Feature-Based, Surface and Direct Modeling: an Aeronautic Point of View

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***Abstract*—Aim of this paper is to analyse and compare the characteristics of *Feature Based* and *Direct Modeling* techniques to determine their pros and cons for typical design processes. The first is one of the most common approach to create CAD models to be used for the machining phase of mechanical parts and assemblies. The second is a new method, alternative to the first one, based on a user-friendly approach, without rigid rules and constraints, that could represent the future of the CAD methodologies. Moreover, the *Surface Modeling* approach is analyzed and compared to the others, due to its common use in automotive and aeronautics fields. Considering the *Feature Based Modeling* as benchmark, three case studies were analysed to examine the peculiarities of these techniques, and to determine and highlight their advantages and their drawbacks. Several aspects were contemplated to perform the tests: the execution time for the realization of each operation, the easiness to create features and geometries, the possibility to adequately modify and upgrade the models and the number of operations needed to get the complete virtual prototype.**

In the end, the results were analysed and discussed focusing the attention on the possibility to adopt the *Direct Modeling* as substitute of the *Feature Based* and/or *Surface Modeling* and of the current CAD techniques.

***Index Terms*—Direct Modeling, Feature Based Modeling, CAD, Surface Modeling, Virtual Prototyping, Top-Down Approach, Main Landing Gear, Wing, Fuselage**

I. Introduction

NOWADAYS the Virtual Prototyping (VP) techniques are fundamental for the design and the production processes. They allow to use digital models in virtual environments to simulate the behaviour and the performances of a product not yet manufactured [1], [2]. The achievable results are often so accurate and realistic to allow to choose the best design strategies to improve the final model since the very starting steps of the production process [2]. They are grounded on robust algorithms, powerful software and user friendly tools that assist and guide the designer to the best solution. One of the most important among the VP techniques is the CAD modeling, that allows to generate the leading actor for each kind of simulation i.e. a virtual model (*Digital Mock-Up*) characterized by physical and mechanical properties. It can be used for digital testing, FEM and Multiphysical analyses, kinematical and dynamical simulations, etc. [3]. The VP techniques are used in many cases, from computer graphics (videogames and renderings) to educational, from medical to industrial fields [3]-[9]. In the last years, they are becoming very important for the design and the development of the nuclear fusion plants and their devices [10]-[15].

A (robust) CAD model can be created by means of several tools and techniques. In particular, parametric (i.e. *NX*, *CREO*, *CATIA*, etc.) and/or non-parametric (*Rhino 3D*, *3DS MAX*, *CINEMA 4D*, *MAYA*, etc.) software can be used [3]. One of the most common approach used to build solid prototypes is the *Feature Based Modeling* (FBM) because of the strong connection between the operations realized to create the CAD model and the real sequence of mechanical tasks done during the machining process. This technique is based on sketches, constraints and rules and in many cases complex models could be generated and cause problems hard to manage.

In the last years, a new technique, called *Direct Modeling*, is becoming very common due to its interesting peculiarities. It allows to operate straightly on the geometry without the analysis and the use of sketches and rules making the modification of each kind of geometry easier. Several Direct Modelers are available on the market (*ANSYS SpaceClaim*, *PTC Creo Direct*, *Autodesk Fusion 360*) demonstrating the growing interest reserved to this new modeling technique by the most important CAD and FEM companies. In particular, *Direct Modeling*, due to some remarkable features and to the integration with the most common 3D CAD and FEM software, could represent the solution to some typical problems of the classical modeling techniques. Furthermore, it might be a first step to win some of the current challenges of the Geometric Modeling as the virtualization of porous medium, or non-homogenous materials in order to vary their density and composition. For instance, it could allow to properly simulate complex substances in biomedical applications [16]-[23].

So, main targets of this paper are: a) to analyse and describe the main features of the *Feature Based*, *Surface* and *Direct Modeling*, b) to make a comparison based on some case studies developed to highlight pros and cons of these approaches. Furthermore, due to the massive use of the *Surface* and of the *Feature Based Modeling* in the aircraft design, an aeronautic point view was considered.

The section II of the paper describes the main concepts of the Geometric Modeling with particular attention to the *Feature Based Modeling*. Sections III and IV analyses the *Direct* and the *Surface Modeling* approaches. The case studies to validate the methodologies used are presented in the section V whereas the results are compared and shown in section VI.

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II. Geometric Modeling

Geometric Modeling allows the mathematical description of shapes. It is based on methods and algorithms implemented to create the replica of objects by means of 2D technical drawings and 3D MCAD in virtual environments. So, it is possible to represent real models characterized by volumetric information and physical properties like mass, density, volume, etc., [3], [19], [24]. In this way, the designer can realize multiphysics analyses with accurate results starting from the use of specific software. For instance, *Computational Fluid Dynamics* (CFD), *Fluid Structure Interaction* (FSI), Electromagnetic (EM) simulations or ultrarealistic renderings for visualization purposes are possible [3], [16], [21].

Many CAD methodologies are available to create the needed virtual prototypes. The most common are: *Solid Modeling*, *Surface Modeling*, *Sheet-Metal Design*, *Chunky Modeling* and so on [3], [16]. Probably, the best modeling technique doesn't exist. Only evaluating the pros and the cons and so the "potential benefits" of each one it will be possible to select the most appropriate choice to design and realize the specific product.

Usually, in the industrial field, solid models characterized by technical features (holes, cut-outs, rounds, etc.) are requested. Whereas, when for styling purposes, profiles or shapes properly designed and optimized are mandatory, surface modeling is to be preferred.

Due to its common use, in this section solid modeling is considered and in detail the *Feature Based* approach is analysed.

Feature Based Modeling (FBM)

A model can be built by means of features. Features are technological operations (extrusions, cut-outs, holes, fillets, etc.) executed on the model. At present, FBM is one of the most common techniques used to realize solid prototypes. The CAD models are built starting from a base component adding material to it or subtracting material from it. Each mechanical operation can be strictly connected with CAD features as extrusion, cut-out, revolve, chamfer and so on. The list of operations has to be carefully planned by the designer in order to properly define the interdependencies between the features. Otherwise, in case of complex parts, conflicts and errors could occur.

The *Feature Based* modelers are *History-Based* software. This implies that each operation is sequentially stored in a history-tree (Fig. 1). It is based on sketches, parameters and features and it can generate rigid sequences and strong interdependencies between the entities created (*parent-child* relationships).

FBM was originally developed to be strongly linked to the CAM (*Computer Aided Manufacturing*) for the design of mechanical parts and mechanism. In fact, if correctly set, the history-tree can represent the exact sequence of mechanical operations done by means of CAM tools (that are often integrated into the most important CAD software as CATIA, NX, CREO). So, the creation of the CAD model coincides with the definition of the manufacturing *Numerical Control Code* (NC code) for the machining phase with higher efficiency and cost reduction.

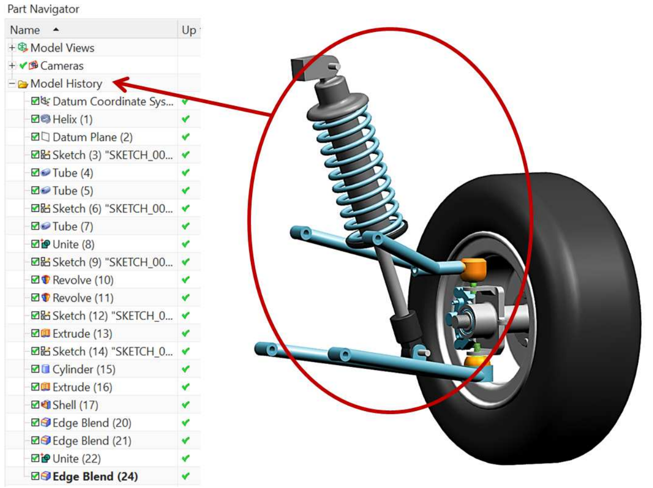

Fig. 1. History-tree of a parametric model realized by means of a *Feature Based Approach* in SIEMENS NX.

Therefore, the *Feature Based Modeling* is a parameter-based approach that can significantly cut-down the costs, the number of input commands and so the time to modify and upgrade the project. This is especially useful in case of re-design and it is suggested for large part assemblies, *Virtual Testing* and *Rapid Prototyping* [16].

The outcome of a FBM approach is a geometric model. It is characterized by modifiable parameters that allow to generate model variants. This is possible thanks to rules, constraints and dimensions properly defined and stored in the history-tree. It implies the easy definition of alternative models just operating on some specific values and geometric objects. In fact, in a parametric model, each entity is associated with several parameters. They control its various properties, such as the length, width and height. When the designer modifies the value of these parameters, the part is "regenerated" and the software repeats the operations of the history-tree creating the new solid. In this way, for example, the designer can test the alternative model starting from different dimensions of the features identifying the "best" variant according to the project requirements.

But this approach can also imply some drawbacks. The most significant is the complexity of the history-tree and the lack of clarity in case of a large number of features of the CAD model realized. For instance, if the modification of the shape of the model is required, the designer has to search for the particular feature in the history-tree and to identify which specific parameter must be changed. This step could be difficult, especially in case of complex assemblies. Another drawback is related to the strong relationships between the many features and entities of the model. For instance, in case of failures, most of the times, the reconstruction of the whole model from the beginning is suggested (if possible) rather than to try to solve the problem.

Although the history-tree and the interdependencies between the features could create problems or difficulties, they represent the main strength of the *Feature-Based Approach*. In fact, they allow to define the rules needed for the "structured modification" of the characteristics and so the possibility of alternative variants of the CAD model helping to manage tons of parts thoroughly. So, if the CAD assembly (or model) is generated according to the best practices of the *Top-Down* modeling and is based on proper skeletons and reference systems, the result will be robust enough respect to each kind of failure [24].

III. Surface Modeling

It allows to define and visualize the external parts of 3D components in a virtual environment. It is obtained starting from curves (i.e. *Splines*, *B-Splines*, *NURBS*, *T-Splines*) and operations on it (extrusions, sweeps, lofts, blends, trims, unite, etc.) and is characterized by control points, spines, guide curves [20]. A surface can be created starting from a net of curves, (some) guide lines and sweep operations. Otherwise, it is possible to build directly its shape and then to manipulate its control points. Usually, a surface has no thickness and physical/mechanical properties [16].

Surface modeling is common in the following fields: *Automotive* (car bodies panels), *Naval* (virtual prototyping of components for CFD analyses) and *Aeronautics* (gas turbine blades, wings, fuselage, *etc.*), Architectural Renderings, 3D Animation and Video Gaming [16], [20].

Several advantages of the Surface Modeling are to be considered [17]:

-- it is less ambiguous than other techniques,
-- it removes hidden line and adds realism,
-- complex surfaces can be easily identified,
-- it supports the NC path generation for complex shaped components, structures, dies, molds and sheet-metal parts used in aerospace and automotive fields.

On the contrary, the surface modeling is characterized by several disadvantages [17]:

-- it can be difficult to construct the model, much more than for other CAD techniques due to complex (in some cases) operations as trim, projection, divide, *etc.*;
-- it takes a lot of time for the creation and for the successive possible upgrade of the model;
-- when, as it usually happens, the solid part is needed, a conversion process, often not free from errors, is mandatory;
-- it can be difficult to calculate the mass and the volume properties related to the model represented.
-- it requires a designer's higher training and mathematical background [17].

IV. Direct Modeling

Direct Modeling is a new CAD technique that allows to straightly modify the geometry and overcome the main drawbacks related to the interdependencies among the sketches, the parameters and the rules defined in a *Feature-Based* approach. It is grounded on the *Boundary Representation* (B-Rep) of the model that is updated and regenerated starting from the constraint equations rather than the history-tree. The designer can modify the model without any info about its creation and without the interaction with rules, parameters and links with other features. So, any model is easily modifiable because the modeling history is not needed [22]. Thus, he can push or pull faces to change the height of a part, or grab edges to define or modify rounds and fillets. So, although the "design intent" could not be kept, a really user-friendly approach derives and guides each operation, making the design phase very easy [3].

Moreover, the designer can forget all the problems related to the CAD formats because it is not important to know which CAD software was used to realize it, avoiding any operation to convert the file into a specific CAD recognizable format. This allows to work in real time with MultiCAD models. Whereas if a FBM software is used, it is not possible to modify the parametric model in a CAD environment different from the one used to build it. In this case, only B-Rep prototypes can be imported without any other entities, or info about it, like sketches, constraints, parameters and features [21]-[23]. So, a *Feature Recognition* phase or an expensive CAD translator are needed. In both cases, the results are often not full parametric models and not free from errors.

In a DM project the non-parametric (B-Rep) model is simplified and subdivided into smaller geometries that can be modified without the typical problems of the history-tree approach.

The easiness of the learning process for a beginner is another aspect to consider. The Direct Modeling techniques result much easier to be studied and used respect to a method grounded on complex sketches, constraints, parameters and features.

Several software based on the *Direct Modeling* techniques are available on the market (*ANSYS SpaceClaim, PTC Creo Direct, Autodesk Fusion 360*). Other solutions contemplate their integration into Parametric CAD software (*SIEMENS NX* and *Solid Edge* with *Synchronous Technology*) [25]-[27].

The main advantages of the Direct Modeling, for instance, are noticeable:

-- in the *Concept Design* phase,
-- in the *simulation processes* (FEM, CFD, *etc.*),
-- in the *Manufacturing* (CAM).

DM is very useful for the conceptual design because the designer can explore new solutions in a very easy and rapid way especially when *Rapid Design* operations and changes are needed and he doesn't have to take into account rules, features, constraints, *etc.*

For the simulation processes it has to be considered that software as *ANSYS Workbench* integrates the *Direct Modeling* techniques with their powerful multiphysics environment. So, it is possible to update the geometry and execute FEM analyses in real time without intermediate steps related to file modifications or conversions [3].

For the manufacturing tasks, the *Direct Modeling* techniques help vary on-the-fly each property of the model representing a valid support for those who work with time and production limits.

V. Case Studies

A. *Description*

Three case studies, based on different peculiarities and characteristics, were considered focusing the attention on aeronautical products and applications. In particular, the Wing, the Main Landing Gear, and the Fuselage of the Boeing B737 aircraft were chosen and analyzed (Fig. 2). For the sake of simplicity, approximated geometries and schematic models, based on their main and not detailed components, were realized. However, the results obtained were good enough to help gather info and data to compare the *Surface*, the *Direct* and the *Feature Based Modeling* techniques.

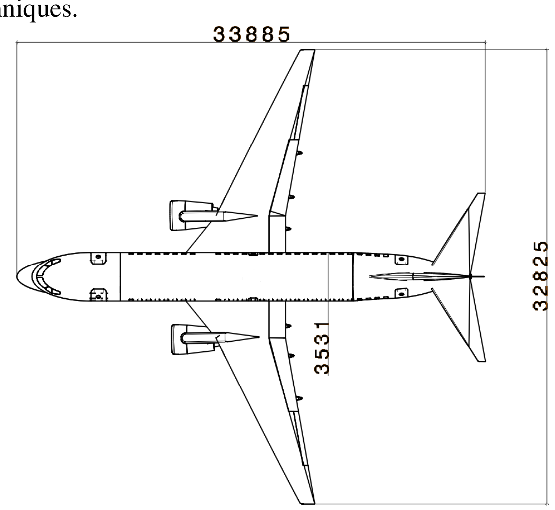

Fig. 2. Example of the plan view of the model realized in the CATIA CAD environment starting from the original dimensions (mm) and features of the Boeing 737 aircraft.

A neutral approach was assumed in order to notice the differences between these techniques without any preference for one respect to the others. The realization of the different models was carried out considering the following main factors.

-- *Lead Time*: the clocked time (measured in minutes) needed to create the 3D geometry.
-- *Rapid Model Editing*: possibility to modify the geometry adequately.
-- *User-Friendliness*: easiness to use, or learn to use, the software and the methods analysed.
-- *Number of operations* needed to realize the final model.

B. *Surface modeling of the B737 wing*

The surface model of the wing of the Boeing B737 was built starting from three different airfoils i.e. the *root*, the *midspan* and the *tip* sections (Fig. 3). The airfoils are described in terms of the coordinates of the points of the profile [28].

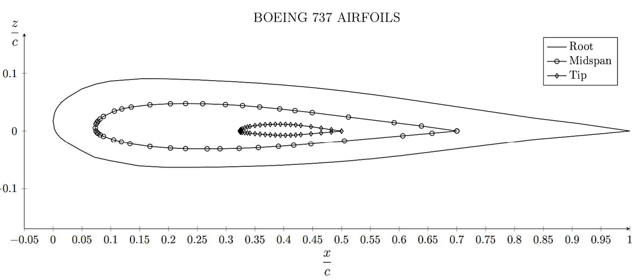

Fig. 3. Airfoils of the Boeing 737 aircraft.

The following tasks (Fig. 4) were set to create the final surface in both the CAD environment:

SURFACE MODELING TASKS
- IMPORT ROOT AIRFOIL,POINTS
- CREATE ROOT SPLINE
- IMPORT MID AIRFOIL POINTS
- CREAT MID SPLINE
- IMPORT TIP AIRFOIL POINTS
- CREATE TIP SPLINE
- CREATE MULTI SECTION SURFACE

Fig. 4. Tasks defined for the creation of the wing skin in both the CAD environments.

In the *Surface* modeler used (CATIA v5), the importing phase of the points was possible thanks to an (external) Excel macro. Instead, the *Direct Modeler* allowed to read text files and simplify and speed up the task.

The editing of the geometry was a little bit difficult in the *Surface Modeler* due to the typical rules and constraints of the parametric approach. The DM instead was very rapid and smart allowing to use a very intuitive method similar to "drag and drop". Furthermore, although the FB modeler has a specific and complete environment dedicated to the surface modeling, it could be hard for a beginner to find the right tool rapidly, otherwise the DM modeler shows a very simple and intuitive interface.

In Fig. 5a the sequence of operations related to the construction of the external part of the wing in the DM modeler is shown. Whereas, in Fig. 5b the history-tree of the final model realized in the surface modeler is presented. It shows a longer list (references, construction entities, operations, *etc.*) due to the typical structure of a *History-Based* model.

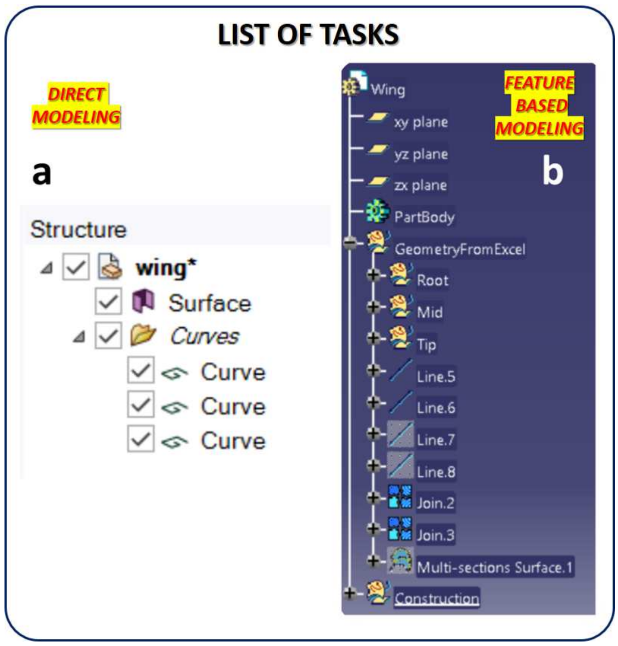

Fig. 5. a) *Direct Modeler* list of tasks, b) *CAD Modeler* history-tree.

After several operations in both the CAD environments, the final model of the skin of the wing of the Boeing B737, completed also by the flaps, was obtained (Fig. 6 and Fig. 7).

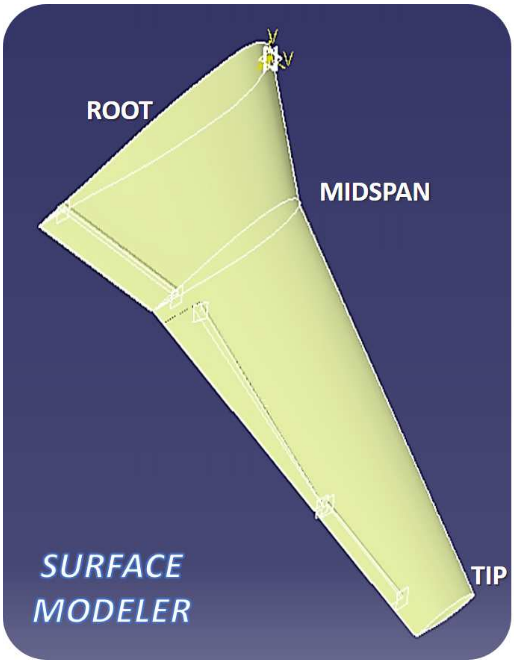

Fig. 6. Skin of the wing of the Boeing 737 aircraft, completed by the flaps, realized by means of the Surface Modeler (CATIA).

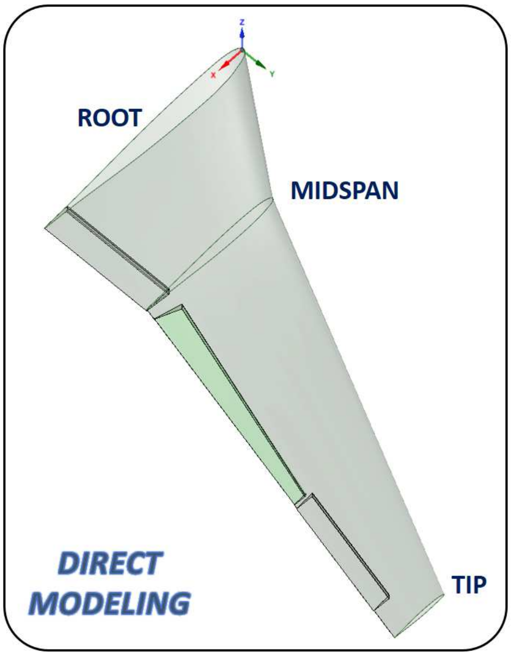

Fig. 7. Skin of the wing of the Boeing 737 aircraft, completed by the flaps, realized following the *DM* approach.

Two different CAD expert users, one for the DM approach and one for the Surface Modeling, realized the two models and answered to some specific questions about the work done. Fig. 8 shows the synoptic table with their evaluations about the methods followed, in order to compare the two approaches (*SM – Surface Modeling*, and *DM – Direct Modeling*) used to build the surface models of the wing of the Boeing 737.

1. LEAD TIME		2. USER-FRIENDLINESS		3. MODEL EDITING		4. NUMBER OF OPERATIONS	
SURFACE MODELER	*DIRECT MODELER*	*SURFACE MODELER*	*DIRECT MODELER*	*SURFACE MODELER*	*DIRECT MODELER*	*SURFACE MODELER*	*DIRECT MODELER*
5 MIN	3 MIN	POOR	HIGH	MEDIUM	HIGH	8	6

Fig. 8. Comparison between *Surface* and *Direct Modeling*.

However, it is important to note that the typical surface modelers are rich in tools and functions for the realization of high efficiency and quality curvatures (Class A surfaces). At present, this is not so true for the DM modelers. So, if complex and detailed results are needed, i.e. high-quality standards in automotive and aeronautical fields, a surface modeler would be the optimal choice.

C. Solid Modeling of the Main Landing Gear

The Main Landing Gear (Fig. 9) of the Boeing 737 was studied. It was simplified by a four parts assembly:

-- *Outer Cylinder*,
-- *Inner Cylinder + axle*,
-- *Rim*,
-- *Tyre*.

Similarly to the previous case study, it was modeled starting from a classic approach (*Feature-Based Modeling*), and then by means of the *Direct Modeling* techniques.

Fig. 9. Example of the simplified model of the landing gear of the Boeing 737 aircraft realized and rendered in CAD environment.

The tasks considered for the virtual prototyping are listed in Fig. 10.

SOLID MODELING
TASKS
- SOLID MODELING OF THE OUTER CYLINDER
- SOLID MODELING OF THE INNER CYLINDER + AXLE
- SOLID MODELING OF THE RIM
- SOLID MODELING OF THE TYRE
- ASSEMBLING ALL PARTS

Fig. 10. Tasks defined for the creation of the solid model of the Main Landing Gear in both the CAD environments.

Each component was realized and then assembled to the others according to a *Bottom-Up* approach. Each part was created starting from a parametrized sketch and by means of features such as: *Pad*, *Pocket*, *Hole*, *Shaft*, *etc*.

Considering the FBM approach for the specific case of the rim, the solid model was realized with three features starting from three different sketches: a circle for the pad, two other circles for the pocket and the last sketch for the definition of the hole. Instead, in the case of the DM only two *Pull* operations, realized simply moving the mouse, starting from two sketches were needed (Fig. 11).

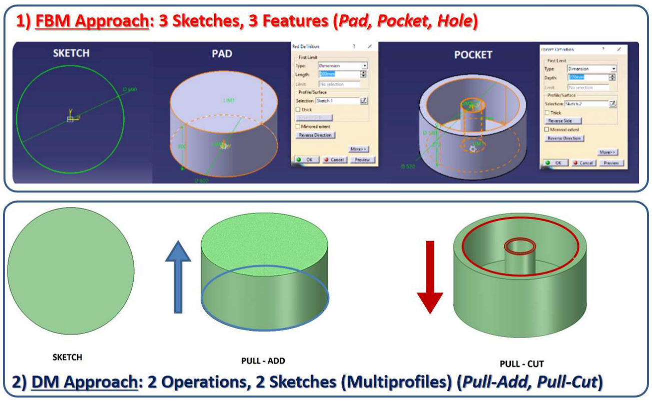

Fig. 11. Comparison between FBM and DM in terms of number of operations.

Fig. 12a and Fig. 12b show the history-tree of the solid model realized by means of the FBM and DM approaches. It is easy to notice how DM techniques strongly simplify the sequence of operations and so the results.

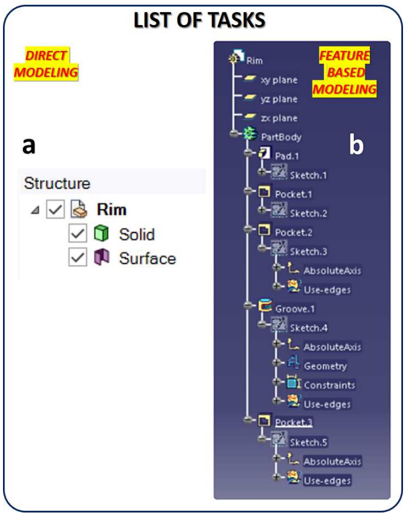

Fig. 12. List of tasks used for the modeling of the rim. a) *Direct Modeler* list of tasks, b) *Feature-Based* history-tree.

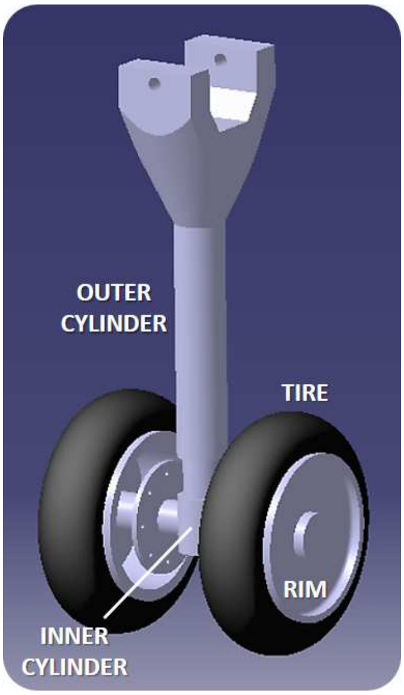

Fig. 13. Simplified CAD assembly of the Boeing 737 aircraft realized following the *Feature-Based Modeling* approach.

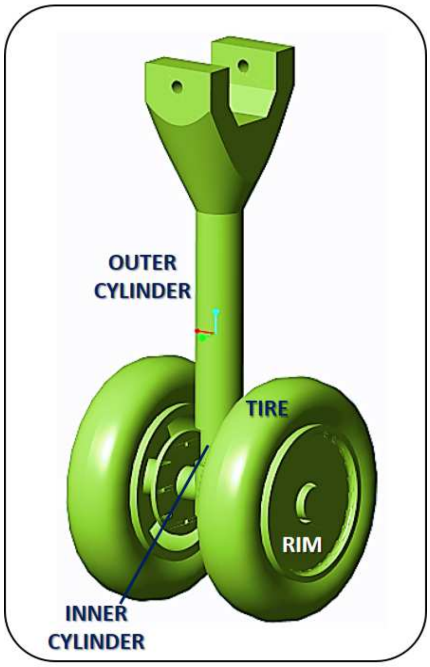

Fig. 14. Simplified CAD assembly of the Boeing 737 aircraft realized following the *Direct Modeling* approach.

The assemblies realized by means of the two alternatives methods analyzed are shown in Fig. 13 and Fig. 14.

Similarly to the case study of the wing, the same two different CAD expert users built the two models and answered to some specific questions about the work done. Fig. 15 shows the synoptic table with their evaluations about the methods followed in this case to allow to compare *Feature Based* and *Direct Modeling* techniques.

1. LEAD TIME		2. USER-FRIENDLINESS		3. EASY EDITING		4. NUMBER OF OPERATIONS	
FEATURE BASED MODELER	DIRECT MODELER	FEATURE BASED MODELER	DIRECT MODELER	FEATURE BASED MODELER	DIRECT MODELER	FEATURE BASED MODELER	DIRECT MODELER
55,8 MIN	53 MIN	MEDIUM	HIGH	MEDIUM	HIGH	18	16

Fig. 15. Comparison between *Feature-Based* and *Direct Modeling*.

D. History based modeling of the B737 fuselage

The last case study was the simplified modeling of the B737 fuselage shown in Fig. 16. Usually, the fuselage is mainly characterized by skin, frames, bulkheads, formers and stringers and it is organized in (numbered) cross-sections. The frames are joined by longitudinal elements (stringers) and covered with an aluminum skin attached by means of rivets.

Alternatively to the previous samples realized by means of the Surface and Direct Modeling approaches, a history-based technique, following a Top-Down procedure, was set to create the CAD models of the Fuselage and of its elements. It was done to show the strength of this approach and why it becomes irreplaceable. In fact, only by means of constrained sketches, features and rules it is possible to create parameters and geometrical links among parts, skins and all the components of the assembly to fully control it in a very short time. For instance, if the modification of some characteristic like the dimensions of the Fuselage, or of the main profile of the stringers or of the distance between each cross-section is required, the parametric approach allows to vary it in real time in a very easy way. Moreover, as these changes are needed for all the cross-sections (as usually happens), when the single element is updated all the modifications are automatically extended to the others components thanks to the geometrical links created. In fact, in this case the use of rules, parameters and constraints makes the final CAD model a powerful and smart tool robust enough respect to each kind of variation or failure.

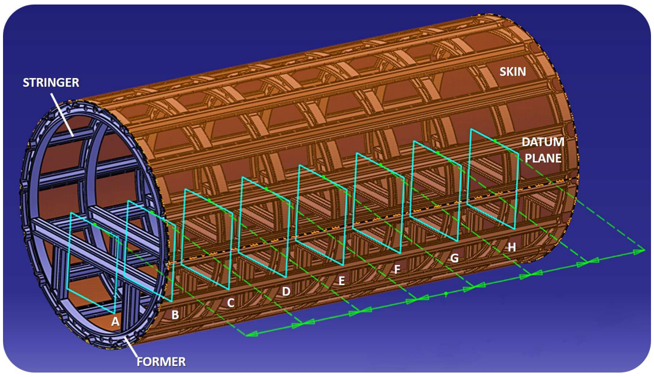

Fig. 16. Part of fuselage of the B737, used as case study, modeled starting from a *Top-Down* approach.

On the contrary, it is important to note that it is very difficult (even impossible in most cases) to obtain the same results counting only on the Direct or Surface Modeling. In fact, it is not possible to define the rules to fully parametrize the elements of the fuselage avoiding its upgradeability.

VI. Comparison

The several factors previously defined helped to compare the results obtained by the three cases studied. In particular, they allowed to identify the pros and the cons of the three CAD modeling techniques analysed (*Feature Based Design*, *Surface* and *Direct Modeling*). It was interesting to notice that the *Direct Modeling* showed the best results for the Wing and MLG case studies in terms of a) *Lead Time*, b) *User Friendliness*, c) *possibility to properly modify the geometry* and d) *number of operations* needed to complete the CAD model. It happened both respect to the *Feature Based* approach, and to the *Surface Modeling*. Furthermore, it has to be considered that its peculiarities are strongly convenient for the conceptual design phase when the freedom to easily modify the models is mandatory for the designer. Moreover, it was interesting to notice that the outcomes obtained showed that DM is particularly useful for the modification of non-parametric prototypes. So, it is possible to vary solids and surfaces without complex operations in real time.

On the contrary, the Fuselage case study demonstrated that the DM is unsuitable when the full geometrical and dimensional control of the CAD assembly is required. In other words, in some cases it is very difficult to replace the benefits of a well "structured" virtual prototype created by means of a robust Top-Down procedure.

However, although the *Feature Based* and *Surface Modeling* are the standards methods for the CAD modeling of complex prototypes to be used in the aeronautics and in the automotive fields, the results obtained demonstrated that the *Direct Modeling* can have a very interesting future among the Geometric Modeling techniques and could be very useful in industrial field too.

VII. Conclusion

In this paper a comparison among *Feature Based*, *Surface* and *Direct Modeling* was presented. Typically, in the aeronautic field, there is a massive use of *Surface* and *Feature Based Modeling* for the design and the virtual prototyping of components as panels, skins, engines, gears, and so on. For this reason, an aeronautic perspective was considered setting a comparison between the results obtained by means of the above mentioned three different CAD techniques for the simplified virtual prototyping of the *Wing*, the *Main Landing Gear* and of the *Fuselage* of a Boeing 737. Two different CAD expert users realized the models and answered to some specific questions about the work done. It allowed to find very interesting and hard-to-beat results in terms of *Lead Time*, *User Friendliness*, *possibility to properly modify the geometry* and *number of operations* needed to complete the CAD model. So, it is possible to think that in all likelihood, in the nearest future, the new *Direct Modeling* approach will represent the powerful evolution and improvement of the most common current CAD techniques.

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