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An integrated re-engineering plan for the manufacturing of aerospace components

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ABSTRACT

Due to a variety of technical problems encountered in advanced mechanical and aerospace industries, traditional reverse engineering in which only a copy of the old component using CAD/CAM systems is developed is less effective. As a matter of fact, re-engineering methodologies should be used to optimize the component/sub-system design concerning new materials and advanced manufacturing technologies often employed in such industries. This may cause to achieve a cheaper, lighter component together with a higher reliability. This paper describes an integrated re-engineering plan for the replacement of aerospace components/sub-systems. As a case study, re-engineering of a rupture disk used as a safety device in a turbofan jet engine is conducted. A new material and a new manufacturing process are suggested for this component to fit in the design with available low cost material and manufacturing process. The obtained results show the effectiveness of the proposed plan.

1. Introduction

As many mechanical and aerospace industries face the pressures of intensive competition exist in the global marketplace, they are being forced to re-engineer their design processes and products to achieve higher efficiency together with reduced development cost [1]. This is the reason why the number of aerospace large systems being developed from scratch is diminishing gradually while the number of previously designed systems in use is very high. As a matter of fact, new products with increased capabilities are created by modifying and combining existing sub-systems. At the same time, the systems which these components/subsystems have been built for have changed considerably. Changes range from changes in available design data and methods to changes in manufacturing hardware and software technologies.

Aerospace systems often operate many complex electromechanical devices that were designed many years ago. Due to the cost of replacement and/or availability problems, these systems may continue to be used for years to come, well beyond their intended design life. In addition, continued maintenance and repair of these old systems require spare parts or devices which may no longer be supplied by manufacturers. In order to determine strategies for re-engineering of aerospace mechanical components, a comprehensive and integrated plan is really needed.

To date, there are only a few articles published in the literature about re-engineering of aerospace mechanical components. Most of these articles are published in the field of computer software technology. The major concern of these articles is re-engineering of legacy computer codes to make them compatible with new hardware and requirements. However, in mechanical based problems re-engineering and reverse engineering (RE) methodologies are substantially coupled to each other. Most of the published papers in this field have only reported the usage of such techniques in design modification and manufacturing of the components (for example see [2,3]).

The basic concepts, definitions and methods of traditional RE have been presented in [4]. An overview of recent advances in the field of RE has been given in [5]. In this overview, recently developed hardware, software packages and the underlying RE algorithms used in manufacturing of mechanical parts, computer arts, medicine, dentistry, product development, manufacturing and virtual heritage have briefly been introduced. In Ref. [6], technical definitions of re-engineering and RE have been given. In this reference, an algorithm for RE including an optimization step has been given. It is then shown that this modified RE method can be used effectively for renewal of legacy mechanical components. The proposed algorithm has been employed to develop a new design for an old gear box, used in an army vehicle, in order to achieve a higher working life together with less weight and lower manufacturing cost. Finally, the authors of this article concluded that a systematic procedure is critical for re-engineering activities.

A feature-based RE of mechanical parts has been discussed in [7,8]. In these papers, a method was proposed which uses manufacturing features as geometric primitives. This RE method facilitates the application of feature-based computer-aided design (CAD) system without considerable loss in accuracy. Using this method, CAD models for the part under consideration is produced compatible with manufacturing constraints to facilitate further geometrical modification in a re-engineering process. An engineering

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application of RE technology has been discussed in [9]. In this article, an application environment for RE implementation has been built using automated coordinate measuring machines (CMMs), CAD and computer-aided manufacturing (CAM) software. The method was applied to develop a core die for air inlet of a diesel engine.

A systematic RE, re-engineering and fast prototype manufacturing (RRF) process have been integrated in Ref. [10] to form a design process system. The developed system allows a geographically distributed team to work on a component design task at the same time. This system was used to re-design components in aging aircraft which were subjected to impact-induced fatigue and fracture events. It is then stated that this system can be effective for reducing data processing efforts and design time.

A reverse innovative design (RID) methodology has been proposed in [11]. RID is a variant of RE design methodology that incorporates computer-aided engineering (CAE) analysis-based product optimization into the conventional RE method. This design methodology is similar in nature to that developed in Ref. [6]. The proposed method consists of digital design methodology incorporating digitizing, modeling with shape and product definition parameters, CAE analysis and rapid prototyping. This design methodology facilitates shape design and associated knowledge reuse by providing 3D digital design applications. The core of this methodology is the definition and construction of feature-based parametric solid models from scanned data. This article also highlighted the importance of 3D modeling strategies for design modification and iteration. The paper focused on developing a technology for producing new designs with shape variations from a scanned physical model. There was not enough emphasis in this paper on simulation, standards, manufacturing procedures and functional tests which are essential concerns in re-engineering of aerospace mechanical components.

As can be seen from the above literature survey, many researchers have discussed in detail special features of re-engineering or RE such as producing geometric electronic data, CAD models, and manufacturing procedures. Integrating these features as a comprehensive plan for systematic re-engineering of mechanical parts would be very useful in practice. From this perspective the present paper aims at introducing a plan for re-engineering of mechanical parts used in aerospace structures and machineries. This plan can be used for modernization of legacy components of such systems. Emphasize was placed on standardization, analysis, simulation and functional tests to provide sufficient reliability required in such systems. This plan considers the following points:

(1) The component/subsystem that needs to be re-engineered fits into a larger system. Therefore, the replacement must interface with existing parts of the system. In this way, quantities such as geometrical dimensions, tolerances, material properties and joints should be matched with other components in that system.
(2) Documentation about the part may be unavailable, incomplete and/or in a form not compatible with existing CAD/CAM facilities. Therefore, RE procedures must be linked to the proposed plan to develop sufficient electronic data that are required for modern CAD/CAM systems.
(3) The effectiveness or working life of the part may be unsatisfactory. For example, the part failure may have been caused by a flaw in the original design, or the legacy part is being used in a condition unexpected in the original design. So that the original part is unsuited for reliable operation. In addition, the original material and/or manufacturing tools for re-manufacturing of the part may not be readily available. In these cases, design optimization is required to improve working performance of the part and/or to match the design with the available materials and tools.

2. Definitions

It is not likely that there will be a single best strategy for re-producing all components/sub-systems. Depending on the part condition and its usage, RE, re-engineering, re-design or a combination of them may be appropriate. If the legacy components/sub-systems have been severely distorted or repaired repeatedly and their technical documents are unavailable, the probability of recapturing accurate initial design data using traditional RE techniques would be very poor. In such cases, re-engineering analysis is necessary to determine the component parameters such as stresses, deformations, tolerances and the like. It has to be noted that re-producing these data may be very costly and time consuming causing economical assessments emerge as a real need.

2.1. Reverse engineering

Reverse engineering involves producing a copy of the original part. The most important action in RE is to develop CAD models (digital drawings) for the component. RE currently concerns technologies such as image processing, computer graphics, advanced prototype manufacturing and virtual reality for creating a computer-based representation of an object.

In many practical cases, there is not enough geometrical data and accurate drawings necessary for creation of 3D CAD models and consequently, prototype manufacturing using traditional CAM systems may not be possible. It is noted that accurate geometric shape and size data are necessary but not sufficient to reproduce the part. Material specifications, manufacturing processes, tolerances, and the like must also be known. Fig. 1 shows the general flow of work in the traditional RE.

2.2. Re-engineering

Availability of new materials, up to date standards, modern manufacturing technologies and CAD methods can favor the choice to improve the design rather than simply trying to copy it. This may cause to achieve a cheaper, lighter component together with a higher reliability. Many aerospace designers currently believed that providing sufficient reliability is the most critical issue in designs. In this way, availability of specialized analysis tools and knowledge databases can be very important for reducing development effort and cost. Fig. 2 shows general procedure of re-engineering of mechanical parts. In this procedure, it is assumed that the geometric data is available and only some modifications to the shape and material specifications are aimed.

2.3. Re-design

In some circumstances, it might be preferable to ignore the original part altogether and to re-design it completely, or to replace it with an equivalent up to date device. Before the re-design can be done, the performance requirements and interfacing constraints such as space/weight constraints, mechanical/electrical connections and the like must be extracted from the existing systems. These dimensions and constraints must be carefully applied to the new design. If documentation is lacking, part geometry, functional and material attributes, etc., may require physical testing of the existing system.

3. The proposed re-engineering plan

Many aerospace system manufacturers are now dealing with increasing demands for the renewal of aging aircraft components/sub-systems. As outlined above, just using RE may not be