Living With a Skill-Gap

Designing Higher Efficiency Fans With a Less Experienced Workforce

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- Joined AMCA in February 2019
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- Projects include webinars, online education modules, presentations at trade shows, AMCA Speakers Network and other duties as assigned.

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Dr. Geoff Sheard

President, AGS Consulting, LLC

- Over 30 years experience in the aerodynamic and mechanical design of rotating equipment
- International expert in fan technology and development of high efficiency fans for commercial and industrial application
- Holds a BEng in mechanical engineering, a DPhil in aerodynamics plus a DSc awarded for the application of aerospace design techniques in commercial and industrial fan design.
- Past President of AMCA and Chairman of the FAN 2012, 2015, 2018 and 2022 conference organizing committee

Living With a Skill-Gap: Designing Higher Efficiency Fans With a Less Experienced Workforce

Purpose and Learning Objectives

The purpose of this presentation is to explain what our industry's skill gap is, the issues making it worse, and why that matters.

At the end of this presentation you will be able to:

1. Outline at least an informal assessment of the extent of the skill-gap in your own organization.
2. Analyze the opportunity that engineering tools offer for mitigating the skill-gap.
3. Identify the organizational benefits associated with the capture of tacit knowledge, and how to go about doing so.
4. Explain the benefit of formalizing, documenting and managing engineering processes and documentation.

Agenda

- The Challenge
- Why do we Need Experience?
- Engineering Tools: Product Selection & Configurators
- Engineering Tools: Parametric CAD
- Engineering Tools: Computational Fluid Dynamics
- Summary and Conclusions

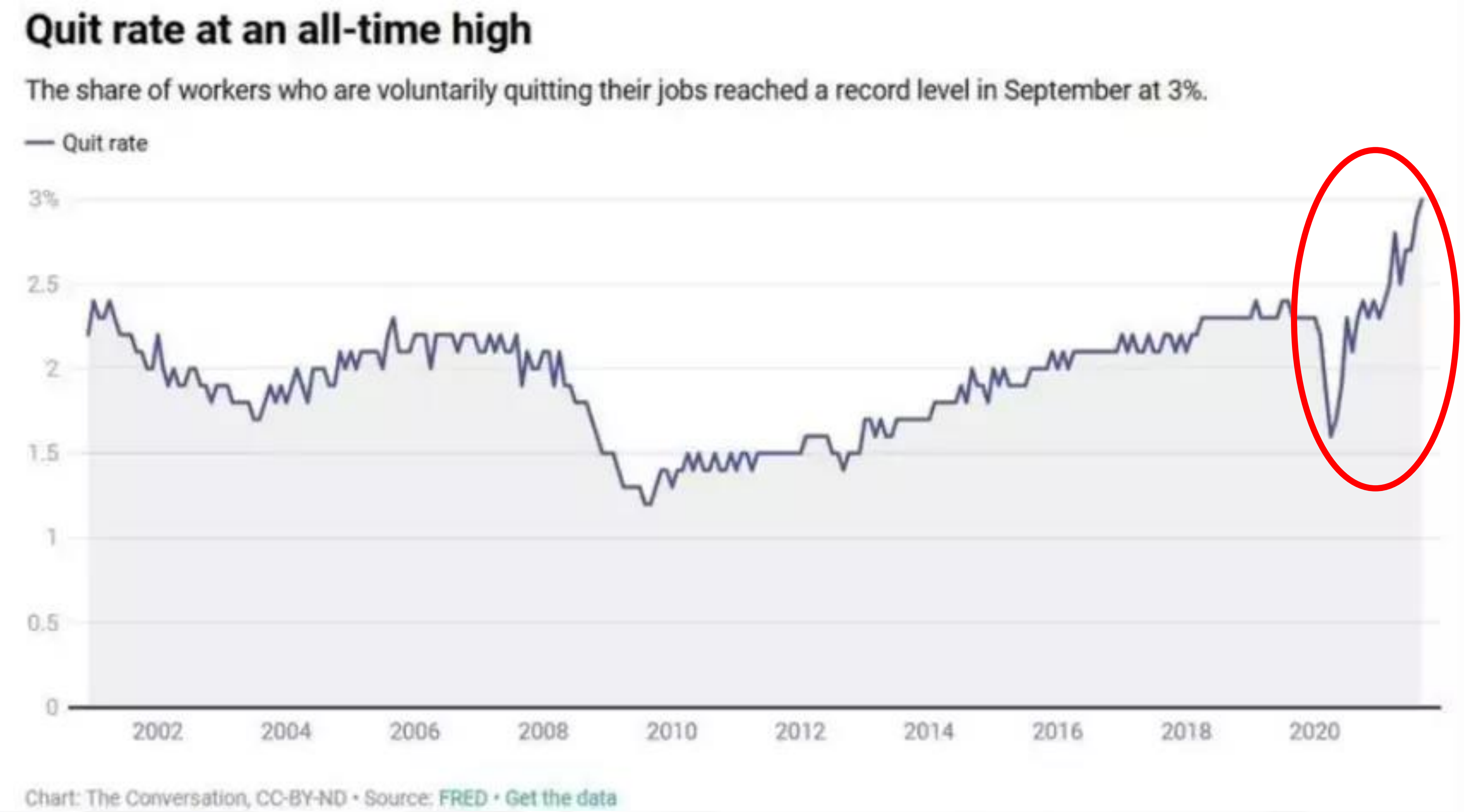
The Challenge

- The air movement industry is traditionally characterized by long-serving employees.
- Over time, they amass tacit knowledge about issues associated with specific products when applied into specific applications in specific locations.
- As long-serving employees leave the industry, those remaining know what to do, but not why.
- With product efficiency being regulated in a market more open to low-cost overseas competitors, businesses are pressured to:
  - Develop higher efficiency fans.
  - Manufacture them at lower cost.
  - Do so with engineers who are less experienced.

A Generational Perspective

- Baby boomers (57-75) average length of time in a job is 8 years and 3 months.
- Gen Xers (41-56) average length of time in a job is 5 years and 2 months.
- Millennials (25-40) average length of time in a job is 2 years and 9 months.
- Gen Z's (age 6-24) average length of time spent at a job is 2 years and 3 months.

The Great Resignation



The Great Resignation

- The "Great Resignation" is a phenomenon that describes record numbers of people leaving their jobs.
- It started in April 2021, when The Bureau of Labor Statistics reported that more Americans quit their jobs that month than any other time in history.
- The Great Resignation is driven by employees re-evaluating their careers and going on to leave their jobs.
  - Resignation rates are highest among **mid-career** employees.
  - Resignation rates are highest in the **technology** and healthcare industries.

The Effect

- It is significant that resignation rates are highest among mid-career employees. It is these mid-career employees that must stay if they are to become tomorrow's experienced employees.
- Millennials (25-40) and Gen Z's (age 6-24) make up a larger proportion of the labor market with each year that passes.
- We are therefore moving towards a situation where employees change jobs on average every two years.
- A consequence of changing jobs every two years is that the average length of service within a company will tend towards one year.

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The Result

- A workforce in which no one stays more than two years, and the average length of service is one year, has consequences for the organization.
- Within the Air Movement community, it is generally accepted that it takes more than one year to train a new engineer.
- Traditionally, new employees have made up only a small proportion of the work-force and are trained "on the job" by more experienced employees.
- If everyone leaves after two years, the organization is continually recruiting employees, who then leave at the point where they would traditionally have been considered fully trained and therefore able to themselves train new employees.

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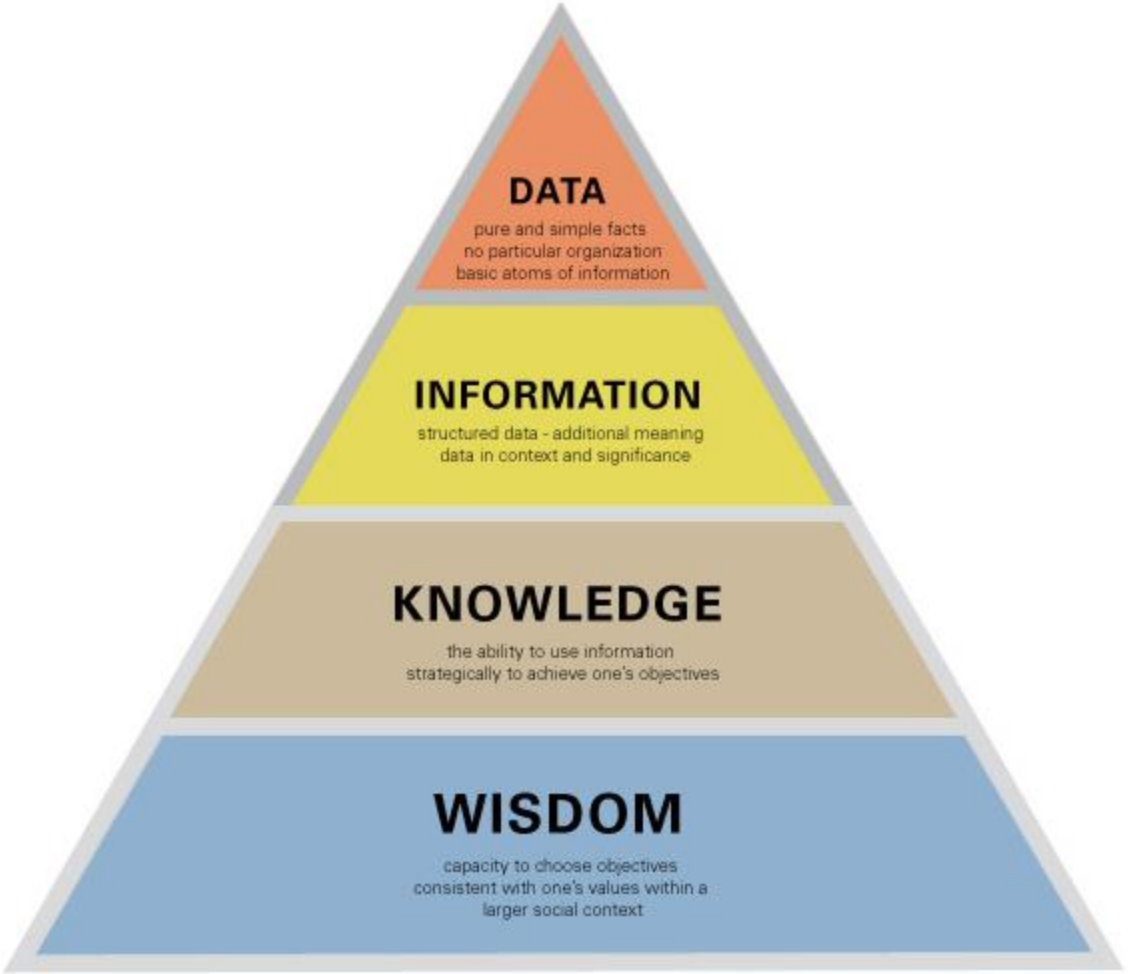
Why do we Need Experience?

- Experience allows you to structure data to turn that data into useful information.
- Understanding the significance of information is the knowledge you need to achieve an objective.
- Knowing how to achieve competing objectives is foundational to the wisdom you need to select those objectives that really matter to an organization and its customers.



(Robert Logan, *What is information?* 2010)

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Tacit Knowledge

- Explicit knowledge:
  - Declarative information
  - Rules and procedures
- Tacit knowledge:
  - Pattern recognition
  - Perceptual discrimination
  - Judging typicality
  - Mental models
  - Mindsets

Experience & Tacit Knowledge

- Experience and tacit knowledge go hand in hand. Over time you amass tacit knowledge, without necessarily knowing you are doing so.
- Asking someone to write down what they know is typically unsuccessful; the nature of tacit knowledge is that the more experienced employees “just know” what to do when presented with a situation.
- The most capable engineers typically develop a form of experience-informed intuition, if it doesn't “look right” it usually isn’t, even if they can’t say why immediately.

Capturing Tacit Knowledge?

- If the tacit knowledge of long-serving employees can be captured, and in some way codified, then that knowledge becomes available to new employees.
- The above is not a substitute for experience, but it can alleviate the problems caused by a lack of experience.
- If we accept that capturing tacit knowledge will at least mitigate the effect of a less experienced workforce, how do we go about capturing it?
- The engineering tools and systems used to design, select and manufacture products can be used to capture tacit knowledge.

Capturing Tacit Knowledge?

- Using engineering tools and systems to capture tacit knowledge makes good business sense.
- An organization’s most senior engineers are typically in demand, resulting in them forming a bottle-neck that ultimately limits the company’s ability to grow.
- If the most senior engineers tacit knowledge related to specific engineering issues can be captured in engineering tools and systems, the bottle-neck senior engineers form is diminished.
- Additionally, captured tacit knowledge in engineering tools and systems reduces the time needed to undertake a particular task. Hence, as tacit knowledge is progressively captured, order-related engineering time is progressively reduced.

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Order Related Engineering

- Reducing order-related engineering time is at the root of any business case for capturing tacit knowledge in engineering tools and systems.
- ***Example***: A large centrifugal fan, historically taking one engineer eight weeks from receipt of order to issuing of manufacturing drawings, was semi-automated though a series of parametric CAD models. Engineering time was reduced to one week, with management choosing to do that work in advance of final negotiations. This allowed the salesman to take the manufacturing drawing pack to final contract negotiations, doubling sales in one year.
- ***Example***: A high speed centrifugal fan historically required $50,000 engineering time. Selection and parametric CAD models reduced this to $12,500, allowing the company to bid and win contracts for smaller fans, quadrupling sales in two years.

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Selectors & Configurators

- A product selector is a software tool that facilitates identification of a suitable product from those products a company sells, and the creation of a quotation for that product.
- A product configurator is a software tool that takes the selected product and creates a bill of materials and other information needed to manufacture the product.
- Ideally the product selector and product configurator are linked, with the output of the product selector forming a direct input to the product configurator.

Selector vs Configurator

Product Selector

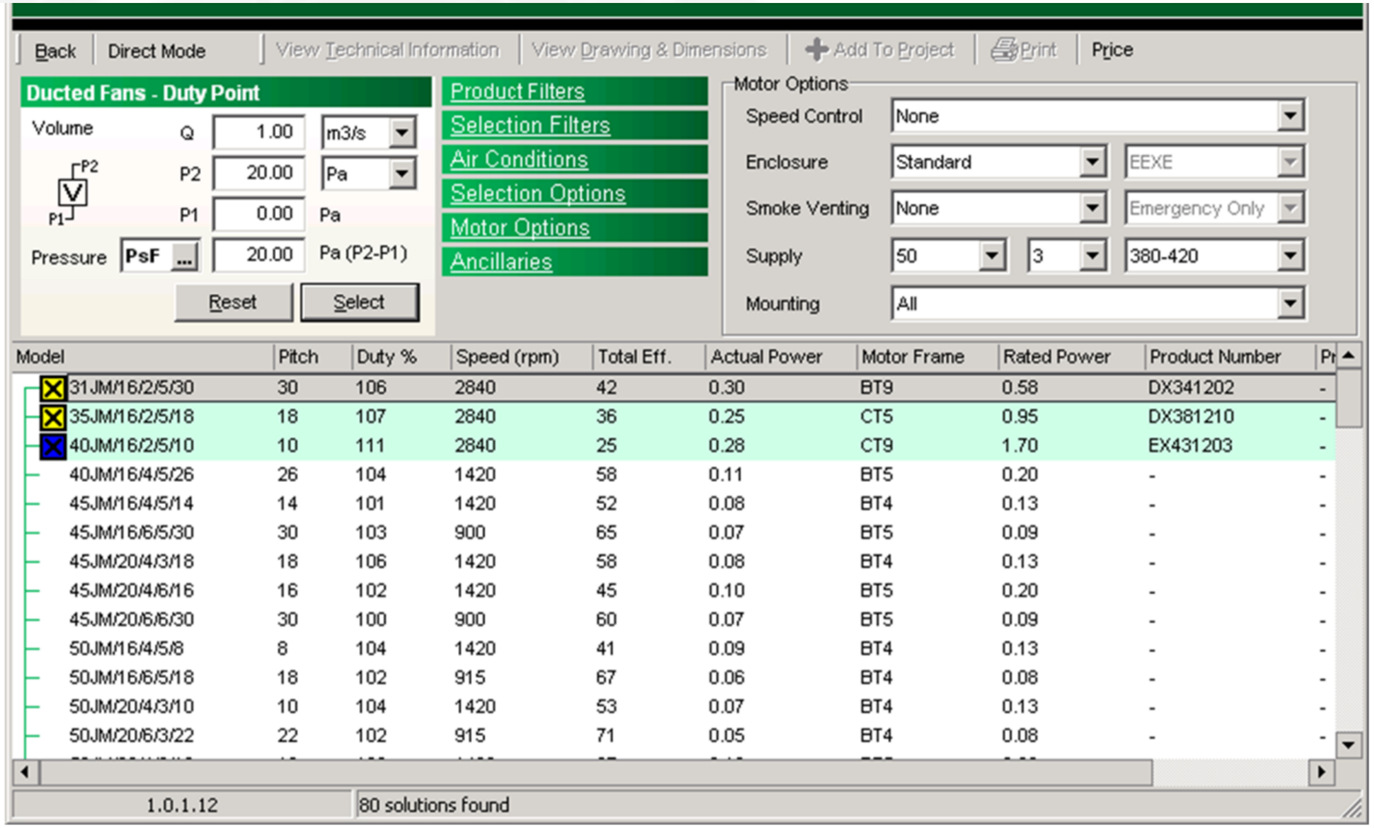
- Performance Data
    - Sound
    - Volume
    - Pressure
    - Absorbed Power
    - Efficiency
- Market Prices
- Dimensional Information

Configurator

- Bill Of Materials
- True Costs
- **INTEGRATED MARGIN**
- Transfer Price (Cost+)
- Stock Levels
- Factory Lead Time
- Drawing Links into Knowledge Worker
- Weights
- Assembly Schedules/Routing

Example Product Selector

- The input to a fan selector is classically target pressure and volume.
- The selector then identifies and lists all those products that can achieve the target pressure and volume.
- The identified products can then be sorted, for example for highest efficiency, lowest noise or lowest cost.
- After deciding on the best product for the application, the selector then classically goes on to create a fan data sheet and quotation.



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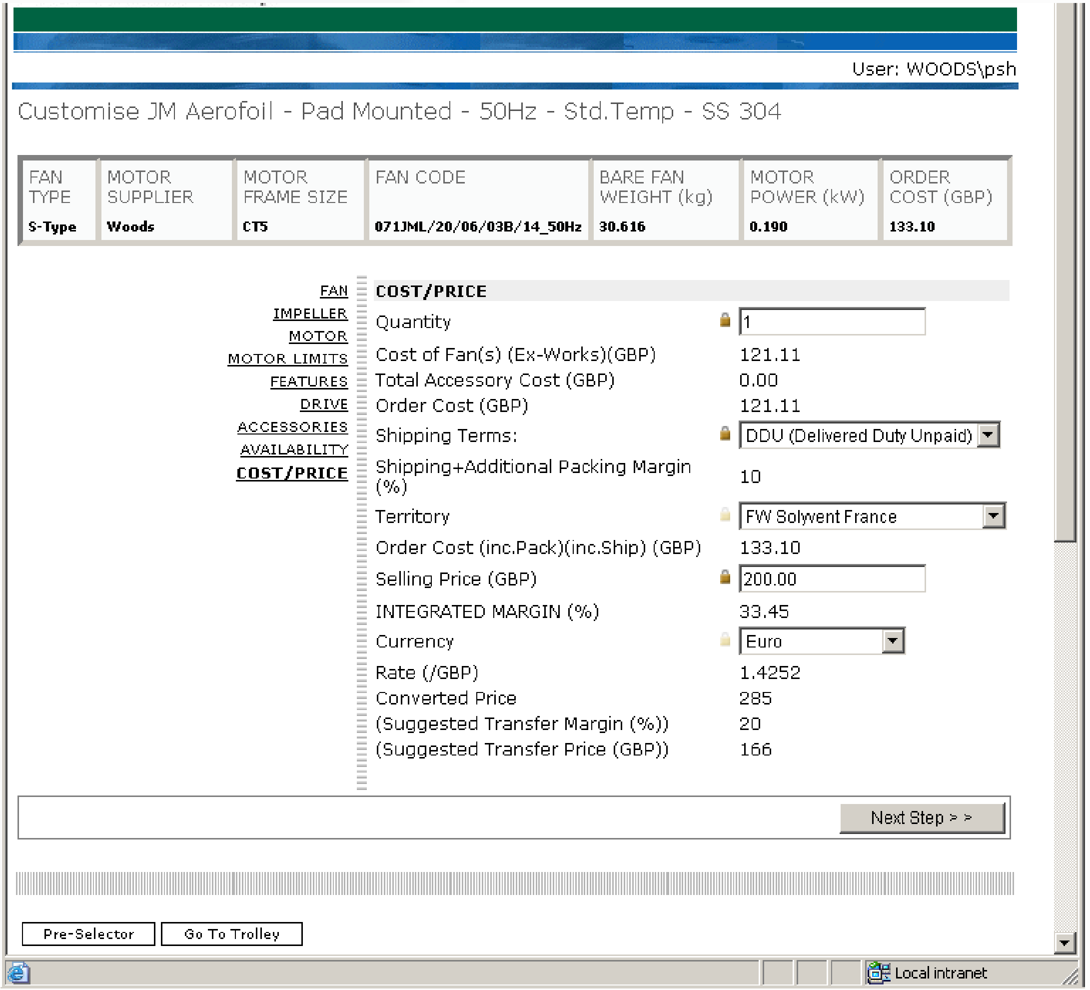
Example Configurator

- The input to a product configurator is classically a product number.
- The configurator then identifies all those parts needed to assemble the product, and the availability of those parts.
- Air movement fans classically have multiple variables when selecting them, blade angle for axial fans and wheel-width for centrifugal for example.
- Air movement fans also classically have multiple options, applicable to different applications. For example, motor vibration or temperature sensors.
- The combination of selection variables and selected options can result in no two nominally identical fand having exactly the same bill of materials.



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How Configurators Work

- Configurators are rule-based, they are programmed by defining the rules that govern how component parts may be combined into a finished product. For example:
  - An axial fan hub may be used with specific blades only. Hence, one rule is the blade part numbers that may be used with the hub.
  - A hub may have 12 ports, and so be able to be fitted with 12 blades. However, it may also be fitted with 6 blade by missing every other blade out, or 9 blade, or 8 blades. The blade allowable configurations for a hub is another rule.
- The act of deciding on each configurator rule, and programing the configurator is an act of capturing tacit knowledge.

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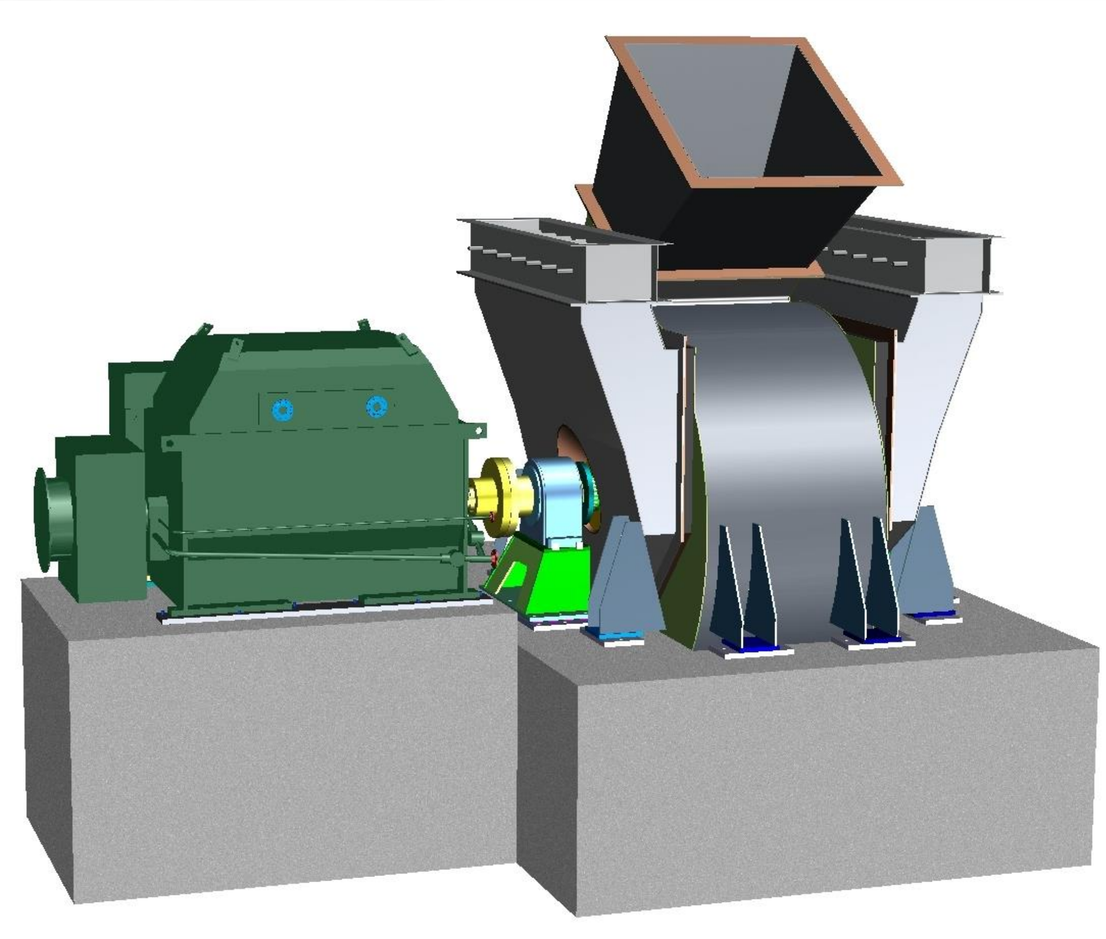
Parametric Modelling

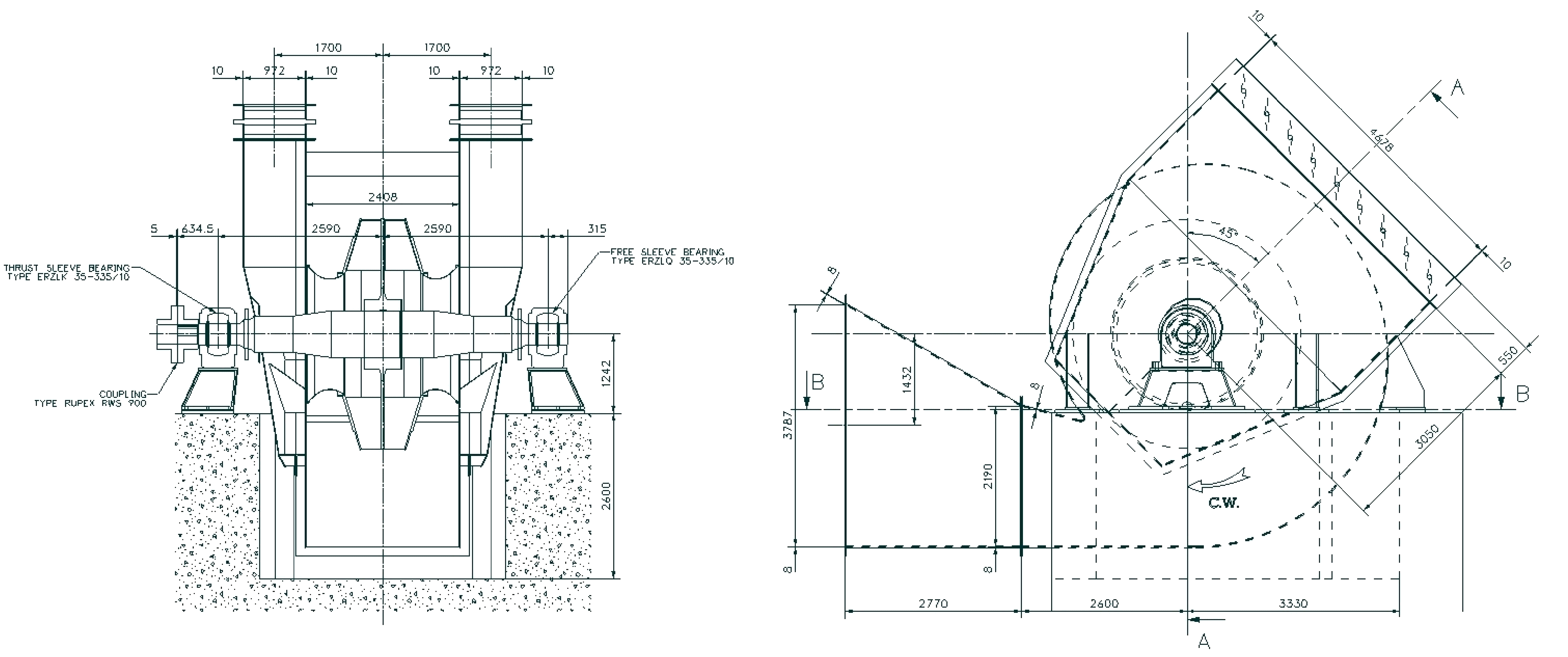
- Parametric modeling is an approach to 3D CAD in which you capture design intent using features and constraints, and this allows users to automate repetitive changes, such as those found in families of product parts.
- Components can be modified by changing the value of the associated dimensions.
- For parametric models to have any legitimacy, they must be based on real engineering information.
- It is the quality of the information used when setting up the parametric model that determines the viability of a modelling solution.

Example – Design to Order Fan

- This type of centrifugal fan is used in process applications.
- The customers want a general arrangement drawing early in the design process.
- A parametric 3D CAD model was developed that allowed a general arrangement drawing to be automatically generated.

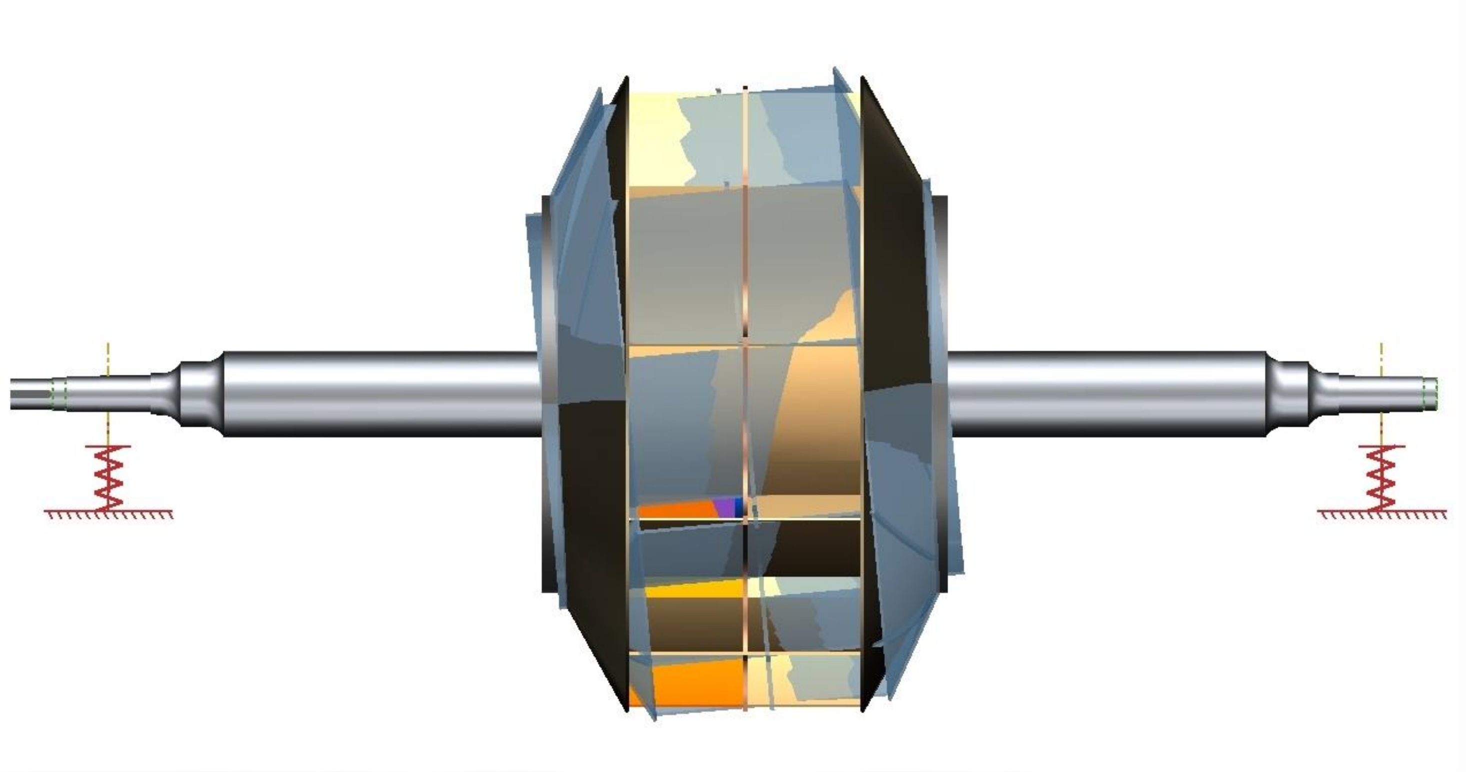


Automatically Produced GA Drawing



Rotor-Dynamic Analysis

- To produce the GA drawing, the distance between bearings needs to be known.
- Calculating the distance between bearings requires a rotor-dynamic analysis of the shaft and bearings.



Rotor-Dynamic Analysis

- The fan selection software was expanded to take key data from the selection, and then run a rotor-dynamic calculation.
- The fan selector was linked to bearing selection software to pull the necessary bearing parameters to run the rotor-dynamic analysis.
- Once bearings were selected, and a rotor-dynamic compliant shaft design completed, a parameter set was passed to the CAD software, and a GA drawing generated.

Applying Parametric Models

- Parametric models can also be applied in a more incremental way.
- An example could be the design of guards for a belt-driven fan; there are specific requirements that must be met for health and safety reasons.
- A single fan may be required to have a range of inlet and outlet configurations and be offered in different arrangement. In combination, they make almost every guard unique.
- A “guard parametric model” can capture the tacit knowledge needed to design a compliant guard.

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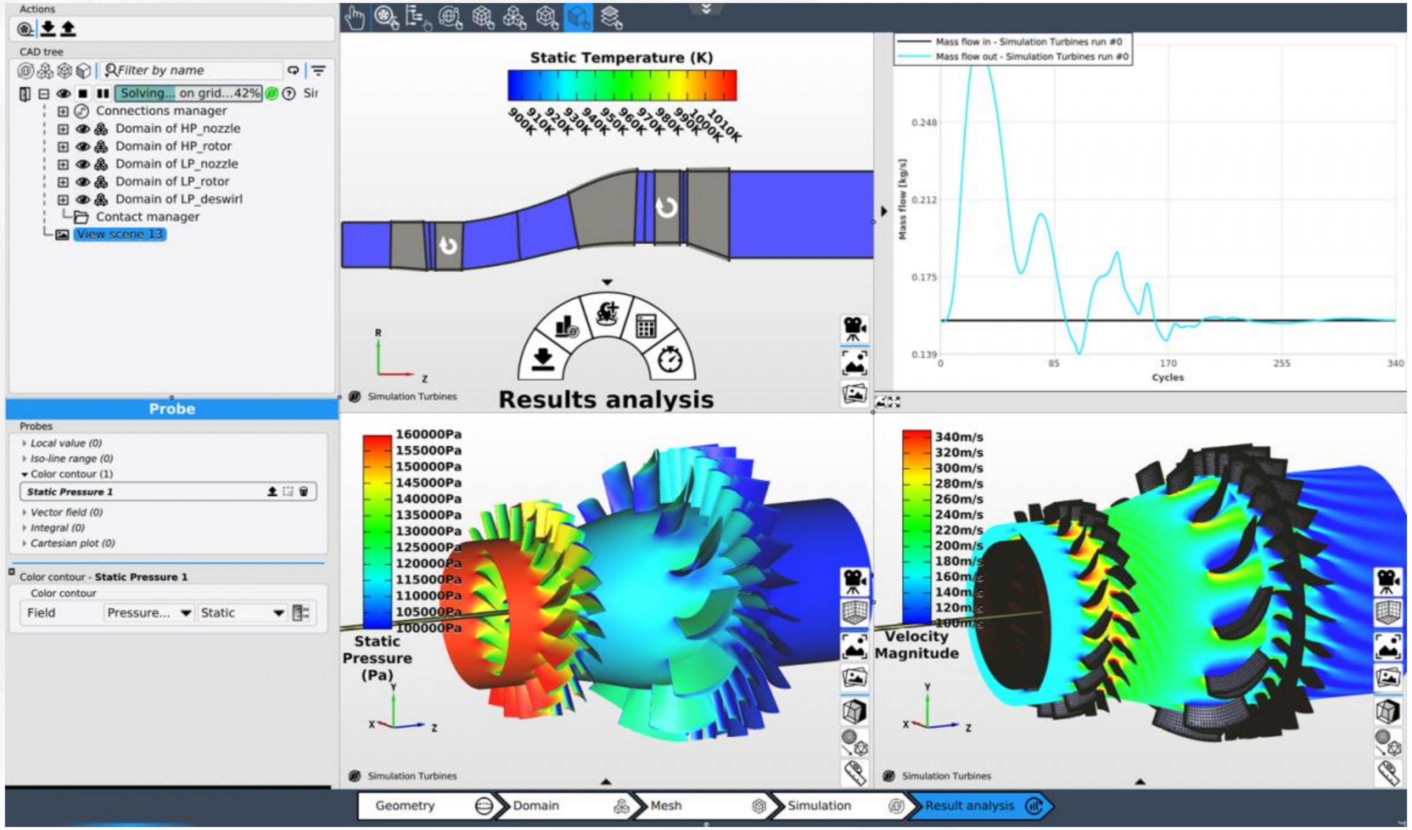
What is CFD?

- Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows.
- Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions.



What is CFD?

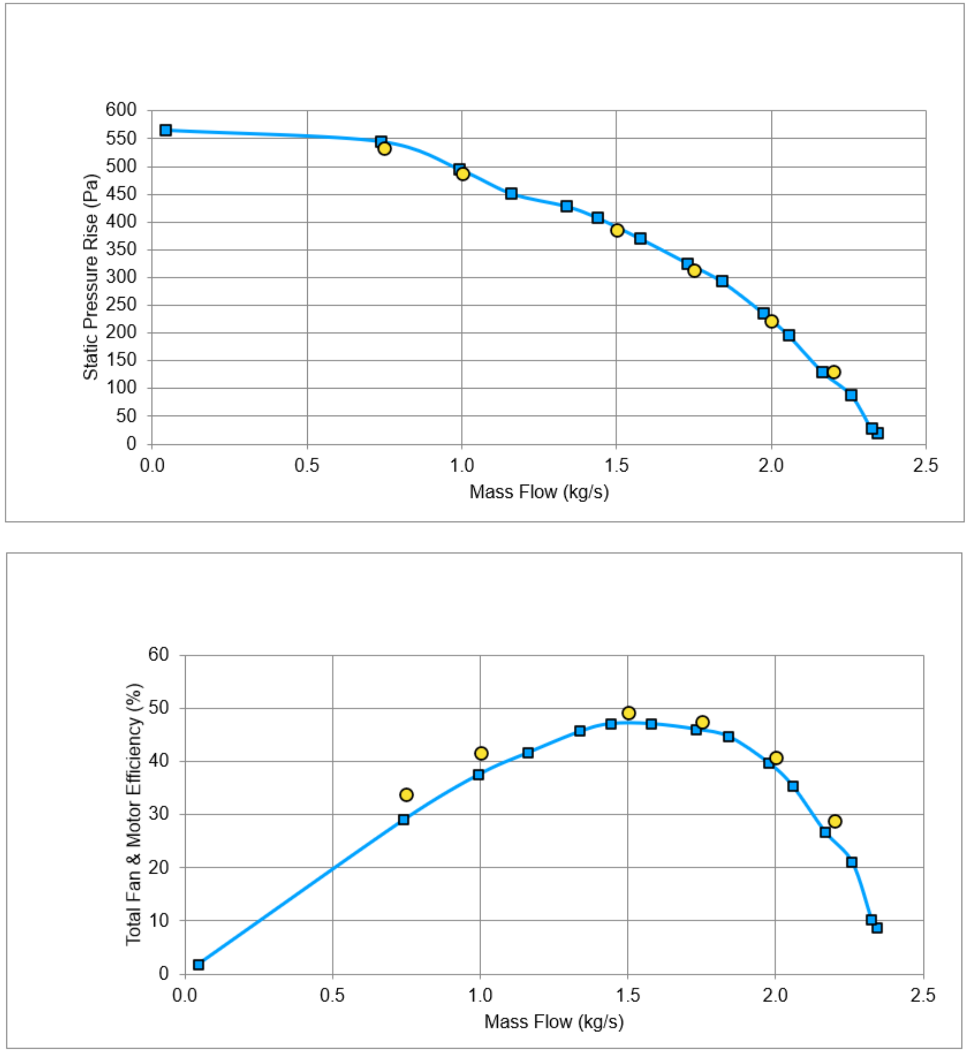
- Computational Fluid Dynamics (CFD) has been routinely used during the design of gas turbines since the 1980's.
- The application of CFD to air movement fans started to become possible around the year 2000 when commercially available CFD codes developed to the point where they solved the physical equations correctly.
- Around 2010, the cost of computer hardware became low enough that air movement fan companies could run fine enough grids to get grid-independent solutions.

Applying CFD to Air Movement Fans

- A challenge when applying CFD to air movement fans is that they are intrinsically less aerodynamic than a gas turbines.
- Air movement fans have motors in the air-stream, motor supports and conduit, all of which is intrinsically non-aerodynamic.
- Hence, applying CFD codes to predict the flow though an air movement fan presents more of a challenge then predicting the flow though a gas turbine. This is a reason why the air movement industry has been slow to adopt and integrate CFD as part of the fan design process.

How Well Does CFD Work?

- In this example we see agreement between laboratory measured data and CFD predicted data.
- This agreement is about as good as the agreement between laboratory and CFD predicted data ever gets.
- Yellow dots, CFD.
- Blue squares, laboratory measured data.



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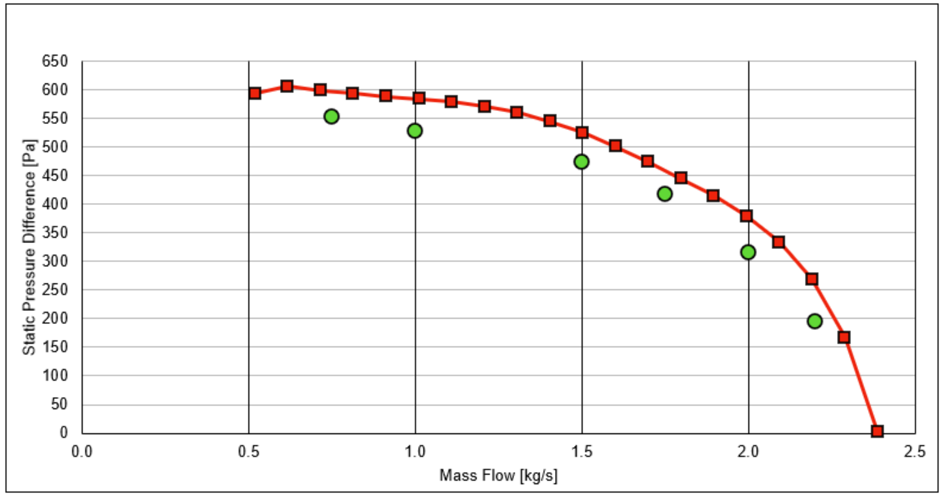
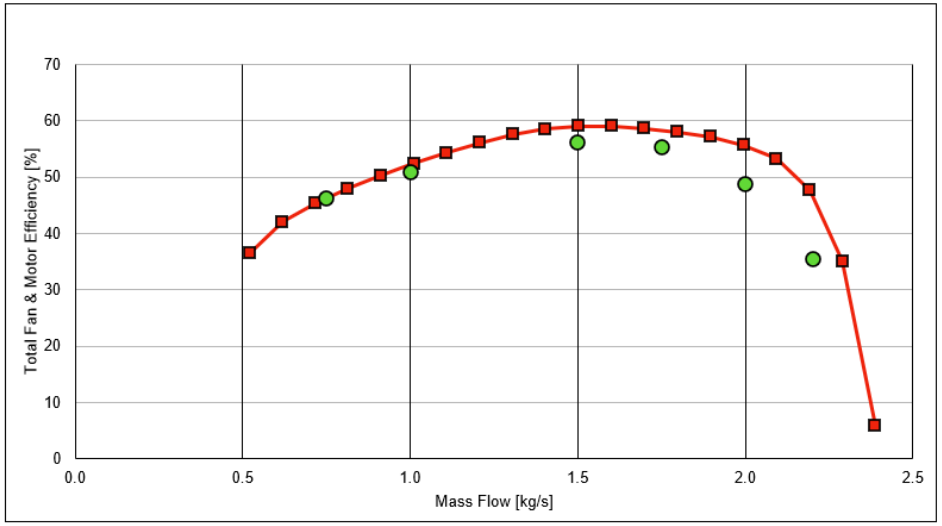
How Well Does CFD Work?

- In this example, you see more typical agreement between laboratory measured and CFD predicted performance.
- The difference may be due to laboratory measurement errors, differences between the tested and modelled geometry or CFD boundary conditions that don't reflect reality.
- Green dots CFD.
- Red squares, laboratory measured data.





Laboratory Errors

- In 2015, Mark Stevens, Executive Director of AMCA, published the results of a round-robin test.
- The same fan was tested in AMCA's own laboratories and also in a series of AMCA accredited laboratories.
- The results were published in a paper presented at the Fan 2015 conference.

fan2015

LAB-TO-LAB VARIATION IN TESTING FANS

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SUMMARY

AMCA International conducted a round robin series of test on three fans to investigate lab-to-lab variation in air performance and sound test results. The purpose of the round robin was to advance the science of testing fans in accordance with ISO and AMCA standards, specifically ISO 5801, ISO 13347, AMCA 210 and AMCA 300, and to advance our knowledge of test result uncertainty such that tolerances for certification programs and acceptance tests are fair and realistic.

INTRODUCTION

Three fans were part of the round robin, and all three were tested on multi-nozzle chambers. Centrifugal and tubeaxial fans were tested using a chamber at the fan's outlet, and both were powered by dynamometer. A vaneaxial fan was tested on a chamber at the fan's inlet and was powered by a calibrated motor. All participating labs used the same motor calibration. All three fans were sound tested in a reverberant room.

What we found is that the agreement between labs is actually very good. The determination of air power, power consumption and sound power through the measurement of pressure, temperature, torque, rotational speed and sound pressure is quite consistent from lab-to-lab, leading to good agreement in test results if the fans are well-behaved. If the fans are not well-behaved, meaning there is a significant amount of swirl at the fan's outlet or the fan's vibration is excessive, lab-to-lab variation can be quite high.

During an analysis of the air performance data from a high swirl fan we were able to tease out from the test results a correlation between air performance and the ratio of the outlet area of the fan to the area of the test chamber. This correlation is well known, but the results appear correlated to fan to chamber area ratios at ratios much higher than had previously been accepted. Sound power data, of course, was strongly correlated to fan vibration. An interesting note is that the uncertainties published in the aforementioned standards do not take into account errors associated with fan outlet area or fan vibration.

The CFD portion of this work focuses on gaining insight into the above mentioned correlation between air performance and the ratio of the outlet area of the fan to the area of the test chamber.

Laboratory Errors

- The same fan produced quite different results when tested in different laboratories.
- These results were for a tube-axial fan, other types of fan have less variation when tested in different laboratories.
- Nevertheless, the above makes the point that laboratories are not perfect, and so perfect agreement between laboratory and CFD predicted performance is unrealistic.

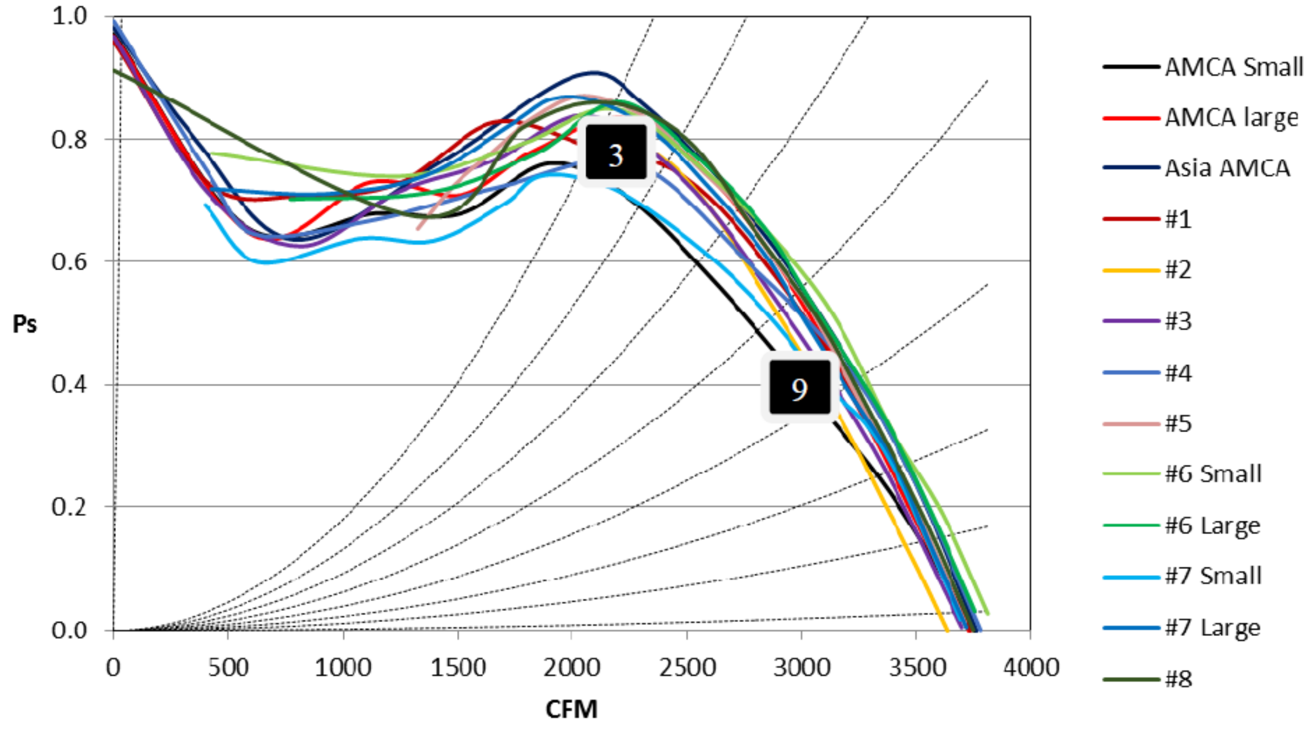


Figure 2: Plot of tubeaxial air performance results

CFD Optimization

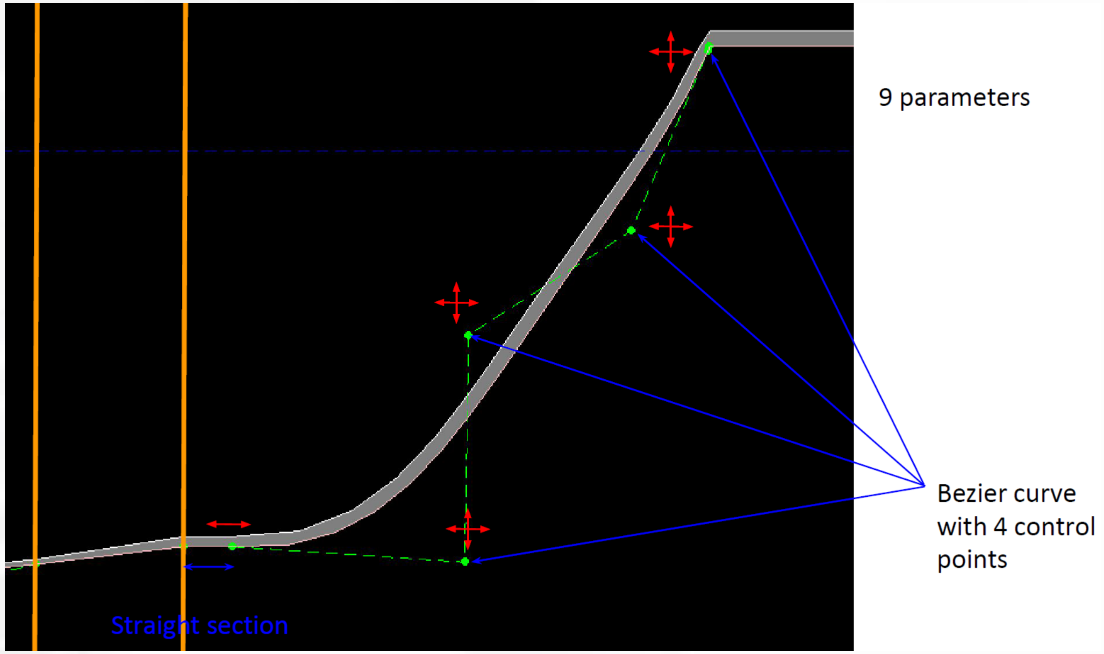
- Designing higher efficiency fans is something that typically a companies most senior engineers would undertake.
- It is possible to use CFD to optimize a fan design.
- If those senior engineers have retired, then CFD optimization offers an alternative.
- The optimization process uses a parametric model of the fan geometry to describe the “design space” within which the optimizer will search for fan geometry that delivers goal performance.

3D CFD Optimization

- A parametric model is set up with a series of parameters, and limits to those parameters that respect manufacturing constraints.
- Sets of parametric parameters are then used to generate fan geometry, following which a 3D CFD analysis is run.
- A set of parameters and its associated geometry is considered acceptable if the 3D CFD predicts pressure-rise and efficiency near to or reaching goal performance at the fan design point.
- Over successive iterations, the optimizer learns which parameter combinations result in pressure-rise and efficiency that approach goals, and through a systematic variation of parameters closes in on the region of design space that gives the highest performance geometry.

Example Parametric Parameters

- The shroud parametric parameters are presented to illustrate the parametric process.
- Four control points are used for the shape of the shroud, plus global parameters that define the position of the shroud in 3D space.



Impeller Parametric Parameters

- The dashboard below shows the impeller parameters, and the upper and lower bound for each.
- When a parameter turns yellow, this indicates that it is against a limit, and that the limit may constitute a constraint limiting the optimizers ability to reach the goal performance.

Name	Lower bound	Value	Upper bound	Status
S1_CAMBER_BETA1	2	8.94072710307	20	
S1_CAMBER_BETA2	30	37.4833463603	45	
Z_LE_HUB	0.12	0.1274044976	0.13	
Z_LE_SHROUD	0.15	0.1526355794	0.155	
Z_TE_SHROUD	0.27	0.3026355794	0.305	
LEAN_BETA	-2	-0.8	1	
CAMBER	0.4	0.437	0.6	
PERIODICITY	5	6	7	
AXIAL_L	0	0.5	1	

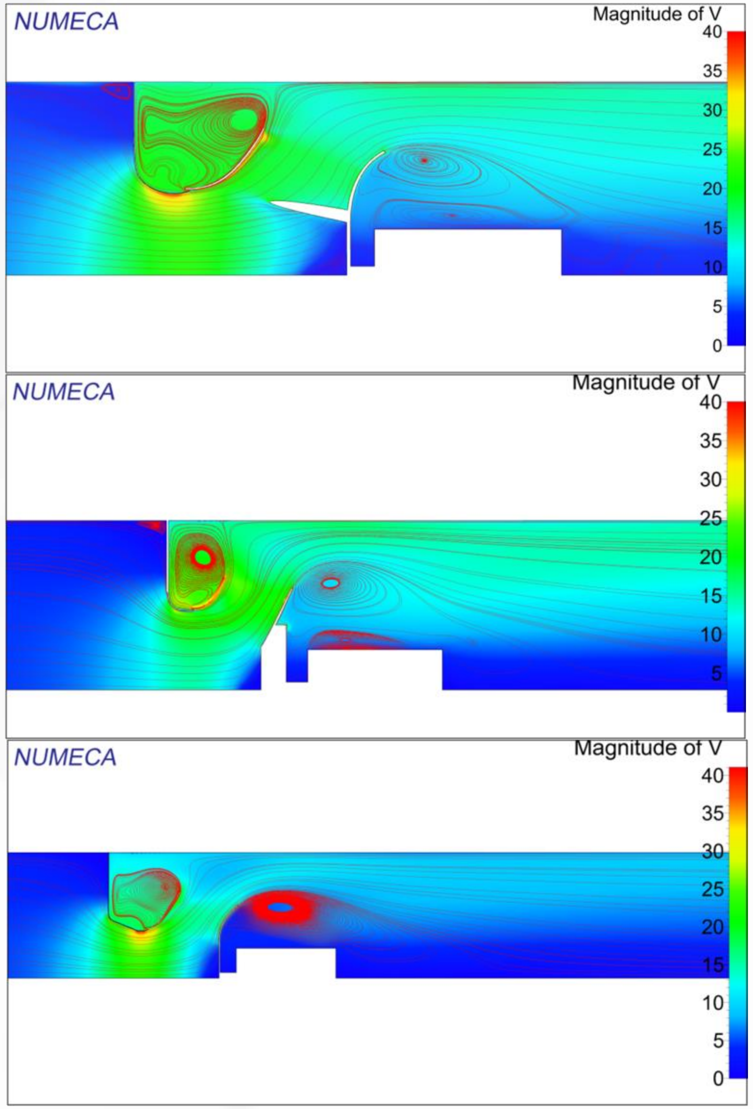
Name	Lower bound	Value	Upper bound	Status
HUB_R2	0.05	0.1107596842	0.13	
HUB_Z3	0.12	0.12059354774	0.14	
HUB_R3	0.15	0.15988474951	0.17	
SHROUD_R2	0.2	0.2	0.25	
SHROUD_Z3	-0.205	-0.2	-0.195	
SHROUD_R3	0.15	0.174	0.19	
SHROUD_Z4	-0.21	-0.203	-0.19	
SHROUD_R4	0.15	0.156	0.17	
SHROUD_Z5	-0.18	-0.156	-0.156	
SHROUD_R5	0.11	0.129	0.129	
SHROUD_Z9	-0.05	-0.0378830762	0	
SHROUD_R9	0.12	0.1368086473	0.16	
SHROUD_Z10	-0.06	-0.0371148883	0	
SHROUD_R10	0.16	0.1828137044	0.21	
SHROUD_Z11	-0.02	-0.0040617395	0.01	
SHROUD_R11	0.18	0.2039189981	0.23	

The Optimization Process

- Having defined the parametric parameters, and the extent to which they can vary, parameters are manually varied until a starting-point geometry is created.
- The starting point geometry typically generates flow and pressure close to the goal, but low on efficiency. The optimizers task is, therefore, primarily to increase efficiency.
- Each geometry is run through 3D CFD at design point flow. If the design point pressure and efficiency are close to goal, high-pressure and high-flow operating points are also run.
- In total, the optimization typically required over 1,000 unique 3D CFD simulations.

CFD Optimizer Output

- In this example the optimized geometry (top) has less separated flow then early iterations (middle and bottom).
- This example is from a project that went on to deliver the highest performing fan in its market segment, whilst also accommodating design constraints to facilitate low-cost manufacturing.
- It is unlikely that this optimum geometry could have been achieved simply by building multiple prototypes, reviewing laboratory results and then building additional prototypes.



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Summary – Product Selectors

- Product selectors provide a way to store laboratory measured performance data and use it to selector products for a particular application.
- The product selector can be expanded to include engineering analysis traditionally performed after receiving an order.
- In this presentation, the example given was the addition of rotor-dynamic calculations and bearing sizing calculations.
- The rotor-dynamic analysis and bearing sizing was previously done by one of the companies most experienced engineers.
- After implementation in the fan selector, the work was done by the salesman when preparing a quotation.

Summary - Configurators

- The process of converting a new order for a specific product into a bill-of-materials and other information needed to manufacture the product typically requires the involvement of experienced engineers.
- The various rules and constraints that experienced engineers know as a consequence of the tacit knowledge they have amassed can be coded into a product configurator.
- Product configurators then automate the process of turning a product code into the information needed to manufacture the product.
- In so doing, the need for experienced engineers to be involved in the processing of individual orders is diminished.

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Summary – Parametric CAD

- Parametric CAD models provide a way to capture the parameters, dependencies between parameter and limits on parameters that define a product and the components of that product.
- The act of defining the parametric relationships within a parametric CAD model is the act of capturing tacit knowledge that is typically otherwise un-documented.
- Once a parametric model has been setup and validated by an experienced engineer, it can be extended and enhanced by relatively less experienced engineers.
- Any development or enhancement of a parametric model constitutes the capturing of knowledge.

Summary – CFD Analysis

- The application of CFD to air movement fans is challenging, as air movement fans incorporate intrinsically non-aerodynamic features.
- In essence, there is nothing harder than predicting "bad" aerodynamics.
- Despite the above caveat, 3D CFD codes can be used to optimize fan performance and have proven particularly good at improving the efficiency of existing products.
- Historically, a companies most experienced engineers would design, build and test prototype fans. In contrast, CFD optimization requires less knowledge of fan design.

Conclusions

- There is no substitute to identifying key staff and doing what is needed to retain them.
- However, the average length of time employees stay with a company is reducing year on year, and organizations must learn to live with that reality.
- Examples are given of how product selectors, product configurators, parametric CAD and CFD may be applied in ways that capture engineering process and associated tacit knowledge.
- Although not a substitute for experience, capturing engineering process and tacit knowledge is a way to adapt to a less experienced workforce.

Resources

- **AMCA International:** *www.amca.org*

- **Laboratory Errors:** Paper: Lab to Lab Variation in Testing Fans
  (Link to paper will be provided on the AMCA website after AHR Expo 2022)
  - Stevens, M & Gyuro, M (2015), 'Lab-to-Lab Variation in Testing Fans'. *Proceedings of the Fan 2015 Conference*. Lyon, France, 15–17 April.

- **Example Product Selector & Example Configurator:**
  - Sheard, A.G., Hunter, P. & Orsvärn, K. (2004), 'An On-Line Infrastructure for a New Global Organisation'. *Proceedings of the 1st International Conference on Economic, Technical and Organisational Aspects of Product Configuration Systems*. Copenhagen, Denmark, 28–29 June. https://backend.orbit.dtu.dk/ws/portalfiles/portal/5285291/PETO+2004+Proceedings.pdf

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If you have any questions, please contact Lisa Cherney, Education Manager, at AMCA International (lcherney@amca.org).

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