Integrated Product Development and DFM Implementation at Pratt & Whitney

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About Pratt & Whitney

Pratt & Whitney is an OEM for aircraft engines and parts as well a provider of maintenance repair and overhaul services and related technologies. The company began producing internal combustion engines for military applications prior to World War II and has grown and established itself as a leading producer of engines for very light jets (PW Canada) to engines for jumbo jets, military jet engines, industrial gas turbines and rocket engines (PW Rocketdyne). The company is currently developing engines for fifth-generation fighters (F135) and the new PurePower® engine family (PW1000) for the next generation of commercial aircraft. There are more than 17,000, Pratt & Whitney large commercial engines installed that have logged more than 1 billion hours of flight. (http://www.pw.utc.com)

Courtesy of markgarfinkel.com

Business Conditions Affecting Jet Engine Manufacturing.

The U.S. commercial airline industry is fast-evolving, labor intensive, capital intensive, hyper-competitive and highly susceptible to the ebb and flow of business cycles, as well as being among the most regulated of deregulated businesses.

Pratt & Whitney and its competitors, General Electric and Rolls Royce have had to change the way they conduct business to meet the risks and demands of the beginning of the 21st Century. The cost to develop a new jet engine can be more than $1 billion and some 2000 sales over 10 years may be required to break even. Replacement and spare parts are an essential element of the business. In the past airframe manufactures have offered alternative engines for a single airframe. Engine manufactures have stiffly competed to gain enough market share to create a profitable business case. Often times engine companies have relied on leading edge technology to market lower fuel and maintenance cost. However, such technologies are costly. The high cost of developing new engines with new technology can easily result in a bad business case with much less than 100% market share. Since the airlines are scrutinizing maintenance cost, it is necessary to offer more durable parts at competitive pricing thus reducing the profit engine manufacturers see from replacement parts. [1]

Modern jet engines today are often developed through partnerships sharing the risk and revenue across multiple global companies, some of which have financial backing from their governments. To sell airplanes and engines in many countries, engine manufacturers have had to accept offset agreements that give a share of production to firms in those countries.

Next Generation Product Family PW1000G

Pratt & Whitney's PurePower ® family of engines for the next generation of commercial aircraft is setting high goals for fuel efficiency, environmental emissions, engine noise and operating costs.

The key to the PW1000G engine's performance is a much higher bypass ratio and the introduction of a reduction gear between the fan and the core engine's low spool. (In a typical design the fan is directly driven by the low spool. The low spool consists of the low pressure turbine and the compressor that drives it). The gear permits the low pressure to rotate much faster than the fan. This allows the low pressure compressor to operate at optimum speed. The lower speed fan reduces the noise level in operation. [2]

So far, a thrust demonstrator engine has flown on a flying test bed. There are already 3 applications for the PW1000G engine. The PW1217G engine at 17,000 lb. thrust will power the Mitsubishi Regional Jet and the PW1524 engine at 24,000 lb. thrust will power the Bombardier C Series™ aircraft. It was recently announced that a PW1000 version has been chosen for the Irkut MC-21.

The Need for a Good Cost Estimating Tool

In *Realistic Cost Estimating for Manufacturing,*[3] the author lists 7 reasons why it is important to have a good cost estimating tool

- Verify quotations submitted by suppliers
- Establish a bid product for a quotation or contract.
- Ascertain whether a proposed product can be manufactured and marketed profitability.
- Provide data for make versus buy decisions
- Help determine the most economical method, process or material for manufacturing a product.
- Provide a temporary standard for production efficiency and guide operating costs at the beginning of a project.
- Help in evaluating design proposals

In light of the dynamic and competitive nature of the jet engine business, the list can be restated more specifically to:

- Understand product cost to support business cases for new programs

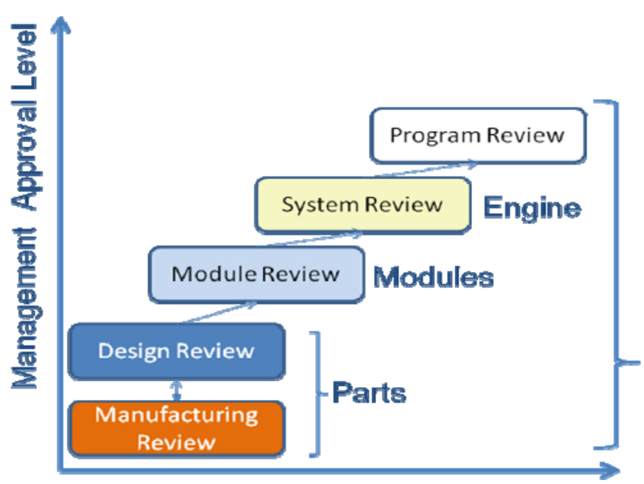
- Establishing Return on investment for new capital investment.
- Evaluate alternate designs and processes for the least cost alternative during product development
- Estimate the cost impact on product design change proposals
- Determining the expected impact of process changes including cost reduction return on investment.
- Measure quotations versus estimated cost for validation of quotes.
- Support Supplier Negotiations
- Determine the value of partner shares.
- Determine expected savings from joint ventures or global sourcing strategies.
- Price spare parts to ensure sales and profit.

Product Development at Pratt & Whitney

There are 5 phases of product development at Pratt & Whitney;

1. Conceptual Design
2. Preliminary Design,
3. Detailed Design and initial verification,
4. Validation and verification and
5. Production Delivery, Service, Support.

Various activities occur at each stage including materials and processes development, test rigs, development parts fabrication, detailed design, system design, engine assembly and testing (sea level and altitude), flight testing and certification. At each phase there is a series of reviews that permit design and development teams (IPT teams) to proceed to the next step. Product Cost is addressed at *each* step as a design parameter along with weight, temperature, performance, aerodynamics and structural analysis.



<u>**Integrating DFMA into the Product Development Process**</u>

Detailed Design Phase
The initial focus of DFM in new product development is the detailed design phase. Standard Work has been revised such that a the beginning of this phase a DFM analysis is created for each part. The analysis will be iterated as the design proceeds. This will allow cost to be factored into design decisions such as material selection, cost versus weight trades and alternate manufacturing processes.

Sourcing and Production
.DFM can be used to support sourcing decisions, validate supplier quotations, support negotiations and assign value to a supplier's suggestions and provide validity to cost reduction projects and, of course, support rational negotiations for procurement contracts. Because sourcing decisions are made at all phases of the Product Develop process or during production, the process for using DFM in sourcing is an ongoing cycle starting with a good DFM analysis (cost model) then receiving quotes, developing cost reduction ideas and implementing those ideas This may include design changes that combined with the new supplier's capability allow cost reductions that were not previously identified.
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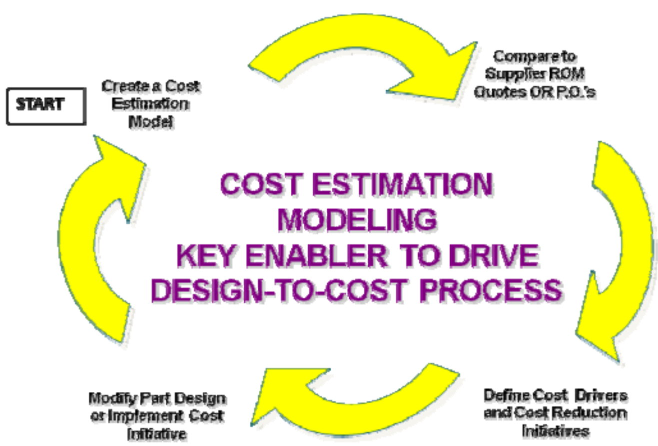


Validation and verification

Due to the importance of safety and performance in jet engines, validation and verification of the design is critical to the success of the program. The typical process for validating the design of a jet engine includes ring test, static testing on the ground, an altitude test facility, flying on a flying test bed and finally fight testing and certification by regulatory authorities.

Even with the best design and analysis tools early testing can show that aspects of the system do not function as expected. These events lead to design changes that must be incorporated as soon as possible and with minimal risk of another test failure. Without a product cost management process, the cost impact of these types of changes is not easily understood and often not even identified. A group of seemingly small cost increases can result in a substantial increase the system cost.

As testing proceeds it becomes successful. When this happens, it becomes more difficult to initiate changes to offset the cost increases changes. With DFM in place, there is a cost estimate that can be easily adjusted to assess the impact of design changes. Pratt & Whitney is planning to update the DFM analysis a part of the approval process for any design change Without DFM , the system can go into production at a higher than planned cost. It then becomes necessary to recover the cost increase through low source costing, process improvements, manufacturing productivity, lower labor cost or supplier negotiations.

DFM Implementation on the PW1524G Engine

Initial part cost estimates for the PW1524 engine were done during preliminary design using spreadsheets. Although, surprisingly accurate, the documentation did not retain all of the assumptions and it was not clear what designs attributes were included in the preliminary estimate. Using cost estimating software allows us to retain all of the detail as well as to ensure everyone doing the analysis was using the same assumptions, and calculating techniques.

To improve the cost modeling process, early in 2009 P&W began using DFM Concurrent Costing Software to determine its applicability to jet engine parts. DFM Analysis was performed on existing parts. It was recognized early on that the software would not cover all of the manufacturing processes across an entire jet engine. Other software packages were reviewed and none were all inclusive. DFMA was chosen because its library structure allowed Pratt & Whitney to enter the specific alloys and their properties, and specific operations including those that are proprietary to Pratt & Whitney. Software was purchased and training began mid 2009.

The first PW1524G engine is scheduled to be assembled and tested in July 2010. The PW1000 management team recognized the need to implement DFMA quickly for it to be effective for detailed design, and to understand cost impact of changes during validation.

A goal was set to complete DFM analyses across 250 parts that make up 80% of the manufacturing cost by April 2010. The implementation plan was scoped to include the following;

- Perform DFM analysis on 250 parts that make up 80% of the manufacturing cost of the PW1524G engine.

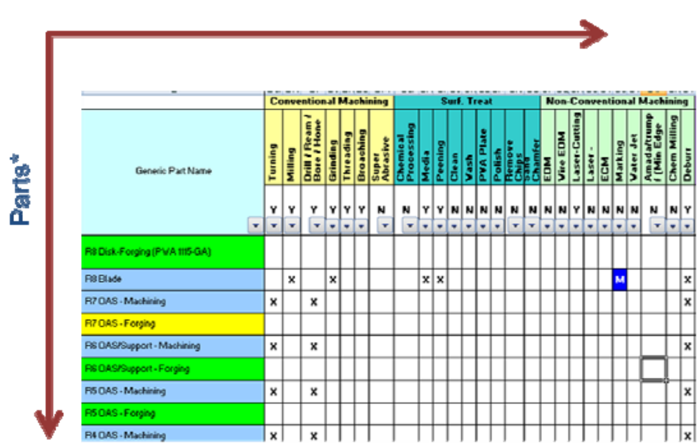
- Create operations and user processes to provide complete analysis of those parts
- Create 70 materials library entries that include the properties and machining parameters for AMS and PW alloys used on the 250 parts.
- Provide training for Manufacturing Engineers and Design Engineers in DFM
- Create an ongoing training course to facilitate company-wide DFM use
- Develop a method of information exchange in expectation of having many DFM users within the company and engineering service contractors
- Create a system for storing the files, change control and allowing non DFM users to access results for reports and comparisons
- Provide standard work along with a review and approval process that ensures consistent use of the tool and high quality results.

The remainder of this paper discusses how P&W completed 250 part cost models in less than 6 months and put infrastructure in place for enterprise wide deployment of DFM to support the cost management process.

Operation and User Process Libraries

Several full time and contract employees were trained in creating libraries. This training was a combination of using the resources easily available (Users Guide and Help information in the software) as well as some face to face training with Boothroyd Dewhurst.

An initial assessment of the 250 parts was completed by Manufacturing Engineers with technical expertise in specific processes. A matrix of the 250 parts and their processes was created to identify which processes within DFM provided calculations consistent with our processes. The remainder either required modification of DFM cost/cycle time formula or creation of a new cost formula where DFM has no similar process modeled.



	Conventional Machining							Surf. Treat									Non-Conventional Machining									
Generic Part Name	Turning	Milling	Drill / Ream / Bore / Hone	Grinding	Threading	Broaching	Super Abrasive	Chemical Processing	Media	Peening	Clean	Vash	PVA Plate	Polish	Remove Chips	Safe Chamfer	EDM	Vire EDM	Laser-Cutting	Laser -	ECM	Marking	Vater Jet	Amada/trump / (Min Edge	Chem Milling	Deburr
	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	Y
R8 Disk-Forging (PVA 1115-GA)																										
R8 Blade		x		x					x	x												M				x
R7 OAS - Machining	x		x																							x
R7 OAS - Forging																										
R6 OAS/Support - Machining	x		x																							x
R6 OAS/Support - Forging																										
R5 OAS - Machining	x		x																							x
R5 OAS - Forging																										
R4 OAS - Machining	x		x																							x

X = Process is needed for part and DFM formula applies
M = Process is needed but DFM does not have formual or it is not applicable
*For enterprise wide implementation use part families instead of individual parts

The list of processes was prioritized by counting the number of M's (missing process in the library) for each column. That is, total count of the 250 parts that needed that process created in the operation or user process library. This established the priority for creating new processes and operations in the libraries. Setting priorities using this method maximized the number of the 250 parts that could be completed and not waiting library work.

The trained process creators were teamed with the appropriate technical experts and created process models using a combination of the following resources;

- Time Element Data; *American Machinist Manufacturing Cost Estimating Guide* by Phillip F, Ostwald (last published in 1983)
- Labor Rate Data: U.S. Bureau of Labor Statistics (www.bls.gov)
- Material Property Data including machining parameters ASM material property data sheets (www.products.asminternational.org) (subscription may be required)
- American Society of Metals (ASM) Handbook vol. 14-21 manufacturing process volumes www.products.asminternational.org/hbk subscription required
- Data already existing within DFM
- Tool and Manufacturing Handbook (TMEH), Society of Manufacturing Engineers (SME)
- Internal Manufacturing Time Standards and Actual Clocking data for checking
- Pratt & Whitney procedures and manufacturing work instructions

The Operation Library additions included:;

- HIP (hot isostatic pressing),
- NDT (nondestructive evaluation) such as fluorescent penetrant, radiography and ultrasonic
- Plasma Spray and Grit blast
- Surface Treatment such as shot peen
- Flow and pressure testing
- Dot Peen Marking

User Processes were created for;

- Isothermal closed die forging
- Seamless rolled ring forging
- Super alloy closed die forging
- Flash Butt Welded Rings
- Special Types of investment casting

User process and operations were reviewed with Manufacturing Engineering leadership, tested and approved before releasing them for general use in the P&W "production" library.

Materials Library

Although the DFM materials library contains many materials used in aerospace, it does not contain all of the 70 alloys used on the 250 parts. Furthermore, the material names are common or descriptive names in DFM. Pratt & Whitney blueprints always call out materials by AMS (Aerospace Material Specification such as AMS 4128) or PWA specification. To mistake proof the library all of the descriptive names were converted to the equivalent AMS or PWA specification number. New materials were added to the library as needed. The American Society of Materials web page (www.asm.com or http://products.asminternational.org/matinfo/index.jsp) is a good source for converting materials between equivalent specification numbers as well as a source for most of the material data needed to add materials to the DFM material library.

Training

Initially training was conducted in workshops with Boothroyd Dewhurst on site consisting of 4 hours of familiarization and 4 hours of application. During the first half of the day each student worked at an individual computer by following the instructor whose computer was projected to a screen. The remaining 4 hours were allocated to each student working on an actual part with the Boothroyd Dewhurst instructor and experienced P&W employees assistance.

Many of the attendees did not expect to be creating analyses after the workshop but needed the ability to view the models and create reports such as procurement, financial and design engineers. In preparation for enterprise-wide deployment, P&W has created a self-paced on line course through the internal intranet. The course follows the same topics as live training but has some 50 questions from which 10 are selected randomly by the program and presented to the student. The student must respond with correct answers for 8 or more to "pass" the course.

Communication and Collaboration

In expectation of having many users and several locations and knowing how important it was that to follow standard work, a collaborative website was developed using the Wiki format (PW Wiki) The Wiki site includes:

- How to set up and access DFM on the internal network including access to P&W Production Libraries

- FAQ's, Tips and Lessons Learned
- Reference Material
- Training and Standard Work information
- A place to submit Software Enhancement Suggestions
- Review Schedule
- Contacts
- A place to submit turnbacks such as indentifying library or network issues

Web Based Results and Results Analysis

With 250 parts already complete and many more coming, it became necessary to create a common database for results. This eliminates the need for those using the data to navigate around network folders to find which parts have been completed and eliminates the need to open individual .pdf or .xls reports to get data. An entry of header data is made indicating an analysis has been completed and approved which triggers transfer of data to a Business Objects database. The database allows users access the results and perform comparisons such as look all the parts at a particular producer, look at all the similar parts in a part family or, look at all the parts in a module or engine model.

In order to control the requirement for every engineering change to have an associated cost model, the database will interface with TeamCenter allowing TeamCenter to control the release of a new or significantly changed design without a cost impact analysis using DFM. Eventually storage of completed analysis will reside within Teamcenter and not in network folders.

Pratt & Whitney
A United Technologies Company

Results

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Process Chart	Cost per part, $							Operation time per Part, s	Initial Tooling Investment
	Material	Setup	Process	Rejects	Piece Part	Tooling	Total		

Lessons Learned (so far)

The process of validating DFM calculations and library data by comparing known part cost should be done on a process by process level not part by part. If the processes and data are valid the part cost estimate will be accurate.

Having standard work, some form of review and approval process is necessary if many people and varied skill levels are doing analysis.

Library should only be customized based on sound data. Assuming labor rate differences can lead to an incorrect result.

Blanket implementation (250 parts) did expedite building the infrastructure but did little to demonstrate the value of DFMA. Working projects with high potential benefit (or pain relief) and working them thoroughly showed the value potential,

There is as much benefit in the questions DFMA creates as there is in the analytical results. Product cost now gets far more attention.

It needs to be clearly understood across the organization whether DFM is being used as a cost estimate or a should cost and in any case not a price estimate.

The software is a tool. Cost estimating and product cost management is a process that uses the tool. A good process is necessary to get full benefit.
A good tool is not effective without a good process. That is why we are here today.

References

[1] Michael L. Dertouzos et. al.; The MIT Commission on Industrial Productivity; Made in America, The M.I.T. Press

[2] Jack Connors; The Engines of Pratt & Whitney, A Technical History; American Institute of Aeronautics and Astronautics Inc., 2009

[3] William, Winchell. Realistic Cost Estimating for Manufacturing; Society of Manufacturing Engineers, 1989

[4] Ostwald Philip; American Machinist Manufacturing Cost Estimating Guide 1983