



## Parametric Design of Aircraft Wing with Curved Leading Edge

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**Abstract.** In order to ease modelling procedures, eliminate repetitive effort and save time, modern CAD tools offer the ability to automate tasks via a programming language. Moreover, when the design is an iterative process, the automation permits updating the design variables to generate a new model at each iteration. Based on UG/OPEN GRIP functionalities, this paper aims at developing a parametric model of a curved leading edge aircraft wing. The model is built by executing a GRIP program in which wing parameter values can be assigned via a dialog box.

**Keywords:** mechanics, modelling of air-structures, Siemens NX systems, GRIP language for Siemens NX system

### 1. INTRODUCTION

Due to the existing competition, manufacturing companies strive to decrease the product life cycle, in order to produce more in a relatively reduced time [1].

Consequently, a need has been raised for an evolution in design tools, namely, Computer Aided Design (CAD) software. One of the requirements is to shorten the time spent in the design process, especially when identical tasks exist while modelling different products. A similar case occurs when the design process consists of repeated activities that can be programmed in a simple loop. Furthermore, solving optimization problems involves updating the model after each iteration by changing the design parameters. To update the model manually, the designer has to perform a complicated and time-consuming job particularly when the model has a large number of parameters [2]. Therefore, the best way to reduce human unnecessary effort and time consumption is to proceed by automation [3]. Most CAD systems offer the ability to automate tasks and access to features via a built-in basic programming language without designer's interaction with the graphic user interface. This can be done by writing a script, in which several functions are called sequentially to exert different tasks, so that when the script is executed, the model in request is generated.

Design automation using the scripting and customization capabilities offered by commercial CAD software has been recently employed in the literature in several researches. In [4], the automatic solid modelling of fins using the GRIP programming language of SIEMENS NX is presented. The reduction in modelling time is shown to be significantly reduced. Another customization tool of SIEMENS NX, namely NX OPEN API, is used in [5] to highlight the benefits of design automation. The VBA programming tool of CATIA V5 is used in [6] for the geometry definition of a helicopter model. In the field of aircraft design and optimization, the parametric generation of the geometry is implemented so that it can be provided to further analysis tools, which is the case of the work published in [7].

In this paper, an automation method for the parametric modelling of an aircraft wing, with a curved leading edge, is presented. The wing is created based on point coordinates of characteristic curves (airfoil, leading edge curve...) and wing parameters (chord, number of spars, ribs ...). The automation is implemented within the integrated CAD/CAE/CAM system SIEMENS NX (formerly Unigraphics NX) using one of its secondary development tools namely UG/OPEN GRIP.

## **2. PARAMETRIC MODELLING**

### **2.1. Overview**

In CAD terminology, the parametric modelling refers to the use of parameters to build the model. These parameters can be dimensions (size of entities), constraints, and relations between geometric entities, material properties (Fig. 1).

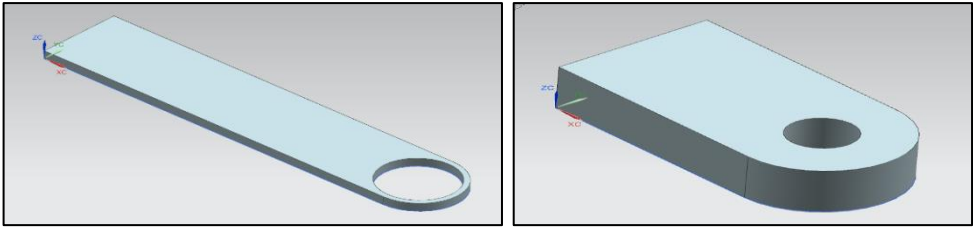


Fig. 1. Effects of parameter modification in a parametric model

Using this methodology, new designs can be generated simply by changing variable values and this defines the design space. In order to solve an optimization problem, CAD models can be connected to optimization codes by associating the parameters with the design variables.

Hence, any change performed by the optimization code on the design variables will be reflected as the update of the CAD model. Searching the optimal solution is then done by choosing the best parameter values combination that satisfies the criteria specified.

## 2.2. Modelling of curves describing the aerodynamic profile

Interpolation tasks are often used in order to provide approximate solutions to approximation tasks. Development of a curve is based on coordinate measurements (Fig. 2) and its reflection in a numerical representation for the approximation of surface spread on the basis of the developed curves, definition and solution of the interpolation task. In order to solve tasks formulated in this way, we register the coordinates of a certain number of points on the curve or surface and then determine the interpolation surface or curve based on the aforementioned measurements.

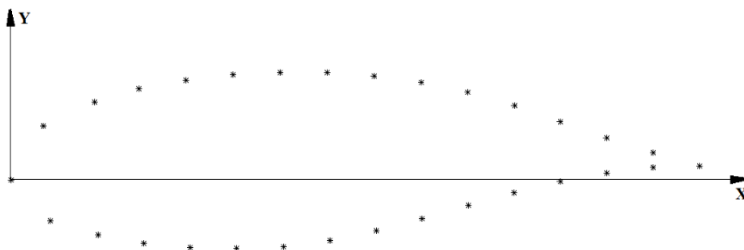


Fig. 2. Points defining of the aerodynamic profile

The developed aircraft wing modelling program uses the spline functions which made it possible to apply the parametric approach to the modelling process of virtual structures.

The B-spline curve [8] has zero value in all parametrisation subintervals, except for  $m+1$ . Such curves can be defined recurrently in the following manner (Eq.1):

$$N_{i,0}(x) = \begin{cases} 1 & x_i \leq x \leq x_{i+1} \\ 0 & \text{for other } x \end{cases} \quad (1)$$

the  $m$  degree B-spline in the interval  $[x_i, x_{i+m+1}]$  is defined as (Eq.2)

$$N_{i,m}(x) = \frac{x - x_i}{x_{i+m} - x_i} N_{i,m-1}(x) + \frac{x_{i+m+1} - x}{x_{i+m+1} - x_{i+1}} N_{i+1,m-1}(x) \quad (2)$$

When taking into consideration equations (1) and (2), we can find a clear form of the B-spline curve of any degree, which is directly used in algorithms designed for determining curves in CAD systems. For the B-spline curve, the linear value is equal to (Eq.3)

$$N_{i,1}(x) = \begin{cases} \frac{x - x_i}{x_{i+1} - x_i} & x_i \leq x \leq x_{i+1} \\ \frac{x_{i+2} - x}{x_{i+2} - x_{i+1}} & x_{i+1} \leq x \leq x_{i+2} \end{cases} \quad (3)$$

For the B-spline curve, the square value is equal to (Eq.4-6)

$$N_{i,2}(x) = \frac{(x - x_i)^2}{(x_{i+2} - x_i)(x_{i+1} - x_i)} \quad \text{where } x_i \leq x \leq x_{i+1} \quad (4)$$

$$N_{i,2}(x) = \frac{(x - x_i)(x_{i+2} - x)}{(x_{i+2} - x_i)(x_{i+2} - x_{i+1})} + \frac{(x_{i+3} - x)(x - x_{i+1})}{(x_{i+3} - x_{i+1})(x_{i+2} - x_{i+1})} \quad (5)$$

where  $x_{i+1} \leq x \leq x_{i+2}$

$$N_{i,2} = \frac{(x_{i+3} - x)^2}{(x_{i+3} - x_{i+1})(x_{i+3} - x_{i+2})} \quad \text{where } x_{i+2} \leq x \leq x_{i+3} \quad (6)$$

When applying the presented approach, we can easily describe the shape of the aerodynamic profile, which can be used to construct the aircraft wing.

The Graphic Interactive Programming (GRIP) language program for the Siemens NX system was developed to carry out the selection of points for the curve representing the airfoil.

### **2.3. Parametric modelling of an aircraft wing**

The earliest stage of the design process of an aircraft wing is the selection of parameters. These parameters concern the shape, dimension and configuration of the wing. From the large number of wing parameters, the following can be listed:

- Airfoil specification
- Root chord length
- Wing span
- Taper ratio (ratio between the tip chord and the root chord)
- Sweep angle and dihedral angle
- Twist angle and incidence or setting angle
- Number of spars (and their configuration)
- Number of ribs (and their configuration)

The airfoil can be specified by its designation (previously designed and published airfoil sections: NACA, Eppler...) or by the coordinates of the upper and lower curves defining the airfoil.

To model a curved leading edge wing, the curve representing the leading edge must be given as a function or as point coordinates. In this case, the trailing edge is supposed to be a straight line, and hence the coordinates of the end point of the trailing edge line must be given as well. Once created the leading and trailing edge curves, the wing skin can be generated after applying the convenient transformations (translation, scaling and rotation) on the root airfoil to create the tip airfoil. This eliminates the need to provide parameters like: wing span, taper ratio, sweep angle, dihedral angle, incidence angle, twist angle. It remains to specify the number and configuration of the spars and ribs to accomplish the modelling.

## **3. DESIGN AUTOMATION**

### **3.1. Siemens NX GRIP automation overview**

SIEMENS NX (formerly Unigraphics NX) is a leading parametric modelling CAD software. It provides a broad set of CAD solutions for the design of complex mechanical products.

As mentioned before, the best way to reduce human unnecessary effort and time consumption is to precede by automation.

SIEMENS NX offers various tools of automation: Knowledge Fusion, GRIP programming, Macros, NX Open, journals, User Defined Objects [1] etc. GRIP [9] (Graphics Interactive Programming) is a convenient, flexible and powerful interactive graphics programming language. GRIP is used to create FORTRAN-like programs to operate the Unigraphics system.

GRIP programming method can be used to automate most of the operations under the UG for developers. Commands are available to create geometric functions and modify existing geometry. GRIP also provides interactive commands. These commands display messages in notify dialogue box, allowing the user to interact with a GRIP program while it is running.

### 3.2. GRIP programming process

In order to automate the modelling using GRIP, four major steps must be followed:

- Create the source file (.grs) which contains the GRIP program.
- Compile the source file (program or subprograms), which converts it into object file (.gri).
- Link the previously generated object files into an executable module (.grx file).
- Execute, or run, the (.grx) file in SIEMENS NX to generate the model.

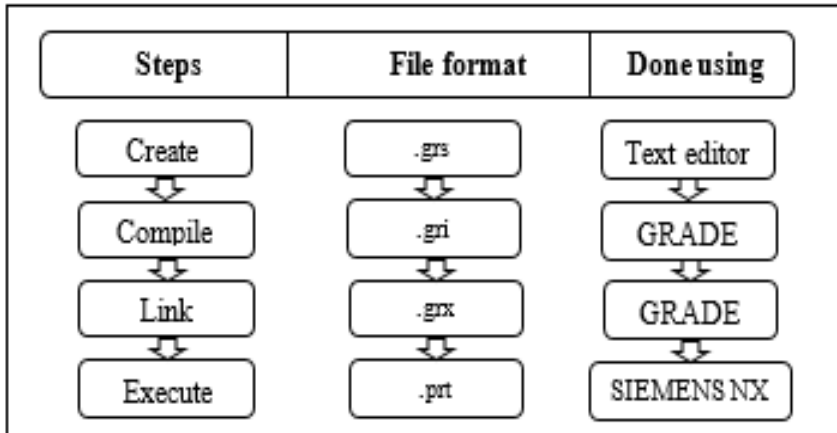


Fig. 3. GRIP programming process.

### 3.3. Model creation algorithm

The point coordinates needed to create the principal curves are read by the GRIP program from files in text format. Corresponding files are:

- Upper.txt: the upper curve of the root airfoil;
- Lower.txt: the lower curve of the root airfoil;
- Curv.txt: the curve of the leading edge;
- End\_point.txt: the end point defining the trailing edge line.

The GRIP definition used is **SPLINE/** with a tangent condition (Z axis vector) at the leading edge :

**SPLINE/U(1..k-1),VECT,0,0,1**

The tip airfoil profile is created by applying multiple transformations on the root profile, namely translation by the wing span, scale by the taper ratio and multiple rotations by sweep, twist and dihedral angles.

These transformations are programmed in the developed GRIP program as follows:

```

CSYS0=&WCS
MAT1=MATRIX/TRANSL,0,span,0
upper curve(n)=TRANSF/MAT1,upper curve(1)
CS(n)=TRANSF/MAT1,CSYS0
&WCS=CS(n)
MAT2=MATRIX/SCALE,taper ratio
upper curve(n)=TRANSF/MAT2,upper
curve(n),MOVE
MAT3=MATRIX/ZXROT,twist angle
upper curve(n)=TRANSF/MAT3,upper
curve(n),MOVE

```

Figure 4 illustrates the structure of the GRIP program and shows the steps to follow in order to achieve the desired wing model. The two loops: ‘*Rib loop*’ and ‘*spar loop*’ are detailed in Fig 5:

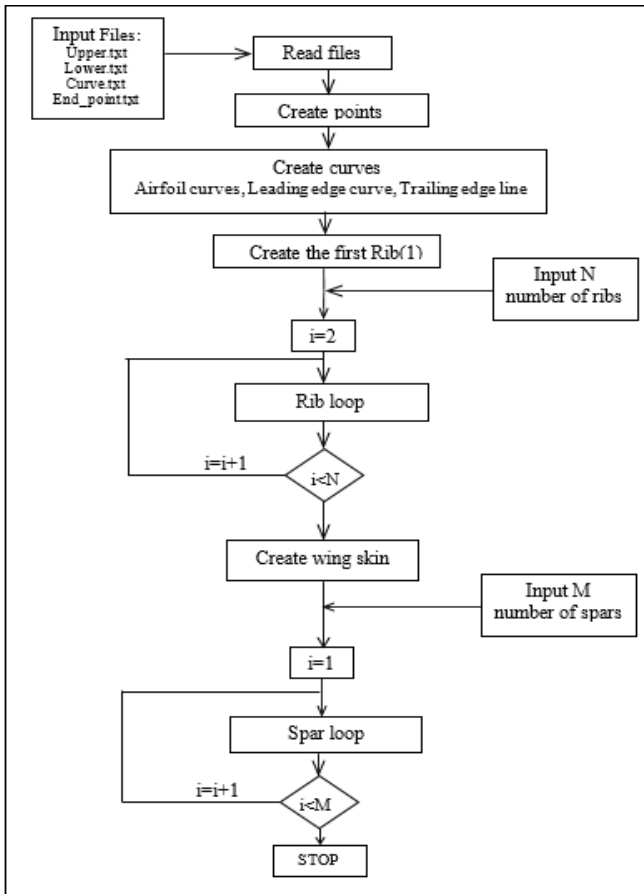
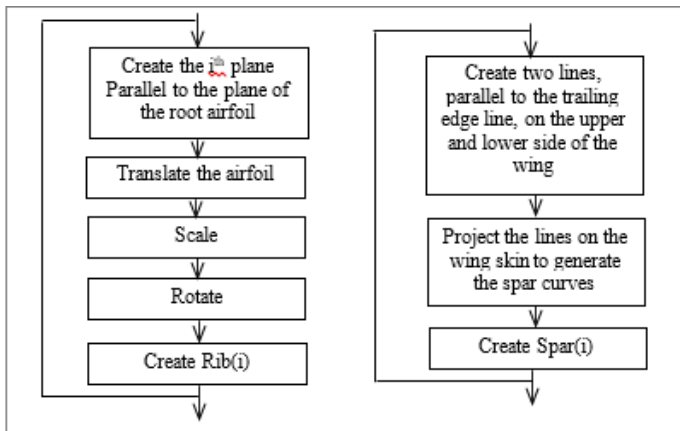


Fig. 4. GRIP program flowchart



(a). Rib loop

(b). Spar loop

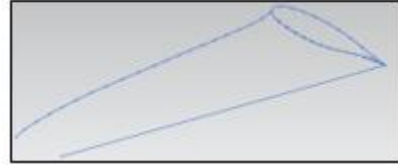
Fig. 5. Details for: a) the 'Rib loop', b) 'Spar loop'



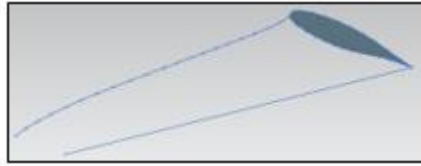
Introducing the number of the ribs 'N' and the number of the spars 'M' can be programmed to be via a dialogue box. Figure 6 (6a to 6k) presents the design process of the curved leading edge (LE) wing, the following screen shots were taken while debugging the GRIP program:



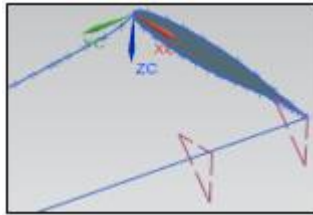
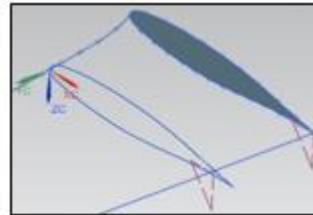
(a) Creation of points



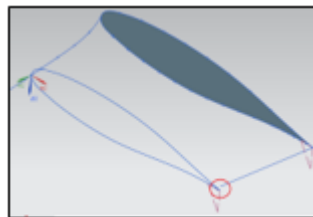
(b) Creation of curves



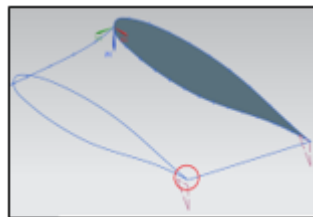
(c) Creation the first rib

(d) Creation of the  $i^{\text{th}}$  plane

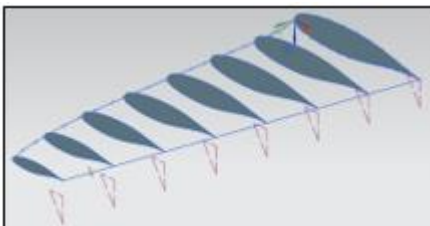
(e) Translation



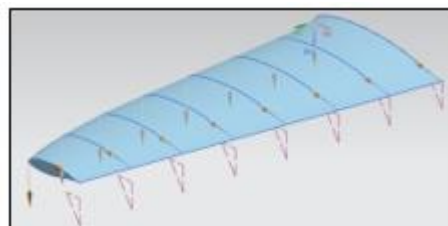
(f) Scaling



(g) Rotation



(h) All ribs created



(i) Creation of the skin

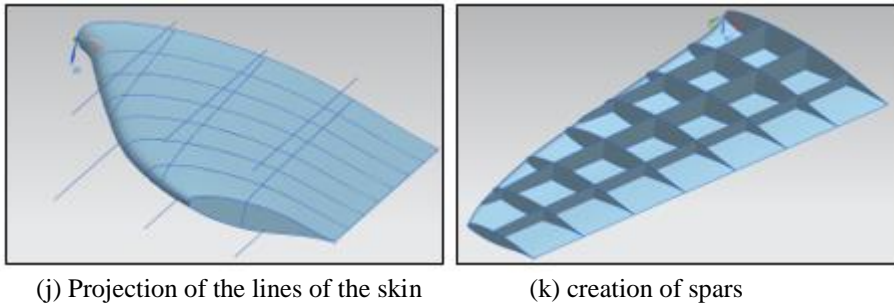


Fig. 6. Curved LE wing modelling

The program written is supported by the ability to introduce parameters via a dialogue box with a data entry menu, using the command: ‘PARAM/’. This allows the assignment of numerical values to variables interactively by the designer.

Figure 7 shows the dialogue box which appears when the program is executed in Siemens NX. The designer can input the desired values of the chord length, the wing span as well as the number of spars and ribs.

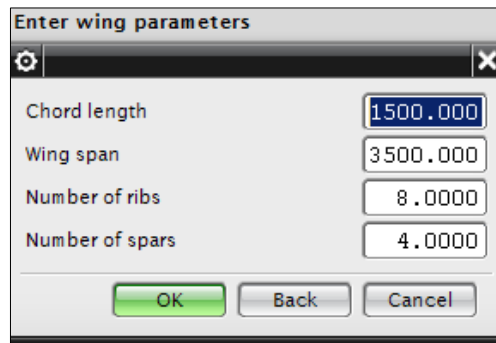


Fig. 7. Dialogue box of parameter input

Totally different models (Fig. 8) are generated when introducing different values of parameters:

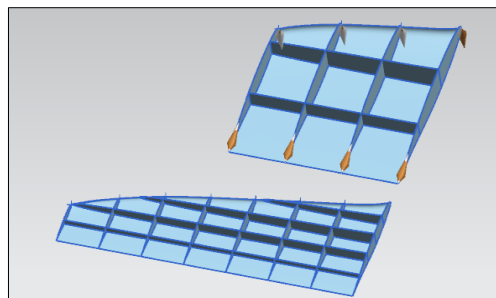


Fig. 8. Effects of parametric modelling

## 4. SUMMARY

In this paper, a method for the automation of parametric modelling of an aircraft wing is presented. The automation is carried out using the functionalities of the CAD software SIEMENS NX via its programming language GRIP. The input data is in the form of text files with the point coordinates of the wing's principal curves. The designer can assign parameters in order to construct the desired model. The program developed can be adjusted to fit a big variety of wing shapes.

It represents a tool that assists the designer to build automatically wing models of different shapes and configurations. It allows as well to avoid monotonous effort especially when the modelling process consists of the same repetitive tasks.

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