# A SIMPLIFIED GEOMETRIC METHOD FOR WING LOADS ESTIMATION

Marcelo Satoru Tamura, marcelo.tamura@gmail.com Flávio Luiz de Silva Bussamra, flaviobu@ita.br ITA - Instituto Tecnológico de Aeronáutica Divisão de Engenharia Aeronáutica Praça Marechal Eduardo Gomes, 50 - Vila das Acácias CEP 12.228-900 – São José dos Campos – SP - Brazil

Abstract. In this work, a simplified method for aerodynamic loads estimation on wing surfaces is proposed. In order to do this analysis, basically only the use of the main geometric data of the wing was necessary. In order to illustrate the performance of the proposed method, it is applied to a 174-seat civil aircraft. Numerical results are compared with three other methods, say, BLWF, Vortex Lattice and Schrenk.

Keywords: aircraft loads, BLWF, Vortex Lattice, Schrenk Method

#### **1. INTRODUCTION**

The structural loads estimation has been an important stage for the aircraft design process since the early years of the commercial aircraft age. Due to the advances and availability of computation resources, more and more detailed analyses became accessible. On the other hand detailed analyses require huge amounts of information and generate a lot of outputs. It often demands too much time to manage the large amount of data and the loads estimation process becomes complicated and not useful to the aircraft preliminary design stage. In this work, a simplified approach to estimate aerodynamic loads in civil aircraft wings is proposed. This approach is suitable for early estimations of aircraft loads due to its simplicity and reasonable accuracy. This method is applied to a 174-seat civil aircraft and the results are compared to those obtained by using known methods: BLWF (Karas and Kovalev, 2001), Vortex Lattice (Melin, 2000) and Schrenk (Schrenk, 1940), so that the performance of the proposed method may be evaluated. The purpose of using the BLWF method is the possibility of considering the fuselage effects on the wing surface loads distribution. This method considers the viscous effects on the wing. The Vortex Lattice is an improvement of the classic Prandtl method, with some differences in the sustaining distribution concepts. Schrenk Method is based on an elliptical lifting coefficient distribution span wise hypothesis on the wing. This method also assumes that the pressure distribution is proportional to the wing area.

## 2. METHOD

The Geometric Method (Tamura, 2006) is the method to be validated in this paper, whose proposal is a quick estimation of the aerodynamic loads distribution on wing surfaces, based on a few aircraft preliminary data. This method is based on the wing surface geometry, and it is intended to be used in the preliminary design stage, when there are only few estimated aircraft data, although the wing geometry, as well as the weight and balance data is usually already available. The basic premise of the Geometric Method is that the pressure is distributed equally, with a constant value, on the wing span wise. This implies that the local lift coefficient,  $C_l$ , is also constant span wise. So the resultant aerodynamic pressure is uniformly distributed on the wing area. The loading distribution L [N/m] is the product of the constant pressure P [N/m<sup>2</sup>] span wise by the chords distribution c[m] span wise, where F is the aerodynamic force and S is the wing area:

$$L(y) = P \cdot c(y) \tag{1}$$

and

$$P = \frac{F}{S} \tag{2}$$

so

$$L(y) = \frac{F}{S} \cdot c(y) \tag{3}$$

C<sub>1</sub>.c is obtained by multiplying the local pressure W by the dynamic pressure q, say:

$$W(y) = \frac{L(y)}{C_i}$$
(3)

then,

$$C_l \cdot c = W \cdot q \tag{4}$$

where

$$q = \frac{1}{2} \cdot \rho \cdot V^2 \tag{5}$$

The local C<sub>1</sub> is obtained by dividing the result by the chord C<sub>i</sub>, on the i station:

$$C_{l} = \frac{(C_{l} \cdot c)}{C_{l}} \tag{6}$$

In order to calculate the global  $C_L$ , corresponding to a given load factor, the equations (8) and (9) may be used, where  $\overline{W}$  is the average pressure applied to the wing surface, m the mass,  $n_z$  the load factor and g, the gravitational acceleration:

$$C_L global = \frac{W}{q} \tag{7}$$

where

$$\overline{W} = \frac{m \cdot g \cdot n_z}{S} \tag{9}$$

The Shear Force and the Bending Moment are obtained by dividing the running load diagrams on vertical strips span wise. The area of each strip represents the aerodynamics Normal Force modulus to be applied to each chord considered in the Shear Force or in Bending Moment calculation. The diagram from Figure 1 has been idealized to allow defining the centers of pressure for Torsion Moment estimation, once the Geometric Method is not able to generate this kind of output. These centers of pressure were previously obtained by the BLWF method.



Figure 1. Center of Pressure on chord [%] per wing station

#### **3. CASE STUDY**

The geometric wing reference data of the 174-seat civil aircraft are shown in the Table 1. In this work, the loads have been estimated considering four cases of global CL: -0.52 and 1.3, corresponding to load factors -1.0 and 2.5 respectively, as well as other two intermediate values, 0.25 and 0.5. For load estimation, the Maximum Take-off Weight was considered as the reference value, whose value is 77,100 kg. After applying the Geometric Method to estimate the considered wing data, a performance comparison with other methods was made in the wing-to-fuselage interface station (Y = 2.25m). The winglet effects have been neglected for all four methods. Based on wing geometric data on Table 1, the first step is defining the local chords distribution, as illustrated in Figure 2. Using Equation (9), we are able to obtain the Pressure distribution presented in Figure 3. The graph shown in Figure 4 was obtained by using Equation (4). The local lift coefficient C<sub>1</sub> (Figure 5) may be calculated by dividing the values shown in Figure 4 by the local chord. By dividing the average local pressure by the local chord, according to Equation (1), we obtain the Running Load distribution as shown in Figure 6.

Wing Span	35.58 m
Wing Area	147.02 m²
Wing Root Chord	6.55 m
Wing Tip Chord	1.71 m
Taper Ratio	0.26
Aspect Ratio	8.61
1/4 Chord Line Sweep	$27^{0}$
Wing Dihedral	$5^0$
Chord Geometric Incidence on Wing Root	0
Variation of Span wise Incidence Angle	$5^{0}$

Table 1. Main	geometric	data o	of the	wing
---------------	-----------	--------	--------	------



Figure 2. Local chord distribution



Figure 3. Pressure distribution



Figure 4. Local  $C_1$  x local chord distribution







Figure 6. Running Loads distribution

# **3.1 Results**

Figure 7 shows the Shear Force estimation from each method. For global  $C_L$  equal to -0.52 and 1.3, the Geometric Method presented a non-conservative maximum difference of 5% when compared to other methods. For global  $C_L$  of 0.25 and 0.5, this difference was less than 1%. In the Bending Moment estimation (Figure 8), the maximum difference value is 12%, more specifically for global  $C_L$  -0.52. As the global  $C_L$  values approach zero, this difference converges among four methods, as shown on Figure 9. Regarding the Torsion Moment (Figure 10), the Geometric Method presented a maximum difference of 3%, as presented in Figure 11.



Figure 7. Shear Force Diagrams



Figure 8. Bending Moment Diagrams



Figure 9. Bending Moment at wing-to-fuselage interface station



Figure 10. Torsion Moment Diagrams



Figure 11. Torsion Moment at wing-to-fuselage interface station

## 4. CONCLUDING REMARKS

The Geometric Method has been presented as a simple and quick load estimation method to estimate aircraft wing running loads. For negative values of Global CLs, the Geometric Method presented non conservative values of Shear Load and Bending Moment, and for high values of Global CLs, the Torsion Moment estimation showed non conservative values if compared with the other methods. However the proposed method has generated reasonably accurate results, in terms of Shear Force, Bending Moment and Torsion Moment, if compared to other more sophisticated methods. Therefore the Geometric Method is indicated to be used in a preliminary stage of the aircraft design, when it is necessary to estimate the aircraft loads with reasonable accuracy and only few aircraft data are available.

## 5. ACKNOWLEDGEMENTS

We would like to thank EMBRAER - Empresa Brasileira de Aeronáutica S.A. - for the financial support.

# 6. REFERENCES

- Karas O.V. & Kovalev V.E., 2001, "BLWF28 User's Guide", TsAGI, Central Aerohydrodynamic Institute, Moscow, Russia, pp. 5-33.
- Melin, T., 2000, "User's Guide and Reference Manual for Tornado 1.0", Royal Institute of Technology KTH, Aerodymics Dept., Sweden, pp. 16-27.

Schrenk, O., 1940; "A Simple Approximation Method for Obtaining the Spanwise Lift Distribution", Technical Memorandums, National Advisory Committee for Aeronautics, Washington, EUA.

Tamura, M.S.,2006, "Estudo de Cargas na Asa de uma Aeronave Comercial", Thesis (Master in Aeronautical and Mechanical Engineering), Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil, 95 p.

## 7. RESPONSIBILITY NOTICE

The authors are the only responsible for the material included in this paper.