ICE heats up design productivity

Networks of hundreds of communications satellites extend the Internet into orbit. Single-stage reusable launchers cut the cost of space transportation by a factor of 10. Hypersonic airliners carry passengers from Los Angeles to Tokyo in 2 hr. Lighter-than-air cargo haulers deliver automobiles directly from plants in the midwest to distribution centers overseas. Robotic spacecraft penetrate the icy surface of one of Jupiter's moons in a search for liquid water and extraterrestrial life.

Conceptual design

Which of these visions will come to life, and which will go the way of the U.S. SST and the Spruce Goose? The answer, and the future direction of the aerospace industry, depends largely on design teams now working in industry and government to define the cost and performance of new ideas. These groups are conducting conceptual design, the first critical step in the life cycle of an aerospace product.

Although funding for this design phase is a tiny fraction of a project's overall budget, the conceptual design team's quality and productivity have a disproportionate impact on the project's success and, over time, on the success of the company. One reason is that conceptual design is usually conducted during the preproject, preproposal, or proposal phase, when budget levels are very low. At this stage, limited "bid and proposal" funds are typically distributed by managers who are motivated to investigate the greatest possible number of concepts for their high-payoff potential. Given limited funds, these managers usually allocate very small budgets for conceptual definition of each of many promising ideas.

When a concept definition activity shows promise, advocates must seek further project funding based on limited descriptions and rough cost estimates. Sponsors must work with the same limited information to lobby for project resources. Although no formal commitment is made, the conceptual design and preliminary cost estimate frequently define the project's key parameters before preliminary designs and detailed estimates are complete.

This problem has caused a few leading aerospace organizations to establish design centers to increase the productivity of the early product development process. Initial attempts emphasized advanced information systems, high-end design tools, and expensive facilities. But recently there has been a growing realization that shifting the emphasis to use of a team is the key to achieving breakthroughs in conceptual design productivity.

For multidisciplinary teams that use rigorous, repeatable processes, information systems play an important supporting role. Putting the team, the products, and the process first has enabled large productivity improvements to be achieved with standard desktop computers and inexpensive facilities. This new methodology is called integrated concurrent engineering (ICE).

ICE and JPL

Research conducted at California Institute of Technology and elsewhere suggests that the improvements resulting from ICE constitute a breakthrough. The Jet Propulsion Lab's Project Design Center (PDC) is an example.

The PDC houses two ICE teams, I and X. Team I does conceptual-level design of space science instrument systems; Team X does the entire integrated spacecraft, mission, and payload designs. Team X has been working for about three years and has completed well over 100 rapid, cost-effective design studies. The team has saved JPL several million dollars in conceptual design costs while producing these designs, several of which have become new space missions involving hundreds of millions of dollars in new business for JPL and its suppliers. It has reduced JPL's space mission conceptual design costs by more than a factor of three and the time required for typical deep space project designs from about four months to less than two weeks.

Because NASA, JPL's primary customer, requests many inexpensive project design studies, Team X does many one-to-two-week designs. Each study includes a mission trajectory design, a cost estimate, and a high-level flight and ground system design. One-week studies can include CAD configuration drawings, performance specifications, functional block diagrams, and equipment lists. The team can also provide rapid prototype models of custom designed spacecraft within two weeks of initiating a study. Last year Team X completed over 30 mission system studies in under 10 months to support development of NASA's solar system exploration road map.

Team I, which is newer than Team X, supports the more detailed definition typically needed for space science instrument proposals. Its objective is to deliver instrument conceptual designs that are near the level of a preliminary design review. The team hopes to achieve this level of detail with integrated structural, thermal, and optical analysis within two weeks of initiating a design study.

TRW tries ICE

JPL is not the only organization benefiting from ICE. Recently TRW's Space and Electronics Group (S&EG) restructured its engineering teams and their design tools to implement the new ICDF. Using a phased approach, the company was quickly able to harvest the benefits of ICE in terms of product quality, conceptual design costs, and turnaround time. In a few months the ICDF team has conducted almost a dozen design studies, achieving a high rate of customer satisfaction. Typical products include detailed technical and cost reports, high-fidelity CAD models, system design trade trees, performance analyses of all major subsystems and functional block diagrams, and flight system development schedules.

Like Team X, the ICDF team also produces prototype models of its spacecraft for configuration studies and marketing purposes. The facility has already helped TRW move into new business areas by reacting swiftly and confidently to new and challenging customer requirements. The company's management is so enthusiastic about the ICDF approach that it is expanding the capability to other segments of S&EG's business.

The seven principles of ICE

Given these successes, it is important to understand the general principles behind ICE so it can be applied properly in other settings. At Caltech, this has been the focus of recent research that included observations of Team X and the ICDF. Also included were several practical experiments with student design teams. This work has shown that ICE works best when the developers consciously or implicitly subscribe to the principles of traditional concurrent engineering coupled with seven key principles of integration. These principles, which take ICE beyond practices commonly in use today, fall into the broad areas of processes, tools, and people. Although each principle provides gains individually, substantial synergy occurs when all are applied together.

Underlying all of these considerations is the fundamental principle of concurrent engineering—design activities carried out simultaneously, usually by teams that work together in one facility. These practices accelerate and improve the entire development process. Manufacturing representatives join the team early in the development cycle to ensure that the design reflects fabrication requirements. The effect is to reduce cost and improve quality.

ICE includes but goes beyond traditional concurrent engineering practices to take full advantage of available information systems and CAD tools, achieved by applying the seven key principles. Beyond enhancing productivity, use of these principles makes conceptual design more systematic and easier to control and measure. Finally, because many mundane tasks are automated in ICE, team members are able to make greater intellectual and creative contributions.

The systematic nature of ICE derives from the principle of well-defined productivity and product needs. This principle is based on the observation that the team must clearly delineate the time and cost savings and the quality improvement goals of the ICE system in light of the types of conceptual designs to be produced. The result is typically a list describing the products that must be created by an ICE system, along with an assessment of how much time and expense can be devoted to the process.

A product list might include descriptions of documentation, cost estimates, technical designs, and market analyses required by the team's employer. The design of the facility, the selection of the information systems, and the choice of design tools all depend on the contents of this list. Likewise, the team and the processes it will use should be selected based on the classes of products it will produce.

Understanding the products is not enough. Historically, most conceptual design teams have not naturally conducted themselves with maximum efficiency, in part because team members tend to understand their own contributions more clearly than those of their colleagues. Thus individuals often vie to drive the design to reflect the concerns of their own technical disciplines, wasting team resources. In some cases, areas represented by team members with strong personalities can be overemphasized in the design process, with detrimental results.

A good team leader can help to mitigate this problem, as can careful planning of what is done and in what order. It is also important to ensure that automated data transfer between workstations can occur in the right order, with team discussions interleaved as appropriate. This generic but flexible plan is called the team playbook.

The playbook must be developed concurrently with the facility's design tools and information system. It also helps to have a daily or hourly schedule that takes a concept design job from the idea stage to the level of maturity needed by the sponsor.

The playbook and the schedule cannot be developed by management or outside consultants; they must be developed by the teams that use them. Without this intellectual ownership, the team will not use such plans effectively. The script and the process plan should be dynamic enough to capture the breadth of the products the team will create, yet disciplined enough to ensure that the team stays on plan and turns out the required products.

State-of-the-art information systems let team members conveniently exchange product design, marketing, cost, and other technical data. When properly implemented, the information system can automatically capture snapshots of the evolving state of a product development team's work in an integrated distributed database. Links between team members' design tools enable changes in the product concept, or in any of the parameters that affect the team's work, to be transmitted to other engineers instantly. This eliminates the need for time-consuming, costly documentation and provides a disciplined understanding of the progress of the team's work.

Tools and facilities

Rapid, integrated, real-time design and analysis tools must be carefully selected and linked for use during team sessions. Two key criteria for tool selection are compatibility with facility information systems and compatibility with the work pace designated in the playbook. Well-trained teams using this class of tools can break the "meeting-design-analysis-documentation-meeting" cycle and stop the endless games of phone tag and e-mail overload of the 1990s.

The breakthrough alternative in ICE is playbook-based design sessions in which discussion, design, analysis, and documentation are done in a real-time, concurrent mode. Design and product refinement iterations that would take weeks in a traditional concurrent engineering approach can be reduced to hours or even minutes.

The information systems and design tools associated with these improvements need not be high-end custom developments. It is much easier to base the information systems on low cost desktop computers with common office application suites. Engineering design tools can be developed using simple visual programming languages and spreadsheets, or accessed via standard interface protocols from these common applications.

While effective teams can work without custom facilities, design centers that support ICE principles can boost team performance significantly. A facility with a proper layout, good acoustics, and appropriate display and presentation equipment helps things go faster and more smoothly. Video and audio teleconferencing should also be available. Variable lighting and variable furniture can help people shift from presentations to work sessions without changing locations.

No process, system, computing tool, or leadership style can substitute for an experienced team and its expertise. The difference in ICE is that the organization must dedicate the team and much of its members' time to the process of producing conceptual designs faster and better. Team members must be well trained and willing to use an integrated set of rapid design and analysis tools.

They also must be willing to work in a fundamentally new way, and this requires a degree of mental flexibility. Some cannot, or will not, adapt to the new environment, and substitutions occasionally must be made when people do not work out. Thus building a team takes time.

Finally, management must support the team, supplying its best people and devoting real intellectual and financial resources to providing the best tools and processes it can offer. The result is a new kind of team that can rapidly produce great conceptual designs at unprecedented savings.

Future development of ICE design center technology will take the process further into the design cycle and integrate it more broadly across multiple organizations. Extending ICE into virtual facilities will enable teams in different locations to work together in real-time design sessions. A great deal of excellent R&D is being conducted on information systems technology related to these developments. This research, though not specifically directed at ICE applications, will benefit ICE facilities and design teams and help to define the role of the aerospace industry in the 21st century.

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CONCEPTUAL DESIGN

Purposes

Investigate the broadest possible range of new business opportunities with limited resources
Develop accurate performance estimates
Correctly evaluate business cases for new concepts
Respond quickly to sponsor inquiries and "what-ifs"
Develop low cost "winning" concepts
Develop high performance "winning" concepts

Desired productivity improvements

Reduce cost of conceptual design
Enhance quality and fidelity of conceptual designs
Enhance accuracy of market and cost estimates
Reduce time/schedule for conceptual design
Include design for cost tools and methods
Include design optimization and full exploration of design trade space

SEVEN KEY PRINCIPLES OF ICE

Processes
- Well understood classes of products
- Team playbooks and schedules

Tools
- Tailored, integrated information systems
- Desktop application-based design software
- Tailored facilities

People
- Dedicated team expert in processes and disciplines
- Institutional stakeholder/management ownership of approach

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