APPLICATION OF MICROCOMPUTER SOFTWARE TO THE AERODYNAMIC DESIGN OF A MOTOR GLIDER

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Abstract

This paper presents a general overview of typical aerodynamic design project work in the Department of Aerospace Engineering, University of Glasgow. Microcomputer software for computer-aided preliminary aerodynamic design of finite wing developed and used at the Department, is introduced.

1. Introduction

The final year project work follows chronologically a course in aeronautical engineering. Honors students are expected to spend between 200 and 300 hrs. on the projects. In the case of aerodynamic design project, in 1987 it was decided to present the students with a technical specification asking them to design an aircraft capable of realizing the mission instead of being pedantically taught how to design one.

A motor glider is perhaps better described as a self launching sailplane. It has, despite the availability of engine power, sufficiently high lift to drag ratio to enable it to sustain flight within moderate currents of rising air.

As materials and engine technology have advanced in recent years, however, the characteristic mentioned above has become almost the only feature of performance distinguishing a motor glider from light aircraft in general. This has meant that the powered flight performance of most of today's motor gliders has become as important as the power-off characteristics as they are sold largely as alternatives to continuously powered light aircraft.

With this in mind, the project described in this paper has concentrated on obtaining satisfactory characteristics for all phases of flight.

In the time allowed for the project, only some aspects of the design process were covered. It was decided that the most economical approach would be to spend a minimal proportion of the time deciding on a basic design layout and then proceed to perform an aerodynamic analysis which would provide sufficient data for fundamental performance parameters to be determined. References 1-10 were recommended for the project. The typical time history diagram for the chosen project is shown in Figure 1.

2. Specification

After a short survey of the performance parameters of currently produced motor gliders a set of specifications were established. These were as follows: Vs (clean) = 18 - 20 m/s, V (cruise) = 45m/s, L/D max = 25 - 30. It was decided that the fuselage design should accommodate two occupants seated side-by-side and provision for a small amount of baggage made.

3. Initial Design

Approximate methods given in Reference 3 were used for obtaining first estimates of gross weight, wing area, drag and rated power. The results are shown in Figures 5, 6, 7, 8, 9 and 10.

Since the detailed design of fuselage structure, internal layout, control and fuel systems was not being carried out in the project, an accurate estimate of the weight and center of mass could not be obtained. It was desirable, however, to have at least an approximate estimate of the center of mass position for the purpose of locating the wing on the fuselage and for assessing static stability. To this end, data governing the proportion of gross weight corresponding to individual aircraft components and systems was obtained for gliders in general from Reference 3. This was

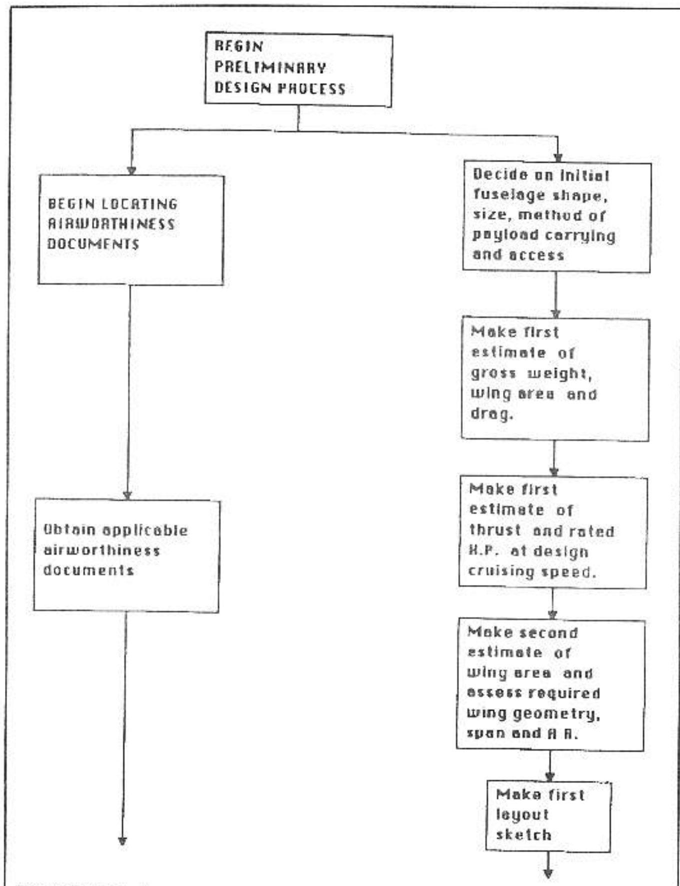

FIGURE 1-A

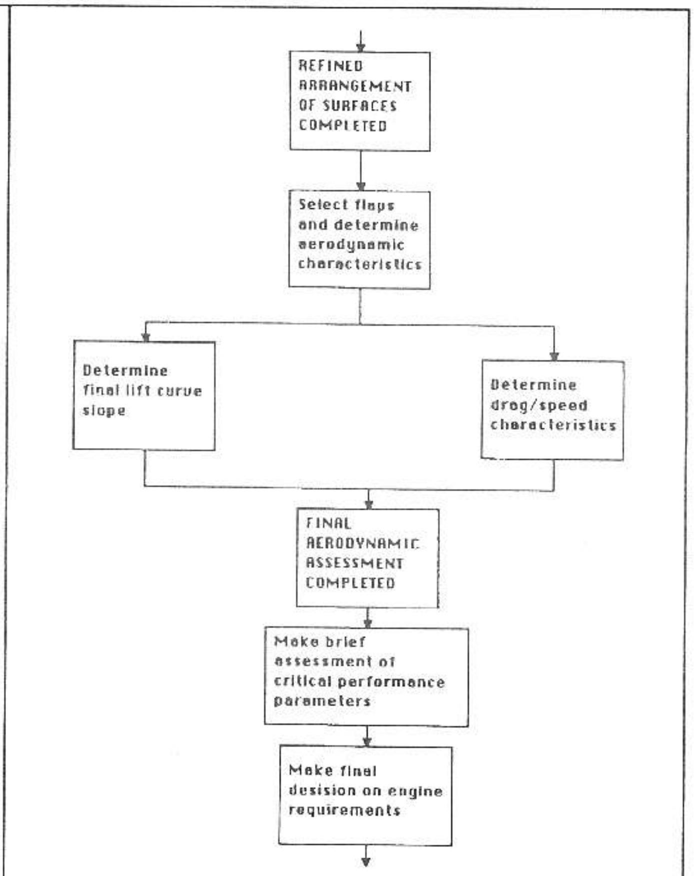

FIGURE 1-C

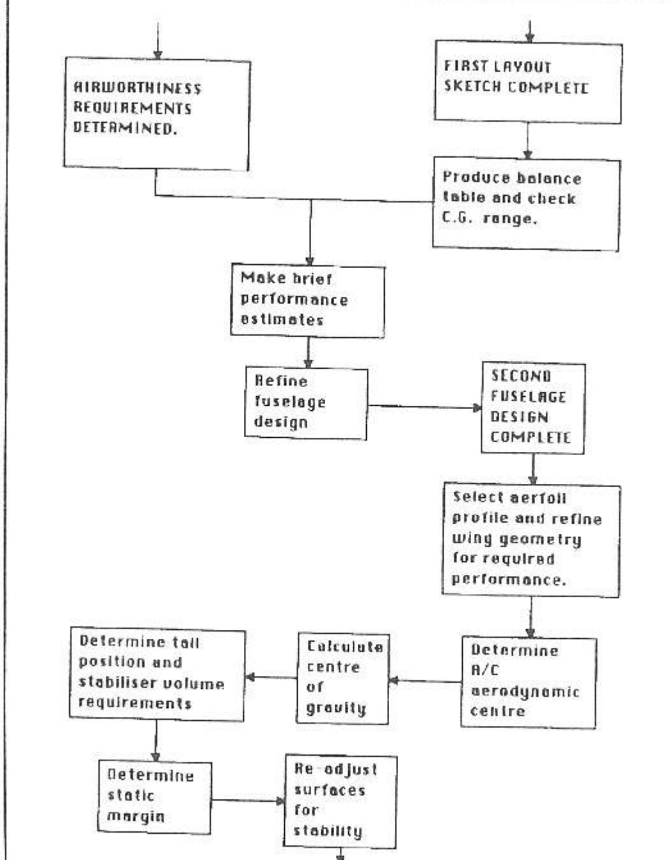

FIGURE 1-B

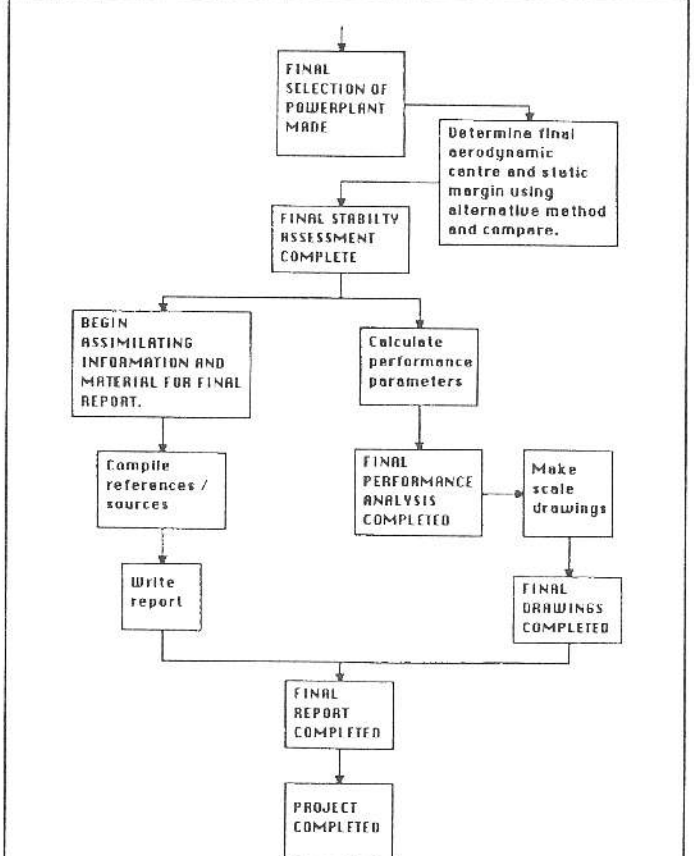

FIGURE 1-D

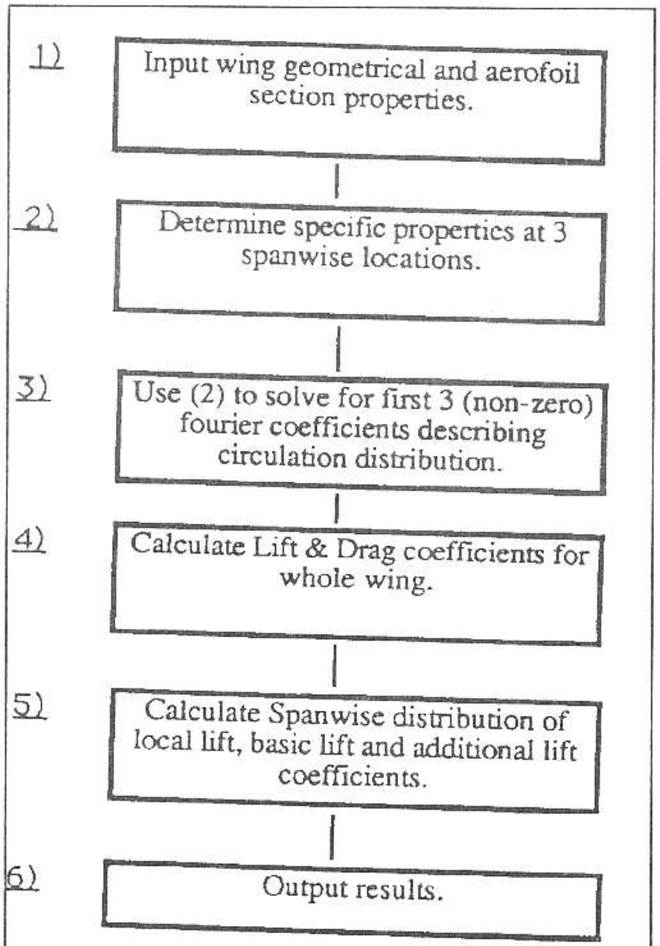

FIGURE 2. Block diagram of FWING Program.

used to construct the balance table of Figure 10.

4. Finite Wing Aerodynamics

In order to assess the suitability of wing designs for the aircraft, a method was required for predicting the relevant aerodynamic properties of a given three-dimensional wing geometry. In particular, the variation of lift and vortex drag with angle of attack had to be determined. A short period of time during the design project was spent investigating several approximations which exist for this purpose. The methods discovered were generally in the form of either a stand-alone equation giving lift coefficients as a function of aspect ratio, or used graphical parameters, variously derived from Prandtl's lifting line theory or empirically. Four examples are cited here as being typical of the methods currently available for preliminary design calculation.

Lowry and Polhams method gives the wing lift curve slope.

Roskam provides a source of semi-empirical expressions supplemented with graphical relations for calculation of a range of aerodynamic derivatives, including lift curve slope and variation of drag coefficient with angle of attack.

Schrenk's approximation gives the distribution of additional lift coefficient over the semi-span.

Prandtl's Classical Lifting Line Theory develops lift and drag characteristics from a purely theoretical fluid-dynamic model of the finite wing.

It was decided to assess the wing characteristics from first principles using Prandtl"s lifting line model for the following reasons: 1) The theory provides a comprehensive source of wing aerodynamic data pertinent to the aircraft design process with comparable accuracy to most semi-empirical methods available. 2) this method would provide the author with a more detailed introduction to the study of wing aerodynamics than had previously been encountered. Also, it would serve as a theoretical background to the origin of many of the approximate methods currently in use.

Implementation

A major disadvantage of using lifting line method is the large amount of numerical computation involved in arriv-

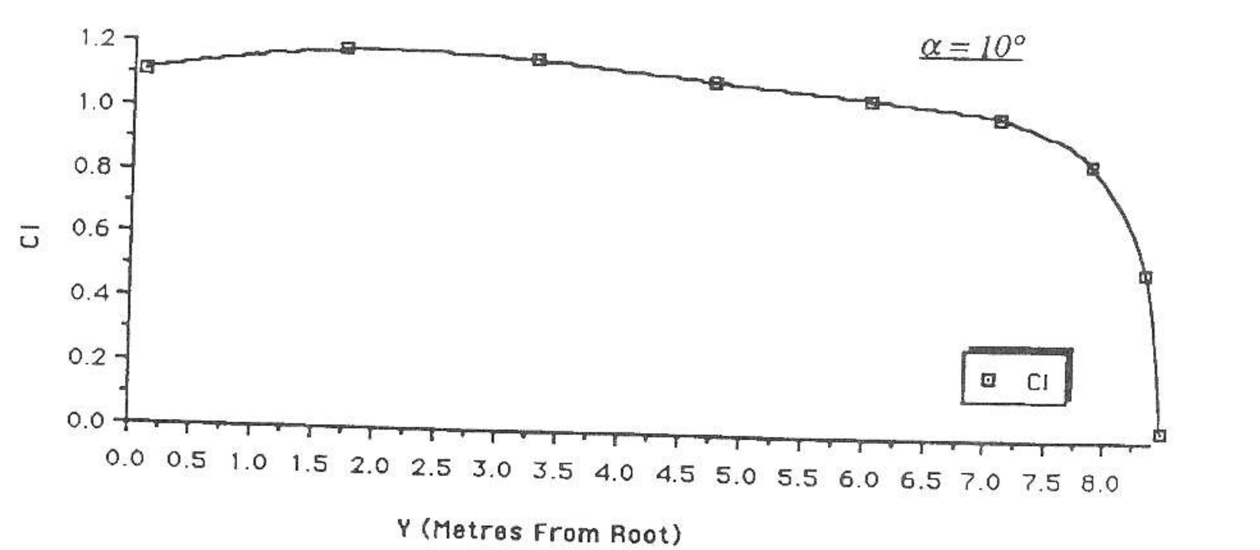

FIGURE 3. Spanwise distribution of local lift coefficient.

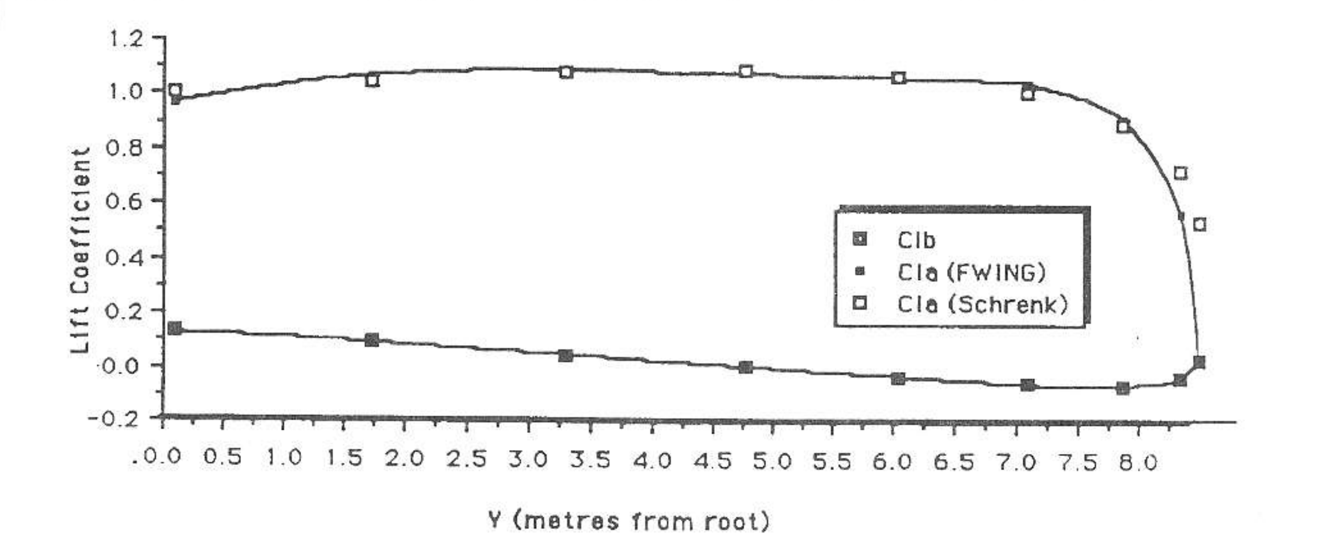

FIGURE 4. Semi-spanwise distribution of basic and additional lift coefficient.

ing at results for a single wing planform geometry. Furthermore, several configurations would have to be analyzed before an appropriate design was found. It was, therefore, decided that the time spent performing the calculation by hand justified the development of a computer implementation of the theory. Although, initially this would involve a substantial amount of time, on completion it was possible to make rapid, detailed assessments of various proposed designs. The lifting line method was implemented in a FORTRAN 77 program, "FWING", from the theory as presented in Reference 8.

Program Evaluation

Relevant aerodynamic parameters were calculated using the following methods, and compared with the output from FWING: 1) Method of Lowry and Polhams for C_{la}. 2) Schrenk's approximation - for spanwise distribution of C_{la} (additional lift coefficient).

The results section and Figure 4 respectively show the comparisons.

Computational Implementation of Lifting Line Theory

The lifting line theory was implemented in FORTRAN and a Schematic diagram of its operation is given in Figure 2. Most input prompts are self explanatory, however, some brief notes on selected items follow.

1) Wing angle of attack is assumed to be the (absolute) angle of attack of the wing root chord line. Two values are required for the calculation of additional lift coefficient C_{la} and basic lift coefficient C_{lb}. 2) Section zero - lift a and

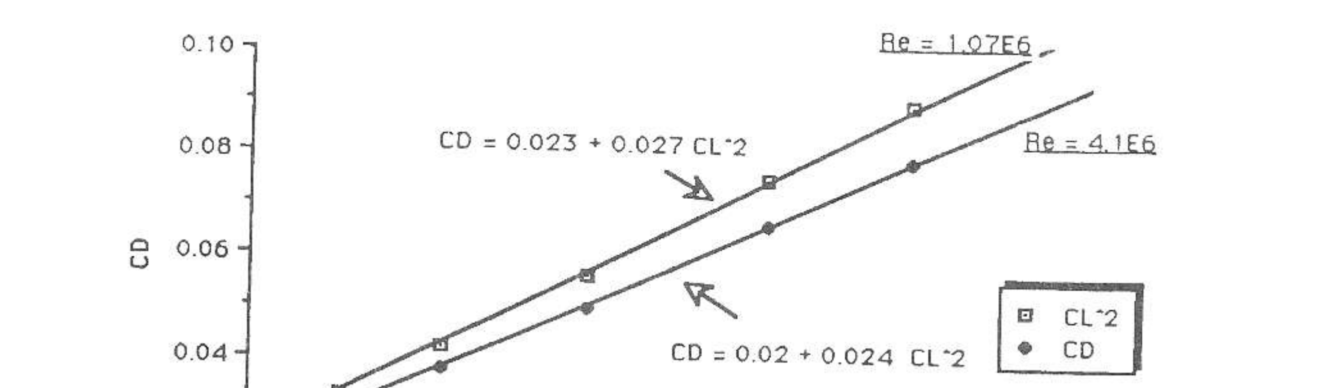

FIGURE 5. Determination of parabolic drag polar.

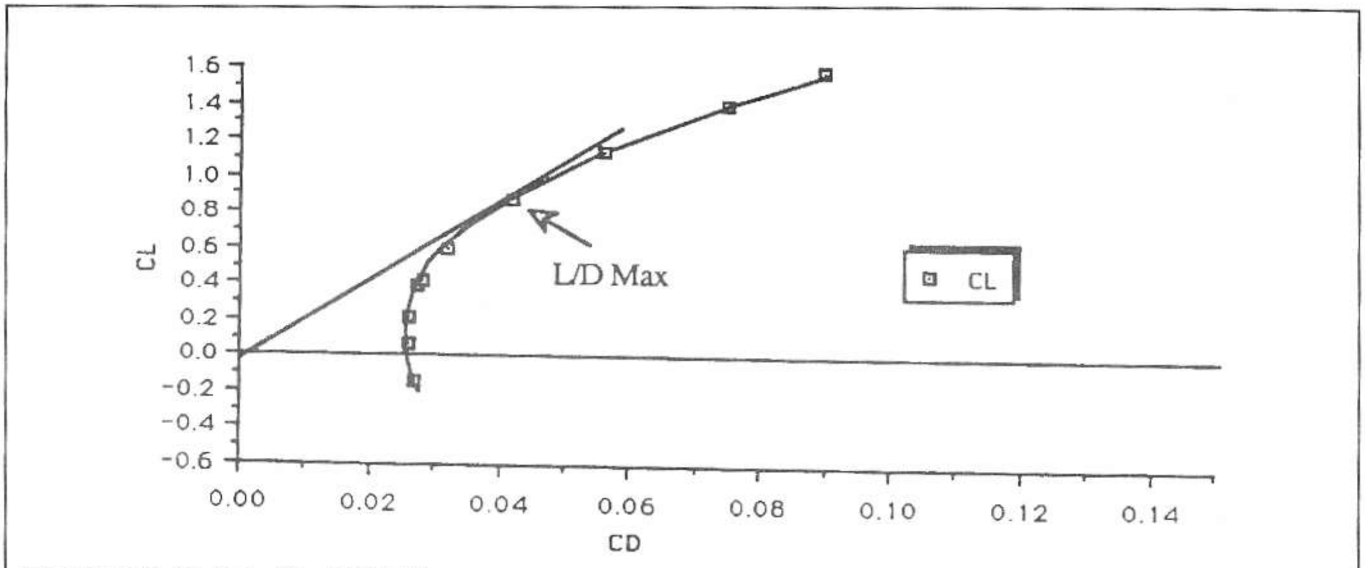

FIGURE 6. C_L/C_D Polar (R_e = 1.7 E6/L)

Section Lift Curve slope - only one value is required since the program does not cater for aerodynamic twist. 3) Geometric Twist is assumed positive for increasing a in the direction of root to tip.

Hardware

An Apple Macintosh Plus was used with the Microsoft FORTRAN compiler.

5. Results and Discussion

The values for the lift curve slope, obtained using FWING and the method of Lowry and Polhams, were found to be within 1% of each other. This implied that the values for lift coefficient and induced drag factors obtained from FWING were also acceptable. Comparison of the output from FWING for lift distribution showed general agreement with Schrent's method at all points along the semi-span (Figure 4). The values for additional lift coefficient C_{la} were generally within 2% and nowhere more than 4% of each other. Since the local lift coefficient C_l, basic lift coefficient C_{lb} and lift coefficient C_L all represented prerequisite data for the calculation of the C_{la} distribution, the former results were assumed to be equally valid.

With regard to the number of spanwise points for which output data is presented, it may be proposed that these should be limited to 3 since only 3 points had been used to determine the circulation distribution. It was, however, decided to allow for any specified number for the following reason. The theory arrives at estimates for lift coefficient C_L and induced drag coefficient C_{Di} based on the

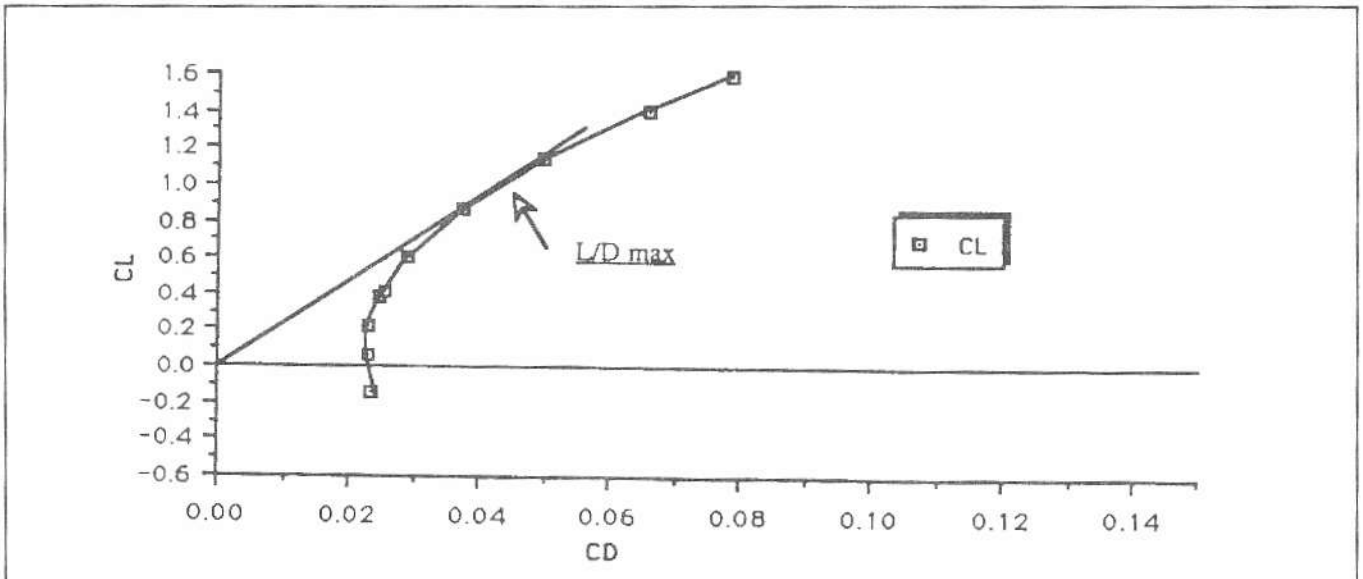

FIGURE 7. C_L/C_D Polar (R_e = 4.1E6/L)

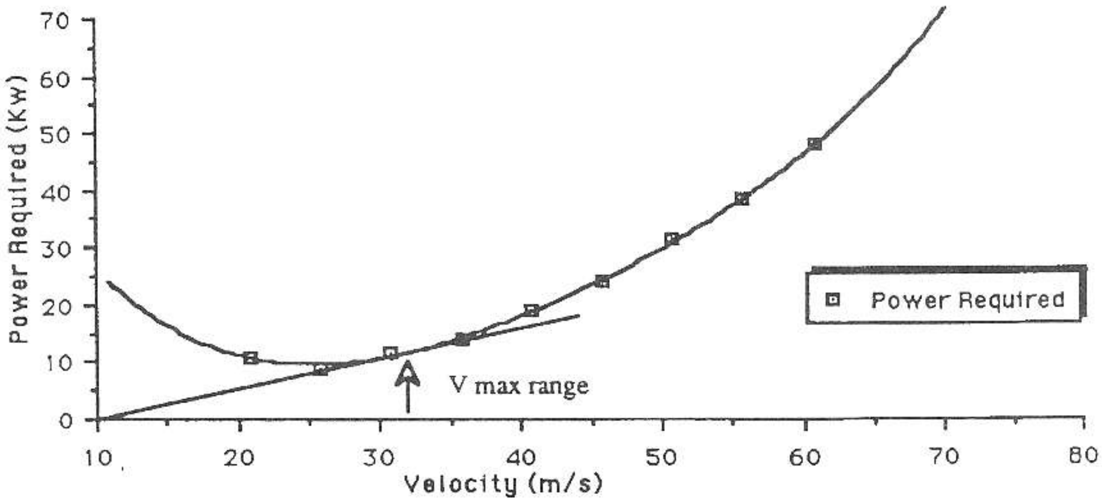

FIGURE 8. Power required for level flight (sea level, ISA).

approximation to the circulation distribution, which is a continuous function in the form of a finite fourier series. Increasing the number of points for output can, therefore, even in the limit, only produce data to the same approximation as the values already calculated for C_L and C_{Di}. All output data is therefore coherent in terms of implied accuracy.

During the course of the work it was discovered that a similar FORTRAN implementation of the lifting line theory existed in the latest edition of Reference 8. This implementation is somewhat more comprehensive in that it caters for sweepback and aerodynamic twist. Also, up to 20 points may be specified for the purpose of determining the circulation distribution. Modification of FWING to meet a similar specification could be carried out by incorporating a routine for inverting the matrix containing coefficients of variables to be solved in one of the program subroutines.

6. Conclusion

In the project it was predicted that the design, at the stage reached, had sufficient aerodynamic qualities to satisfy the initial requirements with respect to performance. It was concluded that the method of Schrenk, Lowry and Polhams and the Prandtl lifting line theory with three ordinates were equally satisfactory for estimation lift-curve slope and lift distribution at the preliminary design stage.

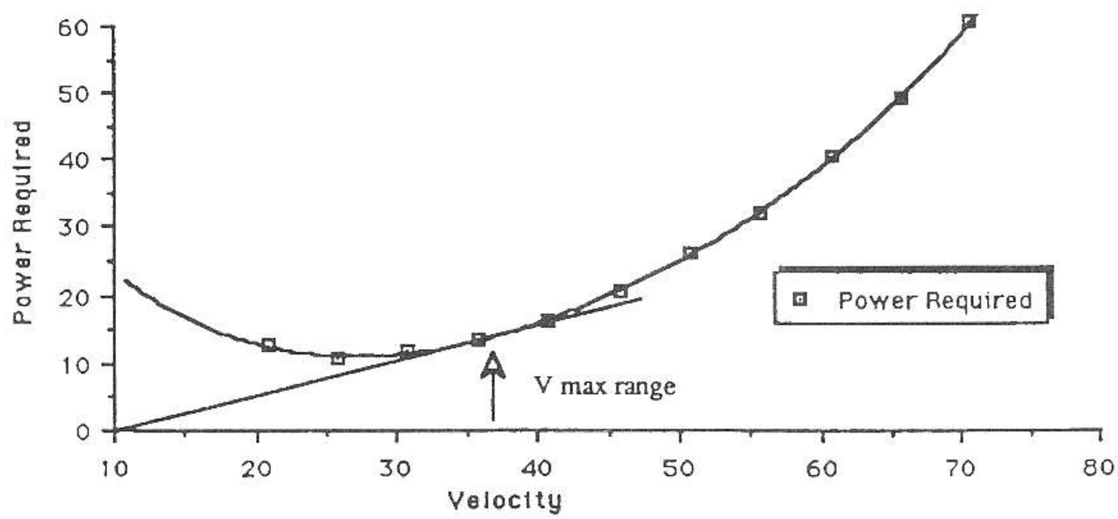

FIGURE 9. Power required for level flight (3000m, ISA).

	A	B	C	D	E	F
1						
2	Aircraft Gross Wt	680				
3	Position Of Wing L.E.	2.35	47	<<<scale dist.		
4	M.A.C.	1.0356				
5						
6	Component	Fractional Wt.	Actual Wt.	Arm	Moment	C.G.
7	Engine	0.080	54.4	2.8	152.32	2.66
8	Prop./ Drive Mech.	0.030	20.4	0.4	8.16	30.00%
9	Wing	0.301	204.476	2.455	501.99	
10	Fuselage	0.190	129.2	2.35	303.62	
11	Tail	0.082	55.76	7.3	407.05	
12	Gear	0.040	27.2	1.87	50.86	
13	Controls	0.020	13.6	1.58	21.49	
14	Equipment / Services	0.030	20.4	0.7	14.28	
15	Useful Load	0.257	174.76	2	349.52	
16	Total	1.000	679.796		1809.29	

FIGURE 10. Balance table.

7. References

1. McCormick, A.W., "Aerodynamics, Aeronautics & Flight Mechanics", Wiley & sons, New York, 1979.
2. Anderson, J.D. Jr., "Fundamentals of Aerodynamics", McGraw - Hill, U.S.A. 1984.
3. Shnton, D. "The design of the Aeroplane", BSP Professional Books, London 1987.
4. Lowry, J.G. & Polhams, E.C., "A Method for Predicting Lift Increments due to Flap Deflection at Low Angles of Attack in Incompressible Flow", NACA TN39 1 1, Jan. 1 957.
5. Hoerner, S.F. "Fluid - Dynamic Drag", Hoerner Fluid Dynamics, Washington, 1957.
6. Shevell, R.S. "Fundamentals of Flight", Prentice - Hall Inc. New Jersey, 1983.
7. Torenbeek, E. "Synthesis of Subsonic Airplane Design". Delft University Press, Delft, 1982.
8. Kuthe, F.F. & Chow, C.J. "Foundations of Aerodynamics", Wiley, New York, 1976.
9. Hahn, B.D. "Problem Solving with FORTRAN 77", Edward Arnold, London, 1987.
10. Abbott, I.H. "Theory of Wing Sections", Wiley, New York, 1976.
11. Roskam, J. "Methods for Estimating Stability & Control Derivatives for the Preliminary Design of Aircraft", University of Kansas.