THEORETICAL BACKGROUND
This report describes the theoretical principles and algorithms as implemented in the modelling module of your ADS software [1]. After a description of the general approach, you will find more detailed information about the iterative algorithms and the various models used.

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1. Methodology

ADS allows you to do your Conceptual design in 3 stages:

1. Designing with fixed constraints
2. Designing with fixed means
3. Designing with fixed geometry

1.1 Designing with fixed constraints

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 total drag will be defined more precisely as the sum of distinct drag components. A weight estimate will be made. All flight conditions will be explored. The stability will be checked. Finally, a virtual 3D scale model will be generated which will enable the results of the design process to be verified and appreciated visually.

1.2 Designing with fixed means

Once satisfied with the results obtained, the designer proceeds to the second stage of the process: the Design with fixed 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 “flexible 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 distinct drag components. A weight estimate will be made. All flight conditions will be explored. The stability will be checked. Finally, a virtual 3D scale model will be generated which will enable the results of the design process to be verified and appreciated visually.

1.3 Designing with fixed geometry

The final stage in the process is the design with fixed 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.
2. Algorithms

Each stage of the Design process is detailed below. The input data required for each stage is listed in [2]. When progressing through the different levels, the software will gradually ask you to insert additional information and data.

2.1 Definition

Let's first define the parameters we will use in this section:

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>Engine power</td>
</tr>
<tr>
<td>Cl_{max}</td>
<td>Maximum lift coefficient</td>
</tr>
<tr>
<td>Cl</td>
<td>Lift coefficient</td>
</tr>
<tr>
<td>CS</td>
<td>Climb slope</td>
</tr>
<tr>
<td>δCl_{max}</td>
<td>Maximum lift coefficient increment</td>
</tr>
<tr>
<td>D</td>
<td>Drag</td>
</tr>
<tr>
<td>L</td>
<td>Lift</td>
</tr>
<tr>
<td>M_{fuel}</td>
<td>Fuel weight</td>
</tr>
<tr>
<td>M_{mot}</td>
<td>Engine weight</td>
</tr>
<tr>
<td>M_{prop}</td>
<td>Propeller weight</td>
</tr>
<tr>
<td>M_{ut}</td>
<td>Useful weight</td>
</tr>
<tr>
<td>M_{d}</td>
<td>Maximum takeoff weight</td>
</tr>
<tr>
<td>M_{v}</td>
<td>Empty weight</td>
</tr>
<tr>
<td>RC</td>
<td>Rate of climb</td>
</tr>
<tr>
<td>R_{h}</td>
<td>Propeller efficiency</td>
</tr>
<tr>
<td>Sa</td>
<td>Wing area</td>
</tr>
<tr>
<td>Tob</td>
<td>Propeller thrust (gross)</td>
</tr>
<tr>
<td>Ton</td>
<td>Propeller thrust (net)</td>
</tr>
<tr>
<td>V</td>
<td>Flight speed</td>
</tr>
<tr>
<td>WA</td>
<td>Wetted area</td>
</tr>
</tbody>
</table>
2.2 Level 1

The iterative process at level 1 is shown in Figure 1. The process starts with the initialisation of constants linked to the selection of input data. Then, only the iterations related to the weight are performed. Finally, the various parameters for the resulting configuration are derived.

![Diagram of iterative process at level 1]

Figure 1: iterative process at level 1
2.3 Level 2

The iterative process at level 2 is shown in Figure 2. As before, the process begins with the initialisation of constants linked to the selection of input data. However, now the iterations performed are related to weight and speed. Once again, various parameters for the resulting configuration are derived, as well as the different types of drag. The drag and thrust curves are plotted (RC, Cs and the propeller performance for speeds ranging from 0 to \( V_{\text{max}} \)). The take-off distance, best climb rate and climb angle are also computed.

![Figure 2: iterative process at level 2](image-url)
2.4 Level 3
At this level, the process is no longer iterative, since the geometry is now fixed. The goal is not to find the performance for a given configuration.

ADS will perform the level 3 as follows:

1. Initialisation of constants linked to the selection of input data
2. Computation of information related to the geometry of wing, empennage, fuselage, WA, \( C_{L_{\text{Max}}} \), \( \Delta C_{l_{\text{Max}}} \)
3. Computation of specific weights, \( M_v \), \( V \)
4. Computation of different type of drag, including interference drag
5. Computation of drag and thrust curves (for speeds ranging from 0 to \( V_{\text{max}} \), calculation of RC, CS, drag, propeller performance)
6. Calculation of best rate of climb
7. Calculation of best climb angle
8. Calculation of take-off distances
3. Principles

The theory, principles and models which have been implemented in the algorithms which are used for estimating parameters (lift, drag, etc…) are given below.

3.1 Aerodynamics

3.1.1 Lift

Source: [3].

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 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.

3.1.2 Lift increment ($\Delta C_{l_{max}}$)

Source: [4].

$$\Delta C_{l_{max}} = base k_1 k_2 k_3 k_4 K_{swp}$$

with:

- base: [4] p240, fig.8.31
- $k_1$: correction coefficient [4]p240, fig.8.32
- $k_2$: correction coefficient [4]p241, fig.8.33
- $k_3$: correction coefficient [4]p241, fig.8.34
- $k_4$: ratio of the flapped wing area to the total wing area
- $K_{swp}$: effect of wing sweepback on the correction coefficient for maximum lift due to the flaps [4]p263, fig.8.55
- $\Delta C_{l_{max}}$ is computed for different flap types (Fig.3):
  - plain flap,
  - split flap,
  - single slotted flap,
  - double slotted flap,
  - fowler flap.
Figure 3: different flaps types and their effect on lift ($C_L$) and drag ($C_D$) coefficients [5]
3.1.3 Drag

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: $C_D = C_{D0} + C_{DL} + C_{Dint}$.

Figure 4 shows a more physical drag breakdown of the total drag in pressure drag, friction drag, induced drag, profile drag, form drag, vortex drag, wave drag and wake drag.

Figure 4: Physical drag breakdown [5]
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.

The different drag components making up the total drag breakdown are computed with the formulas listed below.

### 3.1.3.1 Wings, horizontal tailplane and canard surface (foreplane) Source: [4]

The drag of these three components is computed in the same way: \( C_D = C_{D0} + C_{DL} \).

\( C_{D0} \) is found by processing information from the wing section database. If this data is not readily available, then \( C_{D0} \) is found by using the second equation (which is less accurate than the first).

\[
C_{D0} = R_{wf} RLS R_{D0Airfoil} \frac{W}{A} \\
C_{D0} = R_{wf} RLS C_f L_2 \frac{WA}{S_a} \\
C_{DL} = \frac{C_l^2}{\pi AR_e} + 2\pi C_L Twist IDFLT + 4\pi^2 Twist^2 \frac{ZLDFLT}{\sqrt{1 - MachN^2}}
\]

with:

- \( R_{wf} \) Wing / Fuselage interference factor
- \( RLS \) Lifting surface correction factor
- \( R_{D0Airfoil} \) Zero lift drag coefficient from the wing section database
- \( L_2^* \) Airfoil thickness location parameter
- \( Twist \) Twist angle
- \( IDFLT \) Induced Drag Factor due to Linear Twist
- \( ZLDFLT \) Zero Lift Drag Factor due to Linear Twist
- \( Mach N \) Mach number
3.1.3.2  **Trailing edge devices** Source: [4].

\[ C_D = C_{D0} + C_{DL} + C_{Dint} \]

\( C_{D0} \) is function of the type of the trailing edge device\( C_{DL} \)

\[ C'_{DL} = (k \Delta C_L)^2 \cos(S_{wp}25 Prct) \]

\( C_{Dint} \) is function of the type of the trailing edge device

\[ C_{Dint} = K_{int} C_{D0} \]

3.1.3.3  **Vertical tailplane** Source: [4].

The calculations are the same as for the wing, with \( C_{DL} = 0 \).

3.1.3.4  **Fuselage and nacelles** Source: [4].

\[ C_D = C_{D0} + C_{DL} \]

\[ C_{D0} = R_{\text{aer}} C_f \left(1 + \frac{6 \eta}{\frac{\text{Length}^3}{\text{MD}}} + 0.0025 \frac{\text{Length}}{\text{MD}}\right) \]

\[ C_{DL} = 2 \cdot A_{\text{p}} \cdot n_c^2 \frac{\text{BasArea}}{\text{WngArea}} + \eta \cdot C_{Dc} \cdot A_{\text{p}} \cdot n_c^3 \frac{T_{\text{Area}}}{\text{WngArea}} \]

with:

<table>
<thead>
<tr>
<th>( C_f )</th>
<th>Friction coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Length of the fuselage [m]</td>
</tr>
<tr>
<td>MD</td>
<td>Fuselage mean diameter [m]</td>
</tr>
<tr>
<td>( A_{\text{p}} )</td>
<td>Fuselage angle of incidence [°]</td>
</tr>
<tr>
<td>BasArea</td>
<td>Fuselage base area [m^2]</td>
</tr>
<tr>
<td>Tarea</td>
<td>Fuselage top area [m^2]</td>
</tr>
</tbody>
</table>

3.1.3.5  **Engine installation** Source: [4].

\[ C_D = C_{D\text{cooling}} + C_{DMisc} \]

\[ C_{D\text{cooling}} = 0.00000006 \cdot EBH_{\text{avail}} \frac{OAT^2}{1.225 \cdot V_{\text{WngArea}}} \]

\[ C_{DMisc} = 0.00025 \cdot \frac{EBH_{\text{avail}}}{W_{\text{WngArea}}} \]
with:

- \( C_{D_{\text{cooling}}} \): Cooling drag coefficient
- \( C_{D_{\text{Misc}}} \): Miscellaneous drag coefficient
- \( OAT \): Outside Air Temperature \(^{\circ}\text{C}\)
- \( OAD \): Outside Air Density \([\text{kg/m}^3]\)
- \( EBHP_{\text{avail}} \): Available engine power \([\text{W}]\)

### 3.1.3.6 Propeller Source: \([4]\)

\[
C_D = C_{D_{\text{windmilling}}} + C_{D_{\text{stop}}}
\]

\[
C_{D_{\text{windmilling}}} = 33 \cdot \frac{1}{0.5 \cdot OAD \cdot PropV^2 \cdot PropWngArea} \cdot \frac{EBHP_{\text{prop}}}{PropV^2}
\]

\[
C_{D_{\text{stop}}} = 0.00125 \cdot \frac{\text{Blade Number}}{0.3945} \cdot \frac{Dia^2}{PropWngArea}
\]

with:

- \( C_{D_{\text{windmilling}}} \): Propeller drag coefficient when windmilling
- \( C_{D_{\text{stop}}} \): Propeller drag coefficient when stopped
- \( PropV \): Propeller tip speed \([\text{m/s}]\)
- \( PropWngArea \): Wing area lying in the propeller slip stream \([\text{m}^2]\)
- \( PropEBHP \): Propeller power available \([\text{W}]\)
- \( Dia \): Propeller diameter \([\text{m}]\)
3.1.3.7 Landing gears Source: Didier Breyne.

For a landing gear with fairings:

\[ C_d^0 = 1.5 \cdot 0.14 \cdot \frac{\text{WheelNumber} \cdot \text{TireFArea}}{\text{WngArea}} \]

For a landing gear without fairings:

\[ C_d^0 = 1.5 \cdot 0.24 \cdot \frac{\text{WheelNumber} \cdot \text{TireFArea}}{\text{WngArea}} \]

with:

- WheelNumber: Number of wheels,
- TireFArea: Frontal area of one wheel [m²]

3.1.3.8 Interference drag

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.
3.2 Weights

An estimate of the empty aircraft weight 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 the formulas below. 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.
3.2.1 Wings Source: [6], equation 15.46.

\[ M_{\text{fuel ailes}}(lb) = 0,036 \alpha^{0.758} M_{\text{fuel ailes}}^{0.0035} \frac{AR}{\cos \Lambda} \left(1 - \frac{q}{\cos \Lambda}\right)^{0.004} \left(1 - \frac{100 \ t/c}{\cos \Lambda}\right)^{-0.3} \left(N_{z} W_{dg}\right)^{0.49} \]

with:
- \( M_{\text{fuel ailes}} \) Weight of fuel stored in the wing [lb]
- AR wing aspect ratio
- b wing span [ft]
- q Dynamic Pressure Ratio (lb/ft²]
- c Wing aerodynamic mean chord [ft]
- t/c Wing airfoil relative thickness [%]
- \( \Lambda \) Sweep angle at 25% of the mean aerodynamic chord [°]
- nz ultimate load factor
- \( W_{dg} \) Flight design gross weight [lb]

3.2.2 Propulsion Source: [7], Table 14-5.

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single engine (4 strokes, 2 strokes, Diesel 2 strokes)</td>
<td>Meng = 1.3 x Mdry</td>
</tr>
<tr>
<td>Twin engine (4 strokes, 2 strokes, Diesel 2 strokes)</td>
<td>Meng = 1.4 x Mdry</td>
</tr>
<tr>
<td>4 strokes Diesel</td>
<td>Meng = 1.3 x Mdry</td>
</tr>
<tr>
<td>Rotary</td>
<td>1.9 x Mdry</td>
</tr>
<tr>
<td>Turbo propeller</td>
<td>1.7 x Mdry</td>
</tr>
</tbody>
</table>

The coefficients include the propeller. By subtracting the weight of the propeller, the weight of the installed engine is found.
3.2.3 Propeller Sources: Technical Notes from manufacturers. Analysis by D. Breyne.

Figure 5 shows propeller weight versus power for a given propeller type. The different propeller types are:

HVP: variable pitch propellers with hydraulic pitch control system;
EVP: variable pitch propellers with electric pitch control system;
FP: fixed pitch propellers.

---

Figure 5: Weight of the propeller
3.2.4  Fuselage Source: [6], equation 15.49.

\[ M_{\text{fuselage}}(lb) = 0.052 \cdot S_f \cdot 1.086 \cdot N_z \cdot W_{d_g} \cdot 0.177 \cdot L_t \cdot 0.051 \left( \frac{D}{L} \right)^{-0.072} q^{0.241} + M_{\text{pressurisation}} \]

with:
- \( S_f \): Fuselage wetted area [ft²]
- \( L_t \): Tail length [ft]
- \( L \): Total length [ft]
- \( D \): Fuselage mean diameter [ft]
- \( M_{\text{pressurisation}} \): Weight penalty due to pressurisation [lb]

3.2.5  Horizontal tailplane and foreplane (canard surface) Source: [6], equation 15.47.

\[ W_{\text{HT}}(lb) = 0.016 \cdot (N_z \cdot W_{d_g}) \cdot 0.414 \cdot q^{0.168} \cdot S_{ht} \cdot 0.896 \cdot \left( \frac{100t/c}{\cos \Lambda_{ht}} \right) - 0.12 \left( \frac{AR}{(\cos \Lambda_{ht})^2} \right)^{0.043} \cdot \left( \frac{AR}{(\cos \Lambda_{ht})^2} \right)^{0.043} \cdot \lambda^h \]

with:
- \( S_{ht} \): Horizontal tail area [ft²]
- \( D_{ht} \): Sweep angle at 25% of the mean aerodynamic chord [°]
- \( \lambda \): Tail tapered ratio

3.2.6  Vertical tailplane: [6], equation 15.48.

\[ W_{\text{VT}}(lb) = 0.073 \cdot (N_z \cdot W_{d_g}) \cdot 0.376 \cdot q^{0.122} \cdot S_{vt} \cdot 0.873 \cdot \left( \frac{100t/c}{\cos \Lambda} \right) - 0.12 \left( \frac{AR}{(\cos \Lambda)^2} \right)^{0.043} \cdot \left( \frac{AR}{(\cos \Lambda)^2} \right)^{0.043} \cdot \lambda^h \left( 1 + 2 \frac{H_t}{H_v} \right) \]

with:
- \( S_{vt} \): Vertical tail area [ft²]
- \( \Lambda \): Sweep angle at 25% of the mean aerodynamic chord [°]
- \( \lambda \): Tail tapered ratio
- \( H_t / H_v \): 0 for conventional tail, 1 for T-Tail
3.2.7 Main landing gear Source: [7], equation 14-22a.

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed tail dragger</td>
<td>Weight = 0.8 x 0.045 x M_d</td>
</tr>
<tr>
<td>Retractable tail dragger</td>
<td>Weight = 1.5 x 0.8 x 0.045 x M_d</td>
</tr>
<tr>
<td>Fixed tricycle</td>
<td>Weight = 0.7 x 0.055 x M_d</td>
</tr>
<tr>
<td>Retractable tricycle</td>
<td>Weight = 1.5 x 0.7 x 0.055 x M_d</td>
</tr>
<tr>
<td>Fixed single wheel</td>
<td>Weight = 0.4 x 0.045 x M_d</td>
</tr>
<tr>
<td>Retractable single wheel</td>
<td>Weight = 1.5 x 0.4 x 0.045 x M_d</td>
</tr>
</tbody>
</table>

3.2.8 Nose or tail landing gear Source: [7], equation 14-22a.

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed tail dragger</td>
<td>Weight = 0.2 x 0.045 x M_d</td>
</tr>
<tr>
<td>Retractable tail dragger</td>
<td>Weight = 1.5 x 0.2 x 0.045 x M_d</td>
</tr>
<tr>
<td>Fixed tricycle</td>
<td>Weight = 0.3 x 0.055 x M_d</td>
</tr>
<tr>
<td>Retractable tricycle</td>
<td>Weight = 1.5 x 0.3 x 0.055 x M_d</td>
</tr>
<tr>
<td>Fixed single wheel</td>
<td>Weight = 0.1 x 0.045 x M_d</td>
</tr>
<tr>
<td>Retractable single wheel</td>
<td>Weight = 1.5 x 0.1 x 0.045 x M_d</td>
</tr>
</tbody>
</table>

3.2.9 Fuel system Source: [6], equation 15.53.

\[ W_{\text{Fuel}} (lb) = 2.49 \cdot V_t^{0.726} \left( \frac{1}{1 + V_i/V_t} \right)^{0.363} N_t^{0.242} N_{en}^{0.157} \]

with:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_t</td>
<td>Total fuel volume [gal]</td>
</tr>
<tr>
<td>V_i</td>
<td>Integral tanks volume [gal]</td>
</tr>
<tr>
<td>N_t</td>
<td>Number of fuel tanks</td>
</tr>
<tr>
<td>N_{en}</td>
<td>Number of engines</td>
</tr>
</tbody>
</table>
3.2.10 **Hydraulic system Source : [7], equation 14-35.**
Mhyd = 0.03 x Md

3.2.11 **Control systems Source : [6], equation 15.54**

\[ W_{\text{control}} (lb) = 0.053 \cdot L^{1.536} B_w^{0.374} N_z W_{d_g} \cdot 10^{-4} \cdot 0.8 \]

with:

- \( B_w \)  | Wing span [ft]

3.2.12 **Electrical systems Source : [7], equation 14-36.**
Welec = 0.03 x Md

3.2.13 **Instruments Source : [7], equation 14-38b.**
Winst = 0.015 x Md
3.3 Propeller

The propeller properties (diameter, pitch, number of blades, blade section) are determined with the method described in report [8] and by processing the information in the charts in this report (Figure 6).

![Figure 6: Propeller chart extracted from [8]](image-url)
3.4 Engine

Engine data is processed in 2 different ways, depending on the level of the Design process.

3.4.1 Level 1

At level 1, the algorithms will process statistical curves (Figure 7) in order to determine the weight of the "ideal" engine, as well as its specific fuel consumption for the type of engine selected (two stroke, four stroke, rotary, turbine,...). The engine power necessary to achieve the specified performance is calculated.

![Figure 7 Specific weight of engines (M=P) as a function of engine power](image)

3.4.2 Level 2 and 3

At level 2 or level 3, the designer made a selection of one or more engines which closely match the "ideal" engine. Now, the algorithms will process information from the engine database, which contains information provided by the engine manufacturers, such as:

- Dimensions,
- Weights,
- General performance (engine speed, power and specific fuel consumption),
- Power and fuel consumption curves.
4. Références

[8] Edwin P. Hartman and David Biermann. Naca report n°.640: The aerodynamic characteristics of full-scale propellers having 2,3 and 4 blades of clark Y and RAF 6 airfoil sections. NACA.