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Principles of As-Built Engineering

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Ronald M. Dolin
Jill Hefele

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

Table Of Contents

page

Executive Summary

As-Built Engineering is a product realization methodology currently being developed at the Los Alamos National Laboratory's Center for Advanced Engineering Technology. As its name implies, this methodology is rooted in the notion that life-cycle engineering should be based on what is actually produced and not on what is idealistically or nominally designed. As-Built Engineering is not based on radical new ways of engineering design or manufacturing, but rather is based on new ways of thinking about the much larger issues of enabling a complete product realization infrastructure.

Four primary principals of As-Built Engineering are as follows:

1. It is possible to do customized product realization at mass manufacturing rates.
2. The need for nominal based methods of product realization are no longer necessary and the role of tolerancing in design and manufacturing should be reinvestigated.
3. Products can and should be fully characterized using solid models of their unique as-built attributes. Each individual assembly should possess its own unique model depicting its as-built state.
4. There will always be errors associated with manufacturing and application that need to be acknowledged and captured as unique attributes of each piece-part and assembly.

Customized product realization allows piece parts to be assembled in an optimum way. For example, striving to optimize design parameters during production by either manufacturing or assembling one part to compensate for design deviations present in another part of the assembly. This approach minimizes rejected parts in production because it provides a way to use parts that normally would have been scraped. It also maximizes part reuse in post-production by providing a logical way to determine what optimal piece parts to use in an assembly from an inventory of possible piece parts.

As-Built Engineering provides a methodology for fully characterizing the enduring stockpile. This not only allows for optimally assembled systems and enhanced analysis simulations based on actual product characteristics, but also allows for the monitoring of an assembly's maturation. All post-production activities involving a product would be defined and captured in an as-built model. This has implications in both Surety and Surveillance. As-built models contain the high fidelity product information that can be used for maintenance, simulations, quality assurance, and design analysis.

Benefits of As-Built Engineering include the following:

1. can be implemented without effecting mission critical activities,
2. is robust and allows new processes, technologies, and equipment to be introduced into a product realization infrastructure in a quantifiable manner,
3. provides a way to characterize product information that in turn allows assembly optimization - both during production and in post production.
4. For archival and surveillance, allows a methodology for knowing what you have so that changes in a product can be measured.
5. provides high fidelity product representations that can be used as input into emerging analysis and simulation tools being envisioned by ASCI. These high fidelity representations accurately describe each individual assembly and thus provide a basis for measuring aging and application effects.

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Center for Advanced Engineering Technology

Principals of As-Built Engineering

Authors
Ronald M. Dolin (505) 667-9142; email: rmd@lanl.gov
Jill Hefele (505) 667-9744; email: jill@lanl.gov

Sponsoring Organizations
Los Alamos National Laboratory
Engineering Sciences and Applications Division
Mail Stop P946
Los Alamos, New Mexico 87545

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Abstract

As-Built Engineering is a product realization methodology founded on the notion that life-cycle engineering should be based on what is actually produced and not on what is nominally designed. As-Built Engineering is a way of thinking about the product realization process that enables customization in mass production environments. It questions the relevance of nominal based methods of engineering and the role that tolerancing plays in product realization. As-Built Engineering recognizes that there will always be errors associated with manufacturing that cannot be controlled and therefore need to be captured in order to fully characterize each individual product's unique attributes. One benefit of As-Built Engineering is the ability to provide actual product information to designers and analysts enabling them to verify their assumptions using actual part and assembly data. Another benefit is the ability to optimize new and re-engineered assemblies.

1. VISION

Imagine a product realization infrastructure where every unique and individual characteristic of a particular product is captured and stored in electronic form. This includes all of a product's deviations from its nominal design that occurred during manufacturing, maintenance modifications, and application effects, along with a record of how the product has aged and matured.

Consider the scenario where a customer comes to a design agency with a need for some system to be designed and built, or re-engineered and re-built. The customer in this scenario provides a simple cartoon model and a set of performance parameters that must become part of the final product. The designers and engineers use this simple model and set of performance parameters to develop a design solution. This design exists in the form of a solid model. It is a nominal design that represents an ideal product and/or assembly. This nominal design is used to perform physical and mechanical analysis simulations and specify manufacturing procedures.

Because the design is nominal and no component parts have been manufactured, a single solid model can be used to represent the product. This single solid model is essentially the ideal design specification containing no flaws or inconsistencies. It is the model that will determine how piece parts will be manufactured and against which they will be evaluated.

However, once manufacturing begins, the realities of life begin to chip away at our ideals. Small deviations start to creep into the design during manufacturing and assembly and while the product goes through its service life. These deviations are design inconsistencies that can reduce the validity and relevance of the nominal solid model. Remember that the nominal design represented what we aspired to manufacture and assemble but does not capture the definition of what was actually manufactured and assembled.

Once piece parts begin to be manufactured, deviations appear in the product. The amount that each part deviates from nominal is captured in the piece part inspection. Because each part is different, a separate model is created for every manufactured part representing its current state. These separate models characterize and define the part as it was actually built rather than as it was designed.

At various stages of production the manufacturing engineer generates as-built information. Design engineers and physicists use this as-built information to determine through analysis how to locate features so as to mitigate the effects of manufacturing deviations from nominal. Analysis is also used to adaptively customize mating parts during manufacturing to compensate for existing deviations.

Through analysis, the assembly engineer is able to optimize the assembly of each system in order to come as close as possible to obtaining the performance parameters of the nominal design in each system. Because each system has been custom manufactured and assembled, a unique model is generated for each system to capture the as-built characteristics of the product.

The as-built model of the fielded system is available to the maintenance engineer. During routine maintenance and surveillance, engineers are able to accurately monitor the physical and phenomenological changes of every system in the stockpile. These changes include generalized effects of aging but also the very system-dependent changes that can occur as a result of the various environments each system is exposed to.

The as-built model contains the state of the system being surveyed at the time it was last inspected. Using this information maintenance engineers can measure any changes that have occurred. By tracking changes in the form of an evolving set of as-built models, engineers begin to understand what effect different environments have on various piece-parts in the assembly. This models-based log of each system's maturation also contains maintenance work history and all repairs, replacements, and modifications.

As systems begin to be retired, many piece parts are inventoried for possible re-use and re-engineering. Each inventoried piece-part has an associated as-built solid model. When a system comes in from the stockpile to receive a new part, engineers use the inventory of as-built models in a post-production analysis and optimization simulation to determine which individual piece-part is best suited to be used in the system to optimize design and performance parameters. When the system is returned to the stockpile its as-built state is represented and the level of untested reliability and confidence is quantified.

Suppose that at some point in the future a number of systems in the stockpile are to be re-engineered for a mission different than the one they were initially designed for. Because of the anticipated environments that these modified systems will have to endure, it is thought that some stockpile systems would make better re-engineering candidates than others. Because the as-built models for each system in the stockpile exist, physicists and engineers logically determine which systems to re-engineer.

Using the as-built models, the stockpile is interrogated and an ordered list of candidate systems is generated through analysis and optimization. As the piece-parts are re-manufactured or re-used, their as-built characteristics are once again captured in the form of a solid model that is used by the physicists and engineering analysts to validate the products and to optimize the assembly of the customized products.

Without physical testing, the re-built systems are returned to the stockpile for their new mission, and the reliability and surety of each system's manufactured state is captured and quantified.

2. DEFINITION

As-Built Engineering is foremost a methodology for allowing customized product realization at mass manufacturing speeds, prices, and flexibilities. Customized product realization is a significant philosophical deviation from the popular approach to design and manufacturing that has been used within the nuclear weapons complex for the last fifty years. In fact, As-Built Engineering is a significant deviation from the manufacturing approach used through out the world since the beginning of the industrial revolution.[ref]

As-Built Engineering methodology is rooted in the notion that a products life-cycle support should be based on what was actually produced and not on what was idealistically or nominally designed. It is not possible to consistently manufacture a product to the exact specifications of a design. Also, it is not possible to predict or control the amount of deviation a manufactured part will have relative to a canonical nominal design specification.

The dictionary defines nominal as "existing in name only; not real or actual; theoretical; so-called." [MORR81] Engineers not comfortable with thinking of manufacturing deviations in these terms chose instead to develop an entire approach to engineering that made uncontrollable deviations an acceptable part of a design solution. This approach to engineering is referred to here as nominal based engineering.

Nominal based engineering seeks to create a design that is impervious to small errors in manufacturing. These small acceptable errors are referred to as a part's tolerance and can vary on both the positive and negative sides of nominal. Once nominal based methods of engineering were adopted they began to affect even how design itself was done.

For example, in a nominal design mode an engineer seeks only those solutions to a design problem that are unaffected by small deviations. Often the decision is made to base a solution to an engineering problem on a nominal method that is tolerant of small deviations (such as using a slip fit instead of a pressure fit or a slider action instead of an interlocking mechanism). This decision eliminates design possibilities that require customization and close part matching. [DOLIN95a] [DOLIN90]

As-Built Engineering involves a re-examination of methods of nominal engineering in light of advanced technologies. In our estimation engineering technology has matured to the point where it is now possible to do customized product realization in a mass production mode. This, in essence, brings product realization full circle. Before Eli Whitney and his contemporaries revolutionized engineering with mass production and the concept of interchangeable parts, manufacturing was based on highly customized design. [ref]

Since the industrial revolution, engineers have sought solutions to problems based on nominal designs because they did not want the added constraint or cost of customized manufacturing, even though in some instances a customized solution to an engineering problem can be more optimal and result in better performance characteristics of a design. Today, engineers have the ability to do customized manufacturing using advanced technologies. This returns engineers to where they were before the industrial revolution philosophically. Musgrave pointed out a similar analogy in the area of testing by showing the impact computers had on the way test engineers approached their work. [MUSG88]

As-Built Engineering is not, then, a radical new way of design or manufacturing, but is rather a new way of thinking about the solution space of product realization problem solving and the opportunities created by emerging technologies. There will always be errors associated with manufacturing. Those errors should not be dismissed under the protected umbrella of manufacturing tolerances, but should instead be acknowledged and incorporated into the product realization process and used to help build an optimum product.

Products can and should be fully characterized using solid models. Each individual assembly should possess its own separate engineering model depicting the assembly's unique characteristics. This in turn can be used to feed as-built information to designers and analysts for higher fidelity simulation, and to monitor the changes that occur in a product in its life-cycle.

Customized product realization allows piece parts to be assembled in an optimum way. For example, striving to optimize design parameters during production by manufacturing one part of an assembly to compensate for design deviations present in a other parts of the assembly. This approach minimizes rejected parts in production because it provides a way to accept parts that otherwise would have been unacceptable. It enables a mechanism for optimizing performance characteristics during assembly and for knowing logically which piece-part in an inventory is the best one to be used in a particular assembly.

This does, however, suggest small modifications in current manufacturing processes. Suppose, for example, that you were making two axi-symmetric parts that mated together. Assume one part had already been manufactured but that it did not have the same mass property characteristics as those specified by the nominal design. In other words, the mass, volume, center-of-gravity, and inertia properties deviated from nominal.

Now suppose that the mating part's machining is broken into two independent steps, the turning operations and the milling operations. Once the second part has been turned, it can be inspected, and an as-built model can be reconstructed from the inspection data. The off-axis features of the second part can be incorporated into this as-built model and the engineer can start performing analysis on the two as-built models to determine the optimum configuration for achieving an assembly with mass properties as close to the design specification as possible.

At this stage, the second part's as-built model is a hybrid with the turning portion represented by as-built data and the features represented by nominal data. The engineer is locating the second part relative to the first. Since the second part has not yet had any off-axis features milled out of it, it is axi-symmetric and can be rotated relative to the first part so that design parameters are optimized.

In essence this operation is akin to dialing in the desired performance parameters, which in this example means taking advantage of both parts' deviations from nominal to minimize the effects of manufacturing inconsistencies. This is what is meant by assembly optimization. This locating operation in turn indicates to the manufacturer where to locate the off-axis features on the second part to optimize the assembly.

This approach maximizes part reuse in post-production by providing a logical way for determining what optimal piece parts to use in an assembly from an inventory of possible piece parts.

As-Built Engineering widens the solution space of a design problem. When the first industrial revolutionist set-up their first production lines they profoundly changed how engineers approached problem solving. In a mass manufacturing environment the solution to a problem, in general, is not the overall best one possible. Instead it is usually the best possible solution given that the effects of mass production and part interchangeability have to be considered.

When engineers explore a solution space for the best solution to a problem they are considering only a subset of the overall solution space [KRICK79] [EDIE79] This is because Nominal based engineering has become so institutionalized over the past two-hundred years that today many do not even recognize the trade-offs being made.

Many traditionally human intensive aspects of manufacturing can be automated in an as-built environment. For example, in As-Built Engineering every piece part is inspected--not just when it is completed, but at every crucial stage of the value-adding process of going from raw material to finished product. Things such as loading stock and locating features can all be automated.

The as-built environment is robust enough to allow parts to be manufactured directly off of a solid design model. Because of the inspect-often philosophy, manufacturing can be done reliably using multiple software tools and platforms on different pieces of manufacturing equipment.

In this environment the way parts are inspected needs to change, but can be automated. Engineers need to generate more product information faster than was previously required. They also need to be able to reconstruct a model from inspection data and measure manufacturing deviation relative to the design specifications. This will be possible using emerging technologies.

Decision analysis that has traditionally required human interaction can be automated using heuristic based methods. Whereas before design engineers often had to physically go to the manufacturing area to look at a particular part, in an as-built infrastructure, a part is fully captured and characterized electronically. That electronic model can be sent to the design engineer for review, analysis, and modification. The computer model of the as-built part can be used to determine the next steps in a part's manufacturing. Advanced technologies will enable all of this without creating a manufacturing bottleneck.

As-Built Engineering provides a methodology for fully characterizing the enduring stockpile. This not only allows for optimally assembled systems, but also allows for the monitoring of an assembly's maturation. The only way to understand how a system is aging and wearing is to know its state at any given moment. The current method of having a single engineering model of some nominal system to represent all the actual systems of that design is not practical. As-Built Engineering is based on the premise that each system in the stockpile is different and, hence, needs its own individual model.

Having a separate model for each individual system allows all post-production activities involving a product to be defined and captured in the as-built model. This has implications in both Surety and Surveillance. As-built models contain the high fidelity product history information that can be used for maintenance, simulations, and quality assurance.

3. BACKGROUND

Before the industrial revolutionists defined the mass manufacturing process based on part interchangability, assemblies were custom made. In customized production, each part is manufactured to match its mating parts as closely as possible. [HINDEL86] [HICKS88]

Before mass production, part tolerancing was not necessary. Tolerancing is a direct result of part interchangeability and of the recognition that manufacturing errors can be confined but not controlled. Two things were necessary in order to achieve complete part interchangeabilty. The first thing was that the manner in which engineers designed products would have to be modified in order to allow for designs robust enough to encompass deviations in component part characteristics.

The second aspect necessary for achieving part interchangeability was that tolerances would have to be incorporated into a design. This was because parts vary in mass production, and by designing a product's workability to be invariant under reasonable deviations from some ideal specification (referred to as the nominal design), engineers can achieve generalized interchangeability. In essence, part tolerances are an engineer's way of acknowledging that errors occur in manufacturing, and, while these errors are not predictable and in many cases not controllable, the product must be designed to be robust enough to work regardless of how it falls within the acceptable tolerance band. [ref]

For most mass produced products this nominal philosophy works. In many instances it may not be ideal, but it is expedient. Fifty years of nuclear weapons history shows that this approach works, but is it optimal? In the advent of a nuclear test band and substantial part re-use, re-engineering, surety, and surveillance, does it make sense to continue to use nominal based methods of engineering within the complex?

A part's quality is often measured in its usability. Usability is often measured by whether or not a part falls within some acceptable tolerance band. If a part is within its tolerance band, it is said to pass and to be usable. If one of its measures of acceptability exceeds the tolerance limits the part is declared unusable. This pass/fail approach to manufacturing is pervasive in industry today. [ref]

Tuguchi and others have sought to minimize the effects of pass/fail manufacturing inspection by striving to shrink the zone of acceptability. They continually seek to improve a product's acceptability, striving to make it as near nominal as possible.

Several examples exist demonstrating that products which are built closest to nominal outperform products randomly built from acceptable piece parts.

The reason that Taguchi and others have worked to shrink the tolerance zone is that when the sum of the deviations of each piece-part in an assembly is minimized, the assembly's deviation from design parameters is also minimized. In essence, they were striving for what we call assembly optimization.

Products built very near nominal are close to matching the design's performance parameters. As-Built Engineering provides an additional level of fidelity in assembling near-nominal products. In addition, As-Built Engineering enables performance parameter analysis of products in their as-built state. One primary goal of As-Built Engineering is to create a robust manufacturing environment that enables assembly optimization. [ref]

4. BENEFITS

Perhaps the foremost benefit of As-Built Engineering is that it enables a methodology that allows new processes, technologies, and equipment to be introduced into an existing manufacturing infrastructure without affecting mission critical activities. This means that As-Built Engineering can be implemented with an organization such as the DOE nuclear weapons complex without impacting the quality or reliability of its products. As-Built Engineering would only impact an organization after it had been implemented and engineers began taking advantage of all the powerful capabilities that the increased fidelity and information of the model would make available.

As-Built Engineering is robust. It allows new processes, technologies, and equipment to be introduced into a product realization infrastructure in a reliable and quantifiable manner. This benefit should not be overlooked. One aspect of product realization that concerns a lot of people today is the inability to benchmark the effects on production reliability that any change in process of technology may have.

The primary aspect of As-Built Engineering that enables this entire methodology is the principle that the only measure of importance in product realization is the quality of the final product and final assembly, both of which can be measured. This approach is not concerned with the details of how a product is produced because the product's quality can be measured at various stages of production. In a robust manufacturing environment, how you make something is of no real consequence. The only benchmark is the quality of the end product.

Every piece part and every assembly should be described with its own unique model and product history record. This is different than what is done today where every system in the stockpile is represented by a single model description. In other words, there should not be just a single nominal description representing every W76 in the stockpile, but rather, a separate *model* description for every W76 in the stockpile.

This form of archiving product information allows assembly optimization -- both during production and in post production. It provides a high fidelity representation that can be used as input into emerging analysis and simulation tools being envisioned by ASCI. These high fidelity representations accurately describe each individual assembly and thus provide a basis for measuring aging and application effects.

5. VERIFICATION OF AS-BUILT ENGINEERING PHILOSOPHY

We propose to collaborate on a distributed manufacturing pilot project in fiscal year 1996. The pilot project has two primary goals. The first goal is to demonstrate that it is possible to

a) fully characterize a product using existing technologies,

b) perform assembly optimization, and

c) feed As-Built Engineering information back to designers for re-evaluation of hydro-dynamic and structural analysis.

The second goal of the collaborative manufacturing project is to demonstrate that in a robust models-based manufacturing environment information is captured and used more effectively. We plan to demonstrate that the frequency and duration of visits required by engineers from the DOE design labs to the manufacturing plants can be reduced. We will also demonstrate that the complexity and interactivity of information being exchanged between design laboratories and manufacturing plants can be increased.

The primary benefit of the project will be that it will allow the DOE/NWC to work more closely together using “as-built” engineering information.

The design laboratory role will represent the activities of Los Alamos, Sandia, and Lawrence Livermore National Laboratories. The manufacturing plant role will represent activities of Martin Marietta Energy Systems, Y-12 Plant, and Allied Signal-Kansas City Division. Pilot applications will be simulated NWC/WR components.

5.1 MOTIVATION

The DOE has several ongoing distributed simulation projects that address necessary components of a complete distributed manufacturing environment. Some of those components include network communication, information management, information content, modeling, and computer driven animation. The pilot project seeks to bring these various projects together within a single application.

This project proposes to develop and demonstrate capabilities that allow DOE/NWC parts to be designed, engineered, and manufactured electronically (i.e., without generating any paper based information such as drawings or reports). The project will leverage existing DOE efforts while seeking to enhance the capabilities of those efforts.

The overall benefits to DOE from this project include faster concept-to-part throughputs, minimization of information redundancy, and an ability to simultaneously involve all product development disciplines at all phases of product realization. An even more important deliverable will be the verification of **"As-Built Engineering"** to product realization, stockpile support, surveillance, and surety.

As-Built Engineering is a concept founded on the notion that product representations should be based on what is *manufactured* and not on what is nominally designed. As-Built Engineering allows physicists to better predict design characteristics using electronic part models of actual geometry and topology. Stockpile support engineers are able to determine the best ways to re-engineer and/or salvage parts by knowing actual part characteristics.

Another attribute of As-Built Engineering is its ability to enhance the increasingly important area of product simulation. As-Built Engineering enables scientists and engineers to increase the fidelity of their simulations by providing actual product information pertaining to topology, geometry, tolerance stack-up, feature locations, etc.

This project provides a necessary and critical capability to As-Built Engineering -- part production information. Figure 6.1.1 shows an overall As-Built Engineering vision. This vision represents product realization in terms of a single information hyper-model comprised of several submodels that each contribute to and use hyper-model information. In this representation, model complexity increases as product realization matures.

Notice that product realization does not end at manufacturing but is extended to include the entire product life cycle.

Notice also that the product realization process described in Figure 6.1.1 does not depict the circular information flow we envision occurring in a design-agency to production-plant communication infrastructure. In an As-Built Engineering environment information has an ability to flow bi-directionally to all sub-models simultaneously. [DOLIN96]

Information about the as-built product properties is added to the hyper-model in the manufacturing sub-model. The manufacturing sub-model takes product information from the hyper-model as input and uses that information to manufacture and inspect the part. The manufacturing sub-model then adds value to the product realization process by providing the product's as-built information to the hyper-model. Figure 6.1.2 shows a high level view of this process.

In the simplified scenario depicted in Figure 6.1.2, a product begins its life as a physics concept in the form of a featureless model. This model is passed to Engineering where the engineering features are added and a nominal design is specified. Along with the nominal design are manufacturing specifications, procedures, and tolerances. Once the nominal design is passed on to Manufacturing, it is used to make and inspect the part. An as-built model is generated for each part produced and that information is passed back to Engineering.

Engineering and Physics share the as-built model information. Both can use that information in a variety of ways. For example, physicists can use as-built information to simulate NTS tests and more accurately predict yield and safety. Engineering can use the as-built information to perform accurate

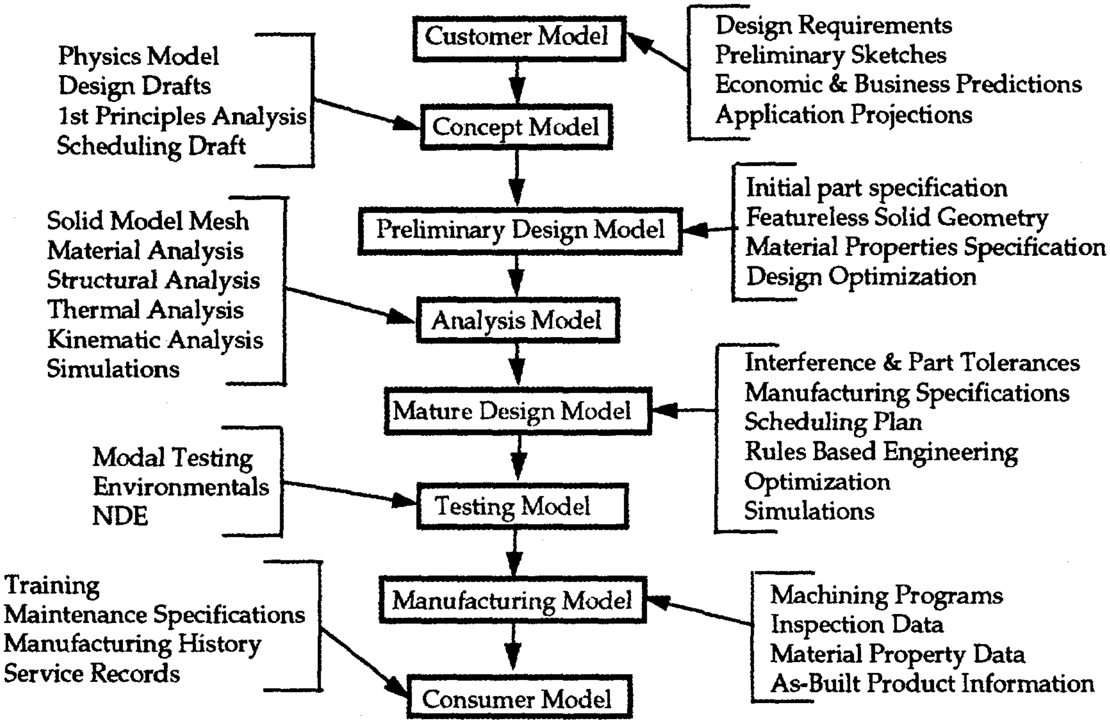

Figure 6.1.1 As-Built Engineering vision in terms of a single information hyper-model

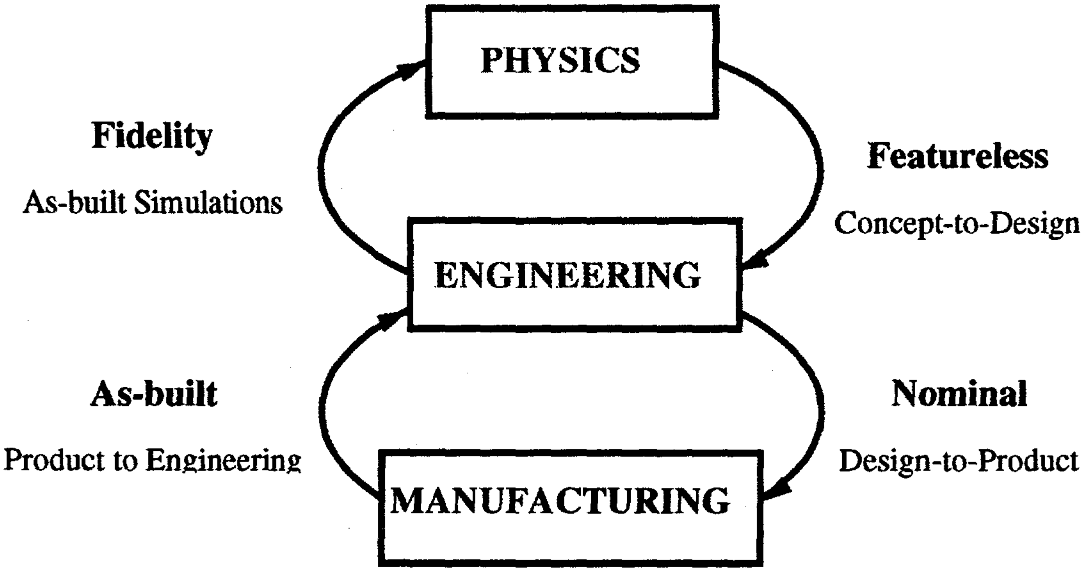

Figure 6.1.2 Circular flow of As-Built Engineering information.

tolerance stack-up analysis, mass property characteristics, stockpile support, part replacement analysis, product management, and archival.

5.2 PROJECT PLAN

The high-level overview shown in Figure 6.1.2 ignores the complexities of what goes on within each of the three boxes. It also does not reveal the enormous technical challenges that must be overcome in order to move product information between the activities defined by the boxes.

The previous discussion provided background and motivation for the ultimate goals and vision of As-Built Engineering. In particular, the previous discussion defined what portion of the overall As-Built Engineering vision this project would address. Specifically, this project is concerned with issues related to flow of information from design to manufacturing and back to design.

The work proposed for this project leverages work being funded by a number of DOE activities. For example, this project leverages work being funded by a Los Alamos CRADA with the Oil and Gas Industry as well as work being funded by the Los Alamos Advanced Manufacturing Program, the DOE Technology Transfer Initiative, and the DOE Advanced Manufacturing National Information Infrastructure programs.

The Los Alamos Oil and Gas CRADA addresses issues surrounding the movement of product information bi-directionally between physics and engineering (i.e., the upper circle in figure 6.1.2). The Los Alamos Advanced Manufacturing Program is funding an investigation into integrating engineering product realization. This information management technology is based on a methodology referred to as Models Based Engineering. [DOLIN96]

In a combined multi-laboratory partnership, the Design Laboratories will investigate what kind of information needs to be provided to the Production Plants. The Design and Production facilities will determine how that information needs to move from design to manufacturing. The Design Laboratories will develop model reconstruction technologies that take inspection data representing a product's as-built characteristics and use that information to reconstruct an As-Built Engineering model.

The Design agencies will also develop methodologies for making As-Built Engineering information available to engineering and physics disciplines. This will include an ability to decompose a solid model into a two-dimensional model that can be used for input to hydro-dynamic and structural analysis codes.

This aspect of As-Built Engineering will provide physicists with higher fidelity models. Today physicists use three-dimensional inspection data that is reduced to averaged two-dimensional axi-symetric topology. The problem with this approach is that if a part was at maximum allowable material for half its topology and at minimum allowable material at its other half, it averages out to be a perfect part exactly at the nominal condition. The part would be represented as ideal, when in fact, it is the worst possible part that could be manufactured and still pass inspection.

Physicists currently can use only two-dimensional input to their hydro-dynamic analysis codes. Our approach enables the input into the hydro codes to consist of data generated from taking arbitrary slices through a part or assembly and transforming the resulting three-dimensional slice curves into a two-dimensional curve. A curve resulting from a plane slice through a solid is a three-dimensional curve in plane that can be transformed into a two-dimensional curve in the XY plane. This capability will allow hydro calculation to be performed on actual product topology as opposed to averaged topology.

Another aspect of this project is that for the first time ever in the history of the nuclear weapons complex, engineers and physicists working together will have the ability to specify how parts are to be located relative to one another in assembly in order to optimize desirable parameters while minimizing the negative effects that small deviations from nominal can have on an assembly. This powerful feature will greatly enhance our predictive and simulation capabilities while increasing the over confidence and reliability of our systems.

5.3 PROJECT SCOPE

Figure 6.3.1 shows a detailed schematic of the proposed project along with an abbreviated schematic of the activities of two of the other leveraged projects. The loop containing the circle with a number one inside it is the primary focus of the Los Alamos Models Based Engineering Project. The loop containing the circle with a number two inside it is the focus of the Los Alamos Global Weapons Information System (GWIS). The larger loop containing the circle with a number three inside it is the focus of this project proposal. All three projects are inter-related and will benefit from the implementation of the principles of As-Built Engineering.

The schematic shows the details for how information is generated and how it flows from engineering-to-manufacturing and from manufacturing back to engineering. The solid arrows represent existing information flow paths. In general, these existing information flow paths currently use information exchange methods that are neither electronic nor models based.

The dashed lines indicate new information flow paths and technologies that this project will seek to develop. The methodologies and technologies necessary to enhance existing information flow paths and to develop the new ones will be the emphasis of this project.

Some of the new methodologies that are currently being considered for this project include electronic ways to send unacceptable product information back to engineering for possible re-engineering or re-manufacturing considerations. Other methodologies to be developed include Microplanner feedback to engineering and methods for sending acceptable product information back to engineering electronically.

Technologies that this project will seek to develop include technologies enabling the specification of engineering models for manufacturing, new ways of inspecting that fully capture three-dimensional surface information, model reconstruction from inspection data, ways of linking manufacturing with other members of a product realization team in

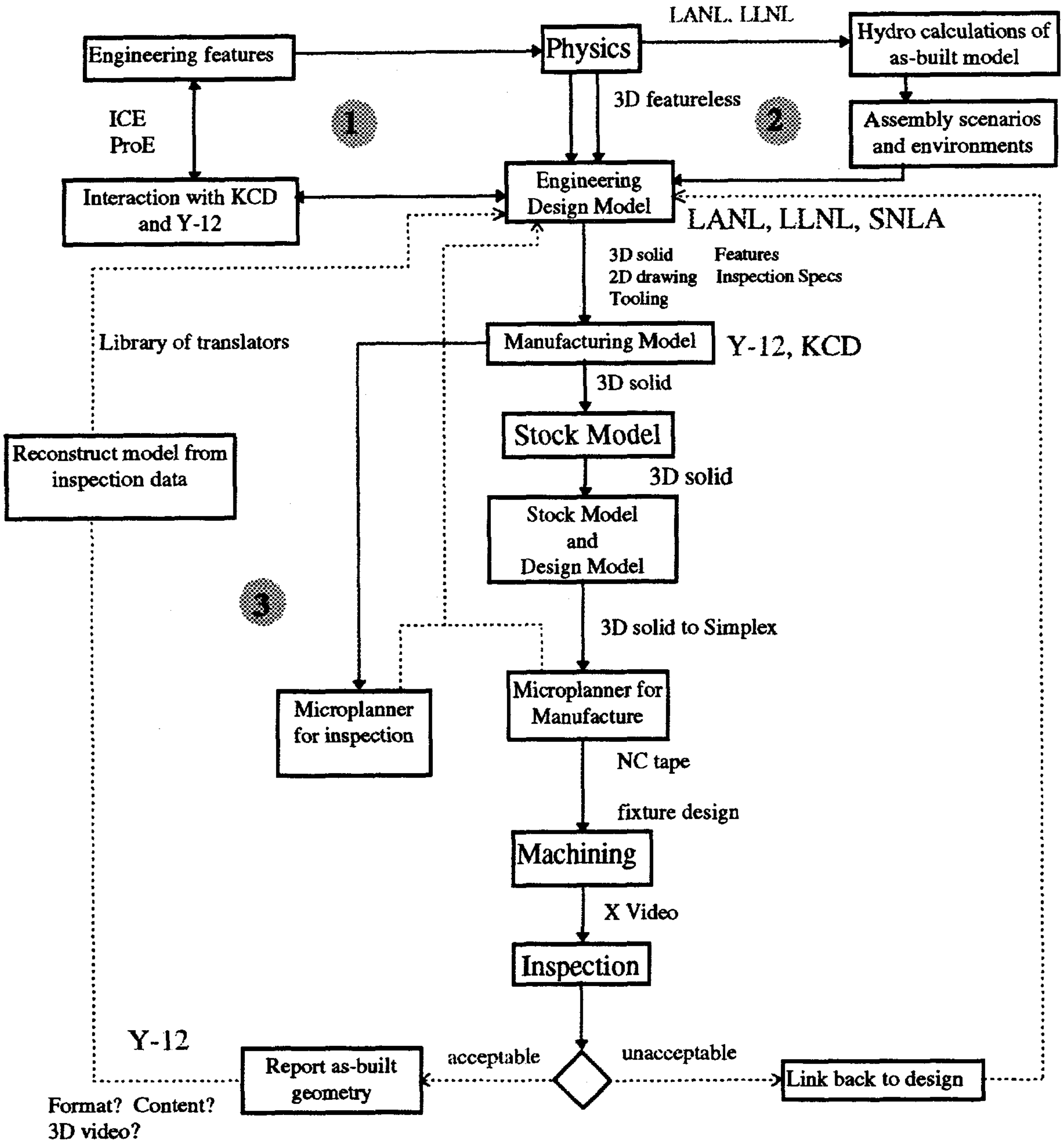

Figure 6.3.1 Details of proposed project

real time (e.g., stereoscopic video to interactively link engineering with manufacturing), and finally, new technologies for improving various aspects of manufacturing like automated fixture design.

5.4 Project Effort

This project involves participation from agencies across the DOE complex. Los Alamos, Livermore, and Y-12 will focus their investigations on issues involved with the production of nuclear part components in a weapons system. Sandia and Allied Signal-KCD will focus on issues involved with the production of a weapons system's non-nuclear parts. We expect the primary level of effort to be in the nuclear part production investigation. Each participating facility has determined their level of effort. The estimates are:

- Los Alamos, .75 fte's
- Y-12, 1 fte
- Sandia, 1fte's
- Allied Signal-KCD, 1fte's

These levels of efforts include time, travel, and some equipment purchases. They include both the research and demonstration activities.

5.5 PROJECT DELIVERABLES

Each facility will participate in one of two proof of principle demonstrations to be held at the DOE headquarters in September 1996. The demonstration will consist of the design agencies (LANL, LLNL, and Sandia) engineering a nominal models based design and sending that design to the production plants (Y-12 and AS-KCD) in an electronic form. Los Alamos and Livermore will each independently engineer separate halves on an unclassified part that will be mated together. Sandia will engineer an unclassified shipping container component. The production plants will manufacture and inspect the products using only the solid model, electronic information exchange, and models based manufacturing methodologies.

Once the parts have been made and inspected, the production plants will send the inspection data to Los Alamos where necessary as-built model information will be generated. The design agencies will take the as-built model information and reconstruct an As-Built Engineering model. This as-built model will then be used to define how to optimize the assembly (i.e., locate the piece parts relative to one another), to fully characterize the as-built product (i.e., individual archiving), and provide as-built model information to Engineering and Physics for higher fidelity analysis and simulation. This entire demonstration will be done electronically with no paper drawings or documentation.

5.6 PROJECT SCHEDULE

This project requires an aggressive time schedule. Work on the project cannot begin before April, 1996. There will be a proof-of-concept demonstration in early September 1996 at DOE headquarters in Washington, D.C. Table 6.6.1 shows the time schedule for the simulated nuclear component portion of the proposal

Table 6.6.1 Time schedule for proof-of-concept demonstration.

Date	**Task and Deliverable**
April 1	a) Rough design specifications. b) Engineering design, models, and manufacturing specifications.
May 1	Iterate on content and context of design to manufacturing information model.
May 1	Manufacture Parts.
May 15	Inspect/qualify parts.
May 21	Make raw inspection data and make ProScan file available to design agencies.
May 27	Receive "As-built" information model from plants, and: a) generate a solid model and perform Delta analysis including mass property comparisons with nominal design, inertia comparisons with nominal design, and center of gravity shifts, and b) take two-dimensional slices of "As-built" information model and compare with the nominal and Physics models. Develop, debug, and benchmark necessary software for this task.
June 3	Verify design on "As-built" product with a) Engineering analysis, b) Assembly optimization process, and c) Physics analysis.
June 10	Send additional manufacturing and assembly instructions back to the plants as a result of what was learned from analysis.
July 29	Proof-of-concept demonstration in Washington.

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