Determination of the operational parameters values for Airbus A300-600ST Beluga aircraft on the basis of CFD tests

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Abstract. The article presents a method for estimating the values of basic operational and aerodynamic parameters of an aircraft. It contains a multistage analysis of CFD test results for the Beluga Airbus A300-600ST model. The first step of the method is to determine the values of aerodynamic parameters such as lift coefficient, drag coefficient, lift force and drag force in specific flight conditions. A comparative analysis of the coefficients of lift and drag force depending on the angle of attack of the aircraft allowed the estimation of the optimal angle of attack of the Airbus A300-600ST Beluga. In the next step, the operational values and the maximum flight ceiling of the aircraft were determined. For this purpose, the results of CFD simulation tests for the optimal angle of attack of the aircraft were used. This article allowed determining the characteristics of the components of aerodynamic force of an airplane depending on the angle of attack, flight altitude and flight speed, determining the optimal angle of attack of the aircraft and calculation of the optimal and maximum flight ceiling values of the Airbus A300-600ST Beluga.

1 Introduction

Aircraft perfection is a parameter that can help determine the optimal angle of attack for an aircraft and its operating altitude. An airplane is aerodyne, which means it is heavier than air and aerodynamic force must be generated in order to start flight. The components of the aerodynamic force are the lift and drag force of the aircraft. To generate lift, the plane must move in relation to the surrounding medium. The force responsible for giving an airship speed is called the thrust [2]. It counteracts the drag force of the aircraft. The forces acting on an airplane during flight are shown in Fig. 1. [7,8].

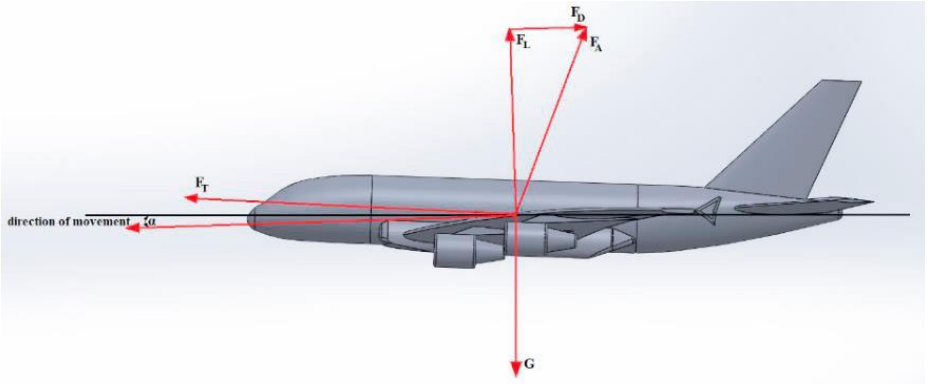

Fig. 1. Forces affecting the aircraft during horizontal flight: G – gravity force, F_T – thrust force, F_A – total aerodynamic force, F_L – lift force, F_D – drag force, α – angle of attack [5].

The lift force is created as a result of the medium flowing around the airfoil. This flow accelerates the air stream over the profile and slows down the stream under the profile, which leads to the formation of a pressure difference between the top and bottom of the airfoil [1, 9]. The generation of the lift is described by the equation (1) [3].

$$F_L = C_L \cdot \rho \cdot S \cdot \frac{V^2}{2} \tag{1}$$

A drag force acts on a moving object in the opposite direction to its direction of movement. It affects the fuel consumption of the aircraft and its flight properties. The drag force can be described by the equation (2) [4, 6].

$$F_D = C_D \cdot \rho \cdot S_X \cdot \frac{V^2}{2} \tag{2}$$

Where:
F_L – lift force value [N],
C_L – lift force coefficient,
F_D – drag force value [N],
C_D – drag force coefficient,
ρ − density of the medium [kg/m^3],
S – wing surface[m^2],
S_X – projection surface per plane perpendicular to the velocity vector relative to the flow of the medium [m^2],
v – object velocity relative to the medium [m/s]
A 3D model of the Airbus A300-600ST Beluga was used to determine the characteristics of the aircraft operating parameters.It is a version of the standard Airbus A300-600 wide-body airliner modified to carry aircraft parts and oversized cargo. Some technical data on Airbus A300-600ST Beluga are presented in the table below.

Table 1. Technical specifications of the Airbus A300-600ST Beluga [10].

Parameter	Unit	Value
Crew		2
Length	[m]	56.15
Wingspan	[m]	44.84
Height	[m]	17.24
Outer diameter of the fuselage	[m]	7.31
Inner diameter of the fuselage	[m]	7,04 - 7,08
Empty weight	[kg]	86500
Maximum takeoff weight	[kg]	155000
Cargo section volume	[m^3]	1500
Engines		2 x General Electric CF6-80C2A8
Thrust	[kN]	257 each
Maximum velocity	[m/s]	240

2 Methodology

The first step in the method for determining the operational parameters of the aircraft was to create a three-dimensional model of the Airbus A300-600ST Beluga in real dimensions, and then subject it to a series of numerical CFD simulations. The model was made with attention to the characteristic geometric features of the aircraft, including type of aviation profile, wing angle. This aviation profile is NACA 63-215.
CFD numerical simulations were divided into two stages, the first of which was the stage of determining the optimal angle of attack for α. For this purpose, a series of CFD tests were carried out under the following conditions: H=0, v=200m/s, P=101325 Pa, T=293K. These conditions correspond to the conditions at 0 m above sea level. The flow model that was used was the turbulent k-epsilon model for compressible gas. The simulations were carried out for various angles of attack of the aircraft in the range from $\alpha = 8^o$ to $\alpha = 20^o$ in steps of 2^o. The values of the lift force F_L and the drag force F_D were determined by analyzing the values of the forces acting in the axes of the model coordinate system.

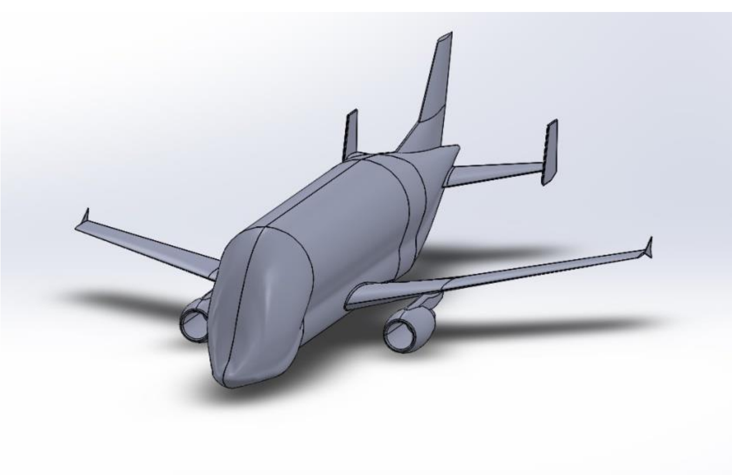

Fig. 2. Airbus A300-600ST Beluga model for research purpose.

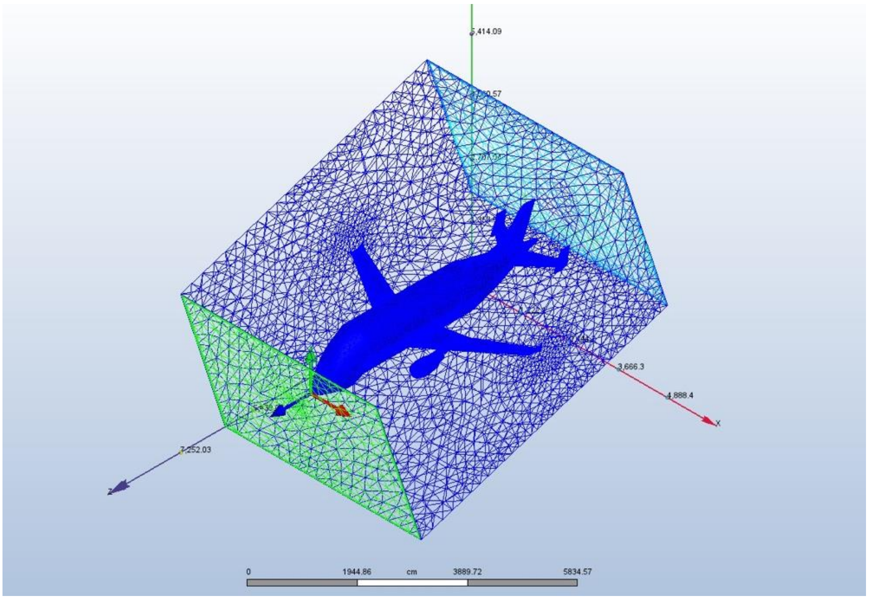

Fig. 3. Coordinate axis system, air model grid and pressure distribution during CFD simulation.

The second stage includes simulations and analysis of simulation results in order to determine the operational and maximum altitude of the aircraft. For this purpose, a series of flow simulations were carried out in flight conditions corresponding to the conditions at various altitudes, based on the conditions of the standard atmosphere for the angle of attack α=18°, speed v=240 m/s and altitudes H=9000, 11000, 13000, 15000 , 17000, 18000 m. As in the case of the first stage of the research, the values of the lift force F_L and the drag force F_D were determined using the values of the forces acting in the axes of the model coordinate system. The presented method can be used as an auxiliary tool in the aircraft design process and in determining its characteristic operational parameters by the manufacturer.

3 Results

The performed CFD simulations allowed, using the dependencies (1) and (2), to determine the lift coefficient C_L and the drag force coefficient C_D (Table 2). The optimal angle of attack is understood to be the angle at which the airplane generates the highest value of lift F_L while generating the lowest value of drag F_D. The analysis of the test results led to the conclusion that the optimal angle of attack for the Airbus A300-600ST Beluga is α = 18°.

Table 2. Results of CFD simulations and data obtained from calculations.

α [°]	F_L [N]	F_D [N]	S [m2]	Sx [m^2]	ρ[kg/m^3]	C_L	C_D	k	v [m/s]
8	6201630	1472940	260	180	1,2	0,99	0,34	2,91	200
10	8165990	1767050	260	181	1,2	1,31	0,41	3,22	200
12	8254590	1709845	260	181	1,2	1,32	0,39	3,36	200
14	8311270	1617200	260	182	1,2	1,33	0,37	3,60	200
16	8843400	1241090	260	183	1,2	1,42	0,28	5,01	200
18	8982870	891589	260	184	1,2	1,44	0,20	7,13	200
20	3567890	12047281	260	185	1,2	0,57	2,71	0,21	200

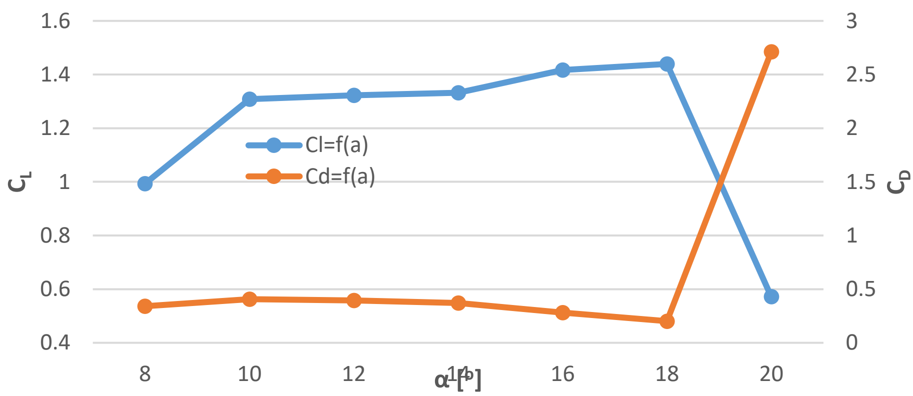

Fig. 4. Values of lift force CL and drag forces CD coefficients as a function of the angle of attack α.

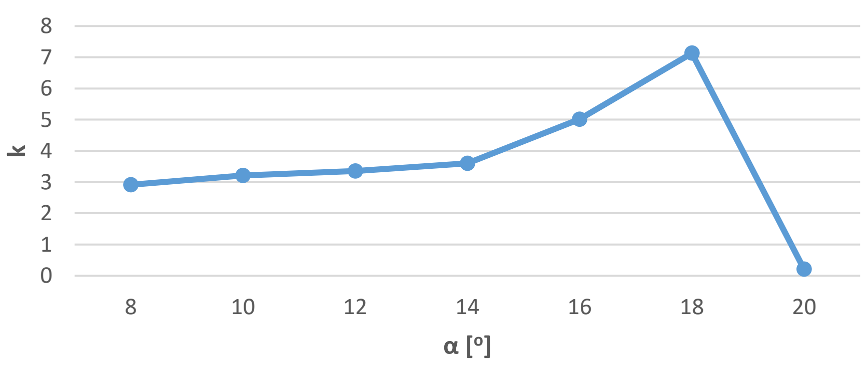

Fig. 5. Value of the lift-to-drag ratio k as a function of the angle of attack α.

In the next step of the research, the maximum flight altitude of the considered aircraft was estimated. The values of the lift force F_L, the drag force F_D, the coefficients of the lift force and the drag C_L and $C_D$are presented in Table 3.

Table 3. Results of CFD simulations and data obtained from calculations.

Altitude [m]	FL [N]	FD [N]	S [m^2]	Sx [m^2]	ro [kg/m^3]	CL	CD	k	v [m/s]
9000	2530070	455077	260	184	0,4544	0,74	0,19	3,93	240
10000	2281510	313868	260	184	0,4135	0,74	0,14	5,14	240
11000	2065960	296398	260	184	0,3532	0,78	0,16	4,93	240
12000	1976560	208756	260	184	0,2986	0,88	0,13	6,70	240
13000	1700440	197764	260	184	0,2569	0,88	0,15	6,08	240
14000	1529000	175346	260	184	0,2145	0,95	0,15	6,17	240
15000	1398870	150146	260	184	0,1846	1,01	0,15	6,59	240

The data contained in Table 3 allowed for the determination of the aerodynamic perfection coefficient k. It is understood as the lift coefficient - to drag coefficient ratio. The maximum value of the k coefficient indicates that the airplane has reached the operating flight altitude. Analyzing the determined data, it can be concluded that the operational ceiling of the Airbus A300-600ST Beluga H_{op}=12,000 m.

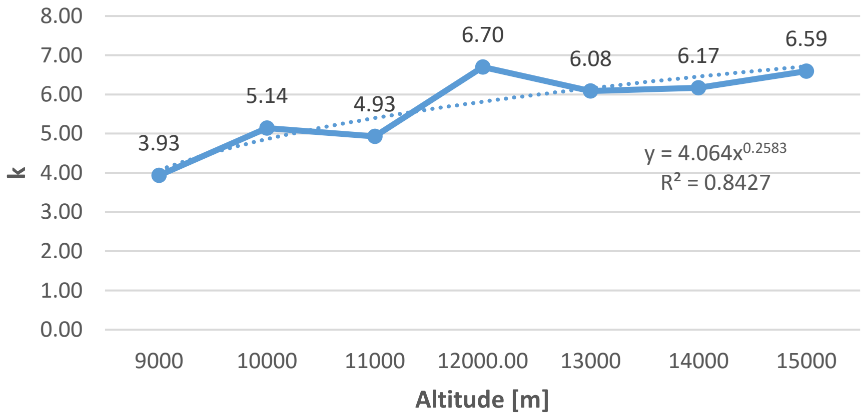

Fig. 6. The value of lift coefficient -to-drag coefficient ratio k as a function of the flight altitude H of the Airbus A300-600ST Beluga.

In order to determine the maximum altitude of the Airbus A300-600ST Beluga aircraft, the lift force values generated during the flight at a certain altitude should be compared with the maximum take-off weight of this airplane of 155,000 kg. In order to accurately determine the maximum flight altitude, the equation of the function describing the value of the generated lift force F_L and drag force F_D depending on the flight altitude was determined. The calculations led to the conclusion that the maximum operating altitude of the Airbus A300-600ST Beluga H_{max} = 14,665 m.

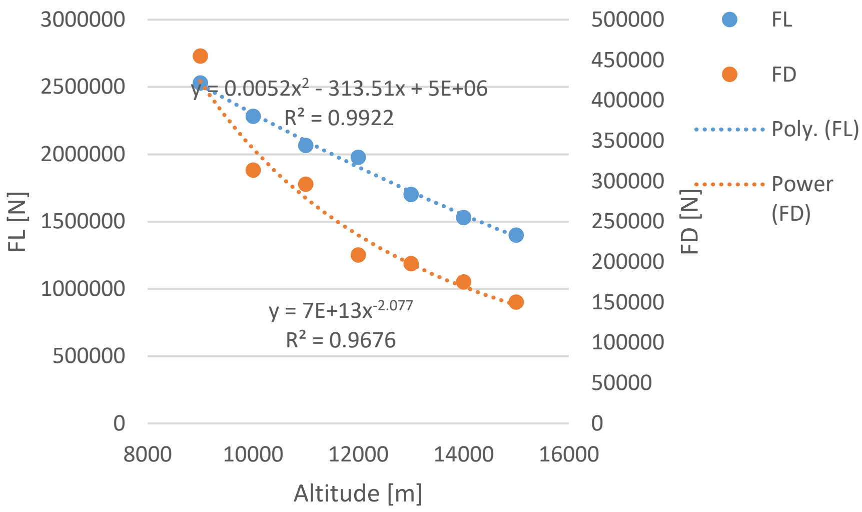

Fig. 7. The value of the lift force F_L and drag force F_D as a function of the flight altitude H based on the tests of the Airbus A300-600ST Beluga aircraft model.

4 Conclusions

The method of determining the value of the aerodynamic force, using CFD simulations, proposed in the article allowed for the determination of the optimal angle of attack, operating flight level and maximum altitude of the Airbus A300-600ST Beluga aircraft. The conducted research allowed to determine the optimal angle of attack for the aircraft at the level of $\alpha = 18°$. The second part of the research included numerical analyzes of the aircraft flow in flight conditions with an angle of attack α = 18o and a variable flight altitude in the range from 9000 to 15000 m. This allowed for the determination of the equation of the function describing the dependence of the generated lift force F_L and drag force F_D on the flight altitude. Knowing the function equation, the maximum flight altitude of the Airbus A300-600ST Beluga H_{max} = 14665 m was determined. The analysis of the test results also led to the determination of the lift and drag coefficients for all tested flight altitudes, the quotient of which gives the value of the coefficient of aerodynamic excellence k. The highest k value was recorded for a flight altitude of 12,000 m, which means that it is the optimal operating altitude of the aircraft.

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