Visit to Ishikawajima-Harima Heavy Industries (IHI) Aero-engines Div. Tanashi Plant, July 16, 1991

Background

My hosts were Mr Nakajima (now at the Mizuho plant) and Mr Ochiai. Both are managers of Production Engineering Departments at their respective plants.

IHI's main business is shipbuilding and heavy construction. Aircraft engines are a small part. The aircraft engine division has 3600 employees and sales of over $1 billion. IHI built Japan's first jet engine during the war, making the first test flight in a small fighter plane in early August 1945. Since then IHI has designed only three engines on its own (plus many research and development engines), relying mostly on manufacturing licenses from General Electric, Rolls-Royce, and Pratt&Whitney for most of its production. Products include aircraft engines, stationary gas turbines for generating electricity, gas turbines for ships, and rocket engines for space. Including several wholly-owned subsidiaries, IHI can produce all of the main advanced technologies required for such products, including intricate investment castings and single crystal or directed grain castings of turbine blades, numerical controlled machining, FMS operation, laser welding and cutting, and some composite materials for nose cones that are transparent to infrared rays. They are especially proud of their ability to laser weld titanium. IHI is also a prominent participant in Japan's proposed Space Station module.

The shop is well equipped with modern equipment, mostly of Japanese manufacture, including several Toshiba 5 axis NC machines of the type sold to Russia, some Huffman laser drilling machines, and the most modern Messer Griesheim e-beam welders. The FMS for aluminum parts comprises 5 Mitsui-Seki machines that run 24 hours/day in a temperature-controlled room.

Software in Use

I was shown two examples of computer use, a shop floor scheduling system they wrote themselves, and CATIA for CAD.

<u>Shop Floor Scheduler</u>

The shop grinds surfaces and dovetails of turbine blades and has about 100 workstations. There are at least 100 kinds of blades and about 300 blades in each batch. The shop handles more than 300 lots per month according to Mr Shibata, who demonstrated the software. It takes about 4 months to process a lot. Each blade apparently requires dozens of work steps. We noted that some of the jobs currently in the shop are 50 to 75 days late and scheduled to stay that late or get even later. The usual response in such situations is to send some work outside, but IHI hopes the scheduler will permit them to improve efficiency and keep the work in-house.

The scheduling system was installed in April, 1991 and they are still improving it, assessing how well it works and learning how to use it. A major feature is its excellent user interface, permitting the shop supervisor to view data about jobs pending or in progress from several viewpoints: by job, by batch, by job step, by machine, and so on. Clicking the mouse on a job reveals a window containing the details of the process. Thus the progress of the job or the scheduled job sequence planned for each machine can be viewed easily.

The objective of the software is to decide which machine should do which task step on which batch next. Different batches are waiting for machines, and different machines, capable of doing only some of the pending tasks, are waiting for work to be assigned to them, while other machines are still busy. The task of the software is "resource selection and task assignment," a familiar task in management science algorithms. Typical criteria are to minimize the lateness of the jobs and/or to minimize the idle time of the machines. Occasionally a special high priority job must be wedged in.

The software was written using a commercial expert system shell to which IHI added its own rules. A clear explanation of how it worked was not available but apparently it runs a number of simulations to verify its predictions. It first assigns jobs without regard to capacity limitations of the machines. Then it tries to shift work from overloaded machines to underloaded ones. Finally, it identifies jobs that cannot be assigned and puts them in a group to be assigned to outside contractors. This appears to be an imitation of how the human schedulers run the shop and does not utilize any of several algorithms in the scientific literature that could potentially solve this problem better.

CAD and CAE

Design is almost 100% paperless in the engine department. CATIA is used for 3D modeling, and CADAM and micro CADAM are used for drafting. The usual CAE functions, such as mass and inertia properties, are done with CATIA. CATIA is also used for making nice pictures to show top management and customers. Piping design and interference analyses between pipes and engine structures are done in CATIA. Data are transferred to SDRC's solid modeler for thermal and stress analysis. CATIA is also used for preparing NC programs. However, the data created by engineer-designers are not sufficient for NC programming and must be augmented. But modifications are difficult because CATIA NC output is not as easy to edit as APT, which has a simple line-by-line format. Also, I was told that CATIA's surface modeling capability is limited since surfaces tend to come out with low amplitude, low frequency waves.

Facilities consist of a Fujitsu supercomputer and a mainframe for supporting aerodynamics, structural and stress analyses, plus an IBM 3090 and 50 graphics terminals running CATIA and 100 PC's running microCADAM.

Today's applications for CAE are structural analysis, weight and moment analysis. Future applications are interface between engine and airframe, assembly procedures and instruction manuals, and a link to CAM.

Medium term they are rethinking the information flow in the design process, hoping to shorten the path. At the moment, parts such as blades are designed in 3D and then 2D drawings are made. In the shop, these drawings must be reconstituted into 3D data so that a workplan (NC programs) can be made.

Longer term they are hoping to create optimization methods for designing blades, disks, and shafts. (GE already does such things either routinely or in their design R&D lab.)

They wish 3D modeling could support dimensioning and tolerancing, and have kept to 2D drawings because of their ability to represent such information. None of my hosts are aware in detail of the extensive CAD/CAE/CAM developed in the auto industry, although they have seen some things demonstrated at trade shows. They are afraid of in-house software development since they think it would be hard to maintain and improve the programs.

In addition, in spite of many years of cooperation between IHI and GE, the IHI people were unaware of the DARPA/DICE project on Concurrent Engineering. GE is a major participant in this project and design of turbine blades is an important demonstration of DICE capabilities.

Product Design Methodologies and Long Term Developments

Even though use of computers in the design process at IHI is a bit behind the state of the art, Mr Nakajima is a careful thinker concerning organization of design processes. He shares Nissan's view that overlapping of tasks is essential to shortening the design cycle, and cycle shortening is a prime objective for IHI. Mr Ochiai feels that having a common database without transcription errors is just as important if not more so.

At present, they are using the development of the new HYPER 90 engine as the base project for design process improvements. This engine design is being funded by MITI and involves many Japanese and foreign companies. A hypersonic civilian transport plane is the eventual target. IHI wants to shorten the development time from a typical 30 months to 20 months. Note that this time is a very small part of the time needed for R&D of a new kind of engine, which, together with manufacturing development and certification, can take up to 8 years.

IHI wants to use the methods and technologies of Concurrent Engineering to achieve this time reduction. The basic approach is, as stated above, to overlap the tasks of design, process planning, and manufacturing development. The most important action is to make sure designs are evaluated promptly for their impact on manufacturing, assembly, cost, and quality. Second, IHI must make a direct link between CAD and CAM. Third, they must improve overall data management, including learning how to manage approval of issuing partial information in an overlapping job environment and how to organize feedback and design critiques that are based on partial information.

An essential element in Mr Nakajima's approach is to restructure the design process to optimize the flow of information. Last year at the Japan-USA Manufacturing Research Exchange, Mr Nakajima presented the following 4-step methodology for finding a good sequence of design tasks:

1. Analyze the steps in the design-development process, find out how long each step takes and what their precedences are, and determine the critical path.

2. Subdivide the steps on the critical path and carefully determine information precedences for the newly subdivided task steps.

3. (Somehow) rearrange the sequence of these steps in view of the information available upstream that is needed downstream.

4. Determine the new length of the critical path and repeat steps 1 - 3 until the best arrangement is found.

Mr Nakajima had no plans to use any computer aids in this activity except for conventional critical path analyses.

As of this year, the methodology presented by Mr Chikata for use on the HYPER 90 project consists of

1. Find critical path as above.

2. Analyze information flows as above.

3. Begin ordering long lead time items and designing tooling and fixturing before design is finalized, using smarter awareness of when critical information is available and guessing the rest.

4. Link CAD data to CAM.

This is a very pragmatic reduction of last year's approach and seems driven by the needs of the HYPER 90 program. The more intellectual approach outlined last year still seems to be under consideration but in the background.

Also under study or active development are

• a version of feature-based design that implements generic pieces of geometry that the designer modifies to suit his needs

• a computer-aided process planning system that uses such features and a group technology segmentation of their parts plus knowledge of expert machinists. This is written in OPS 83 and features easy entry of tabular process data by the designers themselves, since IHI has no knowledge engineers. A major objective is to extend their current ability to sequence single machining cuts into the ability to plan the sequence of major operating steps such as cut, measure, heat treat, and so on. Choice of the last operation to guarantee part quality is an important element of such plans.

• automation of optimized blade design, including direct data transfer between aerodynamics, stress/thermal analyses, vibration, and preparation of process instructions and NC programs, with the goal of reducing blade design time from 6 months to 2. Right now 80% of the time goes to obtaining, translating, and verifying blade shape data from aero design to structural analysis!

Stated only obliquely but clearly on their minds is the shortage of engineers and the need to leverage the experience of their senior people. Much as labor shortages have forced automation of manufacturing, engineer shortages are forcing automation of design processes.