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Impact of System-Level Engineering Approaches on the Airframe Development Cycle Via Integration of KBE with CAD Modeling and PDM

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Executive Summary

Airframe companies have performed numerous studies over the years that conclude the overwhelming percentage of cost to manufacture a new aircraft, is set during the development phase. The majority of this development cost is set during conceptual and preliminary design, typically occurring at the aircraft OEM. If these costs are to be dramatically reduced, the development process must include the expertise of the entire extended enterprise as early as possible in the development cycle. Technology exists today that allows this extended team to collaborate in the design decision-making process. Suppliers, partners, and customers can participate by concurrently performing their own initial development activities, while the OEM team performs their preliminary design work. On the technology side, one of the keys is the integration of state-of-the-art CAD, KBE, and PDM tools such as EDS' Unigraphics™, Unigraphics/Knowledge Fusion™, and I-man™. The challenge is developing processes that use these tools to allow the entire extended team to work concurrently, using a common database, to quickly iterate the design to meet aggressive performance and cost reduction goals.

A new System Engineering approach, made possible through an EDS tool called Unigraphics/WAVE™, enables true concurrent engineering throughout the extended enterprise. At the same time that detail design aspects are being worked, the global, or system-level trade studies can progress. When global changes are finalized, all work progressing within the extended enterprise is updated, rather than lost. This includes work started by partners and suppliers. Through this approach, great strides can be accomplished in the reduction of design cycle time because all work is done in parallel rather than in series. In addition, everyone in the extended enterprise is always working with the same controlled data, which is accomplished through the I-man PDM system.

Performing trades studies and what-if studies using this new process is very rapid, which results in many more product iterations in a reduced development cycle. Also, aggressive performance and cost goals can be met. Even though these system engineering tools and processes are not forms of analysis per se, they greatly aid in the incorporation of mature and late-stage analysis results. For instance, strength analysis can progress late into the design cycle, and still be incorporated into the design because the team's work will be automatically updated. These late results are sometimes not incorporated in the more traditional design process due to schedule concerns, and this can result in increased vehicle weight.

Knowledge-Based Engineering (KBE) enables a richer and more robust design database by including the rationale behind why certain alternatives were chosen for the final product configuration. To decrease the

design cycle time, KBE automates many repetitive tasks. External databases and spreadsheets can also be tied into the KBE process. KBE also enables consistency of engineering data and the enterprise-wide reuse of that data.

The EDS tool Unigraphics/Knowledge Fusion, a merging of KBE and CAD, enables product and process to exist in the one system. With Unigraphics/Knowledge Fusion, a KBE language (Intent!) has been deeply embedded into a high-end product development system (Unigraphics). Intent! is an industry-proven language from Heide Corporation. Many companies have been using Intent! for years to provide KBE benefits to their engineering processes. One of the biggest benefits of this deep embedding is that the output from the KBE system does not have to be translated to a CAD system. With Unigraphics/Knowledge Fusion, the KBE and CAD are one system. The benefits of this merging to the development process include the creation of customized and proprietary applications or “wizards” that guide the user through the automated facility. The KBE data is stored in the I-man PDM system for easy retrieval and use by the extended enterprise. Cycle time is shortened by design reuse and a consistency of process is achieved.

Abstract

A classic airframe development problem is the disconnect between initial layouts/trade studies of structural arrangements and the detail designs that emanate from these layouts. Hence, the process of communicating design change has been time consuming, inefficient, and prone to errors.

This paper describes new methods now available that enable the linkage between system-level layouts and the digital master models. Knowledge-Based Engineering (KBE) tools can now be directly linked to preliminary CAD models to refine concepts. Product Data Management (PDM) manages both the KBE and CAD data. As system-level definition and knowledge evolve, changes are automatically propagated down the hierarchy of airframe definition. The result: cycle time reduction and achievement of aggressive performance targets.

Challenges of the Airframe Design Cycle

To address the challenges of reducing design cycle time and cost in the design engineering process, we must look not only at the technology used, but also at the processes themselves. Due to the complexity of the airframe, it must be broken down into subsystems, which can be designed independently within the context and requirements of the overall aircraft - one example being the wing torque box. This subsystem can be designed in relative isolation, but must adhere to the design requirements of the overall wing subsystem. Subsequently, the wing must adhere to the requirements of the total aircraft system to accomplish design requirements such as performance and cost. A major problem exists in that much of this high-level design intent resides only in the minds of the engineers. One of the challenges is how this design intent can be captured and reused to produce superior designs.

The traditional engineering process is drawing-based, either by manual means or electronically through the use of CAD. Looking at the technology side, parametric design is a production-proven capability in most high-end CAD systems today. This capability allows for definition of hundreds to thousands of

design variables within a detail part. Any of these variables can be modified, with the part being automatically updated. However, one of the limitations of parametrics is the relative inability to handle topological changes. To exacerbate the problem, some CAD systems require the user to parameterize everything in the geometric model. These parametrically driven detail parts, often in the thousands, make up the subsystems that define the aircraft. Another challenge to the design process, is whether engineers can grasp how these parts will behave as a result of high-level design changes.

System Engineering Approach

These challenges necessitate a new approach to the engineering process that takes advantage of the power of parametrics, and captures design intent and allows engineers to exercise a system engineering methodology. Much of the traditional design approach focuses on the parametrics of the detail parts. This is very much a “bottom-up” approach in that the low-level requirements combine to form the overall design. The reason the new approach is called “System Engineering” is that the requirements of the overall aircraft system drive the design in a “top-down” fashion.

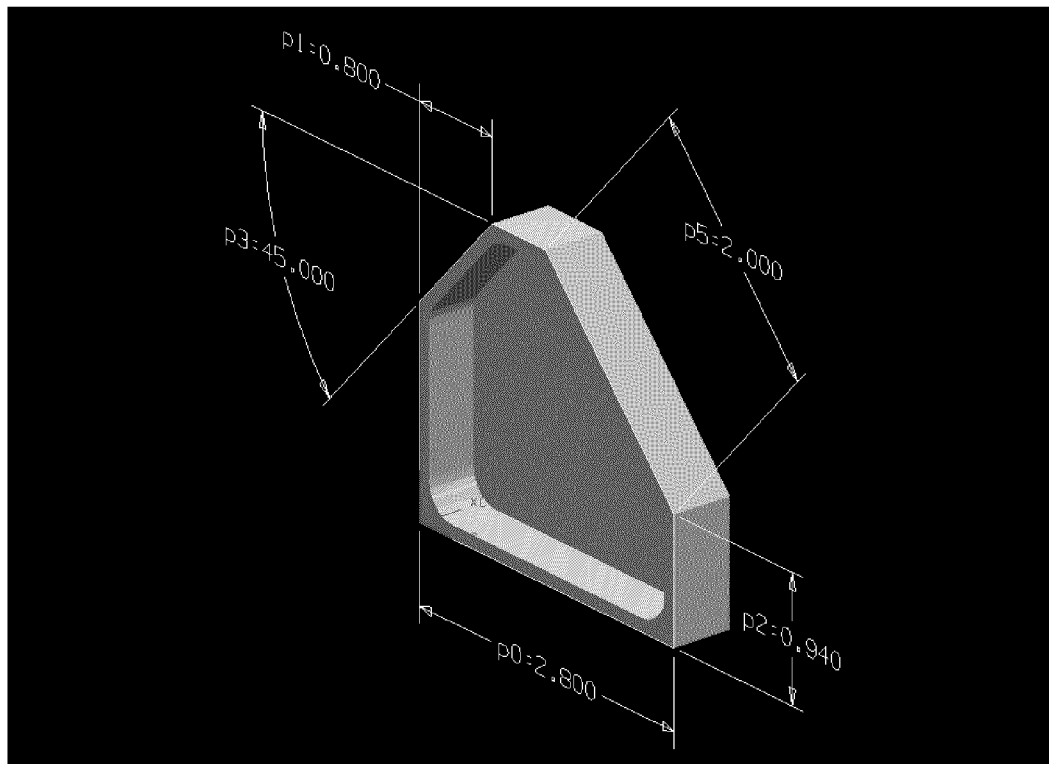


Figure 1
Example of parametrics in a detail part

Parametric design, allows for every design detail to be defined in terms of a parameter. These parameters can be edited at a later time, with the part adjusting automatically to that edit. Figure 1 illustrates these detail part parameters. This technology has been a huge boost to productivity, especially in aerospace. Structural parts are analyzed for strength requirements and the number of analysis/design update

iterations is often quite large. Even though parametric modeling is not an analysis tool by itself, it enables many more analysis/design update iterations to occur in a shortened development period. This allows for earlier incorporation of analysis results, which in turn provides the attainment of aggressive performance goals. The biggest benefit to detail part parametrics is the ability to incorporate mature analysis results late in the part release cycle. In more traditional processes, a design change due to mature analysis results may not be incorporated due to schedule constraints. This often results in the part weighing more than it needs to, with overall subsystem or vehicle weight targets not being achieved. With parametrics, the ability to incorporate last-minute analysis results is very achievable, with the design remaining on schedule.

The challenge posed by parametrics is that even in small parts, the number of parameters can be in the hundreds or even thousands. This can be overwhelming for the engineer attempting to analyze how system-level design changes will affect the thousands of detail parts and the thousands of parameters in each part. In addition to the complexity of the numbers of parameters, another challenge is understanding how the model was constructed in order to effectively make changes. The manner in which the parametrics are applied to a part can be different with every engineer. This can especially be a problem for an engineer looking at a model that they did not construct. Adding part-to-part relationships to the mix, results in a “parametric spaghetti”, in which it is difficult, or nearly impossible, to know what a change to one area of the design will have on other areas. Figure 2 illustrates many of the interpart relationships, which can be present in a product assembly. This issue calls for a systematic approach to the construction of parametric models and assemblies.

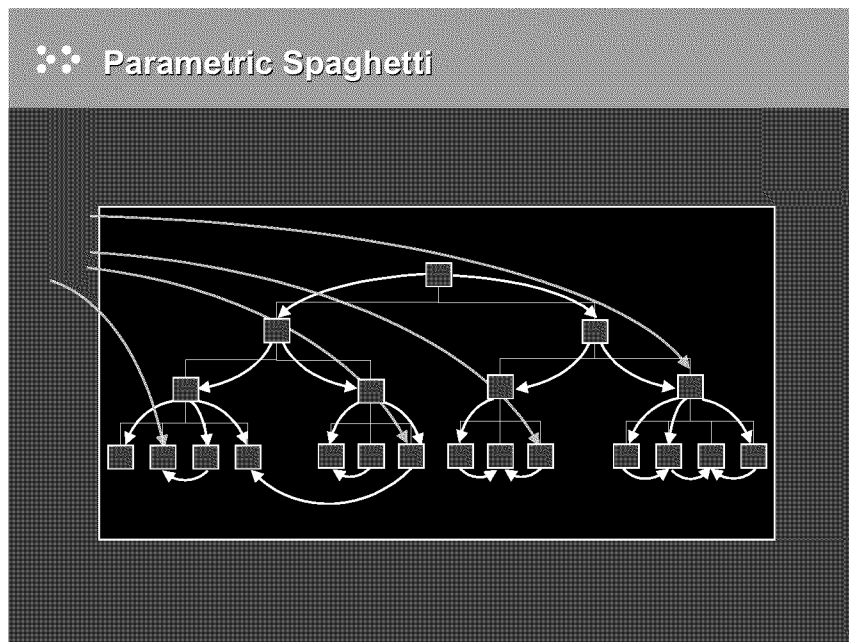


Figure 2
The complexity of interpart relationships

Top-Down design methodology is another key component in this new approach. Whereas a focus on the parametrics of the detail parts tends to lead to a Bottom-Up method, a focus on the overall aircraft requirements and subsequent subsystems tends to drive a Top-Down method. Top-Down is now possible

due to advances in the technology that create a systematic approach to building such a structure, and also provides the ability to control the change propagation at every step in the process.

The system engineering approach is the merging of the Top-Down design methodology with the power of parametrics. The advantage to the design process is the ability to greatly shorten development cycles while attaining aggressive performance goals. The Unigraphics CAD system offers this system engineering approach and is named Unigraphics/WAVE.

To start the new process, one needs to identify the major subsystems that make up the entire product. In the case of an aircraft, the major subsystems include the fuselage, wing, and empennage. These major subsystems can then be further broken down into components of greater detail and function. The entire structure forms an aircraft hierarchy of product requirements and functionality. The concept here is that there are “global” requirements and relationships that tend to drive “local” requirements and relationships (such as those contained with subsystems and subsequent details). The segregation of these global and local relationships is the key to the process. In the well-defined structure of product requirements, only those relationships that pertain to that particular level need to be defined. The upper level relationships need to control only the relationships of those levels directly beneath. This is the mechanism that limits the number of parameters required at each level, thus greatly reducing the complexity at any level.

An example of this hierarchy is the aircraft level and the immediate sublevels of fuselage, wing, and empennage. In the aircraft level, one needs to define only the parameters that control the interfaces between the major subsystems as well as any global requirements, such as the optimal Center of Gravity (CG) for the aircraft. The requirements for the wing and the key design parameters for wing design need to be defined only at the wing level. The parameters that define interfaces to the fuselage, or the design of a leading edge machining, would be defined in lower levels.

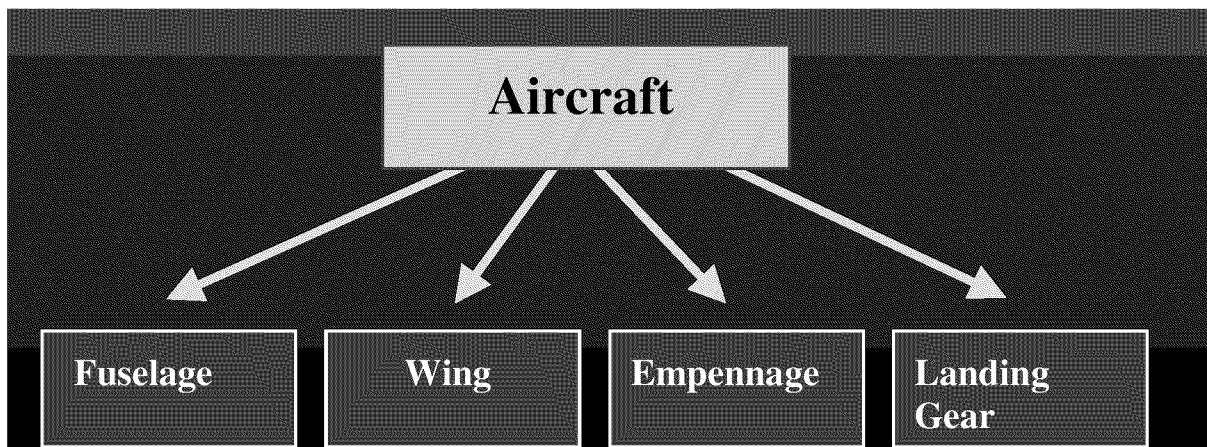


Figure 3
The control structure

The Unigraphics/WAVE Control Structure is the key to controlling the massive quantities of parameters generated in parametric design. For example, at the wing level, a very small number of key parameters drive the total wing design. Often, 20 to 40 key parameters in an upper level, are able to establish control

of the thousands of detail design parameters that make up the entire subassembly hierarchy. Another function of the Control Structure is the definition of interfaces between subsystems and between major elements within the subsystems themselves. The Control Structure assumes the role of system-to-system negotiator when conflicts arise regarding the interfaces. Again, the Control Structure approach captures, electronically, what used to be a manual process of design team communication that may not have occurred.

The Unigraphics/WAVE Control Structure offers a rich set of capabilities to do “what-if” trade studies at a high level. At the wing level, one could study high-level changes to wing plan form shape, including changes to the moldline. Because of the isolation between “global” and “local” relationships, the extensive detail design work progresses unaffected by these trade studies, until that time as the studies have produced a new set of design criteria to be propagated down the design hierarchy (Top-Down design). This approach offers a hard link between high-level layouts, and the master digital models that emanate from those layouts. The traditional approach handles this communication in a manual fashion that is often very ineffective.

The critical element that enables this new process to work, is the ability to finely control change propagation throughout the process. The timing of when and where Top-Down changes are propagated throughout the product structure is tightly controlled. In the above example, the wing plan form and moldline shape are being manipulated in a series of design trade studies. This could potentially cause hundreds or thousands of detail parts to need updating. The person iterating the wing design can isolate these high-level changes from the rest of the team, which produces two major advantages: 1) the rest of the design team keeps working, concurrently, in an uninterrupted fashion, and 2) the person doing the design trades can limit the parametric updates to his set of key parameters. By limiting the set of parameters to a small number, one is able to iterate through a much larger number of trades versus the time it would take to update the entire team through every trade cycle. The fact that the entire team is able to work concurrently, both the high-level aspects in conjunction with the more detailed work, results in shorter overall design cycle times and increases the team’s chances of achieving challenging performance goals.

Product Data Management also plays a crucial role in the process. The entire Unigraphics/WAVE Control Structure as well as the complete assembly hierarchy, is contained in, and controlled by the EDS PDM system named I-man. Product structure in Unigraphics and in I-man is always kept up-to-date and synchronized. In fact, for a team member, partner, or supplier to view the hierarchical structure, they do not have to be in Unigraphics – this can take place in I-man.

Knowledge-Based Engineering

Many companies today employ a Knowledge-Based Engineering (KBE) system to:

- Decrease cycle automating repetitive design tasks.
- Capture and re-distribute critical company knowledge typically residing only in the minds of engineers, designers, and manufacturing personnel
- Ensure engineering rules and best practices are adhered to from design all the way through manufacturing.

- Protect loss of enterprise expertise due to employee turnover.
- Store knowledge in a format that is reusable and easily transportable by the design team.

Fundamentally, the key is re-use – the recycling of company knowledge and best practices that exist in several forms and that are present in every phase of the product life cycle. The various forms of knowledge are many: CAD datasets, CAM datasets, analysis data, text documents, company manuals, spreadsheets, databases, and rules of thumb. Engineers spend huge amounts of time simply searching for the information they need. An important question is the accuracy and relevancy of the data they do find – is the information current, is it the right information for the particular application at hand?

Clearly, a tool that addresses many of these information-type questions is Product Data Management. Robust and mature PDM tools, such as the EDS I-man product, enable the engineer to search for data and know that the data is current and applicable to the task at hand. I-man is capable of managing the many varied forms of data in the enterprise and to manage the life cycle of that data including engineering release. A key is capturing all the above company knowledge and best practices electronically, and making it available to the enterprise under PDM control. When all stages of a product's life cycle has immediate access to this data, cycle time and cost can be reduced significantly.

The Merging of KBE and CAD

Traditional KBE systems tend to be programming tools and are not very graphically oriented. This is typically where CAD systems shine. Designers enjoy the graphical interaction and ease of use of CAD. Creating, editing, and managing parametric features is also a strength of CAD, while being a weakness on the KBE side. Conversely, CAD systems do not handle non-geometric attributes exceptionally well. Non-geometric attributes are handled robustly with KBE. With CAD, you really are seeing the “end result” of an engineering process with limited description of the rationale and history of trade studies that went into that configuration. KBE on the other hand, is geared toward defining and recording processes as well as describing the rationale. CAD can vary a set of features already present in an efficient manner, but KBE is very robust at executing just the unique set of features needed for a set of specified design requirements. Most KBE systems recognize when whole sets of features need to be swapped for other features due to different requirements.

Until recently, the benefits of KBE have been isolated from the CAD environment. With the EDS tool called Unigraphics/Knowledge Fusion, the benefits of a fully merged CAD/KBE capability are now realized. With this merging, a Knowledge-Based Engineering language (Intent!) has been deeply embedded into a high-end product development system (Unigraphics). Intent! is an industry-proven KBE language from Heide Corporation. Many companies have been using Intent! for years to provide KBE benefits to their engineering processes. The term “embedded” needs to be emphasized, as apposed to “integrated” or “loosely associated”. One of the biggest benefits of this deep embedding is that the output from the KBE system does not have to be translated to a CAD system. With Unigraphics/Knowledge Fusion, the KBE and CAD are one system.

Aircraft Floor Beam Example

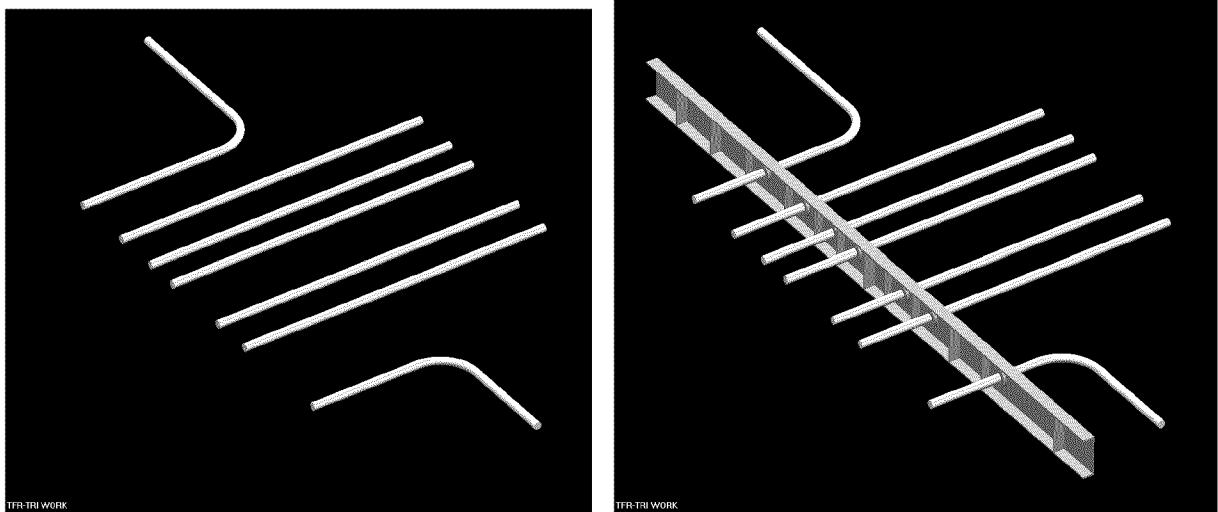


Figure 4

Automatic generation of an aircraft floor beam using a Knowledge Fusion program

Figure 4 shows a part called up from PDM which contains system routings in the under-floor area. Using a Unigraphics/Knowledge Fusion program, a floor beam is generated at the station 0 location. This example demonstrates several advantages of the process:

- A generative approach. A complete floor beam design was created in CAD using a textual KBE program.
- The resulting CAD geometry did not have to be translated from KBE to CAD.
- The resulting geometry in CAD is completely parametric. In Unigraphics, the geometry is comprised of features, which are fully editable at a later time.
- The program was called from the PDM database. In PDM, a library exists of available programs. A particular program can be found using a query on the database.
- The new floor beam is saved in the I-man PDM database. The new Item in the database can be found by queries and contains not just the geometry, but also the KBE rules that govern its construction, and later editing.
- Using I-man, if changes are later made to the program, the user can find out which parts and assemblies have made use of that program and would potentially be affected.

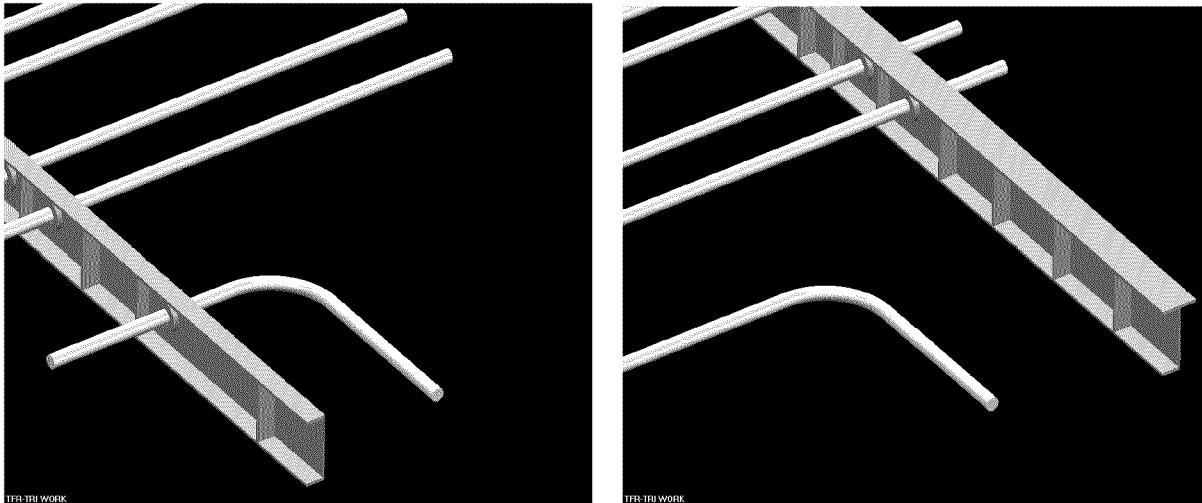


Figure 5

Edits to an existing model that uses a Unigraphics/Knowledge Fusion program

Figure 5 shows the result of editing the previously created model. The station parameter has been edited from 0 to 50, and the non-geometric parameter of “aircraft type” has been changed from “passenger” to “cargo”. This editing demonstrates these advantages:

- The geometric and non-geometric rules that govern the creation and subsequent editing of floor beam parameters, are now stored in the Unigraphics part. These KBE rules become an integral part of a CAD file, which can be edited by the user at a later time.
- Editing of geometry parameters in Unigraphics automatically updates the Unigraphics/Knowledge Fusion rules (which now reside in the CAD file). This demonstrates 2-way associativity - KBE updates CAD, and changes to CAD update the KBE rule base.
- A capability of the floor beam program is to create a set of pad-ups around a system penetration, as well as a through hole, and a support stiffener. A separate program was written that creates this specific set of features. This technique highlights the modular nature of Unigraphics/Knowledge Fusion in that a program can consist of calls to other pre-existing programs. This cuts down on time to create automation programs.
- Figure 5 shows, that at station 0, a set of pad-ups exist for the near system run, but does not exist at the station 50 location since a penetration for the system is no longer required. A look at the feature list in Unigraphics shows that those pad-up features no longer exist in the model. This is a differentiator with pure parametrics. Only those features that are **required** are built in the CAD model.
- We also see from Figure 5, that an additional vertical stiffener has been added to break up the long distance between stiffeners. This could be the result of an analysis routine that calculates minimum distance between stiffeners based on loading, gauges, etc. This analysis routine could be either built into the program or an external program that Unigraphics/Knowledge Fusion communicates with.
- Finally, we see that at station 50, we have also toggled the non-geometric attribute “aircraft type” from a “passenger” to “cargo”. Because of higher loading conditions, the basic beam shape has changed from a “C” section to a more capable “J” section.

Aircraft Stringer Example

The following example takes Unigraphics/Knowledge Fusion one-step further to develop a custom application or “wizard” dialog to perform a specific design task. In this case, a wizard dialog has been created for designers and engineers to quickly create aircraft stringers.

The creation of the custom dialog or “wizard” is an easy process. The user is prompted along the creation process by a series of dialogs that guide the connection of the Unigraphics/Knowledge Fusion program to the wizard. An “Instructions” button can be added to the wizard that takes the user to documentation. In this case, the instructions created are a series of web pages that offer step-by-step instructions, including images, on how to create stringers using the facility. Figure 6 shows the initial web page presented to the user showing the hyper links to other pages.

Instructions For Using Stringer Wizard

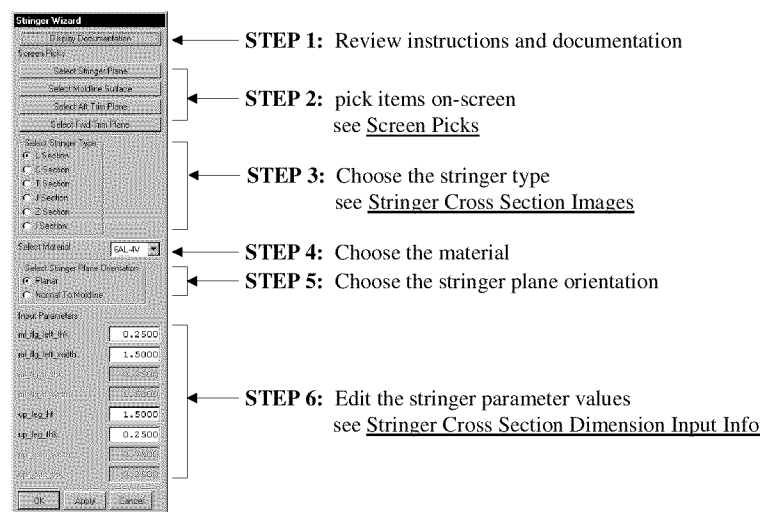


Figure 6

Web-based instructions for using stringer wizard

Figure 7 shows the before and after screen shots of using the Stringer Wizard. The before shot shows a portion of the “given” geometry which is the aircraft loft IML (inner moldline) surface. These items are picked from the screen using the applicable buttons on the wizard. The stringer type chosen for this example is a “Z” section. The material chosen was 6061-T6 Aluminum. The stringer plane orientation selected was normal to the moldline surface.

A crucial benefit of wizard creation is the incorporation of proprietary techniques and standards that are unique to the company. In this way, the most valuable aspects of a companies’ intellectual resources and methods, can be used over and over again in a controlled fashion, to uphold standards and improve design quality.

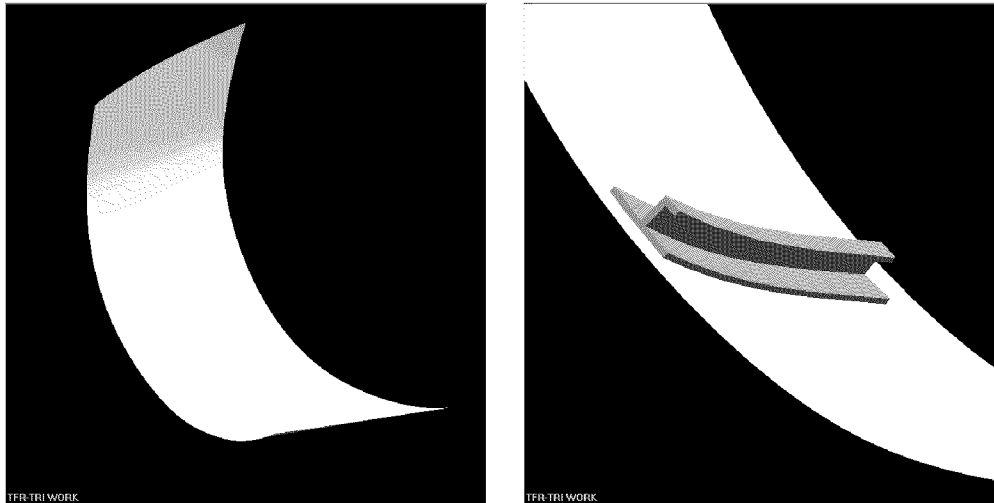


Figure 7

Before and after part creation using the stringer wizard

The Merging of Technologies and Processes

Another capability of Unigraphics/Knowledge Fusion is being able to query external databases and return values. An example of this was the wing, where the system engineering approach to design was used. KBE can add another capability to the approach previously outlined. If there was a database that contained aerodynamic test data, that database could be queried and return values that could help drive the Control Structure of the wing. Once the new values are back in the Control Structure, the hierarchy updates according to the rules already existing in the structure. The update process is governed by controls that have already been put into place. This ensures that the “what-if” process is a rapid one. New configurations can be saved as design revisions in the PDM database and serve as a design history. This is an example of the marrying of a number of technologies: KBE (Unigraphics/Knowledge Fusion), the system engineering Control Structure approach (Unigraphics/WAVE), communication with external databases, parametric design, and PDM (EDS I-man).

Real-time cost analysis of design alternatives and trade studies is also possible using this merging of technologies. The governing formulae that determine product cost can be hard coded into a Knowledge Fusion program. These cost formulae are tied to the actual geometry in CAD parts and also tied to external databases that contain large quantities of cost-related data. Some examples of cost data include:

- In the CAD file, the length of welds between parts or the amount of material removed for a machining.
- In an external database, tables that would list the cost per inch of weld given the type or form of material.

As different design alternatives, such as material choices or product shape and size, are examined, the cost of that alternative is returned in real time. This feedback can dramatically lower total product cost by providing the capability to arrive at cost-effective design decisions quite early in the development process while still achieving the design goals.

Conclusion

The majority of the cost of developing a new aircraft is set during conceptual and preliminary design, typically occurring at the aircraft OEM. If these costs are to be dramatically reduced, the development process must include the expertise of the entire extended enterprise as early as possible in the development cycle. Technology exists today that allows this extended team to collaborate in the design decision-making process and remain associative at all levels in the process. Suppliers, partners, and customers can participate by performing their own initial development activities, while the OEM team concurrently performs their preliminary design work. If the OEM makes a major change, all team members are kept up-to-date. On the technology side, one of the keys is the integration of state-of-the-art CAD, KBE, and PDM tools. These tools allow the entire extended team to work concurrently, using a common database, to quickly iterate the design to meet aggressive performance and cost reduction goals. Aircraft design organizations have demonstrated the savings of these tools and processes in demanding production environments.

A new System Engineering approach (Unigraphics/WAVE) enables true concurrent engineering throughout the extended enterprise. At the same time the detail design aspects are being worked, the global, or system-level, trade studies can also progress. When global changes are finalized, all work progressing within the extended enterprise is updated, rather than lost. Through this approach, great strides can be accomplished in the reduction of design cycle time because all work is done in parallel rather than in series. Everyone in the extended enterprise is always working with the same controlled data, which is accomplished through Product Data Management (I-man).

Knowledge-Based Engineering (KBE) enables a richer and more robust design database by including the rationale behind why certain alternatives were chosen for the final product configuration. To decrease the design cycle time, KBE automates many repetitive tasks. External databases and spreadsheets can also be tied into the KBE process. KBE enables the capture and re-distribution of critical company knowledge that typically resides only in the minds of engineers, designers, and manufacturing personnel. KBE also enables consistency of engineering data and the enterprise-wide reuse of that data. A merging of KBE and CAD called Unigraphics/Knowledge Fusion enables product and process to exist in one system. Benefits to the development process of this merging include the creation of customized and proprietary applications or “wizards” that guide the user through a particular design task. The result is not only a significant reduction in cycle time and cost, but also a great improvement in engineering and final product quality.

References

- [1] “UG/WAVE Product Portfolio Engineering,” Unigraphics Solutions, 1998.
- [2] “Product and Process Knowledge in one System,” Unigraphics Solutions, 2000.

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