Cyon Research™

Classes of MCAE Software: Clarifying the Market

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Executive Summary

How can MCAE be used to drive decisions in a timely way? That is the question both suppliers and customers must answer.

As customers realize the value of MCAE in design, it is increasing profits for large and small companies. It grants the power to move some of the most expensive and time-consuming aspects of the engineering process away from physical prototyping and into the fast, cheap, and safe simulation of electronic/digital prototyping. Companies of all sizes are realizing enormous gains, cutting time-to-market while producing designs that are more reliable and efficient than ever before.

In consequence, the MCAE (mechanical computer-aided engineering) market—which is about $2 billion per year—has reached a point of inflection upward in its growth; earlier segmentations no longer serve to describe it well. Changes are occurring in the vendors' views of their target markets, and products are being modified, and new products developed, accordingly.

This dynamism and the shifting usage patterns of MCAE make this market difficult to comprehend. Our research revealed substantial variances in the ways the market is viewed by different vendors, consultants, and customers.

We have developed a view of the market that we believe will be useful in understanding it. We break down the market into types of customer problems and process issues.

As we see it, the problem types range from "straightforward" to "hairy"; in addition, some problems are "big"; and some problems require manual and semi-automated iterations. In other words, the problems addressed by MCAE suppliers vary in scale, in difficulty, and in the workflow into which their solution must be incorporated.

Moreover, as complexity increases, the problems and processes become difficult to keep track of. Several software systems that are designed to manage the data and processes of MCAE have emerged. We call this MCAE category PSM (digital product simulation management).

Another "slice" (not pictured) of the engineering software market that overlaps with MCAE is PIDO—process integration and design optimization software. The "process integration" portion involves capturing and automating processes using graphical symbolism, facilitating the combining of disparate tools into a single workflow. Thus, everything from specifications through manufactured and delivered products is linked, so that changes in any aspect of the process are reflected in all other aspects.

From our discussions with MCAE suppliers and customers, this seems like a natural breakdown. It forms the basis for a market map of the MCAE software industry. We have vetted this map with MCAE customers, vendors, and other industry analysts, and offer recommendations based upon it to customers' engineers who are considering MCAE.

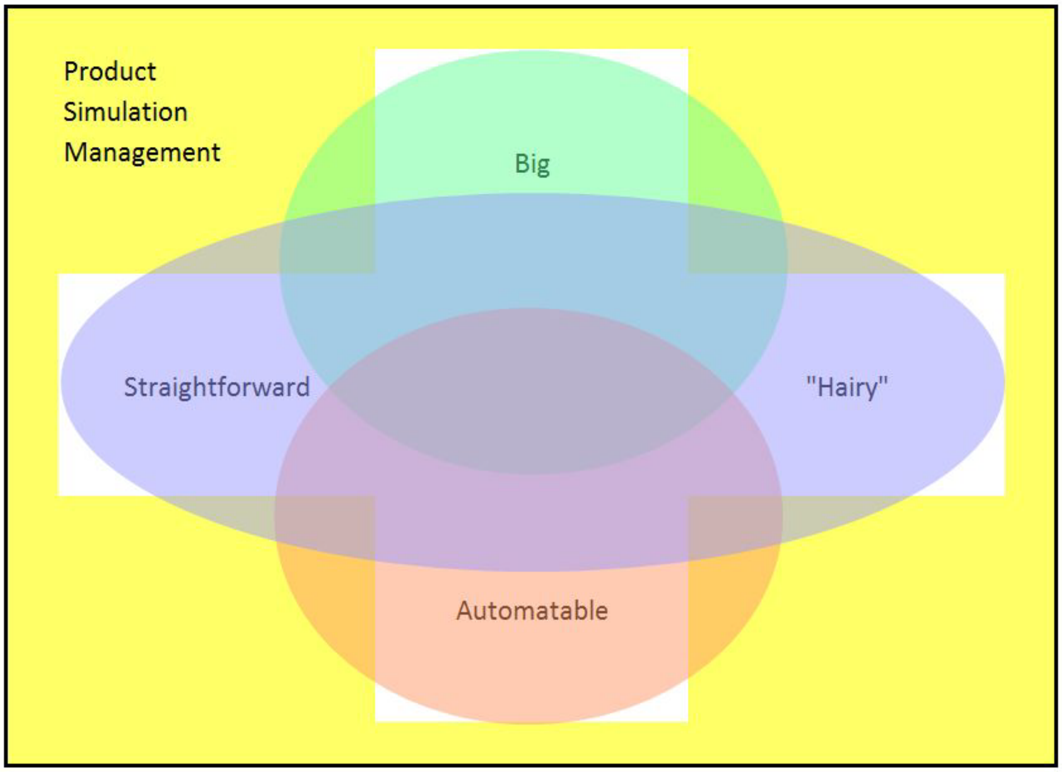

Figure 1. Market Map of MCAE Domains

In this white paper we describe various types of MCAE customers, and identify natural software product groupings in the market. The market map is then discussed in detail, with classes of problems delineated.

We then provide observations and related recommendations to engineers and managers who are considering MCAE.

Note: For a comprehensive glossary of MCAE terms and a history of MCAE, please visit *http://cyonresearch.com/mcaeglossary* *or* *http://cyonresearch.com/mcaehistory*

Introduction

MCAE (mechanical computer-aided engineering) applications began as tools for aerospace stress engineers. Over time, the world of MCAE grew to necessitate data- and process-management tools as well.

Both suppliers and customers recognize the value of comprehensive simulation—the idea that the culmination of all analysis types is to have a digital version of the design to which to apply tests that, if they had to be done with a physical prototype, would be expensive and time-consuming. While existing analysis software is far from this ideal, its value in the partial realization of that dream is great.

The state of the art of MCAE is continually advancing. New algorithms for advanced mechanical simulation take advantage of ever-more-powerful computing platforms. Automatic mesh generation; simplified user interfaces; accommodation of different types of nonlinearity; abstract modeling; and many other feature areas have been improved.

There are hundreds of MCAE products on the market[1] that address a wide variety of problems; but the market itself is not clearly segmented in customers' minds. There is some segmentation based on price, but without any clear relationship between price and capability. And there is no apparent correlation between price and ease of use—if anything, we find that expensive programs are often harder to use than lower-priced ones.

In our study of the MCAD (mechanical CAD) market, we developed a research methodology that defines a market's character. It seemed appropriate to apply that methodology to the realm of MCAE (focusing on geometry-based MCAE) and see if there is a basis for a similar definition of product categories.

The result of this process when we examined MCAD was that we found two clearly defined markets, delineated by price, distribution model, and vendor focus. We labeled those markets "mainstream" (formerly referred to by the industry as "mid-range") and "specialized" (formerly referred to as "high-end").

Upon our first examination of the MCAE market, it seemed that the software products fell neatly into two categories that could also be designated, as in the MCAD market, "mainstream" and "specialized"—with "mainstream" referring to the lower-cost, designer-oriented tools, and "specialized" pointing to the complex, expensive, specialist-oriented tools.

[1] The revenue leaders are (alphabetically) Altair, ANSYS, Dassault Systemes, MSC.Software, and Siemens. These account for approximately two-thirds of MCAE revenues worldwide.

The Complexity of MCAE

Mechanical analysis is a field of immense complexity. It has taken centuries to develop math that models the characteristics and behaviors of physical objects to useful degrees of accuracy, and modern products—ICs, airplanes, cars, consumer products—continue to challenge our ability to come up with ways to understand their behaviors.

Here are just some of the dimensions of the challenge:

- Nature of the problem
- Nature of the question
- Level of uncertainty
- Desired level of precision
- Nature of material
- Sensitivity to the mesh
- Geometry
- Topology
- Connections and Assemblies
- Loading conditions
- Coupled physics
- Dynamics and Motion
- Ballistics & other niche physics

MCAE software and its markets reflect this complexity.

Alas, there does not appear to be such a straightforward delineation in the MCAE market. We found that there is not a clear partition of buyers along the lines of "specialized" and "mainstream," since companies that buy "specialized" systems also buy "mainstream" systems. Also, the distinctions between the product classes seem to lie more along the lines of the user interface than in system capabilities; "mainstream" systems can handle problems as large as those of "specialized" systems.

There are indeed different levels for MCAE products, and the software in the different price categories is sold differently. But those distinctions alone are not sufficient to help either vendors or customers better understand the market.

What, then, are the natural groupings of MCAE products? What must potential customers know in order to make appropriate system selections? What should vendors know about this market if they are to reach more customers?

The goal of this white paper is to resolve these questions, draw conclusions, and make recommendations to customers.

The MCAE Market

As customers realize the value of MCAE in design, it is increasing profits for large and small companies. It grants the power to move some of the most expensive and time-consuming aspects of the engineering process away from physical prototyping and into the fast, cheap, and safe environment of electronic/digital prototyping. Companies of all sizes are realizing enormous gains, cutting time-to-market while producing designs that are more reliable and efficient than ever before.

In consequence, the MCAE (mechanical computer-aided engineering) market—which is about $2 billion per year[2]—has reached a point of inflection upward in its growth[3]; earlier segmentations no longer serve to describe it well. Changes are occurring in the vendors' views of their target markets, and products are being modified, and new products developed, accordingly.

This dynamism and the shifting usage patterns of MCAE make this market difficult to comprehend. Our research revealed substantial variances in the ways the market is viewed by different vendors, consultants, and customers.

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Customer Types

An important aspect of the MCAE market that is immediately evident is that there are two groups of customers:

- **Specialists** focus on analysis in their work. Design or project engineers send them problems to be analyzed, and the specialists employ their skills to provide definitive, accurate, and precise results. These experts typically employ a wide range of MCAE tools, although each individual masters only a handful at most. They may receive models in the form of MCAD data and perform whatever steps are required to prepare models suitable for analysis. They may also create their own models to analyze in

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[2] 2007 MCAE revenues for the top firms:

- ANSYS at $390M
- DS at about $250M for the DS analysis business, including COSMOS, Abaqus, and CATIA Analysis
- MSC at $247M
- ALTAIR at $140M (private)
- Siemens at $120-150M
- CD-Adapco at about $60M
- Moldflow at about $58M
- LMS at $30M (software and related services only – not their testing business)

Total approximately $1.3B; there are also several hundred small companies that build products based on tools like Simmetrix (reported in a personal communication). The bulk of these are very small firms (1-2 people) with highly specialized products, most of which are in the MCAE market. We estimate the total annual revenue of these firms at$700M, bringing the total MCAE market to about $2B.

[3] Cyon Research bases this opinion on the rapid growth in the percentage of mainstream MCAD sales that have MCAE as part of the package. This includes SolidWorks Office Premium, Solid Edge with Femap Express, and Autodesk Inventor Professional (and Inventor Simulation Suite). Together, these products have gone from less than 5% of their respective mainstream MCAD mix to over 20% (based on seat count) over the past five years.

advance of detailed design. They return results to their customers in the form of graphical displays, movies, charts, and tables.

It is not unusual for more than a third of the specialist's time to be spent on "walk-up" problems, brought by engineers who are expecting an immediate answer. These are not restricted to any particular class of problem, but may be of any type.

- **Generalists** are usually design engineers, who use MCAE software in support of their design activities, generally for verification of intuitive assumptions. They are typically seeking insight—figuring out design directions, making a "go/no-go" decision, or identifying potentially problematic areas in their product designs.

Moreover, customer *organizations* also fall into two broad classes:

- **Organizations that can support a dedicated analysis staff.** This group includes large enterprises; PLM-oriented organizations; large teams, with collaboration needs; those who must deal with problems that require supplemental code, in addition to the MCAE package; organizations seeking digital verification, rather than just design improvement—for example, for rapid analysis and validation of design alternatives (RAVDA[4]). By making it possible for designers and engineers to quickly review and evaluate a design alternative with live data, RAVDA enables engineers to work on the design in progress, rather than analyzing and evaluating their innovation against a snapshot of what the design was at some earlier point.
- **Groups in which designers also use MCAE tools**. This class includes not only smaller firms, but also the engineering departments of larger companies, where the designer does the analysis and everything else. According to vendors we interviewed, these focus on trend studies, rather than on multi-digit precision. These organizations need MCAE products that integrate well with their MCAD software and support relatively low levels of analysis expertise with automatic meshing, a simple user interface, clear graphical results displays, and "reasonability" checks.

Since the inception of MCAD, vendors have been promising MCAE software that is so integrated with CAD, so automatic in meshing, and so helpful to the design engineer in terms of appropriately describing boundary conditions, that the need to resort to specialists would be greatly diminished. But despite continued improvements in ease of use, model transfer, automated mesh generation, and other capabilities, there has not been a general uptake of MCAE by design engineers to date.

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[4] In our 2005 white paper, "An Examination of UGS' Repeatable Digital Validation Framework," we introduced the term RAVDA (rapid analysis and validation of design alternatives) and discussed its implications. The paper can be downloaded at http://cyonresearch.com/whitepapers.

We believe that is about to change. The availability of inexpensive MCAE capabilities in mainstream MCAD software seems to have led to an upward point of inflection in the use of MCAE by design engineers who use this class of MCAD[5].

> *There are many people that equate broad access to simulation tools with a requirement to "dumb down" the capabilities of these tools. Beyond that, some still consider simulation the domain of highly trained analysts both today and into the future. This kind of thinking is rooted in an arcane perspective – one that doesn't take into account the sophistication of modern software methods or the power that is now available on desktop computers.*
>
> *The reality is that new solver technologies, modern software design methods, intelligent systems, and raw desktop computing power are making simulation results consistently reliable for a broad class of problems without complex set up or specialized knowledge. This fact is going to lead to a revolution in the use of simulation in product design. It's our duty as software vendors to bring that revolution to our customers.*
>
> - *Andrew Anagnost, Vice-President of Manufacturing CAD/CAE Products, Autodesk*

One challenge of this use by generalists is the tendency to interpret extremely precise results as authoritative, when in fact the results are only as true as the assumptions underlying the analysis. In other words, this approach may carry the risk of 'giving the correct answer to the wrong question.'

So on the one hand, designers without a lot of experience in the use of MCAE can now benefit from it through the improved design of new software. On the other hand, it is easier than ever to get results that are wrong—or worse yet, misleading—yet have them progress through engineering and manufacturing with the "authority" of having come from an MCAE package.

It is important to note that this is not a flaw of MCAE software. If the customer does not define a valid question, the results can be problematic. Vendors designing tools intended for use by the generalist have made addressing the issue of "asking the right question" a major thrust for their research, and hope in the future to deliver software that helps guide the customer to "the right questions."

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Nevertheless, some specialists warn that having easy-to-use MCAE software that invites designers to set up and run analyses without necessarily having a sufficient understanding of the underlying physics can have disastrous outcomes. Other engineering professionals maintain that putting MCAE tools in the hands of designers requires only relatively simple guidelines to avert catastrophic errors, while offering the potential of significant time savings in product development. Our research leads us to side with the latter group; the potential gains are enormous, and the dangers sufficiently well-understood, to prevent untoward outcomes.

Moreover, management must promote an atmosphere of ongoing on-the-job training and access to skilled consultants for mechanical engineers, and must practice diligent oversight. With these conditions in place, and with the advent of more fail-safe and easy-to-use tools from MCAE software vendors, successful use of today's integrated MCAE tools in the hands of design engineers can become a daily occurrence.

Decades ago, MCAE of any kind was only used by experts; MCAE tools were easily differentiated by price. But now, the important distinction is between packages designed for expert and non-expert use. Smaller MCAE vendors are becoming either more innovative or more niche-like—there is a package that offers CFD for blood-flow analysis, for example.

Meanwhile, specialists are focusing more on methods than on performing analyses per se. An important question for MCAE vendors to answer for their customers is: How can MCAE be used to drive design decisions in a timely manner? MCAE is becoming a necessary tool, like CAD. Its power suggests that it might offer strategic business advantages in the future.

In fact, we see the market bifurcating into two groups—specialists, who are engaged more and more with developing methods and templates, while pushing the envelope of the technology; and application-oriented engineers and designers—generalists—who use the templates created by the experts, or themselves acquire sufficient knowledge, to employ MCAE in the workflow of engineering.

Problem Types

One of our goals for the research that led to this white paper was to see if a characterization of the existing products into categories would be helpful to customers and vendors.

Our observation is that tools seem to cluster around their application to certain types of problems. Since this structure is observed, rather than imposed, we think of it as "natural." So we suggest a segmentation of MCAE products based on the types of problem sets they focus on:

Straightforward to Difficult to "Hairy"– The nature of the question being investigated forms the basis for the problem set. Depending on the question(s) asked, different solvers and strategies will need to be employed. The question(s) being asked can range from straightforward to “hairy”; speed to insight is critical.

At the “straightforward” end of the range, problems are addressed individually, with a single type of physics, often by designers within the design process; if multiple types of physics are necessary, they are solved sequentially rather than simultaneously. The use of analysis templates by designers, within the design process, where the template has been created by a specialist, also is part of the straightforward end of the spectrum.

At the other end of the range, “hairy” problems can be transient; dynamic; multiphysics; nonlinear; highly sensitive to mesh conditions; and so on (see sidebar, *The Complexity of MCAE*). Another aspect of this range has to do with relative scale, from component, to sub-assembly, to full system. “Hairy” problems include the domain of full system simulation, as in the case of a full vehicle simulation of ride comfort.

Typical “straightforward” problem:

- Simple data needs, requiring quick insight and validation of assumptions, or the exploration of design directions; addressed individually, often by designers within the design process; also for serial (as opposed to parallel) analyses, and running analyses based on a template, where the template has been created by a specialist.
- Key characteristics: “Round-trip” integration with MCAD is important.
- Examples of software used to address this problem type: SolidWorks Office Premium; Inventor Professional; Algor
- Benefits: Easy set-up of problems; simple user interface; fast response
- Limitations: Problem size and complexity; ability to handle complex inputs

Typical “hairy” problem:

- Projecting behavior of tread on rubber tires under different road conditions and different loading conditions, and different rubber formulations, under different temperatures, look at ride, NVH (noise, vibration, and handling), traction (grip), tire wear.
- Key characteristics: Requires sophisticated software that can handle coupled nonlinear materials, CFD, thermal, dynamics, etc.
- Examples of software used to address this problem type: ANSYS CFX, Abaqus, NX CAE
- Benefits: As an example, reduction of use of expensive laboratory tire-testing facilities and extensive road testing
- Limitations: Problem size and complexity; ability to handle complex multiphysics effects; requires expert analyst specialists

Big – Very large analysis models, with many degrees of freedom (more than 10^8)

- Typical problem: Flutter analysis of a Boeing airliner wing; fine-granularity drop analysis of cell phone.
- Key characteristics: Fine-scale resolution and the ability to address models with large numbers of components and features.
- Examples of software used to address this problem type: Abaqus, Fluent, NX CAE
- Benefits: Solve problems with hundreds of millions of degrees of freedom
- Limitations: Only for expert use; requires specific domain knowledge

Automatable– Problems requiring multiple types of analysis, repeated application of solvers, and automated transfer of data from one program to another; often including the creation of templates, so that generalists can run analyses with repeatable reliability, and validate results of analyses regularly.

Systems designed to process straightforward, big, and hard problems may also offer "automatable" capabilities. This example describes a requirement for a system that handles big problems, offers a repeatable framework, and may be specialized for the automotive industry.

- Typical problem: Evaluate subassembly in context of assembly iteratively, performing multiple parallel analyses and updating in real time—say, for a fuel injection system in a new car model. Also, create templates—standard analytical models for deployment and reuse by generalists.
- Key characteristics: Tools to create templates for use by generalists; tools to create processes, for repeatable validation; tools to create geometry-independent abstract analysis models; tools to drive geometry based on analysis results.
- Examples of software used to address this problem type: RDV (Siemens), MSC SimEnterprise, SIMULIA SLM, Altair PBS, MSC SimManager
- Benefits: Substantial time savings due to not having to redo setups and running solvers in parallel; ability to respond in near-real-time; repeatable tests.
- Limitations: Large upfront commitment to resources and training; specific domain expertise essential.

A critical aspect to understanding this view is that almost any problem can be addressed within any segment. In other words, it is not necessarily *what* the customer is looking at, but *how* he or she is looking at it, that directs the choice of tool.

As an example, consider a cell phone.

> *A "straightforward" view of the phone casing might defeature the model by "removing" the holes where the keypad goes. Doing this would make it easier to ask*

the question: "If someone steps on the phone, will the resulting deflection of the cover damage the circuit board inside?"

A harder question would be, "If I remove the cover, will the closure tab break off?"

A "difficult" question would be, "If I drop the phone, what will happen?" This would also include questions like: "Will the call get dropped?" which would entail a linkage between electronics analysis and the mechanical analysis.

A "big" question for something as small as a cell phone would have the phone modeled without any defeaturing. All the holes, fillets, etc., would be in the mesh model, and the mesh would be very fine; then asking, "If I drop it in a certain way, will the cover break?"

And a question that would fit the category of "automatable" could be "If I drop it, will it break?" In this case, many different runs of the same analysis might be necessary, each with some minor difference in the test conditions, such as the height from which it fell; onto what type of surface; the phone's rotation when it fell; what point on the phone did it land on; etc.

It is easy to see that these groupings do not have distinct boundaries; rather, problems cover a range from "straightforward" to "hairy"; any problem may also be "big" or "automatable." In the range from "straightforward" to "difficult" to "hairy," the bulk of the market dollars are spent addressing problems in the middle.

This is not a sharp partition of the field—it has no mutually exclusive classes, as many products address more than one class of problem. But each product seems to focus more on one area than on others. This may be an artifact of marketing happenstance, or may be a reflection of technical intention.

Other Complexities

Pre-processors, Post-processors, and Solvers

The typical MCAE process consists of the "pre-processing" of MCAD models, to prepare them for analysis with a particular solver; analysis with the solver; and finally, "post-processing" of the solver output into a desired format. Some products have their own pre- and post-processors; there are also products designed as generic pre- and post-processors, that accommodate a variety of solvers.

In order to solve a problem, it must be expressed in a format that a solver can use. Pre-processors are designed to support that need. They accept data in different input formats, allow the placement of loads and connections, and provide output in forms acceptable to specific solvers. Some pre-processors are tightly integrated with the CAD system, importing the model directly from it. Others require the user to re-create the geometry from scratch from within the pre-processor. Pre-processors also allow the user to create and define the placement of loads and mating conditions on the model.

Solvers are programs that apply the mathematics of analysis to the model in keeping with the discipline for which they are designed. For example, NASTRAN, a finite-element analysis solver that had its origins as a project developed for NASA, accepts models and loads and outputs stresses, deflections, and other calculated values, all in numerical terms.

Post-processors take the output of a solver and present the results visually, in a variety of forms.

It is the graphical nature of pre- and post-processors that is opening up the complexity of analysis programs for use by non-specialists.

Product Simulation Management

Of course, MCAE data, results, methods, and processes need to be stored and managed. That's what product simulation management (PSM) software is designed to accomplish. Other industry terms similar to PSM include simulation lifecycyle management (SLM – preferred by Dassault Systemes), simulation process management (SPM – preferred by Siemens PLM), and enterprise simulation management (ESM – preferred by MSC.Software).

Analysis and simulation processes are often uncoordinated and can produce large amounts of uncorrelated data. The purpose of PSM software is to manage simulation and analysis data, input, intermediate, and output; these systems sometimes tie together different types of analysis programs from different vendors. In particular, bringing together physical test data and analysis and simulation data can be challenging; PSM systems support this process.

Consider any company dealing with an "automatable" type of problem, such as the cell phone example above. There may be massive amounts of data generated by such a study. Now consider that there may be many iterations of the design, each with its own set of test runs. In addition, the company may have many lines of cell phones, each of which needs to be subjected to the same set of tests—perhaps to validate "ruggedness" before going into production. Without PSM, dealing with such a mass of data would be difficult, at best. By combining PSM with tools for creating "test templates" (as described in the definition of the "automatable" category), such validation can be straightforward.

- Typical domain: MCAE and simulation data and process management
- Key characteristics: Tools to manage simulation data, constraints, load conditions, analysis results, and related processes
- Examples of software in this class: SimManager, Teamcenter [Analysis], Ansys Workbench, SIMULIA SLM
- Benefits: Data and processes surrounding MCAE and simulation are plentiful and complex. PSM products facilitate the management of the data and the automation of these processes, saving time and enhancing repeatability.

- Limitations: There is a certain amount of overhead involved in maintaining a useful and functional PSM system.

As noted earlier, we have reached an upward point of inflection in the use of MCAE by generalists. This is the primary reason we expect the generalist segment of the market to grow faster than the specialist segment. At the same time, specialists are driving vendors to develop process tools—software that offers ways to apply complex analyses more automatically and more repeatably than is currently possible. This will be a strong driver for increased use of tools by the specialist; hence we expect strong growth in this sector, though not as strong as in the generalist sector.

Another "slice" of the engineering software market that overlaps with MCAE is PIDO—process integration and design optimization software. The "process integration" portion involves capturing and automating processes using graphical symbolism, facilitating the combining of disparate tools into a single workflow. "Design optimization" is a catchall phrase that encompasses the full and growing spectrum of tools addressing this issue.

Primarily used within the aerospace and automotive industries, PIDO use is spreading to other product areas.

Market Map

We use market maps to help visualize the relationships with a market. We offer the market map, not as a precise tool to determine if one product is better than another, but as a "cartoon" to help the reader grasp difficult relationships.

Our "map" (Figure 1) of the MCAE space is based on the classes of problems mentioned above (and delineated further below). While it is possible to place products in the MCAE space (grossly) overlaid onto the problem sets as shown here, we have found it more useful to take the abstraction a few steps further. (Note that these problem-class "bubbles" sit on top of the domain of PSM software.)

In Figure 2, the x-axis is the nature of the question being asked and the y-axis is the scale of the problem in degrees of freedom. The map shows three regions: straightforward, difficult, and "hairy." Straightforward problems are those that are solved in a continuous workflow best served by products with MCAE integral to an MCAD system. "Hairy" problems are complex and big, and often require multiphysics solutions.

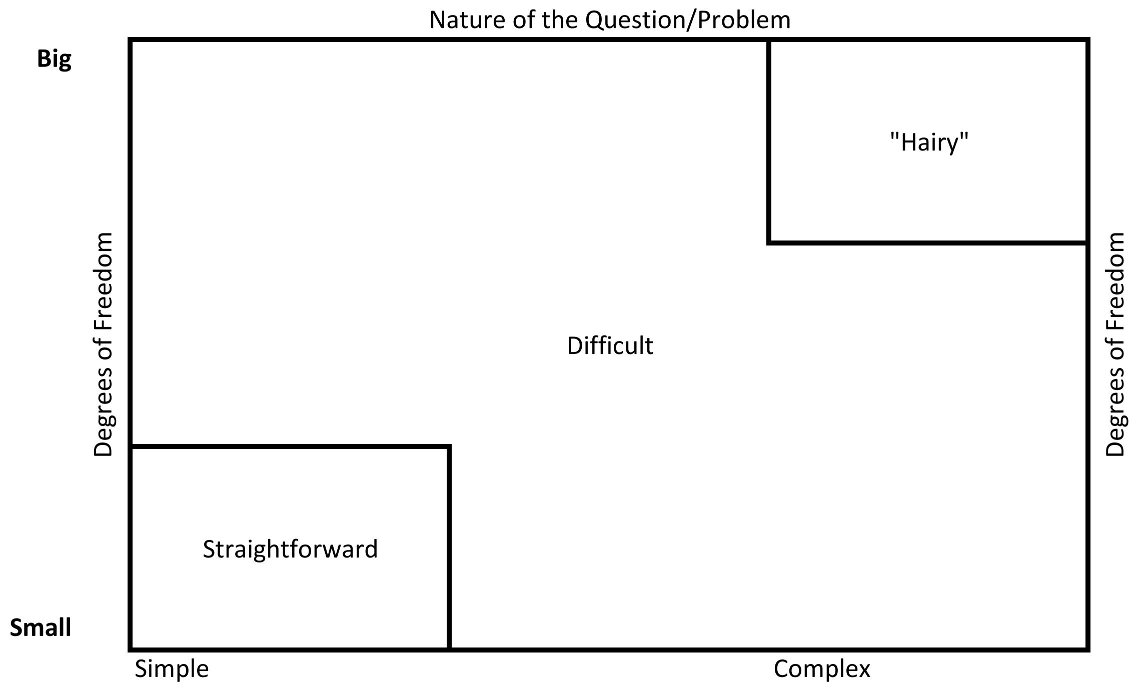

Figure 2. Degree of Difficulty. Relationship between the nature of the question/problem and our classification of "straightforward" to "hairy."

Figure 3 highlights the region where automatable processes make sense (the hatched area). This region is "just right"—not too big or difficult to automate, not so simple as to be of little value.

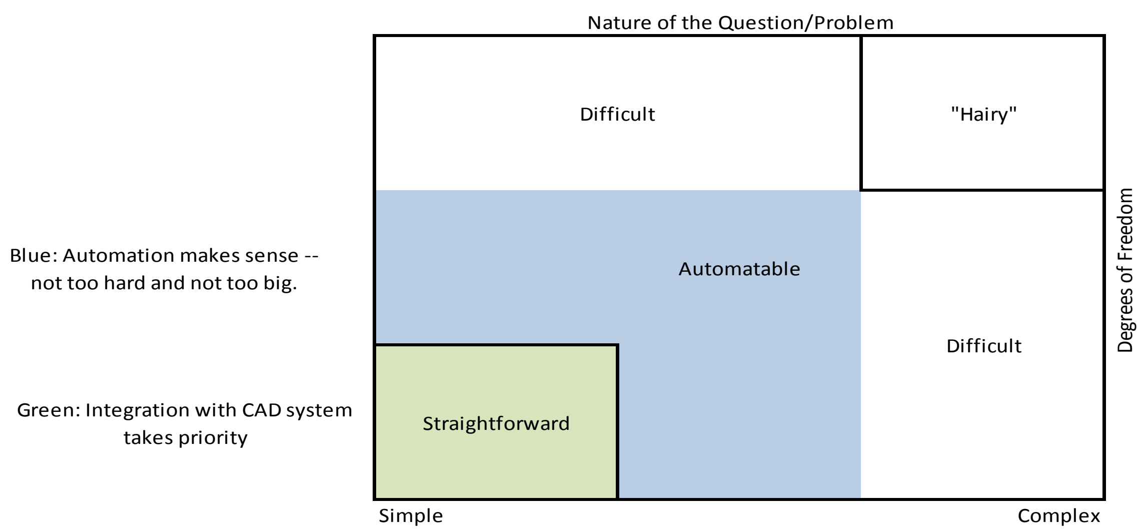

Figure 3. Region of Automation

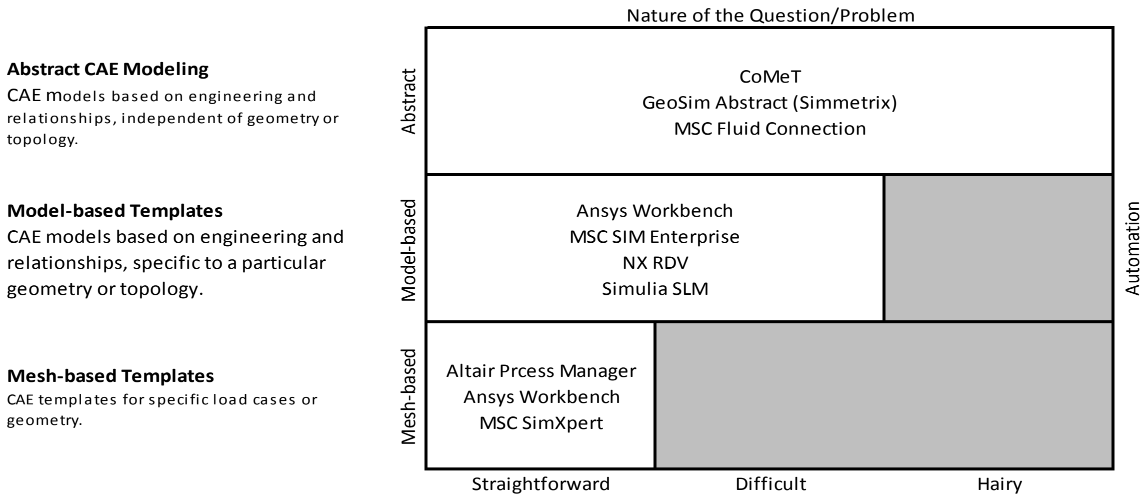

Figure 4. Degree of Automation
Note: The placement of a product within a box is indicative of its primary usage, not its scope.

Figure 4 highlights the products that serve the automatable sector. The y-axis—sector—is divided into three levels of increasing sophistication of automation. On the x-axis are the three regions of the first map.

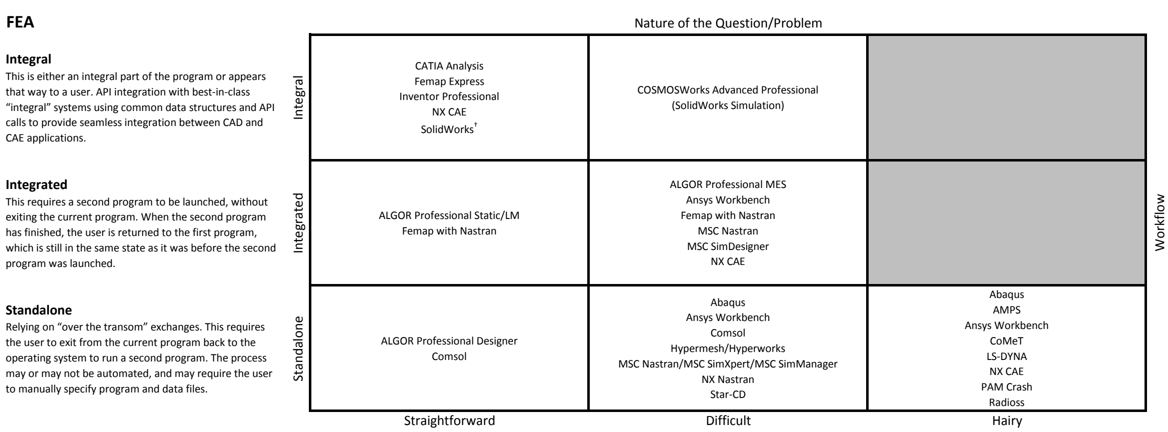

Figure 5. Workflow versus Difficulty for Finite-Element Analysis
Note: The placement of a product within a box is indicative of its primary usage, not its scope. Also, products within a box are not necessarily equivalent and may have differing levels of functionality.
†Includes SolidWorks, SolidWorks Office Professional, and SolidWorks Office Premium

Figures 5 and 6 are similar, but juxtapose workflow integration versus problem set. There is a dichotomy between high workflow integration and the ability to solve "hairy" problems. This chart shows the tradeoff between the choices. You can optimize workflow or you can optimize for capability, but you can't optimize for both—the upper right portion of the diagram is likely to remain empty for some time to come.

There are hundreds of CAE software vendors and many different areas of focus. This table shows a selection of those that address the FEA space, but it is by no means exhaustive.

CFD

Integral
This is either an integral part of the program or appears that way to a user. API integration with best-in-class "integral" systems using common data structures and API calls to provide seamless integration between CAD and CAE applications.

Integrated
This requires a second program to be launched, without exiting the current program. When the second program has finished, the user is returned to the first program, which is still in the same state as it was before the second program was launched.

Standalone
Relying on "over the transom" exchanges. This requires the user to exit from the current program back to the operating system to run a second program. The process may or may not be automated, and may require the user to manually specify program and data files.

Nature of the Question/Problem

Workflow	Straightforward	Difficult	Hairy
Integral	SolidWorks Flow Simulation Nika Star-CAD Series		
Integrated	ALGOR Professional CFD CFdesign EFD.Lab Flowizard	Electronic Systems Cooling (Siemens) Fluent MSC Fluid Connection NX Flow Star-CCM+	
Standalone	Comsol	Flowtherm Fluent Star CCM+	Fluent Star-CD AMPS

Figure 6. Workflow versus Difficulty for Computational Fluid Dynamics
Note: The placement of a product within a box is indicative of its primary usage, not its scope. Also, products within a box are not necessarily equivalent and may have differing levels of functionality.

Observations

In our research for this paper we spoke with executives from all the leading MCAE companies and with many customers, representing a broad range of organization sizes and management levels. Their comments and observations (emphasis is ours) helped us develop the understanding of the MCAE market that is reflected herein.

Several of the interviewees offered cautionary advice; most focused on the need for the customer to understand the analysis. Some specialists are concerned that generalists will misinterpret the results of their own analyses:

Dr. Bill Hall, retired NASA analyst, who helped establish CAE within the space agency:

> *"Just being capable of running an FEA program is not sufficient in providing designers with meaningful analysis results. With today's capability to generate FEA models with automatic mesh generators almost anyone can perform FEA. You have to know about structural mechanics, too.* ***You need to be capable of verifying, through hand calculations or other means, that the FEA results make sense.****"*

William Morgan, of Morgan Design Analysis Ltd., a UK firm that specializes in piston design and analysis:

> *"Analysis tends to require specialists. Very few people can cope with CAD and FEA. This may or may not be a disadvantage, but* ***'dumbing down' analysis is not an option that should be considered.****"*

Marc Halpern, Research Director: Design and Manufacturing for Gartner:

> *"For standard design methodologies, some design engineers can do it. Therefore, in those firms that have full time MCAE needs, experts should offload routine work to those designers. However, the experts should be responsible to ensure that designers conform to best practices. In companies with intermittent need for MCAE and little prior experience, it makes more sense to go to specialty MCAE consultants than try to maintain a dedicated MCAE staff."*

To the credit of the vendors, it must be pointed out that at least some of the packages designed for use by generalists—especially those that work inside MCAD systems—are designed to focus on specific types of problems. Some have in place features to encourage the customer to consider the validity of the questions they ask.

Turning the conversation to the market, we heard:

Dr. Garret Vanderplaats, CEO of Vanderplaats Research & Development, Inc., a CAE optimization software company:

> *"The goal of engineering is design and optimization. We now have well-developed optimization tools. Usability is the weak link–and hence an important area of progress for us."*

Joe Walsh, Vice-President of Business Development, Simmetrix, Inc.:

> *"Used to be only experts used CAE; just price differentiated the categories. But now, it's expert vs. non-expert use that defines the market."*

And finally, regarding ROI, there are two strong trends. First, putting power in the hands of the designer; and second, the power of using templates to automate the process of running analyses and validation:

Richard Bush, Marketing Director, Digital Lifecycle Simulation, Siemens PLM:

> *"Siemens PLM's vision and strategy is to make simulation pervasive across the product lifecycle. Once you have [advanced MCAE capabilities in a development environment], I can think of many good reasons why our customers want to use it in design.*
>
> *"Sometimes the issue is turnaround — designers often ask simple questions; but when they give them to the analysis team, it might take weeks to get them back—and not just because of backlog. Giving the specialist tools so that they can in turn develop tools (or wizards) for their own design teams can enable the designers to safely do the analysis in minutes or hours.*

> ***"[One] German car company is giving analysis tools to their designers to improve the design before the validation phase. A valuable side effect of this approach is that both teams now have a better understanding of the challenges the other teams face."***

Jason Faircloth, Marin Bikes:

> *"I'm the product manager and product designer; we're a small company. Before we got [mainstream MCAD with bundled MCAE],* ***it would typically take me 18 months to bring a new design to market. The finite-element and motion analysis software have enabled me to almost eliminate physical prototypes. With the software, it's now 9 months, and getting faster—and the product is better. This is our future."***

The Future of MCAE

The MCAE market is changing. The center of gravity is shifting from highly technical tools that were strictly the province of trained specialists to powerful, more-accessible products that can be used by "generalist" engineers with relatively little expertise in physics. Even small firms[6] are reporting the reduction—and even elimination—of physical prototypes through the use of appropriate modeling and simulation tools (for example, see earlier comment from Marin Bikes). As MCAE capabilities become even more integrated with mainstream MCAD, this adoption will only accelerate.

New and sophisticated software tools, such as the transformative products of which abstract modeling preprocessors (e.g., those of Comet, Simmetrix) are a harbinger, are poised to radically change the way MCAE is done. Among other benefits, they provide the benefit of the deep analysis knowledge of experts to all design engineers—far beyond the capabilities of templates.

The inexorable increase in computer power is making it possible to make ever-more-powerful tools available to all—for example, to enhance analysis and optimization through the use of statistical variables rather than fixed values.

Another important area of growth is in system-level integration and simulation. PIDO will become more significant as system-level integration and simulation tools evolve.

We believe MCAE will continue its strong growth, and that the "straightforward" category will lead the market.[7] This growth is fueled by the basic economics of the global manufacturing market: Competition is greater than ever; time-to-market more

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[6] Sophisticated analysis is not limited to large firms. Many small firms do some of the most advanced simulation possible.

[7] See footnote 5.

critical in terms of product success; and customers are less tolerant of low quality and delivery delays than ever before. MCAE offers proven results to address these pressures[8].

Supporting these trends are advances in the world of IT. Personal computers are now sufficiently powerful to handle large and complex problems. Parallel computers of immense power have dropped in price. User interfaces have become more refined and understandable. The Internet has grown to enable hitherto unimaginable levels of collaboration, in terms of both bandwidth and speed.

Perhaps most crucially, a generation of engineers has arisen that is totally comfortable with computers, and has high expectations from them. In fact, many engineers now study MCAE as undergraduates. This signals a sea change in the sociology of product design, in which former organizational barriers to the democratization of analysis are melting away.

For large firms, MCAE has long had a role in the engineering process, typically in the hands of analysis specialists. Its role will expand to embrace usage by design engineers. And in small firms, MCAE software is rapidly transitioning from "nice to have" to a competitive essential.

Recommendations

Both customers and vendors would be well-served by understanding the culture that has developed around MCAE—which, like all cultures, is not necessarily strictly fact-based and rational. Says Kishore Boyalakuntla, manager of simulation product management at SolidWorks,

> *"It just makes sense that when product designers create 3D models, they also virtually test their designs and ideas. Since the introduction of easy-to-use, functional and affordable simulation tools, I have seen a significant shift in the marketplace, where designers who have never done analysis have used simulation tools successfully to create better products. Material costs, new product designs and the necessity to increase productivity have significantly increased the adoption of simulation products in both the design and the analyst communities. We have seen several companies where analysis experts take the role of mentoring the designers as they focus on complex simulations.*
>
> *I believe that it is a red herring that designers cannot use analysis successfully to create better products. It is true that analysis results have to be verified against physical testing or hand calculations, but I have found that engineers are skeptical of analysis results and they go to great lengths to make sure the analysis*

[8] There is still much left to invent in our simulation of the real world. The market for new tools at the leading edge of simulation will also continue to grow, though we predict it will not grow as fast as the "straightforward" category.

results are accurate. Each year, more complex functionality becomes "mainstream," with innovations in simulation technology, and we expect the trend to continue. Just like drafting and 3D modeling have merged in the last decade, I expect 3D modeling and simulation to merge in the next decade."

This thought shines a light on an issue of profound importance to businesses considering the use of MCAE. When an issue is cultural in nature, it is by definition hard for members of the culture to discern it.

Over and above the natural groupings of products we suggest in this paper, there are two *usage clusters* that ought to be considered by both customers and vendors. One is when MCAE—of any type—is used for initial validation and insight within the intensely iterative design engineering process; the other is when MCAE is employed for detailed simulation and extensive validation. Each usage cluster either directly reduces or in some cases replaces the use of physical prototypes for product testing. The first demands ease of learning and use, training, seamless integration with MCAD, unequivocal graphical output, rapid turnaround, and guidance on interpretation of results. The second requires superb data and process management, and more ways to "slice and dice" the output, as well as maximum precision, even at the expense of turnaround time.

Both types of usage have their place in product design and manufacturing, even in the same company. But each requires a different user interface, learning curve, level of integration with MCAD, and more.

We recommend that customers considering the acquisition of MCAE software answer the following questions before evaluating new technologies:

- What types of questions are you trying to answer? Look at your problem sets and ask yourself how they fit into our characterization of problem classes. Are they largely "straightforward"? Then give first consideration to MCAE software that is embedded into your MCAD package. If they tend towards the "difficult" or are a good candidate for the "automatable" class, look first at tools that address those problem classes.
- What business goals do you expect MCAE to solve for your company? Examples: reduction in physical tests run, verification of final design integrity prior to prototype fabrication, to satisfy regulatory requirements, verification of design prior to issuing change orders, performance optimization such as strength-to-weight ratio, gain insight into distribution of stresses and temperatures within structures that can't be revealed by physical measurements, validation of design concepts prior to detailed design.
- What is the priority of these goals? Which should be implemented first, second, etc.?
- What sorts of physical problems will need to be analyzed or simulated to achieve these business goals? Examples: modal analysis; stress and deflection under load; fatigue analysis; drop testing; noise, vibration, and harshness; dynamic loading; fluid dynamics, conductive heat transfer, convective heat transfer, radiation heat transfer, manufacturing processes such as stamping and forging, and electric field simulation.

- At what point in your development process do you want most analysis to take place? Examples: prior to initial detailed design; during initial design but prior to final detailing; after completion of final design, following all change orders that affect structural integrity.
- In terms of difficulty, where do your problems fit on the “big-automatable” map?
- What sorts of people will perform each type of analysis? Generalist designers and project managers? Specialist analysts? A mix of both types? Will users be outside contractors, employees, or both?
- Do you currently have expertise in-house to perform the analyses you need? Or must you recruit and hire MCAE experts?

If you have decided to start running analyses earlier in the design process, re-organize accordingly before evaluating new software. If you use specialist analysts, assign them to product teams so that they can analyze products early. It isn’t necessary to invest in new technology to get the benefits of analysis in design development. After specialists start working closely with designers, the improvements needed to improve data flows from CAD to analysis and back again will become clearer.

Once you have prioritized your analysis objectives and reorganized to achieve them, you will be better equipped to evaluate new software technologies. Don’t try to solve all problems at once. Beware of software companies that promise panaceas. Attack the most important business problems first. Then improve other processes in order of priority.

Today’s MCAE software is bringing hitherto undreamt-of capabilities to a wide range of customers. With proper preparation and training, your organization can achieve substantial increases in productivity.

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