ACE in engineering: Pratt & Whitney Turbine Module Center Engineering[1]

Many of the ACE methods used extensively across UTC today originated in Pratt & Whitney's factories. ACE was a new approach that spread to UTC's factories and offices across the globe because its use improved business results. To Pratt & Whitney's engineers, the ideas behind ACE did not seem different from what they already did. UTC's ACE business operating system applies these engineering-like approaches to business and production processes. Disciplined data collection and problem solving process is a foundation for engineering work so it is reasonable to expect that engineers would readily adopt ACE. That was not the case in practice. It took considerable time and effort for engineers to fully adopt ACE, but their continued efforts did eventually produce significant changes with benefits for engineers and customers. The section that follows describes these changes and those outcomes in Pratt & Whitney's Turbine Module Center (TMC) engineering organization. Since the interviews and writing of this case, the Turbine Module Center engineering organization has merged with the Combustors, Augmenters, and Nozzles (CAN) engineering organization to form a new Hot Section Engineering (HSE) organization.

The overall structure of Pratt & Whitney's organization at the time of this study was a dual-reporting matrix. Groups within TMC Engineering report to their respective engineering groups or engine programs *and* to the Turbine Module Center General Manager. All Module Center General Managers report to the VP of Operations. Pratt & Whitney has an Engineering VP running a department that focuses on systems engineering and engineering disciplines[2]. The Operations VP and Engineering VP both reported to Pratt & Whitney's President. TMC Engineering was one of twelve engineering sites.[3] It is responsible for turbine subsystems and components. The department is divided into program engineering and process engineering. Reporting to the Program Engineering Manager (in 2009 given the title Engineering Director), were engineering groups for specific programs. These groups are part of integrated product teams, which meant that they aligned with programs and similar engineering groups for the respective engine subsystems in the other module centers. Reporting to the process engineering manager (in 2009 given the title Deputy Engineering Director) are groups organized into part families (airfoil, rotor, case, and shaft), and groups focused on producibility, process certification, and tools development. Engineers in these groups had matrix reporting relationships to programs and across module centers to others to their programs. [4]

The organization by Module Centers is the result of restructurings that began in the mid-1980s. The first restructuring brought functionally organized production groups together to create focused factories where business unit managers were responsible for cost targets and delivery times. The next restructuring created product centers that placed purchasing, quality assurance, and part design functions under one general manager. The centralized engineering organization was decentralized, initially through the adoption of integrated product development team organizations in the late 1980s, then by reorganization into Component Centers in 1994, and finally in 1999 by combining engineering with production into Module Centers. In 2000, Pratt & Whitney merged its military and commercial engineering organizations. The military engineering facilities in Florida were closed and engineers combined with the commercial engineering groups in Connecticut. Many engineers elected not to move, creating shortages of engineering resources, skills, and knowledge on key engine programs.

Restructurings and personnel shortages have required changes in Pratt & Whitney's engineering organizations. Other sources of changes came from product issues. Pratt & Whitney's response has been to address problems as they arose, often by adopting new methods or restructuring reporting relationships (see reorganizations, business and product events on Figure 1). New engineering leaders, some hired from outside the company, spearheaded the implementation of specific solutions and pressed for broader cultural changes.

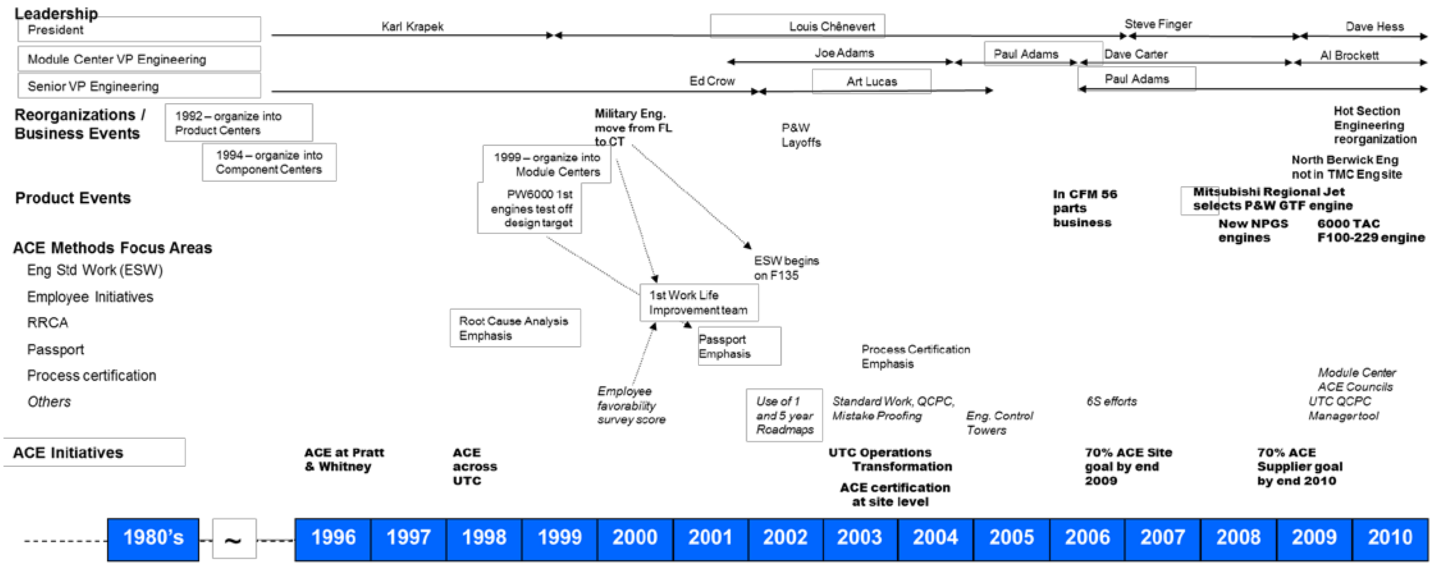

Figure 1 Time Line of Pratt & Whitney's Changes

A few examples illustrate Pratt & Whitney's problem and response pattern. Engine reliability issues led to an emphasis on root cause analysis methods. Shortages of skilled engineers led to the use of engineering standard work, where the resulting pressures on people and low employee survey scores led to work life improvement teams. Development problems with the PW6000 engine led to the use of Passport, a stage-gate product development review process. An engine blade issue led to the further development and greater use of process certification methods.

For TMC Engineering, these efforts took place in parallel ways with on-going ACE activities. Implementing new methods melded with ACE efforts because engineering responses to problems were aligned with or later became specific ACE tools. Its own changes were only loosely connected with corporate ACE efforts in TMC engineering. These new methods and their adaptation to engineering work did produce significant and positive changes in TMC engineering.

ACE Journey

In looking back, TMC Engineering's managers attributed changes to their ACE journey, yet the linkage with ACE tools and problem-solving approaches were only indirect and often inconsistent across these problems. The responsiveness to problems was consistent, resulting in restructuring and process changes while adopting new methods. Corporate ACE initiatives seemed to more or less take place in the background of engineering changes. The corporate applications of ACE to engineering were still evolving. Managers presented the methods they used and changes they made in applying for ACE certifications, but ACE had not been a driving force. This situation changed, however, around 2007 as ACE began to drive unique improvements at TMC Engineering.

UTC developed the ACE Operating System by identifying best practices, at Pratt & Whitney and other companies, and broadly adopted them. In 2004, the emphasis for ACE shifted from a focus on cells to making improvements in sites. Pratt & Whitney's Presidents, beginning with Karl Krapek, then Louis Chênevert in 1999, and Steve Finger in 2006, all championed ACE. The gains achieved by ACE in production and operation setting created pressure for engineering changes. Prior to 2006, the engineering organizations had largely "dabbled" with ACE efforts. In 2006, Finger's near zealous promotion of ACE required that engineering organizations make ACE a priority. This message was given in an off-site with Finger in late 2006 when the seating order put ACE Gold site leaders sitting at the front of the room (leaders from non-ACE Gold sites, including the Engineering VP, sat toward the back). Although Pratt & Whitney's engineering groups performed well, they struggled to consistently achieve the needed metrics when all of twelve engineering cells were a part of one site. People said the difficulty was leadership, and the need for local leaders to be more accountable for improvements.

As an engineering cell, TMC Engineering achieved ACE Qualifying in July 2000 based on its people taking training and making baseline process measurements. It became an ACE Bronze cell in March 2001 by its people demonstrating their appropriate use of ACE methods on improvement projects.[5] In December 2004 TMC Engineering achieved ACE Silver cell certification, this time by demonstrating its abilities to sustain previous changes, aligning its goals using roadmaps, collecting good performance measures, and roll up, report, and regularly reviewing its metrics scorecard.[6] This period, from 2000 to 2006, was when improvement initiatives responding to customer and competitiveness issues were the major source of changes (as shown in Figure 1). ACE was perhaps feeding, but it was not driving, changes. Several engineers shared their perceptions, in private, as to why they had not embraced ACE at that time. To them, ACE was simply common sense; they already used data and logic for solving problems. Learning, demonstrating, and documenting ACE use only added a bureaucratic burden to their busy schedules. Second, the ACE tools and methods for process improvement were too simplistic to apply to engineering work. Third, ACE certification was driven by management, who because of their focus on business goals lacked sensitivity for rigorous data analysis and failed to understand the challenges in solving technical problems. Finally, to them ACE targets were abstract management priorities, and did not relate to the technical results that the engineers valued. In short, while there might be some basis for engineers' complaints, these reactions can be also seen as a human nature and its resistance to organizational change.

Ben Reinert, Deputy Director and Process Engineering Manager for TMC Engineering, was central to leading ACE efforts. He, along with TMC Engineering Director Al Brockett, was well aware of engineers' attitudes. He promoted use of the methods without using the word "ACE." Some engineers were asked to take ACE courses and required to participate in improvement projects. By the end of 2004, 99% of TMC's engineers had completed some ACE training. All engineers had to clean and keep their workspace tidy, and better organize their computer files, under the auspices of "6S,"[7] a requirement for ACE certification. There were individuals that took initiative, such as Kevin McCusker. McCusker is a heat transfer engineer, and was exposed to ACE in working on production problems in a previous job (several engineering managers leading ACE efforts had been exposed to ACE in previous manufacturing assignments). McCusker piloted ACE in his heat transfer group and became TMC engineering's ACE

Pilot. He attended ACE courses on value stream mapping methods and facilitating teams. Much of his ACE education, however, came from his having to interpret how ACE tools and methods applied to engineering. McCusker taught ACE to engineering teams as he helped them carry out improvement projects. Over time, other engineers promoted ACE, usually after they had achieved success with original efforts in their groups. McCusker noted that even the initial resistance to organizing office areas and adopting computer file conventions was later seen as positive when engineers found that they worked more efficiently.

In early 2007 Pratt & Whitney's Senior Engineering VP changed what had been one engineering site with twelve cells into twelve sites. This reorganization was spurred by the UTC corporate goal to achieve 70% ACE Silver and Gold sites by the end of 2009. Achieving Gold status as a single large engineering site with varied activities and multiple value streams was difficult. Splitting into a smaller number of sites, each with approximately 300 people, gave the Module Center Engineering leaders both more responsibility and accountability for ACE. It allowed each leader to be creative in his or her approach. Senior managers were motivated to make ACE progress when their annual incentives were linked to its goals. Some of these managers were ultimately replaced with others who were a good fit for ACE.

In August 2007, TMC Engineering became the second Pratt & Whitney engineering site to achieve ACE Site Gold certification. Achieving Gold site certification required building upon past accomplishments while maintaining ACE Gold metrics. These metrics covered financial, productivity, quality, customer feedback, employee satisfaction, and health & safety measures, and required high performance levels for twelve consecutive months.   In the assessment that conferred the certification, the assessors required specific areas for additional improvement – greater emphasis on QCPC, turnbacks, and teams to respond to them; process certification efforts; creating a continuous improvement ACE culture; and use of SIPOC[8] process mapping. Based on their follow through *and* maintaining ACE Gold metrics, TMC Engineering received an ACE Site Gold recertification in September, 2008. It again achieved ACE Site Gold re-certification in September, 2009 (see Figure 2 for TMC Time Line and ACE focus areas). It was, however, after August 2007 that ACE efforts began driving TMC Engineering's changes.

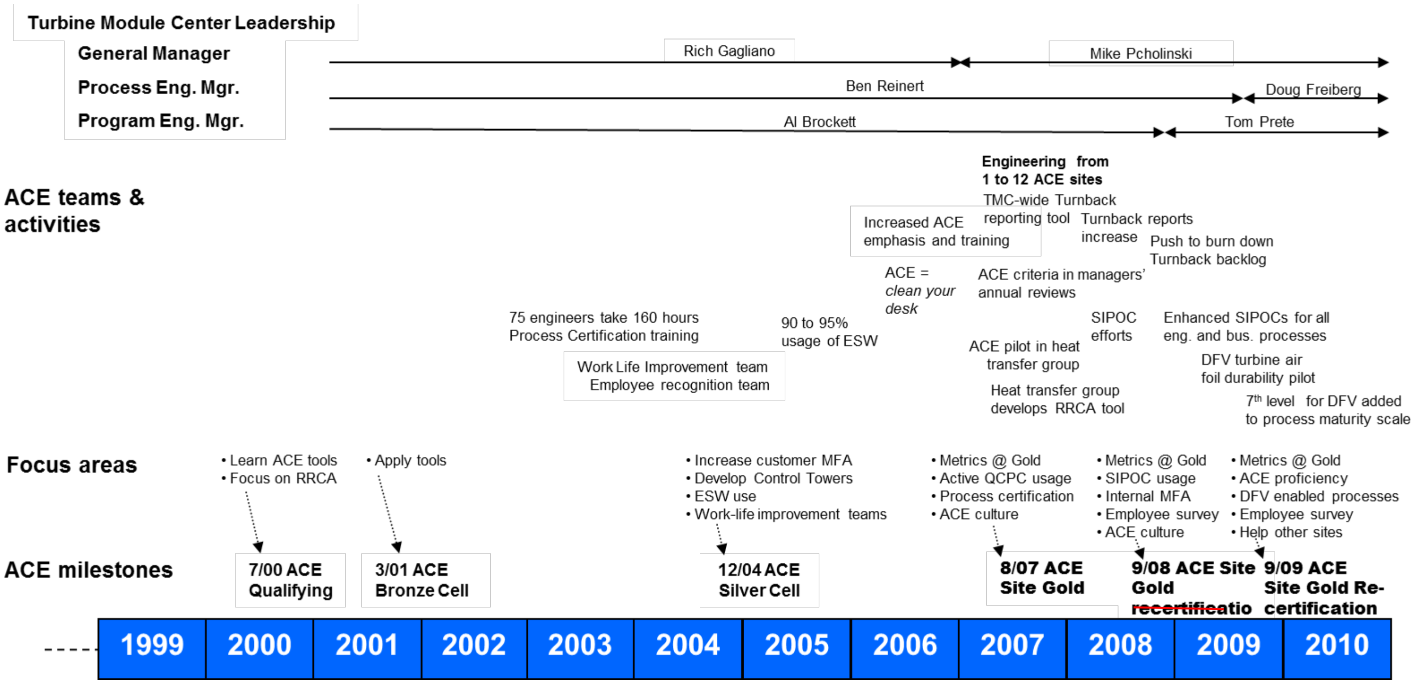

Figure 2 Time Line of TMC Engineering Changes

From adopting to developing ACE

A shift in engineers' orientation to ACE occurred after the 2007 ACE assessment. TMC Engineering's managers and engineers expanded beyond adopting ACE, where they largely complied with requests and met requirements, to using data and process insights that they gained from ACE to guide their changes. This orientation enabled them to not only focus on and make specific changes that improved their engineering work, but also allowed them to bring innovations to ACE.

An example of the shift in their ACE orientation is seen in the SIPOC method requirement. In the August 2007 assessment presentation, John Papadopoulos (UTC Corporate ACE Director), working as one of the two ACE Gold Site assessors, pointed out how a greater use of SIPOCs would help their process certification efforts. The engineers understood but had not made prevalent use of SIPOCs. Papadopoulos specified further SIPOC use as "homework" for a subsequent ACE certification review. Over the next year, efforts led and coached by Kevin McCusker developed detailed SIPOCs for all 43 of its key engineering and business processes.[9] These SIPOC data were then used to perform impact maturity analysis,[10] which along with benchmarking their processes guided subsequent improvement efforts. The link between SIPOC and impact maturity, later called "enhanced SIPOC," was an innovation that was recognized as a best practice, became part of the standard ACE toolset, and recommended to other organizations.

Most of these engineers' work in designing turbines involves conducting various manual and computer-based design, analysis, and testing procedures. Their computer-based tools are either purchased from vendors and frequently customized or are developed by Pratt & Whitney engineers or information technology specialists. Investments in more capable or better integration of computer tools can improve the quality and productivity of engineers' work. TMC Engineering formed a Multidisciplinary Design and Optimization (MDO) Group in 2000 to improve these tools. MDO started with a manager and two engineers developing a computer program to eliminate repetitive data entry activities. Their efforts were very helpful, and increased engineering productivity. The group grew as additional funding became available. Engineers joined this group for specific projects or periods and then rotated back to their regular work. MDO's accomplishments included reducing the time required for a three-dimensional cooling circuit design analysis from fifty-two weeks to one week and the time required for rotor thermal analysis from six weeks to one week. Other projects included automating turbine durability analysis [?], rotor thermal analysis, and rotor design programs. Other centers followed TMC's lead by starting similar MDO groups for improving their engineering tools.

Like ACE efforts, MDO provided quality and productivity gains by improving engineering tools. These efforts benefitted from ACE. As engineering groups progressed in their ACE use, they collected engineering process data. These data enabled returns-on-investment calculations for engineering tools. These calculations allowed Pratt & Whitney's core engineering group, which usually defaulted to politically-driven approaches to allocate funding for improvements, to use data to prioritize and target its investments. Data analysis indicated, for example, that an overall focus on high cycle fatigue failure was needed and led to funding tools with those capabilities. Al Brockett, then promoted to Pratt & Whitney's Engineering Vice President, said that ACE enabled a shift from a focus on work in individual engineering centers to achieving engineering synergies at an enterprise-level. The way that ACE collected and analyzed data, he said, made it an operating system rather than just a toolset for engineering.

An example of TMC Engineering changing itself, improving ACE, and helping others is seen in its application of Design for Variability (DFV) concepts to process maturity measures.[11] As one of several organizations, TMC Engineering participated in a research project funded by core engineering to upgrade their turbine durability tools to include DFV analysis. Through those methods new designs had improve part life and product performance. TMC Engineering's leaders then extended DFV concepts to their process maturity/customer impact analyses. They expanded the 1 to 6 process maturity scale by adding a seventh point, where 7 is a DFV-capable process. Using this analysis, they assessed all 43 of TMC Engineering's enhanced SIPOCs for key engineering processes to identify which ten were most critical to overall turbine design quality. They improved the performance and reliability of these ten processes by adding DFV-capable analysis methods. This DFV example, like many others, exemplified TMC Engineering's shift from just using ACE to achieve certification to developing ACE to guide their own efforts and help others in producing better engineering and business results.

Process outcomes

It is easier to measure the impact of changes in production than it is to assess changes in engineering work. Engineering work has multiple factors and time delays contributing to overall outcomes. TMC Engineering tracked several relevant measures including engineering cost of poor quality (COPQ – a measure of costs to resolve issues with products in the field), engineering escapes (count of errors), and employee survey (employee satisfaction scores). These data,[12] depicted graphically in Figure 3, provide quantitative verification of TMC Engineering's significant changes. As ACE required sites to develop performance, cost, productivity, safety, quality and employee favorability measures, engineering managers and engineering groups demonstrated that they could use ACE methods and their general skills to balance and improve all those outcomes.

Over the period from ACE Bronze, where detailed measures were developed, to ACE Site Gold all of TMC Engineering group's quantitative assessments showed substantial improvement. The cost of poor quality dropped to a fraction of its initial level. Engineering escapes (a count of problems that are found downstream in the development process that can be traced to an engineering or design root cause,) also declined dramatically from its original 2001 level (escapes are infrequent, but a polynomial through the variable data shows an order of magnitude decline). Internal engineering escapes (errors found by internal Pratt & Whitney groups that are traceable to an engineering or design root cause) showed improvements similar to external escapes (external escapes are problems found by customers).

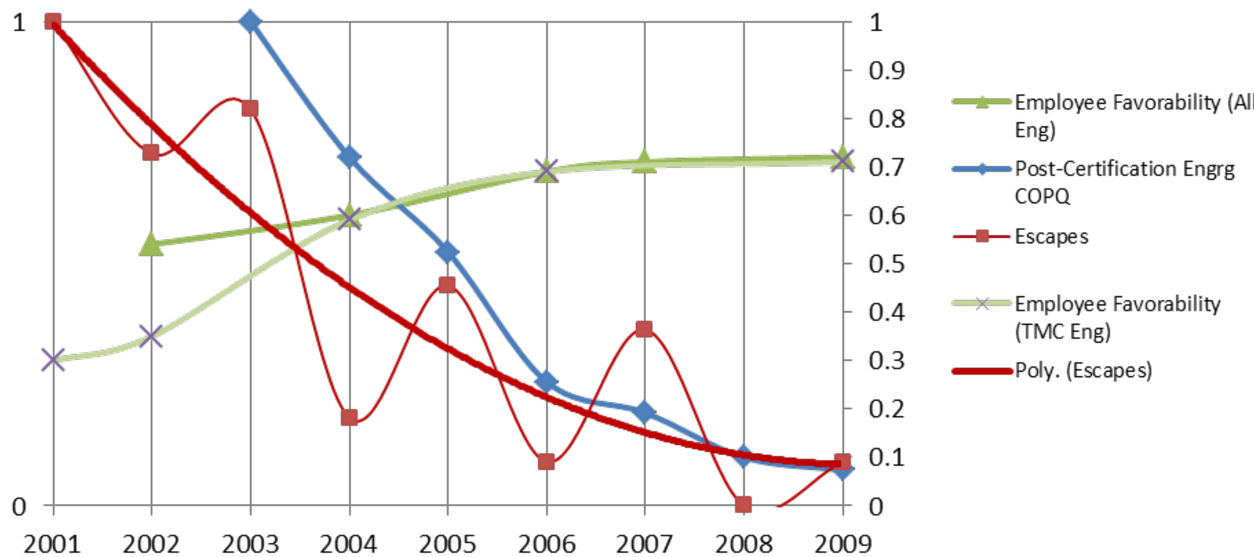

Figure 3 Measurements Showing Engineering Improvement

The impact on people is assessed by "employee favorability" scores from surveys.[13] These data corroborate interview comments by showing both increased ACE engagement and improved work satisfaction.[14] In the past, when someone proposed using ACE methods, other engineers rolled their eyes; now people "no longer apologize for suggesting ACE-like analysis." What had been a resistance to change had become an acceptance that the new way of doing things that resulted from ACE projects did indeed bring benefits to engineers in their daily engineering work.

Product outcomes

Productivity, quality, reliability, or on time delivery are important, but only if there are also product advances. For example, the use of Six Sigma methods improved processes at 3M but led to overall declines because they constrained product innovations.[15] Two innovations show that ACE efforts have not undermined but contributed to product developments.

In November, 2009 Pratt & Whitney introduced a new configuration, the F100-PW-229 EEP engine (EEP stands for Engine Enhancement Package).[16] The new engine provides a 50% improvement in engine cycles over current models, cutting maintenance cost by 30 percent and extending the normal maintenance interval from seven to ten years.[17] The EEP engine aligns engine service with airframe maintenance, potentially save the Air Force and other customers hundreds of millions of dollars through the F100's expected 2045 service life.[18] When EEP engines were available for foreign military sales, the first six contracts all ordered Pratt & Whitney's engines, including governments that previously only ordered F16 jets with General Electric's F110 engines. The gains associated with the EEP engine trace directly to improved turbine durability.

TMC Engineering was one of twelve engineering sites in Pratt & Whitney. Other sites used ACE to achieve gains in their engineering work. An overall technical achievement expected to have a huge business impact is Pratt & Whitney's new PurePower engine (previously known as the geared turbofan or GTF engine). The more fuel efficient, low noise engine design uses a scalable architecture for an engine family providing thrust ranging from 10,000 to 40,000 pounds. It is a lighter-weight engine, with hundreds fewer airfoils and fewer life-limited parts, making it easier and less expensive to maintain. The PurePower® engine was named one of "The 50 Best Inventions of 2011" and "the most important development in aviation in 2011" by Time magazine.[19] Comparable engines from General Electric and Rolls Royce are "in various stages of development" and are "years behind Pratt in bringing a totally new engine to market."[20] This engine has been selected as the exclusive engine for Bombardier CSeries, Mitsubishi Regional Jet, Embraer second generation E-Jets, and Irkut MC-21 narrow-body aircrafts and will be an option on the Airbus A320neo. Expected to enter service in 2013, Pratt & Whitney had over 3000 orders as of year-end 2012.   In February, 2013, after more than 4,000 hours of engine testing, the Pratt & Whitney PW1500G engine was certified by Transport Canada, marking the first time any production version of the geared turbofan has been approved.[21] TMC Engineering and turbine performance contributed significantly to the overall design, as did other engineering groups who were also improving as part of their own ACE journeys.[22]

Endnotes

[1] The section is summarized from the TMC Engineering case study report that was co-investigated and co-authored with Eric Rebentisch, Research Associate, Lean Advancement Initiative, MIT Sociotechnical Systems Center.
[2] Systems engineering includes Design & Component Integration, Propulsion Systems & Analysis, System Validation, and Advanced Technology & Preliminary Design. The development of engineering disciplines includes Aerodynamics, Mechanical, and Materials Engineering.
[3] The Turbine Module Center was merged with the Combustors, Augmenters, and Nozzles (CAN) center in late 2009 to create the Hot Section Center. The respective engineering groups were merged to become Hot Section Engineering.
[4] The number of people employed at TMC Engineering changed over time. These numbers were the size of the group at the end of 2004. As economic conditions declined, TMC Engineering did less work with contractors, and other organizational changes resulted in the engineers in the North Berwick site moving to that site's personnel.
[5] The ACE tools TMC Engineering demonstrated itself competent to use of were RRCA, MFA, Passport, 6S, Standard Work, QCPC and mistake proofing.
[6] Called "ACE Control Tower" in Pratt & Whitney.
[7] 6S is a variant of a workspace organization tool that borrows its name from the first letters of its elements: Sort, Straighten, Shine, Standardize, Sustain, and Safety.
[8] SIPOC is a method within ACE for process control and certification; the name is an acronym for process elements: "S" for suppliers of the process, "I" for the supplier's and other inputs to the process, "P" for the process or tasks that are performed, "O" for the outputs of the process, and "C" for the customers that who receive these outputs. For more about SIPOC, see the section on that method in ACE Tools and Methods, Appendix B, UTC ACE Operating System Case Study.
[9] These efforts required a representation of all its processes that included data for suppliers, inputs, process operations, outputs and customers; required appropriate measures for all process inputs and outputs; and connecting these measures to the TMC Engineering metric scorecard.
[10] Impact maturity analysis is used to plot process maturity against their impact on the customers. High impact/low maturity processes would receive much higher priority for improvement efforts than would low impact/high maturity processes.
[11] Design for Variability (DFV) involves basing design decisions on an understanding of the variability in a system's components. These methods use a statistical rather than nominal design approach to make design choices that lessen the impact of real-world variability on overall performance. The implication of DFV is that design tools are capable of running the multiple analyses needed to assess the effects of that variability.
[12] These graphs are of normalized numbers as Pratt & Whitney did not want to release absolute numbers. The measures were captured as part of ACE efforts, not all were available starting in 2001.
[13] Employees submit anonymous responses. The employee favorability scores are expressed as percentages of Pratt & Whitney's engineers who responded that they were 'satisfied' or 'very satisfied.' These measures are from five questions related to the importance of ACE, the employee's organizational unit's application of ACE, overall management practices, pay & benefits, and their employment.
[14] These data are shown as actual percentages using the scale on the right-hand side of graph, is given for all of engineering and for just the TMC Engineering site. Both these curves show steady, statistically significant, improvement from 2001 to 2009. TMC Engineering had over a 2.5x increase in favorability scores from 2001 to 2009. [14] For all of Pratt & Whitney engineering (all twelve engineering sites), the employee favorability increased 50%.
[15] Hindo, Brian "At 3M, a struggle between efficiency and creativity." Business Week, 11 June 2007
[16] Pratt & Whitney's F100 engine powers 100% of the USAF's F15 and 62% of its F16 fighters (the General Electric F110 engine is the alternative F16 engine). This engine has been in service for over 30 years, and its 220 version is the safest fighter engine in U.S. Air Force history. See F100-PW-229 Case Study, downloaded from www.pw.utc.com/Services/Military on 5/6/2010.
[17] F100-PW-229 case study, downloaded from http://www.pw.utc.com/Services/Military/Material+Services/F100-PW-229 on 5/6/2010.
[18] See Parmalee, P. "Industry Outlook," *Aviation Week and Space Technology*, Feb. 1, 2010, page 16.

[19] See Time Magazine, and information downloaded from http://www.pw.utc.com/products/commercial/purepower-pw1000g.asp on 1/30/2012.
[20] Saunder, P. “Pratt Battles Back with New Engine,” *Wall Street Journal*, April 30, 2010, downloaded from http://online.wsj.com on 5/7/2010.
[21] Norris, Guy. "Pratt & Whitney GTF Certified For CSeries," Aviation Week Intelligence Network, February 20, 2013, downloaded from http://www.aviationweek.com/awin/ArticlesStory/tabid/975/Status/IPAddress/Default.aspx?id=%2farticle-xml%2fawx_02_20_2013_p0-550987.xml
[22] For example, CSMC Engineering was the first Pratt & Whitney ACE engineering gold site to be certified.