Sensitivity analysis and optimization of a trainer aircraft configuration using open source tool SU2

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Abstract

Geometry modification of the HANSA aircraft using drag sensitivities is presented. Shape optimization of the new generation HANSA aircraft has been carried out using the open source tool SU2. Optimization studies of the wing has been performed. A drag reduction of around 56 counts per wing is obtained.

Key words:Sensitivity analysis, Shape Optimization, Drag reduction.

1 Introduction

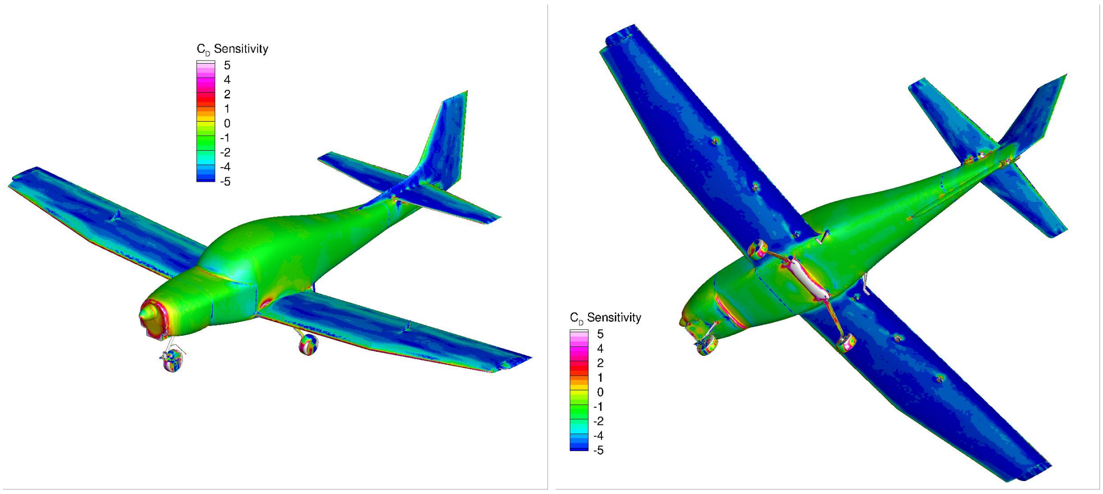
Flow sensitivities are the derivatives of the variable which we would like to minimize/maximize (lift, drag etc..) with respect to a set of parameters that describe the flow for example the shape of the body. These are interesting as they reveal the amount of change of these parameters to the flow variable. Three dimensional, compressible equations using open source SU2 has been used to derive the sensitivities and for optimization studies. Discrete and continuous adjoints are used to compute the sensitivities. The full wing shape optimization is performed using the discrete adjoints.

HANSA is a trainer aircraft being designed & developed by CSIR - National Aerospace Laboratories. A sensitivity analysis of the initial version revealed the regions where geometrical modifications are needed. One of the main objectives is to reduce the drag on the current configuration so that the aircraft becomes more efficient and also for realizing better performance. Active interaction with the CAD designers resulted in a number of geometrical changes [4]. This resulted in a drag reduction of around 72 counts over the initial version. The sensitivity study was an initial step and from a designer perspective provides a very useful information regarding the possible change in the geometry which needs to be made to obtain a reduction in drag. One would then like to have have the sensitivities embedded into an optimization cycle. As a further study a full wing body optimization was carried out resulting in a 56 counts reduction in drag on the wing alone [2, 3, 4, 5].

2 Methodology and results

A 25.5 million mesh has been used for the computation. The governing equations have been discretized using the Jameson Schmidt and Turkel (JST) scheme with Spalart Alamaras (SA) turbulence model, both for the direct as well as the adjoint solver. Implicit Euler is used for time discretization. Mach number of 0.15, Reynolds number of 4 million and an angle of attack of 5^o have been chosen in this study. A drag based cost functional has been used for the adjoint solver. The adjoint solver has been validated against standard configurations as in [1]

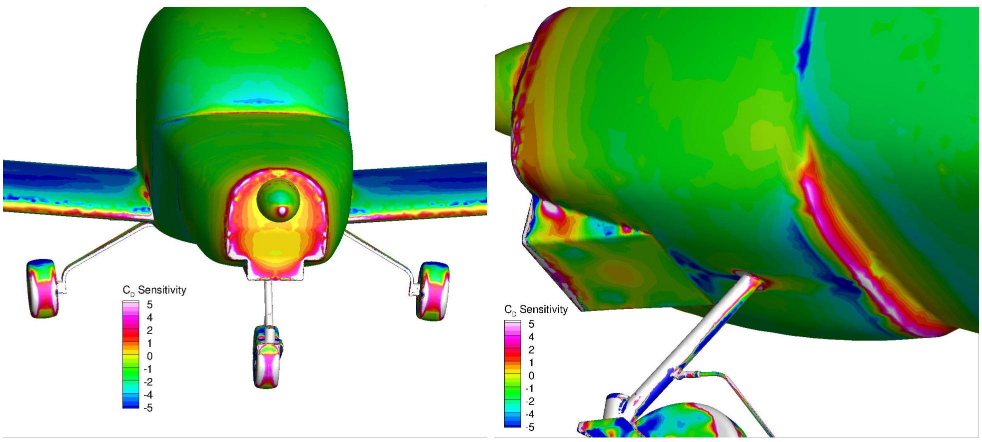
The direct solver has been validated with the experimental data. Figure 1 shows results for overall drag sensitivities of the full aircraft. As observed the major contribution of the drag is due to the wing, landing gears and cowling.



(a) Overall aircraft sensitivities:top view

(b) Overall aircraft sensitivities:bottom view

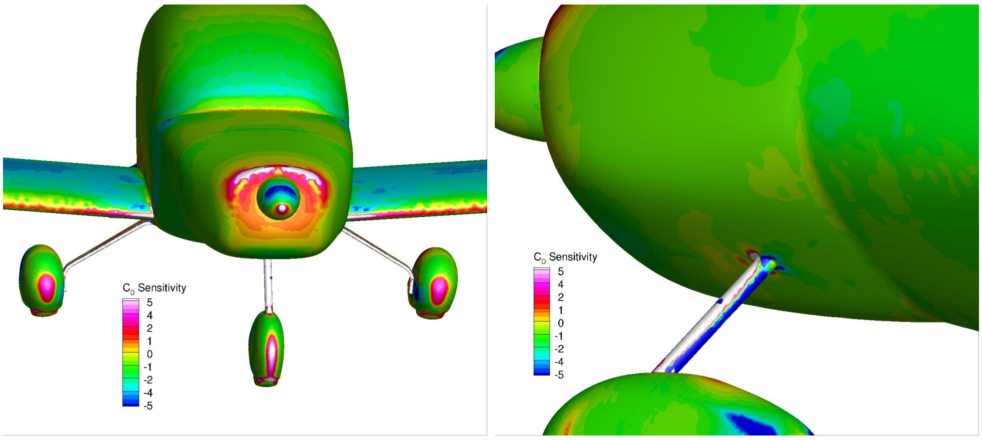
Figure 1: Overall sensitivities on the full aircraft (values scaled for confidentiality).



(a) Cowling region front view

(b) Cowling region rear view

Figure 2: Sensitivities on the cowling region (values scaled for confidentiality).



(a) Cowling region front view (b) Cowling region rear view

Figure 3: Sensitivities on the cowling region after modification (values scaled for confidentiality).

As shown in figure 2 the major the vertical step at the interface of the cowling with the fuselage shows a high value of sensitivity. Also high values of sensitivities is observed on the cowling edges and the landing gear assembly.

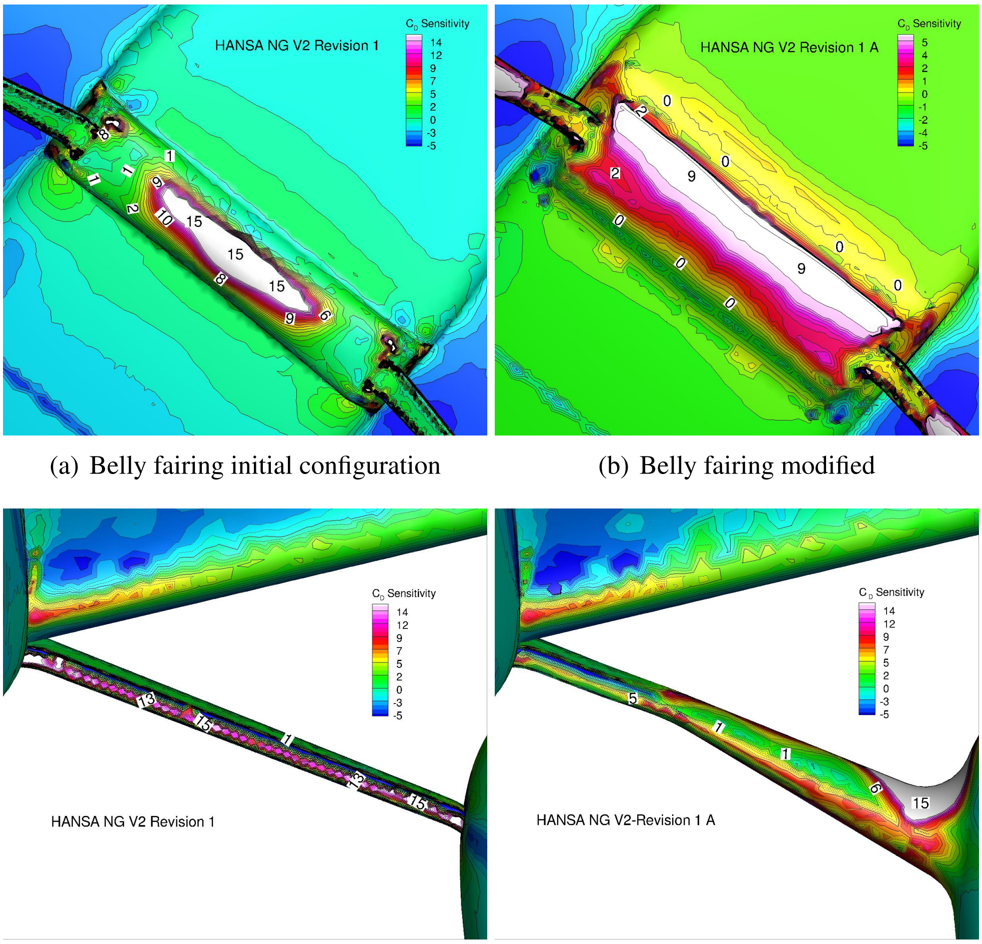
In a joint work with the CAD designers the following modifications were further proposed for further drag reduction. As a first step, the bottom vertical step at the inter-junction of the front fuselage and cowling is eliminated and the front portion is made smoother as compared to the flat vertical face of the existing cowling. The main concern was to make the cowling surface more convergent and reduce the exposed wet area for the air flow. The sensitivities after modification is shown in figure 3.

The modification helps in streamling the flow better as seen in the reduction of the values at the cowling-fuselage junction. However there is still a significant high values around the top edge of the cowling, suggesting areas where further shape modifications possible. Since it is well known that bluff bodies generate more pressure drag, we have identified the original landing gear assembly to represent the bluff body configuration. The RANS computations also clearly demonstrate this by showing a high pressure drag contribution from the landing gear assembly. Hence, we opted for wheel fairings similar to [6] which are aerodynamically shaped covers enclosing the wheel, wheel hub and the strut partially. This gives a streamlined configuration around these regions.

The belly fairing (MLG and fuselage fairing) in the initial configuration was a bluff body. To reduce the drag from this geometry, the fairing is widened and maintaining continuity with fuselage in all directions.

The sensitivities for the belly faring and MLG strut is shown in figure 4. There is a reduction in the sensitivities after modification, both on the MLG strut and the bottom faring due to the streamlining of the flow in these regions. The modified configuration resulted in a drag reduction of approximately 72 counts.

The overall optimization procedure for wing body optimization is summarized in figure 5. Every design cycle involves solving a direct solver, which solves for the flow-field forward in time. A discrete adjoint solver is used backwards in time to compute the functional gradients



(a) Belly fairing initial configuration

(b) Belly fairing modified

(c) MLG strut initial configuration

(d) MLG strut with strut socks

Figure 4: Sensitivity analysis comparison of belly fairing and MLG strut (values scaled for confidentiality).

which is then fed into a elastic solver to deform the geometry and the mesh. The process is repeated until a predefined convergence criteria on the gradient to obtain the improved shape.

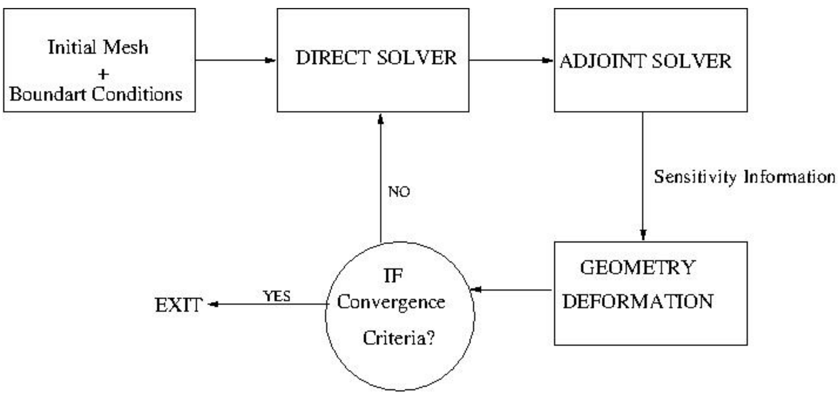


Figure 5: Overall optimization procedure.

A drag based cost functional has been used for the optimization procedure. An FFD box of size $11 \times 9 \times 2$ has been used in this study for both the configurations as shown in figure 6. Wing thickness constraint has been imposed along the root chord. The discrete adjoint solver is solved using the same discretization settings as the direct solver. The whole procedure has been run on the CSIR-4PI anantha machine on 480 processors. The overall computational time of the complete optimization process is around 7 days.

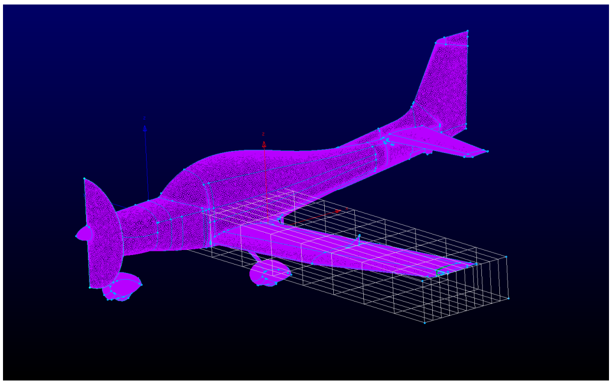


Figure 6: Mesh with FFD box.

The drag history shows a reduction of around 28 count per wing as shown in figure 7. The corresponding lift history in figure 8 shows a reduction of around 3% over the un-optimized case. However the lift vs drag history in figure 9 shows an increase from a value of 16.65 for the un-optimized case to a value of 17.35 for the optimized case. The minimum thickness changes by around 5 mm during the optimization process.

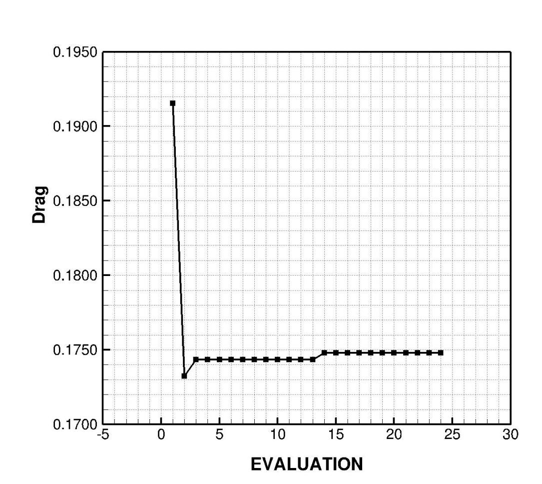


Figure 7: Optimization history for drag (values scaled for confidentiality).

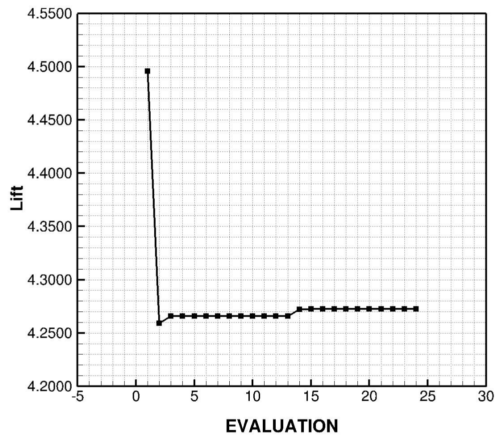


Figure 8: Optimization history for lift (values scaled for confidentiality).

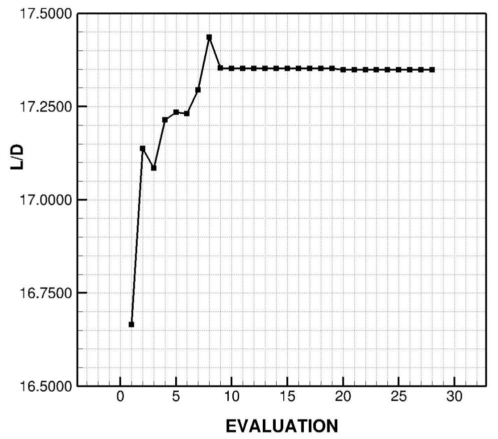


Figure 9: Optimization history for Lift/Drag.

3 Conclusions

Drag sensitivity study of the HANSA aircraft configuration has been carried out. Regions which are sensitive to geometry modifications have been identified. Modification based on the sensitivity analysis resulted in a drag reduction of 72 counts. Wing shape optimization resulted in a further reduction of 56 counts.

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