The paper describes the triumphs as well as some of the problems in tooling and manufacturing process development. To achieve the accelerated schedule, Westinghouse decided to team with the part machining suppliers to develop a game plan that allowed for true concurrent engineering. The result was the conceptual design stage for a few months. Normally, this type of modification would be planned and implemented over many months. In order to achieve the desired performance goals and meet the customer’s delivery requirements, this project would have to move very quickly. The project time frame required that from the conceptual drawing to start of production be no more than eight weeks.

To achieve the accelerated schedule, Westinghouse decided to team with the part machining suppliers to develop a game plan that allowed for true concurrent engineering. The resulting plan was to complete the part design at the same time that all the machining tooling and manufacturing process development was being completed. As a result of combining the resources of the turbine manufacturer with those of the machining vendors, it was possible to implement a complicated part upgrade in a matter of weeks not months.

By utilizing 3-D computer models to define the part configuration as well as to build the machining tools and develop the machining process, the team was able to meet the challenge. The final design was optimized for performance as well as ease of manufacturing. This paper describes the triumphs as well as some of the problems that the team encountered along the way to delivering the final engine hardware.

Project History
As the level of competition continues to grow within the gas turbine market, every manufacturer is continuously striving to meet and exceed their customer’s expectations. This was certainly the goal of Westinghouse Electric Corporation when the decision was made to upgrade the 501FA Row 2 vane segment to the 501FC configuration. In simple terms, the upgrade was to increase the life of the part without inflicting a penalty on engine performance. Additionally, it would be necessary to achieve the necessary service life and still utilize the existing machined parts. Due to pre-existing customer delivery commitments, there was no time available to consider a change to the part casting design. All enhancements would have to be the result of changes accomplished by machining or fabricated components assembled to the existing part.

To achieve the required part delivery date, many of the normal vendor selection steps could not be completed in their usual fashion. At the start of the project, Westinghouse had to make a decision on all the required vendors that would be involved before the final design was available. It was therefore necessary to create a team of partners, not just subcontractors/vendors. If this program was to succeed, every player involved would have to work as a true team player, each supporting the other. Since this method of operating is not an everyday occurrence, support from the highest level in each organization was requested and received.

Not only is management support a necessity for a partnering approach, a cultural shift between purchasing and vendors must also occur. During the startup of this project, it was necessary to start tooling and development work first and then to negotiate price. Such an arrangement could only be achieved by partners who have had a long-term successful relationship.

Overview of Part Design
In order to achieve the desired engineering goals, a scheme had to be found to increase the cooling for the part. As with any re-design effort, a variety of changes take place.

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The original part configuration can be seen in Figure 1. To meet the required cooling enhancements, Westinghouse Engineering devised the cooling design shown in Figure 2. Simply put, the required part modifications added cooling holes and channels to the inner part diameter. These modifications could be accomplished by two diverse methods. The new features could be cast into the part or they could be created by machining the existing cast parts. Since time was a governing factor, the casting approach (with a lead time of 20 to 26 weeks) was not a very viable option. That left only machining as a practical solution.

IMPLEMENTATION PLAN

This project was started by Westinghouse presenting conceptual drawings to Metem Corporation for review as to whether the desired modification could be accomplished. The concept drawings represented a very simplistic view of the part but were detailed enough to show the complexity of the required machining operations. It quickly became apparent that in order to achieve the desired part features as well as to meet the required delivery schedule, all design and development work would have to be a collaborative effort.

As the initial review was being completed, it became very evident that the part would undergo many design iterations as the project moved along. Since the entire program was in a state of constant evolution, it can best be described in ten distinct steps:

Step 1: Westinghouse creates initial design concept.
Step 2: Initial concept reviewed for manufacturing by Metem.
Step 3: Metem provides comments for design changes to allow for use of off-the-shelf or in-stock tooling components, as well as ideas to maximize the producibility of the part.
Step 4: Westinghouse evaluates manufacturing suggestions.
Step 5: Westinghouse creates 3-D computer model of agreed upon part design.
Step 6: Westinghouse and Metem verify transfer of electronic data.
Step 7: Metem designs and builds tooling based on 3-D computer model.
Step 8: Metem develops machining process, revisions to tooling and process are made as problems are encountered (all work is completed in conjunction with Westinghouse Engineering).
Step 9: Final part results are verified by Westinghouse and Metem.
Step 10: Westinghouse finalizes part design based on part inspection data provided by Metem.

DEVELOPMENT WORK

Within this project a variety of developmental tasks had to be accomplished simultaneously. Not only did machining tooling have to be designed and built, but the actual part design itself had to be completed.

In the area of the part design a variety of analytical problems had to be resolved. The first task was to build a 3-D computer model to define the part and the new cooling enhancement features. This work was accomplished using Computervision CADDS 5 software. This same model was then used by Metem to evaluate the required machining operations and to make suggestions to Westinghouse for improved producibility. One advantage that both parties enjoyed in using the 3-D model was the identical CAD software at each site. The exchange of electronic data became no more than reading a computer tape directly. The second design task that Westinghouse had to accomplish was to ascertain the acceptability of design suggestions made by Metem. To do this, Westinghouse Engineering utilized CADDS 5 software as well as FEM and Flow Network analysis. When all the design analysis was complete, a final 3-D model was created. The final model was then transferred to Metem to be used in designing the machining tooling.

After the part design was agreed upon, the next major task was to design the necessary production tooling. To design the tooling, Metem utilized the Westinghouse 3-D model and CADDS 5 software. Each tool was designed around the computer model. The type of tooling design work completed around the model can be seen in Figure 3. By using the same computer model at Westinghouse and Metem, it was possible to do design modifications via telephone calls rather than traveling from one facility to the next for face-to-face meetings. By avoiding the necessity to travel from one site to another to solve problems, the flow of ideas and solutions to problems became very easy and fast.

Since all the tooling was designed around a CADDS 5 computer model, it was possible to use the available Computervision CAM software to generate the necessary machining programs. The availability of a quick means of generating machining programs became a great aid in reducing machining cycles. By using the 3-D computer model, it was possible to simplify the tooling required to machine the part. In general, the complex features required to be machined in the part were generated by computer software and not hard tooling.

As with any project, no task is ever accomplished without at least encountering a few problems. One example of a typical problem encountered pertained to what should have been a very simple cover plate. The plate was intended to cover a machined pocket on the part inner diameter. This item was designed to fit a specific part contour. When the machining operation for the pocket was being developed, it was found that a small design change could greatly simplify the tooling. If the original contoured 3/16" thick plate was replaced by a simple 1/8" thick flat plate, a number of days for process development could be saved. Here seemed to be a great opportunity to save time. However, the cover plate material had already been
delivered to the vendor who was to machine it. The only solution was to modify the delivered plate material. To complete this modification required that all team members work towards the optimized completion of the entire project, not just their own area of concern. While this example was not a major problem, it does illustrate that for concurrent engineering to work all areas of a project must be flexible and work to find viable solutions.

ADDITIONAL CONCURRENT ENGINEERING

In addition to the previously described machining project, this part was also undergoing several other re-engineering efforts. Since the re-design effort was basically to increase service life, all areas of the part had to be examined. While the machining effort was proceeding, it was found that an impingement plate would have to be added (to fully optimize the available cooling air) and a thermal barrier coating (TBC) applied to the part. Once again, the only tactic available to meet the required delivery date was to use a team approach.

The impingement plate was to be provided by Corry Manufacturing Company (Corry, Pennsylvania). As with the machining re-design, the impingement plate design was sent to Corry for review and comment. The comments were then analyzed by Westinghouse and incorporated into the design. By Corry and Westinghouse working together, it was possible to design, build tooling and produce the impingement plates in four weeks.

At the same time that Metem and Corry were completing their projects, Engelhard Surface Technologies (East Windsor, Connecticut) was tasked with developing a TBC application process. While the application of TBC is well established, it was necessary in this case to develop a process to coat blind spots of the part. Normally, the application of TBC assumes that there is complete line of sight to all areas of the part being coated. With delivery schedule for the part already short, Engelhard had to develop the coating process so that it would be ready and qualified at the same time the part modification machining was complete. Once again, Westinghouse and the vendor took a team approach. The only way a coating process could be available in the required time frame was to drive the specification to suit the process capability. By ensuring that the specification suits the process, Engelhard was allowed to concentrate on the application problems and not have to match a process to a general specification.

DELIVERY SCHEDULE

When all is said and done the one true measure of a project's success is at the customer's doorstep. At the beginning of this program a time frame of eight weeks from conceptual design to completion of the machining modification was established as a baseline.

Evaluating the results with respect to the required delivery dates yields some interesting conclusions. The actual time period from original concept drawings being presented to the machining vendor to completion of the first machined production part was nine weeks. At that time, the impingement plates and coating process were also available. While the actual time achieved was one week longer than the baseline, the results did deliver the finished parts for final engine assembly in time to meet the customer need date.

EVALUATION OF PROJECT RESULTS

One of the easiest methods to evaluate the success or failure of a project such as this is to see how many of the original milestones were achieved.

Since at the time of the writing of this paper, the modified engine components have not actually run in an engine, only theoretical performance results are available. Utilizing existing 501F engine data, Westinghouse was able to construct a computer model of the operating conditions for the original 501F Row 2 vane segment. The results of this computer modeling are shown in Figure 4. Figure 4 shows a graphical representation of temperature distribution for the inner sidewall of the Row 2 vane segment. The technical milestone was to reduce the operating temperature in this region of the part. By using the same part operating data but with the modified cooling scheme, the computer model was re-constructed to calculate the expected results. The predicted lower operating temperatures can be found in Figure 5. The resulting lower predicted operating temperature validates the theoretical results of the part re-design effort.

However, even the best theoretical results are of little value if the actual engine components cannot be produced. As can be seen in the actual part photographs shown in Figure 6, it was possible to create a manufacturing scheme to produce the required part. It was further possible to make the modified parts in the required time frame. By these measures, the production milestones of the program were achieved.

A final test of success would be to ask the participants if they would do it again. The resounding answer to this question by all the team members involved was a yes.

CONCLUSION

With the successful delivery of the modified parts, it became very evident that this concurrent engineering/manufacturing approach could be of great value on other projects. It seems appropriate then to review some of the lessons learned by this team.

1) All team members must understand that no matter how well they plan and work together there will be rough spots to get through.
2) Every participant must be pro-active.
3) When problems arise, each player needs to thoroughly evaluate the impact of any corrective action before implementing it. The entire team needs to decide if the results are acceptable before any one player takes action that will impact the project schedule or cost.
4) Let manufacturing and producibility issues drive the design.
5) All team members must be flexible to discuss design needs and problems; a rigid approach by any individual will quickly become a roadblock.

In many ways, the need for the team to be flexible cannot be stressed enough. It must be realized that additional team members or resources may be required as the project progresses. The team must be able to recognize when additional help is needed, and the team must be able to obtain the required capability. If the overall project is to succeed, no team member can be allowed to become a roadblock. The overall project completion is what is important, not necessarily which member is doing the most work or which player is right or wrong.

With the proper team members and management support, this project provided a very good example of what can be accomplished by utilizing concurrent engineering on real life problems.

![Diagram of ORIGINAL INNER SIDEWALL - 501FA ROW 2 VANE](attachment:figure1.png)
POCKET AIR FEED SLOTS
SHROUD COOLING HOLES
RADIAL COOLING HOLES 1 FOR EACH END FACE
COOLING POCKETS AND RIBS
POCKET AIR FEED SLOTS
SHROUD COOLING HOLES

MODIFIED INNER SIDEWALL - 501FC ROW 2 VANE
FIGURE 2
NOTE: FOR CLARITY ONLY THE INNER DIAMETER OF VANE SEGMENT IS SHOWN.
Figure 4
Calculated Temperature Profile for Original 501FA Vane Inner Sidewall
FIGURE 6
CALCULATED TEMPERATURE PROFILE FOR MODIFIED 501C VANE-INNER SIDEWALL
VIEW SHOWING FINAL INSTALLATION OF IMPINGEMENT PLATE AND HONEYCOMB SEAL

VIEW SHOWING THE FINAL APPLICATION OF THERMAL BARRIER COATING

PHOTOGRAPHS OF COMPLETED 501FC ROW 2 VANE SEGMENTS

FIGURE 6