Progress and Potential in Agile Engineering for Turbomachinery

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CONCEPTS NREC

1. Introduction : *Undercurrents*

- Engineering design is changing very rapidly
- These changes can be quantified
- The modern engineer must be a manager of advanced technology, not a number cruncher
- Design is subject to performance, life, size, weight, cost, & acoustics criteria: multi-disciplinary optimum
- A new design cannot fail, it must succeed in the market
- Narrow based black box design just over the horizon
- Design and have fun

New Product Evolution

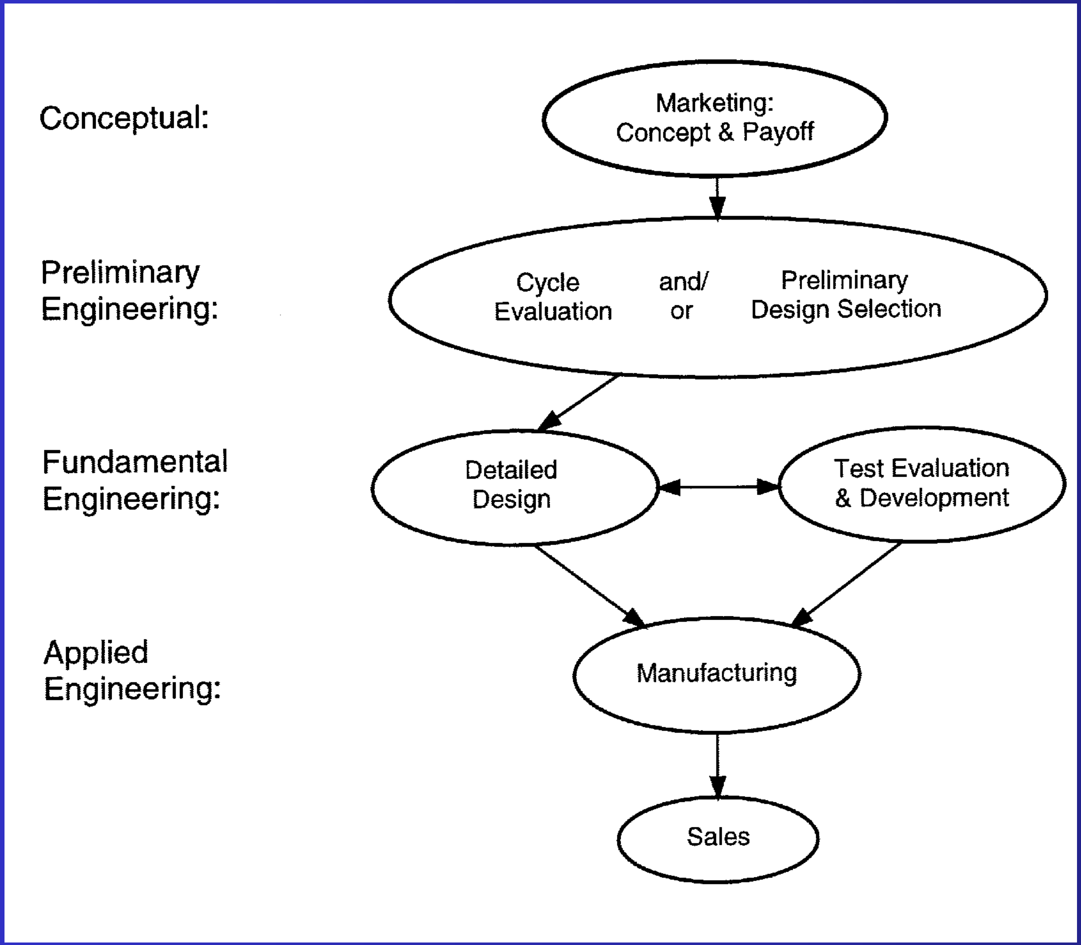

Figure 2. Evolution of a turbomachinery product.

- Four basic steps
- Involves diverse technologies and procedures
- Turbomachinery world has changed dramatically
- Agile Engineering^{SM}; concurrent & seamless
- Large companies are adopting due to cost of development

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3. AGILE ENGINEERING℠ TODAY

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AGILE ENGINEERING℠ :

Agile Engineering℠ is a concurrent engineering process that uses well integrated, user-friendly, task specific design tools to cover the broadest set of technological disciplines including educational needs. The seamless interconnectivity of all tools required by an engineer in a specific process is required. Consequently, Agile Engineering℠ improves workplace efficiency, design team effectiveness, and overall profitability.

Agile Engineering℠

Consider Figure 3

- –a total system
- –each part is a common process today
- –seamless flow and control is achieved via OLE
- –fast preliminary studies can be conducted
- –detailed, comprehensive final designs are effected

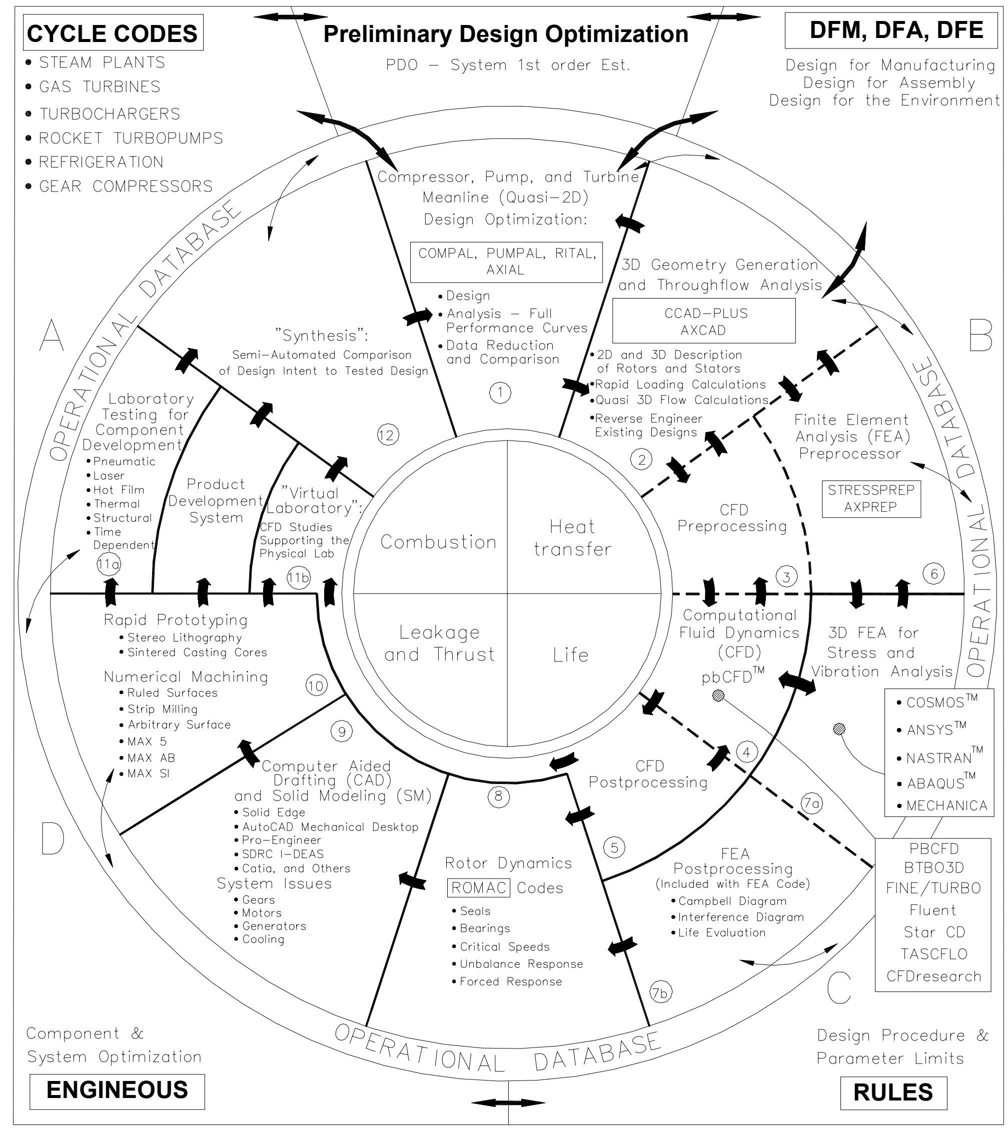

Figure 3. The integrated turbomachinery agile engineering design and technology system.

CONCEPTS NREC

Agile Engineering℠ (2)

- The modern engineer must be a manager of advanced technology, not a number cruncher

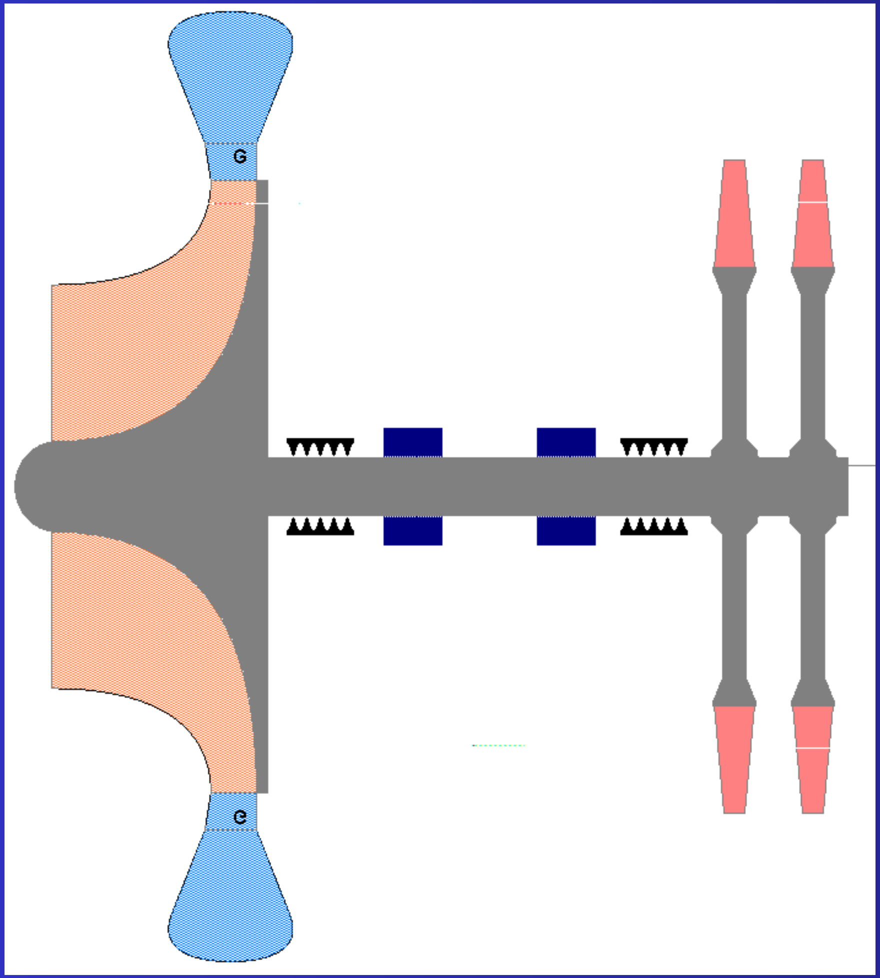

Figure 4. Possible 2D graphical view of first generation PDO code.

PDO may emerge as a real time saver for new product layout and concept development

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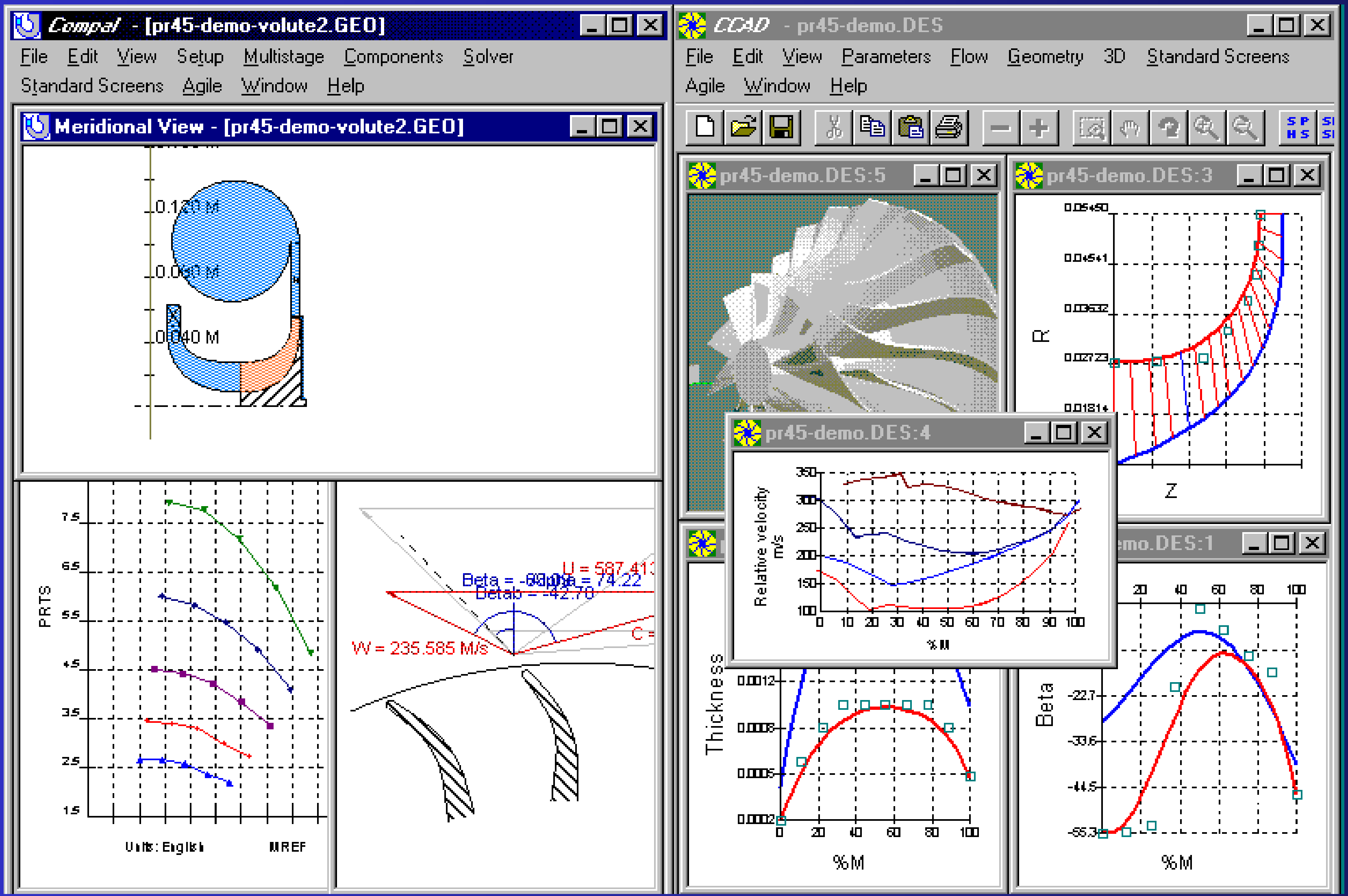

Figure 5. A modern compressor or pump agile design suite.

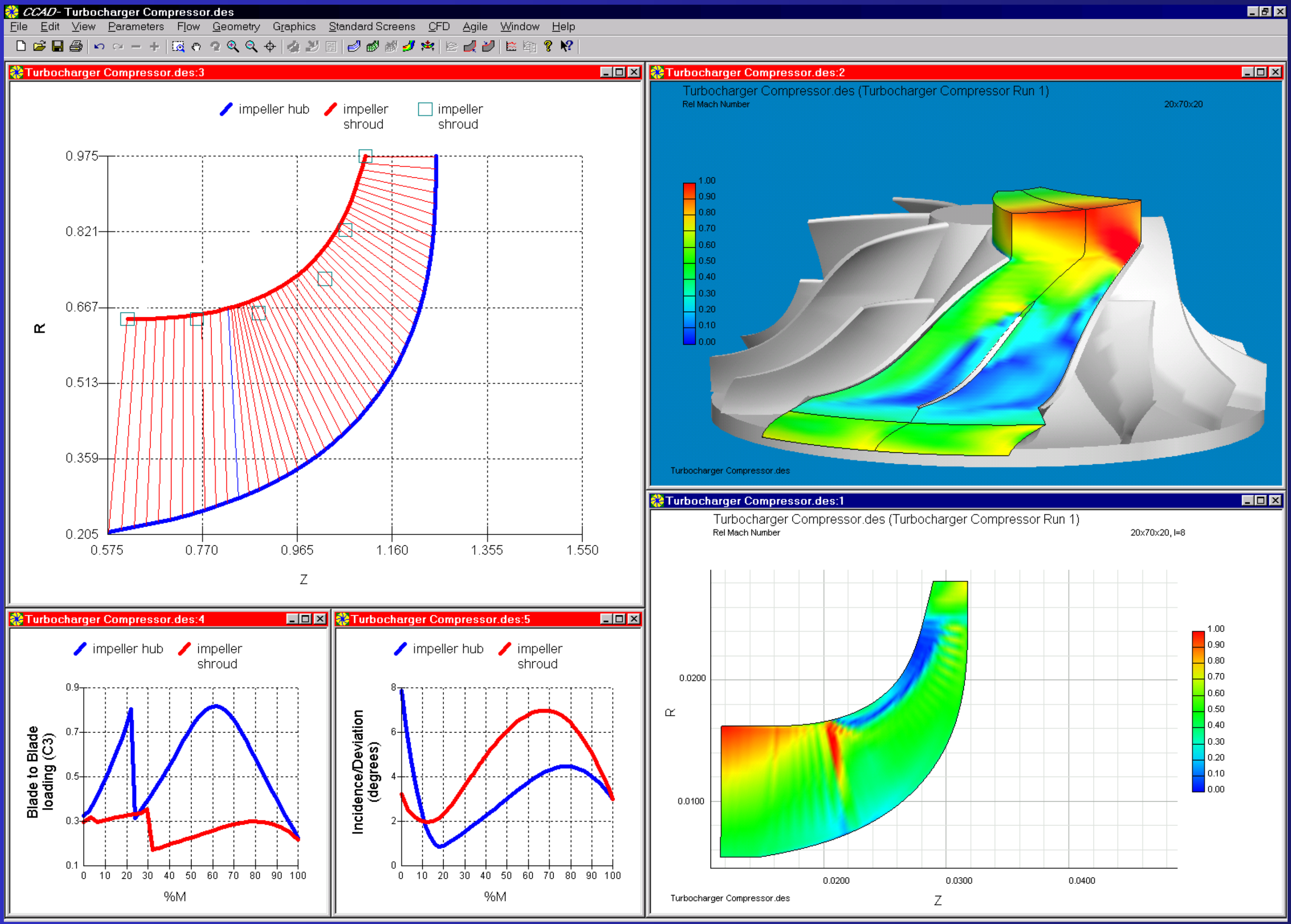

Figure 6. OLE interconnected blading design and CFD analysis.

CONCEPTS NREC

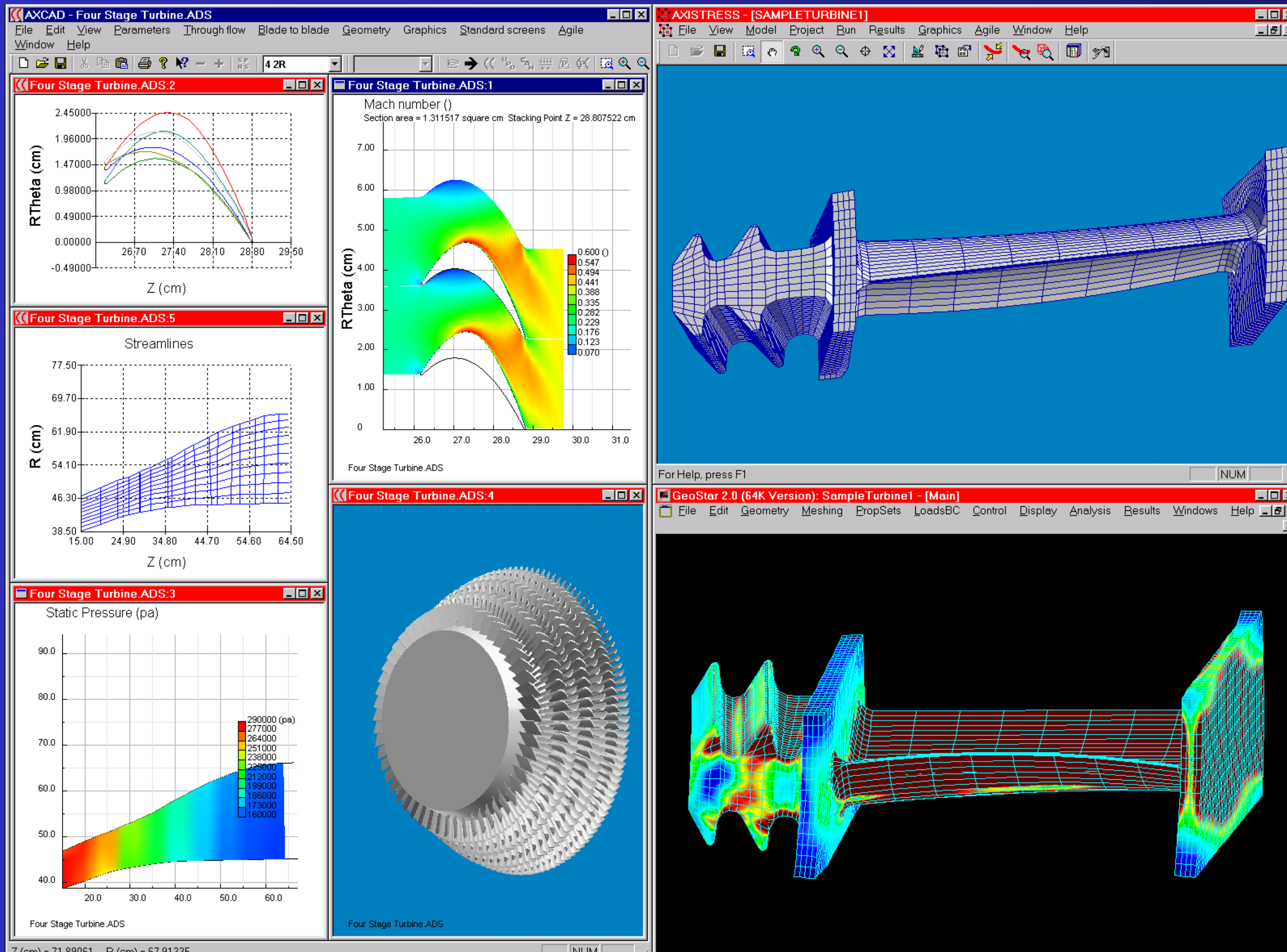

Figure 7. OLE interconnected blading design and stress analysis.

CONCEPTS NREC

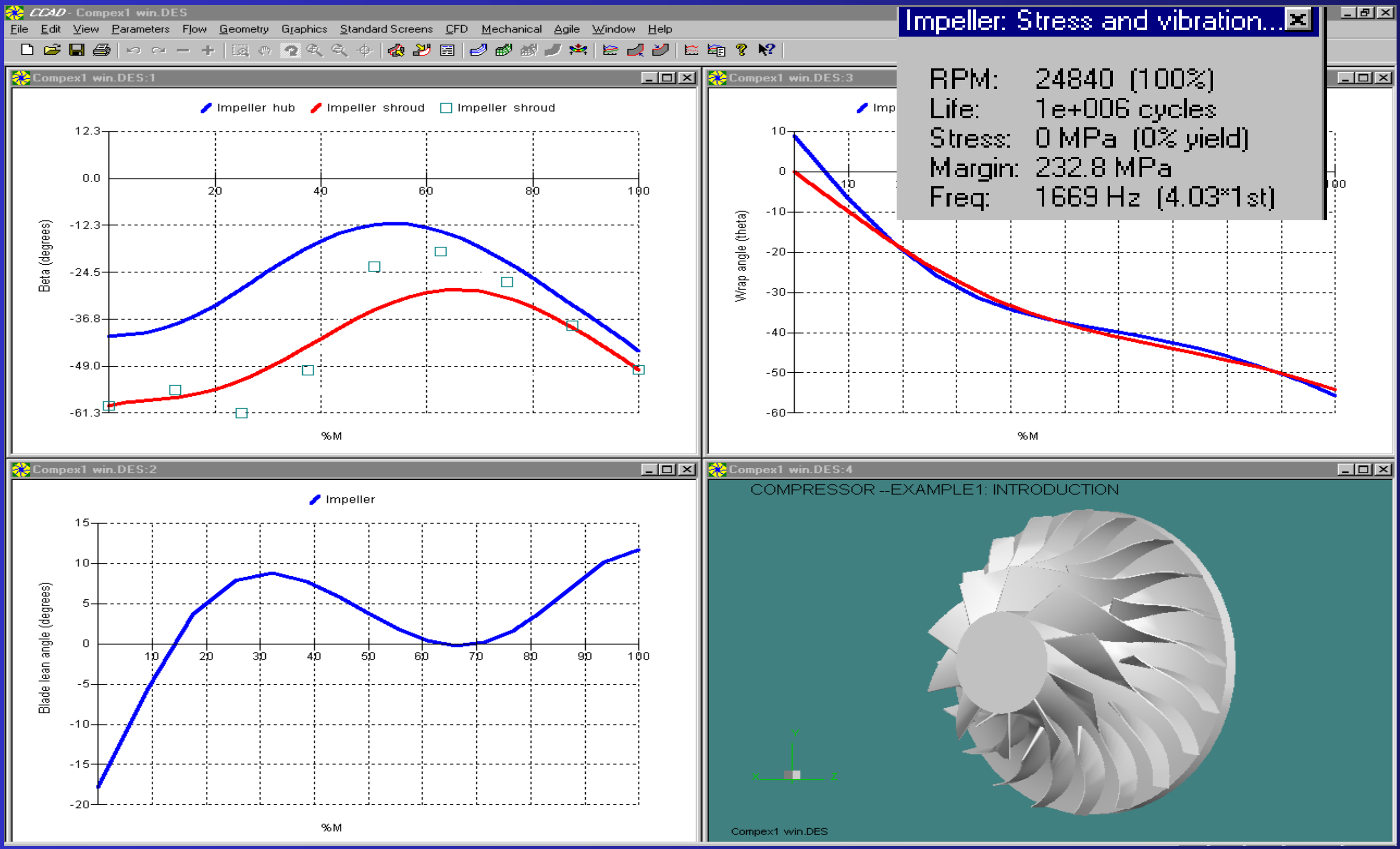

Figure 8. Blading design with persistent structural or life calculations as inset.

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Agile Engineering^{SM} (9)

- Rapid prototyping is a key to modern system development
- Includes NC machining and stereo lithography plus numerous other methods
- See Figures 9 , 10 and 11

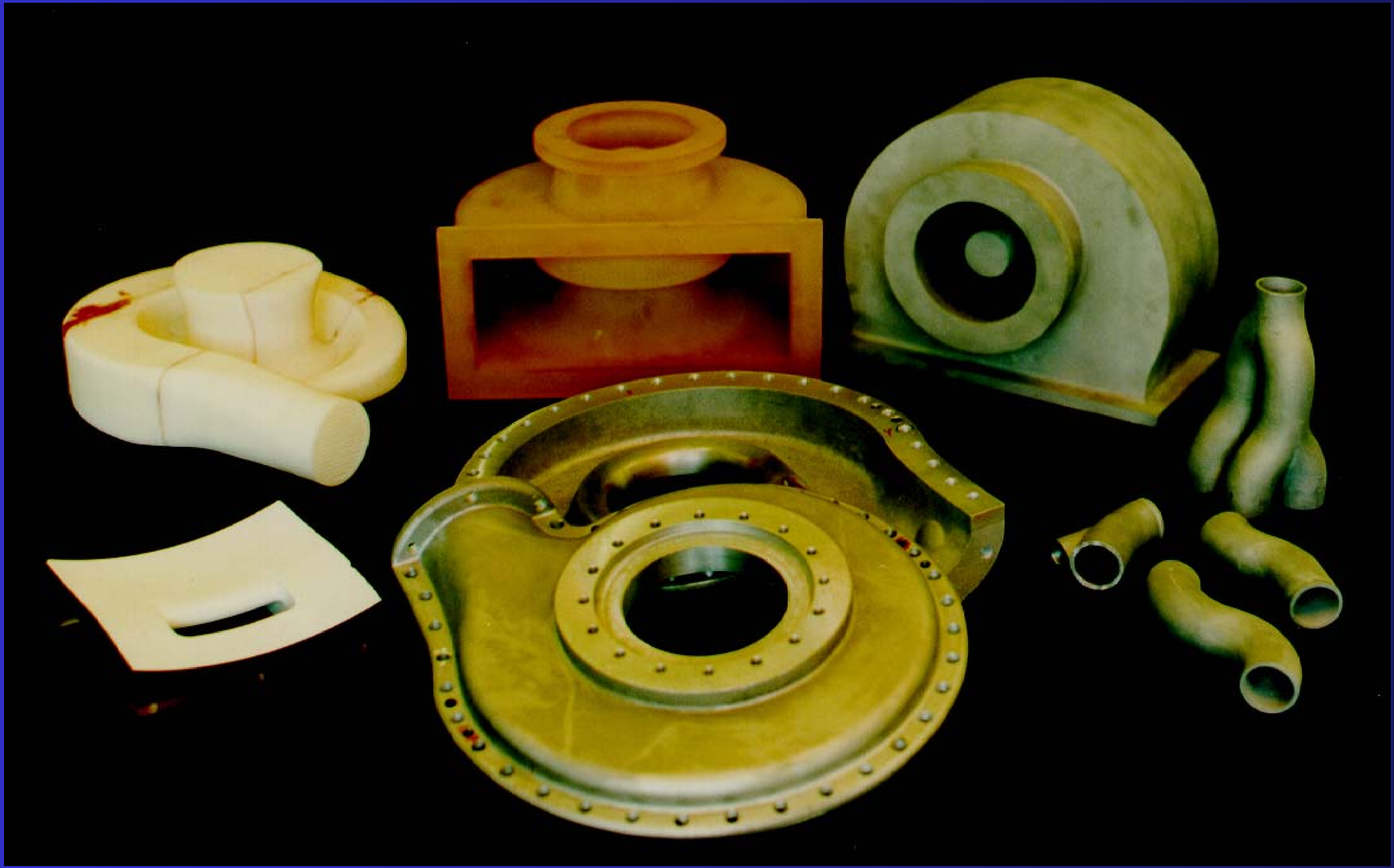

Figure 9. Rapid prototyping of various turbomachinery inlet and exhaust 3D devices. Such technology greatly reduces the time from concept to working prototype.

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Figure 10a. NC machining is cheap, extremely accurate, and comparatively easy to integrate into the development process.

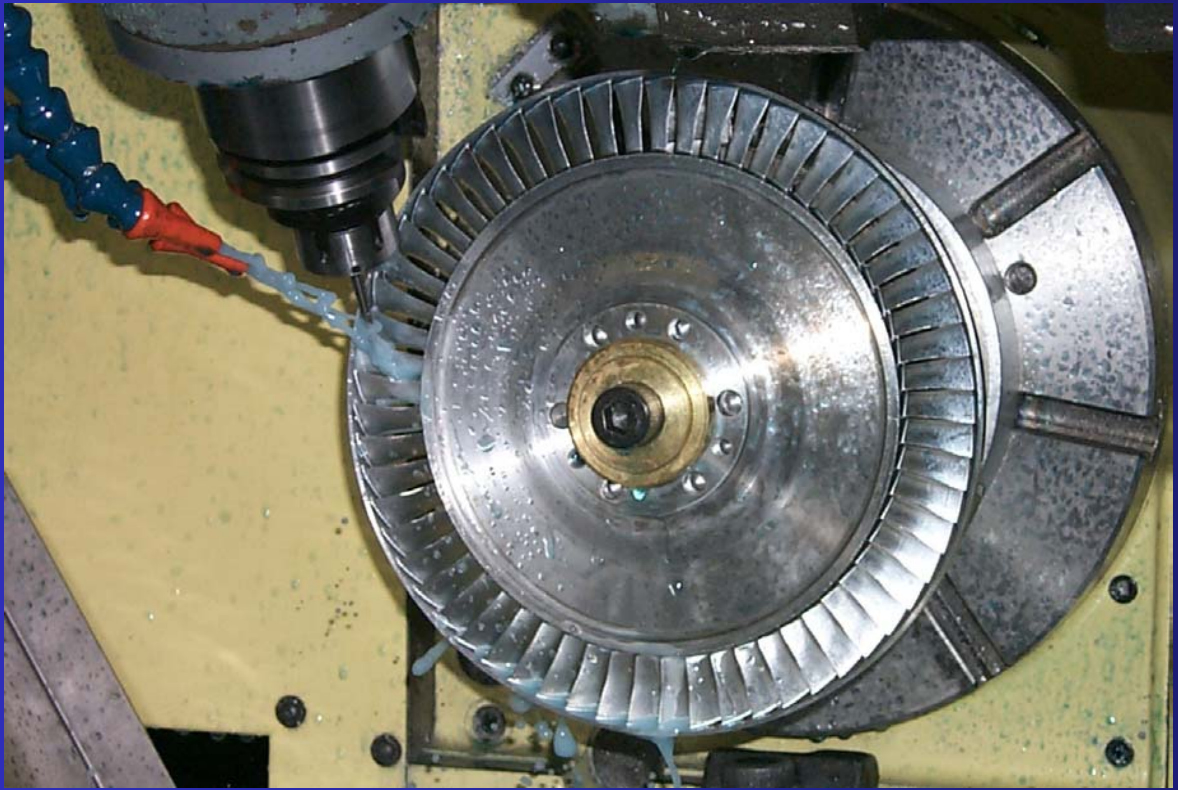

Figure 10b. Advanced NC machining of an axial turbine blisk using MAX-SI.

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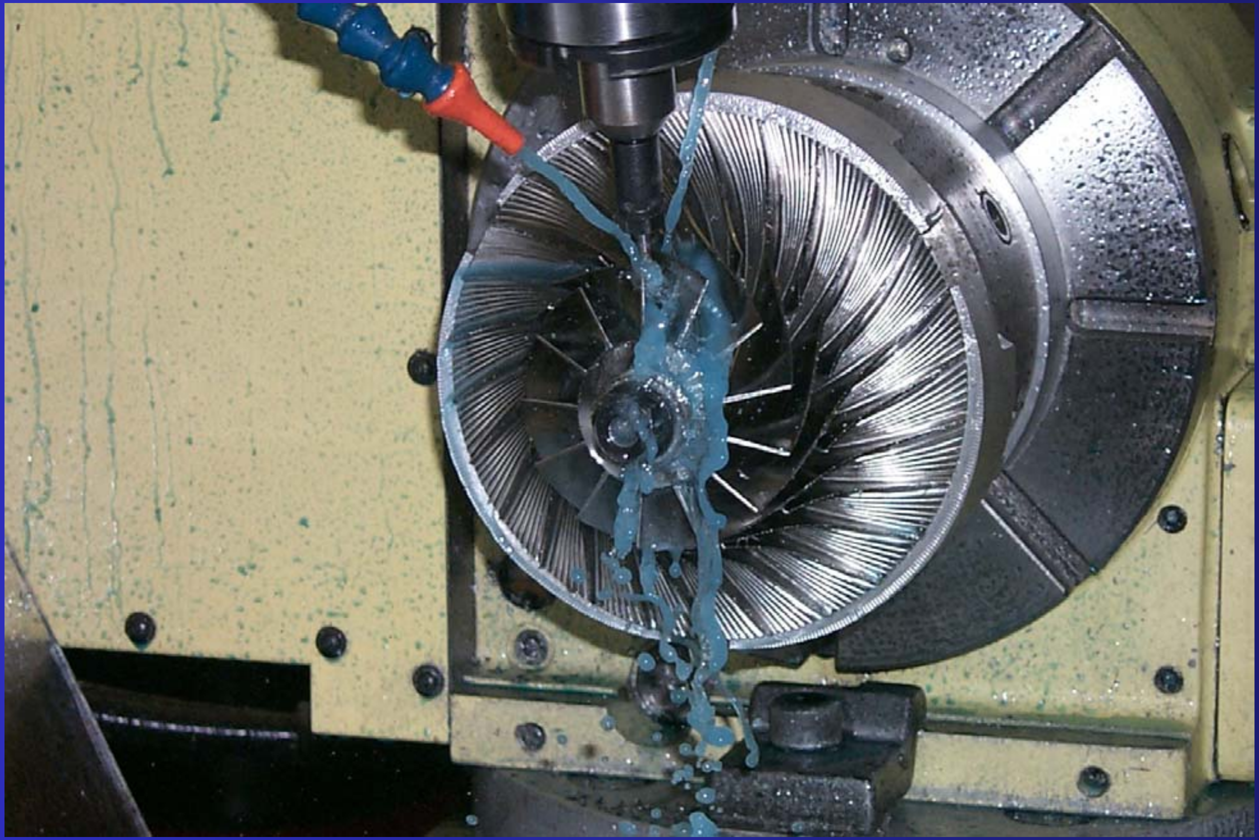

Figure 11. Conventional flank milling of an advanced centrifugal compressor using MAX-5.

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Agile Engineering^{SM} (10)

- The performance design world needs extended graphics
  - Need to click and drag and create a window with automatic pbCFD on any segment of a layout to study local flow phenomena
  - Complex casing parts must be included for stress and thermal analysis

VITALITY IN THE CONTEMPORARY MARKETPLACE

AXIOM: A wise designer will track the eventual cost of a product from onset to market entry.

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DFM/A: Design for Manufacturing/Assembly - 1

- A protocol widely used for mass production products.
- Now being adapted for ‘engineered products’, i.e., low volume production with a specific engineered purpose.
- Precise costing will be possible.

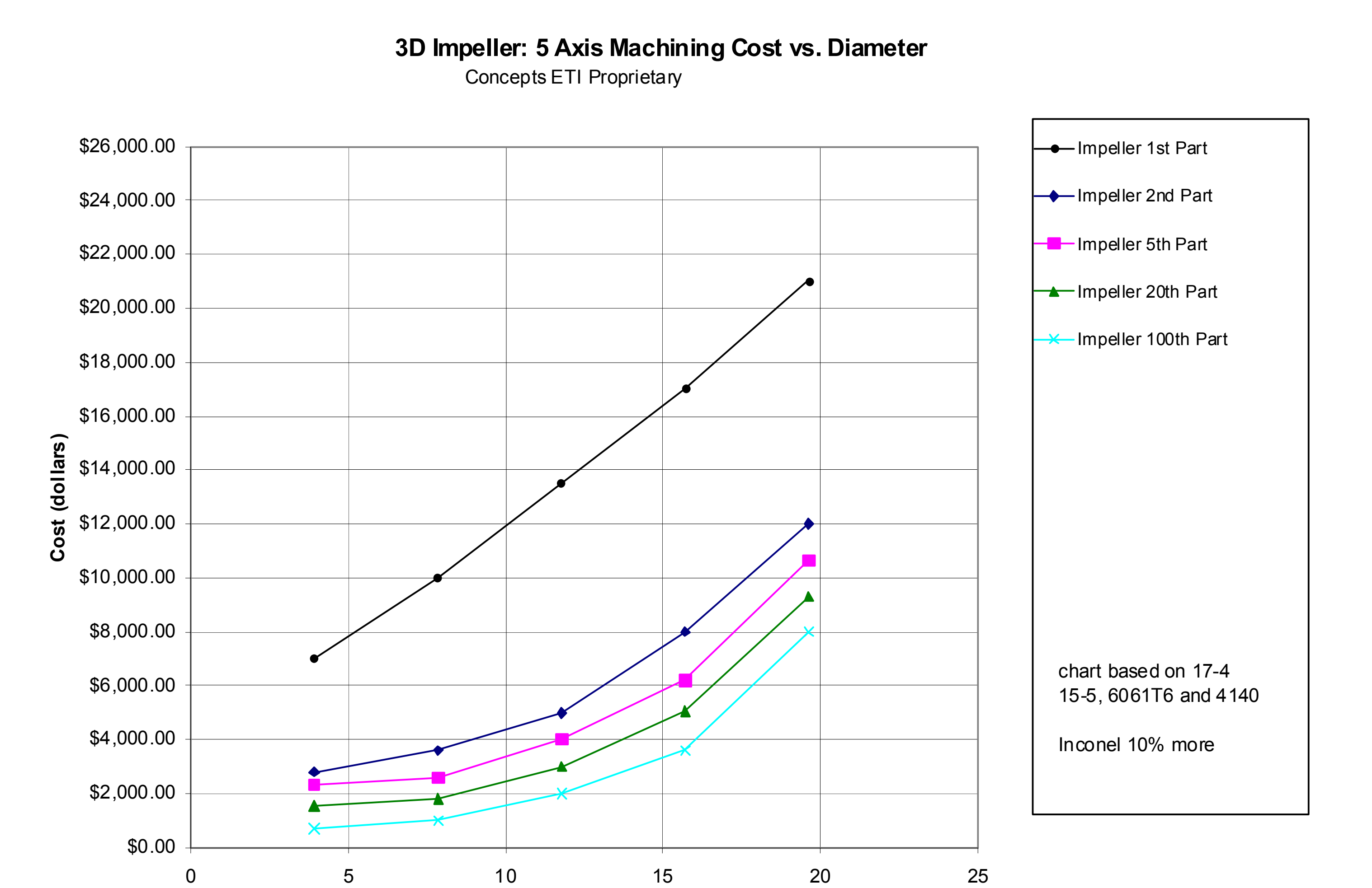

Figure 13. Fabrication costs of 5-axis NC machined radial flow open impellers (excluding inducer pumps) for 1st through 100th part.

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DESIGN FOR ASSEMBLY STRUCTURE CHART REPORT
Boothroyd Dewhurst Inc. knight
Turbopump Assembly (PUMP_DFA)

Date of printing 1:30pm Tue. Aug25, 1997

=Part =Subassembly/PCB =Operation =Excluded =Children hidden =Children visible

Time shown in seconds,filter:None

(1) Turbopump Assembly		3856.51
1.1 main shaft	1	3.45
1.2 (2) Housing, Fuel Pump assembly	1	22.50
2.1 Housing Fuel Pump	1	11.20
2.2 Reorientation	1	4.50
2.3 Shroud, Stationary Fuel Pump	1	9.00
2.4 Screw 100° CSK	20	184.00
2.5 E-ring, metal	2	23.74
2.6 Reorientation	1	4.50
2.7 (3) Housing Assembly, Turbine	1	17.10
3.1 Discharge Flange, Turbine	1	6.70
3.2 Nozzle Ring, Turbine	1	6.70
3.3 Casting Manifold T.I.	1	14.90
3.4 Reorientation	1	4.50
2.8 Bolt, Radial attachment	12	30.40
1.3 Reorientation	1	4.50
1.4 (4) Turbine Disk assembly	1	9.00
4.1 Shroud, Turbine	1	5.70
4.2 m/c cut seam weld	1	15.30
4.3 Turbine Disk	1	9.00
4.4 Pin Dowel	4	13.52
1.5 Bolt, Tension	4	45.50
1.6 E-ring, metal	1	8.57

Figure 15.
A sample page printout from the DFA analysis of a rocket turbopump.

CONCEPTSETI

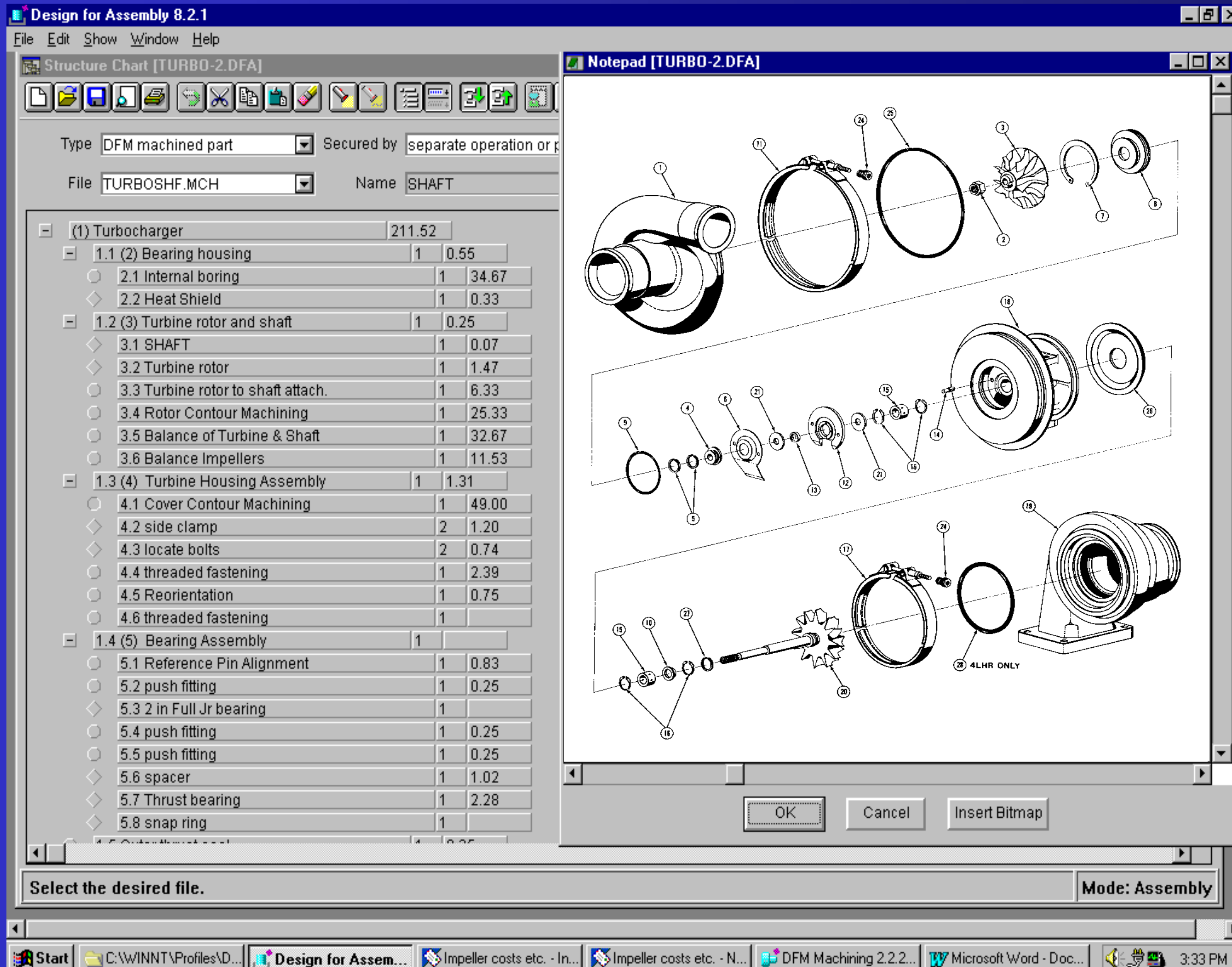

Figure 16. DFM process selection of all components as a function of production run size (data necessary for low volume – 2 or 3 up to several hundred – ‘engineered products’).

CONCEPTS ETI

4. A TEST OF AGILE ENGINEERING

A live design, build, and test seminar

November 16-20, 1998

In 3 days a stage was designed, built and tested including traversing

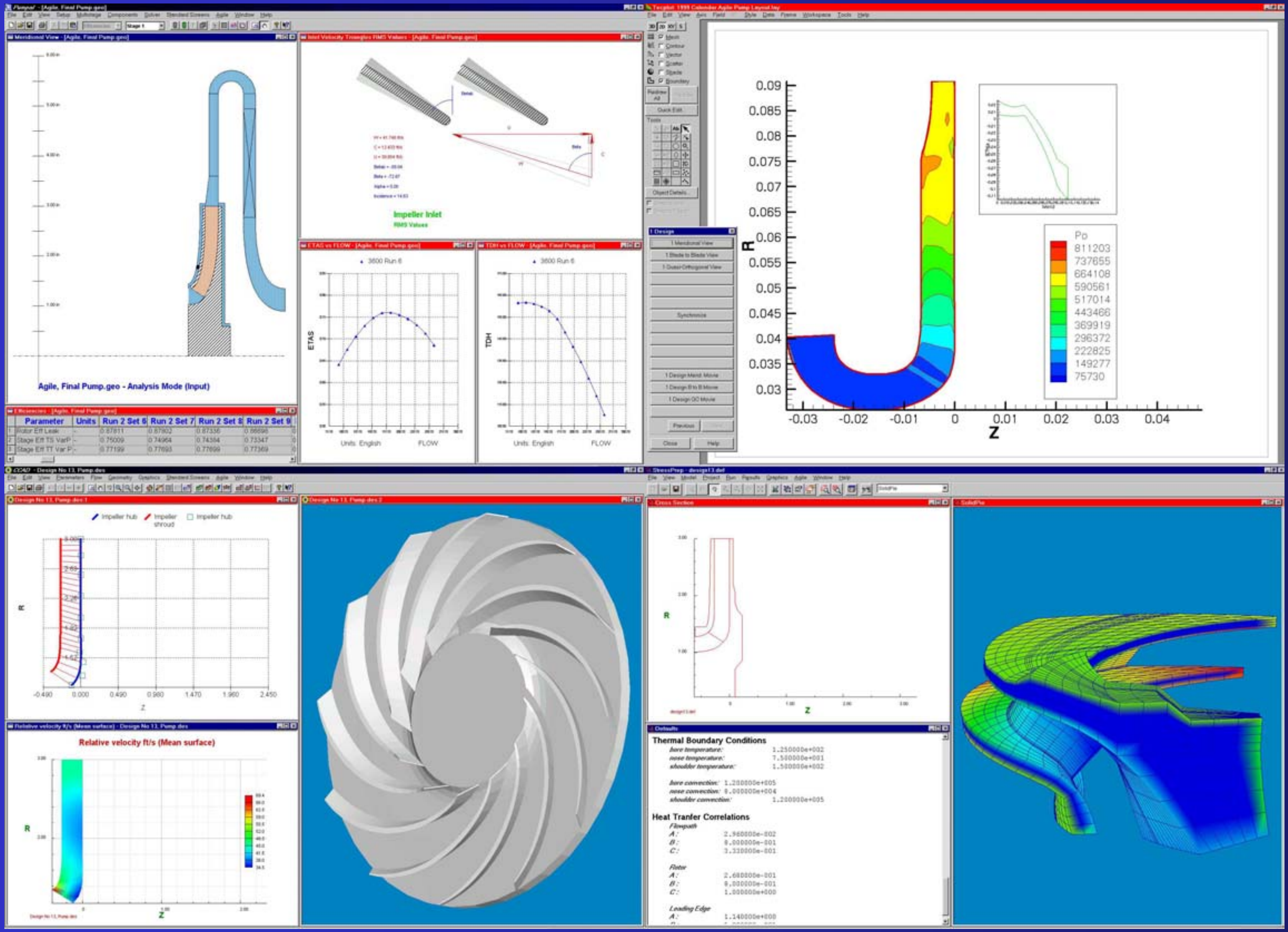

Figure 17. Agile linking (via OLE) of meanline calculations with blading calculations, with CFD calculations, and with structural calculations; the linking shares common data and allows control from one code over another.

Agile Engineering Seminar - 4

- Baseline performance established from variable Reynolds number gas-dynamic rig and from pump rig at 0.75 (efficiency) before 11/16.
- Current performance now at 0.80 level of efficiency.
- Seminar rich in data, insights, training.

5. FUTURE DEVELOPMENT AND ECONOMIC EVALUATION

Future Development & Economics

- Figure 18 shows cost history
  - dotted lines essentially from 1993 publication
  - there has been a dramatic drop in eng. cost
  - more cost reduction is to be expected

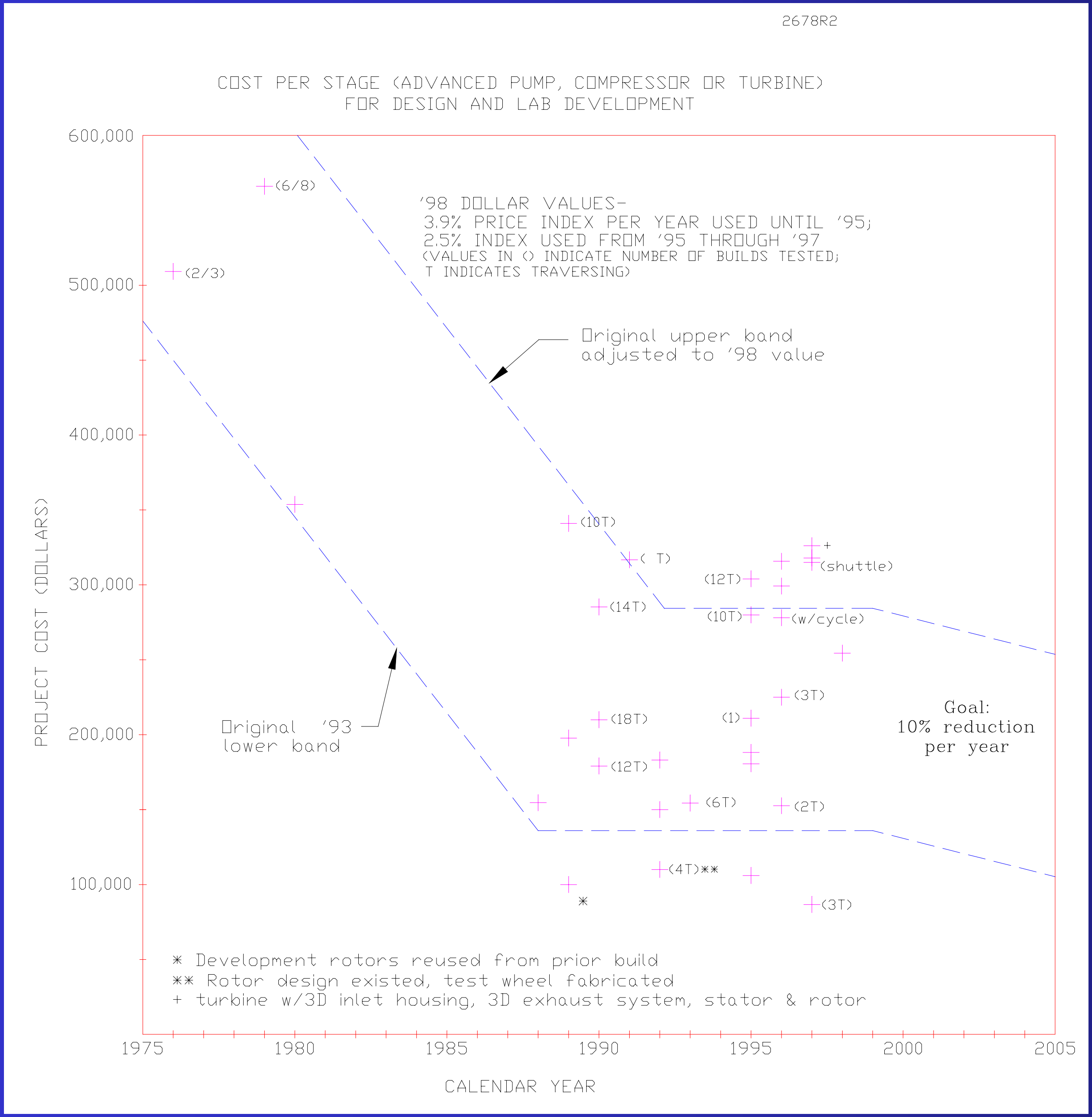

Figure 18. Turbomachinery stage cost reduction (late 1970s to late 1990s) due to Agile Engineering[SM]. Further reduction in costs anticipated.

6. Validation

VALIDATION - 1

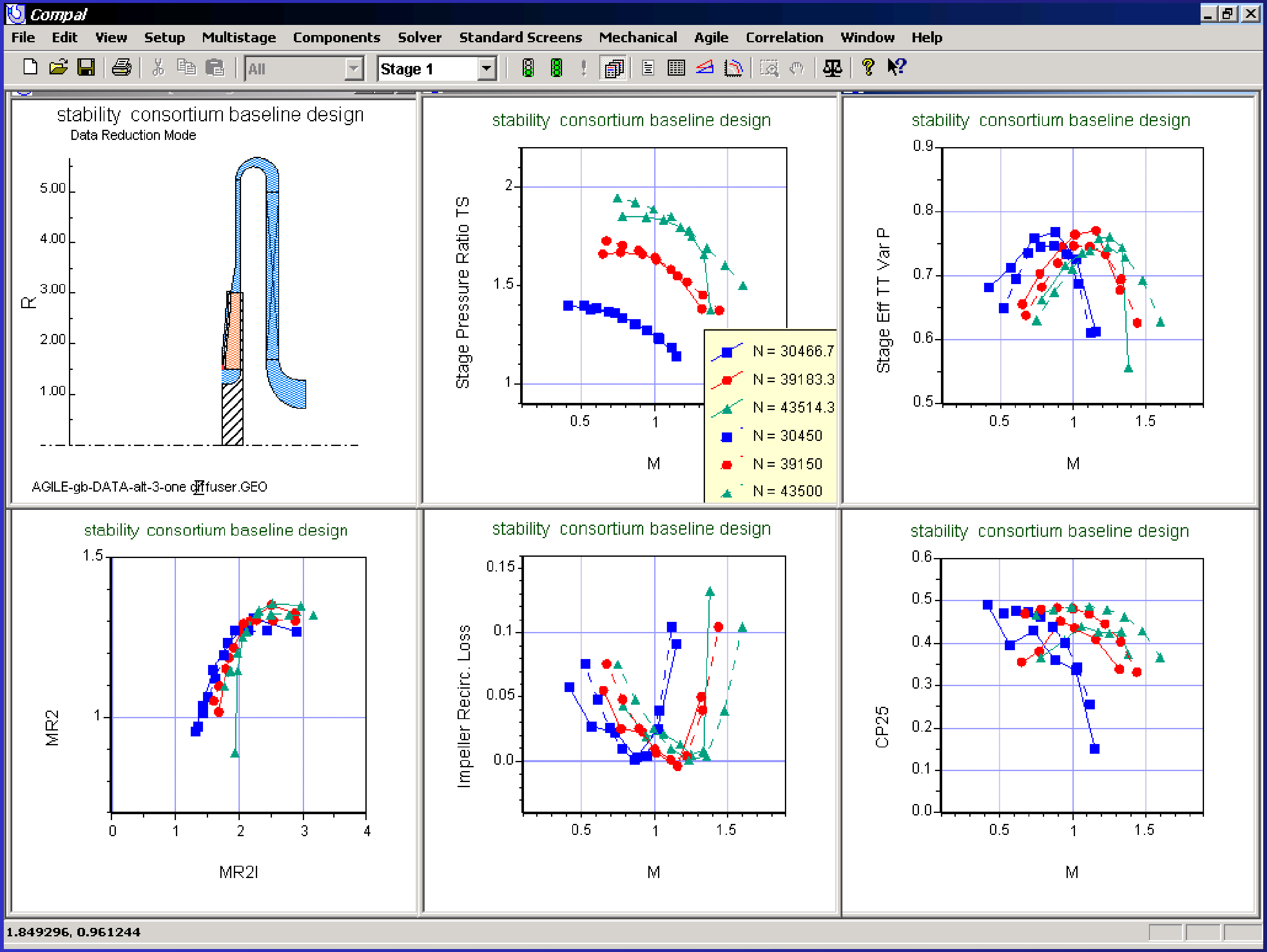

Figure 22. A comparison of meanline modeling (dash lines) and measured data

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VALIDATION - 2

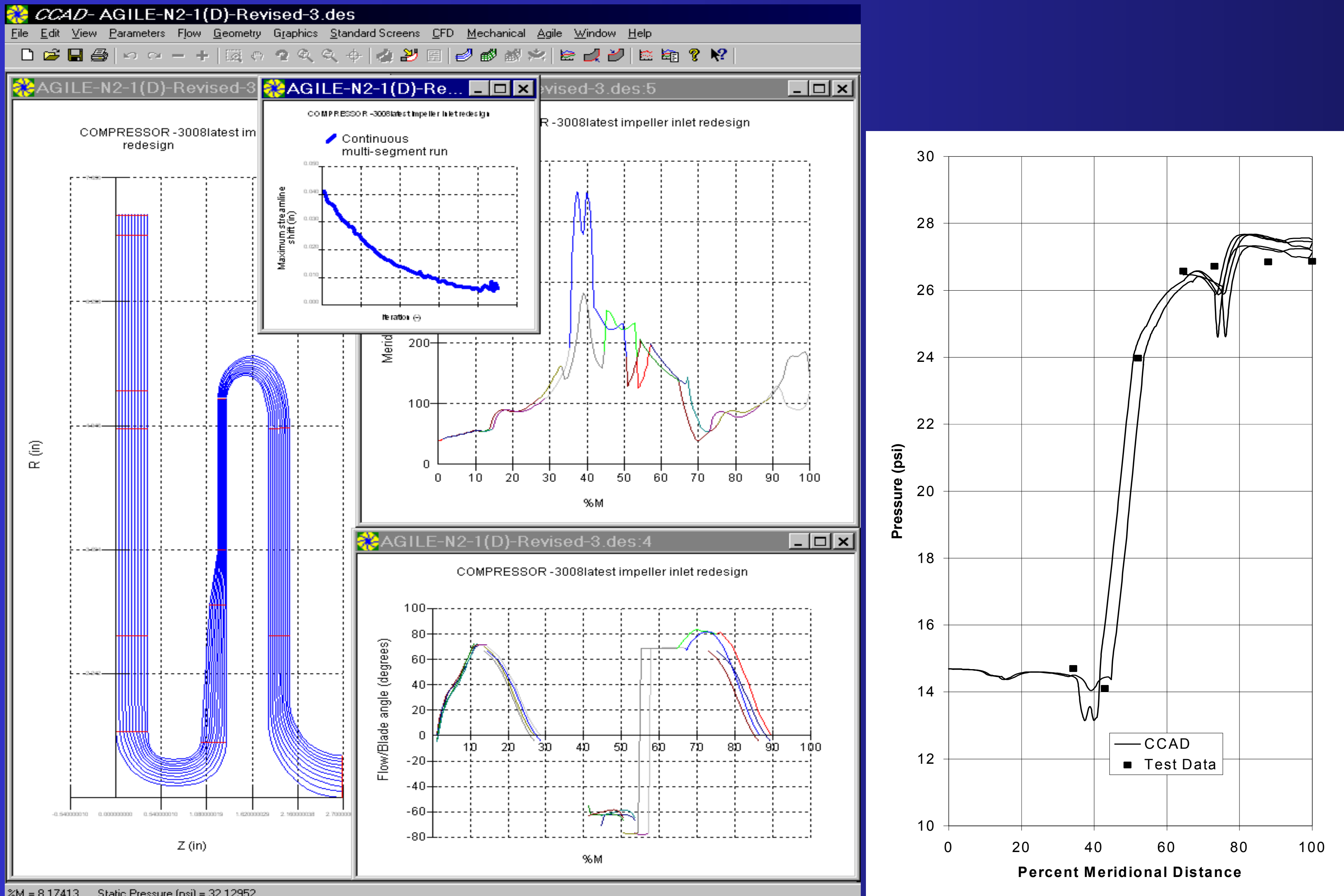

Figure 23. Continuous multi-segment streamline curvature calculations for eleven elements

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VALIDATION - 3

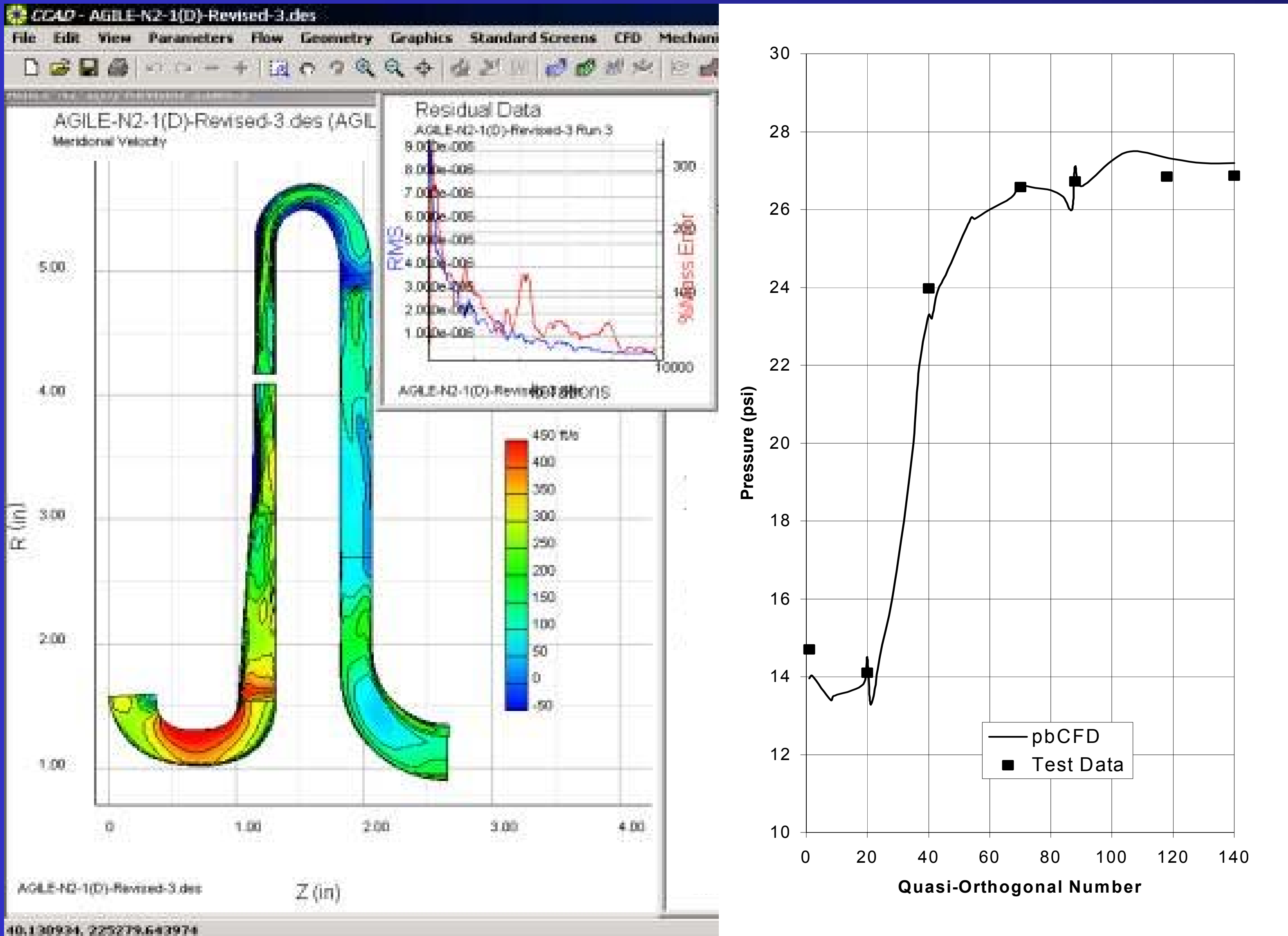

Figure 24. Complete stage CFD calculations for the industrial compressor stage.

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VALIDATION - 4

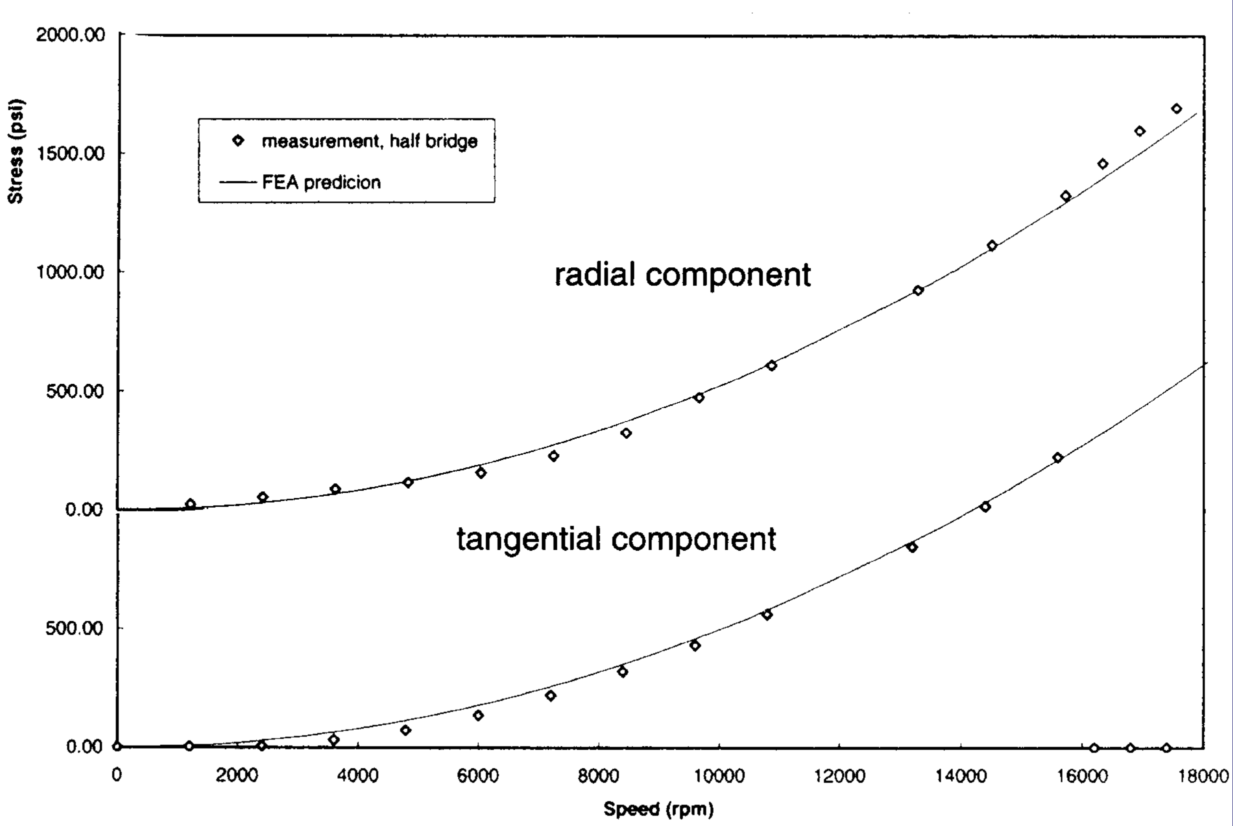

Figure 25. An example of validation for structural needs: a comparison of both a radial and tangential component of stress measured in a rotating impeller using telemetry compared against finite element stress calculations. Both the finite element grid breakup, as well as the solver, are apparently working quite well.

DESIGNING WITH BUSINESS MODELS

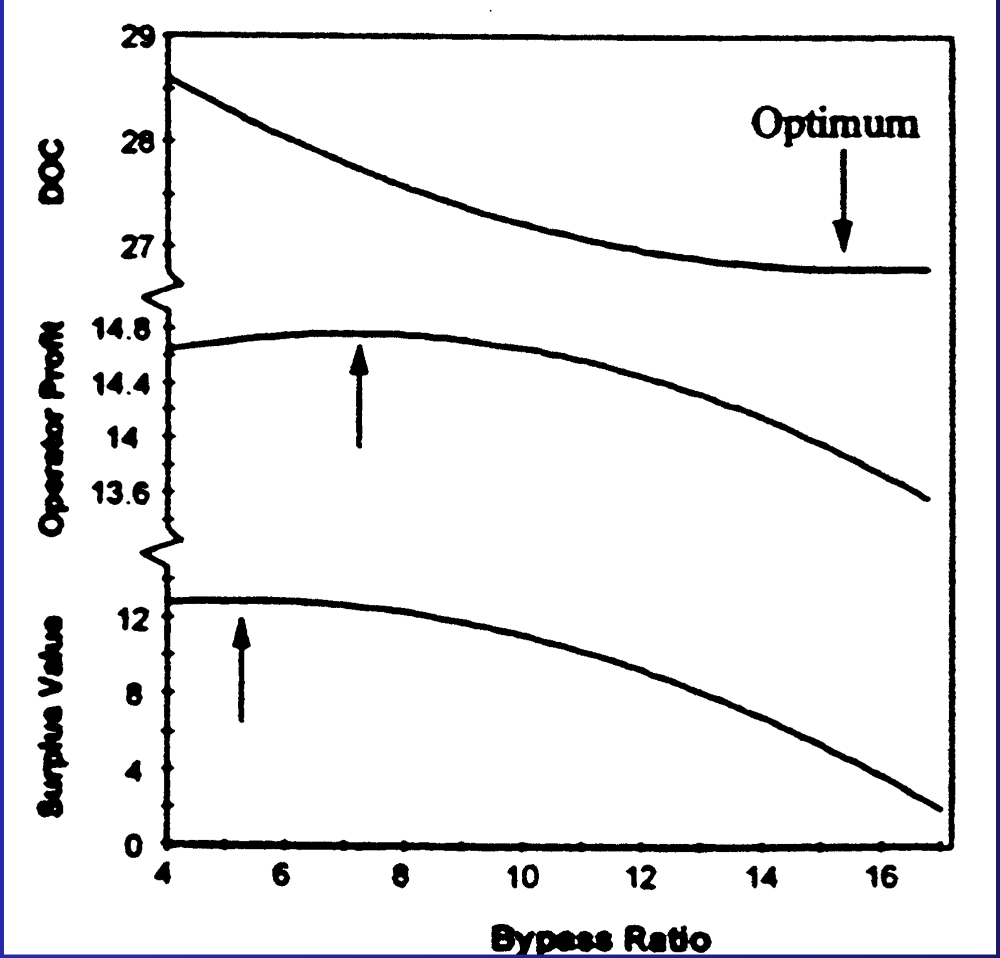

Figure 26. Impact of designing to maximize surplus value.

7. EXPECTATIONS FOR THE 21st CENTURY

21st CENTURY

- Broad based black box design:
  - not for a long time to come
- Narrow base black box design:
  - just over the horizon

    (expert optimizers with Agile Engineering SM Systems)
- Routine performance machine design will be well automated by 2005

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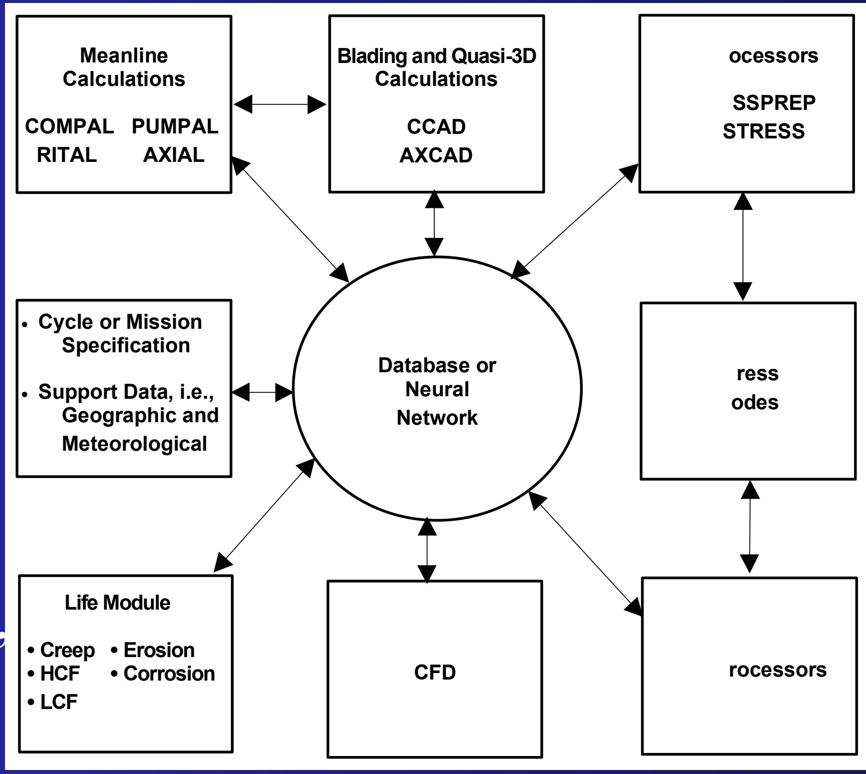
ADVANCED LIFE EVALUATION

- Must address diverse failure modes.
- Multi-disciplinary.
- Vast database.
- Frequent recalculations.
- Large need for data sharing.
- Needs to be done fast.
- Needs to be done in background, semi-automatically, so far as possible.



THE FUTURE

- Advanced Machines - look towards 2010 year
  - Total System Engineering
    - all disciplines
    - powerful optimization tools
  - Much lower cost than today
  - Much better engineering than today

The Future : Design Validation

- Tools are becoming more precise (but more development needed) and we are pursuing more and more validation studies. Validation against real machine data will become the standard for system selection!
- Genetic algorithms becoming potent and will be strong in 3 to 5 years with a real reduction in design time.

Agile Engineering℠ and the Future

- More complex and challenging designs
- Tougher operating specifications
- Better tools for design
- Exceedingly more complex design iterations
- *An engineer is a manager of technology !!*
- More fun (!)
- Greater value to society

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