ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20250321123810

Preliminary communication
Received: 2025-03-21, Accepted: 2025-04-25

Calculation Driven Parametric Design of a Mechanical Assembly on the Example of a Hook Block

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Abstract: Parametric modeling is a common technology in numerous CAD software packages. One of the advantages of applying parametric modeling is the possibility of forming families of models that share a geometric structure with differences in dimensions. The user is left to generate a new set of dimensions. This paper presents an investigation of the possibility of upgrading the parametric modeling system with the calculation of the mechanical components in the form of a computer program. The user enters a set of operational requirements on the target mechanical assembly based on which the computer program calculates the needed dimensions of mechanical components to fulfill given requirements. The results of these calculations are used to parameterize the model. This approach is demonstrated using the example of a Hook Block model developed within the 3DExperience (3DX).

Keywords: CAD; engineering template; generic model; parametric modelling; product families

1 INTRODUCTION

Different CAD systems have become a mainstay of tools for industrial design in the past decades and have become highly developed software solutions that offer robust and powerful means for product development. However, further development is still ongoing as new potential for production improvement appears in combination with other technologies. Some of the development relates to long-standing problems such as the transfer of models from one CAD system to the other [1], the recent proliferation of AI tools presents a possibility of combining AI and CAD to generate new product design [2] or to combine AI, CAD, VR, and additive manufacturing to expedite the design process [3].

Apart from the development of the structure of the CAD model, the question of numerical values for dimensions, choice of material, and similar properties remains. Software solutions for engineering calculations are also heavily applied in everyday work. Hence, the idea of combining these two types of tools is heavily investigated. Examples include the design of single components such as gears by programming ACMA standards using Visual Basic where the results are supplied to the gear model developed in SolidWorks [4], but also for the design of assemblies such as the computation of heat transfer used to parametrize heat exchanged CAD model [5].

In both cases, the structure of the product remains unchanged and only the dimensions are affected by the computation. However, cases of systems with structure variations based on input parameter values are also common. One used approach is to develop a CAD assembly model in *ProEngineer* with all possible options for individual components, such as the case of automotive steering wheel joints design presented in [6]. Based on the results of calculations performed in Excel, out of all structural options for a single component, a chosen option is parameterized while all other options are suppressed.

It may be argued that this approach has two disadvantages. Firstly, additional computational resources are needed to handle all non-used options. Secondly, in the case of sharing such a model outside of the organization with a potential client, significant proprietary knowledge may be unwillingly shared. This paper explores an alternative approach by creating a parametric model and the so-called engineering template of the Hook Block with the ropes, inside the CATIA V6 module of 3DExperinence. The engineering templates are based on parametrically constructed generic models (generic models). Generic Product) of certain standardized assemblies or parts. The generic model itself contains all the necessary calculations necessary for its creation, all the catalogs of standard parts that can be used in it and is designed to adapt to the input parameters or geometry specified by the user (end user).

2 HOOK BLOCK

Fig. 1 shows a standard Hook Block with marked parts for which it is necessary to define a sizing algorithm, which includes the Hook itself, bearing, bracket, nut, support plate, shaft, and pulley assembly. The structure and standard dimensions have been selected according to DIN 15400, DIN 15401, DIN 15402, and DIN 15412. According to the standards, standards Hook sizes are defined using a value called Hook number *HN*, which unambiguously determines their shape and dimensions. Depending on the Hook Number, the load class and the permissible load of the Hook depend on the load class, the material, and the safety factor. The load class considers the frequency of application and the spectrum of loads to which the part is exposed.

Once the standard Hook is chosen, all other standard parts of the Hook Block are then selected according to the Hook Number of the chosen Hook. In the final model, the user will enter/select the values of the three named parameters, the model will conduct the required calculation of the Hook Number, and all the standard parts will be chosen automatically.

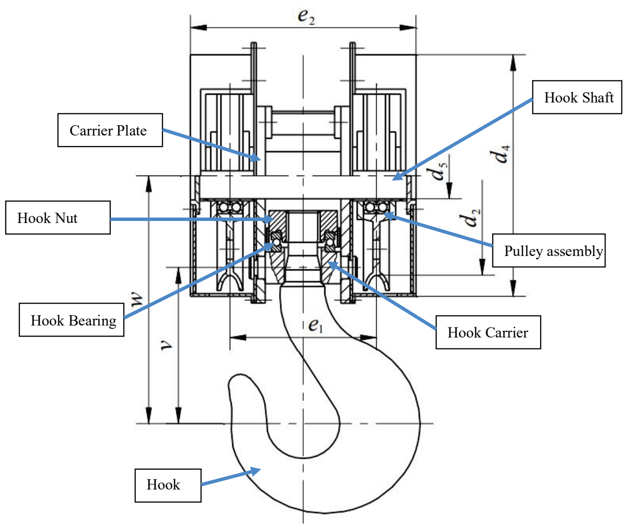

Figure 1 Hook Block structure

3 INPUT PARAMETERS

After defining the basic calculation algorithm, it is necessary to determine which input parameters the user will enter, and what is their range. This will further define which branches are needed in the calculation, and what the configurations in certain ranges of these parameters will look like.

The main input parameters of the model will be the maximum weight of the load, the quality of the material, and the drive group. The latter can be defined according to the purpose of the crane, which in this case was carried out using the DIN 15018 and HRN EN 13001-1 standards. Additional parameters that the user selects in principle include:

- Type of Hook,
- The shape of the rope assembly,
- Configuration of ropes,
- Type of rope, etc.

As this paper seeks to show the very potential of using engineering templates, the above additional parameters will not be used as a choice option. Rather, these options will be chosen according to programmed criteria.

Furthermore, the model works inside a certain range of values that the user can enter. The lower limit of the load capacity is set at 2 t, since below that load capacity there are significant changes in the geometry of the Hook carrier which is out of scope for this paper. A maximum weight of 50 t has been selected for the upper load limit, which covers the range of a typical crane. After determining the input parameters and their ranges, it is necessary to define how the calculation or structure of the Hook Block will change depending on which part of the range the values set by the user are located.

The main influence on the design and structure of the assembly is the number and arrangement of load-bearing ropes, and they in turn depend on the maximum load capacity of the Hook Block. To reduce the complexity of the model, the number of wearable ropes is limited to 1, 2 or 4.

It is necessary to determine which load capacities a certain number of ropes correspond to. The selection will be guided by established industry practice. Due to the simpler selection of configurations, the load capacities are implemented in approximately equivalent ranges of Hook numbers (Tab. 1).

Table 1 Recommended number of Hook pulleys as a function of Hook number [7]

n	1	2	4
Hook number	2,5...6	8...25	32...80

4 3DEXPERIENCE SOFTWARE PACKAGE

3DX CATIA is structured in several applications. The following are used herein:

- Part Design Essentials (part modeling),
- Generative Wireframe & Surface (enables usage of wireframe geometry i.e. skeleton model),
- Assembly Design,
- Engineering Rules Capture (adds rules and reactions to the model, written in Enterprise Knowledge Language (EKL)),
- Structure Design and Steel Outfitting Design (standard profiles and parts),
- Collaborative Lifecycle (managing of elements within the catalog).

Fig. 2 shows the data flow diagram of the proposed calculation driven parametric design tool. Details are described in the following sections.

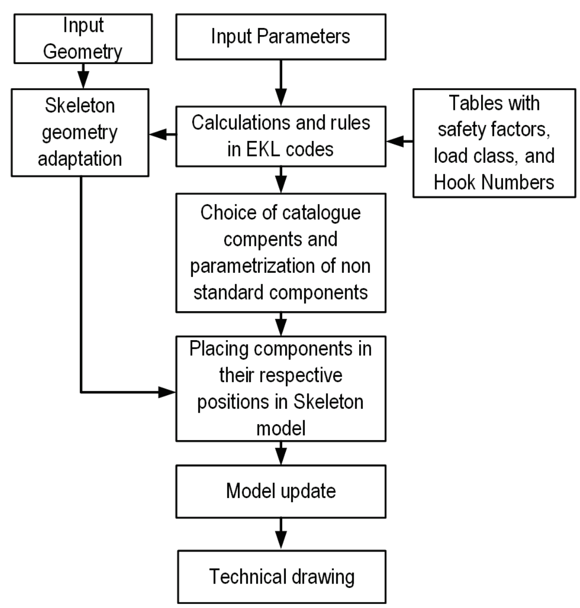

Figure 2 Flow diagram of developed calculation driven parametric design tool.

5 ENGINEERING TEMPLATE

Within 3DX CATIA there is a type of model called *Engineering Template* which is a customizable product model based on the principle of parametric modeling. It can adjust its geometry according to the needs of the user by simply changing the input data and the set parameters.

The advantage of an Engineering Template over other models, such as *PowerCopy* or *User Feature*, is that the model automatically adjusts to user-defined input data when instantiated and is not just a copy of a generic model.

The main disadvantage is the need for a complete definition of input data, most often based on geometric elements and parameters, and the need for the user to accurately prepare the circuit before instantiation. With *PowerCopy* or *User Feature*, the instantiation process is much simpler and requires less preparation, which reduces the possibility of errors. Also, the process of creating an *Engineering Template* is more complex and takes much longer, so it is avoided to use it for instantiating simple models, for which the previously mentioned options are more often used.

For the proper function, the Engineering Template must include:

- References
- Input
- Parameters

The References are the basis for creating an engineering template. The model is made as a standard product with certain additional requirements that are later required when creating a template. An essential property of the elements that make up the input geometry is the need to be isolated from the rest of the product and are used only if selected as an Input by the user and defined by Parameters which are values either provided by the user or read/calculated by the model.

6 LOCAL CATALOGUES

Since the model will use standard parts and assemblies, it is necessary to compile a catalog that will contain them and that will be linked to the template. Catalogs must contain parts in all sizes and load capacities necessary to meet a given range of parameters.

To limit the necessary elements of the catalog, a test calculation was carried out for the highest load capacity and the most unfavorable load and material conditions of the Hook. According to this calculation, it is evident that the maximum Hook Number would be 80, therefore, all elements of the catalog relate to Hook number up to that number.

The first step in forming a catalog is to create a master catalog that will contain all the chapters into which individual elements will be further classified. The chapters within the catalog are as follows:

- Hooks,
- Hook carriers,
- Hook nuts,
- Bearings (both for Hooks and pulleys),
- Pulleys (standard dimensions for pulley).

7 HOOK BLOCK ENGINEERING TEMPLATE

To create a template, it is first necessary to create a parametric model of the Hook Block, which will contain geometry, parameters, and necessary elements, i.e. parts. Development of the Hook model will be divided into several stages:

- Creating input geometry and entering input parameters,
- Programming (the calculation for all components)
- Creation of skeletal geometry that will be adapted to the results of the calculation,
- Introduction of catalog components into the assembly,
- "In-context" design of other necessary components.

The first step to create a parametric model of the Hook Block, as previously stated, is to select the input geometry. An optional reference point (Optional Reference Point) will be used as the input geometry for instantiating the template into the assembly. The reference point can determine the exact position of the Hook Block, with the possibility of rotation around all three axes. The point will be set as an optional input, which will allow instantiation without selecting the input geometry, and the Hook Block will be instantiated to the origin of the global coordinate system of a particular circuit.

The skeleton model (Fig. 3) will be created as a separate 3D shape (3DShape) within the assembly. It will contain all the necessary geometry and parameters according to which the appropriate components will be selected from the catalog, i.e. new elements will be modeled.

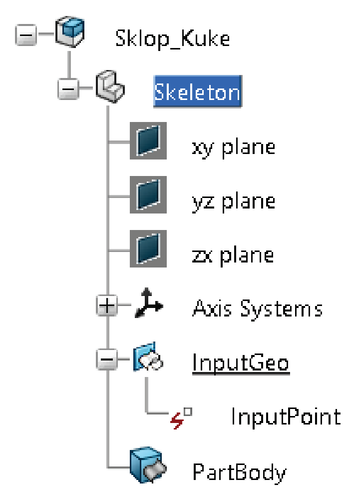

Figure 3 Feature tree with 3DShape and Input Point

The next step in the process is to enter the input parameters and other parameters that will be calculated using them and are needed to perform the calculation. All parameters are grouped within the *Knowledge Engineering Specification* module which allows the user to set the parameters to the highest level in the tree. The advantage of this configuration is that all elements within the tree will be able to use these parameters directly and refer to them. For the sake of clarity, the parameters are grouped within individual sets.

Material parameters are connected to the input parameter of the material strength class via the Design Table. For the load class and Hook material, an Excel table was created to be used as the *Resource Table* associated with the model. A resource table is a form of table that allows the loading of a series of resources, whether they are Excel spreadsheets, Word documents, etc., directly from the working server into the model. Resources in a table don't become part of the model until they're directly invoked, that is, instantiated. The advantage of using the *Resource table* is that the user can very easily put a large number of different elements at his disposal without the need to enter each element individually into the tree and then activate/deactivate them.

To choose the correct load class and corresponding safety factors it is necessary to write a code defined by the choice algorithm. For this purpose, the *Reaction function* within the *Engineering Rules* module is used, which will run the code, when there is a change in the input parameters. The full codes is shown in Fig. 4.

The code is written in ECL (*Enterprise Knowledge Language*) which is a specialized programming language designed to work in CATIA. It is based partly on the C++ programming language with some functions specific to this field of application.

```
let PG(DTSheetType)
set PG=CreateSheet("PG")

let Mat(String)
let Pog(String)
let i(integer)
let j(integer)
let row(Integer)
let col(Integer)

row=PG.RowsNb
col=PG.ColumnsNb
i=1
j=1
for i while i<=row
{
        Mat=PG.CellAsString(i,1)
        if LiftingHook_MaterialGroup==Mat
        {
                break
        }
}
for j while j<=col
{
        Pog=PG.CellAsString(0,j)
        if Load_Group==Pog
        {
                break
        }
}
cn=PG.CellAsReal(i-1,j-1)
vn=PG.CellAsReal(row-1,j-1)
```

Figure 4 Reaction for selecting powertrain factors and safety factors

With the specified factors and input parameters selected, it is possible to determine the required Hook Number. To select the Hook Number, a similar code is written (Fig. 5), which compares the calculated Hook Number with the standard numbers from the table and selects the first one larger than the calculated one.

```
let BK(DTSheetType)
set BK=CreateSheet("BK")

let i(integer)
let row(integer)
let br(real)
let kt(real)
row=BK.RowsNb
i=1
br=Max_Load/(1T*cn)
for i while i<=row
{
        kt=BK.CellAsReal(i,1)
        if br<kt
        {
                break
        }
}
Hook_Number=kt
```

Figure 5 Reaction for selecting Hook Number

With the selected Hook Number, it is possible to start making skeleton geometry (Fig. 6). The overall skeleton geometry is based on a combination of points, lines, and planes interconnected with parameters. The diameter parameters are used to determine how the geometry of the skeleton is changed using formulas and rules.

Since it is necessary to change the position of the coordinate systems by changing the catalog elements, a *Deign Table* was created that contains dimensions depending on the number of Hooks, and its change was determined using Reaction.

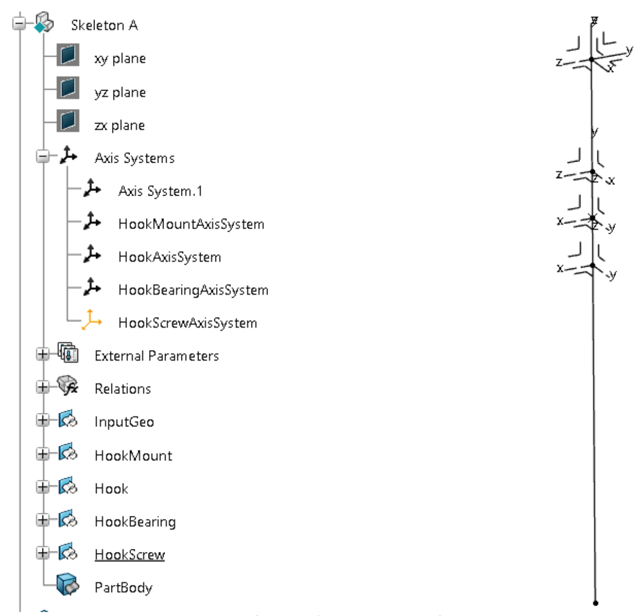

Figure 6 Positioning System for Hook Block Catalog Models

The next step is to fill in the *Resource Table* with all the catalog parts for which positioning systems have been added. Each part within the table is assigned an abbreviated name that will be used when editing the *Product Table*. With the help of additional coordinate systems, the positions of the ropes were determined. Using the *Product Table*, the number of ropes in the assembly will change according to the calculated number of Hooks. Fig. 7 shows the final Hook Block.

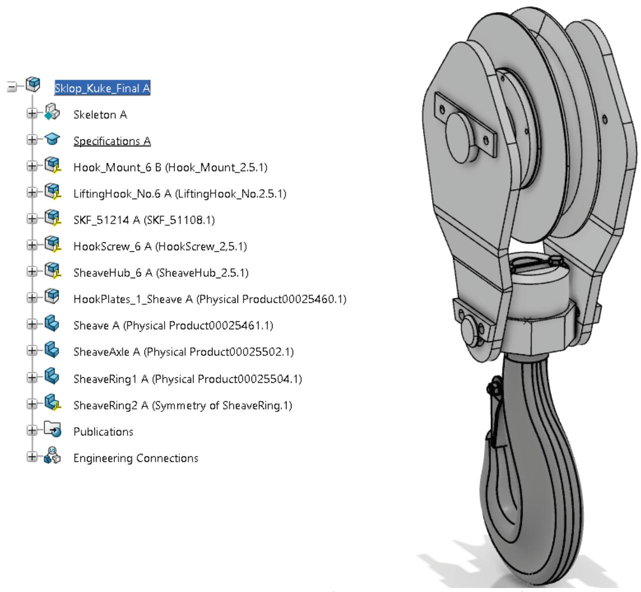

Figure 7 Hook assembly for Hook numbers up to 6

8 TEMPLATE OF TECHNICAL DOCUMENTATION

As part of the generic model of the Hook Block, it is also possible to add technical drawings of the assembly, i.e. individual components. For elements modeled as part of it, the technical documentation is created according to a standard process, and after the template is instantiated (Fig. 8), these dimensions in the drawing are automatically updated.

The biggest problem when creating a circuit drawing is during significant changes to the configuration of the assembly, where it is no longer possible to easily adjust the dimensions. One option to solve this problem could be to create a larger number of drawings for each significant configuration change and use the ECL code to activate/deactivate them as needed.

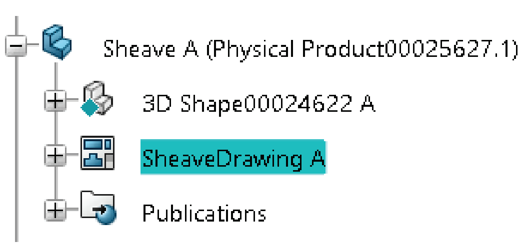

Figure 8 Thechnical Documentation added to the rope tree

Automation of the creation of technical documentation from an instantiated engineering template is still a novelty and as such has not been fully developed in the *3DExperience* software package. The principle applies to simpler assembly and workshop drawings, but for more complex products it is not possible to produce sufficiently accurate documentation that does not require intervention and corrections by the user. In addition to the above, it also requires a significant expenditure on working hours in preparation for the documentation to be of acceptable quality.

9 TEMPLATE INSTANTIATION

The created engineering template of the Hook Block can now be fully tested in the reference assembly. The *Physical Product* will be used as a reference assembly, in which a model of a simple crane and a separate *3DShape* have been added (Fig. 9). In preparation for instantiation in *3DShape*, it is necessary to add the point at which the template is to be instantiated, otherwise it will be instantiated at the origin of the main assembly.

After the parametric assembly of the Hook has been made, it is possible to make an engineering template from it. To instantiate the template itself, it is necessary to select the *Engineering Template Instantiation option* in the *Assembly* module (Fig. 10).

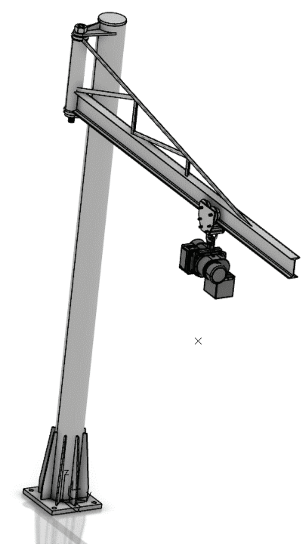

Figure 9 Physical Product with Template Instantiation Reference

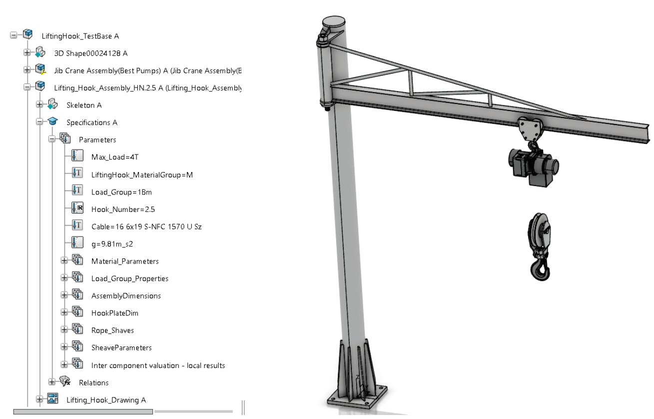

Figure 10 Physical product with added developed Hook Block

It is necessary to select the engineering template that is required to be instantiated which is possible by selecting the template directly or by selecting the template in the catalog.

Finally, by clicking on the OK button, the template is instantiated in the assembly. It is also possible to instantiate a template multiple times in a row by selecting the Repeat option. Instantiating a template creates new references for all elements of the assembly. This makes it possible to make changes to the instantiated assembly without changing the elements of the original model.

By entering the parameters of the assembly, the given input parameters, the calculated number of Hooks, and the required dimensions of the rope are visible. The parameters can also be subsequently changed as needed, which will result in the adaptation of the model itself.

10 CONCLUSION

In this paper, the process of creating an engineering template of the Hook assembly based on the parametrically designed model in the *3DExperience* software package is described. For the creation of the parametric model, an algorithm for calculation, design, and sizing of the Hook Block is defined.

The use of parametrically designed models and engineering templates can significantly speed up the process of making products that use a larger number of standard elements or elements for which there are predetermined calculations. The use of parametric models also accelerates the process of modification of existing models due to the possibility of modifying the parameters, according to which the adaptation of the rest of the model is made. The creation of the models themselves requires more time and higher proficiency in a certain software package.

Parametric modeling and the use of engineering templates represent a higher step of 3D modeling and product design that is increasingly applied in modern industry and knowledge of their principles will become an important skill for many engineers.

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