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AEROSPACE
ENGINEERING

Progress in Control Actuators for Dynamic Stall Alleviation

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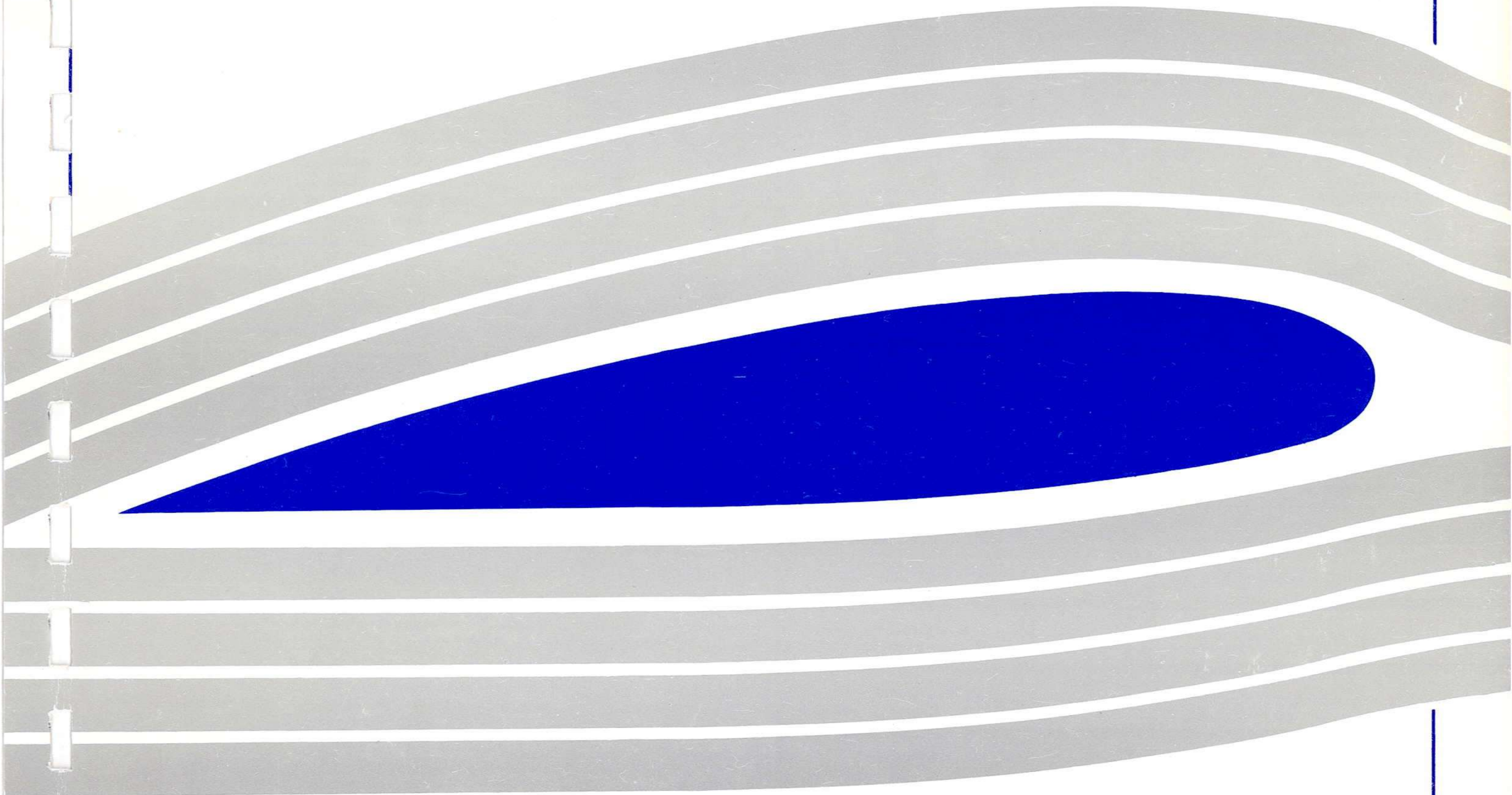
Aero. Report 9919



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1. Summary

This paper reports on a continuing investigation into trailing edge actuators for use in dynamic stall alleviation. A discrete vortex code is used to model the flow over a NACA 0015 section as it pitches from 0 to 40 degrees at pitch rates from 0.0266 to 0.0974. Various static actuators have been modelled, including a blunted trailing edge, notches of varying depths, and trailing edge flaps. These experiments show that static actuators do not have enough of an affect on the flow over the airfoil to provide an effective solution. This investigation will therefore continue by investigating the use of dynamically moving actuators.

2. Introduction

Retreating blade stall is detrimental to the performance of helicopters as it limits the flight envelope and places high vibratory loads on the blades. As the need for more manoeuvrable aircraft grows the interest in dynamic stall alleviation has increased. Dynamic stall occurs during forward flight on the rapidly pitching retreating blade. As the airfoil pitches past the static stall angle, flow reversal starts near the trailing edge. The reversed flow region expands upstream towards the leading edge growing to form a large scale vortical structure known as the Dynamic Stall Vortex. As it convects across the airfoil surface it produces increased lift until it detaches when there is a large loss of lift accompanied by a large nose down pitching moment break.

Two approaches to the problem of controlling dynamic stall could be taken. One could be to harness the increased lift generated by the dynamic stall vortex, this would involve attempting to capture the vortex on the airfoil surface. The second

approach is to prevent the formation of the Dynamic Stall Vortex altogether. A lot of research into the second approach has been done with most of it concentrating on leading edge actuators. Very positive results have been gained using actuators such as leading edge flaps[4], a rotating nose[5], dynamically deforming leading edge[6] and leading edge suction[7].

However the environment at the leading edge is hostile, erosion problems and the large loads applied here would make any complicated leading edge devices very difficult and expensive to apply to real airfoils. This study will therefore concentrate on actuators situated behind the leading edge, however it is not known whether trailing edge actuators will affect the flow enough to provide a realistic solution, this will be investigated in this report.

This study will be confined to incompressible flow and will use a two-dimensional discrete vortex modelling code of the flow over a NACA 0015 section. Dynamic Stall is particularly hard to model because the intricate vortex structure requires complicated grid generation to match the moving boundaries. This code is particularly suitable because the results produced using this code compare well to the experimental data available at Glasgow University, and it is fast, producing results in a matter of hours making it a useful engineering tool. One further advantage to this code is the animation feature which helps to analyse the effect that the actuators may have on the flow over the airfoil.

Fig 1. Example of animation

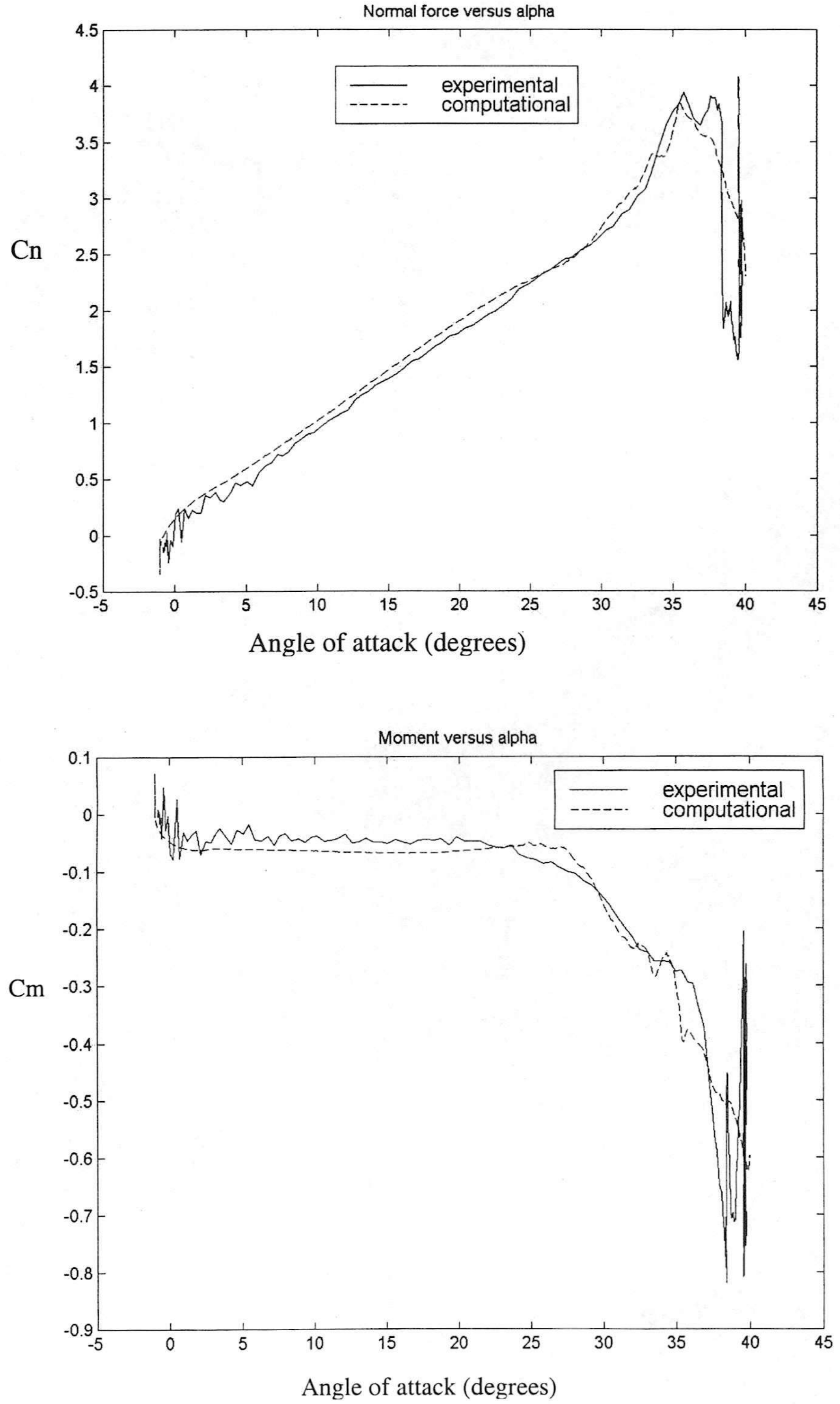
3. Project Outline

The project will take the following form:

1. Validate code by comparing results with experimental data.
2. Compare dynamic stall on clean airfoils and airfoils with static actuators (e.g. fixed flaps, notches.).
3. Compare dynamic stall on clean airfoils and airfoils with dynamic actuators (e.g. oscillating flaps, scheduled flaps.).

4. Code Validation

The first step is to validate the code by comparing the results gained using the code with experimental data available at Glasgow University. The general trend of the lift and pitching moment curves compare well, in particular the pitching moment break point is predicted accurately. The post stall behaviour does not compare as well because there is no turbulence modelling in the code and therefore the vortices do not dissipate as they should. This should not affect this study as we are mainly interested in the pre stall behaviour.



<u>Fig 2. Typical comparison between experimental and computational results</u>

(NACA 0015, k= 0.0974, Re = 1.225×10^6)

5. Static actuators

The next step is to model various static actuators to see how they affect the flow over the airfoil. Several different static actuator types have been modelled so far,

5.1 Blunt Edged Airfoils

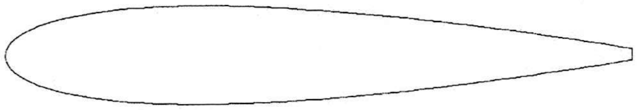
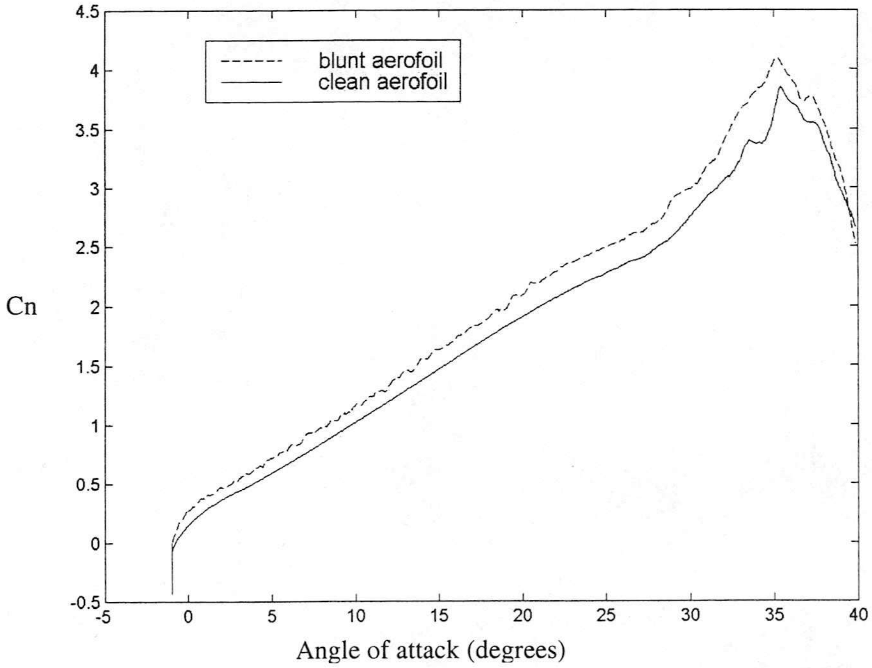


Fig 3. Blunt edged airfoil

The blunt edged airfoil does not affect the flow significantly, the lift is decreased slightly but the pitching moment break point occurs at around the same point.



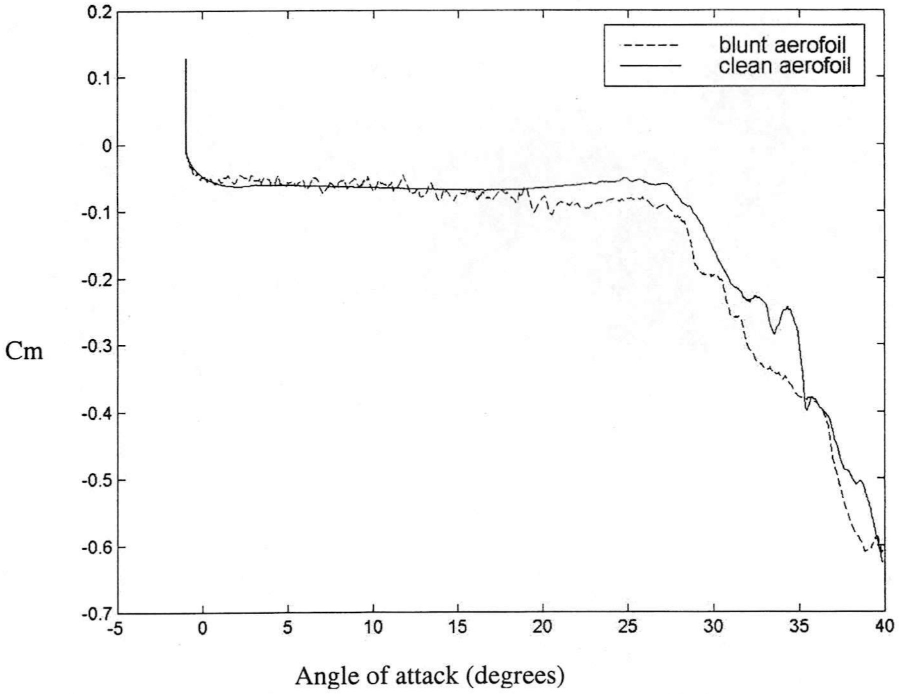


Fig 4. Comparison between clean airfoil and blunt airfoil

(NACA 0015, k= 0.0974, Re = 1.225 x 10^6)

2. Notched Airfoils

Two different types of notches have been investigated so far, a shallow notch and a deep notch.

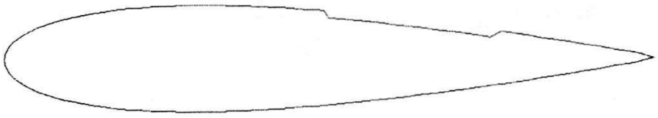


Fig 5. Airfoil with shallow notch

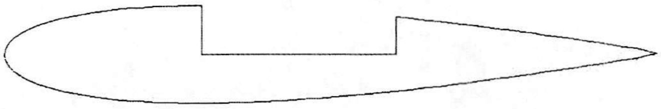
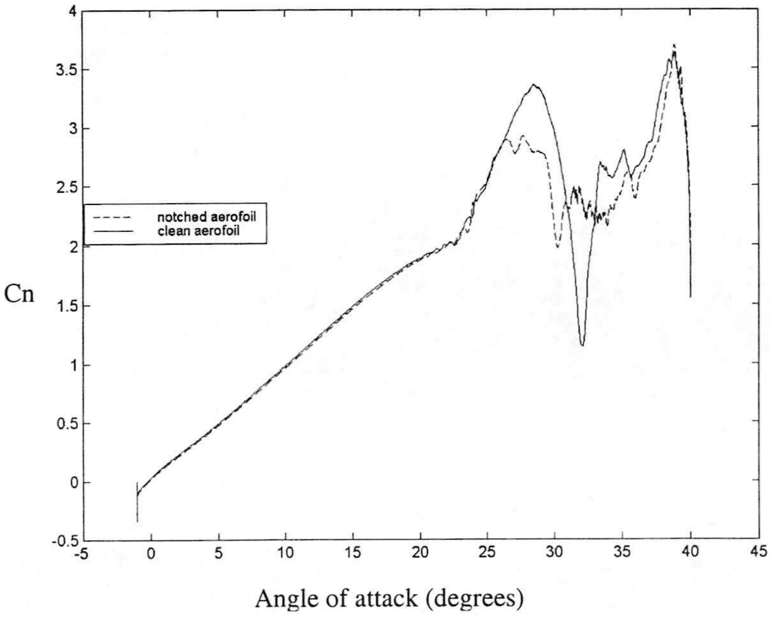


Fig 6. Airfoil with deep notch

The result for the airfoil with the shallow notch show that the lift is not affected significantly until after the pitching moment break when the peak lift produced is not as large. The animation showed that the notch inhibited the flow reversal across the airfoil with the dynamic stall vortex never reaching the leading edge of the airfoil and detaching from around the notch area. The pitching moment break is much larger as the vortex is kept closer to the airfoil as it detaches.



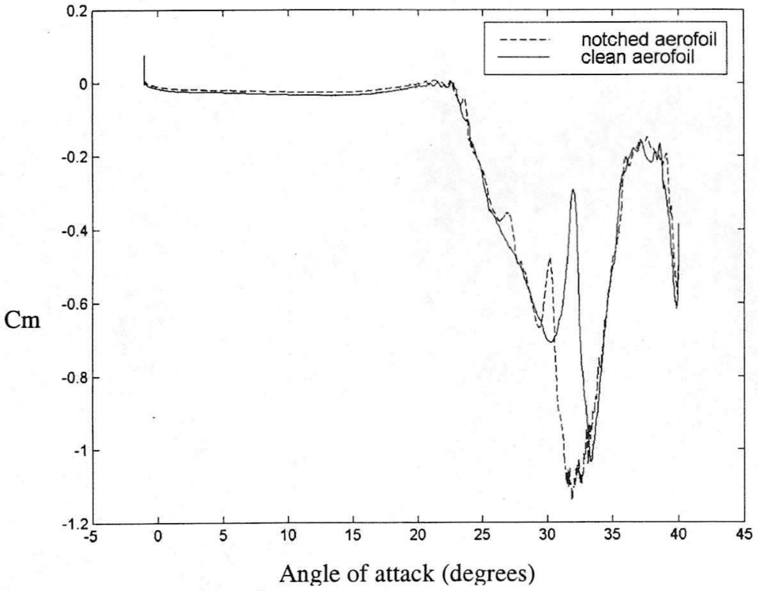
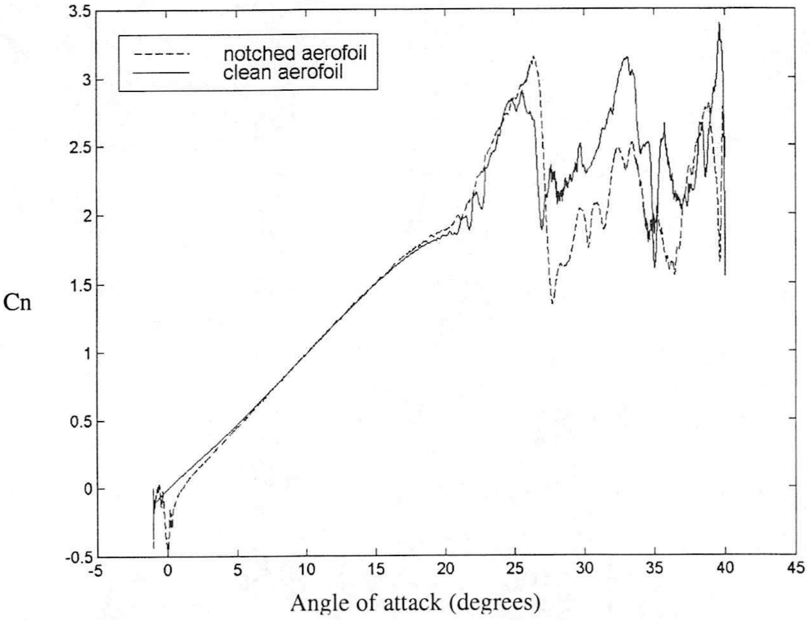


Fig 7. Comparison between clean airfoil and airfoil with shallow notch

(NACA 0015, k= 0.0974, Re = 1.225 x 10^6)

The results for the airfoil with the deep notch show a change in pitching moment near the beginning of the pitching motion. The animation showed a large vortex rolling out of the notch.



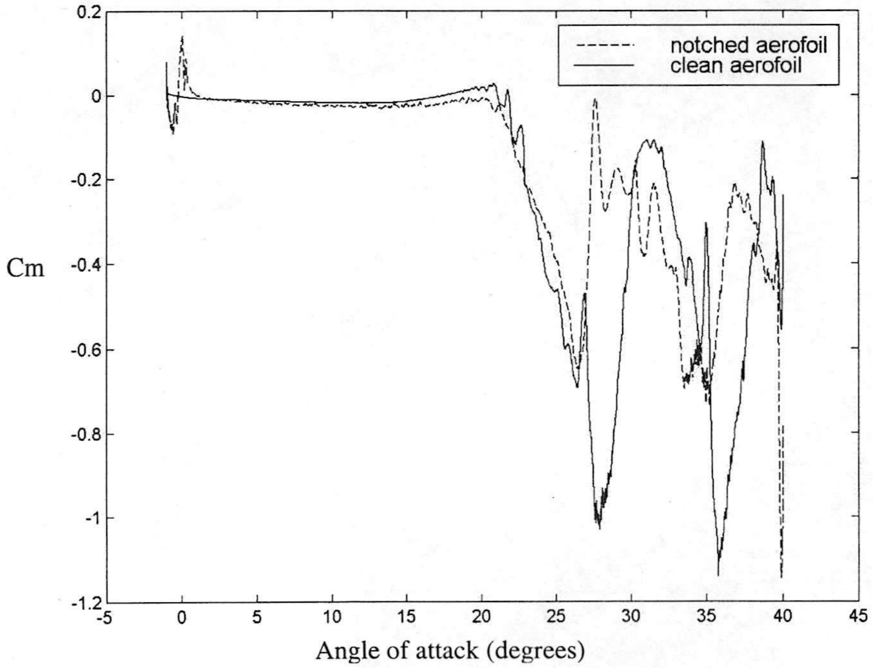


Fig 8. Comparison between clean airfoil and airfoil with deep notch

(NACA 0015, k= 0.0974, Re = 1.225×10^6)

5.3 Airfoils with static flaps

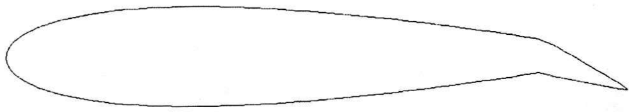
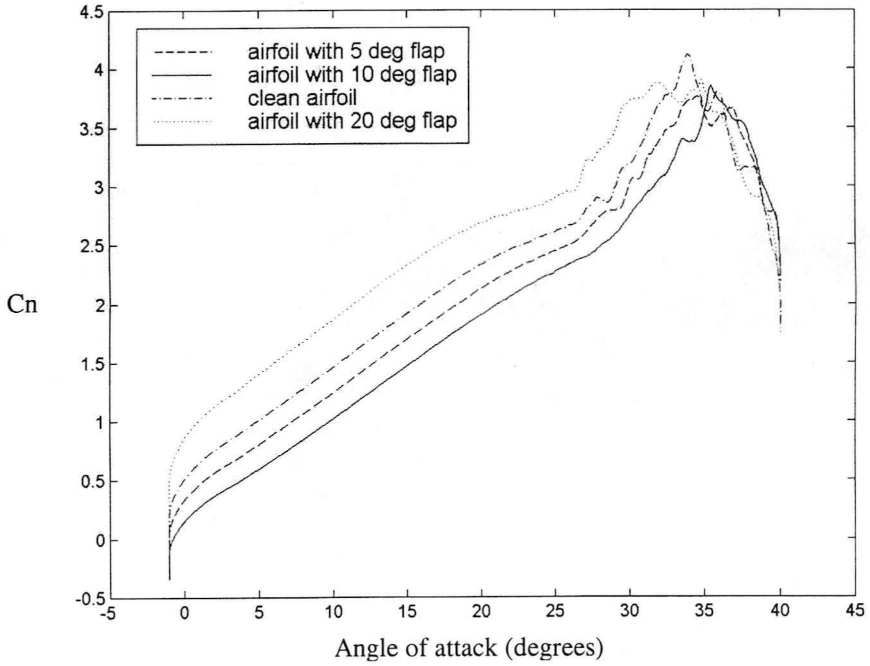


Fig 9. Airfoil with flap

The airfoil was modelled with a 15% chord flap at flap angles from -20 ° to +20°. The flap is just a simple attached flap. The results for the airfoils with positive flap show that the lift is increased with the pitching moment break occurring sooner, and as can be expected the airfoils with negative flap do the opposite, decreasing lift and delaying the pitching moment break.



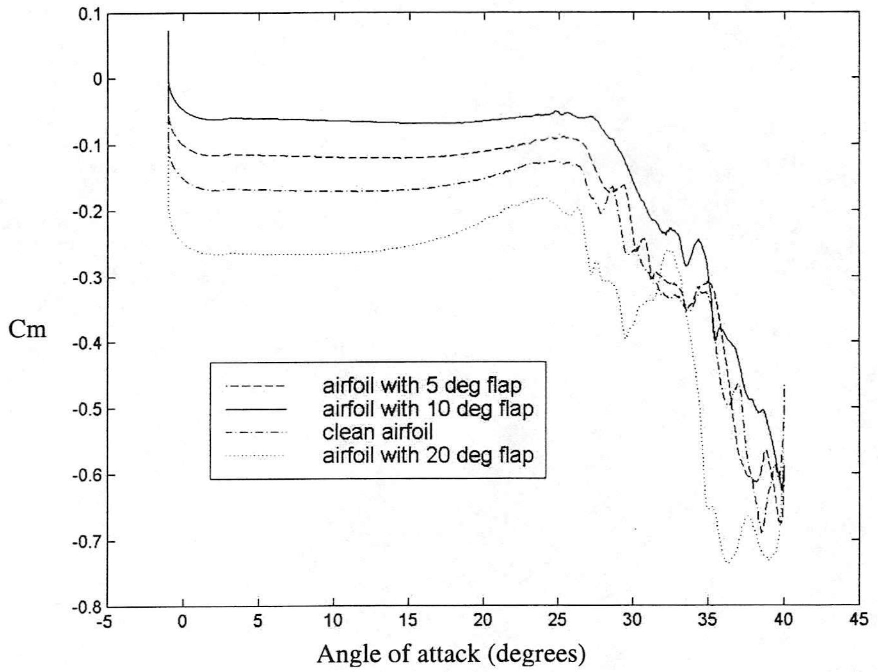


Fig 10. Comparison between clean airfoil and airfoil with positive flap

(NACA 0015, k= 0.0974, Re = 1.225×10^6)

Dynamic Actuators

As the code is incompressible the main problem with modelling dynamic actuators is that the volume within the body must remain constant. We started with the simplest actuator to model which is the flap. The flap was modelled statically as a simple wedge shape, but the volume inside the wedge is different for each flap angle so another way of modelling the flap had to be found. We then investigated modelling the flap as a separate airfoil free to rotate inside the main airfoil, however as the flap rotated the volume changed inside the main airfoil. One solution is to have slight notches where the main airfoil meets the flap so that only the circular leading edge is able to rotate inside the main airfoil with the volume remaining constant.

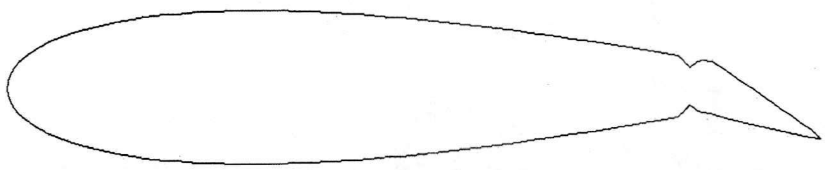
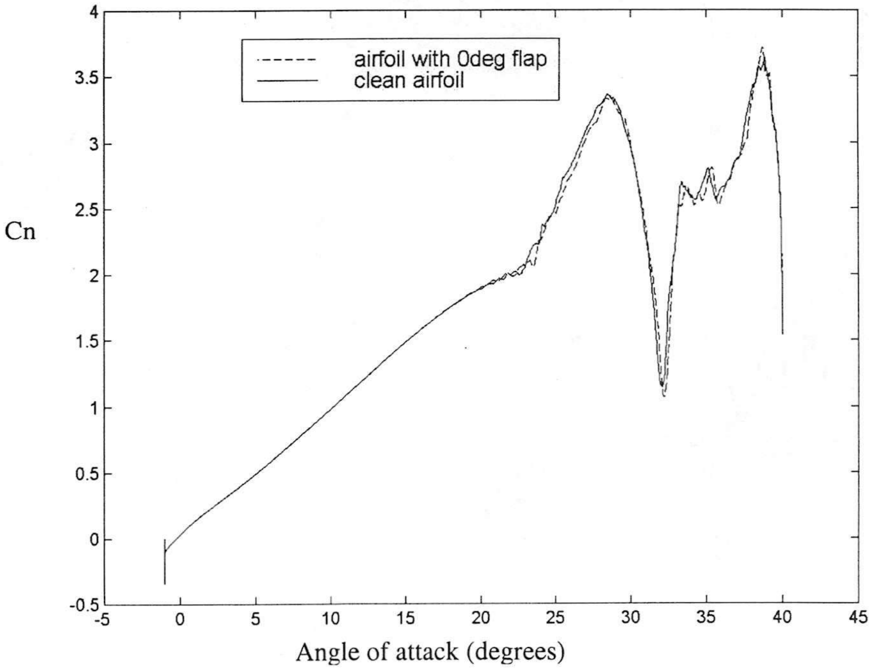


Fig 11. Airfoil with flap

The notches may however affect the flow giving false results so we compared the results from the clean airfoil case with the airfoil with the flap at 0°. The notches on the airfoil do not affect the flow significantly.



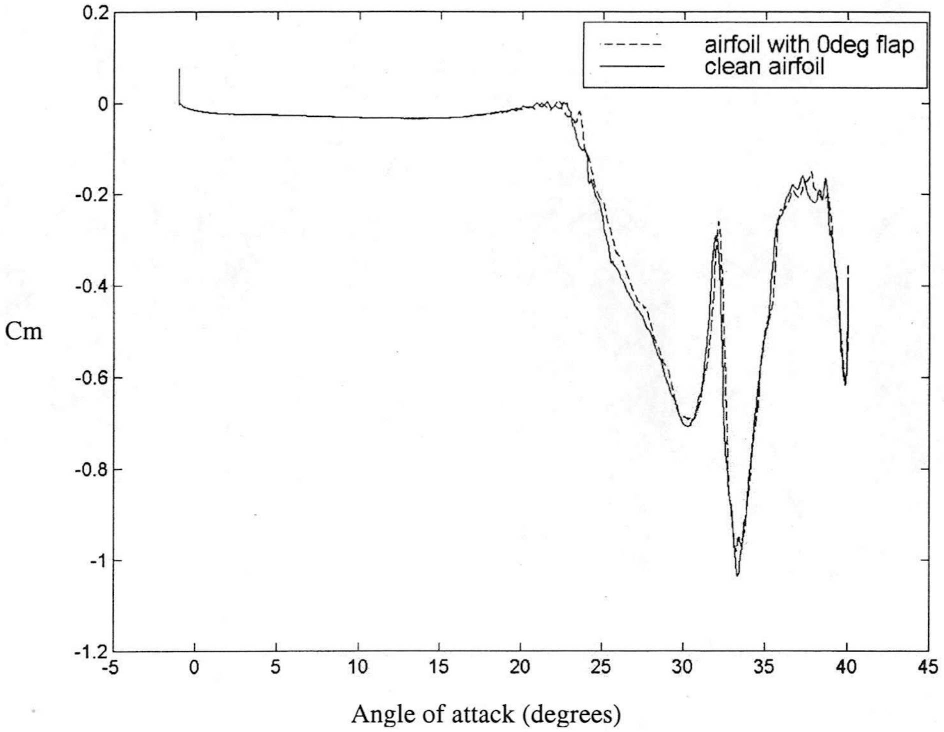


Fig 12. Comparison between clean airfoil and airfoil with flap at 0°

(NACA0015, k = 0.0974, Re = o.1225 x 10^6)

7. Conclusions

All of the static actuators investigated in this report so far have affected the flow over the airfoil to some extent. None of them however provided a solution to the problem of dynamic stall. Further investigation into the use of dynamic actuators may provide more useful results.

8. Future Work

Future work on this project will include continued investigation into different static actuators. This would include different sizes and types of flaps, possibly including gurney flaps and

slotted flaps. Further investigation will also be carried out into different depths, lengths and types of notches, for example, a notch where the back wall blends into the airfoil trailing edge. The addition of dynamically moving actuators to the code will also be carried out, for example, oscillating and scheduled flaps. There will also be investigation into other possible solutions. A wind tunnel test will be designed and ultimately a model will be built and tested in the wind tunnel.

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