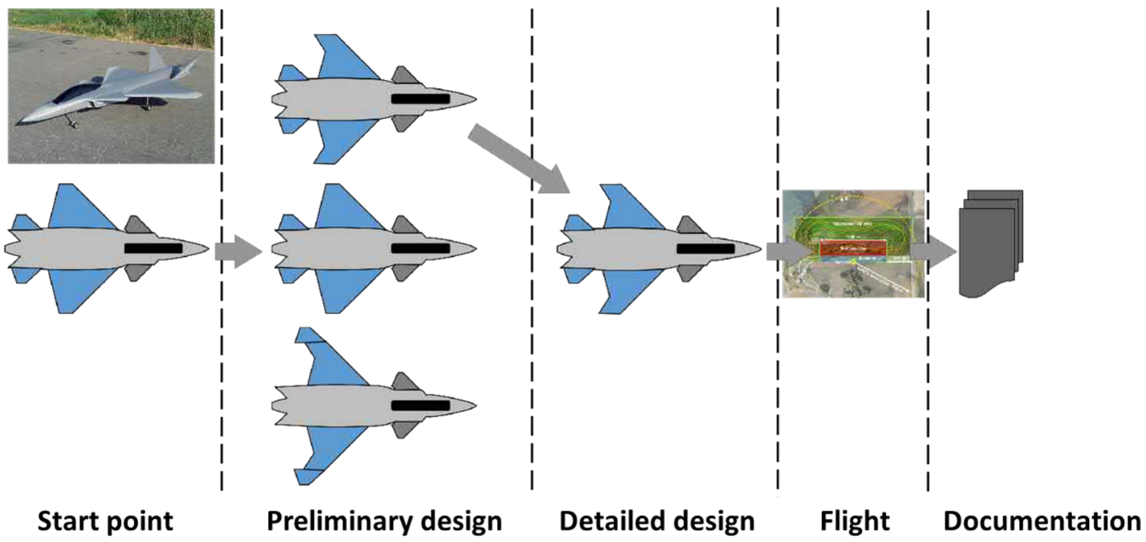


Figure 1 – The project idea.

The demand for testing technologies using flying demonstrators in a cost-effective and risk-mitigating way is increasing. The methods and tools used today for the design of new aircraft have evolved to the point where model based system engineering is a key to success. Using flying sub-scale demonstrators in combination with numerical calculations (CFD) and wind tunnel testing creates confidence in the flight mechanical simulation models. The later two are usually the a base when investigating the aerodynamics of a new configuration while the sub-scale flight testing can be used to increase safety and decrease cost for high-risk testing in a flight mechanical perspective as for SAAB 35 and X-31 in [4] and [5]. This lay the foundation for good flying qualities and an effective control system design.

2. Study

As a case study, a new wing geometry is designed for a remotely controlled flying demonstrator known as the Generic Future Fighter (GFF, [1]), shown in Figure 2. This jet-engine-powered sub-scale aircraft, previously developed at Linköping University as a research platform, is instrumented with sensors such as IMU, GPS, magnetometers and air-pressure transducers, as well as a custom-made nose-boom measuring angle-of-attack and angle-of-sideslip. The on-board data acquisition system logs the sensor measurements, the pilot commands or the automated control inputs, and the deflection of each control surface at sampling rates up to 100 Hz.

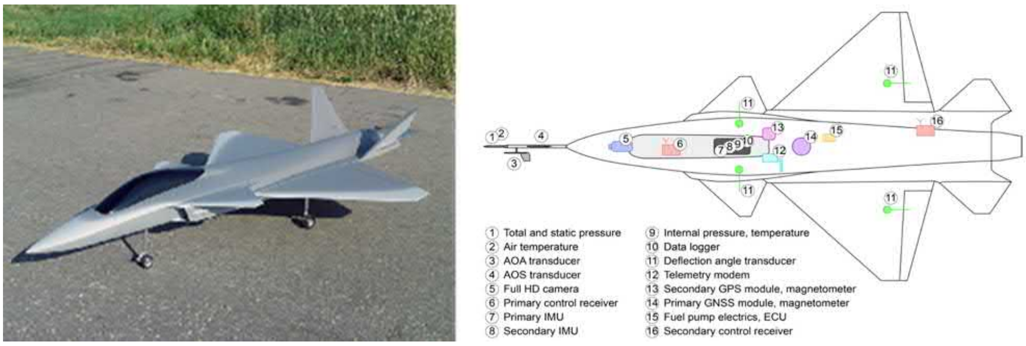


Figure 2 – The GFF aircraft and its data acquisition system.

The goal of the current work is to demonstrate the potential of using the Swedish resources in the field of aeronautical engineering in an efficient way. The project is not specific for military products, on the contrary, they can be used for all types of aircraft. The manufacturing of the GFF is relative low cost compared to larger test aircraft. It is flown within Visual Line Of Sight (VLOS) often on an airfield close to Linköping [2]. This has some limitations, but makes the operation very time and cost effective, see Figure 3.

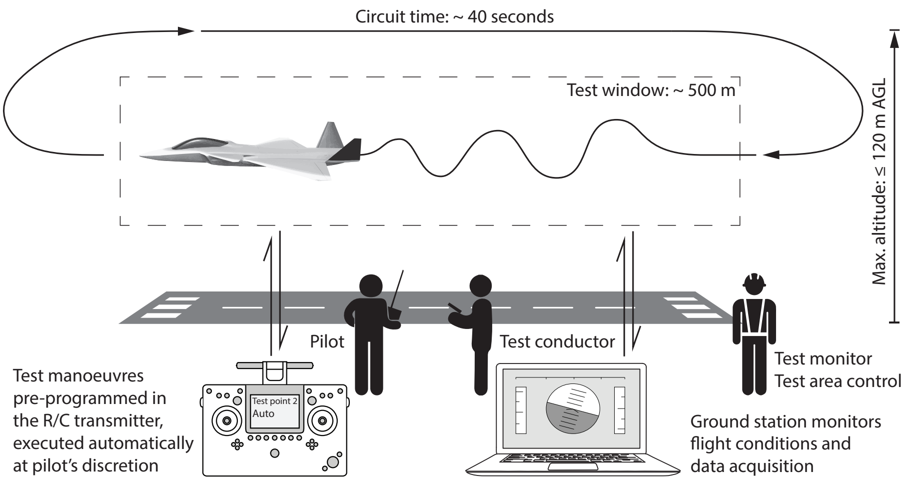


Figure 3 – Cost-efficient flight testing within VLOS using both manual piloting and automation.

As a project initialisation, LIU shared the GFF geometry with both Saab and KTH. There were some problems in the beginning with double curved surfaces to be overcome since not all partners shared the same CAD system (NX/CATIA). Several ways to overcome this were tested, which took quite some time. This was however resolved by using solids instead of surfaces in the transfer of the geometry.

2.1 Preliminary design

At Saab, the design process was initiated. Some basic limitations were used for the design so that the flying characteristics of the GFF with the new wings should be easy to handle. This was done since the radio-controlled aircraft do not have a flight control system and it is flown in visual range. These limitations were:

1. To keep the wing root chord unchanged so that the new wings can be mounted to the existing GFF demonstrator aircraft.
2. To keep the wing area approximately the same in order to achieve a similar wing loading.
3. To keep the position of the quarter mean aerodynamic chord point the same to get the resultant lift force of the wing in approximately the same place.
4. To, as much as possible, use leading and trailing edge sweep angles that already exist on the GFF aircraft to have the same design philosophy regarding stealth as before.

As a first conceptual approach five different variations of the original basic wing was suggested, shown in Figure 4. These were derived using simple handbook formulas. From these, two were chosen for further analysis. These are shown in Figure 5 together with the original wing planform.

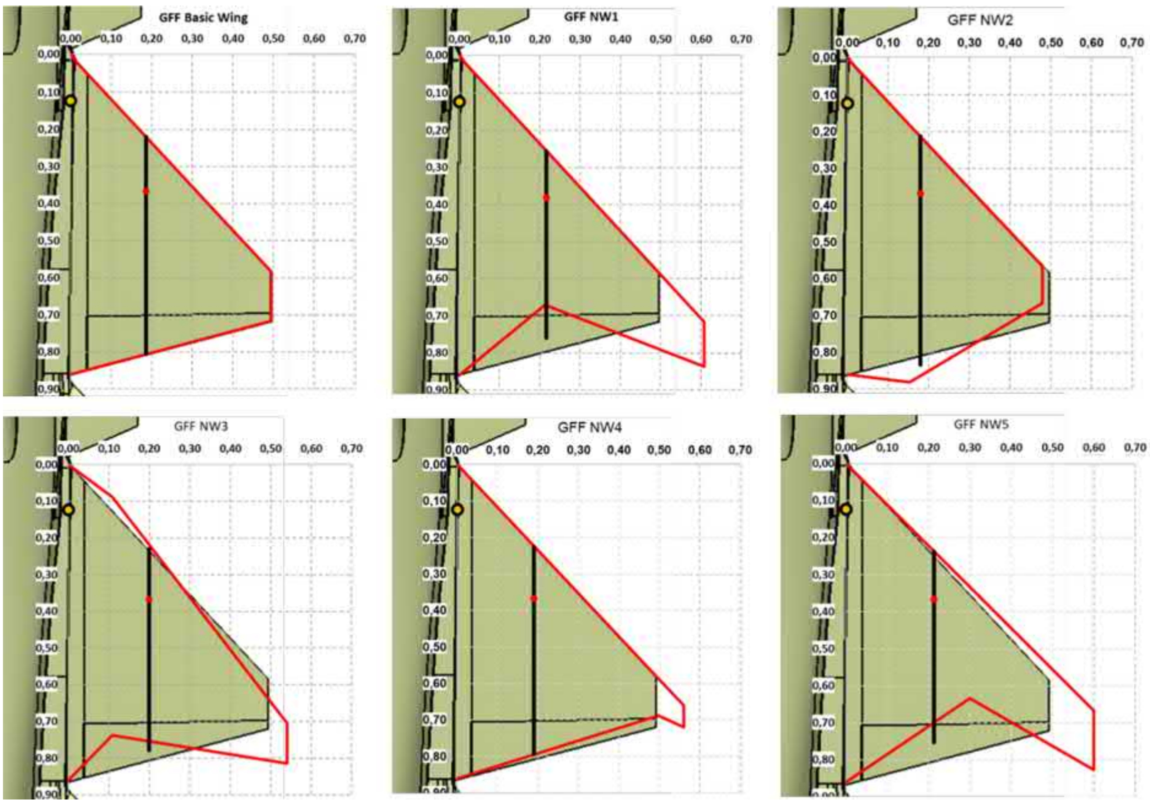


Figure 4 – Wing planform of the original aircraft and the five different concepts.

Some Euler and Naiver Stokes CFD calculations were performed for the stability characteristics. It took almost four full days to get meshes with acceptable accuracy for the original and chosen new wing concepts as there were some fairly small surfaces in the geometric model that posed some problems. A down selection was made to the top configuration in Figure 5. As a complement to

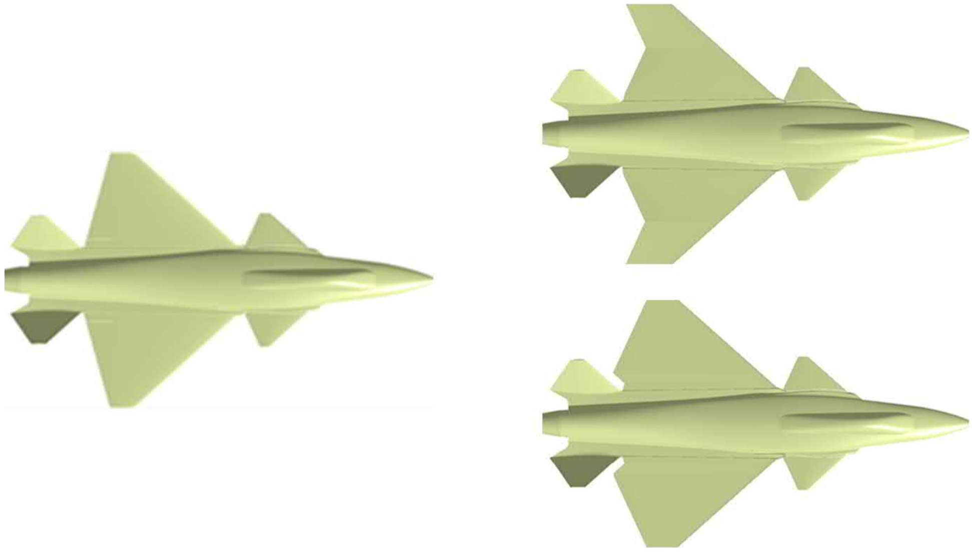


Figure 5 – The geometry of the original aircraft and the two suggested variations.

the CFD calculations, a quick check of the control surface effectiveness was performed with a panel code [3] since the wing trailing edge geometry had changed resulting in separated elevator and aileron surfaces compared to the trailing edge elevon arrangement of the original design, as can be seen in Figure 6. With the preliminary design freeze, work with the detailed design begun.

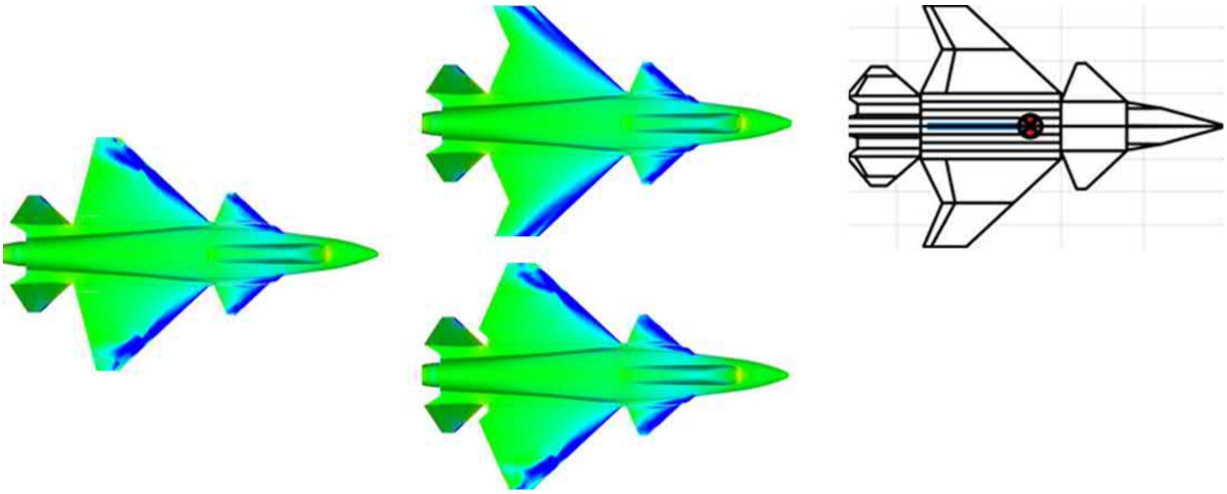


Figure 6 – CFD results used for configuration choice, Euler and panel code.

2.2 Detailed design

For this part of the working process, both CFD calculations and wind tunnel testings were made. For the CFD calculations, the process follows a normal way of working. Euler calculations have been the dominant CFD method used. An example for this can be seen in Figure 7. With the mesh created earlier only additions of control surface deflections were needed. Here several different configurations for different control surface settings and number of calculations cases in the form of angle-of-attack, angle-of-sideslip as well as the damping derivatives have been calculated. Figure 8 show the different settings as well as the angle-of-attack and angle-of-sideslip calculation points. The blue points are made for symmetrical cases while the red ones are added to these for asymmetrical configurations. For the damping derivatives only zero angle-of-attack and angle-of-sideslip were used. Otherwise time dependent calculations would have been needed, which would have taken longer time. In total more than 3000 Euler calculations have been performed for each configuration. This amounts to about seven days effective calculation time.

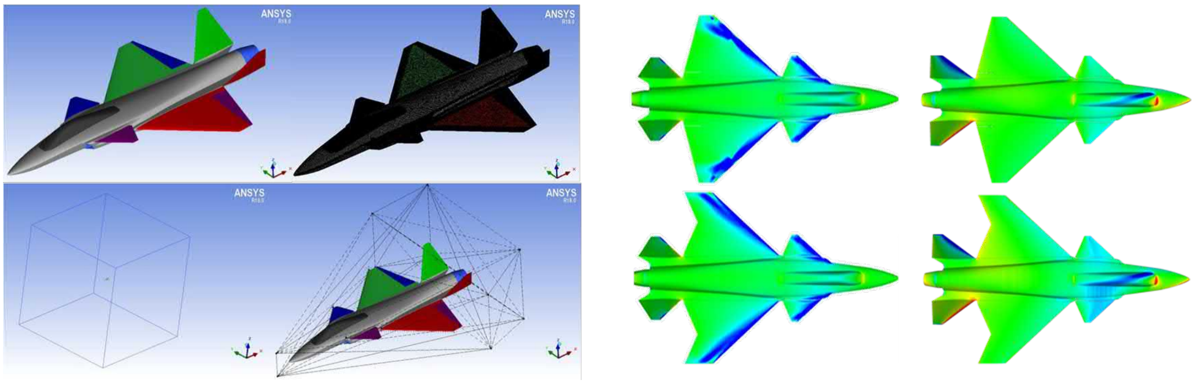
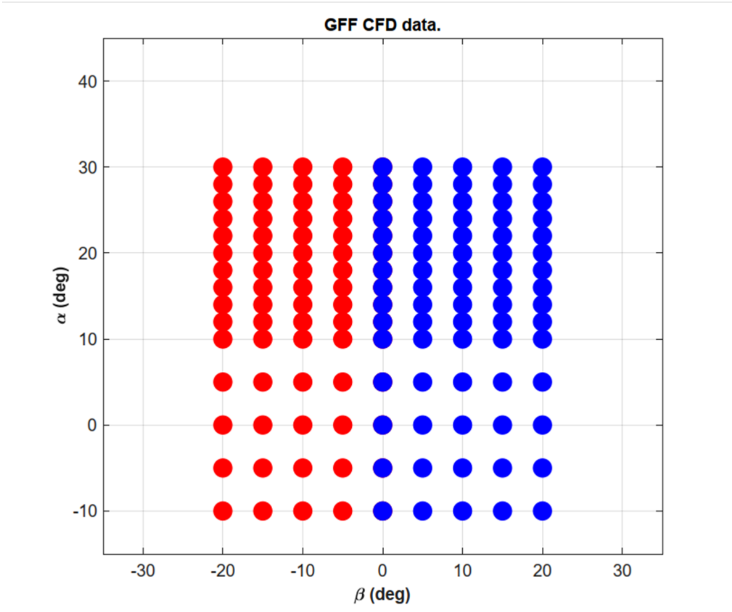


Figure 7 – CFD process.

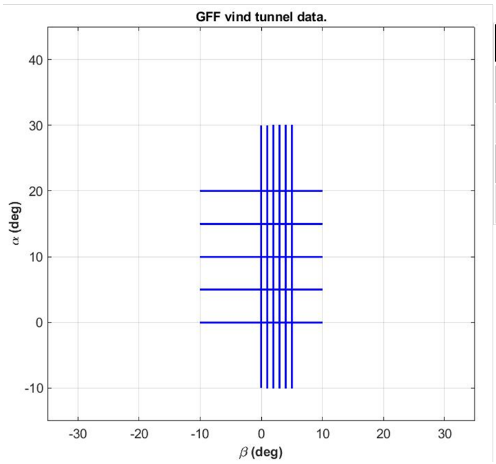


Original and new wing

Config.	δ_c	δ_e	δ_a
1	0°	0°	0°
2	±5°	0°	0°
3	0°	±5°	0°
4	0°	±10°	0°
5	0°	±20°	0°
6	0°	±2.5°	±2.5°
7	0°	±5°	±5°
8	0°	±10°	±10°
9	0°	0°	±5°
10	0°	0°	±10°
11	0°	0°	±20°

Figure 8 – CFD envelop and control surface configurations.

The preparation of the CAD geometry for the manufacturing of the wind tunnel model took about five days. This included making the wind tunnel model modular consisting of four pieces, a nose cone, the front body with the canard, the mid-body with wings including the trailing edge surfaces and the aft body including the V-tail. This is an efficient way of dividing the geometry since only the canard part or the mid-body part of the model had to be changed to get the new control surface configurations. The construction also included the connection of the balance for measuring forces and moments. Since the wing geometry is relative thin, some alterations had to be made to keep the wind tunnel model from deforming during the tests. An effective way of producing 3D-printed wind tunnel models was used. This process took 10 days. Although the 3D-printing is getting better and better some minor adjustments to get the separate pieces to fit together was needed. This was made by hand and took an additional two days. For the test the wind tunnel velocity was 25 m/s for the major part. Angle-of-attack sweeps were performed with an angular speed of approximately 0.05 deg/s and sideslip angle sweeps were performed an angular speed of approximately 0.08 deg/s. The tested envelop is shown in Figure 9. The actual test time in the wind tunnel was five days, making the turn-around time from that CAD geometry was sent to KTH until the test data was delivered to Saab about tree and a half weeks. The process used, shown in Figure 10, is very efficient compared to similar tests usually used in industrial. In addition to the performed test, the combinations of canard and trailing edge deflections can be made in the future to see if there are interference effects between these surfaces. This was not included in the current project.



Original wing

Config.	δ_c	δ_e	δ_a
1	0°	0°	0°
2	±5°	0°	0°
3	0°	±10°	0°
4	0°	+5°	+5°

New wing

Config.	δ_c	δ_e	δ_a	$\delta_{f,L/R}$
1	0°	0°	0°	0°
2	±5°	0°	0°	0°
3	0°	+10°	0°	0°
4	0°	0°	+10°	0°
5	0°	0°	0°	+10°/+10°
6	0°	0°	0°	+10°/0°

Figure 9 – Wind tunnel envelop, where the deflection of the the entire trailing edge on the Left/Right side for the new wing is denoted $\delta_{f,L/R}$.

Figure 10 – Wind tunnel process.

2.3 Flight

In section 2.1 it was stated that the GFF with the new wings were designed so that the flying characteristics should be easy to handle with approximately the same wing area and the resulting lift force in the same position as the original wing configuration. The aerodynamic part has been confirmed in CFD and wind tunnel test. This was important to get confidence in the flying and handling qualities of the new concept. The flight test part begun with the construction and manufacturing of the new wings. For this, new moulds were made. The wing surfaces are made in carbon fibre and wood is used for the internal structure. The manufacturing also included the installation and testing of new servos. The control system hardware was changed so that the wings are changeable between the original and new wings since there are different number of control surfaces for the two configurations. The new control surfaces needed calibration to get them ready for flight. This also included checking the angle-of-attack and sideslip angle vanes. New mass and inertia properties had to be measured [6] with the new wings mounted to get new model data for both landing gear in and out. This is very important because it affects the flying and handling characteristics of the aircraft. Together with the aerodynamics from the wind tunnel test and CFD calculation and the engine characteristics, which have not changed, the aircraft was ready for flight. The test plan consisted of three flights, of which the first was to get a feeling for the new handling characteristics and the two others were used to collect data. The whole development from the mould to the flight is shown in Figure 11. The whole process has taken little over two month effective time. In the moment of writing, the maiden flight with the new wings have not been performed, but the time for this is very near. This event is dependent on weather and availability of a runway that can be used. The flight testing of the new wings will take somewhere around three to six days to perform including data compilation. Data from earlier flights with the original configuration is given in Figure 12 showing the envelope flown as a comparison to the wind tunnel tested and CFD calculated data.

Figure 11 – Flight test process.

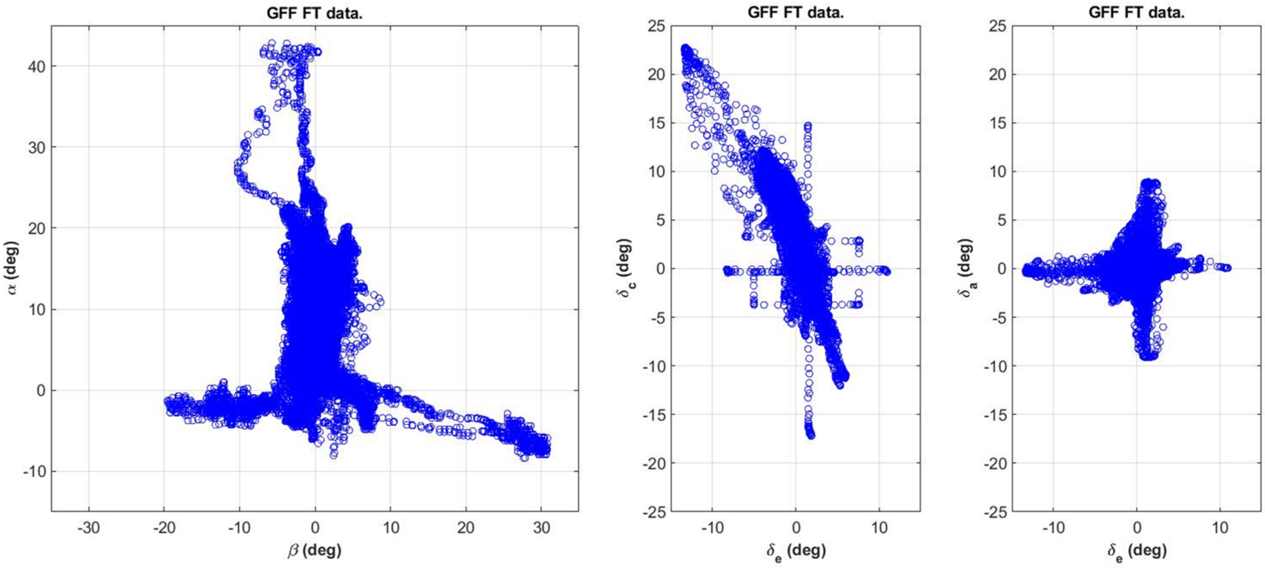


Figure 12 – Flight test envelop and configuration for the original wing configuration.

3. Results

There are several results from this project. The main one is the rapid process that can be used to demonstrate new aircraft technologies and innovative configurations as described in this paper. The current status of the project is shown in Figure 13. The flight testing part of the project is to be performed very soon and then the analysis, which has begun, will be put together and documented in order to close the project. This project was limited to making a new design for the main wing on the GFF radio-controlled aircraft. This was the scope that was possible within the budget. It is estimated that a project like this, from the point of a conceptual design to a documented result, could take somewhere around six to twelve month for a design of a whole new aircraft configuration including CFD, wind tunnel as well as flight testing. Other results from the current project are a wind tunnel model at KTH, a radio-controlled aircraft at LIU, a CFD mesh at Saab and data from the calculations and tests performed. All of this can be used in education and research to further enhance and explore the field of aeronautical engineering. Furthermore, parts of the process and way of working have already been used outside the project. For example, wind tunnel testing of a Windex 1200 glider at KTH as a student project [7], some GFF flight test data have been used for a project in a Machine Learning (ML) course and another interesting case is the use of the whole CFD and wind tunnel process for a Saab internal research project of a Future Combat Air System (FCAS) [8] as shown in Figure 14.

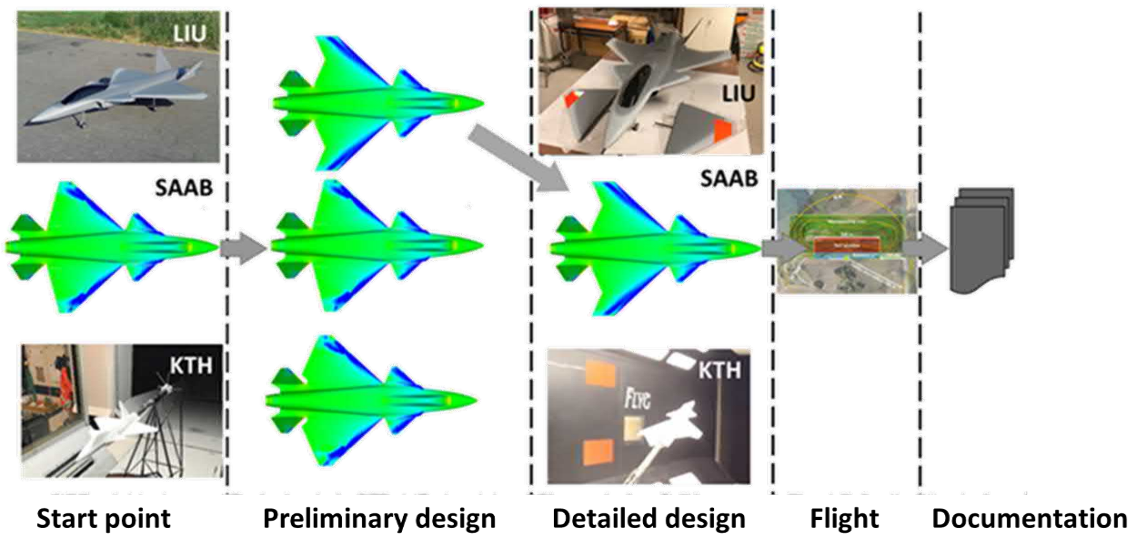


Figure 13 – Current project status.

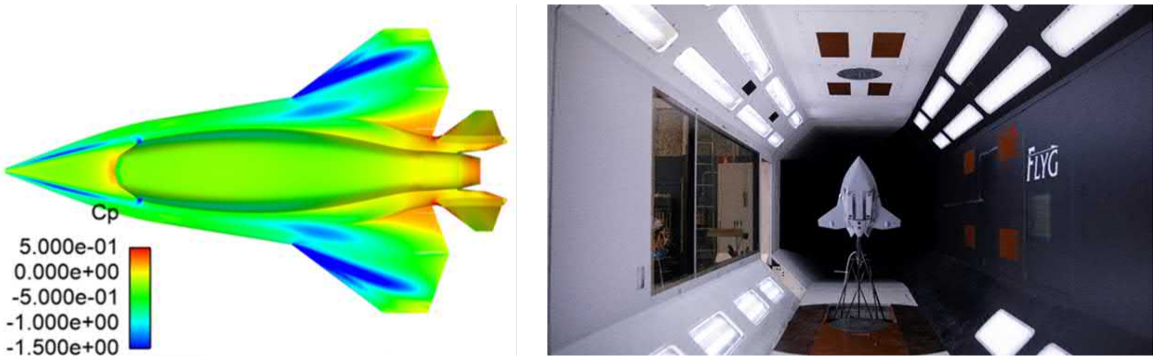


Figure 14 – Industrial research project of a future UAV.

4. Conclusion

The aim of the project described in this paper was to demonstrate the potential of using the Swedish resources in the field of aeronautical engineering in an efficient way. A new main wing to the existing flying demonstrator GFF was designed using CFD calculations and wind tunnel testing. The the radio-controlled demonstrator aircraft will be flown very soon after the writing of this paper. The project cost and man hour spent is low compared to larger test aircraft. This includes the manufacturing and testing of the GFF wind tunnel model and the new wings to the radio-controlled aircraft. This project was limited to design a new main wing for practical reasons, but using the same design and test process for a fully new sub-scale demonstrator aircraft is estimated to take about six to twelve month. The project has also produced interesting data that can be used for education an future research.

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6. Copyright Statement

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