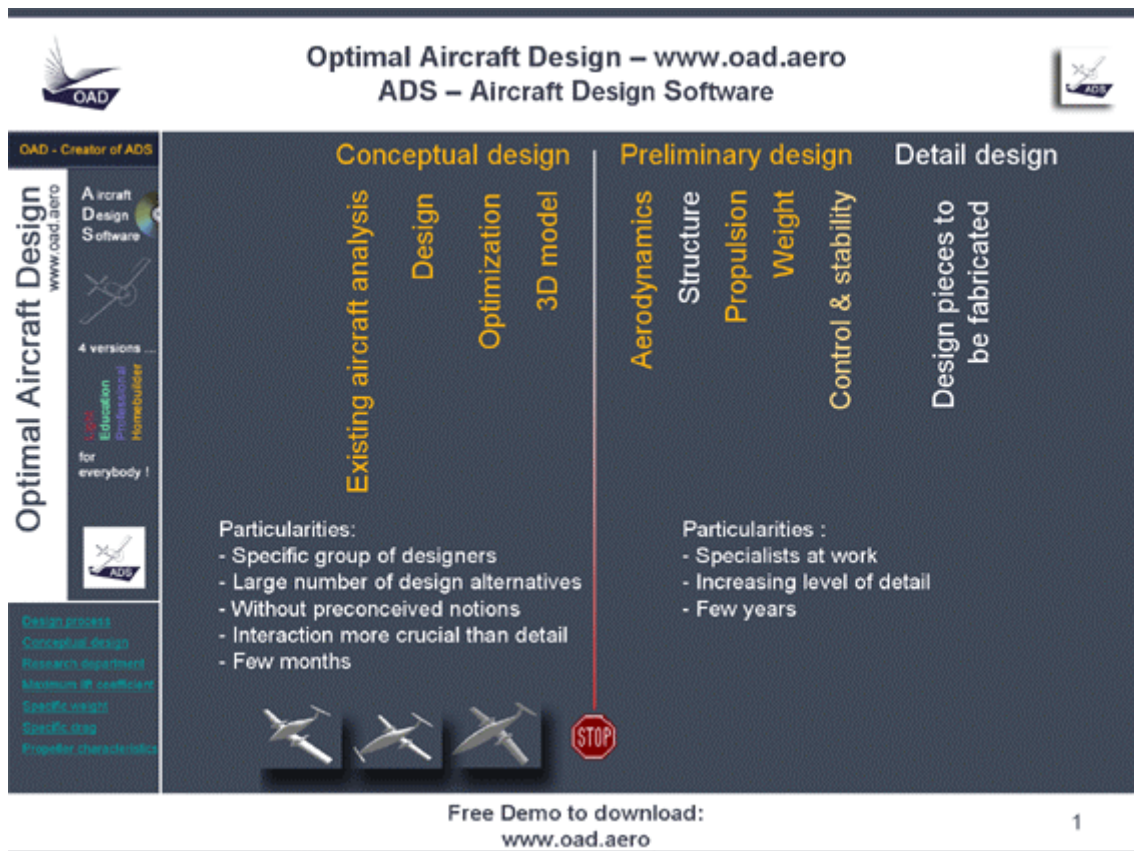


1 General description

OAD

OAD was set up to develop and sell ADS, which stands for Aircraft Design Software. This software is dedicated to take you through nearly the entire aircraft design process for any aircraft configuration including light aircraft, UAV and commuter category aircraft.



Optimal Aircraft Design – www.oad.aero
ADS – Aircraft Design Software

Conceptual design
 Existing aircraft analysis
 Design
 Optimization
 3D model

Preliminary design
 Aerodynamics
 Structure
 Propulsion
 Weight
 Control & stability

Detail design
 Design pieces to be fabricated

Particularities:

- Specific group of designers
- Large number of design alternatives
- Without preconceived notions
- Interaction more crucial than detail
- Few months

Particularities :

- Specialists at work
- Increasing level of detail
- Few years

Design process:
 Conceptual design
 Research department
 Maximum lift coefficient
 Specific weight
 Specific drag
 Propeller characteristics

Free Demo to download:
www.oad.aero

1

When you plan to design an aircraft, or anything else, nearly always you will follow a similar pattern. The design process is divided in 3 major phases: the conceptual design, the preliminary design and the detail design. In very large companies, like Boeing or Airbus, the conceptual design is made by a specific group of engineers trained for this job. Their job is to find the optimum aircraft configuration to fulfill the customer's specifications. No prejudice, every solution must be considered to be feasible. At the end of their work, the aircraft general layout is frozen. No major modification can be done without the risk of scrapping the whole project. It is often mentioned that 95% of the development costs are determined by the choices made during the conceptual design phase. During the preliminary and detail phase, more and more specialists come into play and the level of detail is steadily increased.

During the conceptual design, you start from specifications, your own specifications, or specifications coming from a customer, and the objective is to determine the main characteristics of the aircraft, its dimensions and how much power is needed to reach the expected performances.



When you plan to design something new, the first thing you have to do is to look around you to seek something similar to the thing you plan to design. And you will analyze it in detail. After analysis, you will know everything about its performances, dimensions, masses, aerodynamics, quality and so on. This analysis is vital for both the engineer and salesman. The engineer will come up with an order of magnitude, the salesman will be able to better compare the new product with its competitors.

Then, the next step is to design the aircraft. In this phase, starting from specifications you will have to find the characteristics of the aircraft, its dimensions and how much power is necessary to reach the expected performances. You will find the characteristics of the aircraft (dimensions and power) but are you sure that they are the optimal characteristics, the characteristics that fulfill in an optimal way to the specifications. Certainly not!

You play with a large number of parameters. You will be very lucky to immediately find the optimal combination of these parameters. It is then necessary to make an optimization in order to find the best combination.

It is also very useful to visualize on a 3D model the new design in order to make a rapid control and to check that there is no interference between the different parts of the aircraft.

With ADS, You can do all of this very quickly and efficiently in the same software.

Demo

ADS is a windows application. You have the main window. On the left-hand side you have a direct access menu to go, with a single click, to the main modules. On the right-hand side you have the tutorial that explains how to tour the software, and you have the On-line help window that helps you to enter the information in the data acquisition windows.

The first module, remember the design process, is the Analysis module. In this module, we analyze in detail an existing aircraft in order to know its characteristics. If you fill out all of the field, ADS will be able to compute lots of very useful information: the aerodynamic quality of the whole aircraft, the specific weights, the specific drag, the propeller characteristics and efficiency, and so on. Look at the On-line help window. And let's go to the Wing, Trailing edge devices acquisition window. You have to select the TED Type. The On-line help gives you the right definition of the term, the units in use, some historical values, shows you a drawing, writes an equation if the information you have to enter is the result of an equation, and gives you additional information about the term. Before starting the run, let's have a look at the performances window. In cruise we only entered the flight speed, weight and altitude. Let's start the run. The results of the whole aircraft are displayed in the first window. But you can also display the information related to a specific item. Let's have a look on the wing. Let's have a look on the weight. The specific weights have been calculated. Let's have a look on the performances in cruise. Remember, you only entered 3 items (speed, weight, altitude) and because it has been able to compute the total wetted area of the aircraft, it can compute a lot of additional things like the propeller characteristics (efficiency, ...), the aerodynamic efficiency, the specific drags.

Now let's have a look again at the acquisition windows. You probably ask yourself: "where can I find all the information I have to enter in the software?" The data sources are: the press articles, the manufacturer's website, the aircraft owner's manual, and a 3-view drawing. We have developed a digitizer to exploit 3-view drawings. You scan a picture and generate a bitmap file. Then you import the file in ADS. You georeference this image. This is done by giving the aircraft length and the wing span for example. And then you can exploit this image and retrieve a length, a length ratio, an angle, and a surface. This is very simple and very accurate. And you cannot imagine how many information you can extract from a plain drawing.

During the design process we advise you to analyze at least 10 aircraft before starting your own design.

When you have analyzed about 10 aircraft, you start to design your own aircraft using the design module of ADS. You have to input about 70 items. A progress bar shows the input you have already entered and how many are remaining. We invite you to consult the On-line help window to enter the



right value, you may catch some information from engines, airfoils and tires database. All the information you have to enter is necessary to compute the performances of the aircraft, its empty weight, the specific drags, the centre of gravity position and the 3D model. When everything has been defined, you start the run. The calculation will take a while. During this time, ADS computes the main dimensions of the aircraft, its performances during the cruise, the takeoff, and the climb. If we design a twin-engine aircraft, the performances will also be computed with one engine inoperative. The centre of gravity positions are computed. The stability is determined and the 3D model is generated.

When the results are displayed, the first thing we have to do, is to check the 3D model and watch if the 3D model looks like an aircraft. Let's say a few words about the 3D model. This module runs like a light expert system. For example, in the acquisition window, you have never introduced information about the landing gear except the tire size. The length of the gear has been defined from the propeller diameter and the minimum propeller ground clearance. The lateral position is defined so that the angle formed by a line connecting the wing tip and the contact point of the main gear with the ground and the horizontal is greater than a minimum value. The longitudinal position of the gear is defined according to the centre of gravity position of the aircraft. The shape of the fuselage is generated to be aerodynamically clean and to localize the main bulkhead at the trailing edge of the wing, ... The results are presented in the same manner. The characteristics of the wing, the tails and the fuselage are presented in some specific windows. The specific weights are also given. The performances for cruise, climb and takeoff are displayed. The speed polar is given in a table as well as in a graph. The centre of gravity is displayed in a graphical way. The specific CG are displayed. The CG position of the aircraft at empty weight and at all-up weight are displayed. The fore and aft limits are also displayed. The CG can never go beyond these limits if it is to remain stable as well as controllable.

When you have designed an aircraft and you think that the selected configuration is the right configuration, you have to check its feasibility. This is done using the Statistical module. You compare your design with all the others that are contained in the database. You select one or two parameters and you visualize the information in a graph. If your new design is better than the best aircraft you probably have been too optimistic with the data you entered in the acquisition window (too low friction coefficient, ...). On the other hand, if your design is far worse than the worst, you may question yourself if it is worthwhile to spend time and money to develop something that would not be possible to sell. If you are between these two limits you will probably succeed in your design. This final check is vital in the design process.

Let's say a few words about the databases

You have aircraft, engine and airfoil databases included in ADS. To access to the engine database, click on the left menu. You select an engine in the list. And all the information about this engine is displayed in the window. This information concerns the dimensions of the engine, the different systems that are part of it, its weight, its performances. The performances curves are also displayed.

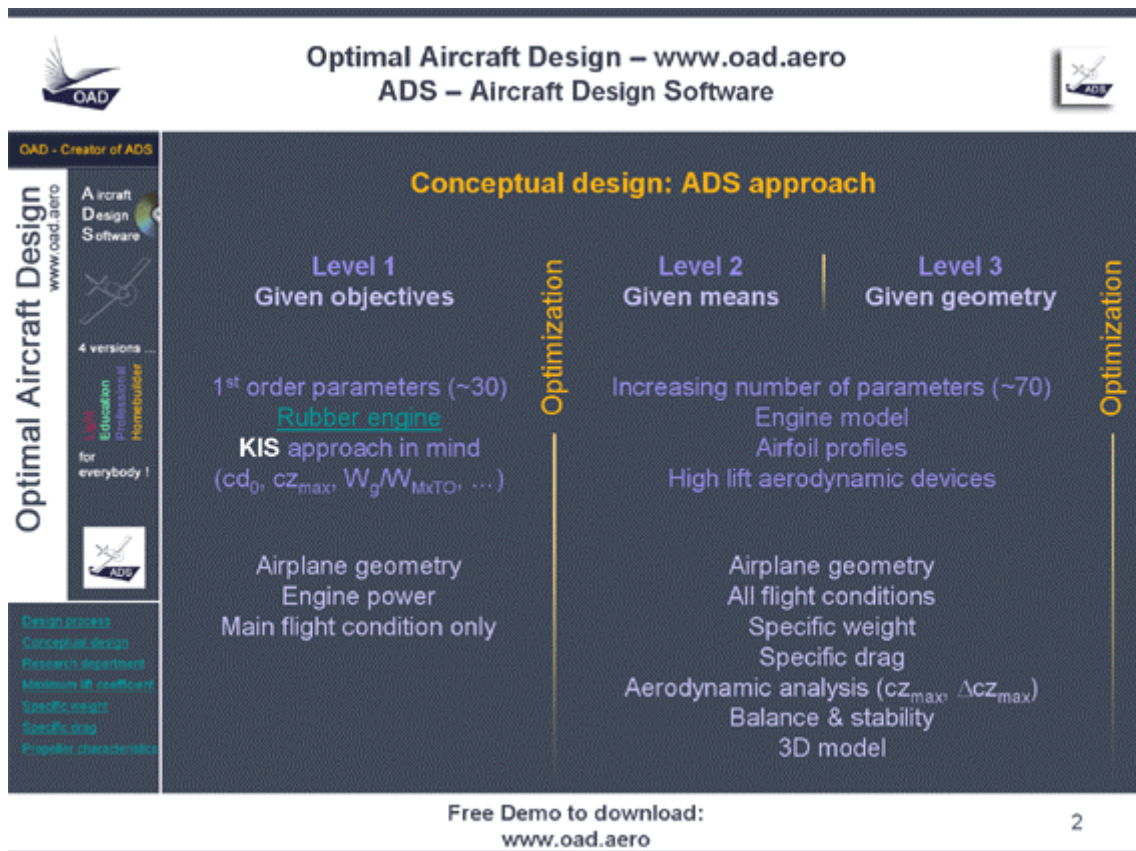
In the same way, click on the left menu to access to the airfoil database. You select an airfoil in the list. And all the information about this airfoil is displayed in the window. This information concerns the coordinates of the airfoil profile and the aerodynamic data. The aerodynamic data are given for different Reynolds numbers. The design module of ADS uses at any time this information to compute, at a given flight speed, the drag and the lift of any lifting surface.

That ends this very quick tour of ADS. If you wish, we can go further in the design module itself or we can speak about the algorithms used to compute the specific weights, the specific drags or the propeller efficiency. We can also simulate the work done in a research department of a company.

2 Conceptual design

Introduction

With ADS the design process in itself is divided in 3 phases (3 levels). The first level is called the design with “given objectives”. The second level is called the design with “given means”. And the third level is called the design with “given geometry”.



Level 1

For designing a new aircraft, the designer may start with a set of specifications and use this information as input data. His goal is to find the parameters of the most optimized aircraft configuration which will meet the design specification.

Initially, the designer should start without prejudice and keep all options open. He should consider any imaginable and possible solution (fixed or retractable landing gear, two stroke or four stroke engine, rotary or turbine engine, taildragger or tricycle landing gear, canard or tandem configuration, etc...), including those which may appear unconventional.

To achieve this, he will study a limited set of parameters. Only “1st order parameters” will be evaluated, i.e. those parameters which will significantly affect the results. For example, he will not assume a predetermined engine, but instead he will assume an engine of a predetermined technology.



The level 1 analysis uses a “flexible engine” (rubber engine) The engine power required to meet the design specification will be calculated. At a later stage, the designer will search in an engine database to find “the real engine” which will best match the “flexible engine”.

The results of the level 1 design process will allow the designer to define an aircraft configuration which will meet the design specification. The geometry (wing and tail sizing, etc...) of the aircraft is calculated as well as the thrust (engine power, propeller properties). Only the main flight condition (typically cruise flight) will be explored, as the input data are not accurate enough to explore other flight conditions (climb, take-off, descent).

We do not compute the maximum lift coefficient but we choose a given value keeping in mind the KIS approach (Keep It Simple). We do the same with the aerodynamic efficiency of the aircraft. We know that a high value of lift coefficient will lead to a sophisticated and expensive wing design. This is the same for the aerodynamic efficiency. A low value of surface roughness will lead to expensive molds or expensive manufacturing methods.

Optimization

While making the conceptual study of a new design, it is important to plan as many solutions as possible to be able, in the end, to keep the best one, i.e. the one that responds in an optimal way to the specifications requirements.

ADS offers a specific module to carry out this optimization. In order to do that, the user has to specify the variables that he wishes to make vary from a lower limit to an upper limit as well as the variation pitch

Given the fact that there are so many results and in order to facilitate their analyses, the user can also determine some limits so that only the results that fit within those limits will be taken into consideration. Those limits are determined, most of the time, through an in-depth analysis of the existing aircraft.

Once the optimized design is finished, only a limited number of about ten different configurations will remain.

Level2

Once satisfied with the results obtained, the designer proceeds to the second stage of the process: the Design with “given means”.

The number of parameters used will increase and the input data will become more accurate. Certain information will be sourced directly from product databases. The “flexible engine” is substituted by a real engine which closely matches the properties of the “rubber engine”. Values, which in the previous stage were selected by statistical analysis, will be verified by extensive algorithms. The increase in lift for the type of flaps used will be computed. The total drag will be defined more precisely as the sum of specific drag components. A weight estimate will be made. All flight conditions will be explored. The stability will be checked. Finally, a 3D model will be generated which will enable the results of the design process to be verified and appreciated visually.

Level 3

The final stage in the process is the design with “given geometry”.

One goal is to show what the effect would be of parameters that are “off-target”. What will be the impact on the aircraft performance if the weight of the aircraft turns out to be slightly different? What margins are acceptable? Where is the limit to be set?

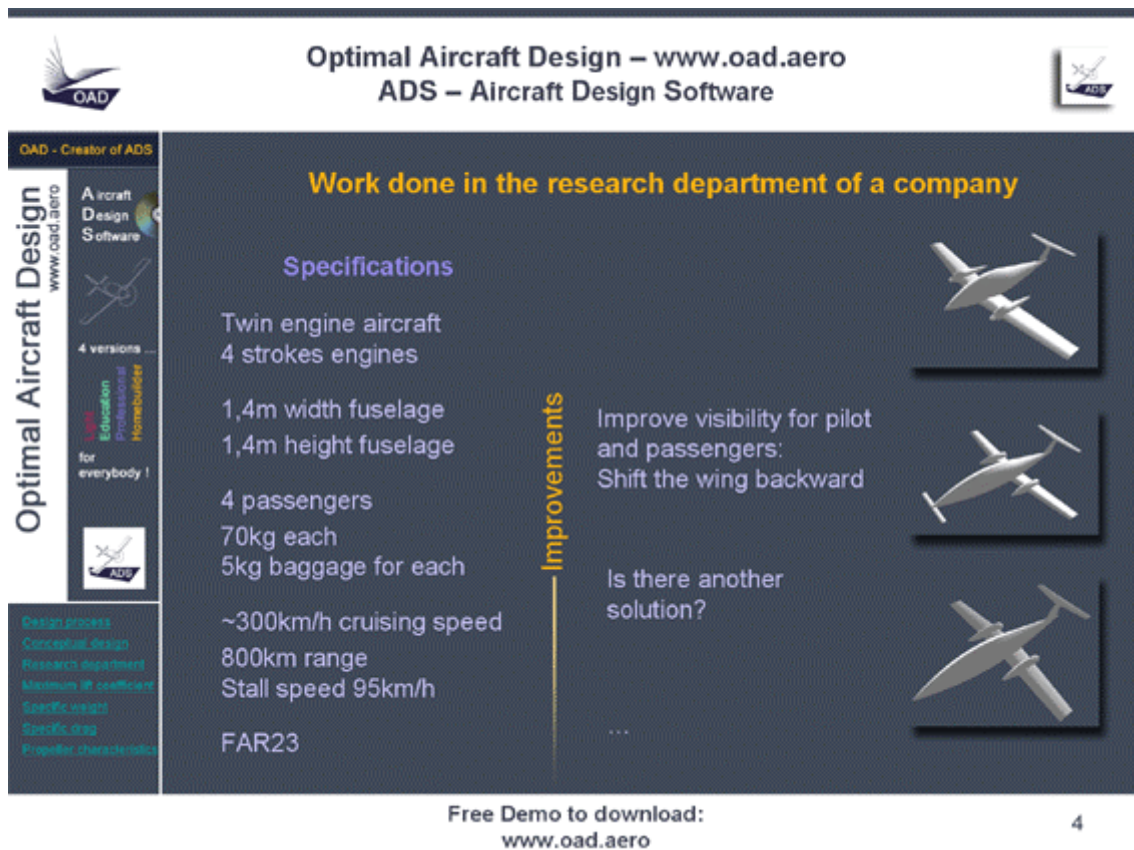
It is also possible to show the impact of modifications to an existing aircraft. What is the overall impact on the aircraft of a wing modification? Change in weight, change in drag, change in performance,... The improvements obtained in reality can often be very different from what was initially expected or aimed for.



It is also possible to analyze the performances (take-off, climb and cruise) of a given aircraft for different flight conditions (flight weight and flight altitude).

3 Work done in the research department of a company

Now imagine that you are at the head of a research department of a company. A customer comes to you and asks you to design a new twin-engine aircraft. Its specifications are listed here under. He has very strict requirements on particular things and gives you freedom in other areas.



The screenshot shows the ADS software interface. At the top, it says "Optimal Aircraft Design – www.oad.aero" and "ADS – Aircraft Design Software". The main title is "Work done in the research department of a company".

Specifications

- Twin engine aircraft
- 4 strokes engines
- 1,4m width fuselage
- 1,4m height fuselage
- 4 passengers
- 70kg each
- 5kg baggage for each
- ~300km/h cruising speed
- 800km range
- Stall speed 95km/h
- FAR23

Improvements

- Improve visibility for pilot and passengers: Shift the wing backward
- Is there another solution?
- ...

On the left side, there is a sidebar with the text "Optimal Aircraft Design www.oad.aero" and "Aircraft Design Software". Below this, it says "4 versions" and lists "Education", "Professional", and "Homebuilder" for "everybody!". At the bottom left, there is a list of design processes: "Design process", "Conceptual design", "Research department", "Maximum lift coefficient", "Specific weight", "Specific drag", and "Propeller characteristics".

At the bottom, it says "Free Demo to download: www.oad.aero" and the number "4".

You enter the data in ADS. You get one solution.

Then you decide to change one parameter. You will shift the wing backward to improve the visibility for the pilot and passengers. The longitudinal position of the wing will be changed from 20% to 50% of the fuselage length. ADS computes. Of course there is a problem. The centre of gravity is too much forward, and you have to solve the problem:

1. Change from tractor to pusher. ADS computes. The modification improves the design but it is not sufficient.
2. Change from a standard configuration to a 3-surfaces configuration. We define the characteristics of the canard surface using the historical value proposed by the On-line help. ADS computes. Again this modification improves the design. If we increase the size of the horizontal tail we will probably succeed.
3. We increase the size of the horizontal tail. ADS computes. Now it is OK. You can propose a second solution.



After 10 “clicks” we can come up with a new design that fulfills the customer’s specifications. Of course, you may imagine that this design will be probably more expensive than the first one. We have added additional components (canard surface), we have increased the size of the tail. Now the question is: “Is there another solution, different from the last one which improves the visibility without adding additional components on the aircraft?”


Remember what is the problem if the canard surface is removed. ADS computes. The CG is located too much forward. What can we do to solve the problem? ... We can try to sweep the wing forward. We change from 5° to -5° . ADS computes. Now it is OK. You can propose a third solution.

Very quickly, with ADS, you are able to define the main characteristics of different designs (performances, weight, CG, stability, ...) and select the most appropriate configuration.


4 Algorithms

Maximum lift coefficient

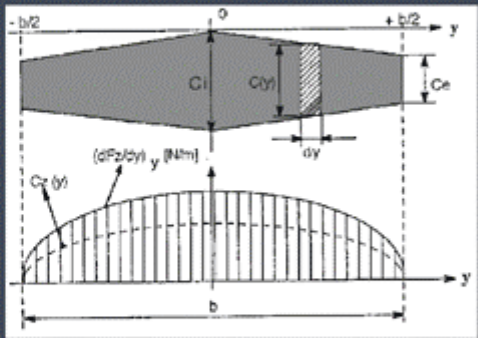
Wing lift is found by computing the spanwise distribution of the lift coefficient, based on the theory of a "loaded line". The local lift is computed taking into account the wing planform and other properties such as airfoil profile, twist and incidence. The maximum wing lift is generated when somewhere along the span, the local lift coefficient reaches the maximum lift coefficient of the wing section.



Optimal Aircraft Design – www.oad.aero
 ADS – Aircraft Design Software



Algorithms: maximum lift coefficient



Lift distribution along the span function of:

- Airfoil profile
- Incidence
- Twist
- Sweep angle
- Plan form

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5



Specific weights

An estimate of the empty weight of the aircraft is made by making a weight breakdown for the major components of the aircraft: wing, engine installation, propeller, fuselage, horizontal tailplane, vertical tailplane, foreplane (canard), main landing gear, nose or tail landing gear, fuel system, hydraulic system, control systems, electrical systems, instruments.

The weight breakdown is made by using formulas. Most often these formulas were derived in an empirical way from the analysis of a large number of existing aircraft. Each result is multiplied by a correction coefficient in order to take into account several aspects, such as materials used, the ability of the designer to build lighter, etc... These correction coefficients are generally found after a detailed analysis of existing aircraft which are similar in concept to what the designer has in mind.

The screenshot shows the software interface for 'Optimal Aircraft Design - www.oad.aero ADS - Aircraft Design Software'. The main content area is titled 'Algorithms: Specific weight' and displays the 'Wing weight' formula:

$$W_w = MCF_w \cdot 0,14278 \cdot TR_w^{0,64} \cdot \left(\frac{A_w}{(\cos \Lambda_{25w})^2} \right)^{0,6} \cdot \left(\frac{100 \cdot (t/c)_w}{\cos \Lambda_{25w}} \right)^{-0,3} \cdot q_{cr}^{0,006} \cdot S_w^{0,758} \cdot (1,5 \cdot n_i \cdot W_{TO})^{0,49} \cdot W_{fw}^{0,0035}$$

Below the formula, there are three dots '...' indicating further details or options. The interface also includes a sidebar with 'Optimal Aircraft Design' branding and a list of design process steps: Conceptual design, Research department, Minimum lift coefficient, Specific weight, Specific drag, and Propeller characteristics. At the bottom, it says 'Free Demo to download: www.oad.aero' and the page number '6'.

Specific drags

A traditional drag breakdown is made as follows:

- C_{D0} : zero-lift drag (friction drag),
- C_{DL} : induced drag,
- C_{Dint} : interference drag caused by interaction of the different parts of the aircraft.

The drag coefficient is therefore: $C_D = C_{D0} + C_{DL} + C_{Dint}$.


The total drag of the aircraft is calculated as the sum of the drag of each major part of the aircraft: wing, trailing edge devices, horizontal tailplane, vertical tailplane, foreplane (canard), fuselage, propulsion (engine installation), propeller, nacelle, landing gear, interference.

During the conceptual design of the aircraft, the interference drag is difficult if not impossible to determine. ADS uses a method based on reference aircraft as described below:


- The designer has specified the “aerodynamic quality” of the aircraft for the design flight condition being considered. This value was determined from the analysis of similar aircraft. As a reminder, the “aerodynamic quality” is the total drag coefficient of the aircraft.
- During the design process, the drag breakdown for the major aircraft components is initially worked out for the design flight condition.
- Next, the interference drag is computed for the design flight condition by subtracting the total drag (the “aerodynamic quality” specified by the designer) and the sum of the drag breakdown calculated above.
- Then, the relative interference drag is calculated and expressed as a fraction of the total drag.

It is assumed that the relative interference drag is constant for all flight conditions.





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ADS – Aircraft Design Software



OAD - Creator of ADS


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www.oad.aero

Aircraft Design Software

4 versions

Education
Professional
Homebuilder

for everybody!



Algorithms: specific drag

Wing drag coefficient

$$C_{D_{Wing}} = R_{wf} \cdot R_{LSE} \cdot C_{L_e} \cdot L_e^* \cdot \frac{WA_{Wing}}{S_{Wing}}$$

$$C_{D_{Wing}} = R_{wf} \cdot R_{LSE} \cdot C_{D_{Wing,ref}}$$

...

Interference drag coefficient

$$C_{D_{Interference}} = C_{D0} \cdot \left(\frac{C_{D_{Dfus}} + C_{D_{Dnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}}}{C_{D_{Dfus}} + C_{D_{Dnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}}} \right)$$


$$C_{D_{Interference}} = C_{D_{Wing}} \cdot \left(\frac{C_{D_{Dfus}} + C_{D_{Dnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}}}{C_{D_{Dfus}} + C_{D_{Dnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}} + C_{D_{Dnacnac}}} \right)$$

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7

Propeller characteristics

The propeller properties (diameter, pitch, number of blades, blade section) are determined using Propeller chart extracted from NACA reports. A blind test has been conducted with MT-Propeller in Germany. We sent to them the propeller specifications. They calculated the new propeller using their own methods and, in our side, we calculated the new propeller using ADS. The results concerning the propeller efficiency was as close as 0,1 percent. So we can claim that the methods we use to compute the characteristics of the propeller are very correct!



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ADS – Aircraft Design Software



OAD - Creator of ADS


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Aircraft Design Software

4 versions

Level Education Professional Homebuilder

for everybody!



Design levels

Conceptual design

Research department

Maximum lift coefficient

Specific weight

www.oad.aero

Propeller characteristics

Algorithms: propeller characteristics

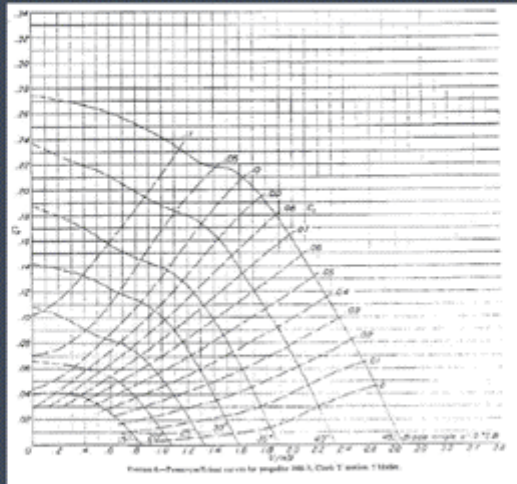


Figure 6—Propeller efficiency curves for regular 3-blade Clark Y section 7 blade.

Propeller characteristics:

- Diameter
- Efficiency
- Pitch angle
- ...

Copy from NACA TR 640 (1938)

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