WAVE TECHNOLOGIES FOR THE DESIGN OF PRODUCTION TOOLING IN AIRCRAFT INDUSTRY

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Abstract. The paper proposes the design of 3D tooling models in CAD systems based on top-down design strategy using WAVE technologies. This technique allows parallelizing some design efforts on process engineering (PE), which generally reduces product costs and production time.

1. Introduction
At present, the main objective of engineering and design is the design of electronic analogs (EA) and electronic analogs of assembly units (EA AU) using various computer-aided design system (CAD) not only from metal but also from ceramics and polymers [11-13]. However, if the transition towards molding-free production of parts and assembly units (AU) is almost complete [1], then the transition towards drawing-free production is at its initial stage therefore in most cases the product takes its real geometric shape only after being produced ‘in metal’. In this case, within the ‘EA-drawing-workpiece’ chain the EA only serves as the primary source for paper drawing thus imposing some restrictions on product geometry resulting from traditional graphics of a product through drawing on paper.

2. Problem statement
As previously noted, the preparation of drawings imposes a number of restrictions, so let us consider them in more detail [2]:
- Incompleteness of graphic information.
  The complexity of shapes and geometric relationship of elements in AU may only be thoroughly described by a certain quantity of types and sections and in fact, the more complex a product is, the bigger quantity of elementary units it includes, and the more drawing form sheets are required for a comprehensive view of an engineering thought, thus resulting in failures in subsequent process flows (PF).
- Lack of associativity.
  Each element describing the design and each drawing sheet is independent in itself therefore any adjustment leads to the fact that a considerable part of graphic information shall be manually updated.
- Lack of coherence.
  Assembly drawings (AD) forming a conceptual model of information on geometric relationship and interaction of components cannot influence on correctness of workpiece drawings. Parts and units
only have geometric relationship when such relation is manually applied on drawing without any failures. Moreover, the concept of drawing-free design still remains valid, which requires additional graphics and dimensioning on AD.

At the same time, the appearance of modern solid-state CAD systems and their introduction in design documentation (DD) in the majority of companies was made at the level of a simple tool, which replaced a drawing table and a pencil and failed to fully exploit its potential. This resulted in the situation when restrictions typical for a traditional method were reflected in CAD systems during the design of 3D EA [2]:

- Incompleteness of graphic information:
  EA are designed according to a flowchart when some geometric constructions are missing (for example, without some radiuses, facets, threads, etc.) since there is a tendency and focus of paper drawings on simplifications therefore the EA is not suitable for different calculations (for example, strength) and parts control via inspection machines (IM) though all these elements are present in the drawing.

- Lack of associativity.
  Low parametrization ratio and lack of direct dependence ‘geometry EA_1 – geometry EA_2 – geometry EA_N’ lead to the fact that when one dependent EA is changed in AU, the others shall be manually edited, which finally increases the design effort and does not exclude the probability of new mistakes, as well as makes the search of alternative solutions following the ‘what-if’ principle more complicated.

- Lack of coherence.
  The AU developed on the basis of the so-called build-up strategy (from elementary details to AU), where all designed EA are directly indicated in the assembly irrespective of each other in addition to their low parametrization level, leads to the fact that upon any change in EA AU structure the integration process shall be repeated again.

3. Problem solutions. General file structure

The above disadvantages may be solved by the top-down design strategy ‘from structural master geometry (SMG) or conceptual parameters to individual nodes and detailed EA included into them’. In this case, at each design stage the relations between separate AU and EA are maintained at all levels of constructive structure of a workpiece, and the geometry becomes consistent thus excluding additional check and coordination. Moreover, such approach allows experimenting with the structure of a future product in a safer and less intensive manner through the selection of the most suitable idea from a number of creative ideas of a designer thus fulfilling the potential of the so-called conceptual experiment [3].

Let us consider the general file structure (Fig. 1) presented below.

![Figure 1. General file structure](image_url)

**Figure 1.** Shows that the structure includes the following files:
- CS_ (control structure) – a file of control structure where all files required for design and coordination are kept thus representing a conceptual model with general geometry and parameters of the entire product.

- WP_ (work part) – a file of the work part where all geometric constructions required for this item are associatively related to dependent elements in AU, unit node, etc.

- Part_number – a file of a detail including the associative EA copy from WP_. If WP is changed the EA placed in part_number is automatically updated.

- AP_ (Assembly part) – a file representing EA AU with included in its structure and associated between Part_number files. Since the geometry design is made in WP_ and the main part of links to geometry is located there, the AP_ is uploaded from excessive information and has correct physical characteristics.

- Part_number_DR – a file including association drawing created from a workpiece or an assembly unit.

To implement the dependent geometry, the so-called WAVE technology is implemented in the Siemens NX CAD system. WAVE is a tool providing for associative copying of geometry from one file of a model into another. It is possible to copy any geometric object - solid and sheet bodies, coordinate systems, auxiliary axes and planes, sketches, curves and points, as well as numerical parameters. All changes in initial geometry are by default monitored in all its WAVE copies [2]. The associative copies of objects are created using a WAVE link. The WAVE link is an operation referring to the creation of an assembly part of associative geometric objects linked to other parts of the same assembly. Depending on the established option, this operation also allows creating non-associative objects [4].

Next, the paper considers the use of WAVE technology via examples of production tooling design used to manufacture and assemble parts and nodes of aircraft equipment (AE).

4. Shape-generating molding tools

The shape-generating molding tooling is intended for fabrication of parts from workpiece sheets via forming, molding, stretching, etc. [5].

In terms of design, the shape-generating molding equipment represents metal or moulded pig duplicating external or internal contour of a workpiece.

Form blocks and stretch dies (Fig. 2) are considered the main types of the shape-generating molding equipment used in aircraft industry.

![Figure 2. a) – form block; b) – stretch die](image)

One of the features of irregular production tooling design from sheet material is that the equipment shall duplicate internal or external contour of a workpiece. Besides, the springing angles of a material to reduce manual modifications after forming shall be considered [5].

Let us consider in more detail the design of the shape-generating molding equipment using WAVE technologies. At first the design engineer creates the structure of files described earlier (STEP 1, Fig.
3) and places all geometry necessary for the design into the working file of equipment - WP_Part_number via WAVE link editor. Then by copying and expanding the boundaries, a surface tool is created for workpiece blanking, flanging, bending, etc. (STEP 2, Fig. 3). Afterwards, a solid workpiece is prepared, which will form the basis for a form block (STEP 3, Fig. 3). Cuts and pimples (STEP 4, Fig. 3), as well as pin holes are created from a workpiece via the surface tool through ‘Cutting’ operation. Risks of a workpiece contour, risks of wearing ease, risks of bending input and output, etc. are projected on the obtained solid-state model. (STEP 5, Fig. 3). The finished solid workpiece and all risks are placed in the workpiece tooling file – Part_number via the WAVE link editor (STEP 6, Fig. 3).

![Figure 3. Design of a form block in CAD system](image)

The above technique can also be applied to design stretch dies, stamps, as well as for machine systems to process an irregular workpiece thus installing it on support assemblies, etc.

Next, let us consider the design of assembly production equipment.

5. **Design of stack-assembly tooling (SAT) using WAVE technology**

SAT is applied in aircraft industry in the conditions of non-conveyor production to assemble aircraft nodes and units into a single piece. SAT represents a frame with knife switches, supports, and various clamps and clips to ensure precise positioning of an assembly object and to perform the required technological operations [6]. As a rule, this type of equipment is the most labor consuming, responsible, difficult to design and expensive to produce therefore the aircraft manufacturing enterprises put a lot of effort to decrease the cost of every stage of SAT life cycle (LC).

Figure 4 shows that every stage may and in most cases has the need to redesign initial EA AU on the basis of different observations and suggestions in the course of design coordination and piloting in production [7].
Figure 4. EA development, coordination and production of a workpiece ‘in metal’

It is advisable to use WAVE technologies to save time and increase labor productivity of a design engineer for EA AU redesign (especially large workpieces that include dozens of elementary parts). Regarding SAT design, a variety of fixture elements is directly dependent on the geometry of frame elements of an aircraft design and on their arrangement in relation to main planes of an aircraft. As a result, even minor changes, for example, change of skinning curvature, will cause serious changes in equipment geometry, which are extremely difficult to correct manually and may lead to fundamental mistakes due to carelessness. This only counts in favor of WAVE technologies since if there are more interdependent elements, it is much simpler, quicker and safer to redesign the EA SAT.

Below the paper considers the design of a ‘Knife switch’ workpiece included into EA SAT needed for the assembly of an aircraft lower panel.

Figure 5 shows that the EA structure is similar to the structure considered earlier in item 2. There are two main CS and WP files and additional files, from which the geometry is partially borrowed.

The authors note that the number of additional files necessary for EA design depends on various factors (approaches to design, complexity of a workpiece, etc.) therefore the structure presented here is quite specific. Figure 6 shows the disclosure of files and assemblies loaded in CS.
Let us comment on these files:
- EA AU file represents a model of a lower panel of cargo aircraft, for which the equipment is designed;
- SMG stringer file – a file including link surfaces ‘removed’ from stringer caps for putting the risks of axes on knife switches and supports;
- SBE support file – an assembly including EA of supports necessary for the protection against attachment hole coupling and knife switch geometry checking without its loading in the main AU;
- SMG file – a file including section planes, pitching planes and other planes necessary in EA design.

After all necessary files are loaded in CS, the designer goes to WP file and creates the necessary associative copies of elements via the WAVE link. In this case, it includes the outer skinning, section plane (SP), from which a knife switch, PSS, and a response support body will be designed. A strip body may also be linked for associativity between a knife switch with a support. Figure 7 shows the general scheme of elements described above.

![Diagram of associative links](image)

**Figure 7.** Example of geometry borrowing from a structure into a working WP file

Once all necessary associative copies are included into the working file, the designer begins designing a knife switch [8, 9]. Proceeding from the fact that the required skin has different cuts it is rational to create its copy and expand it to a fixed length to make sure that the skin contacts with the working surface of a knife switch (STEP 1, Fig. 8) or has a guaranteed gap to install rubber gaskets or clips. Then, the obtained surface is displaced in relation to the support on an equidistant curve specified in fixture technical design specification (STEP 2, Fig. 8). Using a link plane, the designer first finds the intersection of a displaced surface and planes, then shifts a curve to the left and to the right via equidistant lines and finishes a knife switch contour (STEP 3, Fig. 8). The next step is the knife switch body (STEP 5, Fig. 8), which is created by cutting a knife switch body using a displaced surface obtained at STEP 2. This leads to a working zone, where the distance from a working zone of a support to a knife switch is quite accurate. STEP 6, Fig. 8 shows the designed sketches of the knife
switch top and bottom (a cut for fitting to a holding frame via response compensator and a hole for fitting to a support via a clamp).

Then, the designer projects cuts for stringers. First, (STEP 7, Fig. 9) the designer finds the intersection of stringer bodies with SP plane thus getting section profiles, and then in relation to them (STEP 8, Fig. 9) the sketch of cuts is drawn. The final stage is to create a cut via the Boolean operation (STEP 9, Fig. 9). STEP 10 usually covers the last geometric elements of a knife switch, such as cuts for holding washers, and spherical radius, etc. The final stage of a full-fledged model includes the risks of axes of stringers. For this purpose, the file with stringer SMG (STEP 11, Fig. 9) is activated in a working environment and the risks of axes are built via crossing of necessary surfaces and a knife switch body. STEP 12 shows the final EA model of a knife switch.

Figure 8. Design of a knife switch in Siemens NX 7.5
The final stage (STEP 13, Fig. 10) is to create a WAVE link between the WP file and a file, where a copy of EA of a knife switch will be stored. For this purpose, the designer activates a file and links a body and stringer risks of axes into it. The design tree (Fig. 10) shows that all operations are kept in the WP file, and the working file only stores associative copies, which, in case the WP file is changed, are reconstructed automatically. Moreover, such EM makes it possible to facilitate the complex AU. Now the file of a knife switch can be uploaded in the general SAT assembly (STEP 14, Fig. 10). Other knife switches (taking into account technical design specification) and supports are designed in a similar manner.
The number of dependent elements and WAVE links may always be changed via the ‘Display browser’ [8, 9]. Figure 11 shows an example of a knife switch and a number of links in it, as well as types of ratios between workpieces.

**Figure 10.** Design of a knife switch in Siemens NX 7.5 (completion)

**Figure 11.** Types of ratios between workpieces using the example of the designed EA of a knife switch
6. Research prospects. Ontology and WAVE

With regard to further development of the given study, the authors aim to increase the automation level and possibilities of conceptual experimenting with production tooling (PT) design. To implement this idea it is advisable to consider mutual integration of design ontology and WAVE technology. Figure 12 shows direct ‘kind-type’, ‘part-whole’, and other links between PT elements and aircraft (AC) parts [10].

The creation of similar links within the subject domain, definition and commenting of concepts of the future will make it possible to create a flexible ontology model, which will foster not only the structuring of PT types in relation to PF of an enterprise, but will also contribute to the success of experimenting with tolling designs thus selecting the most rational type to meet the requirements of workpiece and AU production in aviation industry.

7. Conclusions

The considered approach to the top-down design strategy and the use of the WAVE technology based on Siemens NX 7.5 makes it possible to eliminate all the above design restrictions. Thus, with regard to incompleteness of graphic information it should be noted that EA becomes a key source of geometric parameters, it is created in the context of a situation, and serves a situation as such for other interconnected EA. The designed EA may be successfully applied for other needs in adjacent structures of an enterprise.

Besides, it increases the associativity level of elements, since as was already proved before, the EA and AU design utilizes a large number of links, borrowings, parametrization and reuse. It is positive that the associative models are updated automatically when numerical parameters or geometric links are changed, and the need of manual modification of EA or DD is minimized.

Regarding the third restriction the authors note that the coherence of EA and AU designed following the top-down strategy is reliable since all elements are developed under conditions corresponding to a specific situation. All changes made to any design part concern other parts depending on it and result in closing a gap between high-level parameters and elementary parts.

In conclusion it is possible to state that the potential of parametric three-dimensional modeling alongside with the WAVE technology is the most fully utilized by the top-down design strategy. The
The proposed technique allows reducing development time and efforts, as well as decreasing the number of design mistakes at the stages of development and production.

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