Beyond Point Design Evaluation

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KEYNOTE PAPER SUMMARY

The Problem

Moore's Law (stated by G. Moore, one of the founders of Intel, in 1965) implies that computer processor speed has increased by a factor of almost two every year for over three decades, and will continue to do so for the foreseeable future. It is as if the computer-aided engineering (CAE) community has been blessed with a geometrically increasing "budget." But how is that budget being spent in the thermal/fluid analysis arena?

The answer is that most of the budget is absorbed by increasingly larger (more detailed) models, with added phenomenological modeling absorbing most of the remaining budget. Improved graphics, user interfaces, and interconnection/interchange between software has also taken advantage of faster machines. Nonetheless, the basic approach of *point design evaluation* remains largely unchanged: assume a fixed design in a specific environment, then predict the steady-state and/or transient performance of that design.

Point design evaluation represents not what an engineer needs to accomplish, but rather what is convenient to solve numerically assuming inputs are known precisely. Specifically, point design evaluation is merely a *subprocess* of what an engineer must do to produce a useful and efficient design. Sizing, selecting, and locating components and coping with uncertainties and variations are the real tasks. Point design simulations alone cannot produce effective designs, they can only verify deterministic instances of them.

The need for fabrication and test can certainly be reduced using analytical methods, and hence analysis software has become popular and increasingly widespread in both aerospace and terrestrial industries over the last ten years. However, stand-alone point design evaluation methods are also rapidly approaching a point of diminishing returns, and fewer software providers are expected to remain ten years from now as the market begins to saturate. To continue growing instead, real contributions to product robustness must be made along with reduced cost and time to market. Commercial companies unable to quantify productivity and product improvements might find themselves waiting for the results of expensive analysis that aren't helping as much as they thought. Software that spends the budget provided by Moore's law more wisely will be more likely to endure.

As an example specific to the use of CFD techniques for thermal design: Why perform expensive and detailed point design simulations when the heat transfer coefficients are only accurate to within 20 to 50%? Closure of the momentum and energy equations at the wall ultimately requires some trade-off between a very fine mesh and an empiricism. The error terms for energy solutions are larger than those for momentum solutions because the former is based upon the latter: *heat transfer coefficients are highly derived and can have relatively large uncertainties.*

Even if further improvements in CFD technology were to completely eliminate this uncertainty and yet maintain reasonable run times, there remain variations in environment, usage, fabrication, installation, etc. Would the resulting software be able to address these issues fast enough to contribute to the thermal/fluid design? If so, could it then operate orders of magnitude faster, as needed to support multidisciplinary product-level decisions in a reduced time-to-market environment?

A Proposed Solution

Perhaps it is time to start employing the computational budget provided by Moore's Law to better contribute to engineering productivity: to build a better product faster rather than to spend months investigating detailed facets of a single design candidate. This means treating all classes of uncertainty and variation directly, maximizing any available information gained by concurrent testing, and perhaps avoiding the stack-up of margins in worst case design scenarios.

This new approach also means realizing that thermal/fluid analysis is usually a small part of the design of most products, and that our specialty must be able to make timely and perhaps automated contributions to top-level design synthesis: thermal/fluid analysis must eventually disappear into a mosaic of larger considerations and higher-level analyses.

Technologies to accomplish these ideals exist and are maturing. They are designed to exploit existing point design simulations executed iteratively, *providing that underlying point design evaluations are fast and flexible enough.* [See full presentation for details of these technologies.] Unfortunately, few general-purpose thermal/fluid simulation codes have such an emphasis, especially in the 3D CFD realm, and it will take years of development to retrofit them to be ready.

First, the thermal/fluid models must be completely parametric: accepting and propagating changes based on a few key parameters (e.g., dimensions, properties, initial or boundary conditions, etc.). This also means application of scaling factors ("fudge factors") and other methods of controlling a model's predictions as needed for calibration tasks and uncertainty analysis. Ideally, it also means the software must have an application programmer interface (API): it must accept commands (including new values of parameters) externally and produce outputs iteratively, without requiring excessive overhead for restarting a problem dynamically.

Second, phenomenological accuracy may need to be sacrificed for increased solution speed. Point design evaluations must be executed hundreds to thousands of times in the environment envisioned. Perhaps it is therefore better to use a scaled/calibrated empiricism instead of a "first principles" approach for the underlying point design evaluation.

A simplified and parametric thermal/flow analysis trades accuracy within a *single* relatively slow evaluation for the ability to run multiple faster analyses and thereby:

1. automatically calibrates a model to available test data, effectively eliminating or at least reducing uncertainties such as heat transfer coefficient and contact conduction by using analysis not to attempt to replace testing with more and more detailed analyses, but rather to extend (and therefore significantly reduce the need for) testing with fast-to-generate and fast-to-solve analyses;
2. allows remaining variations and unknowns to be evaluated together statistically, to determine tolerancing, to focus on critical (bottle-neck) uncertainties, and to avoid margin stack-up; and
3. produces a sensible, robust, and efficient design in the first place using automated design synthesis and optimization techniques. Using multidisciplinary techniques, this design synthesis can transcend thermal/fluid considerations, including cost and reliability models, etc., although the need for fast solutions becomes even more critical in those cases.

Conclusions

Currently, thermal/fluid analysis software packages, especially 3D CFD codes, compete against each other mostly on the basis of phenomenological capabilities ("*this* software handles such-and-such phenomenon whereas *that* software doesn't"). Speed, flexibility of solutions, and interconnectibility with other software are largely secondary considerations.

Available codes are approaching these capabilities asymptotically, and the next generation of codes must distinguish themselves in a different manner. If the contentions of this presentation are correct, then in the future speed and flexibility will become primary considerations.

It was once noted that as a technology matures, it disappears. (Consider, for example, the ignorance that most people have about the internal working of the electronic devices they use, much less about electricity itself: its generation and distribution.) Perhaps in the future, the thermal/fluid codes that survive will be those that were able to swallow their pride and fade into the background of a larger design environment.

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