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Three Enabling Technologies for Integrated Product Development

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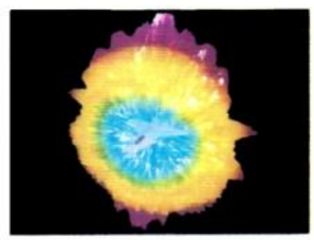
feature based parametric design & analysis

stereolithography

visual product development



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THREE ENABLING TECHNOLOGIES FOR INTEGRATED PRODUCT DEVELOPMENT

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ABSTRACT

The aerospace industry, long a National leader in meeting seemingly impossible challenges, faces major challenges today that threaten its very survival. Key among these challenges is the ability to produce affordable products that meet increasingly demanding requirements. The concepts embodied in Integrated Product Development (IPD) are being implemented by many aerospace companies to meet these challenges. This paper presents three automation technologies that enable the IPD process by improving team communication, reducing iteration time, and improving insight. They are parametric, feature based design and analysis, stereolithography (automated fabrication), and visual product development. When implemented in the context of a functional IPD environment, these tools can make significant contributions to the production of highly competitive aerospace products.

INTRODUCTION

The aerospace industry is no stranger to challenges. One hundred years ago, the challenge was powered manned flight itself. Seventy years ago, it was a structurally stable single wing configuration. Forty five years ago, it was jet propulsion, followed soon after with the challenge to fly faster than the speed of sound. As little as 30 years ago, the challenge pushed out to Mach 3 and beyond, and into space. Putting men on the moon became a challenge that rallied the spirit and resources of the entire Nation. Over the last ten years, the industry has met the challenge of operating a reusable transportation system in space and a world wide airline transportation system within the atmosphere.

Each of these challenges, seemingly impossible in its day, has been met and has formed new foundations for even more challenging ventures. The industry has successfully and consistently met the challenges of faster, farther, bigger, and more maneuverable. Today, however, despite its past successes, new challenges are faced that threaten the very survival of the aerospace industry. These challenges reflect a rapidly changing world, more demanding requirements, increased competition, a decreasing business base, and the need for affordable aerospace systems.

TODAY'S CHALLENGE

Since World War II, the aerospace industry has enjoyed a relatively stable business environment. The consistent level of prosperity during this period meant that technology, and technology generated advances, could be handled with very little apparent financial pain or sacrifice. At the same time, a focused, monolithic threat rallied public approval for both a strong defense and a preeminent role in space exploration. Cost and efficiency, while important, took second place to expanding the technology and performance envelope.

Today's environment has seen rapid and fundamental changes, however. The focused threat evaporated, almost overnight. A sluggish world economy, widespread social unrest, increased expectations, reordered priorities, and increased foreign competition have propelled cost and efficiency into major developmental considerations.

This is not to imply that the emphasis on improved performance has abated. On the contrary, as was demonstrated in the Gulf War, the demand for new technologies like stealth and advanced avionics continues. The resulting dichotomy requires the mastery of increasingly complex physical phenomenon with decreasing resources.

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In balancing the complex issues of cost and performance, it would be difficult to imagine sacrificing the survivability demonstrated over Baghdad by the F-117A to keep costs under control. Nor is it realistic to assume social priorities will suddenly shift back to the patterns of the past fifty years. The reality and the challenge faced by the aerospace community today are that it must accomplish far more for far less. Its products must continue to push technology and performance, while at the same time slashing costs and striving for the utmost in true efficiency.

While some companies may find this environment hard to cope with, the fact remains that the breadth of opportunities available in the past, no longer exists. In 1943, for example, over 85,000 defense related aircraft were produced in the US.[1] In contrast, projections for Fiscal 1993 are 394, less than one half of one per cent the level of fifty years ago.[2] To make tens of aircraft per year, rather than thousands, requires increased commitment to efficiency and streamlined operation.

Thus the challenge to the aerospace industry in the 90's is to survive in this radically different environment, and survival is predicated on making affordable products, even in the face of more demanding requirements and limited production runs.

MEETING THE CHALLENGES OF THE 90's

The challenge is clear. The question of "how" is less obvious. A brief look at the evolution of product development in the aerospace industry over the last 50 years offers some potential insight.

Many of today's aerospace companies trace their roots to the 20's, 30's and 40's. Small teams of talented people with broad skills and creativity provided the core for developing new, state-of-the-art products. Small administrative support teams supplemented the core team to permit them to focus on the end product. Where customers were involved in the development process, they participated, directly mirroring the size and efficiency of the core team. Responsibility and communication were not buried under the weight of large, complex organizational structures. Team members were intimate with the products that they designed and produced and the activities needed to meet day to day, week to week schedules. The result of this parallel team process was rapid, relatively low cost production. This process is illustrated schematically in the upper half of Figure 1 with the overlapping color bars indicating the parallel integration of team activities.

As business grew and complexity increased, the individual team members were often replaced by specialist organizations which were initially designed to mimic the performance of the individuals they replaced, and to handle the increasing work load.

As these organizations grew in size, however, communications became more difficult and focus shifted from the product to the organizations. Rewards and status shifted from being product oriented to organization oriented. As requirements increased and communications became less effective, more people were added to the functional organizations to keep up, thus further complicating communication, resulting in a spiral of diminishing returns. In many cases these large organizations lost contact with their original "roots". To manage the increasingly complex communication problems, the concurrent development efforts were replaced by formalized serial hand offs of information and decision making. Customers and support organizations followed suit (if not hastened the process).

At the time, however, the cost implications of the changes were not entirely clear, nor were they judged to be of great importance. There were plenty of large contracts with their associated large profits. Furthermore, the increasingly demanding requirements were deemed to necessitate more time and larger, more specialized organizations. These developments are illustrated in the lower half of Figure 1.

Today, the aerospace industry inherits these large organizationally oriented processes. Unfortunately, the premise that large specialized organizations and increased development times are needed to handle increasingly demanding tasks is flawed, especially when costs and a shrinking business base are considered. Minimum cost for a project are driven more by human interaction factors than by product complexity. Maintaining team continuity and motivation dictate a development window of 6 to 36 months, independent of product complexity, as shown in Figure 2. Increasing development times to compensate for increased complexity moves the project to the right of the optimum cost area into an area of sharply rising costs. While yearly expenditures may be decreased (frequently to accommodate funding

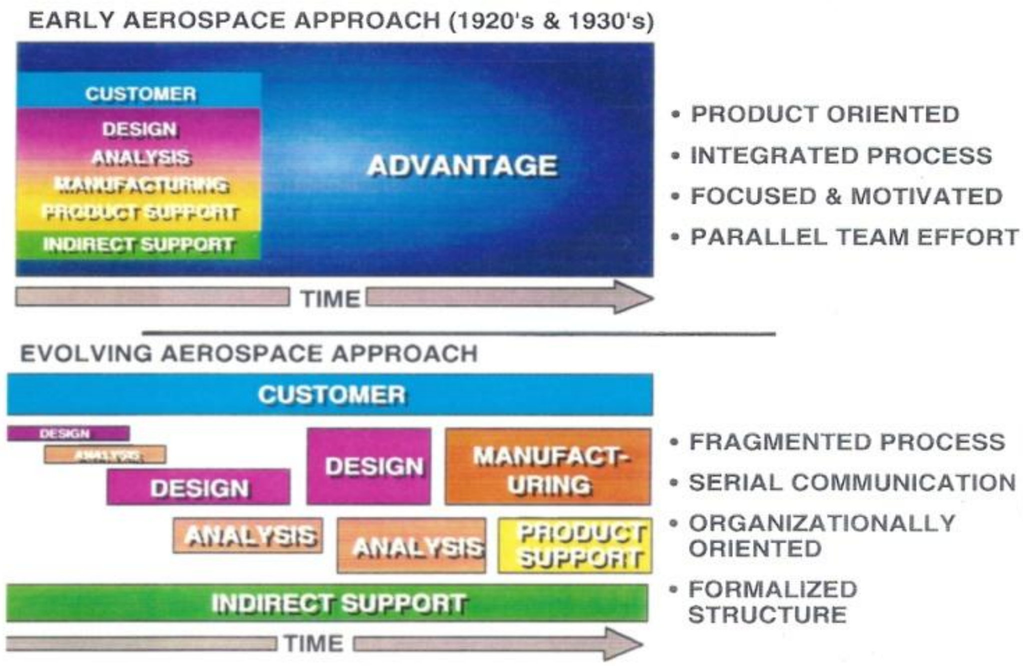

Figure 1. Schematic Comparison Of Two Approaches To Product Development

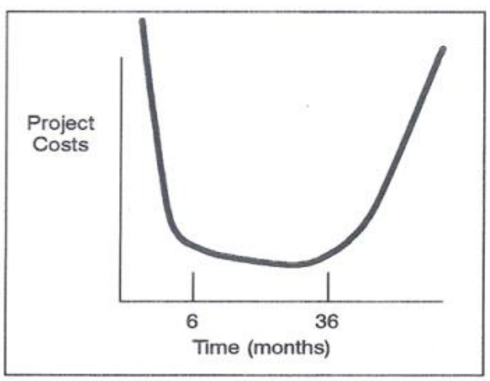

Figure 2. Relation Of Project Cost To Project Duration

shortfalls), total project cost escalate because of inefficiencies in communication, continuity, and motivation.

Likewise, the widely accepted practice of increasing team size, to compensate for complexity, complicates communication to the extent that cycle times may actually increase. In some cases, increasing team size may also mask the true nature of the problem

As a result, increasing either team size or the length of the design cycle is not the answer to affordability, and indeed can result in escalated costs. Short project times and small teams should **not** be viewed as measures of success or as goals, but rather as fundamental requirements for success and affordability.

THE IPD PROCESS

Integrated Product Development (IPD), or Concurrent Engineering as it is sometimes called, has generated increasing interest in recent years as members of the aerospace community (and industry in general) seek to recapture the benefits of earlier processes. Small, multidisciplinary teams, focused on the end product, working in parallel, and empowered with the responsibility, authority, and budget control to create customer oriented products, are the cornerstones for IPD.

Key questions remain, however. How can the methods identified with IPD work in the face of increasingly demanding requirements? How can a product be fielded in the optimized human behavior oriented 6 to 36 months, shown in Figure 2, in light of the increased complexity of modern aerospace systems. How can the paradox of affordability and complexity be met in today's aerospace environment?

A SOLUTION TO THE AFFORDABILITY PARADOX

At least part of the solution lies in the intelligent use of modern automation technologies.

By almost any measure, the advances in computer technology have been spectacular. Figure 3 represents the trend in most measures of computer capability, be it MIPS (millions of instructions per second), MFLOPS (millions of floating point operations per second), disk space, memory, through put, interactivity, etc. The one notable exception to the trend, shown in Figure 3, is cost/performance which continues to fall at an increasing rate. The result is the raw capacity to improve individual and team productivity, to enhance communication, to provide insight into complex physical phenomenon and to provide the ability to rapidly iterate through design space to optimize products.

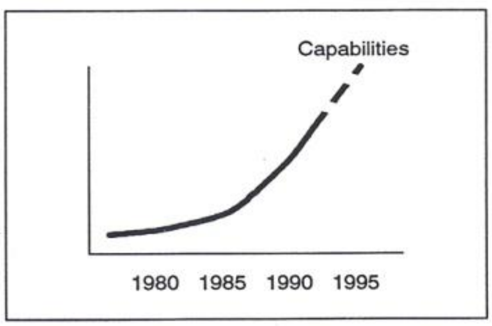

Figure 3. Computer Technology Trends

Hence, the capability exists to keep IPD teams "virtually" small.

Three of the most promising IPD enabling technologies are covered in this paper. They include (1) parametric, feature based design and analysis, (2) stereolithography (automated fabrication), and (3) visual product development.

PARAMETRIC, FEATURE BASED DESIGN AND ANALYSIS

Design is a highly iterative process. The ability to make rapid changes to a concept enables the ideas of each of the members of the product team to be incorporated into the design in a timely fashion. It also permits the exploration of a wider range of viable options thereby increasing the probability of finding an innovative, optimized design.

Manual drafting techniques, long the lynch pin of the aerospace design process, require a lengthy, tedious process to incorporate change. Computerized methods, both 2d and 3d, have relieved some of the tedium of capturing and documenting the design, but they still remain abstractions of the end product made of points, lines, and surfaces. Changes to the design still require scrapping of significant amounts of work to redescribe the new geometry. To increase the length of a simple box, for example, would require the erasure of 8 of the 12 lines that describe the box as shown in Figure 4(a). The eight lines must then be redrawn at the increased length.

New third generation computer based design tools are now available that can significantly reduce design and design iteration times. These tools are based on the concept of feature based parametrics. Rather than drawing parts as collections of points, lines, and surfaces, the feature based approach describes products as a collection of geometric features. The features in turn are defined by parameters which can be changed to generate new or modified shapes. With this approach, design time concentrates on capturing design intent rather than design detail. This approach results in a generally more intuitive way of describing three-dimensional geometry and an easier, faster way to modify designs. For the parametric approach, shown in Figure 4(b), the length parameter is changed by typing one number, which in turn regenerates the new part. Thus, in this simple example, the parametric approach requires only 1/16 of the number of steps required of traditional design system.

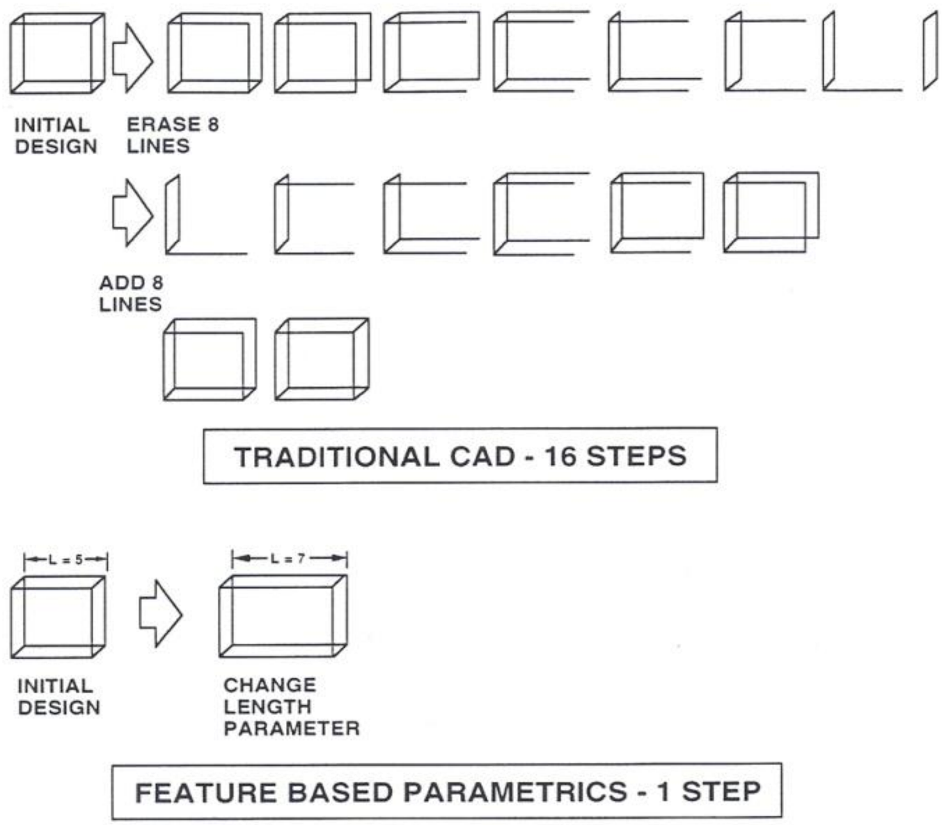

Figure 4. Traditional vs Parametric Based Design

Since the features can be solids based, rigorous changes to the geometry, even the investigation of tolerance stack ups, are quickly handled. New features can be added by simply sketching the new geometry, regenerating the solid, and modifying dimensional parameters as necessary. In another basic case, Figure 5 shows parametric modifications of a simple bracket including hole relocation and the addition and modification of a slot. Total time for the creation and modification of this solid object was less than an hour.

The value of feature based parametrics to the IPD process can be seen in the design of a wing rib spar joint. The design team, during the conceptual design phase, recognized the high payback potential of the joint which would have occurred over a hundred times in the complete wing structure. The multidisciplinary IPD team, which included design, structures, and manufacturing, brainstormed various alternative joint designs. The intent was to produce a single design concept that would meet structural requirements and that could be cost effectively fabricated and assembled. In the week following the initial brainstorming session, three of the most promising concepts (Figure 6 a, b, and c) were created parametrically. In a final one hour team meeting, the concepts were interactively reviewed, and the best candidate selected. In addition, improvements to the selected design were incorporated in real time. They included transferring the locating tab from the rib to the spar which cut

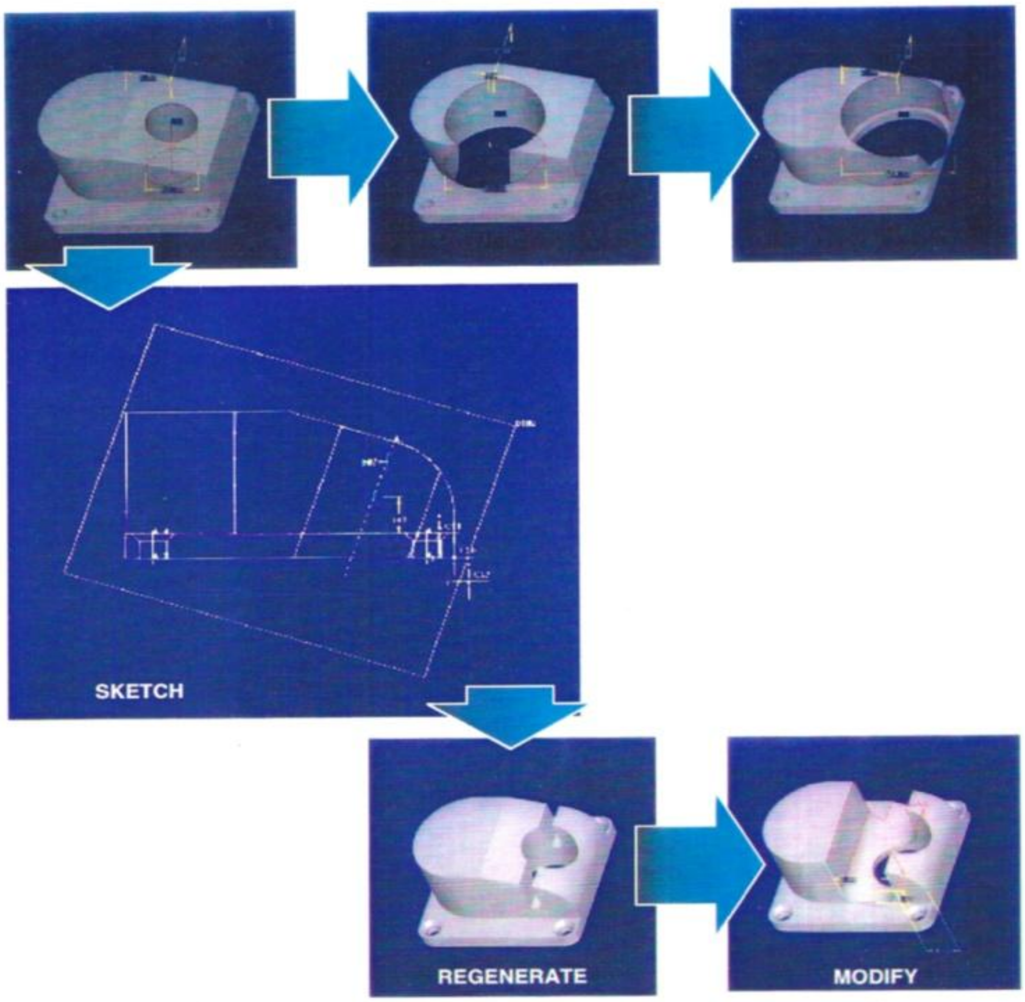

Figure 5. Examples of Rapid Design Changes Using Feature Based Parametrics

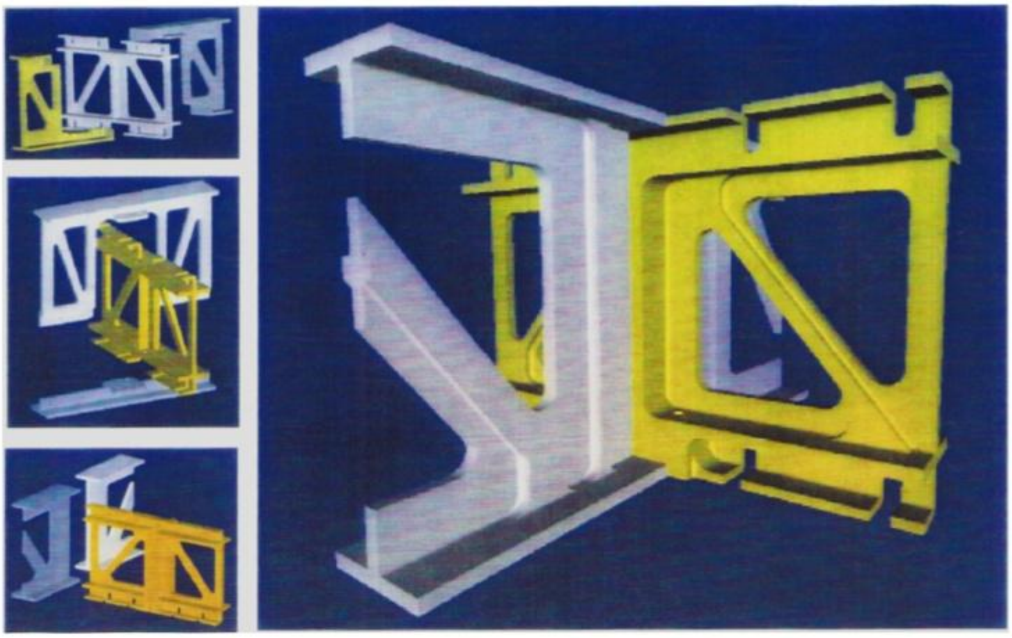

Figure 6. Feature Based Parametric Wing Spar Joint Design

the rib billet thickness in half, adjusting fillet radii to match best manufacturing practices, and modification of the stiffener geometry to reduce scrap caused by cutter grab. The rapid changes enabled by the parametric approach permitted the team to interact effectively to rapidly converge on an optimized design (Figure 6(d)) that could be replicated over a hundred times.

The parametric approach can also generate new time saving work methods. For example, feature based parametrics can be used to create conceptual templates which capture the general design intent of a class of products. As a result, new projects need only adjust parametric values to customize the design for specific requirements, avoiding starting each design from scratch. This process is illustrated in Figure 7 where (b) and (c) are simple parametric variations of (a). By changing only the value of two parameters, leading and trailing edge sweep angles, entirely new vehicles were created. Furthermore, details of the design intent like surface intersections, continuity, and length were maintained as originally defined. While the time for the parametric design was equivalent to that of more traditional design methods, each subsequent variation took under an hour to regenerate.

In an aerospace setting, this technique has the potential of far reaching cost consequences. Data bases of canopies, wings, spars, etc., can be built parametrically by recognized "masters," and then this expertise can be reused over and over without having to reinvent the wheel.

The concept of parametric design can be extended to parametric, geometry based analysis as well. This approach then provides a viable tool for conducting true multidisciplinary optimization.

The bottom line is faster iterations through improved individual and team productivity and the ability to develop improved physical understanding of alternatives.

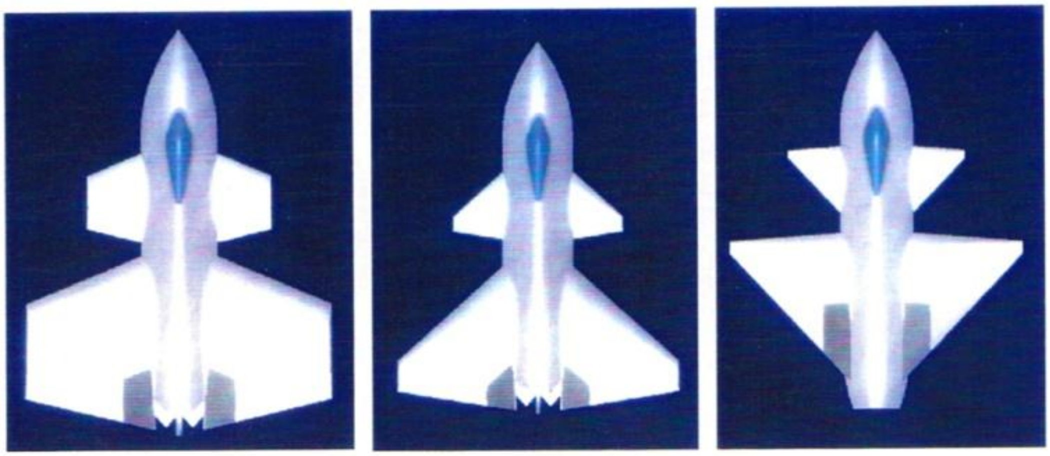

Figure 7. Creating Time Saving "Conceptual Templates" Using Feature Based Parametrics

STEREOLITHOGRAPHY (AUTOMATED FABRICATION)

The ability to create plots directly from an electronic drawing data file made possible the widespread acceptance of first generation Computer Aided Design (CAD). Two dimensional drawings, the mainstay of aerospace manufacturing, could then be created automatically.

In 1986, a new technology was introduced that was the three-dimensional equivalent of 2d CAD plotters. This new type of hardcopy device produced 3d parts directly from a 3d design database, opening broad new vistas for improving product development.

The original process was called stereolithography. In this process, the 3d CAD geometry, in the form of triangular facets, is converted to a series of 2d contours or slices. Each slice is then drawn by a laser on the surface of a vat of light sensitive liquid polymer. The polymer hardens locally where it is exposed to the laser beam as shown in Figure 8. The process repeats for each slice, with the part being lowered one thickness into the vat between each slice. When all of the the contours are drawn, the finished part rises out of the tank as illustrated in Figure 9.

The result is a detailed part with a high degree of fidelity to the electronic CAD database, produced with virtually no manual operations and at a fraction of the cost and time required for traditional methods.

At Lockheed Advanced Development Company (LADC), stereolithography has been used for a variety of applications, some of which are shown in Figure 10. They include concept modeling, configuration tracking, manufacturing aids, test models, and analysis interpretation models.

Because the models can be produced in 12 to 56 hours wall clock time, stereolithography enhances the ability of the IPD team to understand even the subtle 3d implications of the design, during the de-

Figure 8. Close Up of the Stereolithography Process

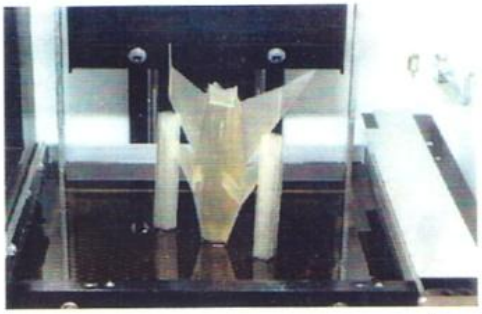

Figure 9. Finished Stereolithography Part Rising From Polymer Bath

Figure 10. Stereolithography Generated Parts

sign process, not after it is complete. The team can use "tactile lofting," for instance, to feel the quality of the surfaces they create.

Because it reduces the time and cost required to make test models, understanding of complex physical phenomenon can be measured fast enough and in enough detail to impact the design, not just verify its adequacy after the fact. Complex details like boundary diverts, ducts, and sting mounts, as shown in Figure 11, can be grown directly into the model further reducing costs and improving the accuracy of the test results. As a result, important design information can be obtained cost effectively from testing, even during the conceptual design phase.

For manufacturing, stereolithography models reduce the risks of misinterpretation of two dimen-

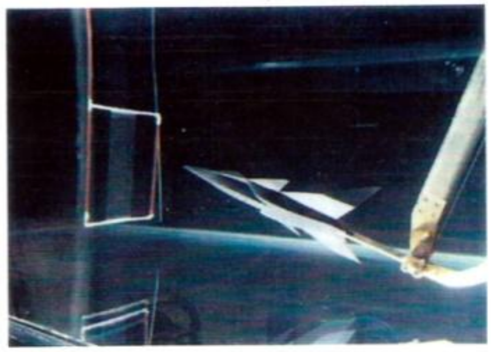

Figure 11. Water Tunnel Model (with Ducts, Diverters, and Mount) Grown with Stereolithography.

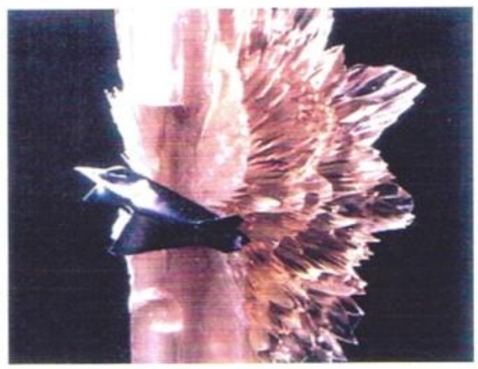

Figure 12. RCS Fuzz Ball Grown with Stereolithography

sional drawings, thereby reducing manufacturing uncertainty and cost. The models can also be used in profilers or as master molds to further reduce costs.

In addition to these typical geometric applications, stereolithography has been used at LADC to provide insight into complex analysis results. As an example of this capability, the radar cross section fuzz ball shown in Figure 12 links the signature of a vehicle with its design features in a form that is easy to interpret. The tens of thousands of analytically predicted points of the model would be far too expensive and difficult to produce by traditional methods, yet they can be grown automatically with stereolithography.

variations on the basic theme of stereolithography have been introduced by several other vendors[3,4]. Together, they have been referred to by the more general terms of automated fabrication, rapid prototyping, and free form fabrication. They include powder based selective laser sintering, fused deposition, photoetching, and laminated object manufacturing.

More important than the technologies incorporated in these devices is the impact they will ultimately have on the entire aerospace product development process. As they evolve to produce production parts and ultimately whole assemblies, they represent the potential for the full electronic integration of manufacturing into the product development process.

VISUAL PRODUCT DEVELOPMENT

Computer graphics have seen increasing value as an aerospace development tool. Initially used as a part of computer aided design systems or as a specialized presentation and analysis tool, the field has evolved with the potential to be an integral part of the product development process, linking design, analysis, manufacturing, and support with a common visual language.

Through the use of "visioneers," (visualization engineers) or visual renaissance teams (made up of mixes of engineers and visualization experts) as an integral part of the product team, a complex set of computer graphics tools can be brought together to improve communications and insight. They have the ability to become the "glue" that can tie together the diverse backgrounds of multidisciplinary development teams.

While true visual product development remains an art combining a complex mix of hardware and software, the power of today's computing systems enables fast enough turn around in skilled hands to impact the basics of the development process itself. Now, even in conceptual design, the visioneer can work side by side with the designer to envision the operation of a new vehicle, or with the manufacturing planners to show how the vehicle components could be designed into efficient fabrication segments or brought together on the assembly floor (Figure 13), or with the product support engineer to understand accessibility issues.

For almost a decade, visualization has been used to represent complex flow fields and structural interactions. As new, even more demanding requirements like stealth performance become integral to the vehicle design, the high band width tools of visual product development take on increased importance. Developing an understanding of the electromagnetic response of a vehicle requires the interpretation of tens of thousands of data points arrayed around the vehicle for each target frequency. Then, with the shape of the fuzz ball identified, key features of the signature must be related back to design features of the vehicle. Visualization techniques, like those shown in Figure 14, make this possible, significantly enhancing the performance of the end product without causing costs to sky rocket.

While visual product development can be effectively implemented today, improvements in user interfaces and simplified hardware will make it an indispensable tool for every member of an IPD team in the near future. In addition, the extensions of visual product development like on line audio and multimedia will change the basic way that information is handled, enabling even further gains in productivity.

Thus, visual product development is an evolving tool that improves the IPD environment by improving productivity through enhanced communication and insight.

SUMMARY

Three automation technologies have been presented that provide a sound foundation for the con-

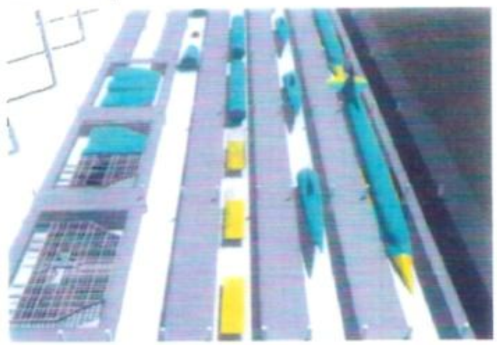

Figure 13. Visual Product Development of Manufacturing Layout

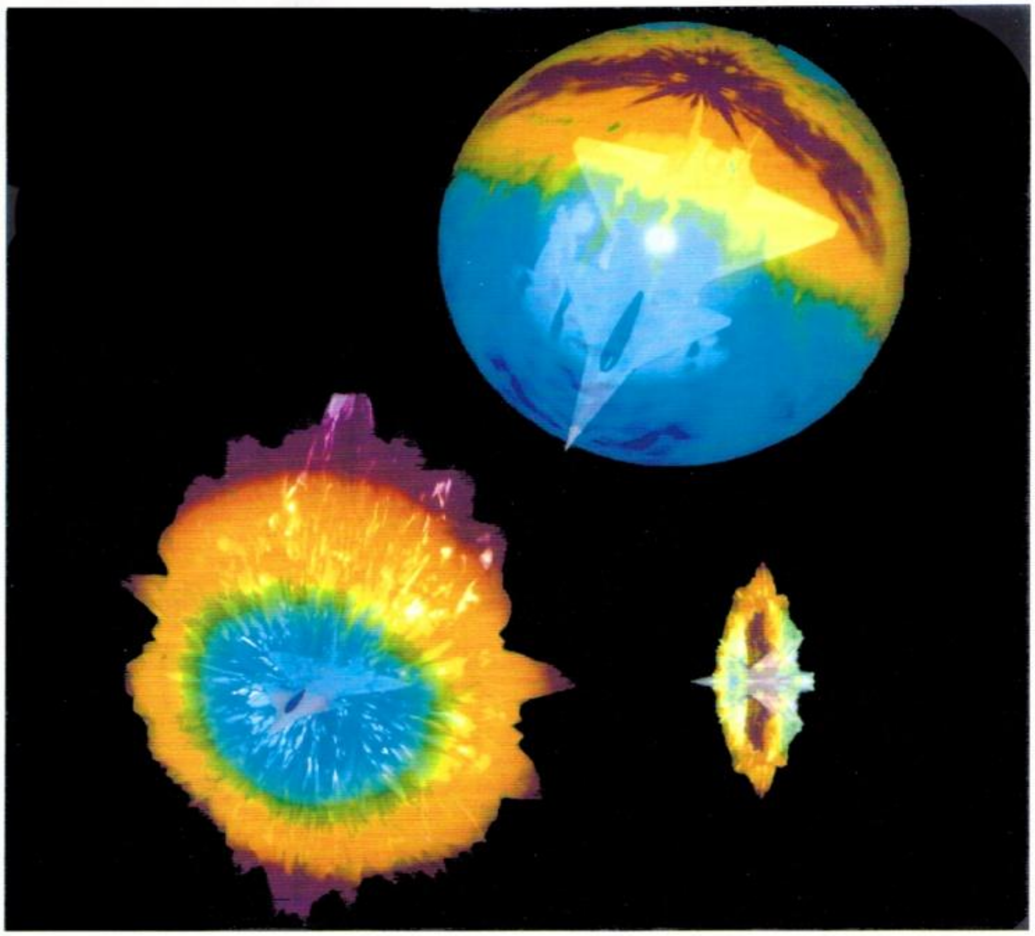

Figure 14. Visual Product Development Applied to the Visualization of Vehicle Signatures

cepts of integrated product development. These technologies, used intelligently in combination, can provide the communications, insight, and rapid response required to produce affordable, competitive products in the 90's, even in light of increasingly difficult product requirements. When applied by creative, empowered teams as part of a focused, streamlined product development process, these technologies can help the aerospace industry meet the challenges of the 90's with the same success that it has demonstrated in the last 90 years.

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