Three-dimensional Model Based Manufacturing Work Instructions

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ABSTRACT

The conventional method for developing manufacturing work instructions is to translate multiple-sheet two-dimensional (2D) engineering drawings into extensive instructional text with nominal graphics for mechanics to follow on the factory floor. As design is progressing into a three-dimensional (3D) model based design environment, additional features and capabilities, available only in 3D design, can be incorporated into manufacturing work instructions. Advanced manufacturing work instructions, created in 3D with these new advantages, have become a highly productive tool in helping the mechanics improve manufacturing efficiency. These Model-Based Instructions (MBI) create multiple views and present easy-to-follow assembly sequence with all needed reference information available on-line to the mechanic.

INTRODUCTION

The engineering community has been designing in three dimensions (3D) for decades, however it has clung to many legacy, two dimensional (2D) articulation and delivery methods. A paradigm shift is occurring throughout the engineering and manufacturing communities toward 3D model based instructions in lieu of traditional 2D text and drawing sheets. Since engineering designs are being created and released in a 3D only format, processes and systems infrastructure were developed for the authoring and delivery of MBI to the factory floor.

The MBI format leverages features and capabilities associated with 3D engineering to provide additional information to the mechanic previously not available in the conventional 2D engineering and textual work instruction format. The MBI allows the mechanic to rotate, measure and manipulate the 3D geometry to furnish a comprehensive view of the product design.

Higher quality and more consistent assembly techniques are defined through MBI. The ease of accessing engineering definition, additional information and clarity associated with the 3D model through the MBI translate into cost and quality improvement. Quality is better as this approach minimizes mistakes associated with 2D engineering drawing sheet ambiguity. Mechanics learn their tasks more rapidly and can assemble the product easier. MBIs enable flexibility in the work force so product can be produced at an increased rate with fewer defects and at a lower cost.

Based on the successful implementation of the MBI approach on the Chinook assembly line, future opportunities to apply MBI to other product lines is being explored throughout Boeing.

APPROACH

Requirements

Historically product data was delivered to Boeing's shop floor, engineering, external customers, suppliers, and partners in the form of 2D drawings (paper or electronic). With the transition to a Model Based Definition (MBD) there are no 2D drawings created. Paper drawings are no longer available for delivery to our shop floor or customers. With MBD, all Product and Manufacturing Information (PMI) is annotated directly on the 3D model. This new paradigm created an opportunity to come up with a creative and inventive way to deliver engineering to the shop floor to assist in the build of our product.

To help address the requirements for the project we documented the methodology taken to capture the requirements of the participants in the projects. Our methodology consisted of three phases, and three sets of deliverables, as depicted in figure 1.

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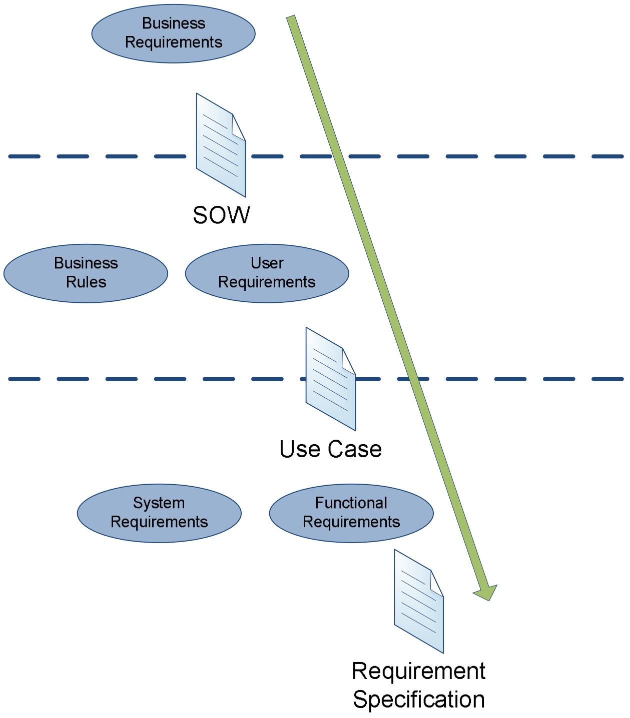


Methodology
Figure 1

Phase One:

The first phase was to capture the business requirements and produce a Statement of Work defining the overall project direction. Our statement of work was to:

Deliver 3D MBD to downstream users on the shop floor that conveys the design intent consisting of:

- Model integrity
- PMI
- Engineering Design Intent
- Attributes
- Notes

Phase Two:

The second phase was to capture the end users requirements and business rules needed to perform their function. The Business Rules and User Requirements combined to create a set of Use Cases.

Our Use Cases were comprised of the following requirements:

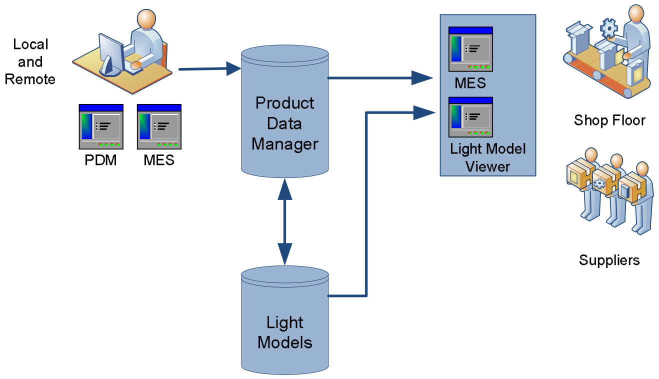
- Allow the reuse of engineering MBD for the downstream shop floor users
- Provide the engineering CAD data in a light form, with out compromising the integrity of the engineers intent
- Provide remote access to view the MBI from suppliers' sites
- Provide the capability for partners to create MBIs
- Provide the capability to create product data that represents the product
- Capability to Create, Modify, Copy, and reuse work instructions
- View
- Markup
- Print
- Measure accurately
- Integration with current systems

Phase Three:

The third phase was to analyze the Use Cases and develop a Requirement Specification that took into account the functional and system requirements. These requirements consisted of:

- Configuration management for all the data
- System must be reliable
- Security - lock down the system and allow access to only personnel who require it
- Integration with current systems
- Automation for the creation of the light models
- Archival capabilities
- Available 24x7
- Work within the current physical architecture already in place
- Provide a system architecture that allows for fast loading of the data to the shop floor

Computing System Architecture



System Architecture
Figure 2

The system architecture for the delivery of 3D data to the shop floor is depicted in figure 2. The fundamental structure of the system centers on Boeing's commercial off the shelf (COTS) Product Data Manager (PDM) system. The PDM houses all the engineering data and is the sole authority for configuration control of engineering data. The PDM contains everything from engineering notes to 3D CAD data. This is the entry point into the design engineers' vault for the manufacturing engineer to build his 3D plan for use on the shop floor. The light models are automatically generated routinely and saved on their own file structure. This external file structure allows for faster viewing of the data.

The user can log-in locally or remotely through a secure bridge. Each user is enrolled in a functional role to enable the PDM to recognize them. This log-in ensures data security in accessing the proper data. The manufacturing engineer starts the MBI using the engineering data and creates manufacturing views of the engineering data for consumption on the shop floor. The 3D manufacturing view is stored in the PDM for retrieval and use by the MES. The PDM houses all the data and provides the configuration management control needed to ensure the right data is being delivered to the right job at the right time.

The manufacturing engineer's next step is to map the manufacturing view inside the PDM to the MES. Once this is linked and signed off by the ME organization the MBI is ready to be viewed on the shop floor.

On the shop floor, the MES manages and monitors work-in-process on the factory floor including manual or automatic labor and production reporting, as well as on-line inquiries and links to tasks that take place on the production floor. The MES is the link to the PDM, which contains the 3D data for viewing by the factory mechanics. The factory mechanics use the same MES and PDM system as the office personnel. The only difference between the office and the shop software is that the shop does not have the capability to create an MBI; they only have the capability to read the data. When the shop floor mechanics work on a job in MES, they will call up a 3D plan by simply selecting an MBI icon from their MES screen and the system will load the data for them to use from the PDM and the light model storage file.

LEGACY 2D VS. 3D MODEL BASED DEFINITION

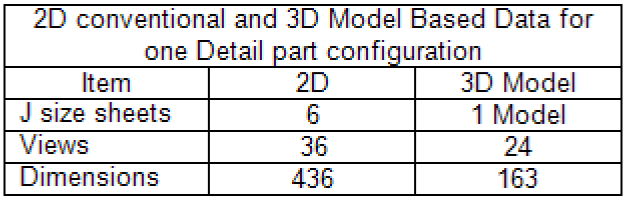
This is an example of a complex detail parts' 3D model based data compared to conventional engineering. This part is not representative of all the structure on the aircraft but, it illustrates the amount of clarification that can be obtained with these new processes.

The following demonstrates the excessive amount of conventional engineering through which the ME must filter to obtain the relevant data for authoring textual instructions for the part used in the comparison below.

- Comparison represents one complex detail part and is derived from 21 J size conventional drawing sheets with multiple configurations
- The drawing also contains six detail parts, 13 assemblies and four installations
- There are 190 views shown to define configuration: 130 for details; 37 assembly and installations; 23 configuration orientation views
- 1,261 dimensions are required to define these configurations

The table shows the difference between 2D and 3D model based data required to author either conventional work instructions or an MBI for this part.

Table1. Comparison of 2D and 3D data



2D conventional and 3D Model Based Data for one Detail part configuration		
Item	2D	3D Model
J size sheets	6	1 Model
Views	36	24
Dimensions	436	163

With new advances in Model Based Definition we are now able to insert the dimensions, GD&T and annotations directly into the CAD model, thus eliminating the need for drawings. There is much less chance of error using a single model to author and implement an MBI than interpreting conventional engineering.

SYSTEM QUALITY ATTRIBUTES

Performance

Performance was measured by the response time that is acceptable for operation of the system. Our performance goal was to reduce the legacy 2D process shop floor time by at least 50 percent. The legacy process included having to retrieve blue prints from the crib and to interpret those prints. The legacy methodology allows the mechanic to read and understand textual process instructions while accessing multiple views in multiple engineering drawings. The mechanic has to interpret and integrate both the manufacturing process and the engineering product definition. The 2D legacy process leaves a large amount of interpretation on the shoulders of the mechanic.

The MBI process enables real time retrieval at the workers station on the shop floor, and real time updates to the Model Based Instructions. Pushing one button in MES imports the engineering parts consumed on that job into the MBI. Launching and retrieval of the light models contained in the MBI takes no more than 45 seconds. Reviewing the data in the MBI is quicker and easier then navigating through multiple drawings and multiple views of conventional 2D engineering.

Robustness

All the information for the job is contained in an MBI, which is created directly from the engineering product data. The MBI contains all of the product and process definition required to build the assembly. MBI views (Pallets) are created and walk the mechanic through the build process. Each pallet contains all the information required to perform that task in the correct sequence. Pallets are authored by the ME to give the most definitive view of the engineering and process work content. Pallet orientation, coloring and hiding of parts and visualization of engineering attributes are all part of the MBI authoring process designed to provide all the information in one place.

The process to manipulate and maintain the single source data is very robust. The ME cannot alter the engineering data. They can only change the way it is presented to the mechanic on the factory floor.

Usability

Usability is seen as the ease of use and is a term used to denote the ease with which people can employ a particular tool or other human-made object in order to achieve a particular goal.

Once the MBI is accessed, the mechanic has the ability to maneuver with ease within the 3D world of the MBI. They can rotate the geometry to see the part from another perspective. They can zoom in or out for a different perspective of the product.

An advantage of working in 3D is the capability to turn parts off to better see structure obscured by them. This functionality can also be used to isolate an individual part and perform more detailed analysis on the isolated part. Once the mechanics finish analyzing the isolated part, they can easily return to the original state of viewing the assembly by selecting a view pallet that will turn back on all the geometry. There is little chance of getting lost in 3D cyberspace.

Visualization

Model based work instructions use the 3D engineering part and tooling definition to create multiple views (pallets). These pallets integrate engineering requirements, manufacturing processes and installation sequencing so the mechanic has all the information he requires to perform his job in a visual format.

Once the mechanics click on the pallet the MBI becomes interactive. This allows the mechanics to rotate, measure, and manipulate the 3D geometry giving them a comprehensive view of the product design and assembly process they never had before.

Another critical portion of information integrated into the MBI is reference structure. When the author shows the installation sequence of parts, or the usage of the tools, he incorporates existing aircraft structure into that pallet. This is a good point of reference for the installation of parts. The reference structure is pulled from engineering data and can be manipulated and viewed as the parts actually are being installed on the job.

Accuracy

MBIs use light models that are derived from the engineering data. These light models are both accurate and precise as previously mentioned, the ME cannot change the 3D models; only manipulate the way they are viewed.

Both the 3D Model Based Definition parts and the MBI are configuration managed, released, and stored in our PDM. This ensures configuration control at all times.

With 3D MBD, tolerances, flag notes, and engineering process requirements are linked directly to their respected feature.

The 3D Models within the MBI provide the ability to measure from all features in a clear, accurate and concise manner.

DEPLOYMENT PLAN

MBD and MBI were deployed in key areas of the Chinook helicopter value stream to obtain cost benefits. These savings enabled the U.S. Army to purchase new airframes in lieu of reworking existing 40 year old airframe structures.

Aft Fuselage

The CH-47 aft fuselage is the largest piece of structure to use MBI's. Philadelphia assembles five major sub-assemblies built by its Major sub-tier supplier, Boeing Macon. Boeing Macon also deployed MBIs at its facility for fabrication and sub-assembly of these parts.

Ramp & Aft Pylon

Deployed MBIs for final integration of small sub-assemblies and details were obtained from the Boeing Philadelphia Composite Center of Excellence, sheet metal and machine part suppliers.

Table2. MBI quantity per assembly

Section of A/C after redesign	MBI
Aft Assembly PHL – Jig and Floor positions	131
Crown Assembly - MCN	65
LH Side Panel Assembly - MCN	52
RH Side Panel Assembly - MCN	51
Bottom Assembly – MCN	49
Tail cone Assembly - MCN	17
Ramp Assembly – PHL	65
Pylon Assembly – PHL	45
Total	475

The MBI deployment was based on the structured release of the 3D MBD data and waterfall schedule to support the manufacturing assembly build sequence.

ACCOMPLISHMENTS

MBD and MBI were deployed to production processes in high value areas of the Chinook helicopter, at both the Philadelphia site and the sub-tier supplier – Boeing Macon. This was the first production deployment of these processes between the Philadelphia and Macon Boeing sites.

MBI processes and infrastructure were created to support Boeing's strategy of *Design Anywhere, Build Anywhere*. This capability enables the Manufacturing Engineering plan authoring work share for other Chinook configurations as well as other Boeing programs. Macon MBI work was recently accomplished in Philadelphia for a Chinook configuration.

Using MBD and MBI reduced engineering and planning errors impacting the shop floor. The accuracy and presentation of the engineering, tooling and assembly process data enabled first time quality improvements in the shop. This eliminated nonconforming conditions normally associated with new program startups. An analysis was performed comparing the redesigned MBD and MBI Ramp & Pylon, to the conventionally engineered Cabin. This analysis identified a 58 percentage point reduction in engineering escapements to the factory floor and 47 point reduction in factory defects.

The MBIs ease of use, abundance of information and speed of accessing engineering and process information allowed the mechanics to move down the learning curve more quickly. An analysis was done comparing the expected learning curve based on a conventional redesigned ramp assembly and the actual learning curve yield utilizing the new MBD and MBI processes. The new process yielded a 12 percent improvement in efficiency over the first six units.

LESSONS LEARNED

Process

Engineering must follow strict MBD process design standards to support downstream tessellation MBI requirements. To reduce process escapements, design checklists were updated to ensure compliance to these standards. Manufacturing engineers utilized an excessive amount of reference geometry when authoring the original MBIs. This degraded the start up performance of the MBI on the shop floor. We have updated the authoring process to minimize parts in the reference geometry. The parts eliminated had no adverse impact on part installation. In addition, this reduces the amount of memory used by the reference geometry and significantly increases the response time. Jobs that install parts in the same area of the aircraft can use the same reference geometry. We have documented a process to create enough reference geometry to support multiple jobs and then reuse that model. This is a significant time saver for MBI authoring. Software testing is critical. We have implemented more stringent testing processes prior to deploying software upgrades.

System

The seamless integration of the systems for the MBI process (PDM, MES, reference geometry and tooling retriever, and Vis-mockup) made the process for authoring and viewing on the shop floor more user friendly. Color printing capabilities are important for those mechanics who do assembly work inside the aircraft. These aids are used in compliance with ISO standards. High end technical PC desktops are required to handle increased memory and video requirements for authors and shop floor users. After additional testing and validation, we have created two standard PC configurations that are more cost effective then issuing Technical PCs to all users. We now have a standard shop floor configuration PC with additional memory and updated graphics card. For authoring we have another standard PC configuration, which has even more memory and graphics capabilities. These configurations are more cost effective when you are equipping the entire shop and authoring community.

People

Support for this new computing infrastructure and process was lacking from the hardware, software, and support perspective. Initially, the Information Technology (IT) community was not adequately prepared for deployment and support of MBI tools. Manufacturing Engineering performed software loads manually as well as conducted follow up technical support. This included trouble shooting issues on the shop floor. Manufacturing Engineering worked with IT to create an enterprise help desk check list that enables them to identify the type of error and quickly resolve it. ME now only gets involved when it is strictly an MBI authoring issue. Training was done by the MEs both in class and ad hoc on the factory floor. Training documentation was developed and delivered by the MEs.

The Training Organization now delivers the instruction course materials. Hands on training provided in a computing lab is preferable to lecture.

Cultural

MBD and MBI processes are a paradigm shift to both the Integrated Product Team and Assembly Build Team value streams. This can be categorized in four general demographic groups.

New hires – Coming into the company these employees have no preconceived notion of how their skills will be implemented in the design, work instruction authoring or how the information is presented on the shop floor. They accept the data as it is presented. They see that these engineering requirements and work instructions are clear and concise thereby allowing them to learn quickly and decreasing the anxiety associated with being productive in a new environment.

Personnel Transfers – As requirements dictate, the program moves both experienced and newer personnel from team to team. The MBI process is an enabler for a flexible workforce and makes it easier for the program to move employees from area to area with minimal disruption to the teams. These employees come into an area using MBD and MBI with either anticipation in using the new process and technology that Boeing is deploying or with apprehension. In either case, basic group dynamics compel these individuals to use this technology until they realize the advantages.

Technical Zealots – These individuals like new technology and are proud that Boeing is developing and using this new technology in product development. They see Boeing's television commercials and tell their friends and family that these are the tools they use at work. It gives them a sense of satisfaction to have the latest and greatest technology and information at their finger tips to improve their ability to do their jobs. It gives them a sense of fulfillment to officially document their vast knowledge and skills, instead of using tribal knowledge, to pass on that important information to other employees to help them do their job more effectively in the future.

Tribal knowledge experts – These are people who are experts at their job either from their own accomplishments or experiences passed on from the person before them. The Challenge is overcoming their paradigm that no one else does it better and it is harder for others to understand their part of the process or product. This new technology threatens their expert status because the whole value stream is better defined and this mitigates the "tribal knowledge" requirements associated within their piece of the design, planning, or manufacturing phase of the value stream. They are proud of their knowledge within the community and feel threatened that they will no longer be "the expert" because the new processes clearly document and disseminate all the information that used to be passed on from mentor to protégé via on the job training during the succession transition. They also feel that their jobs can now be outsourced or they are going to become obsolete because they may not still be the "go to guy" for this area. They need the reassurance that this new process is only as good as the information it contains and product and process experts will always be required for all aspects of the value stream no matter how advanced the information systems infrastructure becomes. Experience will always be an integral part of the work process.

FUTURE DIRECTION

Leveraging model based data is an important element of Boeing's technical strategy. Boeing will continue to work closely with commercial software providers and academia as an industry leader to develop robust model based work authoring and delivery solutions. Boeing will continue to build integrated solutions exploiting engineering data reuse, interoperability and control throughout the value stream and product life cycle. Utilization of evolving and powerful off the shelf technologies will be leveraged to support efficient, high quality, data driven expert work instruction authoring and delivery solutions.