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Expedient Prototyping Modeling and Design for Military Vehicles with Evolving Requirements & Developing Interface Control Documents with Specifications for Competing Military Hardware.

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Introduction:

The focus of this paper will be to discuss the design processes used in the past and how top down design could be utilized to become more efficient, faster, and seamless than traditional bottom up design that is typically used in the military. Many programs suffer from evolving requirements or changes in technology that require modifications that are expensive and timely. The benefit of traditional bottom up Computer Aided Design (CAD) is that parts can be made by many individuals and then assembled into the model; similar to building with Legos, one piece at a time. This enables a substantial amount of resources that can be applied to develop a product. The problem is that it is very expensive and not very efficient. Furthermore, the ability to use multi-functional disciplines is very difficult. Work is typically segmented into individual departments such as Structures, Powertrain, Seating/Flooring, Electronics, Armor, Etc. Meaning that changes in the powertrain subassembly will not be viewable in the seating/flooring or structure subassembly. Aside from the engineering aspect, the CAD modeling is also compartmentalized. For example, the industrial designer will develop sketches of concepts. However, the data is not parametric with the concept design and detailed design. So the visual aids will be utilized by the concept and design team, but the actual design data is not utilized and any updates by concepts will not drive the industrial design. The significant inefficiency is the transition between concepts and detailed design between different departments.

Drafting on the board can be exceptionally quick, but the downside is that the data is on paper and the data then needs to be converted to CAD for modeling and simulation analysis, configuration management, interference/clearance analysis, center of gravity, weight, future revisions, etc.

Top down design has one similarity to drafting on the board where the concept is sketched first and then the individual parts are sketched from the top concept. Additionally for CAD Top Down Design, the conceptual sketch can then associatively drive individual part design. When said conceptual sketch changes, individual parts change automatically. This is not the case for board drawings.

In 2005, the 939 Add on Armor (AOA) program was a significant success. The AOA cab went from an idea to a prototype ready for mine blast testing in two months and one additional month was needed to produce the automotive AOA kit. Oddly, the lead design engineer was exceptional at drafting and the kit was done on the board. This was OK for the prototype, but 3,000 kits were required and seven (7) depots would be supporting this program every day, all day that spanned six (6) months. Transferring drawings on paper all across the country and revising the drawings on paper would be extremely slow and configuration management would be very difficult to maintain. So, the individual parts were then redone in CAD so the drawings could be shared with all the depots manufacturing the hardware. The time to do this process was five (5) months. So the time to move to production expanded to 8 months. Had this program been done by skeleton modeling with a top down design CAD approach, the part modeling time would have been substantially shorter as the drawings would not of had to been done twice, on paper and then in CAD.

Figure 1: M939 AOA Kit

A recent article in Advances in Mechanical Engineering [1] points out many approaches of top down design. One such approach used in the past was interference and location design parameter. Generally this is a skeleton modeling with coordinate systems and the parts are placed by coordinate systems. This has the benefit of a bottom up approach where individual parts can be made and then placed in the assembly without impacting or requiring geometry from other parts. This is helpful for making revisions, but this approach is still primarily driven as a bottom up approach.

The traditional design using top down has one skeleton model per assembly and the parts have published geometry.

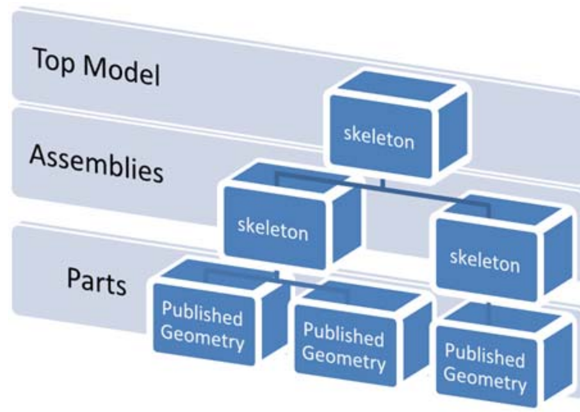

Figure 2: Traditional Top Down Design

A similar approach was also taught in advanced assembly management in Creo 2 in 2006 [2]. The class taught of having skeleton models in assemblies. This was more useful as multiple skeletons could be added to an assembly. Caution had to be taken using this approach as the skeletons were in an assembly with parts and it was very easy to modify, create or delete features in the skeleton when the intent was to perform that action in the assembly or part level.

In 2006-2007 a major effort titled the Monster Garage Project [3] was undertaken to improve performance, payload, and protection to the High Mobility Multipurpose Wheeled Vehicle (HMMWV). Many concepts were identified and several were implemented. One concept was further funded by the Under Secretary of the Army. This program was the double "V" hull for enhanced underbody protection. The program was titled the High Mobility Multipurpose Wheeled Vehicle (HMMWV) Improvement (HIP) Program [4]. The initial approached used the typical bottom up design. The program took approximately 5 month to develop a new hull design, floors, seats, ballistic glass, and doors, build the porotype and test. The effort was more substantial than the M939 effort and the time to complete the effort was as expected.

However, the evolving requirement required modifications to the hull survivability demonstrator to meet the level of threats that transitioned from current design requirements, threshold, and objective. Although modifications were not significant it took three (3) to four (4) months to make the design changes as one modification to one part resulted in a modification to the adjoining parts. In all, four (4) prototypes were tested and one prototype was tested twice (one time unsuccessfully). Although the technology was successful and surpassed all expectation, the time to develop the technology was too long and the champion for the project, the undersecretary for the army, retired. Also, at the conclusion of the HIP

Figure 3: HMMWV Improvement Program (HIP) Double V Hull Survivability Demonstrator

last test, a new vehicle platform was being tested, the Mine Resistant Ambush Protected All-Terrain Vehicle (M-ATV). This vehicle not only addressed the underbody survivability, but also addressed performance and payload.

This inefficiency in design development for rapid prototyping lead to an effort to determine a way to expedite modifications. The HIP effort was a collaborative effort between industry and the United States Army Tank Automotive Research, Development and Engineering Center (TARDEC). One of the engineering partners was Motorsports International that utilized a subcontractor who is the founder of E-Cognition. The individual had worked closely with PTC in support of companies such as Penske Racing and Miss Budweiser. More recently E-Cognition has been supporting Boing. Initially done as an effort to make design changes more efficient and quicker, the program quickly determined that the use of top down design could also leverage a significant amount of other capabilities in Pro-E to aid the engineer and management to improve design and concepts. By adding mathematical calculations and knowing empirical data not contained in the model the skeleton models could be optimized to theoretically provide the same mine blast protection yet reduce the weight and height of the vehicle. This was done for the HIP cab and it was determined that the weight could be reduced by over 1,500 lbs and the height reduced by 6 inches and provide the same ergonomics and mine blast performance. A significantly more refined design in shown in figure 4 as compared to figure 3.

Figure 4: Optimized Light Tactical Vehicle

The skeleton model used for the light tactical vehicles was also copied and modified for the TARDEC Mech-V program. To improve interior spacing, the lead engineer wanted to know if they could have a shallower V in the middle of the vehicle. It took three (3) days to provide an engineering judgement it would pass mine blast testing based on the results correlated to empirical data. This was done the first week of the program, before detailed design work started, and long before the mine blast analysis was completed. Being able to conduct optimization analysis in the area of stress, deflection, weight, volume, etc on a skeleton model can be used to further improve performance.

A factor that might be overlooked in top down design is expertise. Transforming from bottom up to top down design requires knowledge up front and a "learn as you go" approach will most likely result in failure, cost over-run and schedule slippage. This occurred on a program where the expert in top-down design was removed from the program to utilize more in-house expertise. Subsequent problems ensued due to the complexity of having the part design being driven by the parametric relationship of the skeleton model that was developed by the individual no longer on the program.

Figure 5: Expeditionary Fighting Vehicle (EFV) [5]

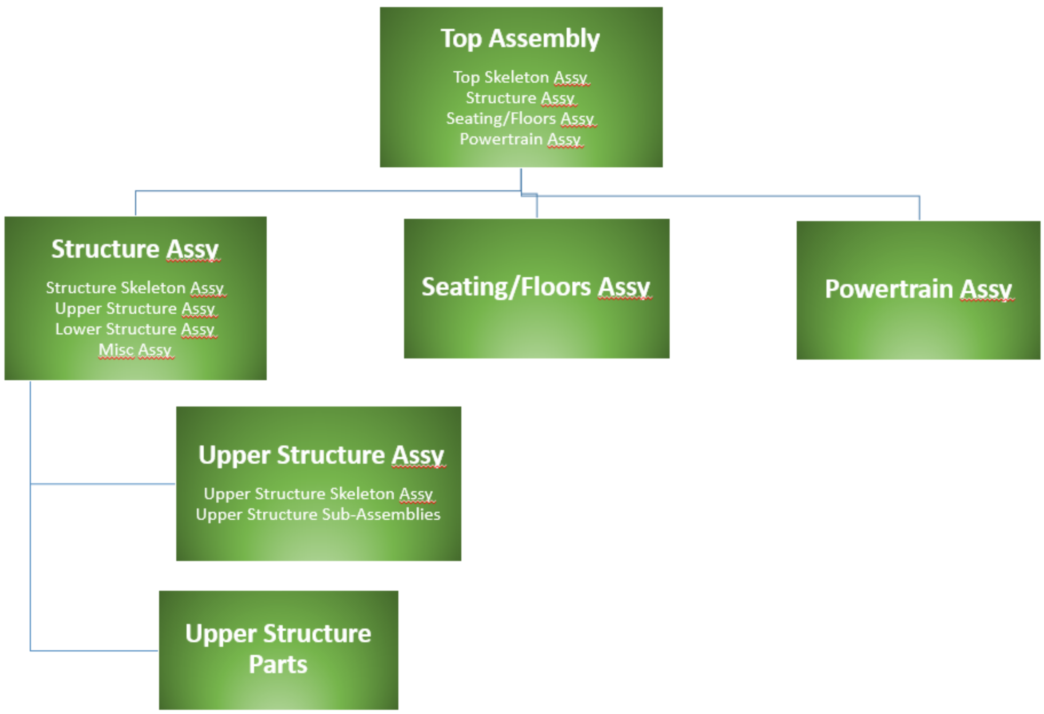

Figure 6: Sample Assembly Structure for the ACV

In 2012-2013, TARDEC was tasked to develop a hull design that would improve the underbody survivability to the Amphibious Combat Vehicle with three (3) crew and seventeen (17) passengers (Expeditionary Fighting Vehicle (EFV) replacement) and a combat weight of less than 80,000 lbs. Fortunately, top down design and advanced assy management was allowed to be used for this project. This was a very large and complex program. This vehicle had to operate in land and in water

Because of top down design TARDEC was able to evaluate a threshold survivability performance and then subsequently an objective level performance by simply changing the thickness numbers in the skeleton model and then regenerating the model and obtaining the weight and then making an IGES file for analytics to mesh and run the analysis on the new model. Due to limited funding, manpower was limited to two engineers and 100K of contractual support to develop a threshold level mine blast model and a subsequent objective level mine blast model in seven (7) months this included time to complete mine blast analysis. The concept utilized a "W" underbody shape. This was the first "W" shape for a combat vehicle and no empirical data existed for a design guide. Top down design with pro-E optimization was used to determine the angles of the "W" shape and plate length. The key factor in all of this was that the concept was being optimized for weight and performance with a circular loop with analytics and at the same time detailed design was able to be done on the individual parts. Furthermore, the part geometry and edge preparation was parametric and driven by the concept skeleton models. So as enhancements could be determined they were driven down to the parts that were automatically updated with no or little user input to modify the parts.

The entire model or nearly the entire model is geometry driven. Meaning that a change to the skeleton model could change thousands of features. This is beneficial if the length, width, or height is changed or plate thickness is changed in the model. This is also true if changes such as going from friction stir welding to gas metal arc welding or vice versa occurs.

For the Amphibious Combat Vehicle (ACV) program, an expert in top down design supported the program. During the program, a concern arose about the significant amount of skeleton models. The idea was to somehow combine the skeleton models in an assembly within the assembly. This would enable the engineer to work on the skeleton models in an assembly mode that would show the geometry and detail required and reference data without having to open the actual assembly model. It was determined that if you use a motion skeleton in Pro-E, that one could assemble all the skeletons into a skeleton assembly within a model assembly. This approach was used for the TARDEC Amphibious Combat Vehicle Hull Survivability Demonstrator Program. This process allows for better workflow as work can be done in multiple disciplines without impacting each other while major changes can be made at the top and instantly driven down to all the parts.

More importantly, because we used a top down design, when the Program Manager (PM) decided to go from friction stir welding requirement to gas metal arc welding (GMAW) with mechanical locks, we were able to integrate joint surfacing into the skeleton model and change the FSW joint to a GMA welded joint with mechanical locking feature in approximately 1 month. The mechanical locks are fully parametric and will update to maintain a 0.015 inch clearance between the joint and lengthen or shorten the tab if the overall vehicle length is increased or shortened. A report of this effort is in the technical information center titled "Amphibious Combat Vehicle Hull Survivability Demonstrator".

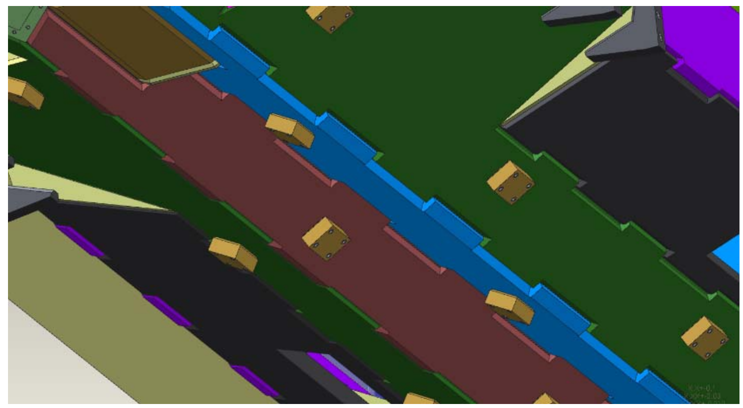

Figure 7: ACV Plate Interface Geometry

A full TDP of the drawings and weldments was provided to the Program Manager Advanced Amphibious Assault (PM-AAA) and the model and drawings are loaded into Windchill. To date, that is the most complex top down design that has been done for a ground military vehicle known to the author.

To get an idea of the complexity of the plate geometry driven by the skeleton models, figure seven (7) shows part of the vehicle showing the plate interface geometry driven by the skeleton models. Top Down design also enables more cohesion and synergy between TARDEC Advanced Concepts and TARDEC Center for Systems Integration (CSI) Mechanical Systems team. With top down design it is possible that the skeleton models could be jointly created to directly feed changes from Advanced Concepts to drawings at CSI and CNC machine programing with parametric technology currently available. Figure 8 is a proposed sample process for top down design for a military vehicle program. The idea is that the process can become more parametric and more efficient and maximize resources that can be utilized for the program.

The second focus of this paper is to highlight some of the issues with modeling kits or packaging military vehicles. TARDEC Center for Systems Integration is as the title states. Our primary function is to integrate technology onto military vehicles. We do not provide configuration management for military vehicle CAD models. This is typically done by the prime contractor. So, all the hardware integrated onto a vehicle platform is done as a kit and does not impact the vehicle configuration, typically.

Historical Reference: During Operation Enduring Freedom/Operation Iraqi Freedom (OEF/OIF), add on armor kits were developed for multiple systems. One primary issue that evolved during this time was the problem of only one individual could have the top model out for assembly and reference. The other primary issue was that the kits were being added to CAD models with very large assemblies. Models would often take 20 minutes to load and manipulation was painfully slow. To further compound the problem is that the lead engineer was usually the engineer using the top assembly. So the best talent is being wasted on waiting for models to regenerate on the screen to refresh after a change. This lead to the use of simplified reps that substantially reduced the time to load the models, however, the working time was still significantly long. Plus the entire model had to be opened to make the simplified rep and any hardware not in the simplified rep would require updating.

In 2013, TARDEC supported the survivability program for the Program Manager for the Light Armored Vehicle (PM-LAV). The focus of TARDEC-CSI support was to determine energy attenuating (EA) seats and flooring for all the variants and the entire fleet of vehicles. The problem with a program like this is that the data is proprietary to GDLS. The CAD cannot be released to other contractors. However, to reduce cost, open completion would be the most efficient. The program then created a skeleton model of the LAV fleet of vehicles to capture the space claim for the seats and provide the appurtenance information via CAD, Drawings, and documentation. TARDEC Survivability, Advanced Concepts, and TARDEC Mechanical Development Team with the oversight and support

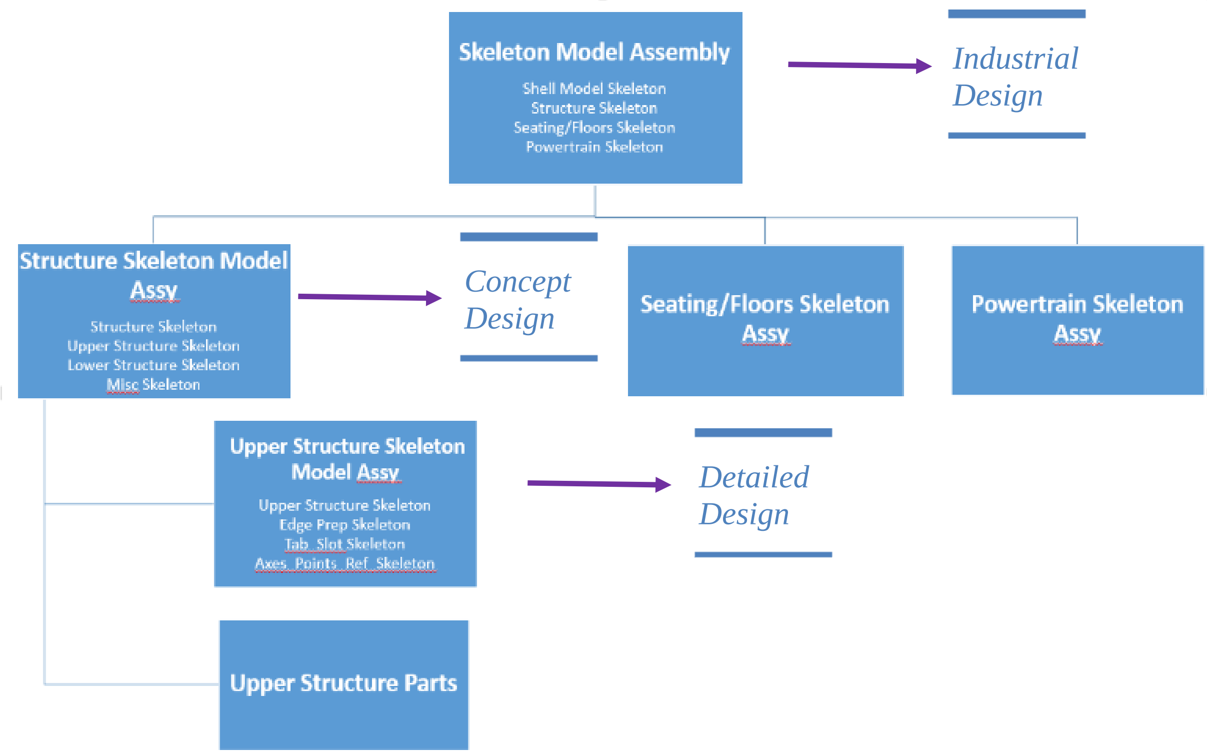

Figure 8: Proposed Top Down Design Process

of PM-LAV developed a mine blast seat specification and interface control document. The anticipated cost for the seats was reduced by not having to sole source the seats and with this approach, new technology could easily be integrated when needed. The current military specification for EA seating, MIL-PRF-32563, was derived from this approach. This approach was also utilized for the development of the driver's seat lift mechanism and locking pin for PM-LAV. Both of which are at level III, completed testing and are in process of procurement.

A pilot effort to reduce the integration time for the Stryker is currently being developed. This is a skeleton model derived from the main Stryker model that can be used to install hardware without having to load the main model. This approach is being developed to avoid having to make simplified reps that are inefficient for most of our work. The skeleton model assembly can load in seconds where the main model can take up to 15 minutes to load. Furthermore, for kits, the model is not supposed to be assembled to main hull models so it has to be stripped away from a main model if being loaded into Windchill. Substantial problems in the past have resulted from having to work with main vehicle models to install kit models. The skeleton modeling enables the capability to install kit hardware and break the assemblies down between departments such as propulsion, electronics, seats, driveline, suspension, pneumatics, HVAC, Armor, etc. Allowing a greater teaming effort for design and integration.

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