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Designing low-emission aero-engines using adjoint methods

Dheeraj Agarwal1, Ilias Vasilopoulos2, Trevor T Robinson1, Marcus Meyer2, Cecil G Armstrong1
1School of Aerospace and Mechanical Engineering, Queen’s University of Belfast, UK
2Rolls-Royce Deutschland (RRD) Eschenweg 11, Dahlewitz, Germany

E-mail: d.agarwal@qub.ac.uk

As demand for air transport increases, the need to enhance the aircraft performance and reduce emissions also increases. One route to aircraft engine performance improvement, investigated in this work, is to use the parameters defining features in the CAD model geometry (Fig. 1) as the design variables in the optimization loop. One advantage is that it eliminates the need to reconstruct the design model for the purpose of optimization, allowing a more efficient and integrated optimization process. Another advantage of using the feature based model is that the optimized model produced can be directly used for the downstream applications, including manufacturing and process planning.

Adjoint methods have been the subject of considerable research in recent years [1], and can be used to compute the gradient of a large number of design variables at minimal cost. The goal of this work is to present an efficient CAD-based adjoint process chain for calculating parametric sensitivities (derivatives of the objective function with respect to the CAD parameters) in timescales acceptable for industrial design processes. This approach differs from other methods due to the fact that it works with existing commercial CAD packages (unlike most analytical approaches) and it can cope with the changes in CAD model topology and face labeling which hamper similar approaches [2].

The approach is demonstrated on a Nozzle Guide Vane (NGV) of a high pressure turbine (HPT) provided by Rolls-Royce, which governs the engine mass flow (and by association the capacity) and defines the narrowest cross section of the turbine. Optimizing this can significantly reduce the amount of energy required to provide a certain performance.

\[ \Delta J = -\int \phi V_n dA \] (1)

A 3D parametric CAD model of a NGV was built in Siemens NX, defined using geometric parameters, as shown in Fig. 2, and capacity is considered as the objective function.

\[ (\Delta J/\Delta p) \text{ needed in a gradient-based optimization algorithm, where} \]

The change in capacity (improvement in performance) caused by each parametric perturbation is predicted by taking the inner product of the sensitivity map with the corresponding design velocity field to the parameter. The obtained derivatives are shown in Fig. 3, where they are compared with central Finite Difference values showing good correspondence.

\[ \Delta J = -\int \phi V_n dA \]

The computational cost to perform one flow analysis takes nearly one day, thus doing a finite difference study would for the NGV test case (12 design variables) would result in 3 weeks of time, whereas the proposed approach takes only two days (1 CFD + 1 adjoint). The computation of design velocities is done in parallel to the flow analysis and takes only 45 minutes.

**REFERENCES**