Digital manufacturing technologies for missile development

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ABSTRACT

The digital revolution is now breathing the walls of manufacturing as media, banking, consumer goods, healthcare and other industries are constantly disrupted. Digital manufacturing provides the ability to conduct a full production process in a virtual world. In this way, engineers digitally describe, schedule, build 3D models using CAD software, track, build analysis. Digital manufacturing involves the end to end digitization of all physical assets and their integration in to digital eco systems with value chain partners. Digital manufacturing is the driver for the fourth industrial revolution which is termed as Industry 4.0. This paper explains about the digital manufacturing technologies used for the development of missile.

1. Introduction

Digital manufacturing combines desktop design software – the sort that can be run from your home computer- and both traditional and new manufacturing equipment including 3D printers, Computer Numerical Control (CNC) machines that use digital instructions to operate a variety of cutting and millings tools, and laser cutters. Digital manufacturing begins with software. Using software that has been used by industrial designers for decades, one can design and render a 3D model of the object for production. Designers need not start from scratch. The open source movement- a worldwide movement of inventors, programmers and designers who make their work available to others free of charge- provides a wide range of designs that can be directly manufactured or built on to create custom designs for particular needs. Designers can also take advantage of 3D scanners which can make a digital model of a physical object, saving the designer the trouble of redesigning the object from scratch and allowing the production of exceedingly exact copies. [1] Manufacturing process analysis is necessary for manufacturing companies to improve market competition [2]. The use of the digital manufacturing models is suitable for designing new production systems or improving the existing ones [3].

Digital manufacturing can be used to produce components for missiles that are more effective than those produced by traditional industrial processes. NASA is currently using selective laser melting, a process similar to 3D printing which uses a laser to harden layers of metallic powder into an object, to produce components for the Space Launch System. The space launch system is a heavy lift rocket intended to carry robotic and manned missions to “nearby asteroids and eventually to Mars.”[4]

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2. Geometric Modeling

Geometry plays a crucial role in the design and production of discrete mechanical goods. In early times artisans "carried geometry in their heads" or relied on physical models and analogues. The rise of mass production and job specialization led to the adoption of engineering drawings as a medium for geometric specification, and recently the advent of computers, NC (numerically controlled) plotters, and cathode ray tube (CRT) displays has led to a growing wave of "computerization" of drafting activities. [5]

3. Tolerance Allocation

Tolerance allocation is the process of determining allowable dimensional variations in products (parts and subassemblies) and processes (fixtures and tools) in order to meet final assembly quality and cost targets. Traditionally, tolerance allocation is conducted by solving a single optimization problem. [6] There are two main types of tolerance allocation processes. 1.Quality-Driven Tolerance Allocation: We apply the ATC (analytical target cascading) methodology to a quality-driven optimization formulation that considers product tolerances only, and conduct a parametric analysis with respect to available budget in order to quantify costquality trade-offs. 2. Cost-Driven Tolerance Allocation: Here, we apply the ATC methodology to a cost-driven optimization formulation. We first consider product tolerance allocation only, and then we also conduct process tolerance allocation in order to compare the two sets of results.

4. Finite Element Analysis

The basic idea in FEA is to divide the body or structure into smaller finite dimensional components called "Finite Components." The original body or structure is then treated as an assembly of these associated elements at a finite number of joints called "Nodes" or "Nodal Points." Simple functions for approximating the displacements over each finite element are chosen. This will represent the displacement within the element in terms of the displacement at the nodes of the element.

5. Computational Fluid Dynamics

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems that involve fluid flows. During this process preprocessing the geometry of the problem is defined then volume occupied by the fluid is divided into discrete cells called mesh. This mesh may be uniform or non-uniform. The physical modeling is defined – for example, the equations of motion + enthalpy + radiation + species conservation. Boundary conditions are defined. This involves specifying the fluid behavior and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined. The simulation is started and the equations are solved iteratively as a steady-state or transient. Finally a postprocessor is used for the analysis and visualization of the resulting solution. Computational fluid dynamics (CFD) is increasingly applied throughout the development cycle of advanced tactical missiles.

Examples of CFD in the missile development process: (a) supersonic inlet, (b) full airframe aerodynamics, (c) control jet interaction, (d) jet-vane thrust vector control, (e) force body rocket sled test, and (f) IR seeker window environment.

This increased reliance on CFD is due, in part, to the increased demands being made on the missiles for higher speed, greater maneuverability, multiple missions, and the maturity of the CFD discipline. Recent CFD developments in multizone structured, unstructured, and adaptive grids, along with multiprocessor algorithms, have drastically reduced the time required to obtain results. Another factor in the increasing role of CFD is the engineering efficiency it brings to the missile system design and development process.[8]

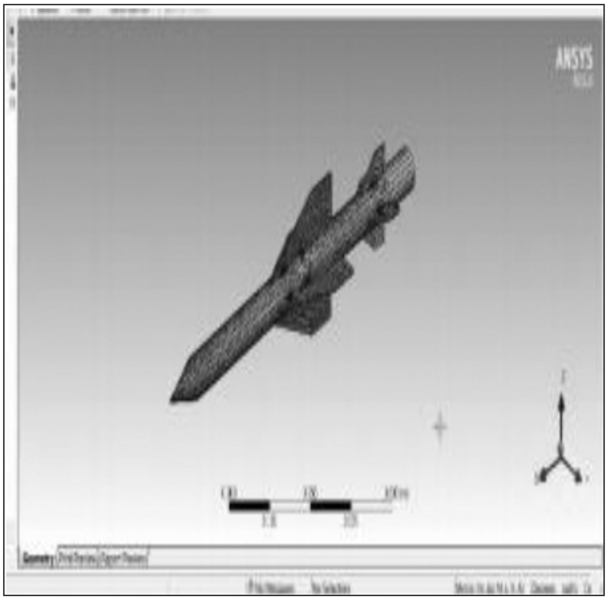

Fig. 1. Source [7].

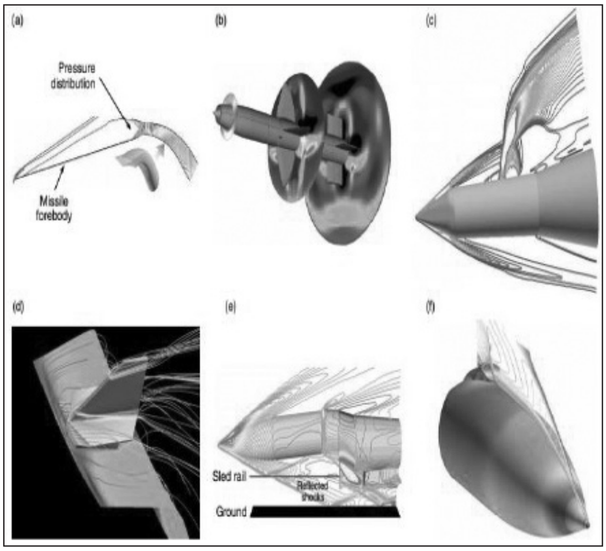

Fig. 2. Source [8].

6. Structural Optimization

Structural optimization is the task of finding the best way for a material assembly to withstand loads. To correct ideas, think of a situation where

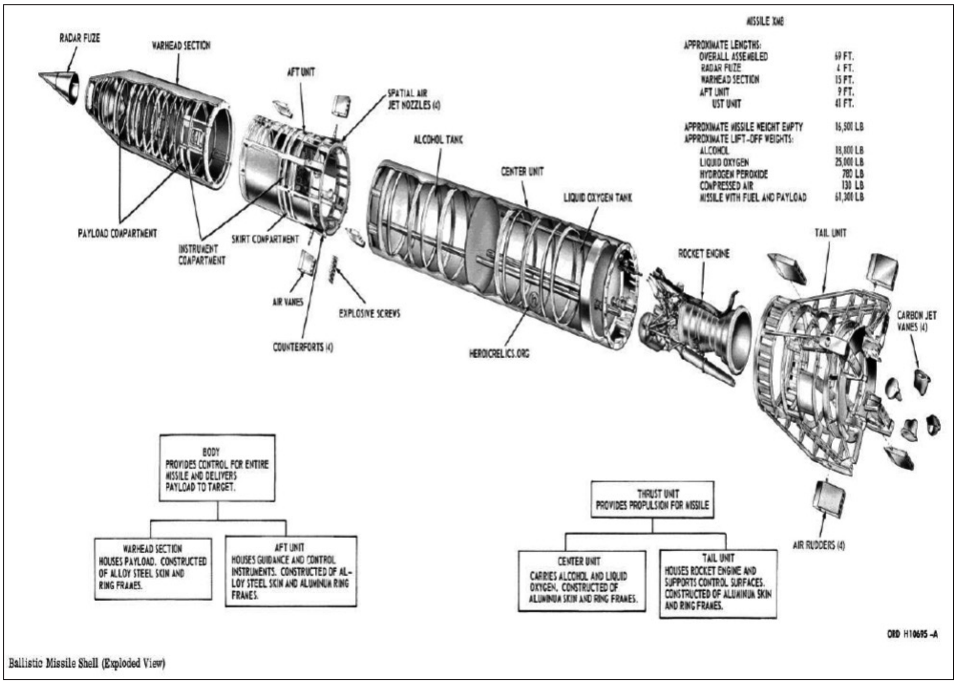

Fig. 3. Assembly of missile parts, source [10].

a load is to be transmitted into a fixed service from a region in space. Stresses, displacements and/or geometry are quantities that are typically limited in structural optimization problems. Note that most quantities that one can think of as constraints could also be used as measures of "best," i.e., as objective functions. Thus, one can put down a number of measures on structural performance, weight, stiffness, critical load, stress, displacement and geometry and a structural optimization problem is formulated by picking one of these as an objective function that should be maximized or minimized and using some of the other measures as constraints.

7. Mechanism Simulation

Mechanical simulation is used to forecast product performance, refine designs and verify product behaviour before manufacturing a missile. In addition, simulation also help to test system design to verify the efficiency of product design in worst case scenarios.

8. Assembly Simulation

Simulation is used throughout all stages and phases of a missile project. Starting with a set of requirements, very simple models of the missile are used to perfect the basic relationships in the scenario. Initially, models are developed that include limits imposed by operation and the laws of physics. The models are implemented on a digital computer and the simulation generated data is the basis of further development of a particular subsystem. The models are refined and updated to a desired level and hardware requirements are generated based on insights gained from the simulation. [9] The hardware developer and manufacturer produce a prototype of the subsystem hardware. The simulation models are further refined and used as a check on the hardware during development and testing. The data base obtained from testing the hardware provides for a type of subsystem model validation. Simulations used throughout the development phase of an air-to-air missile, for example, require the development of several different simulation programs. Typical simulation models include: a six degrees-of-freedom (DOF), and a simplified six DOF model, warhead effectiveness model, and hybrid computer simulation model for hardware-in-the-loop simulation. The system simulations are typically all digital, non-realtime, modular structured for subsystem components association with program subroutines.

The six DOF's Include the aerodynamics in plane and out of plane forces and moments, induced rolling moments, fin hinge moments, body bending, detector models including rate gyros and accelerometers, integrating rate gyros and antennas including the gimbals systems. The simplified six DOF's has reduced complexity in the aerodynamic models, no roll or out of plane motion, perfect integrating rate gyros and antenna stabilization loops. The simplified models are used to define the firing envelope of the missile. Frequently a simulation will include seeker noise and detector errors allowing the radom variable to be studied using a Monte Carlo approach.

9. Manufacturing Process Simulation

It allows organizations in the manufacturing industry to analyze and experiment with their processes in a virtual environment, reducing the time and cost requirements associated with physical testing.

10. Manufacturing Process Optimization

Modeling and simulation is an important process in developing product. The production cycle of all device levels. Generally a model is a simplified representation of a device or system function or functionality. Examples of models include diagrams, scale models and mockups, and logic flows; some of these can be implemented into computer programmes. Generally speaking, simulations consist of connected collections of models within a time period.

11. DFM

Design for Manufacturing (DFM) refers to design operation focused on reducing the cost of production and/or marketing time for a product while maintaining a satisfactory quality standard. A primary DFM strategy includes reducing a product's number of components.

12. DFA

Design for Assembly (DFA) includes simplifying the instructions and methods for mounting and connecting the parts of a component. Below Fig.3 shows assembly of missile parts.

13. Conclusions

1. Trends call for an increased need for rigour, systematic measures, an atmosphere that embraces sensitive problems, and a process that is open to inspection. New tools are needed to be able to understand and monitor the increasing number of parameters and conditions.
2. With the decline in the number of experienced engineering personnel in military industries and services, the rise in system complexity and a decline in failure tolerance, the long-standing tradition and culture of systems engineering will become increasingly important in air and missile defence systems of the next century.

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