COMMENTS ON THE DEVELOPMENT OF AIRFOILS RELATED TO STANDARD CLASS GLIDER PERFORMANCE

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1. Introduction

The performance of a glider depends essentially on the aerodynamic properties of the wing section. This is studied e.g. in References 1-4. The effect of the drag polar shape of the wing section on the optimum wing area and attainable cross country speed is studied in ref. 5. In the study of Ref. 5 the significant parameters of the drag polars considered are the minimum drag coefficient and the width and shape of the low drag bucket. The results revealed that the selected wing section has a significant effect on the optimum wing area (or the aspect ratio as the paper dealt with Standard Class gliders only) and that the optimal wing section characteristics depend significantly on the day's weather.

The intention of this study was not to deal with aerodynamic optimization but to find out how the airfoil drag polars have evolved during the last 15 years in some particular gliders. The design of the wing section and testing of some of the high-performance gliders have been well documented (e.g. Ref. 6). However, for some glider types the thickness ratio is the only hard fact that is attainable. For some reason particularly the gliders that seem to have a dominant role in World and European Championships are the least known in the aerodynamic sense. There is practically no data published on the aerodynamic properties or even on the geometry of the wing sections of these gliders. The absence of this geometrical data has so far efficiently prevented any efforts to conduct a more detailed study. To determine the coordinates of a wing section by measurements has been too troublesome a process to allow for further study.

The present study was encouraged mainly by two reasons: the possibility to utilize a relatively easy method to measure the airfoil coordinates directly out of a full scale glider and the promising development of computational methods to calculate the aerodynamic properties of airfoils (Ref. 7, 8, 9). With access to these two methods the authors decided to study the aerodynamic properties of some interesting airfoils.

Selecting the glider types to be considered was limited by the availability of different glider specimen. We chose three aircraft and denote them here as X-1, X-2 and X-3. They represent the evolution of single seat gliders by one specific manufacturer within the last 15 years. Our aim was to find out how the wing section drag polar has evolved from one type to another.

Gliders X-1 and X-2 are Standard Class gliders but X-3 is a 15 m Class Glider. However, the authors decided

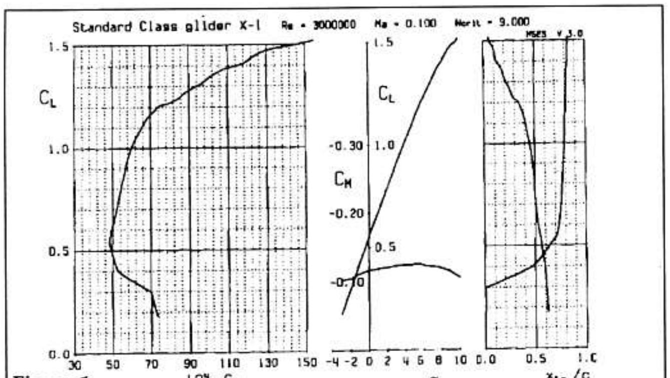

Figure 1.

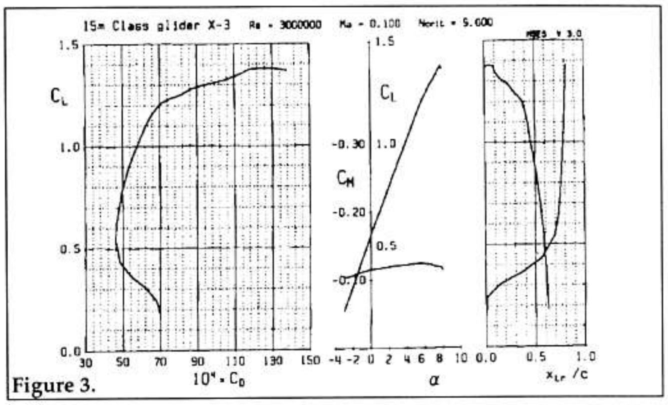

Figure 3.

to study also the airfoil of X-3 with flaps set to 0 degrees. X-3 was chosen because there seemed to be a significant geometrical resemblance between the airfoils of X-l and X-3 and we wanted to find out what had been achieved with the minor changes.

2. The measuring of the airfoil geometry's

An interesting part of this project was to utilize a new method for measuring the shape of an airfoil. The following is a brief description of the measurements.

2.1 The measuring method and equipment

The airfoils were measured right out of a full scale glider by illuminating the profile with a sector of laser light. A picture of the red line drawn on the wing by the laser beam was then recorded on a video tape later to be analyzed by a computer program.

The laser beam was spread into a sector of a plane with a lens that is actually a small cylinder of transparent plastic. First the positions of the light source and the camera were fixed. Then a calibration object was put in the field-of-sight of the camera, which was a plate that had needles stuck in precise rectangular positions on it. The needles were illuminated by the laser light. Now that we had a picture of these needles from a fixed angle and knew their actual positions we could use the computer to find out the transformation of the coordinate system. Next the fixed system of the light source and the camera was moved to illuminate the wing at another desired location.

The measurement of each section was made in four parts: the upper and lower surfaces with the trailing edge in the picture and then the leading edge seen from the front from both slightly above and below. At the junction points there were two adjustment marks attached to the surface of the wing within a short distance from each other. This enabled connecting the measured pieces of the airfoil together.

Finally a polynomial fit to both surfaces was made to smoothen out possible errors.

2.2 The spanwise location of the measurements

In order to analyze the profile drag of the whole wing, the spanwise variation of the airfoil geometry should be considered. The airfoils were measured at several spanwise locations but because we wanted to keep this study brief, the decision was made to concentrate on only one wing section of similar location for each glider. In order to get the most representative samples, the airfoils used for comparison were measured near the wing root, however clearly out of the fairing region.

3. The determination of the aerodynamic properties of the airfoils

The aerodynamic properties of the measured airfoils were calculated with MSES software designed by Mr. Mark Drela, the Associate Professor of Aeronautics and Astronautics at MIT. This program is an Euler solver and is described in detail in Refs. 7, 8 and 9. The software should work very well even with flow cases at a low Reynolds number. There is a slight underestimation in drag coefficient values compared to measured values but the shape of the drag polar is predict-

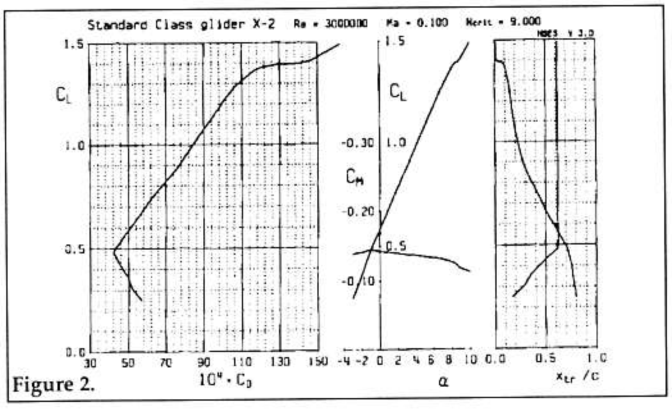

Figure 2.

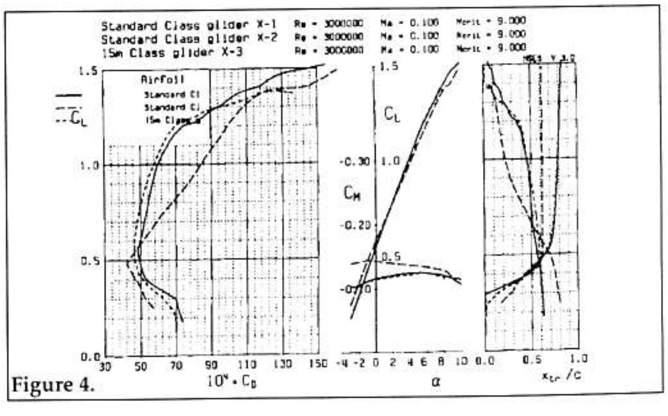

Figure 4.

ed very well.

The MSES software incorporates a possibility to predetermine the boundary layer transition location and in case of a free transition there is a laminar separation bubble model built in. These features enable the calculation of airfoils with or without a transition device.

This software was very suitable for our purpose since the accuracy in predicting the relative differences in drag coefficients and the correct shapes of the drag polars were essential in this comparison.

4. The results

The results of the aerodynamic calculations of each airfoil are presented in Figures 1 through 3 and they are all plotted on Figure 4. All calculations were carried out using a Reynolds number of $3 \cdot 10^6$. In addition to the aerodynamic coefficients (lift, drag and pitching moment) the location of transition is presented. The zig-zag tape on the lower side of the airfoil of glider X-2 was modeled by fixing the transition location as seen in Figure 3.

Comparing the drag polars of airfoils X-l and X-3 reveals a strong resemblance in the shape of the polars. This is not surprising because of the similarity of the geometry's of these two airfoils. The drag coefficient values of the airfoil of X-3 are predicted to be lower than those of the airfoil of X-l almost throughout the whole lift coefficient range. This seems to be a reasonable result because the section of X-3 is somewhat thinner than that of X- I .

Even though MSES is capable of calculating the drag polar all the way to the stall, the parts of the drag polars that exceed $C_L = 1.0$ are neglected. This is due to the Reynolds number of $3 \cdot 10^6$ which is too high for the thermaling conditions.

The minimum drag coefficient value is achieved at approximately the same amount of lift in the cases of X-l and X-3. There are practically no differences in the lift or moment coefficients of these two airfoils.

The drag polar of the airfoil of glider X-2 differs significantly from the other two, both in absolute minimum values and the shape of the polar. The minimum drag coefficient is as low as 0.0042 with a Reynolds number of $3 \cdot 10^6$. However, with increasing lift coefficients the drag values show a steep increase. Another penalty for the case of X-2 comes out of the moment coefficients: The airfoil of X-2 has higher nose down moment values throughout the angle of attack range than the other two.

Referring to the study of Ref. 5 the glider X-2 could be characterized as a better performer than the other standard class glider X-l only in atmospheric conditions where strong thermals are prevailing. This, as a matter of fact, is in accordance with practical experience of many pilots. By comparing only the root wing sections of these gliders we can't actually evaluate the aircraft against each other, but we can get an idea of the significance of the shape and size of the low drag bucket in the polars of the respective airfoils. It seems obvious that the airfoil of X-2 has been designed for best performance in very good soaring weather, whereas the airfoils of X-l and X-3 have been optimized in a more conventional sense to achieve a wide low drag bucket.

5. Acknowledgments

This study was realized only due to the possibility to utilize the extensive airfoil calculation software MSES. So we would like to thank Mr. Mark Drela, the Associate Professor of Aeronautics and Astronautics at MIT, for kindly granting us permission to use his software for this purpose.

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