New methodology and code for Hawker 800XP aircraft stability derivatives calculation from geometrical data

N. Anton, R. M. Botez and D. Popescu
ruxandra@gpa.etsmtl.ca
École de technologie supérieure
Laboratory of Research in Active Controls, Aeroservoelasticity and Avionics
Montréal, Canada

ABSTRACT

The new FDerivatives code was conceived and developed for calculating static and dynamic stability derivatives of an aircraft in the subsonic regime, based on its geometrical data. The code is robust and it uses geometries and flight conditions to calculate the aircraft's stability derivatives. FDerivatives contains new algorithms and methods that have been added to DATCOM's classical method, presented in a USAF Stability and Control DATCOM reference. The new code was written using MATLAB and has a complex structure which contains a graphical interface to facilitate the work of potential users. Results obtained with the new code were evaluated and validated with flight test data provided by CAE Inc. for the Hawker 800XP business aircraft.

NOMENCLATURE

c	MAC (Mean Aerodynamic Chord)
c_L	local aerofoil section lift coefficient
c_{Lmax}	maximum aerofoil section lift coefficient
q/q_∞	dynamic pressure ratio
x_{CG}	distance between the centre of gravity of the aircraft and the quarter-chord point of wing MAC, parallel to MAC, positive for CG aft of MAC
C_D	drag coefficient
$C_{D\alpha}$	drag due to the angle-of-attack derivative
C_{Dq}	drag due to the pitch rate derivative
$C_{D\dot{\alpha}}$	drag due to the angle-of-attack rate derivative
C_L	lift coefficient
C_{Lmax}	wing maximum lift-coefficient
$C_{L\alpha}$	lift due to the angle-of-attack derivative
C_{Lq}	lift due to the pitch rate derivative
$C_{L\dot{\alpha}}$	lift due to the angle-of-attack rate derivative
C_m	pitching moment coefficient
C_{m0}	zero pitching moment coefficient
$C_{m\alpha}$	static longitudinal stability moment with respect to the angle-of-attack derivative
C_{mq}	pitching moment due to the pitch rate derivative
$C_{m\dot{\alpha}}$	pitching moment due to the angle-of-attack rate derivative
C_{lp}	rolling moment due to the roll rate derivative
C_{lr}	rolling moment due to the yaw rate derivative
$C_{l\beta}$	rolling moment due to the sideslip angle derivative
$C_{l\dot{\beta}}$	rolling moment due to the sideslip angle rate derivative
C_{np}	yawing moment due to the roll rate derivative
C_{nr}	yawing moment due to the yaw rate derivative
$C_{n\beta}$	yawing moment due to the sideslip angle derivative
$C_{n\dot{\beta}}$	yawing moment due to the sideslip rate derivative
C_{yp}	side force due to the roll rate derivative
C_{yr}	side force due to the yaw rate derivative
$C_{y\beta}$	side force due to the sideslip angle derivative
$C_{y\dot{\beta}}$	side force due to the sideslip rate derivative
H	altitude
M	Mach number
α	angle of attack
Λ_{LE}	quarter-chord sweep angle at leading edge
κ_{Ls}	stall factor in the relation for maximum lift coefficient
$\kappa_{L\Lambda}$	sweep factor in the relation for maximum lift coefficient
$\kappa_{L\theta}$	twist factor in the relation for maximum lift coefficient
$\kappa_{\Lambda 1}$	sweep co-efficient
$\kappa_{\Lambda 2}$	sweep co-efficient
θ	total twist (geometrical and aerodynamic)

Paper No. 3454. Manuscript received 13 May 2009, revised version received 30 September 2009,
2nd revised version received 6 December 2009, accepted 29 January 2010.

1.0 INTRODUCTION

In this paper, we describe how we used and improved DATCOM procedures[1] for the estimation of the semi-empirical aerodynamic coefficients and stability derivatives, based on geometrical aircraft data. The main advantage of these procedures is their collection of non-iterative faster methods – in terms of execution time – compared with the numerical aerodynamic computational fluid dynamics methods used within the aeronautical field.

Digital DATCOM[2] is the first implementation of the DATCOM procedures in an automatic calculations code. Better estimation has been presented[3] for the cambered fuselage pitching moment, compared to the one given in the DATCOM procedures. In this new estimation, the equations using the thin aerofoil theories for the calculation were modified[4,5]. The results obtained with this new estimation, expressed in terms of the cambered fuselage pitching moment, were different for an asymmetric fuselage with respect to the DATCOM procedure, but remained the same for the symmetric fuselage.

The ADVANCED AIRCRAFT ANALYSIS (AAA) is a code, created by the American company Design, Analysis and Research Corporation (DARcorporation). This code is a computational tool used in the iterative process for preliminary aircraft design, and uses methodologies described in the Roskam[6,7] and Roskam and Lan[8] books. This code has ten independent modules, including one which provides the estimation of aerodynamic coefficients and stability derivatives for the subsonic regime[9].

The MISSILE code[10] was developed by ONERA, in France, for the aerodynamic characteristics estimation of missiles at angles of attack up to 40°, for control surfaces angles of ±30° and at different rolling angles. The MISSILE and AAA codes use the DATCOM methods.

The DATCOM procedures review allowed us to discover its lack of methods for the calculation of the angle of attack at zero lift (α_0) and the pitching moment coefficient at zero lift (C_{m0}). Furthermore, the available methods in the procedures for the wing lift-curve slope calculations have not taken into account the aerodynamic twist, the stall angle (α_{CLmax}) and the maximum lift-coefficient estimations. Almost all methods of DATCOM procedure, concerning the fuselage aerodynamic, are applied to bodies of revolution.

Stability derivatives are considered to be part of an aircraft's intrinsic parameters, as they are dependent on its geometry and flight condition. A cost-effective way to reduce the necessary amount of flight test data is to estimate the aircraft's stability derivatives from its geometrical data, by use of efficient numerical prediction methods.

In Section II a brief description of the classical DATCOM method is presented, followed by the Hawker 800XP aircraft presentation given in Section III.

The new FDerivatives code and its graphical interface (Section IV) does not only allow designers to evaluate derivatives, but also to evaluate new aircraft design concepts, to predict their performance, and to make modifications before performing more detailed design evaluations.

This section also contains a logical description of the code. All of the parameters involved in the stability derivatives estimation procedure are calculated with the new code for the following three configurations: Wing alone (W), Wing – Body (WB), and Wing – Body – Tail (WBT), from the essential geometrical data.

All improvements that were added to the DATCOM method[11] are covered in Section V. For example, the wing lift-distribution method is improved, the drag coefficient for WB configuration is calculated using a new nonlinear regression analysis, the longitudinal dynamic stability coefficients C_{Lq} and C_{mq} are estimated by considering their dependence on the dynamic-pressure ratio, and new functions are implemented for rolling-moment, side-force and yawing-moment coefficients due to the time variation in the sideslip angle, for the WBT configuration.

In Section VI, the stability derivatives obtained with FDerivatives are validated and presented for various flight cases, expressed in terms of Mach numbers and altitudes, for which experimental and geometrical Hawker 800XP aircraft data is available.

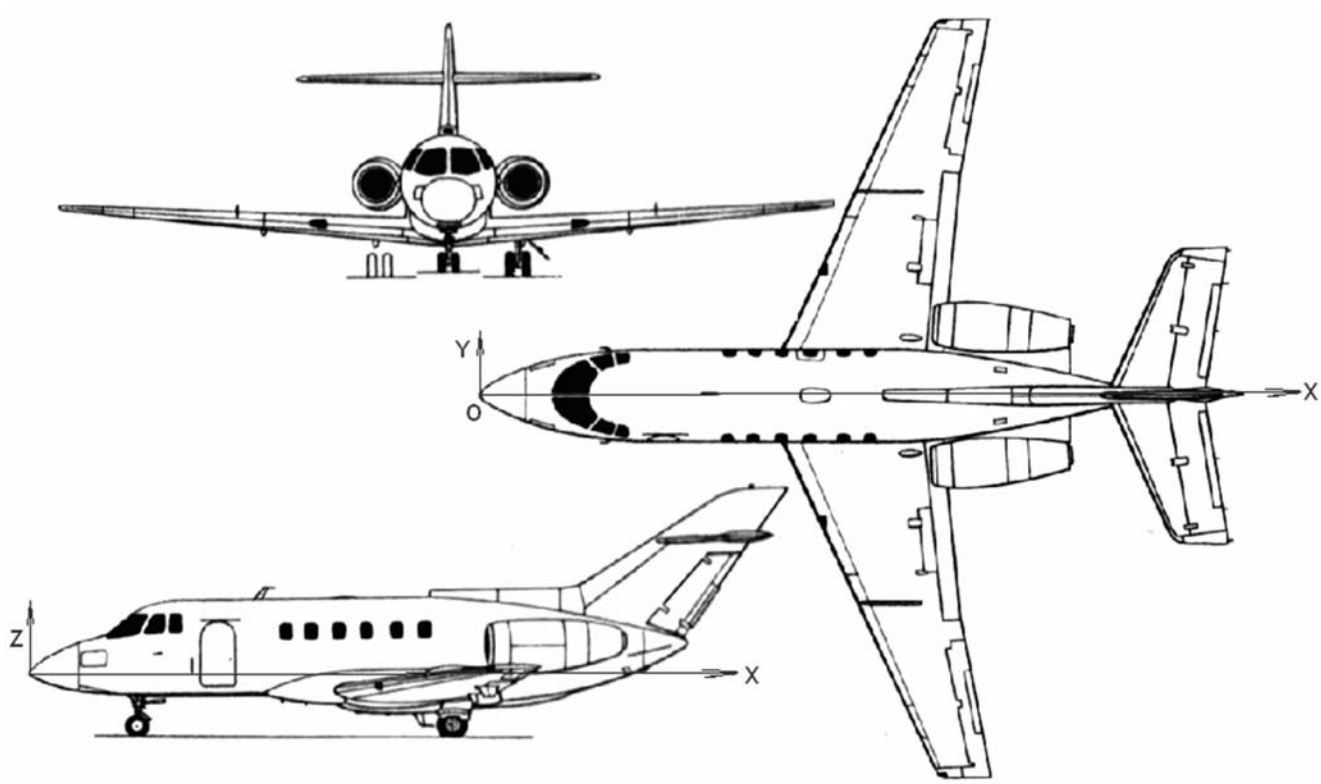

Figure 1. Three views of the Hawker 800XP aircraft.

The aircraft data (geometrical and experimental) available in the literature is used for validation of the FDerivatives code and methodologies for the *W* and *WB* configurations. The flight test and geometrical data for the Hawker 800XP were provided by CAE Inc at subsonic speeds and since their numerical values are confidential, they are not presented. Results obtained with the FDerivatives code were validated at an altitude of 30ft and a Mach number between 0·2 and 0·6 for the WBT configuration of the Hawker 800XP. For future work, we are considering the validation of the stability derivatives obtained with FDerivatives code for the WBT configuration of the Hawker 800XP aircraft on a Cessna Citation X research aircraft simulator at the LARCASE laboratory.

2.0 BRIEF DESCRIPTION OF THE DATCOM METHOD

The static and dynamic derivatives may be estimated from a knowledge of aircraft geometry alone[1], using the DATCOM method. The traditional WBT geometries, including the control effectiveness for a variety of high-lift/control devices, are treated in the USAF's Stability and Control DATCOM program. The Digital DATCOM program written in FORTRAN[2] is used to validate a number of stability derivatives obtained with FDerivatives code, which are the ones described in the next two paragraphs.

1. All of the static stability derivatives (longitudinal and the lateral-directional) are expressed in the stability-axis system. The body-axis normal force and the axial-force coefficients are also estimated. For various flight conditions, i.e. Mach numbers (speeds) and angles of attack, and for all three configurations, the longitudinal drag, lift, moment, normal and axial coefficients C_D, C_L, C_m, C_N and C_A and their corresponding lift, moment, side-force, normal and roll derivatives with respect to the angle of attack and sideslip angle $C_{L\alpha}$, $C_{m\alpha}$, Cy_β, $C_{n\beta}$ *and* $C_{l\beta}$ are obtained.
2. The lift, moment, roll, side-force, and normal dynamic derivatives with respect to the pitch, angle of attack, roll and yaw rates C_{lq}, C_{mq}, C_{La}, C_{ma}, C_{lp}, C_{nr} *and* C_{lr} are also obtained. In the FDerivatives code, other functions available within the DATCOM method are implemented for the calculation of drag, side force, normal and roll derivatives with respect to the sideslip angle rate β such as $C_{\dot{D}\alpha}$, $C_{y\dot{\beta}}$, $C_{n\dot{\beta}}$ *and* $C_{1\dot{\beta}}$ and .

3.0 AIRCRAFT MODEL

The Hawker 800XP is a midsize twin-engine corporate aircraft with low swept-back one-piece wings, a high tailplane and rear-mounted engines, for which the maximum Mach number is equal to 0·9. This aircraft operates in the subsonic and transonic regimes. Three views of the Hawker 800XP aircraft are represented in the OXYZ reference system

The most important geometrical characteristics of the Hawker aircraft, estimated from its geometrical drawings and verified with other methods available in the literature, are found for two different surfaces – fuselage and lift surfaces such as wing, horizontal tail and vertical tail:

1. The length and the position of the gravity centre for the body;
2. The reference area, span, aspect ratio, Mean Aerodynamic Chord (MAC), thickness ratio, leading-edge sweep (inboard/outboard), semi-span of exposed surface, root chord, tip chord and MAC for the wing, horizontal tail and vertical tail surfaces.

4.0 FDERIVATIVES' NEW CODE

The new features (i.e. advantages) of the FDerivatives code, developed at the LARCASE laboratory with respect to the DATCOM Digital code, are described next.

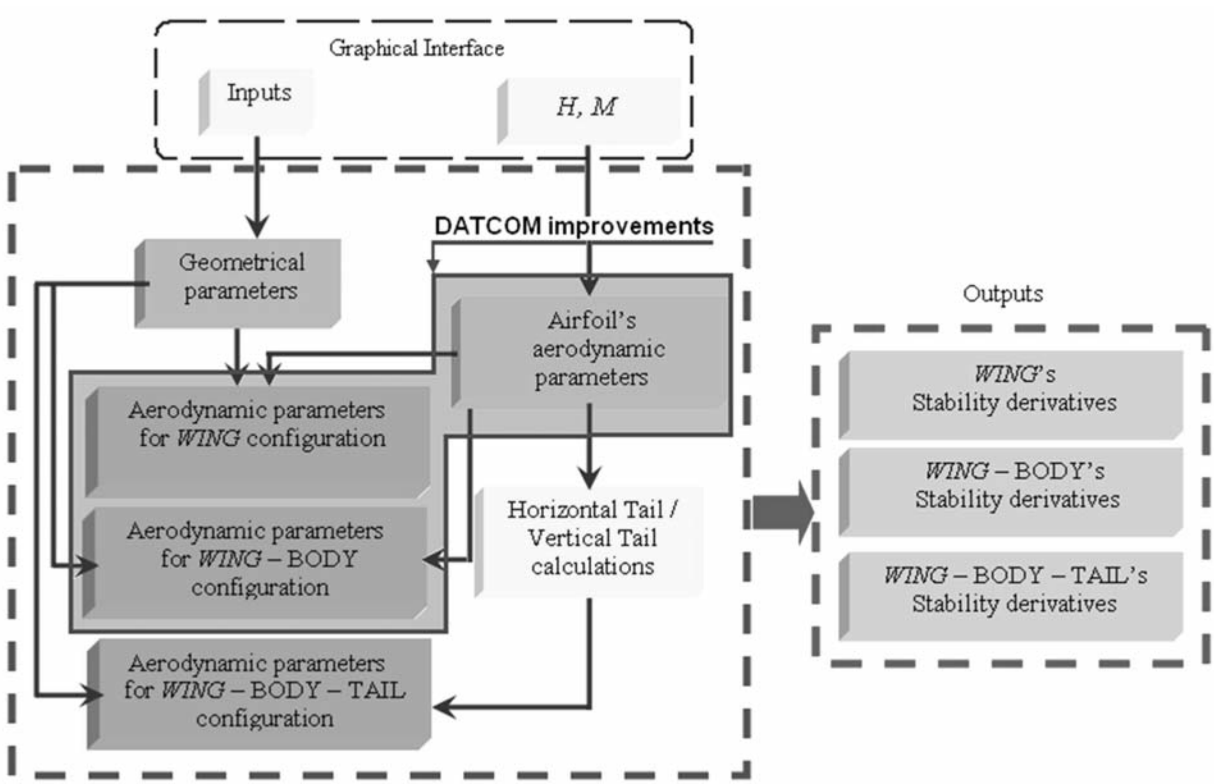

Figure 2. Logical scheme of FDerivatives code.

The principal main advantage of this new code is the estimation of the lift, drag and moment coefficients and their corresponding stability derivatives by use of a select few aircraft geometrical data: area, aspect ratio, taper ratio and sweepback angle for the wing and the horizontal and vertical tails. In addition, the aerofoils for wing, horizontal and vertical tail, as well as the fuselage and nacelle parameters, are introduced in a three-dimensional plane.

The FDerivatives code was written on MATLAB and has a complex structure which contains a graphical interface to facilitate the work of potential users. The code uses a total of 82 MATLAB functions; the aerodynamic coefficients and their stability derivatives are calculated with 24 of these:

- 3 functions for estimation of the lift, drag and moment coefficients C_L, C_D and C_m;
- 6 functions for estimation of the static derivatives $C_{L\alpha}$, $C_{D\alpha}$, $C_{m\alpha}$, $C_{y\beta}$, $C_{n\beta}$ and $C_{l\beta}$;
- 15 functions for estimation of the dynamic derivatives:
  - (*i*) 3 pitch rate (q) derivatives C_{Lq}, C_{mq} and C_{Dq};
  - (*ii*) 3 angle-of-attack rate ($C_{\dot{\alpha}}$) derivatives $C_{L\dot{\alpha}}$, $C_{m\alpha}$ and $C_{D\alpha}$;
  - (*iii*) 3 roll rate (p) derivatives C_{lp}, C_{np} and C_{yp};
  - (*iv*) 3 yaw rate (r) derivatives C_{nr}, C_{yr} and C_{lr};
  - (*v*) 3 sideslip angle rate ($\dot{\beta}$) derivatives and .

The 58 other functions are needed to define necessary geometric factors (two- or three- dimensional) and for proper definition of certain aerodynamic functions.

Figure 2 shows the logical scheme of the code, in which the inputs are the geometrical parameters for the three configuration types, and for the flight conditions characterised by Mach numbers and altitudes. The outputs are the stability derivatives for all three configurations, having already taken into account the values for Mach number and altitude. This code will be improved by calculation of the control surface (elevator, aileron and rudder) derivatives[12].

The main function of the FDerivatives code is located in the MATLAB file DATCOM.m, which calls the other MATLAB functions and the text files. Modifications were made in the aerodynamics and derivatives functions. For example:

- The wing lift-distribution is calculated using the method presented by Sivells[13] and Phillips[14]. In this paper it is assumed that aerofoil section characteristics are not constant across the aerofoil span;
- For *WB* configuration, the drag coefficient is calculated using a new nonlinear regression analysis and the pitching moment was improved[15,16];
- The longitudinal dynamic stability coefficients C_{Lq} and C_{mq} are estimated by considering their dependence on the dynamic-pressure ratio;

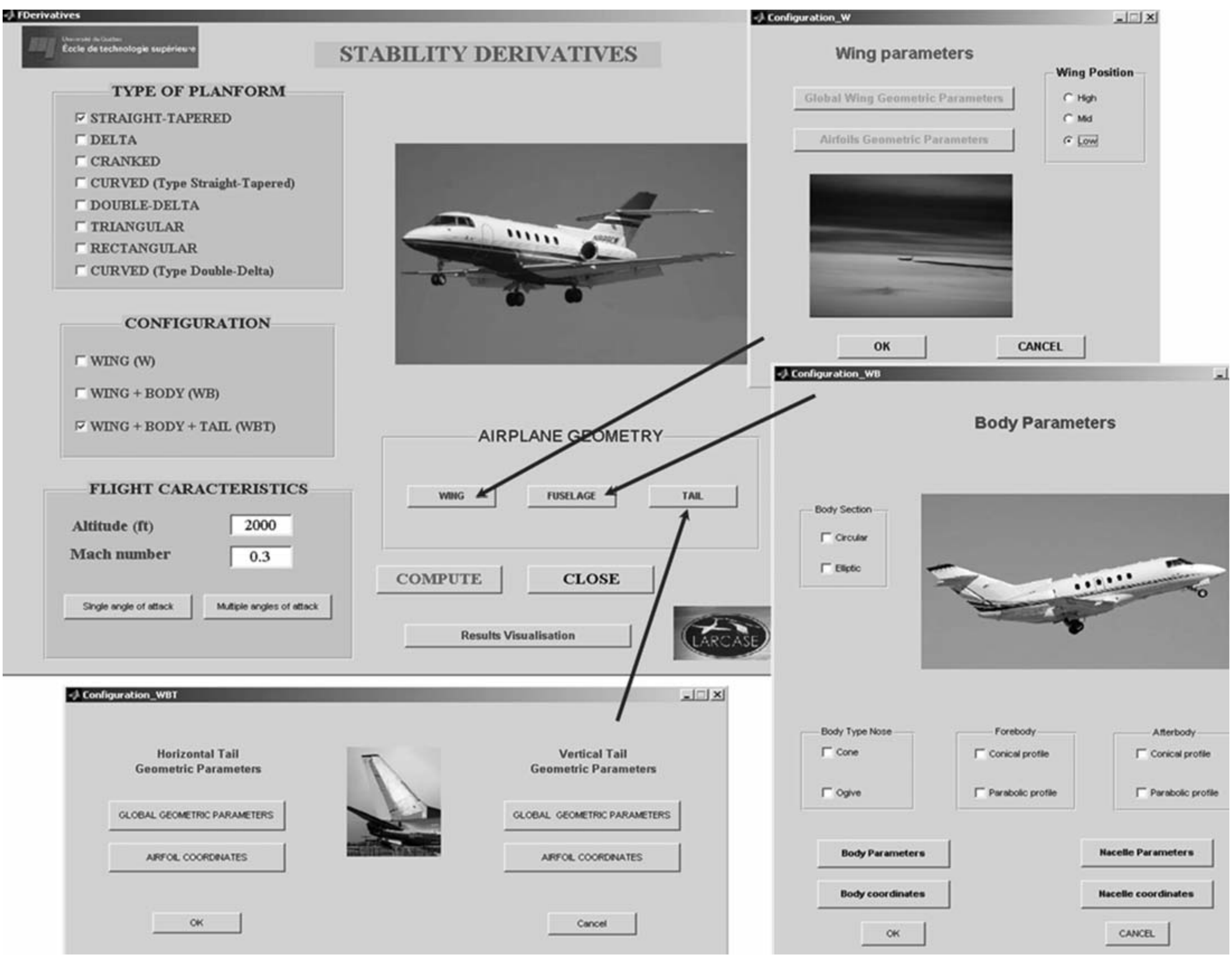

Figure 3. Graphical interface of the FDerivatives code.

- The new functions were implemented for rolling-moment, side-force and yawing-moment coefficients due to a time variation in the sideslip angle, for *WBT* configuration.

The primary functions for the aircraft and aerofoils' geometry estimation are aircraft_geometry.m, which has the global aim to determine the wing, horizontal/vertical tail, body and nacelles geometries, while the function aerofoil_properties.m is used to define the geometrical and aerodynamic characteristics of different aerofoils (two-/three- dimensional).

The zero-lift angle and pitching moment for a wing section are calculated using the thin wing section theory[17]. The details are presented in the Section 5.

The graphical interface for the stability derivatives calculations (Fig. 3) allows users to make changes easily and rapidly in the aircraft geometrical data, and to choose different flight conditions. For the same aircraft configuration, it will be possible to change only the aerofoil's geometries.

In the main window, called Stability Derivatives, the platform's (wing) type, configuration, flight conditions (Mach numbers, altitudes and angles of attack ranges) are defined. It is possible to fix the wing position and its roughness. For each of the three major components (Wing, Horizontal/Vertical Tail), global parameters and aerofoil coordinates situated at the root, MAC and tip sections are considered. The Horizontal stabiliser may be positioned on the fuselage or on the Vertical stabiliser. The inputs to the body configuration are the three global parameters: body length, position of the gravitational centre and the fuselage coordinates (in three dimensions) relative to the reference system (Fig. 4). The positions of the nacelles are described by their number, axial positions, lengths and coordinates relative to the reference system.

The outputs of the FDerivatives code are saved in three formats: jpeg, MATLAB figures, and text files, which contain all of the numerical data.

5.0 DATCOM IMPROVEMENTS FOR STABILITY-DERIVATIVES CALCULATIONS

In the new FDerivatives code, it has implemented an additional number of derivatives, calculated with DATCOM methods, which are not implemented in the Digital DATCOM code. In addition, the method for lift-coefficient estimation has also been improved, and lift-coefficient values were found that are closer to the experimental values than are Digital DATCOM values. Table 1 shows all of the improvements associated with the FDerivatives code[10].

Table 1
Outputs for Wing – Body – Tail configuration

Static derivatives

C_L	C_D	C_m	$C_{L\alpha}$	$C_{D\alpha}$	$C_{m\alpha}$	$C_{l\beta}$	$C_{n\beta}$	$C_{y\beta}$
◆	●	●	●	■	●	●	●	●

Dynamic derivatives

C_{Lq}	C_{Dq}	C_{mq}	$C_{L\alpha dot}$	$C_{D\alpha dot}$	$C_{m\alpha dot}$	C_{lp}	C_{np}	C_{yp}
●	●	●	●	■	●	●	●	●
C_{lr}	C_{nr}	C_{yr}	$C_{y\beta dot}$	$C_{n\beta dot}$	$C_{l\beta dot}$			
●	●	■	■	■	■			

● DATCOM method

■ DATCOM method implemented in the FDerivatives code

◆ C_L estimation method improved in the FDerivatives code

A. The lift, drag and moment coefficients as well as their static and dynamic derivatives were calculated for a three- dimensional flow around the aircraft.

B. The DATCOM method assumes that aerofoil section characteristics are constant across the aerofoil span, and so keeps only the root section for the entire wing (or the horizontal and vertical tails). With these conditions, it cannot obtain a good aircraft configuration using Digital DATCOM code – a better estimation is needed for the lift-coefficient. The FDerivatives code achieves this by considering several sections across the wing span, taking ten sections into consideration.

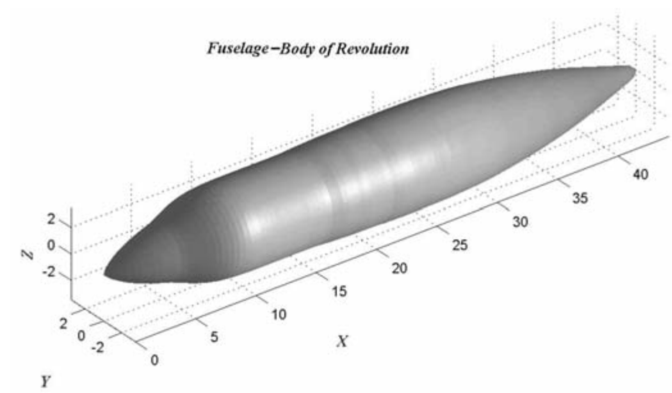

Figure 4. Fuselage represented as a body of revolution.

With the FDerivatives code:

- The total twist (aerodynamic plus geometrical) is estimated, compared with only the geometrical twist estimated in the DATCOM method;
- Several sections are considered across the wing span and are estimated with good precision by taking into account the wing root, the MAC and the tip aerofoils.

To obtain the global lift coefficient for a wing with a nonlinear twist, a lift-line type method is used[13].

The wing lift-distribution is calculated using the induced angle of attack for a finite wing span and the aerofoil lift data are then calculated at ten wing sections along its span. These ten wing aerofoils are situated at the root, MAC, tip and seven other intermediate bi-dimensional sections. If the aerofoil coordinates are not all given as inputs, FDerivatives code has a function that can reconstruct them for any intermediate aerofoils.

The determining lift-distribution method used in this code uses successive approximations. For each aerofoil section, a section lift-coefficient distribution is assumed, and then the bi- dimensional lift coefficients are calculated. Equation (1) developed by Phillips[14] is used here to estimate the maximum lift coefficient C_{Lmax}

$$C_{L\max} = \left(\frac{c_L}{c_{L\max}}\right)_{\substack{\theta=0\\ \Lambda=0}} \kappa_{Ls}\kappa_{L\Lambda}\left(c_{L\max} - \kappa_{L\theta}C_{L\alpha}\theta\right) \qquad \ldots (1)$$

This method applies to any wing geometry, including a twisted wing, and is intended to replace the old algorithm used in the DATCOM method for a linear twisted wing.

The original formula contained a stall correction factor which was eliminated in FDerivatives code. The maximum lift coefficient for the entire wing is then calculated for various flight conditions with the following equation:

$$C_{L\max} = \left(\frac{c_L}{c_{L\max}}\right)_{\substack{\theta=0\\ \Lambda=0}} \kappa_{L\Lambda}\left(c_{L\max} - \kappa_{L\theta}C_{L\alpha}\theta\right) \qquad \ldots (2)$$

The sweep correction factor depends on the aspect and taper ratios, as shown in Equation (3)

$$K_{L\Lambda} \cong 1 + \kappa_{\Lambda 1}\Lambda - \kappa_{\Lambda 2}\Lambda^{1.2} \qquad \ldots (3)$$

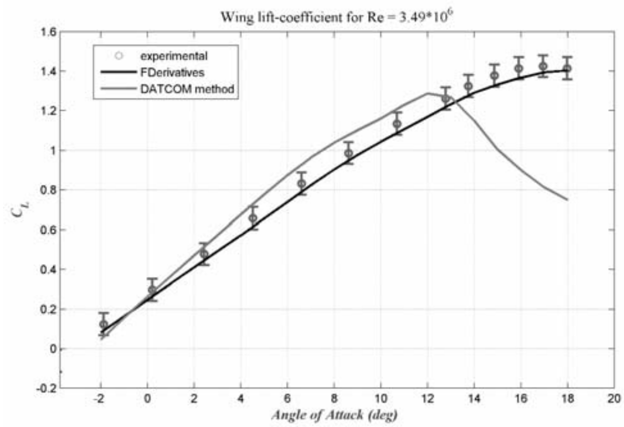

Figure 5. Lift coefficient distribution for the *W* configuration at Re = 3·49·10^6.

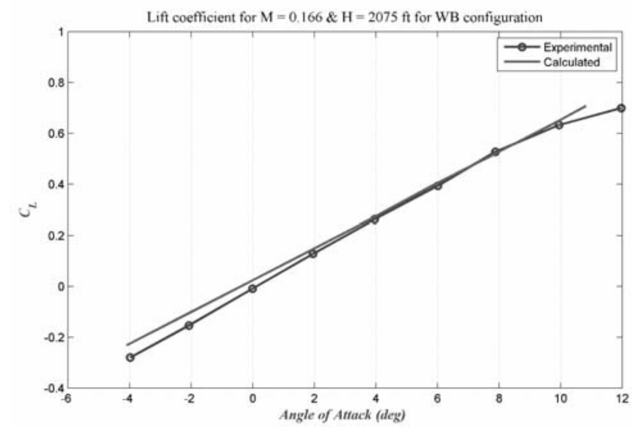

Figure 6. C_L versus α (experimental *versus* calculated) for *WB* configuration.

The maximum lift coefficient of the section C_{Lmax} used in Equation (2) is calculated in the section for which the lift coefficient has the highest value. After obtaining the lift distribution along the wing span, the stall coefficient (corresponding to the maximum lift coefficient) of the entire wing is obtained using Equation (2).

Because the experimental data for W and WB configurations for the Hawker 800XP are unavailable (are provided by CAE Inc. just for WBT configuration), we need to validate the results obtained with the FDerivatives code by using other aircraft models founded in the literature for which experimental data are available for complete aircraft configurations.

The first set of results expressed in terms of lift-coefficient *versus* the angle of attack is shown in Fig. 5 for the wing characteristics (Table 2) at Mach number 0·35 and altitude H = 4,500ft[18]) . The maximum lift-coefficient C_{Lmax} obtained with and without corrections (see Equations (1) and (2)) are compared with the experimental C_{Lmax} shown in the lower part of the Table 2[18]. The relative error between the experimental and calculated values without the stall correction factor is 0·22%, and with the stall correction factor is 8·7%. The formula necessary to estimate the maximum lift coefficient is the same with Equation (2).

Table 2
Wing characteristics

Aerofoils	Root section	NACA 4420
	Tip section	NACA 4412
Taper ratio		2·5
Aspect ratio		10·05
Span		15ft
Area		22·39ft^2
Root chord		2·143ft
MAC		1·592ft
Tip chord		0·8572ft
Geometrical twist		–3·50
Aerodynamical twist		–3·40
Sweepback angle of leading edge		120
Dihedral angle		20
Reynolds number		3,490,000

Results

C_{Lmax} experimental	C_{Lmax} with correction Equation (1)	C_{Lmax} without correction Equation (2)
1·37	1·2510	1·3730

The lift-coefficient's curve (Fig. 5) estimated with the method implemented in FDerivatives code is contained in the marginal error calculated for the experimental data. This error represents 3·5% of maximum lift-coefficient provided by the experimental. On the other hand, the results provided by DATCOM method are quite far from experimental, where the slope of the lift-coefficient is different and the maximum lift-coefficient appears for a lower stall angle.

The WB model configuration is presented by Letko[19], in which the lift and drag coefficients obtained experimentally for a Mach number of 0·166 and an altitude of 2,075ft are also given. The geometrical characteristics for the wing and fuselage are given in Table 3:

Table 3
Basic model geometrical characteristics

Fuselage	
Length	40·0in
Fineness ratio	6·67
Wing	
Span	36in
Area	324in^2
Aspect ratio	4·0
Taper ratio	0·6
MAC	9·19in
Quarter-chord sweepback angle	0°
Twist	0°
Dihedral angle	0°
Aerofoil section	NACA 65A008

Figure 6 shows the very good validation (near-overlap) of calculated with experimental lift-coefficient, both versus angle-of-attack data, using the new FDerivatives code.

C. Better estimation of drag for the WB configuration by using a new nonlinear regression analysis. Better estimation of pitching moments for the WB configuration.

This method evaluates and combines the isolated moment due to lift of the wing and of the body, with allowance for their effect on each other. The wing pitching moments due to effective wing lift includes the effects of body up-wash on the wing and wing carryover onto the fuselage. These are accounted for on the basis of relations already in the DATCOM method. Fuselage and nacelles' free moments due to induced flow from the wing can be estimated by the technique developed by Multhopp[15]. The sum of these two contributions added to the wing pitching moment due to wing drag gives a better estimation of the pitching moment than the linear regression analysis method in DATCOM for a WB configuration.

The new FDerivatives code has changed the way the total moment coefficient is computed. The nacelles' contribution is included and the total moment is presented as a sum of the moment given by the Wing-Body-Nacelles (WBN) and the Horizontal Tail (HT) contributions:

Figure 7. C_m *versus* α (experimental and calculated), *WB* configuration.

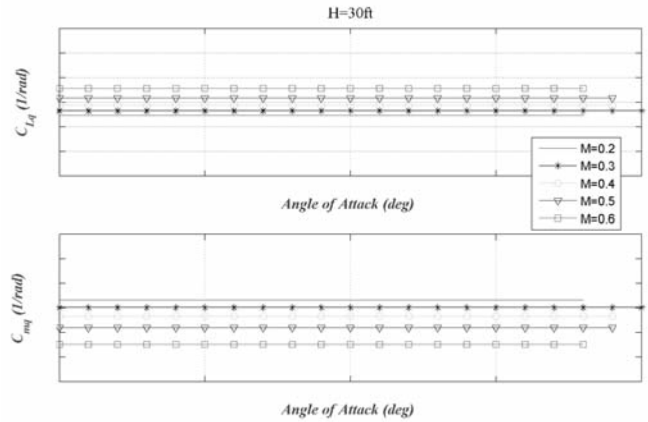

Figure 8. C_{Lq} and C_{mq} *versus* α, Hawker 800XP, WBT configuration.

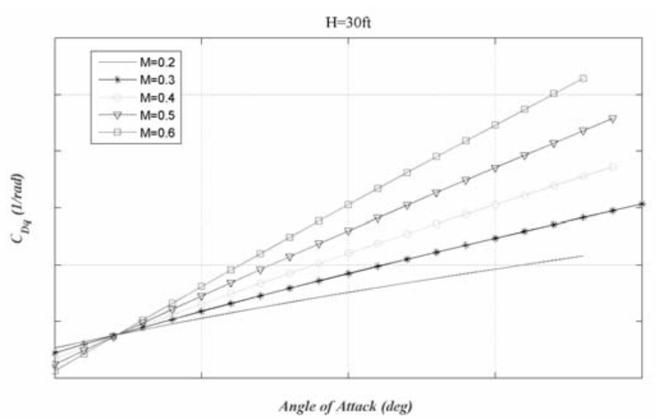

Figure 9. C_{Dq} *versus* α at the altitude H = 30ft and q = 5deg/s.

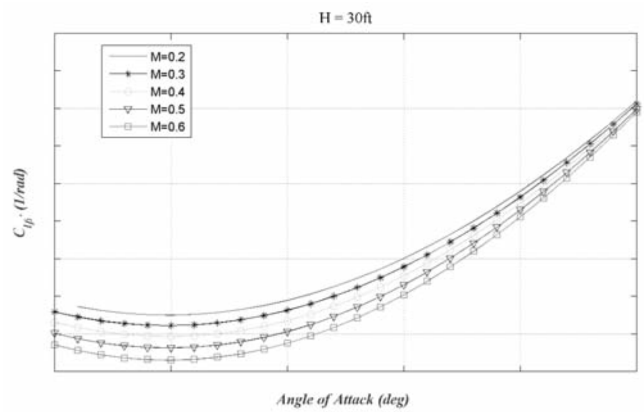

Figure 10. $C_{1\dot\beta}$ *versus* α at the altitude H = 30ft.

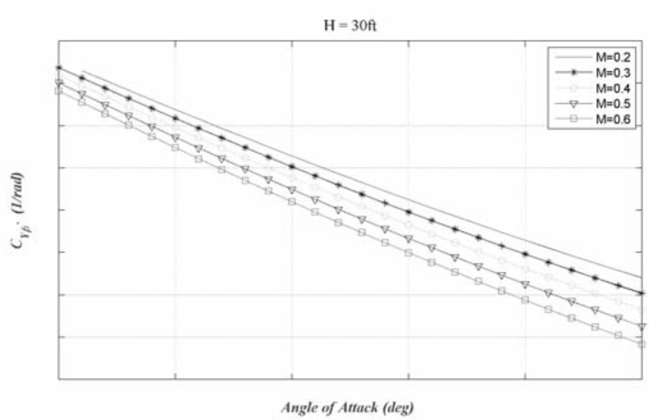

Figure 11. $C_{y\dot\beta}$ *versus* α at the altitude H = 30ft.

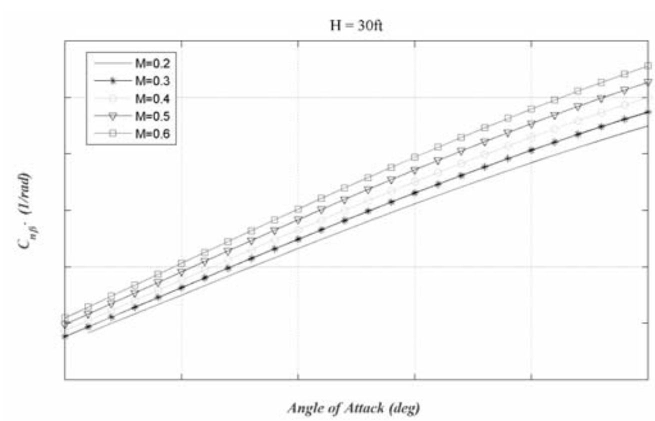

Figure 12. $C_{n\dot\beta}$ *versus* α at the altitude H = 30ft.

$$(C_{m0})_{total} = (C_m)_{WBN} + (C_m)_{HT} \qquad \ldots (4)$$

$$\left(C_m\right)_{WBN} = \int_0^{C_L(\alpha)} \left(\frac{dC_m}{dC_L}\right)_{CG} \mathrm{d}\left(C_L\right)_{WBN} + \left(C_{m0}\right)_{WBN} \qquad \ldots (5)$$

where $\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_{CG} = \frac{x_{CG}}{\bar{c}} + \frac{\Sigma(C_{m\alpha})}{\Sigma(C_{L\alpha})}$ is estimated as a function of gravitational centre position and

$$(C_{m\alpha}) = (C_{m\alpha})_{free} + (C_{m\alpha})_{drag} + (C_{m\alpha})_{BN} + (C_{m\alpha})_{W(B)+B(W)}$$

$$\left(C_{m0}\right)_{WBN} = \left[\left(C_{m0}\right)_W + \left(C_{m0}\right)_{BN} + \Delta C_{m0}\right] \frac{\left(C_{m0}\right)_M}{\left(C_{m0}\right)_{M=0}}$$

The moment coefficient's contribution to the body $C_{m0})_B$ is defined[16], where the fuselage's zero pitching moment coefficients and the two-times-zero pitching moment coefficients provided by the nacelles are also given. Figure 7 shows the moment coefficients (experimental and calculated) versus the angle-of-attack.

The longitudinal dynamic stability coefficients C_{Lq} and C_{mq} computed in Digital DATCOM are assumed to be linear. In the

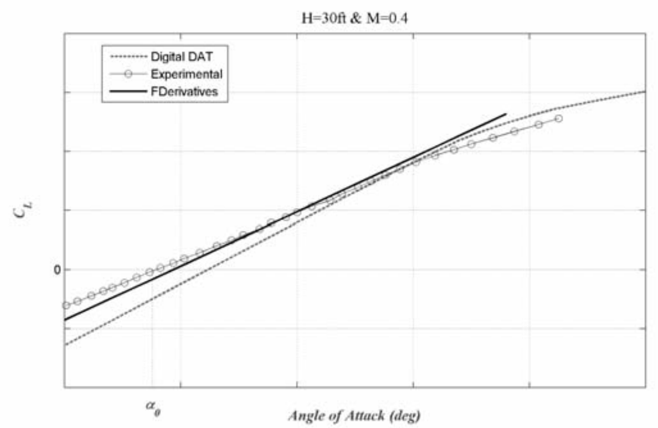

Figure 13. C_L *versus* α at M = 0·4.

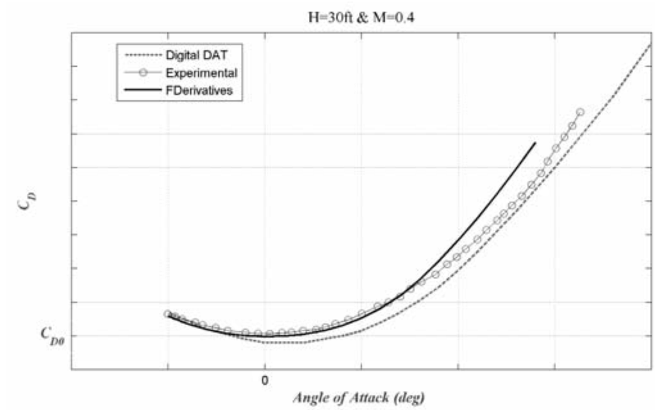

Figure 14. C_D *versus* α at M = 0·4.

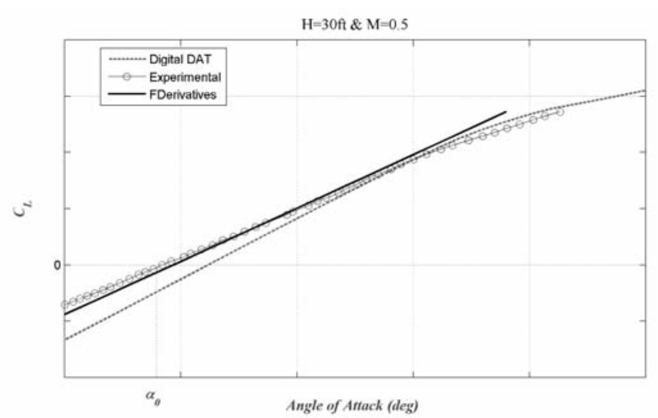

Figure 15. C_L *versus* α at M = 0·5.

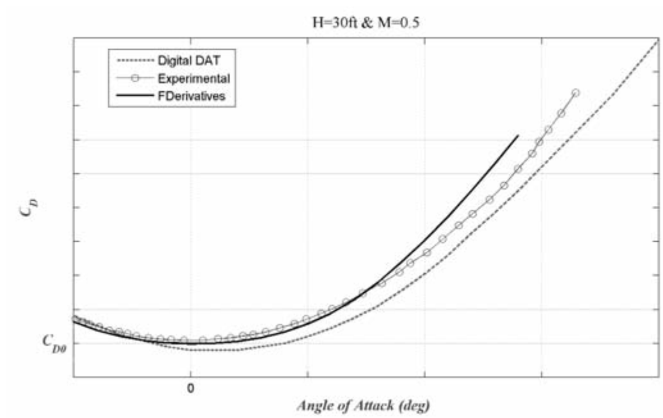

Figure 16. C_D *versus* α at M = 0·5.

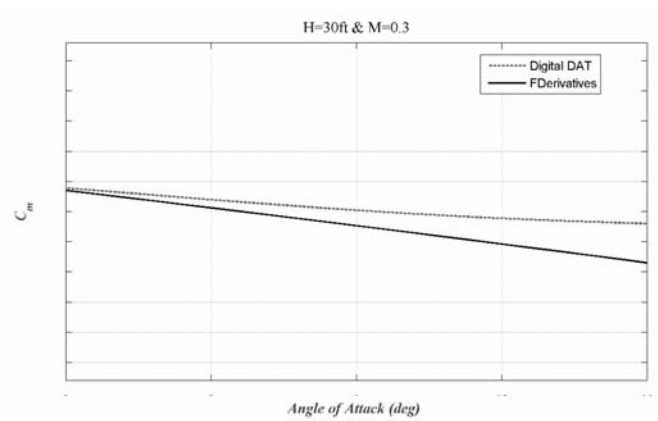

Figure 17. C_m *versus* α at Mach number = 0·3.

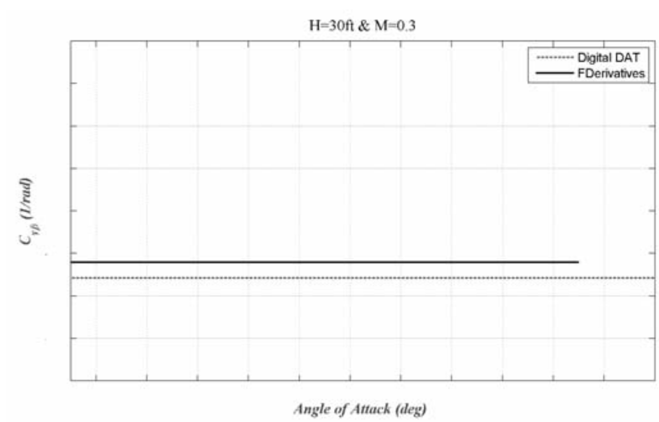

Figure 18. $C_{y\beta}$ *versus* α at Mach number = 0·3.

FDerivatives code, these derivatives are estimated by considering their dependence on the dynamic-pressure ratio (q/q_∞).These two derivatives are represented for different Mach numbers versus the angle of attack at the altitude of 30ft in Fig. 8. The linearity appears only if the ratio $q/q_\infty = 1$.

In addition, C_{Dq} is computed in the new code using the method described in DATCOM, and depends on the pitching rate q, which is defined in the interval (0° to 10°) deg/s. The variation of C_{Dq} with the angle of attack for different Mach numbers is presented in Fig. 9 for M = 0·2 to 0·6 and altitude H = 30ft in the WBT configuration, where the pitch rate q = 5 deg/s.

E. The zero-lift angle and pitching moment for a wing section are also calculated in the FDerivatives code, using the thin wing section theory[17] and a Fourier method. Very good approximations for the zero-lift coefficients and pitching moments are obtained using the Pankhurst method[17].

F. In the subsonic regime, the new FDerivatives code was improved by taking into account equations for the following dynamic stability derivatives (with the results presented in Figs 10 to 12):

- Rolling moment coefficient due to a time variation in the sideslip angle $C_{l\dot\beta}$ for the WBT configuration,
- Side-force coefficient due to a time variation in the sideslip angle for the WBT configuration,

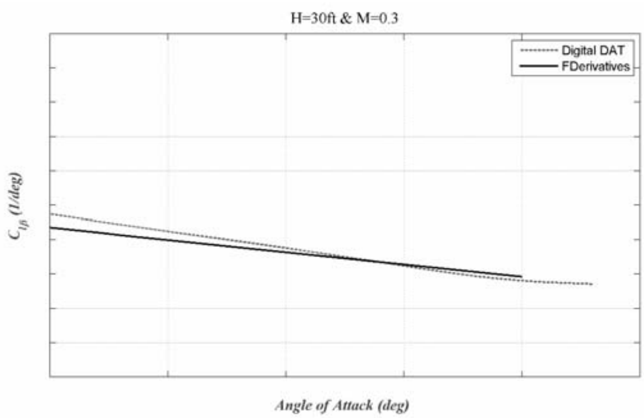

Figure 19. $C_{l\beta}$ *versus* α at Mach number M = 0·3.

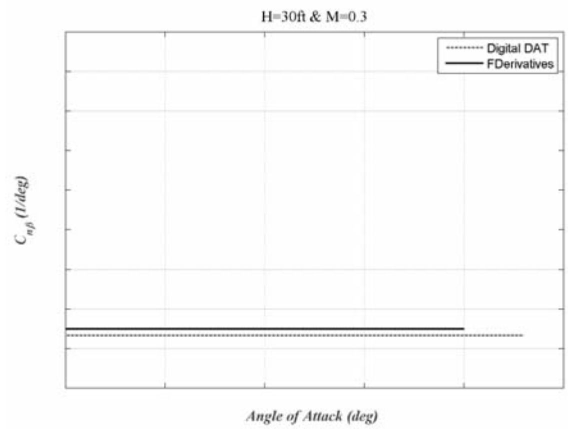

Figure 20. $C_{n\beta}$ *versus* α at Mach number M = 0·3.

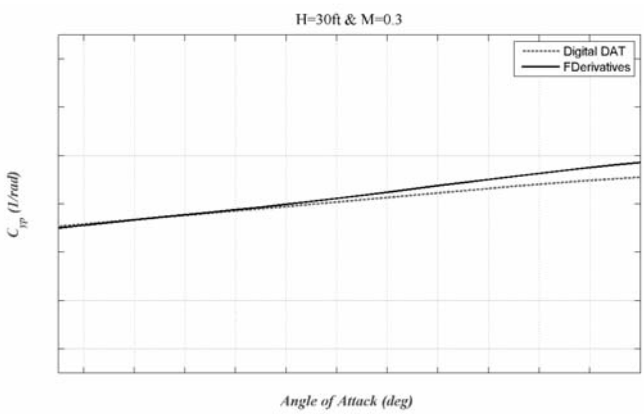

Figure 21. C_{yp} *versus* α at Mach number M = 0·3.

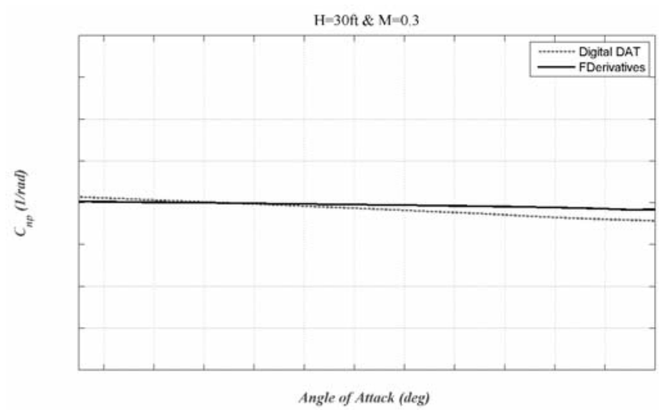

Figure 22. C_{np} *versus* α at Mach number M = 0·3.

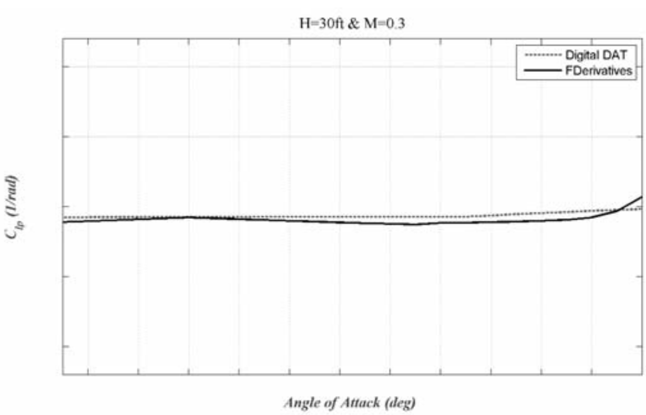

Figure 23. C_{lp} *versus* α at Mach number M = 0·3.

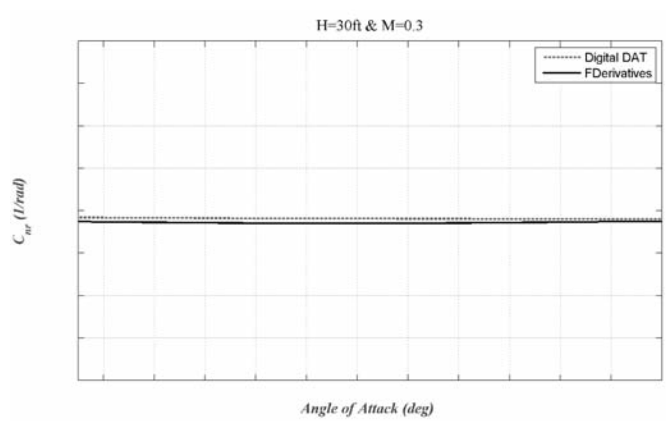

Figure 24. C_{nr} *versus* α at Mach number M = 0·3.

- The yawing-moment coefficient due to a time variation in the sideslip angle $C_{l\dot{\beta}}$ for the WBT configuration.

6.0 VALIDATION RESULTS OBTAINED FOR THE ENTIRE HAWKER 800XP AIRCRAFT

Results are presented in terms of stability derivatives for the flight cases expressed by the following air conditions:

- Altitude = 30ft;
- Mach numbers = 0·2, 0·3, 0·4, 0·5 and 0·6;
- Angle-of-attack = –5° to 20°deg.

To validate the results, expressed in terms of lift and drag coefficients obtained with the FDerivatives code, these types of results are compared with the numerical results obtained from the Digital DATCOM code and experimental Hawker 800XP results (that means the flight tests), as shown in Figures 13 to 16, for Mach number M = 0·4, 0·5. The FDerivatives curves are closer for the experimental data, then the Digital DATCOM code are. The flight test and geometrical data were provided by CAE Inc for the Hawker 800XP, and for this reason, the results are confidential and no numbers are shown on the graphs.

From the above figures, we can see that differences appear for angles of attack greater than 10°degrees.

Results expressed in terms of derivatives with the exception of the three results presented in part F (Figs 10 to 12) obtained with the new FDerivatives code are slightly different from those obtained with the Digital DATCOM program (Figs 17 to 24), due to the fact that FDerivatives code is improved with respect to the DATCOM method implemented in Digital DATCOM code.

7.0 CONCLUSION

The new FDerivatives code was conceived by using different methods found in the literature, along with the main method presented in DATCOM. This new code was designed to obtain all of the aircraft stability derivatives by considering only a small amount of geometrical data as inputs. The code is very easy to modify, as it gives the user the possibility to choose the number of derivatives, the aircraft configuration and the flight cases. All the outputs become inputs for a model that will be implemented in an aircraft simulator at LARCASE laboratory.

The lift-coefficient method implemented in the presented code is better than the lift calculated with the DATCOM method due to better evaluation of the wing geometry – much closer to a real wing with changes in geometry and aerofoil characteristics, and with a nonlinear twist. Other derivatives, which are not calculated in the Digital DATCOM code, are implemented in this new FDerivatives code.

To estimate the aerodynamic characteristics and stability derivatives for a single aircraft configuration, FDerivatives provides the best results. The user needs only to employ the proper dimensions for the desired configuration. This code represents a significant amount of work – it contains over 10,000 lines of MATLAB and 226 text files. Its methodology and a part of results are validated using the Hawker 800XP aircraft flight tests and the rest of them are verified with the Digital DATCOM results.

ACKNOWLEDGMENTS

We would like to thank to CAE Inc for its invaluable support of this work.

REFERENCES

1. The USAF Stability and Control Digital DATCOM – AFFDL–TR–79–3032.
2. http://www.pdas.com/datcom.htm.
3. BLAKE, W.B. and ETAN, D.K. A cambered body method for missile DATCOM, 23rd AIAA Applied Aerodynamics Conference (6-9 June 2005), p 11, Toronto, Ontario, Canada.
4. WILLIAMS, J.E. and VUKELICH, S.R. The USAF Stability and control digital DATCOM, Volume I. Users Manual, p 317, AFFDL-TR-79-3032, St. Louis, Missouri, USA: McDonnell Douglas Astronautics Company, St. Louis Division, Wright-Patterson Air Force Base, 1979.
5. WILLIAMS, J.E. and VUKELICH, S.R. The USAF Stability and Control Digital DATCOM, Volume II. Implementation of DATCOM Method, AFFDL-TR-79-3032. 155. St. Louis, Missouri: McDonnell Douglas Astronautics Company, St. Louis Division, Wright-Patterson Air Force Base, 1979.
6. ROSKAM, J. *Methods for Estimating Stability and Control Derivatives for Conventional Subsonic Airplane*, Lawrence, Kansas, USA, 1973.
7. ROSKAM, J. Airplane Flight Dynamics and Automatic Flight Controls, DARcorporation, Lawrence, Kansas, USA, 1995.
8. ROSKAM, J. and LAN, C.T.E. Airplane Aerodynamics and Performances, DARcorporation, Lawrence, Kansas, USA, 1997.
9. http://www.darcorp.com
10. CHAMPIGNY, P. and DENIS, P. The ONERA aero prediction code "MISSILE", ONERA–TP–04–112, France, 2004.
11. POPESCU, D. Nouvelle implémentation de la procédure DATCOM pour le calcul des coefficients aérodynamiques et des dérivées de stabilité dans le domaine subsonique de vol, Master Thesis, ETS Montréal, 2009.
12. ROSKAM, J. Airplane design Part VI: Preliminary Calculation of Aerodynamic, Thrust and Power Characteristics, DARcorporation, Lawrence, Kansas, USA, 2000.
13. SIVELLS, J.C. and NEELY, R.H. Method for calculating wing characteristics by lifting-line theory using nonlinear section lift data, NACA–TN–1269, Washington, UK, April 1947.
14. PHILLIPS, W.F. and ALLEY, N.R. Predicting maximum lift coefficient for twisted wings using lifting-line theory, *AIAA J Aircr*, May-June 2007, **44**, (3).
15. MULTHOPP, H. Aerodynamics of the fuselage, NACA–TM–1036, Washington, USA, December 1942.
16. ETKIN, B. and REID, L.D. *Dynamics of Flight, Stability and Control*, 3rd ed, John Wiley & Sons, 1996, **2**, p 25.
17. ABBOT, I.H. and VON DOENHOFF, A.E. *Theory of wing sections*, Dover Publication, New York, USA, 1959.
18. NELLY, R.H. and BOLLECH, T.V. Experimental and calculated characteristics of several NACA 44–series wings with aspect ratios of 8, 10, and 12 and taper ratios of 2.5 and 3.5, NACA–TN–1270, Washington, UK, May 1947.
19. LETKO, W. and RILEY, D.R. Effect of an unswept wing on the contribution of unswept-tail configurations to the low-speed static- and rolling-stability derivatives of a midwing airplane model, NACA TN 2175, Washington, USA, August 1950, pp 25-26.