AGS CONSULTING, LLC

Large Industrial Air Movement Devices

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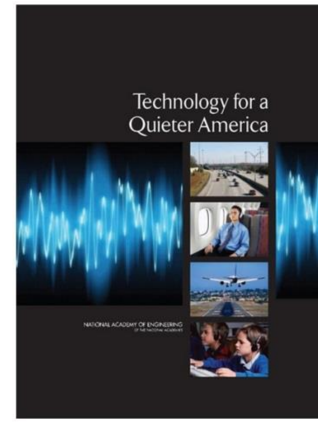
Engineering a Quieter America: Progress on Consumer and Industrial Product Noise Reduction

- This workshop is a Follow-up Workshop to the National Academy of engineering Technology for a Quieter America Report (2010). The 2010 final report may be down loaded from:



http://www.nap.edu/catalog/12928/technology-for-a-quieter-america

- This workshop was organized by the INCE Foundation, TQA Follow-up team, and INCE/USA.

- The workshop was held 6-7 October 2015 at the National Academies Keck Center, 500 5th Street, NW, Washington, DC 20001.

Progress Made by Noise Control Engineers Over the Past Few Decades

- The air movement community and academic community working with it report the results of their research once every three years at the world's only conference focused exclusively on air movement fans.

- The last two conferences in the series, Fan 2012 and Fan 2015 took place respectively in April 2012 and April 2015.

- Prior to the 2012 conference, the majority of papers presented focused on fan noise. They primarily reported empirical research. When the reported research did utilize computational methods it was typically to predict flow-field features that could then be correlated with fan noise.

- At the 2012 conference the first papers were presented that reported the application of computational methods for the prediction of fan noise.

Progress Made by Noise Control Engineers Over the Past Few Decades

- At the Fan 2015 conference there were 37 papers focused on nine aspects of fan noise:
  - heating, ventilation and air conditioning of cars;
  - tip leakage noise of axial fans;
  - signal processing for noise source localization and characterization;
  - noise of centrifugal fans;
  - prediction of axial fan noise by hybrid method;
  - sound quality;
  - Lattice Boltzmann methods;
  - tonal noise modelling;
  - installation effects.
- Unlike previous conferences in the series, the majority of papers reported the use of computational methods for the prediction of fan noise.

Progress Made by Noise Control Engineers Over the Past Few Decades

- Professor Stephane Moreau, University of Sherbrooke, Canada gave a key-note lecture at the Fan 2015 conference 'Numerical and Analytical Predictions of Low-Speed Fan Aero-Acoustics'.

- Professor Moreau observed that analytical methods can now be used to model the unsteady pressure generated by near-field noise sources that can then be related to fan far-field noise.

- The practicality of predicting the unsteady pressures associated with near-field noise sources requires the use of a large eddy simulation of the flow-field.

Progress Made by Noise Control Engineers Over the Past Few Decades

- The formidable computational effort associated with the use of large eddy simulations is simply beyond that available to design engineers working within the air movement fan community.
- Consequently the use of Reynolds-averaged Navier-Stokes (RANS) simulations of the flow-field provides a way to predict fan broadband noise in combination with a series of modelling assumptions.
- These assumptions provide a way to account for the flow-field physics not inherently modelled by a Reynolds-averaged Navier-Stokes simulation and in so doing facilitate the prediction of fan noise using available computational capability.

Projections of Further Noise Reductions Anticipated in the Future

- In August 2015 the Air Movement and Control Association (AMCA) published the White Paper 'A Review of the Fan 2015 International Conference on Fan Noise, Technology and Numerical Methods'.
- The white paper concluded that there is a rising awareness that product ranges developed over decades will need to be re-developed in less than one decade in response to current and forthcoming regulatory requirements.
- This realization is driving the development of computational methods that can predict far-field broadband noise and spectrum.

Projections of Further Noise Reductions Anticipated in the Future

- Although these computational methods are not yet ready for routine application by air movement fan manufacturers, pressure to reduce the time taken to bring new products to market has resulted in their development now being a focus of the academics working with the air movement fan community.

- The organizing committee of the Fan 2018 conference expects papers reporting the development and application of computational methods that can predict far-field broadband noise and spectrum to dominate the Fan 2018 conference technical program in April 2018.

Current and Forthcoming Regulatory Requirements

- Within Europe the European Commission is reviewing Regulation 327/2011, defining the ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW.
- Within the USA the Department of Energy has established an ASRAC Negotiation Rulemaking Working Group 'Commercial and Industrial Fans' with an input power of between 1 HP and 200 HP.
- Current European minimum allowable fan and motor efficiency levels and forthcoming US minimum allowable fan and motor efficiency levels are planned to come into effect on January 1st 2020.
- An assumption underpinning the rulemaking in both Europe and the US is that fan efficiency may be increased whilst maintaining acoustic performance.

Commission Regulation (EU) no. 327/2011 (2011), Official Journal of the European Union, 1 June, *http://www.amca.org/UserFiles/file/COMMISSION%20REGULATION%20%28EU%29%20No%20327-2011.pdf*.

US Department of Energy (2013), 'Energy Conservation Standards Rulemaking Framework for Commercial and Industrial Fans and Blowers', US Department of Energy, 1 February.

Current and Forthcoming Regulatory Requirements

- As minimum allowable efficiency is increased, it becomes progressively more difficult for forward-curved centrifugal fans to meets regulatory requirements.

- Forward-curved centrifugal fans classically have a low efficiency compared to a backward-curved centrifugal fan.

- However, forward-curved fans typically run at half the speed of an equivalent backward-curved centrifugal fan.

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Current and Forthcoming Regulatory Requirements

- Therefore the forward-curved fan typically has both a lower overall noise than a backward-curved fan, and significantly lower tonal peaks associated with blade passing and its harmonics.
- Further, a forward-curved fan is relatively insensitive to inlet flow distortion when compared to either backward-curved centrifugal or axial flow fans.
- Although an equivalent duty point axial flow fan can match forward-curved fan noise, it typically does so with a fan of significantly larger diameter.
- Consequently, if forthcoming regulation effectively eliminates forward-curved fans as a consequence of their low efficiency, noise control engineers will have to develop other fan types to match their acoustic performance. This represents a significant challenge.

Products Where the Noise Levels are Lower Now Than They Were Previously

- There is a general trend towards both overall broadband and one-third octave bands becoming part of air movement fan specifications.

- Although acoustic specifications may not necessarily be lower than they have been previously, they are increasingly being required in combination with increased aerodynamic performance that naturally results in increased fan noise.

- An example would be central tunnel ventilation fans. These are typically reversible fans, required to generate 1,200 Pa static pressure rise in both forward and reverse direction while generating no more than 85 dBA.

- Recent specification require 3,400 Pa static pressure rise while generating no more than 85 dBA.

Products Where the Noise Levels are Lower Now Than They Were Previously

- Reversible tunnel ventilation fans are typically able to generate up to 2,000 Pa static pressure rise in a single stage, therefore a two-stage fan is required to generate 3,400 Pa.

- On the following slide is an example of the fan, transform, silencer and damper package for a 3,400 Pa static pressure duty point with 85 dBA acoustic specification.

- The counter rotating fans (Concept 1) are the traditional tunnel ventilation fan solution when a pressure rise beyond that achievable in a single stage is required. Note the size of the required silencers compared to either Concept 2 or 3.

Products Where the Noise Levels are Lower Now Than They Were Previously

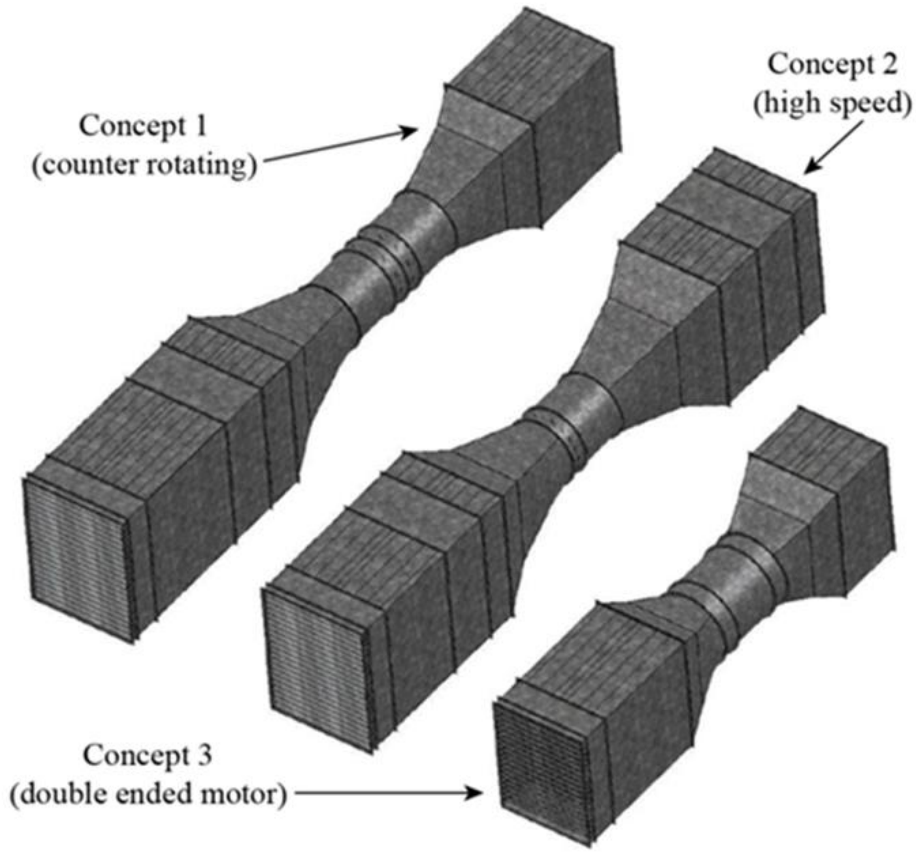

Figure originally published in Sheard, A.G., Daneshkhah, K. and Corsini, A. (2013), 'Fan Conceptual Design as Applied to the Marmaray Tunnel Ventilation System'. *Proceedings of the 58th American Society of Mechanical Engineers Gas Turbine and Aeroengine Congress*. San Antonio, Texas, USA, 3–7 June, Paper No. GT2013-94548.

Products Where the Noise Levels are Lower Now Than They Were Previously

Concept 3: a 2.8 meter diameter double ended motor reversible tunnel ventilation fan capable of generating 3,400 Pa static pressure.

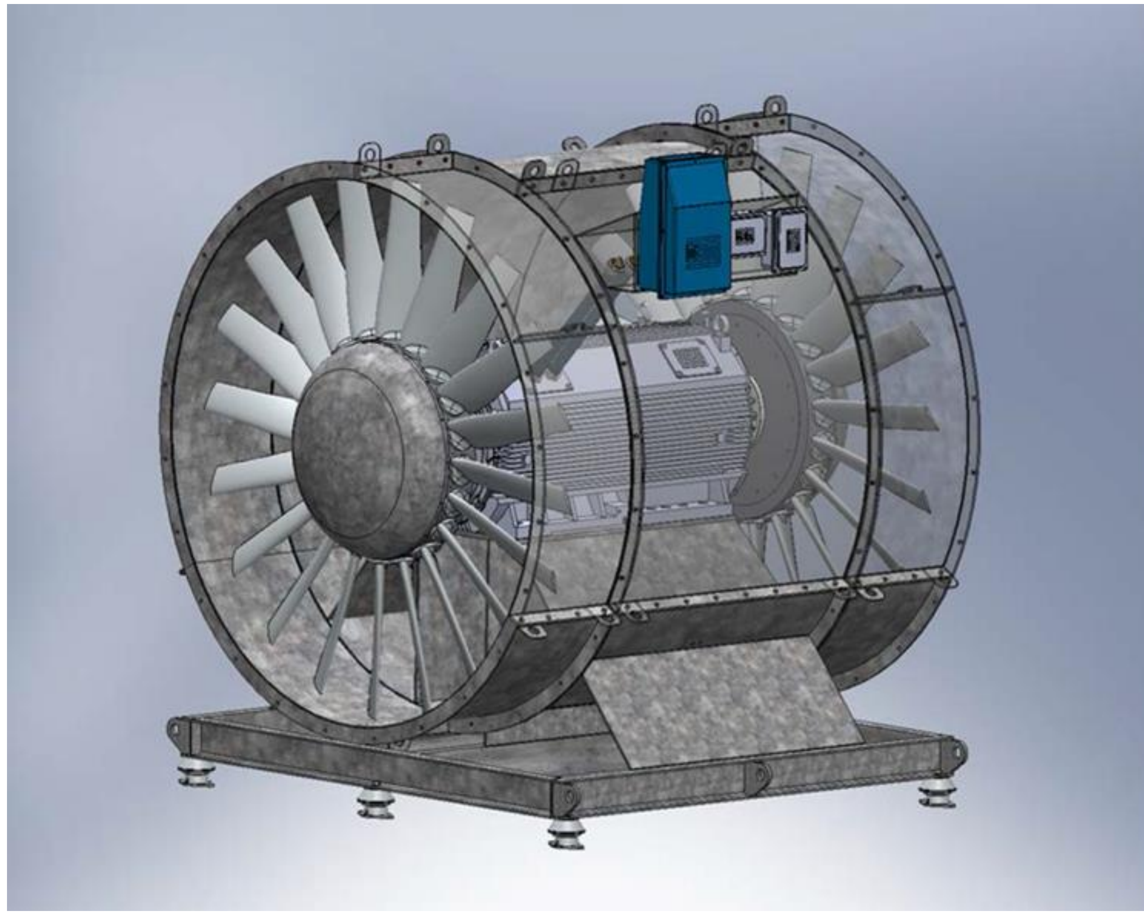

Figure originally published in Sheard, A.G. and Daneshkhah, K. (2012), ‘The Conceptual Design of High Pressure Reversible Axial Tunnel Ventilation Fans’. *Advances in Acoustics and Vibration*, vol. 2012, Article ID 562309, pp 1–11.

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Products Where the Noise Levels are Lower Now Than They Were Previously

- The silencers needed to achieve the 85 dBA specification for Concept 3 are significantly smaller than those required for other concepts.

- The Concept 3 two-stage tunnel ventilation fan is quieter than the other concepts as blade passing speed are lower. However the design required the application of industrial turbomachinery design tools. Empirical fan design tools were not capable of modelling effect of inter-stage vane configuration or the clocking of one impeller relative to the other.

- Poor inter-stage vane design results in separated flow features that are acoustically productive and increase fan far-field broadband noise.

- Inappropriate clocking on one impeller relative to the other resulted in an undesirable tonal peak in far-field noise.

How much lower is the noise now?

- Noise control engineers have maintained reversible tunnel ventilation fan noise constant whilst increasing air performance.

- However, there are air movement fan market segments where lowest noise is a key source of competitive advantage. Therefore noise control engineers are focused on reducing noise whilst maintaining air performance.

- An example is the market for fans fitted over the tube-bank of a compact cooling unit. Fan acoustic emissions dominate compact cooling unit tonal and broadband noise. Consequently the lowest noise fan is also the lowest noise compact cooling unit.

How much lower is the noise now?

Noise control engineers are therefore focused on developing low-noise fan technology to maintain market share in a competitive compact cooling unit market.

Figure originally published in Bianchi, S., Corsini, A. and Sheard, A.G. (2012), 'Installed Aeroacoustic Performance of Cooling Axial Fans Fitted with End-plates', *Noise Control Engineering Journal*, vol. 60, pp. 519–527.

Are the lower noise levels the result of efforts by noise control engineers?

- Noise control engineers have been successful in reducing air movement fan noise by adopting experimental and computational methods originally developed by the aerospace fan and compressor community, Sheard (2015).

- Measuring the span-wise distribution of fan blade trailing edge near-field noise and far-field noise simultaneously has facilitated identification of those near-field noise sources that are coherent in the far-field.

- Noise control engineers have associated experimentally identified near-field noise sources that are coherent in the far-field with near-field flow-field features predicted using a computational simulation of the blade-to-blade flow-field.

Sheard, A.G. (2015), 'Innovation in Industrial Turomachinery', Doctor of Science (DSc) thesis, Aston University, Birmingham, UK.

Are the lower noise levels the result of efforts by noise control engineers?

- Noise control engineers then modify fan blade geometry to minimize or eliminate the near-field flow-field features identified as the aerodynamic origin of fan far-field noise.

- On the following slide is an example of span-wise coherence between experimentally measured fan near- and far-field noise.

- The studied fan is intended for application over the tube bank of a compact cooling unit.

- In this example five separate near-field acoustic features were identified that are coherent in the far-field.

Are the lower noise levels the result of efforts by noise control engineers?

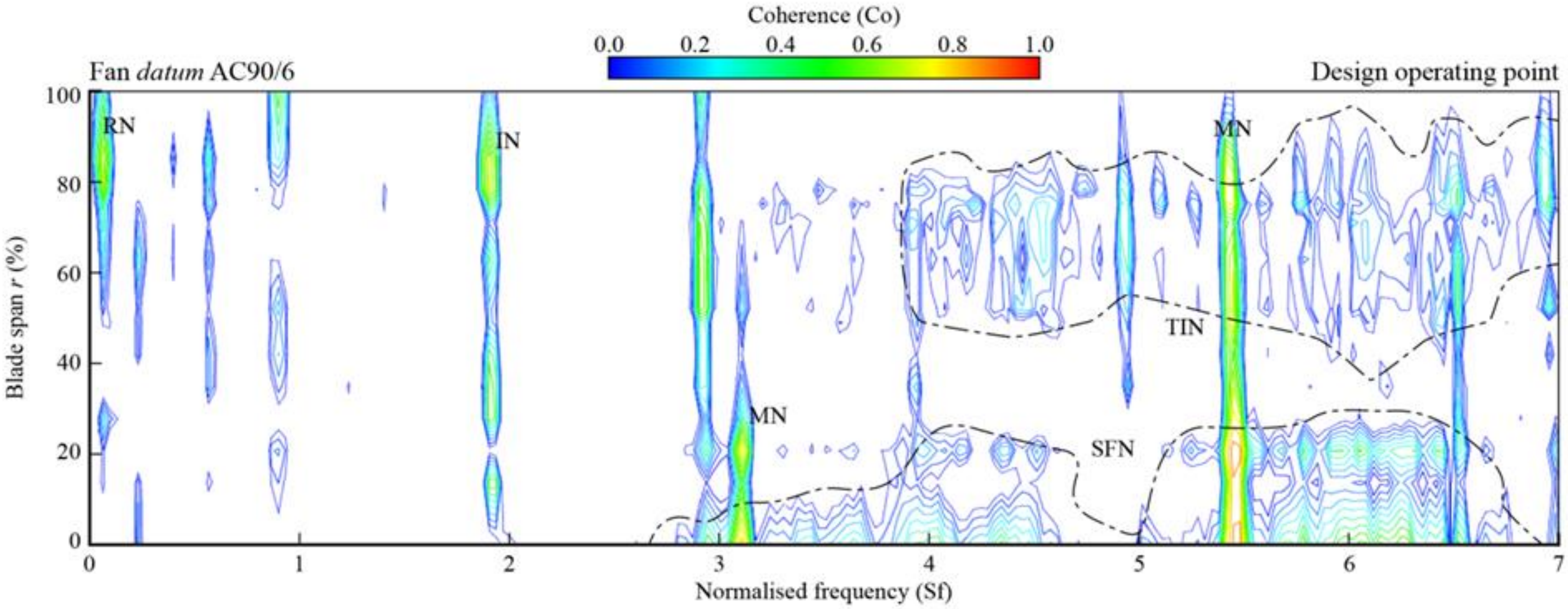

Figure originally published in Bianchi, S., Corsini, A., Rispoli, F. and Sheard, A.G. (2009), 'Detection of Aerodynamic Noise Sources in Low-speed Axial Fans with Tip End-plates', *Proceedings of the IMechE Part C, Journal of Mechanical Engineering Science*, vol. 223, pp. 1379–1392.

Are the lower noise levels the result of efforts by noise control engineers?

- On the following slide is an example of a blade-to-blade flow-field computational simulation of a fan intended for application over the tube bank of a compact cooling unit.

- In this example the intensity and trajectory of three blade tip-to-casing leakage vortex (TLV1, TLV2 and TLV3) have been characterized for a datum fan without a fitted blade-tip end-plate, with a constant thickness blade-tip end-plate and a variable thickness blade-tip end-plate.

Are the lower noise levels the result of efforts by noise control engineers?

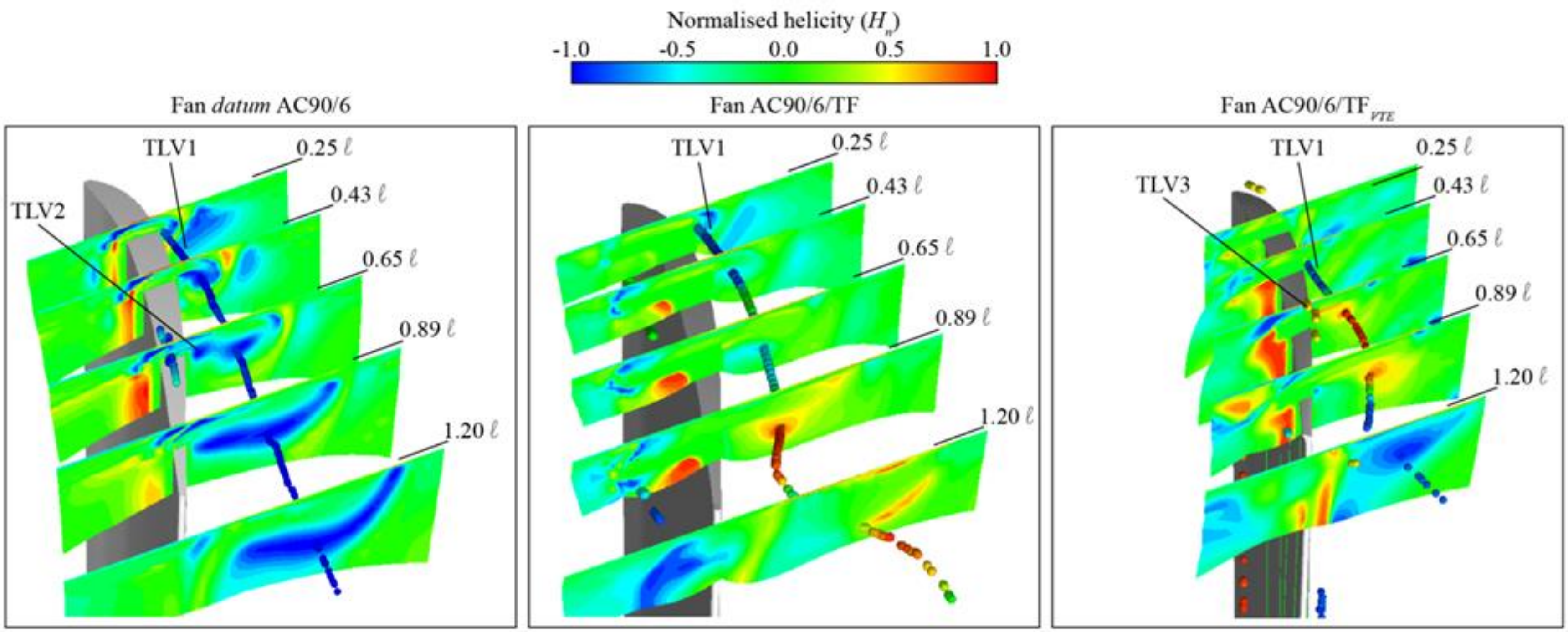

Figure originally published in Corsini, A., Rispoli, F. and Sheard, A.G. (2007), ‘Development of Improved Blade-tip End-plate Concepts for Low-noise Operation in Industrial Fans’, *Proceedings of the IMechE Part A, Journal of Power and Energy*, vol. 221, pp. 669–681.

What types of engineering noise abatements were found to be useful?

- Noise control engineers have found the use of blade-tip end-plates a particularly effective passive noise control technique.

- The experimental and computational techniques presented in the previous slides are used to optimize blade-tip end-plate geometry to eliminate acoustically productive near-field flow-field features that constitute the aerodynamic origin of fan far-field noise.

- In the example on the following slide the final end-plate design ($AC90/6/TF_{MVB}$) reduced fan far-field noise be 3dBA compared to the same fan fitted with the original blade-tip end-plate (AC90/6/TF).

What types of engineering noise abatements were found to be useful?

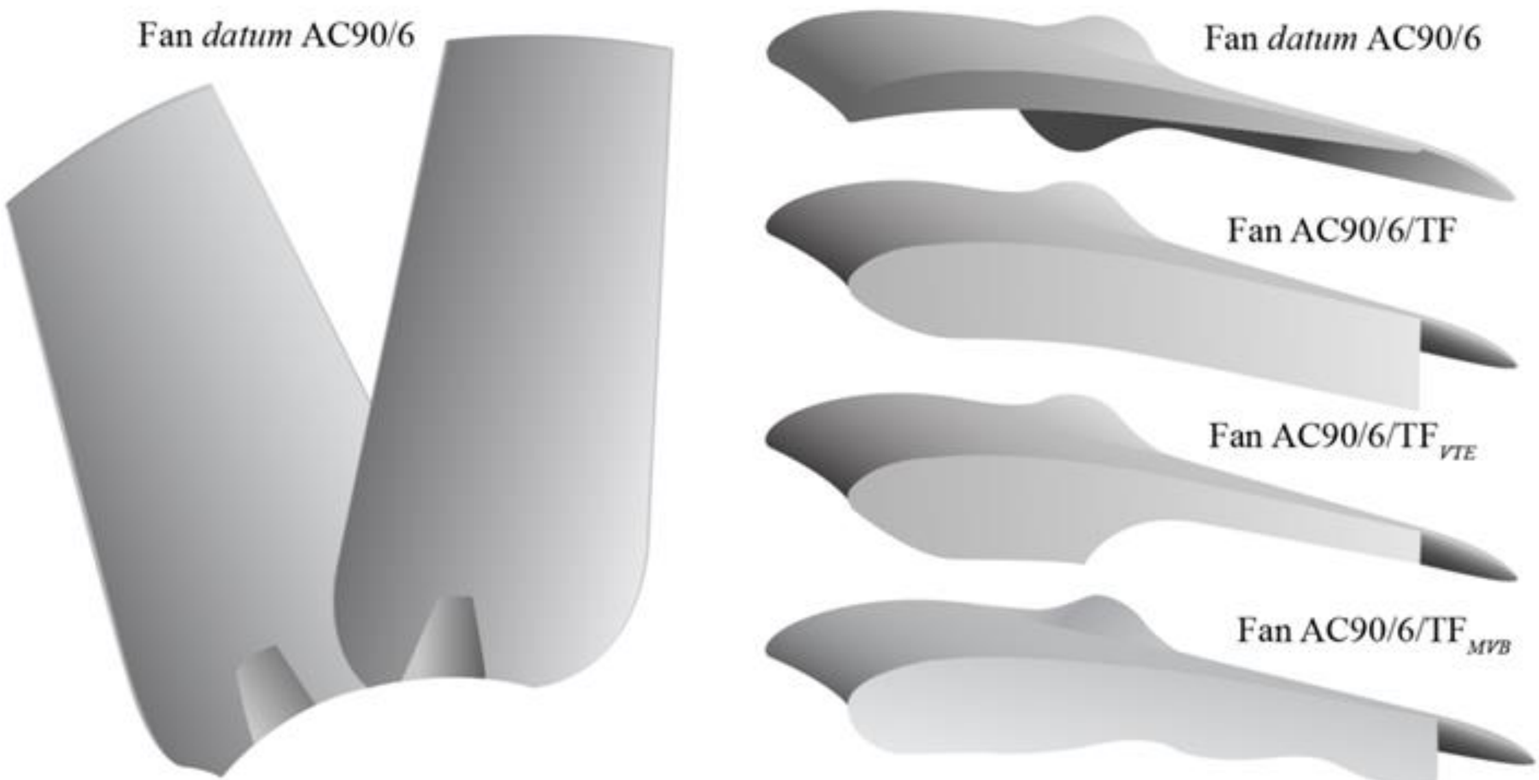

Figure originally published in Corsini, A. and Sheard, A.G (2013), ‘End-plate for Noise-by-flow Control in Axial Fans’, *Periodica Polytechnique, Mechanical Engineering*, vol. 57(2), pp. 3–16.

Manufacturing Costs, Efficiency, Life Expectancy and Weight

- In the compact cooling fan example, the blade tooling was modified to incorporate an optimized blade-tip end-plate without increasing blade manufacturing cost.

- Efficiency of the datum fan when fitted with blades incorporating the optimized blade-tip end-plates increased slightly.

- The life expectancy of the compact cooling unit fan when fitted with the optimized blade-tip end-plates was unchanged compared to the same fan without fitted blade-tip end-plates.

- The weight of the fan increased marginally with the fitted blade-tip end-plates, but not significantly enough to impact negatively shipping costs.

Customer Demand and Regulatory Requirements

- In the compact cooling unit fan example, noise control engineers developed the low-noise blade-tip end-plates in response to customer demands.
- The current regulatory environment in Europe and forthcoming regulatory environment is the USA is driving the air movement fan community to develop more aerodynamically efficiency products.
- Regulatory requirements will likely result in product ranges developed over decades being re-developed in less than one decade.

Customer Demand and Regulatory Requirements

- The empirical techniques historically employed by air movement fan designers have reached their capability limit. It is simply not possible to develop the necessary volume of new products in less than a decade using them.

- Consequently the air movement community is adopting computational methods to predict air performance, and the academic community with which it works is developing computational methods able to predict fan far-field broadband noise and spectrum.

Lower Noise, Consumer Acceptance and Contribution to the U.S. Economy

- Air movement fan applications may be divided into two categories
  - those that are in close proximity to people; and,
  - those that are not.

- Those applications that are not in close proximity to people have generally not demanded lower noise levels. However, in some cases they have required the same noise level with higher air performance. This has resulted in technical challenges noise control engineers have had to overcome.

Lower Noise, Consumer Acceptance and Contribution to the U.S. Economy

- Those applications in close proximity to people do place an on-going demand on noise control engineers to develop and apply new low-noise technology.

- Although lower noise air movement fans are more acceptable to consumers, the US market remains driven by first-cost and lead time. Fan efficiency and noise remain secondary considerations.

- Forthcoming regulations may result in fan efficiency becoming a market driver. However as it is minimum fan efficiency that is being regulated and not fan noise it is unlikely that air movement fan manufactures will focus on developing lower noise fans.

Summary and Conclusions

- The forthcoming regulatory environment in the USA is not driving increasingly stringent noise control. However, by 2020 it will mandate minimum allowable fan efficiency.
- The number of air movement fans that will require optimization or replacement to meet forthcoming efficiency requirements is high enough to make necessary the adoption of computational methods.
- Empirical design methods are neither capable to delivering new products that reach the required efficiency or delivering the volume of new products needed prior to the 2020 introduction of minimum allowable fan efficiency levels in the US.

Summary and Conclusions

- Computational methods will increasingly be used to both design air movement fans and predict air movement fan air performance.

- The academic community working with the air movement fan community is focused on developing computational methods that can predict fan broadband noise and spectrum.

- Computational methods that can predict fan broadband noise and spectrum are required by the air movement fan community. It is simply not practical to build and physically test the volume of new air movement fans that will need developing to meet forthcoming regulatory requirements mandating minimum allowable fan efficiency.

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