SOFTWARE DEVELOPMENT AND VALIDATION FOR SUBSONIC AND TRANSONIC AIRCRAFT CLASS 2 DRAG POLAR DETERMINATION

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Abstract. *The objective of this work is to elaborate and validate a computational code for subsonic and transonic aircraft class 2 drag polar determination that produces results as close as possible to reality and to be used during the preliminary design phase. It is employed Dr. Jan Roskam´s methodology (Kansas University) as the primal source of information, but to achieve the proposed objective, it is also taken into consideration methodologies provided by TsAGI institute (Russia), by Dr. Egbert Torenbeek, by Dr. Sighard F. Hoerner and by some papers on similar subject whenever it is identified deficiency in the main methodology. The code structure is assembled in MATLAB® and performs the calculation in a bottom-up manner, that is, by analyzing the aerodynamic, geometric and environmental effects on the drag of all aircraft components. After this, the code summs-up the results and, finally, the complete aircraft class 2 drag polar is obtained. The code validation for four aircraft shows that the differences between the obtained results and the real aircraft are, in general, lesser than 7% in total drag, a good value for the preliminary design phase. To complement the code validation, the results obtained are also compared with commercial software like Roskam's "Advance Aircraft Analysis" (AAA) and TsAGI's "Boundary Layer Wing Fuselage" (BLWF). Therefore, the developed computational code is a useful contribution tool for situations that require quick and reliable estimations of aircraft drag.*

Keywords*: aircraft design, drag coefficient, performance, drag polar calculation*

1. Introduction

The drag polar is an equation that connects the lift and drag forces that are actuating on the airplane during its whole trajectory, fact that makes it essential for the calculation of airplane performance, since the variables that control the performance, such as the fuel consumption, flight time and load capability, are deeply connected to the amount of drag produced due to the airplane geometry and the lift required for a successful mission. There are, nowadays, several methodologies that estimate drag polar. The references cited in the end of this work hold large amount of information on that subject, providing a good background for the reader. There are also several software that estimate drag polar, of which we can mention two of them: the Advanced Aircraft Analysis (AAA) from DAR Corp. and the Digital USAF Stability and Control (DATCOM). However, the program code that makes all calculations and considerations of the adopted methodology to achieve the drag polar is not frequently available. Thus, the need for this work arose because both professional airplane designers and students of aeronautic engineering during several times face the necessity to modify the program code in order to either change the imposed conditions by the current methodology or even to change the methodology itself and the output of data to achieve better results, problem that the author himself had faced during the aeronautic design phase of the professional master degree course of the Engineering Specialization Program (PEE-EMBRAER/ITA). Another great advantage of owning such a code is the possibility to include it as a subroutine of other program codes, such as, for example, in a Multi-disciplinary Optimization (MDO) applied to aircraft design. Thereafter, the owning of such a program code provides, besides the convenience inherent from commercial software, like better speed and reliability on the drag polar calculation, the possibility to modify the adopted considerations and methodologies, warranting more freedom for the input of data. The main methodology is the Dr. Jan Roskam's, professor from Kansas University, because, beside of the fact that it is already an acknowledgeable method, the author of this work had been in contact with him via video conference during PEE. Regarding the code, it was intended to assemble it under MATLAB®, once it is becoming the standard language adopted by aeronautic engineers of the majority aircraft manufacturers. The so called POLARISc2 code was developed to calculate the subsonic and transonic class 2 drag polar (the class 2 drag polar is that which evaluates each aircraft component drag) using semi-empirical methods that provide results as close as possible to reality and to be used during the preliminary design phase. It will be presented the code application for four aircraft and its validation by the comparison with real results. Let's make it clear that this work is part of the professional master degree thesis of the author, thereafter, it is presented here only the main results obtained. The complete version can be found in (Takara, 2004).

2. Development

2.1 Methodology

As mentioned before, the main methodology used herein is the Dr. Jan Roskam's and it is based on (Roskam, 1990). Nevertheless, other methodologies like Torenbeek, TsAGI, Hoerner are also considered in some calculations whenever it was identified deficiency on the main methodology. This way, it can be considered that the code developed by the author, the so called POLARISc2, is a software that uses the "best practices" of the methodologies cited before. So, to achieve such a code that comes up with best results, a long iteration between bibliography research, computacional work on MATLAB® and validation was made. The code applies only to airplanes with essentially straight tapered wings, sweep angle not greater than 35° and aspect ratio greater than 4, consideration adopted by Professors Roskam and Torenbeek, and to flight cases where the boundary layer is completely turbulent, consideration which ignores the short range of laminar flow on the wing in high Reynolds number. The POLARISc2 is a 5,000 lines code structure assembled in MATLAB® where it is made all calculation of aircraft lift and drag characteristics necessary to obtain the final drag polar. An example of POLARISc2 output is presented in the appendix.

In Fig. 1, it will be shown the block diagram that sumarize the code structure:

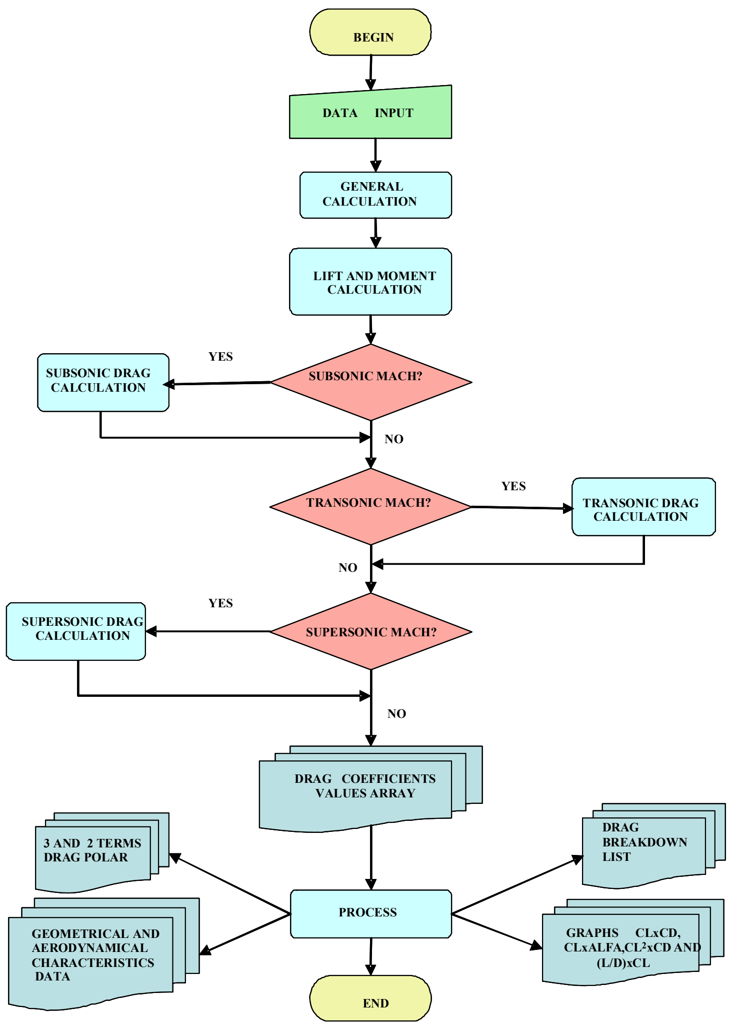

Figure 1. Block diagram for POLARISc2 code

In the next topic, it can be found the main formulation used to achieve the total airplane drag coefficient. So it is presented only formulation for lifting surfaces and revolution surfaces. For secondary components like canopy, windshield, flap, slat, landing gear and miscellaneous, the author suggests the reader find it in (Takara, 2004), (Roskam, 1990) and (Torenbeek, 1982).

The total airplane drag coefficient is normally broken down into the drag of its components. The subscripts indicate which is the component:

$$C_D = C_{D_{WING}} + C_{D_{FUSELAGE}} + C_{D_{EMPENAGE}} + C_{D_{NACELLE-PYLON}} + C_{D_{FLAP}} + C_{D_{LANDINGGEAR}} + C_{D_{CANOPYWINDSHIELD}} + C_{D_{STORES}} + C_{D_{MISCELLANEOUS}} \quad (1)$$

2.1.1 Lifting Surfaces

Following, it is presented subsonic and transonic formulations for drag coefficient determination of wings, horizontal tails, vertical tails, pylons and any other lifting surface. The majority of equations above can be found in (Roskam, 1990) and in (Bolsunovsky, 2003).

(i) Subsonic regime (M ≤ 0.6)

The wing total drag ($C_{D_{WING}}$) is represented by

$$C_{D_{WING}} = C_{D0_{WING}} + C_{DL_{WING}}, \quad (2)$$

and it is function of (i) the parasite drag ($C_{D0_{WING}}$) and (ii) the induce drag coefficient ($C_{DL_{WING}}$).

The parasite drag coefficient is defined by

$$C_{D0_{WING}} = R_{WF} \times R_{LS} \times C_{f_{WING}} \times \left(1 + L' \times \left(\frac{t}{c}\right) + 100 \times \left(\frac{t}{c}\right)^4\right) \times \frac{S_{WET_{WING}}}{S}, \quad (3)$$

and it is function of (i) the turbulent equivalent flat plate drag coefficient ($C_{f_{WING}}$) which depends on the Reynolds number, the Mach number and the surface roughness and it is used to calculate the friction drag coefficient that acts over the wing wetted area ($S_{WET_{WING}}$), (ii) the form factor (L′) that depends on the maximum relative thickness and it is used to calculate pressure drag coefficient, (iii) the mean relative thickness (t/c), (iv) the wing to fuselage fairing interference factor (R_{WF}) and (v) the lifting surface correction factor (R_{LS}).

The induced drag coefficient is defined by

$$C_{DL_{WING}} = \frac{\left(C_{L_{WING}}\right)^2}{\pi \times A \times e} + 2\pi \times C_{L_{WING}} \times \varepsilon_t \times v + 4\pi^2 \times \varepsilon_t^{\ 2} \times w, \quad (4)$$

and it is function of (i) the lift coefficient ($C_{L_{WING}}$), (ii) the aspect ratio (A), (iii) the geometrical twist (ε_t), (iv) the Oswald efficiency factor (e), (v) the induced drag factor due to a linear twist (v) and (vi) the zero-lift drag factor due to a linear twist (w). Its is considered that $C_{DL_{WING}}$ doesn´t have any compressibility effect influence until the free stream Mach number reaches 0.6.

(ii) Transonic regime (0.6 < M ≤ 1.2)

The total wing drag coefficient ($C_{D_{WING}}$) is represented by

$$C_{D_{WING}} = C_{D0_{WING}} + C_{DL_{WING}}, \quad (5)$$

and it is function of (i) the parasite drag ($C_{D0_{WING}}$) and (ii) the induce drag coefficient ($C_{DL_{WING}}$).

The parasite drag coefficient is defined by

$$C_{D0_{WING}} = \left[R_{WF} \times R_{LS} \times C_{f_{WING}} \times \left(1 + L' \times \left(\frac{t}{c} \right) + 100 \times \left(\frac{t}{c} \right)^4 \right) \times \frac{S_{WET_{WING}}}{S} \right]_{@M=0,6} + C_{DW_{WAVE}}, \tag{6}$$

and it is important to note that, to the transonic regime, $C_{D0_{WING}}$ is dependent of two different contributions: (i) the first one is the same used in the subsonic regime formula but all the calculations must be performed using the Mach number of 0.6, as indicated in the index “@ M=0,6”. It is assumed that all friction and pressure drag keep constant with Mach number along all the transonic regime. (ii) The second contribution refers to the wave drag coefficient ($C_{DW_{WAVE}}$). The author of this work realized the Roskam method for wave drag determination was giving high values and far from the reality found in wind tunnel and flight tests so it is strongly suggested the use of Professor Victor Barinov method from TsAGI because the results for all cases studied with this method showed closer to reality than Roskam´s. The author talked to both professor Roskam and professor Bolsunovsky, collegue of professor Barinov, to verify the cause of this problem, so after a lot of iterations with DAR corp., the professor Roskam company, it was realized the Roskam method doesn´t give good values for wings with thickness ratio greater than 10%; however any advice was previously inserted in Roskam books and in the software AAA. The author suggested DAR corp. the insertion of this advice because significant errors in wave drag coefficient can be generated in transonic regime.

Professor Anatoly Bolsunovsky brought from Russia a relatively simple method that gives reasonable estimations results for wave drag. Following it is presented this method that is valid for modern conventional aircraft wings in transonic regime. The wave drag coefficient is giving by the formula

$$C_{DW_{WAVE}} = 0.0035 \times \left[\frac{0.11}{(0.11 - M + M_{DD})} \right]^3, \tag{7}$$

where (M) is the free stream Mach number and (M_{DD}) is the drag divergence Mach number linked to the aircraft lift coefficient (CL. By the way, the (CL) effect is not considered in Roskam method.

The (M_{DD}) is defined by

$$M_{DD(CL \neq 0.5)} = 0.05 + M_{DD(CL=0.5)} - 0.2 \times C_L^2, \tag{8}$$

where the drag divergence Mach number to (CL) equal to 0.5 ($M_{DD(CL=0,5)}$) is giving by the formula

$$M_{DD(CL=0.5)} = 0.805 + 0.005 * \Lambda_{c/4} - \left(\frac{t}{c} \right)_{mean}, \tag{9}$$

where $(\Lambda_{c/4})$ is the wing ¼ chord sweep angle and $\left(\frac{t}{c} \right)_{mean}$ is the wing mean relative thickness.

The induced drag coefficient ($C_{DL_{WING}}$) is defined by

$$C_{DL_{WING}} = \frac{(C_{L_{WING}})^2}{\pi \times A \times e} + 2\pi \times C_{L_{WING}} \times \varepsilon_t \times v + 4\pi^2 \times \varepsilon_t^2 \times w, \tag{10}$$

and it is function of (i) the lift coefficient ($C_{L_{WING}}$), (ii) the aspect ratio (A), (iii) the geometrical twist (ε_t), (iv) the Oswald efficiency factor (e), (v) the induced drag factor due to a linear twist (v) and (vi) the zero-lift drag factor due to a linear twist (w). It can be noted that the transonic method to determine ($C_{DL_{WING}}$) is the same used in the subsonic regime. The explanation for this case is that the method presented in (Roskam, 1990) requires a lot of extrapolations that come up with bad values if compared to reality. So the author proposed the use of the subsonic method because it is simple and the effect of wave drag expected, the (CL) effect, for this regime has already considered in wave drag calculation.

2.1.2 Revolution surfaces

Following it is presented transonic and subsonic formulations to estimate fuselage and any other revolution surfaces with cylindrical shape.

(i) Subsonic regime (M ≤ 0.6)

The fuselage total drag ($C_{D_{FUS}}$) is defined as

$$C_{D_{FUS}} = C_{D0_{FUS}} + C_{DL_{FUS}}, \tag{11}$$

and it is function of (i) the parasite drag coefficient ($C_{D0_{FUS}}$) and (ii) the induced drag coefficient ($C_{DL_{FUS}}$).

The parasite drag coefficient is defined by

$$C_{D0_{FUS}} = R_{WF} \times C_{f_{FUS}} \times \left(1 + \frac{60}{\left(\frac{l_f}{d_f}\right)^3} + 0.0025 \times \left(\frac{l_f}{d_f}\right) \right) \times \frac{S_{WET_{FUS}}}{S} + C_{Db_{FUS}}, \tag{12}$$

and it is function of (i) the equivalent friction coefficient ($C_{f_{FUSELAGE}}$) that depends on the Reynolds number, the Mach number and the the surface roughness, (ii) the wetted area ($S_{WET_{FUS}}$), (iii) the form factor or "slenderness" that is the length to diameter ratio $\left(\frac{l_f}{d_f}\right)$, (iv) the wing to fuselage fairing interference factor (R_{WF}) and (v) the base drag coefficient ($C_{Db_{FUS}}$).

The induced drag coefficient is giving by

$$C_{DL_{FUS}} = 2 \times \alpha^2 \times \frac{Sb_{FUS}}{S} + \eta \times cd_c \times \alpha^3 \times \frac{S_{plf\ FUS}}{S}, \tag{13}$$

and it is function of (i) base area ($S_{b_{FUS}}$), (ii) the aircraft angle of attack (α), (iii) the reference wing area (S), (iv) the experimental cylindrical drag coefficient (cdc), (v) the plantform area ($S_{plf_{FUS}}$) and the drag ratio between a finite and infinite cylinder (η).

(ii) Transonic regime (0.6 < M ≤ 1.2)

The parasite drag coefficient is defined by

$$C_{D_{FUS}} = C_{D0_{FUS}} + C_{DL_{FUS}}, \tag{14}$$

and it is function of (i) the parasite drag coefficient ($C_{D0_{FUS}}$) and (ii) the induced drag coefficient ($C_{DL_{FUS}}$).

The parasite drag coefficient is defined by

$$C_{D0_{FUS}} = R_{WF} \times \left(C_{Df_{FUS}} + C_{Dp_{FUS}}\right) + C_{Db_{FUS}} + \left(C_{D_{WAVEFUS}}\right) \times \frac{S_{FUS}}{S}, \tag{15}$$

and it is function of (i) the equivalent friction ($C_{Df_{FUSELAGE}}$), (ii) the wetted area (S_{FUS}), (iii) the wing to fuselage fairing interference factor (R_{WF}), (iv) the base drag coefficient ($C_{Db_{FUS}}$) and (v) the pressure drag coefficient ($C_{Dp_{FUS}}$).

The induced drag coefficient is giving by

$$C_{DL_{FUS}} = \alpha^2 \times \frac{Sb_{FUS}}{S} \tag{16}$$

and it is function of (i) base area ($S_{b_{FUS}}$), (ii) the aircraft angle of attack (α) and (iii) the wing area (S).

The results of this transonic methodology showed indifferent with the increase of angle of attack, so it was detected the same of occurred in the transonic wing where the subsonic methodology gives better results if compared to reality. So the subsonic method was adopted again. This fact could be verified by the author when he compared wind tunnel test data of several aircraft induced drag.

It is considered that the fuselage wave drag coefficient $C_{D_{WAVEFUS}}$ has effect only at Mach number over than 1.0. This drag is estimated with a graph found in (Roskam, 1990) on page 50.

3. Results and validation

Next, it is shown a summary of the results obtained with POLARISc2 and its appropriate validation.

The validation was divided in two parts: the first is a comparison with AAA and BLWF software results and the second one refers to the comparison with wind tunnel and flight tests results. The aircraft used to this validation are four conventional regional jets and due to information security, their real names will be omitted and adopted the identification of aircraft 1, 2, 3 and 4. All the flight conditions information necessary for analysis are mentioned in the tables or in the text.

Table 1 presents the difference in (%) between the AAA and POLARISc2 results for the aircraft 1 @ Mach number 0.6, altitude of 35000ft and lift coefficient of 0.4. Note the short difference on the total drag coefficient (CD). The results compared were the wetted area (Swet), the component zero-lift drag including wave drag effect (CD0), the component induce drag (CDL) and the component total drag (CD).

Table 1. Cruise results comparison @ M=0.6 with AAA

	Swet (%):	CD0 (%):	CDL (%):	CD (%):
Wing	-0.09	-3.03	0.00	-1.45
Fuselage	0.35	0.00	0.00	0.00
Horizontal Tail	-1.71	-4.76	0.00	-4.76
Vertical Tail	10.94	6.67	0.00	6.67
Pylon	*	*	*	-5.01

obs:* Comparison is not possible because AAA doesn´t provide this value.

Table 2 presents the difference in (%) between the AAA and POLARISc2 results for the aircraft 1 @ Mach number 0.8, altitude of 35,000ft and lift coefficient of 0.4. Note the considerable difference on the total drag coefficient (CD). The explanation for this discrepancy is that AAA estimates for induced drag and wave drag provide high values that are not representative if compared to reality. As mentioned before, the author changed the POLARISc2 main methodology due to achieve better results.

Table 2. Cruise results comparison @ M=0.8 with AAA

	Swet (%):	CD0 (%):	CDL (%):	CD (%):
Wing	-0.09	-49.72	-40.18	-46.08
Fuselage	0.35	1.35	0.00	1.35
Horizontal Tail	-1.71	-31.25	0.00	-31.25
Vertical Tail	10.94	6.25	0.00	6.25
Pylon	*	*	*	-24.02

obs:* Comparison is not possible because AAA doesn´t provide this value.

Table 3 presents the differences in (%) between the BLWF and POLARISc2 results for the wing-body configuration of aircraft 1 @ Mach number 0.6 and 0.8, altitude of 35,000ft and lift coefficient of 0.4. Note the short difference on the summation of the induced, wave and zero-lift drag. The results compared were wing-body the lift coefficient (CL_{wb}), the zero-lift drag (CD0), the wave drag (CDwave). the induce drag (CDL) and the component total drag (CD).

Table 3. Cruise results comparison @ M=0.6 and 0.8 with BLWF

	CLwb (%):	CD0 (%):	Cdwave (%):	CDL(%):	Drag sum(%):
Difference @ M=0.6	0.00	-3.10	0.00	4.74	2.41
Difference @ M=0.8	0.00	-7.76	8.95	1.66	-0.81

Table 4 presents the differences in (%) between the wind tunnel/flight tests and POLARISc2 results for aircraft 1, 2, 3 and 4. Note the short difference on the total drag coefficient (CD). It is important to clarify that although the results of CD are reasonable, the results of the total aircraft zero-lift drag coefficient (CD0) and the total aircraft induced drag coefficient (CDL) for flapped configurations with deflection angles below 10° don´t presented good values because for this deflection range POLARISc2 is supposed to make several extrapolations that can lead to significant errors.

Table 4. Comparison with wind tunnel and flight test data

Aircraft	Regime	Altitude(m)	Landing gear	1st. Flap(°)	2nd. Flap(°)	Slat(°)	Mach	CG(%)	Reynolds	CL	CD(%)
Aircraft 1	Cruise	6641	UP	0	0	0	0.50	10	20000000	0.40	4.93
Aircraft 1	Cruise	10887	UP	0	0	0	0.80	10	20000000	0.40	6.19
Aircraft 1	Cruise	122	UP	35	15	25	0.20	10	14909686	1.77	6.78
Aircraft 1	Take off	30	DOWN	5	5	15	0.23	10	17665964	1.31	4.75
Aircraft 1	Take off	122	UP	10	10	15	0.22	10	16874062	1.39	2.43
Aircraft 1	Take off	122	UP	20	12	15	0.21	10	15730058	1.59	2.81
Aircraft 1	Take off	122	UP	20	12	25	0.20	10	14781738	1.80	3.01
Aircraft 1	Landing	30	DOWN	20	12	25	0.19	10	14509159	1.67	2.13
Aircraft 1	Landing	30	DOWN	35	15	25	0.18	10	13826197	1.84	5.59
Aircraft 2	Cruise	1178	UP	0	0	0	0.30	12	17580000	0.40	0.40
Aircraft 2	Cruise	10453	UP	0	0	0	0.78	12	17580000	0.40	0.82
Aircraft 2	Take off	4000	UP	9	0	0	0.30	12	13442847	1.50	2.97
Aircraft 2	Take off	3417	DOWN	9	0	0	0.27	12	12807195	1.50	5.26
Aircraft 2	Take off	3039	UP	22	0	0	0.24	12	11806529	1.50	0.59
Aircraft 2	Take off	3054	DOWN	22	0	0	0.23	12	11298043	1.50	5.14
Aircraft 2	Take off	3095	DOWN	45	0	0	0.23	12	11253348	1.50	2.13
Aircraft 3	Cruise	1178	UP	0	0	0	0.30	15	17580000	0.40	3.01
Aircraft 3	Cruise	10453	UP	0	0	0	0.78	15	17580000	0.40	1.57
Aircraft 4	Cruise	9754	UP	0	0	0	0.40	25	6777408	0.38	6.45

obs: POLARISc2 was compared with wind tunnel test data only in the aircraft 1 analysis. For the other aircraft, it was compared with flight test data.

4. Conclusion

It was developed a computational code called POLARISc2 that estimates the aircraft drag polar using semi empirical methods for preliminary design phase purposes. Roskam was considered as the main methodology but whenever identified deficiency on it, other methodologies like Torenbeek, TsAGI, Hoerner were used as an alternative to achieve better results. The code validation was made by comparing POLARISc2 with data achieved by AAA and BLWF software and wind tunnel/flight test data. After a long iteration between bibliography research, computacional work on MATLAB® and validation, the results obtained with POLARISc2 showed very close to reality. In general, for the cruise regime, it was found differences with reality not greater than 6,5% for the total aircraft drag, and for flapped configurations differences were not greater than 7%. It was verified that the code is valid only on the following conditions: (i) airplanes with essentially straight tapered wings, (ii) sweep angle not greater than 35°, (iii) aspect ratio greater than 4, (iv) boundary layer completely turbulent and (v) flap deflections over than 10°. The main modifications proposed by the author in the main methodology were the insertion of the TsAGI wave drag method and changes on induced drag estimation of revolution surfaces and lifting surfaces in transonic regime.

It is considered that 8% of difference with reality in total drag is a reasonable result in preliminary design phase. All the POLARISc2 results showed values below 7% of difference. So, it can be concluded that POLARISc2 code is a useful and valid tool for situations that require quick and reliable drag estimations.

5. Acknowledgements

EMBRAER and the PEE coordination;
Professor Dr. Anatoly Bolsunovsky from TsAGI-Russia;
Professor Dr. Jan Roskam from Kansas University.

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7. Responsibility notice

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

8. Appendix

Following, it is presented a simplified example of POLARISc2 output.

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-------------------------------------------------------------------------------------------
                              PARABOLIC DRAG POLAR EQUATION
                                (M=0.20,Reynolds=14909686)
-------------------------------------------------------------------------------------------
A/C 3-therms drag polar:....  CD=0.11377-0.03839*CL+0.05917*CL^2
A/C 2-therms drag polar:....  CD=0.09749+0.04096*CL^2
-------------------------------------------------------------------------------------------
                                  DRAG COEFICIENT BREAKDOWN
                                (M=0.20,Reynolds=14909686)
-------------------------------------------------------------------------------------------
                             Parasite:      Wave:                Induced:
WING:.......................  0.00581      0.00001      0.04411*CL^2-0.00003*CL+0.00029
FUSELAGE:...................  0.00698      0.00000      0.01132*CL^2-0.02974*CL+0.01880
HORIZONTAL TAIL:............  0.00193      0.00000      0.00015*CL^2+0.00001*CL+0.00000
VERTICAL TAIL:..............  0.00155      0.00000      0.00000
CANARD:.....................  0.00000      0.00000      0.00000
NOZZLE:.....................  0.00000      0.00000      0.00000
WINDMILLING:................  0.00000      0.00000      0.00000
STORES:.....................  0.00000      0.00000      0.00000
MISCELLANEOUS:..............  0.00000      0.00000      0.00000
ELEVATORS:..................  (It was included in Trim Drag)
SPOILERS/SPEED BRAKES:......  0.00000      0.00000      0.00000
LANDING GEARS:..............  0.00000      0.00000      0.00000
INLET:......................  0.00015      0.00000      0.00000
CANOPY:.....................  0.00000      0.00000      0.00000
WINDSHIELD:.................  0.00020      0.00000      0.00000
PYLONS:.....................  0.00036      0.00000      0.00000
NACELLE:....................  0.00307      0.00000......
0.00359*CL^2-0.00863*CL+0.00498
FLAPS:......................  0.05436      0.00000      0.01534
                              -------------------      ---------------------------
A/C Total drag:.............      CD0=0.07443           CDL=0.05917*CL^2-0.03839*CL+0.03934
```