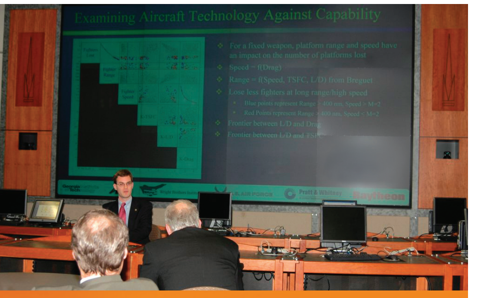
Graduate researcher Pat Biltgen demos in the CoVE at Georgia Tech.



CHALLENGE

Help organizations from industry, military and government develop the world's most sophisticated engineering designs, while improving safety, reducing environmental impact, and lowering acquisition and operating costs.

SOLUTION

Using JMP® to weigh options in the early stages of design, when what-if scenarios are played out and the many tradeoffs considered.

RESULTS

Interactive analysis and data visualization result in better, more innovative designs for complex systems.

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With JMP®, research engineers at Georgia Tech's Aerospace Systems Design Laboratory address the challenges of creating the next generation of rockets, jets and other complex engineering projects.

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Georgia Institute of Technology's Aerospace Systems Design Laboratory (ASDL) enables these dreams to come true. With end goals of improved safety, reduced environmental impact, and lower acquisition and operating costs, Director Dimitri Mavris, Michelle Kirby and the other research engineers use state-of-the-art JMP software in a one-of-a-kind laboratory setting. There they help organizations from industry, the military and government develop the world's most sophisticated engineering designs.

Most of the projects are related to aerospace, and all are complex. "The systems designs are so interdependent that collaborative planning becomes more valuable than in other engineering disciplines," says Kirby. "Aerospace is the discipline where interaction is most key."

And this is the lab to do that work, says Mavris. "ASDL is the only group that is this advanced in systems-of-systems thinking. We are at the cutting edge right now."

Before ASDL, explains Mavris, universities were producing graduates who lacked some of the qualifications industry leaders sought when hiring employees. Mavris set out to close that gap, launching ASDL in 1992 to link education and industry, detailed design and manufacturing, and science and engineering. "Students come in as propulsion or fluid specialists, and leave as more valuable systems integration specialists," says Mavris. Despite the fact that government and industry spend some $8 million at the lab in a given year, Mavris says: "We're not here to make money; we're here to create the next generation of engineers."

While Mavris and his 25 staff members groom graduate and undergraduate students for real-world success, the 200 students themselves help create the next generation of affordable and high-quality complex systems for industry and government.

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> "For every product, the breakthrough has almost always been in JMP."
>
> Dimitri Mavris
> Director of Georgia Institute of Technology's Aerospace Systems Design Laboratory (ASDL)

Adding the 'genius' of JMP®

In 1994, Mavris discovered JMP statistical discovery software from SAS and decided to add it to his laboratory's tools. When he saw JMP demonstrated in a life sciences environment, Mavris says, he knew the software would enable his team to conduct true experiments. He recalls, "I watched a demo with mice, and I saw rockets." Right away, he knew JMP would allow the interactive analysis and data visualization needed to figure out the best scenarios for such complex systems. "The visualization…whoever discovered that visualization is a genius," Mavris says.

"We don't want homegrown tools anymore," he says. "We want a complete package, and that's what JMP is. I consider it an empowering tool, a tool for the practitioner. It empowers you to do 100 times the work you could do." Mavris says he had tried Minitab, but, "we assessed it and it wasn't standing up." Now, in addition to JMP's use in the lab, JMP is used by nearly every student that comes through the master's program.

> *"The visualization…whoever discovered that visualization is a genius." –**Dimitri Mavris***

A collaborative visualization environment

But just using JMP in the traditional fashion wasn't enough. This interactive statistical software warranted a special environment, says Mavris. "We wanted to create an entity like no other." And that he did. The resulting lab is called the Collaborative Visualization Environment, or CoVE, and it features a 10-foot tall by 18-foot wide multimedia wall made out of 12 screens. "It creates a mosaic of information…a place to showcase all of this data."

Why so big? Because the number of variables is huge, as are the models. And the huge display enables research partners to clearly see and understand the systems models. Prior to building the CoVE, Mavris would show JMP profiler displays that would have to be scrolled, which would result in a less effective presentation. "After you scroll up and down a few times, you lose your audience," he says.

But not in the COVE, says Mavris. "After they see it, they get it. For every product, the breakthrough has almost always been in JMP."

Exploring options interactively

Some of the physics-based computational dynamic models, like those from NASA, are expensive to run and simply cannot be run in real-time for what-if analysis. Yet hands-on decision making depends upon real-time modeling. Mavris' challenge: How can his team explore options interactively, when it takes hours to just run one design past the physics models? The answer: surrogate modeling. Like the name implies, surrogate statistical models can represent expensive physical models, proprietary mathematical models or computer-intensive simulations.

The surrogate models actually become the communication tool for the huge, sometimes secret and often competitive types of projects ASDL takes on. If the engineers worked with all of the real parameters, vendors or groups of research partners would have to share proprietary information. And sharing is difficult because of competitive concerns among their partners, Mavris says. "So surrogate models are a safe way to share information hypothetically without worry. These models cannot be reverse-engineered, so it's how we get around political and organizational barriers."

Imagine working on something that won't go into production for a number of years. Engineers shouldn't be constrained by current parameters, which will be outdated by the beginning of the production process. Instead, the partners can use variables rather than constants. And planners don't have to be constrained by knowing what will happen in the future. All the plans can be carried out hypothetically and conditionally, Mavris says.

"And with such huge amounts of data and so many variables, surrogates allow us to look at information in bulk instead of focusing on details," Mavris says. "They actually speed up the process." Mathematical models of this scale are too big to easily and quickly conduct what-if scenarios. So surrogate ones are done first, then the expensive, mathematical one that follows should be accurate. Those are run on a Dell supercomputer system that, when combined with a similar system for the Georgia Tech physics department, provides 1,024 processors running in parallel.

Filtered Monte Carlo in action

Another important way of modeling at ASDL: Filtered Monte Carlo. Graduate researcher Pat Biltgen demonstrated how JMP is used in a military target simulation involving Air Force strike aircraft and anti-aircraft defenses. The goal is to see what weapons system will penetrate to a target, and what the characteristics of successful systems are. The major technical challenge in this research is the need to quickly execute probabilistic analyses and visualize complex, multidimensional results.

Using surrogate models, point designs can be quickly generated using accurate approximates of physics-based design tools. Surrogate models also enable rapid Monte Carlo Simulations to be run nearly instantaneously. These two techniques are combined to enable capability-based design and technology exploration. Using uniform distributions on the subsystem-level input parameters, the effectiveness of a proposed solution at the "system-of-systems" level can be quickly evaluated. The Filtered Monte Carlo technique is then used to "filter" or reduce the number of solutions from hundreds or thousands to a handful of points by applying constraints at the top level and identifying solutions that are left at the system and subsystem level.

Now the job has changed from exploring a complex, multidimensional mathematical space into querying a database of simulations very rapidly. Even with hundreds of thousands of points, engineers can show all the possibilities graphically in many directions with scatterplot matrices. Then they start brushing points, or dragging over areas that they want to select–or infeasible points they want to exclude –until they see points defining the opportunity space that satisfies what they are looking for.

Whereas profiling only shows up to three dimensions at a time, Filtered Monte Carlo shows opportunities in many more dimensions. Each point is a probe, and each surviving point that is not excluded by the conditioning remains to define further options. And that's what the engineers are after: options. A mathematical optimization will just find one solution, but a Filtered Monte Carlo will find all the combinations that work. It will present choices. After all, there are many ways to hit the target.

Another technique used in this exercise is the surface profiling feature that generates three-dimensional "cubes" that exercise the parametric surfaces captured by the surrogate models. Biltgen, describing the 64 discrete behaviors the team can show in the Air Force simulation, said, "We could have eight cubes and all of those cubes start break-dancing as the parametric slide bars are moved." Biltgen's description: "This is an awesome capability!" According to Biltgen, the ability to simultaneously query complex multidimensional spaces in a graphical manner is an enabler for capability-based design. "The primary problem that we have is that we can generate hundreds of thousands of designs, but no one is ready to see hundreds of thousands of designs," says Biltgen. "The visualization capabilities of JMP bring the decision maker into the process and allow him or her to see large amounts of information that cannot be explained in any other way," he says.

"We could have eight cubes and all of those cubes start break-dancing as the parametric slide bars are moved. This is an awesome capability!"

*– **Pat Biltgen***

"Aerospace is the discipline where interaction is most key."

–Michelle Kirby

"Awesome" might also describe the next generation of business jets–another ASDL project. Here, engineers analyze performance trade-offs in the early phases of design, allowing consideration of variables involving noise-level requirements, environmental emission standards and fuel consumption goals. "The methodology maps propulsion characteristics to overall system metrics such that the entire design space can efficiently be examined," write Simon Briceno and Mavris in *Quiet Supersonic Jet Engine Performance Tradeoff Analysis Using a Response Surface Methodology Approach*. "The design essentially has an analytical means to examine every conceivable alternative within the design space."

The result: a quiet supersonic jet engine that meets all regulations and costs less to operate. "They allow the decision maker to play what-if games and make tradeoffs in design early, knowing the system-level consequences of those tradeoffs. Also, the designer is given an understanding of the magnitude of impacts that different design parameters can have on responses."

In a paper written for a World Aviation Conference, ASDL's Peter Hollingsworth and Mavris look at a practical what-if scenario for the Hypersonic Strike Fighter, a fighter jet that can exceed five times the speed of sound. And they conducted the concept exploration in the presence of open and evolving requirements. One what-if question: What if they wanted to change a hypersonic vehicle from a land-based aircraft to a carrier-compatible system?

"Most likely," states the paper, "the designers would have never considered implementing the modularity or technologies necessary to achieve carrier compatibility in the initial vehicle design. Because of this, the addition of the carrier compatibility requirement (restraint) may render the system infeasible."

Rendering hypersonic fighters, supersonic jets or any other complex system infeasible is not an option anybody wants to consider. Says Kirby, it's better to weigh all of the options in the early stages of design, when what-if scenarios can be played out and the many tradeoffs considered. "JMP is at the core of this; it's been key," says Kirby. "After all, we are JMP power users."

If these engineers can make rocket science look easy, imagine what you can do with JMP. Find out at

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