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A NEW APPROACH FOR ESTIMATING THE DISTRIBUTION OF THE LIFTING FORCE FOR SIZING OF A STRINGER OF AN AERODESIGN CLASS AIRPLANE

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Abstract. *The present paper presents a simplified approach based on the Schrenk approximation method, which consists in finding the loads acting on the wing of an aircraft of different planforms, using the arithmetic average process between the analyzed wing and an ideal distribution on an elliptical wing and trapezoidal, with the same geometric characteristics. Thus, in order to design the stringer, a new proportionality factor, based on the dimensionless velocity, is used to estimate the distribution of aerodynamic loads in various maneuvers used in the mission.*

Keywords: *Method of Schrenk, wing, aerodynamic load, spanwise, stringer, aerodesign.*

1. INTRODUCTION

The conceptual design of an aircraft is established at the initial stage of the design process. This stage, in principle, is difficult, especially in relation to some characteristics of the aircraft: wing shape, tail type, load, the propulsive system itself, since for the accomplishment of mission, there are many possible choices of aircraft. However, the area of operation of the aircraft would basically depend on the definition of these characteristics previously mentioned. Thus, knowledge of the envelope of operation of the propulsive assembly of the aircraft is of fundamental importance for its conceptualisation. As an example, **Figure 1** shows an example of an operational envelope for various propulsive aircraft.

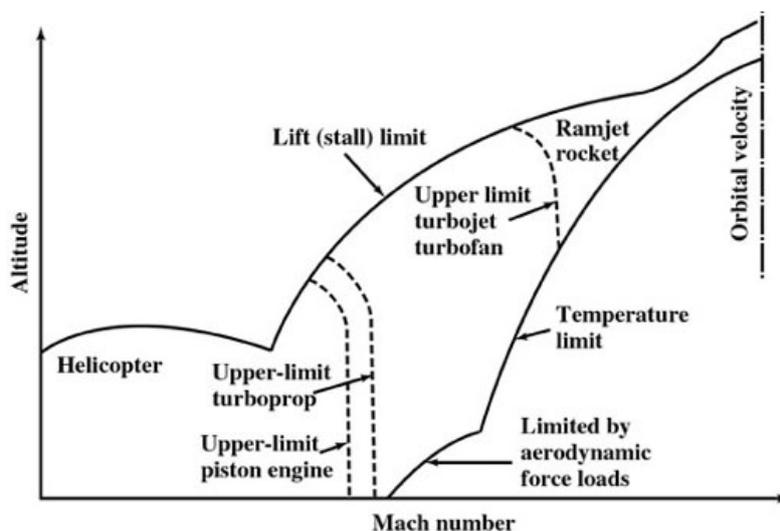


Figure 1. Operational envelope for various propulsive systems, Source: Mattingly (1996)

After defining the conceptual design of the aircraft, the stage of the preliminary calculations begins; that is, the stage of initial estimates of the requests underwent by the aircraft during the possible mission, in which it will be used. For this step, it is essential to estimate the loads acting on the wing of the aircraft.

On the other hand, the availability and existence of several methods to determine the loads, makes a spot analysis of the problem necessary. Hence, an assessment of the initial data is necessary, as a form of decision of the method to

be applied. Thus, preliminary characterisation of the type of aircraft is required; here we opted for the Aerodesign class, which guided the choice of method.

An Aerodesign class aircraft is a small-scale prototype aircraft designed to simulate the flight conditions of a freighter-type underpowered aircraft. It is radio-controlled and features a two-stroke glow engine driving a propeller.

Figure 2 presents an Aerodesign-type aircraft, as developed by the Zebra team of Aerodesign, from UNESP - Ilha Solteira Campus. This project resulted from the work developed by undergraduate students.



Figure 2. Aerodesign class aircraft designed and built by the Zebra Aerodesign team.

Therefore, these initial estimates for the proper sizing are difficult to obtain. Thus, a method based on the smallest number of design variables is necessary to perform the preliminary calculations.

Thus, the method chosen and that best applies to these design features would be the modified Schrenck method. This approach is based on the estimation of the distribution of the lifting force along the wingspan, without the need to evaluate or even choose the aerodynamic profile of the wing, and it can be applied to the most diverse wings. From this, the lifting distribution along a wing defined by the arithmetic mean between the wing analysed and an ideal distribution on an elliptical and trapezoidal wing, with the same geometric characteristics Schrenk (1940).

$$L(y)_{TS} = \frac{L(Y)_T + L(Y)_E}{2} \quad (1)$$

For wing trapezoidal.

$$L(y)_T = \frac{2L}{(1 + \lambda)b} \left[1 + \left(\frac{2y}{b}(\lambda - 1) \right) \right] \quad (2)$$

For wing elliptical.

$$L(y)_E = \frac{4L}{\pi b} \sqrt{1 - \left(\frac{2y}{b} \right)^2} \quad (3)$$

Apply Scherenck's method, the estimation of the aerodynamic loads in the wings is related to the mission requests, associated to the velocities of the structural limits, which bound the performance of the aircraft, being expressed in the form of another type of operational envelope known as Diagram Vn, Which is shown in **Figure 3**.

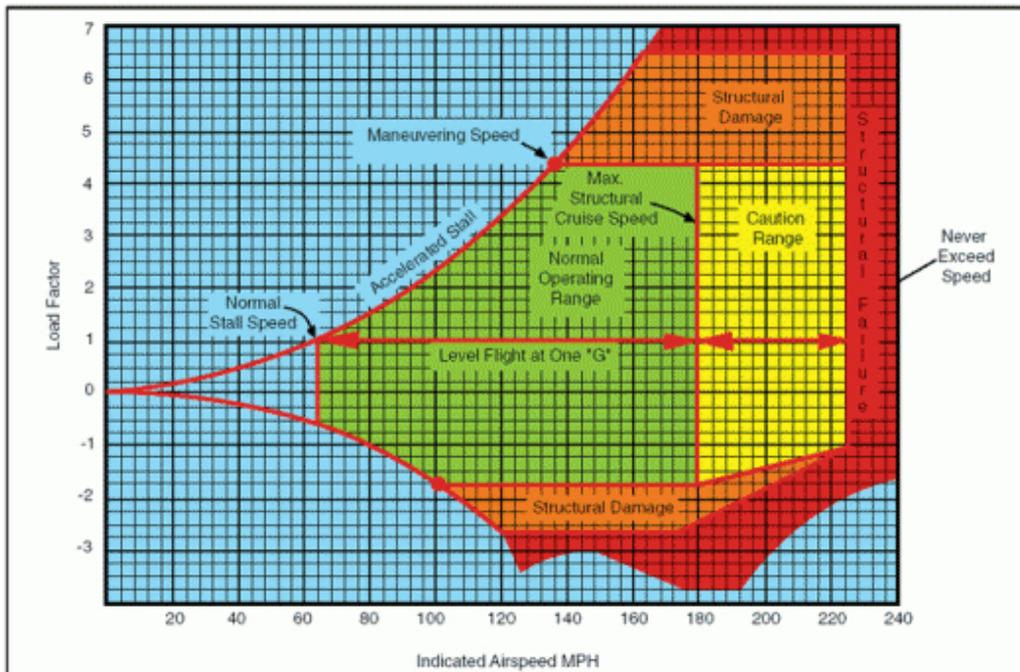


Figure 3. Representation of a Vn Diagram, Source: Chuan-Tau Edward Lan (1997)

This operational envelope is limited by the limiting speeds and the load factor of the aircraft. Thus, the Schrenck estimate can be evaluated using a new proportionality factor ($V_{maneuver}/V_{ref}$), in order to determine the distribution of the aerodynamic loads of the wing to the most diverse Maneuvers of the aircraft. With these distributions and applying the Tsai-Hill failure criterion, one can estimate the wing stringer, able to withstand such requests. **Figure 4** shows the stringer sized by the modified Schrenck method.

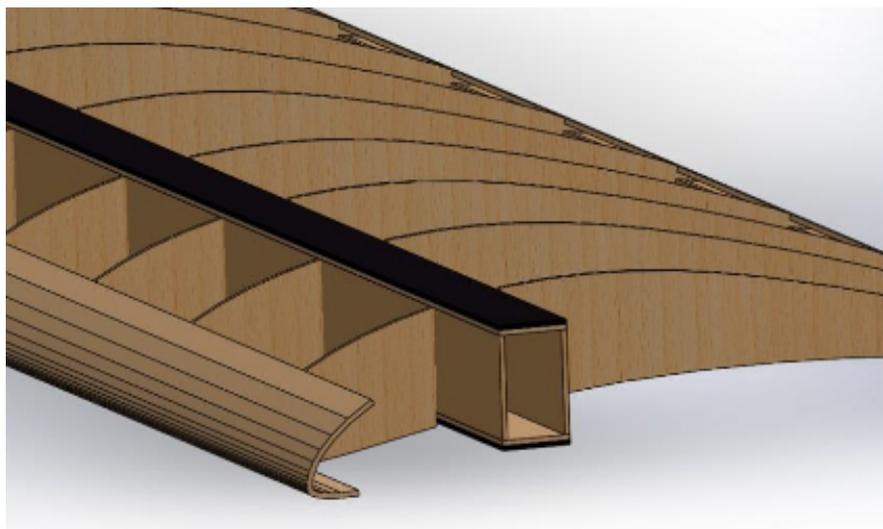


Figure 4. Stringer sized by the modified Schrenck method.

2. RESULTS AND DISCUSSION

Figure 5 shows the lifting distributions along the half wingspan for various wing schemes using the Python® software and applying the Schrenck method.

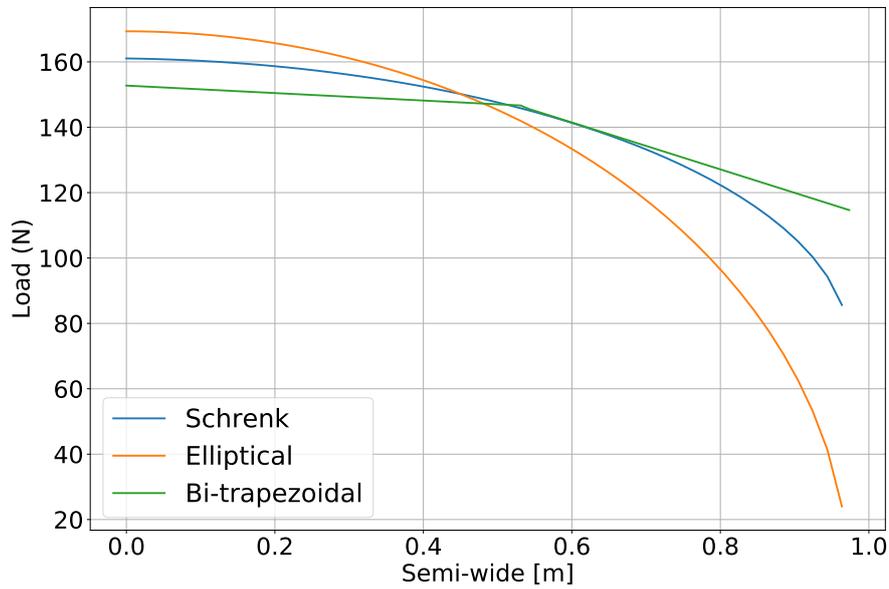


Figure 5. Load distribution in various planforms of application of Schrenk method..

Figure 5 shows the analytical curves to obtain the loads acting on different wing planes. As seen previously, the analytical models do not contemplate the velocity variation as an effect. However, it is easily seen that the Schrenk method is a less conservative method than that obtained by the elliptical wing for the first quarter of the wing, but it is more conservative in terms of wing tip. This fact, which is very important for estimating different elliptic planes due to the strong wing-tip drag generated during the mission, especially in the takeoff, the requests at the tip are higher, making even the simple Schrenk method provide better corrections.

On the other hand, comparing the final result of the wing design with the preliminary design analyzed by the Schrenk method, after the construction of wing prototypes together with the numerical simulation applying VLM (Vortice Lattice Method) by CFD student XFLR5[®], the actual distribution of wing loads is obtained for the most diverse requests during the mission. The actual loads obtained are shown in **Figure 6**.

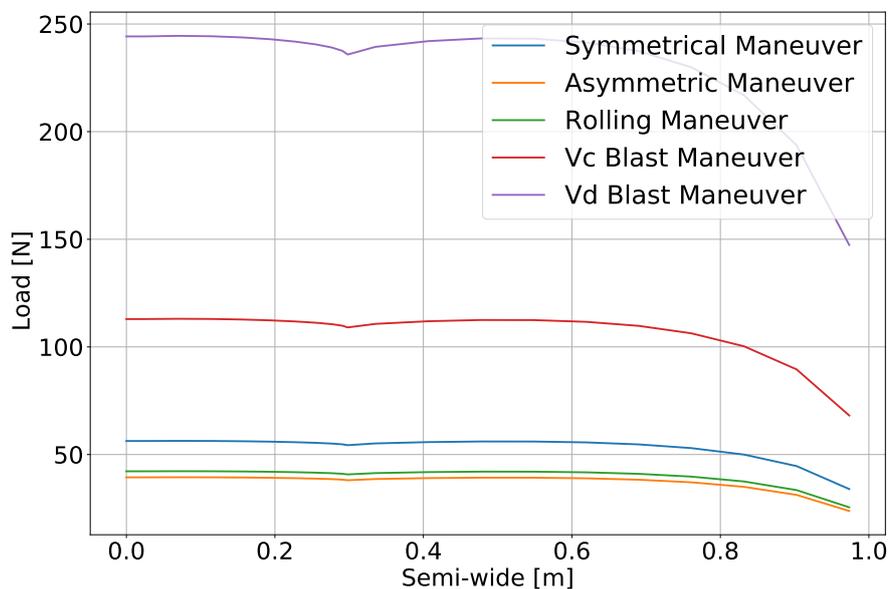


Figure 6. Load distribution obtained by the VLM method in XFLR5[®] software.

Through **Figure 6**, it is possible to see that the Schrenk method encompasses most of the wing requests for various maneuvers of the aircraft. However, the method does not contemplate the most critical request that is the rajava for the speed of diving, being able to lead to the fracture of the stringer during the flight. This leads to changes during the project, which is more the same allied to the greater expenditure of time due to the project corrections.

Thus, the proposed modified Schrenk method is aimed to applying a proportionality factor with respect to an actuation speed with a reference velocity, as presented in the **Equation 4**.

$$L(y)_{TS} = \frac{L(Y)_T + L(Y)_E}{2} \frac{V}{V_{ref}} \frac{\rho}{\rho_{ref}} \quad (4)$$

In the **Equation 4** can be easily seen that the method has also as reference the variation of densities, providing a provision of actuation and location variation effects of the aircraft. For the present work, the reference speed used was the cruising speed, presented by V_c . **Figure 7** shows the results obtained for various maneuvers applying the modified Schrenk method.

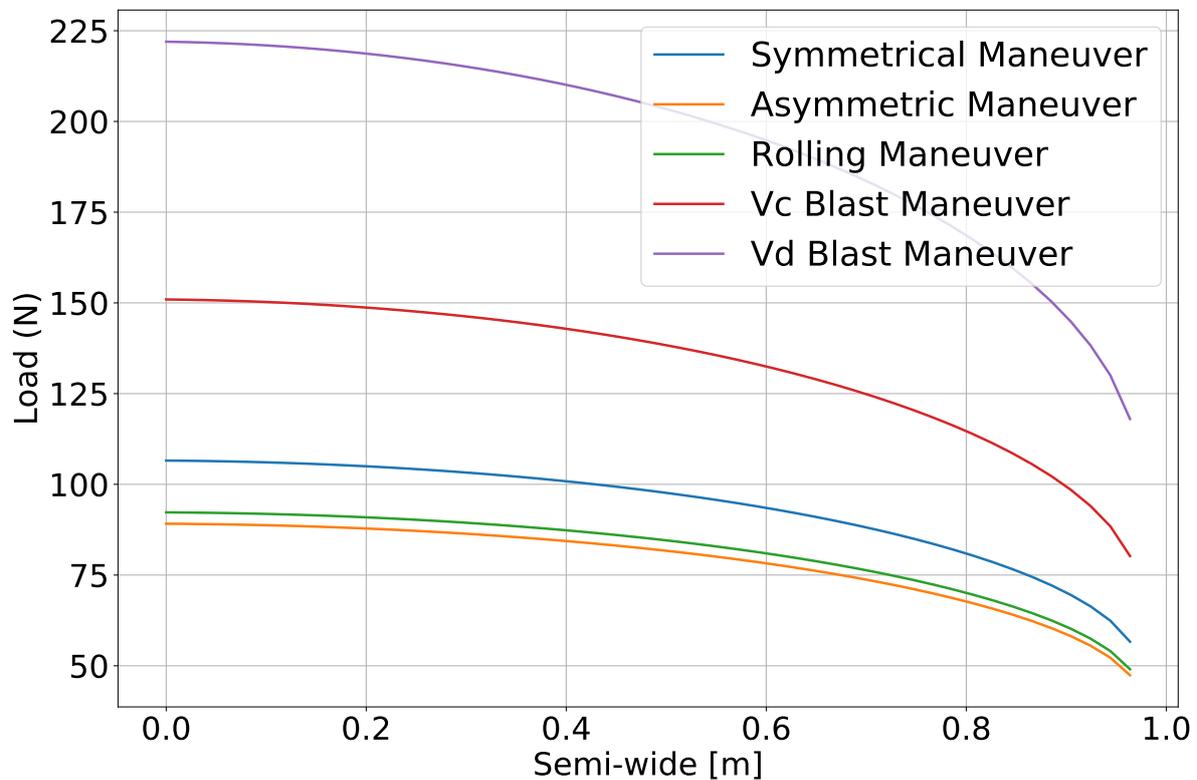


Figure 7. Loads in the form of bi-trapezoidal type for all request maneuvers of the aircraft apply Schrenk's modified method .

As shown in **Figure 7** it is possible to obtain a behavior closer to the real, **Figure 6**, applying the proposed proportionality factor. Consequently, with the modification of the method, it is already possible at the preliminary stage of the project to obtain a stringer closer to the real one, which results in a smaller number of changes during the other project stages, which is closely tied to a lower cost involved with these changes.

By obtaining the distribution of aerodynamic loads on the wings for the various requesting maneuvers as shown in **Figure 7**, the critical stresses can be obtained and with the application of the Tsai-Hill failure criterion, the geometry of the stringer can be obtained. For a bi-trapezoidal form, the thickness of the stringer can vary. A portion of the geometry, also the height of the stringer is fixed in relation to the limitation of the profile heights chosen during the conceptual design. In the case was the Selig1223, Lyon *et al.* (1997), airfoil. **Figure 8** shows the fixed geometry of the half wing profile.

The results obtained by the proposed method are presented in **Table 1**. To obtain them, it is considered that the stringer is made as a balsa wood sandwich and carbon fabric laminated with epoxy resin.

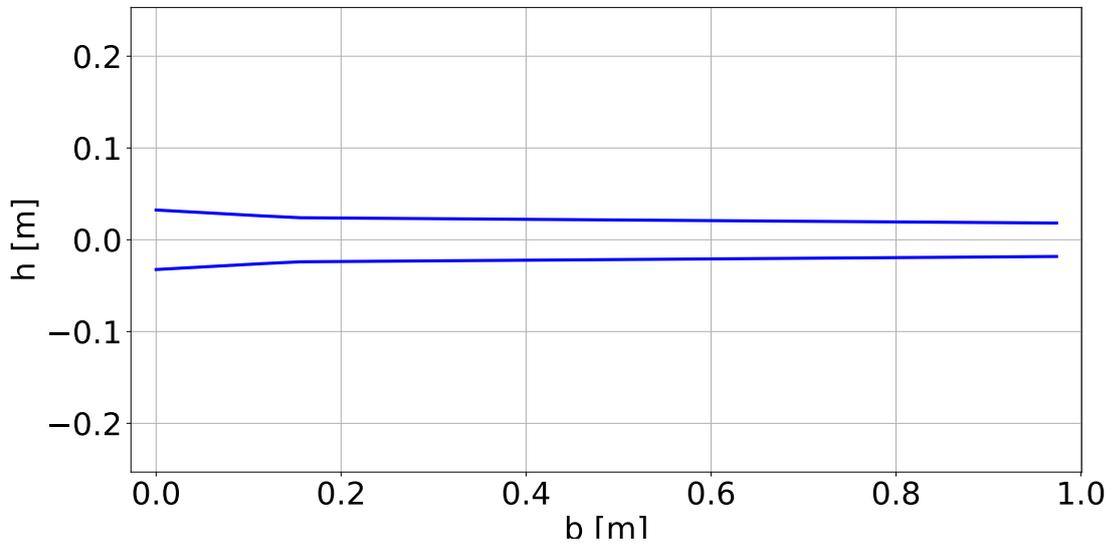


Figure 8. Representation of profile heights used for the stringer dimensioning.

	Symmetric	Asymmetric	Roll	Blast Vc	Blast Vd
Stringer thickness [mm]	4.70	3.18	3.18	8.73	18.25

Table 1. Stringer thicknesses obtained by the modified Schrenck method.

It can be inferred that this new simplified approach based on the Schrenck model applied as an estimate of the aerodynamic loads in the wing is effective for the stringer sizing, and so, already presents a distribution of loads slightly superior to that obtained by other numerical methods. This fact provides a natural safety factor for the approach taking into account that, when analysing the operating voltages and applying the criterion of Tsai-Hill's failure, that the safety factors, even being close to unit, were efficient in experimental flights for all missions. **Figure 9** shows the safety factors obtained after applying the failure criterion.

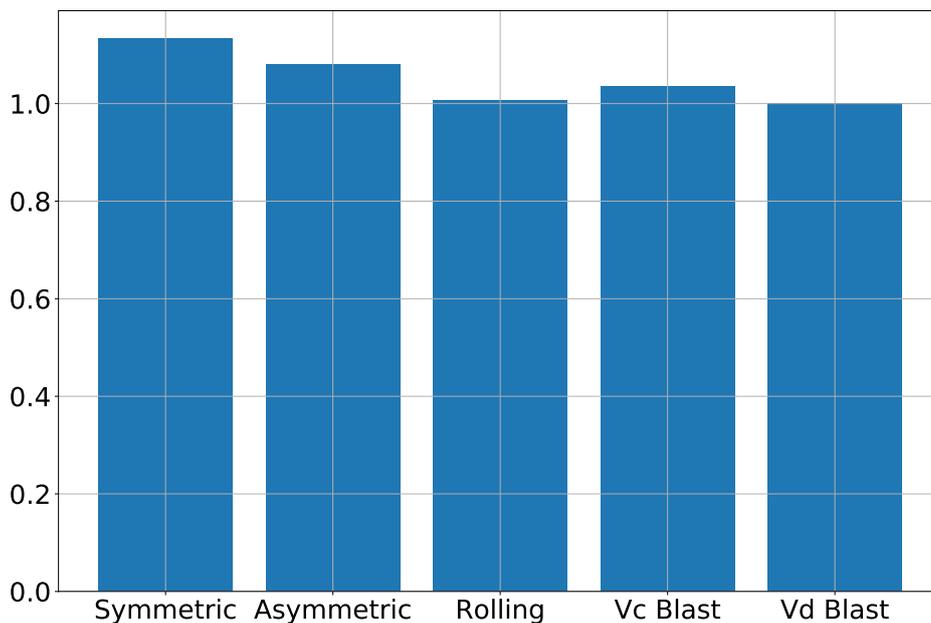


Figure 9. Safety margin obtained after stringer dimensioning

3. CONCLUSIONS

This new simplified approach, based on the Schrenk's method allows in a simplified way to perform calculations for the distribution of the wing lift of different forms, other than the elliptical, in order to allow structural analysis and development of the wing. Applying the proposed method in the initial stage of the project, it was verified that provides results close to the final results, obtained with tests performed in the aircraft, resulting in a reliable method with low changes during the course of the project.

Also regarding to the low changes during the course of the project, provide a shorter design time, and already in the preliminary stage the method is able to obtain results close to actual requests. Thus, during the design stage is possible the development of project sectors related to the wing structure to advance without the initial need of data obtained by other sectors, such as aerodynamics, which would provide the performing and performance loads, that define the velocities of maneuvers, and these can be estimated through the history of aircraft projects of similar classes.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

- Chuan-Tau Edward Lan, J., 1997. *Airplane: Aeronamics and Performance*.
- Lyon, C.A., Broeren, A.P., Giguère, P., Gopalarathnam, A. and Selig, M.S., 1997. *Summary of Low-Speed Airfoil Data*. SoarTech Publications, Virginia Beach, Virginia.
- Mattingly, J.D., 1996. *Elements of Gas Turbine Propulsion*. International Edition.
- Schrenk, 1940. *A Simple Approximation Method for Obtaining the Spanwise Lift Distribution*. National Advisory Committee for Aeronautics.