Orbiter/External Tank Mate 3-D Solid Modeling

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ABSTRACT *– This research and development project presents an overview of the work completed while attending a summer 2004 American Society of Engineering Education/National Aeronautics and Space Administration (ASEE/NASA) Faculty Fellowship. This fellowship was completed at the Kennedy Space Center, Florida. The scope of the project was to complete parts, assemblies, and drawings that could be used by Ground Support Equipment (GSE) personnel to simulate situations and scenarios commonplace to the space shuttle Orbiter/External Tank (ET) Mate (S0004). This mate takes place in the Vehicle Assembly Building (VAB). These simulations could then be used by NASA engineers as decision-making tools. During the summer of 2004, parts were created that defined the Orbiter/ET structural interfaces. Emphasis was placed upon assemblies that included the Orbiter/ET forward attachment (EO-1), aft left thrust strut (EO-2), aft right tripod support structure (EO-3), and crossbeam and aft feedline/umbilical supports. These assemblies are used to attach the Orbiter to the ET. The Orbiter/ET Mate assembly was then used to compare and analyze clearance distances using different Orbiter hang angles. It was found that a 30-minute arc angle change in Orbiter hang angle affected distance at the bipod strut to Orbiter yoke fitting 8.11 inches. A 3-D solid model library was established as a result of this project. This library contains parts, assemblies, and drawings translated into several formats. This library contains a collection of the following files: stl for sterolithography, stp for neutral file work, shrinkwrap for compression, tiff for photoshop work, jpeg for Internet use, and prt and asm for Pro/Engineer use. This library was made available to NASA engineers so that they could access its contents to make angle, load, and clearance analysis studies. These decision-making tools may be used by Pro/Engineer users and non-users.*

I. Introduction

The scope of this project was to provide 3-D solid models for the Orbiter/ET Mate per Operational Maintenance Instruction (OMI). The task involved creating parts, assemblies, and drawings and making them available to NASA engineers. Additional tasks included translating 3-D models into a common language, securing engineering drawings, and collecting operational manual documents. A secondary benefit was the creation of a 3-D solid model library that engineers may use in their design and analysis activities. This library contains parts, assemblies, and drawings that may be used by NASA engineers as tools: for angle, load, and clearance analysis.

II. Main Text-Descriptive Information

A basic understanding of simple part construction and assembly modeling is necessary before Pro/Engineer may be used as an engineering tool. Pro/Engineer is a 3-D feature based parametric solid modeling system (Lamit, 2004). When using this software the "geometry drives the dimension"(Toogood, 2003). All parts were built using a base feature. All features are extruded or revolved to create the basic part shape. These features are called parent features. These features are then cut to create slots and holes. These features are called child features. The use of parent child relationships allow for more complete and easier part revision. Fillets and rounds are added last. Suppression of fillets and rounds may be necessary before compiling finite element analysis information.

Assembly modeling involves the combination of two or more part components. Using assembly methods sub-assemblies and final assemblies may be created (Toogood, 2003; Shih, 2003; Kelley, 2001). Assembly components are put together using assembly constraints. When a component becomes part of an assembly, it is considered placed (Toogood, 2003; Toogood 2001). This means that it is fully constrained (Steffen and Graham, 2004 and Parametric Technology Corporation, 2003). Mate, align, and insert are the main constraint methods.

With a basic understanding, advanced techniques allow design animation and mechanism simulation. Pro/Engineer's Design Animation option lets you organize parts and assemblies in an animation (Williams, 2003). After routines have been coordinated, the animation may be played back. This module lets you run, create, and manage an animation. When using this option, animation may be created by linking a series of snapshots. A time line is used to control motion. Motion is a module of Pro/Mechanism. Its use is in the finalization of a design. After a mechanism has been designed, it may be tested using forces. Loads generated may be measured. Use of these mechanisms in engineering analysis give engineers an analysis tool.

Mechanism animation simulation is possible using the following methods. They include the Design Animation Option of Pro/Engineer (Image driven), and the Motion Simulation Option of Pro/Mechanica (kinetic driven)(Gagnon, 2003). The process includes: configuring joint axis settings, defining drivers and motion, reviewing mechanisms, reviewing motion analysis, optimizing mechanism designs, calculating degrees of freedom, and setting range of motion. The language of mechanisms includes terms such as fix, welded, and translate. Mechanisms are used for motion analysis.

The export and import of different types of files is critical to allow full use of each part model. Pro/Engineer has proven to be a top choice for input and output data exchange. Using Pro/Engineer, data exchange is quite possible between Catia, Unigraphics, Solidworks, and AutoCAD software programs (Trainer, 2003). These data exchanges may be made using STEP, IGES, ACIS, Parasolid, STL, VRML, and DXF file formats. Pro/Engineer will import the following file formats: STL, VRML, STEP, IGES, faceted, Catia SOLM, CGM, CADAM, Medusa, DXF, and DWG. It will export the following file formats: STEP, SET, IGES, Medusa, CGM, DXF, DWG, ProductView, and Shrinkwrap. Direct translation is possible to Catia, PDGS, CADAM, Medusa, Stheno, AutoCAD, DFX, DWG, Parasolids, and ACIS file format. Other translation possibilities include IGES, STEP, SET, VDA, ECAD, CGM, Cosmos/M, Patras, Supertab, SLA, CGM, JPEG, TIFF, Render, VRML, and Inventor.

Pro/Engineer data exchange capabilities make it good software for handling files from many different sources.

The method in which prototype models are built is called stereolithography. The process is called Fused Deposition Modeling (FDM). Sterolithography lets the designer complete the full design process, from initial concept to replica of a product. It is necessary to set Pro/Engineering's chord heights to .001 prior to creation of a tessellation file. A Pro/Engineer part file is translated into a tessellation file (.stl). This file is then used to create a machine code for prototype model construction. ABS or polycarbonate plastic is placed in .010-inch layers to build-up the part shape and size description. Wax is used to support the plastic during construction. The wax is cleaned from the part using an ultrasonic cleaning process. The resulting prototype is quite accurate in dimension. Many prototype models were built to check form, fit, and function.

Approximately 100 parts, assemblies, and drawings were created to accomplish our task. An Orbiter model was obtained from the NASA engineering design support group (YA). This orbiter model originally came from Boeing. See Figure 1.

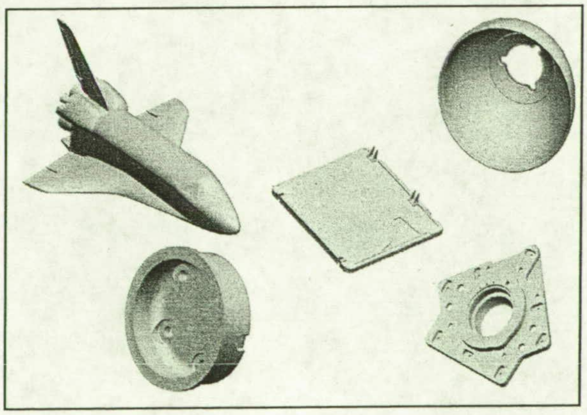

Figure 1. Orbiter and Assorted Orbiter Parts

An ET model was revised to reflect its new design. Lockheed/Martin was instrumental in obtaining ET and ET attach part drawings. See Figure 2.

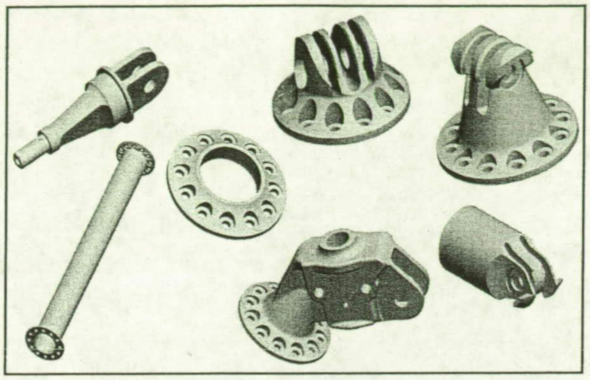

Figure 2. Assorted ET Attach Parts

These drawings reflected the parts needed to build the Orbiter/ET structural interfaces. See Figure 3.

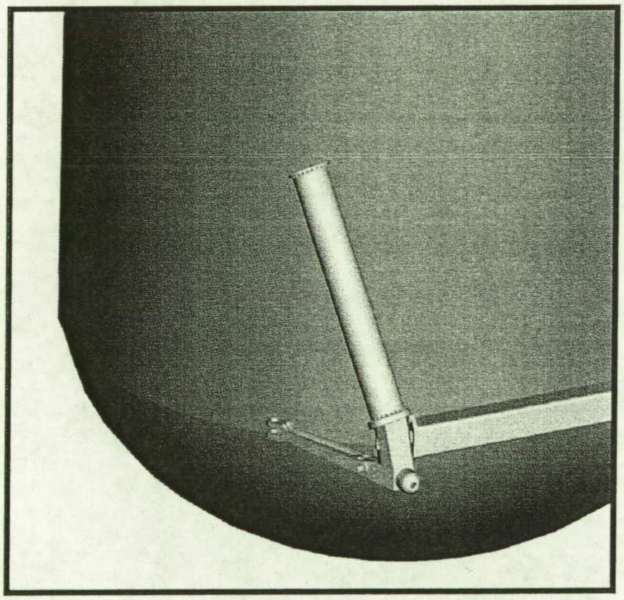

Figure 3. Aft Left Thrust Strut Assembly and ET

There were four principle sub-assemblies. These included the Orbiter/ET forward attachment, aft left thrust strut, aft right tripod support structures, and crossbeam and aft feedline/Umbilical supports. See Figure 4.

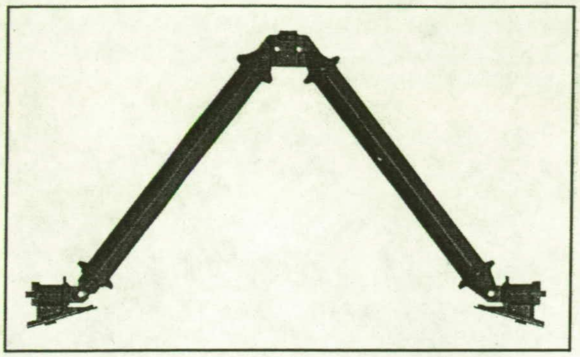

Figure 4. Orbiter/ET Forward Attachment Assembly

These assemblies were used to attach the Orbiter to the ET. Two additional assemblies were built showing an Orbiter hang angle of 90°, and 90° minus 30'. See Figure 5.

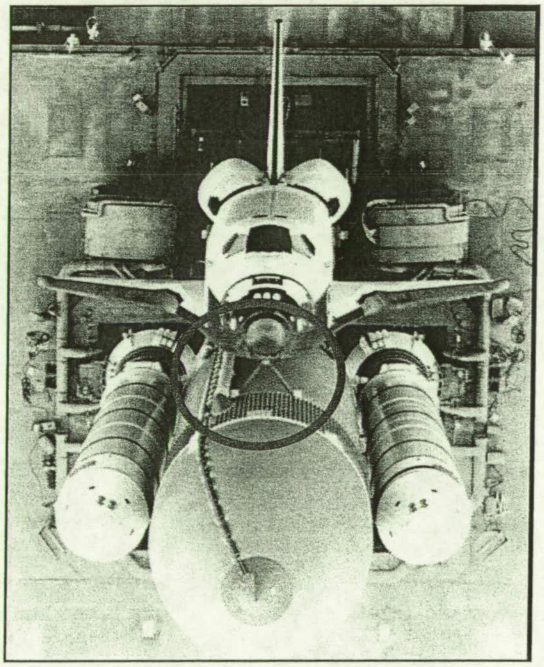

Figure 5. ET, Orbiter, and Attachment Assembly

Clearance distances were observed and compared at both hang angles. See Figure 6.

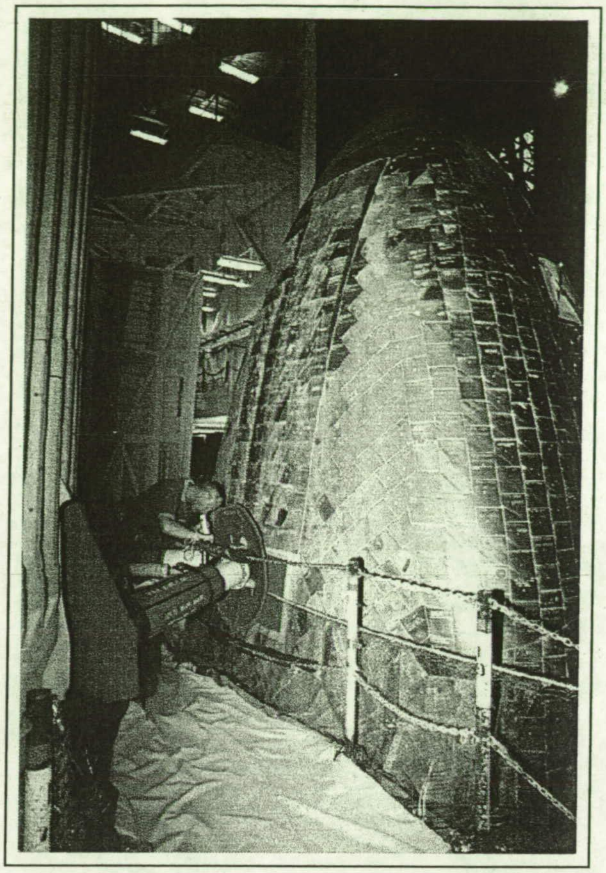

Figure 6. Orbiter/ET Forward Attachment

There were a number of unique parts. One of these parts was a ball interface fitting. See Figure 7.

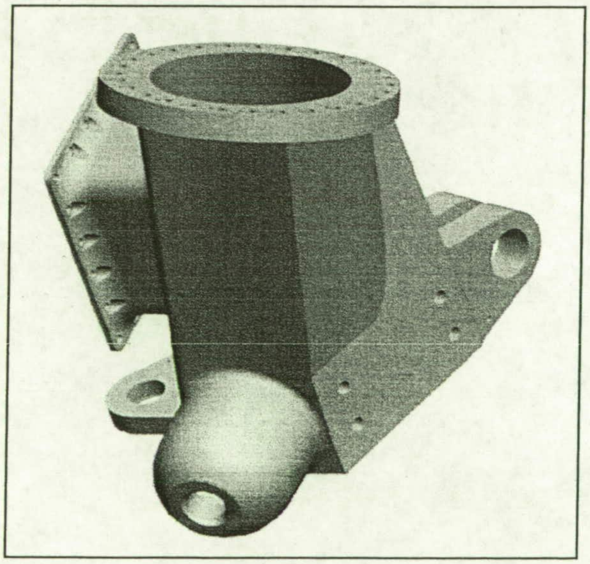

Figure 7. Ball Interface Fitting Shaded

This part was quite complex and required the interpretation of machining and forging drawings when building the 3-D solid model. See Figure 8.

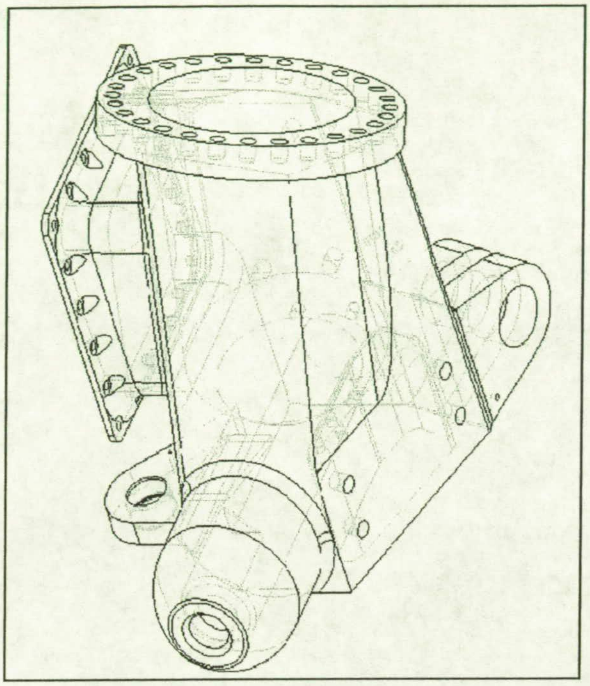

Figure 8. Ball Interface Fitting Wire Frame

A number of primary and secondary views had to be understood before construction of the 3-D model was started. The yoke fitting was as complex as the ball fitting.

The Orbiter/ET forward attachment assembly contains a revised forward attach fitting. See Figure 9.

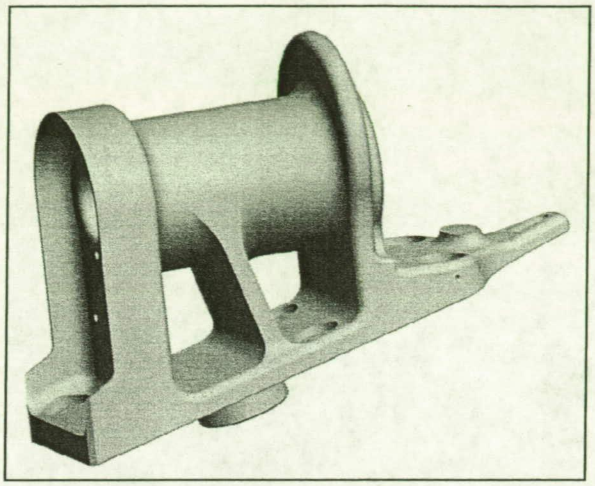

Figure 9. Old Design Forward Attachment

This part was recently redesigned with the heating element being moved from the spindle area to the foot of the part. See Figure 10.

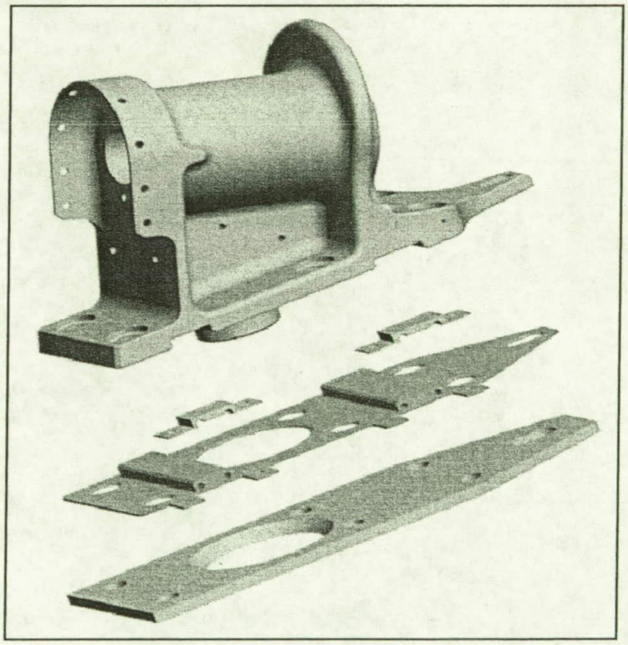

Figure 10. New Design Forward Attachment

It was revised to improve heat exchange rates at a point where ice has been forming at the conjunction of the attach fitting and ET. These Orbiter/ET interfaces include: the Orbiter/ET forward attachment; aft left thrust strut, aft right tripod support structure, and the crossbeam and aft feedline /umbilical supports. See Figure 11.

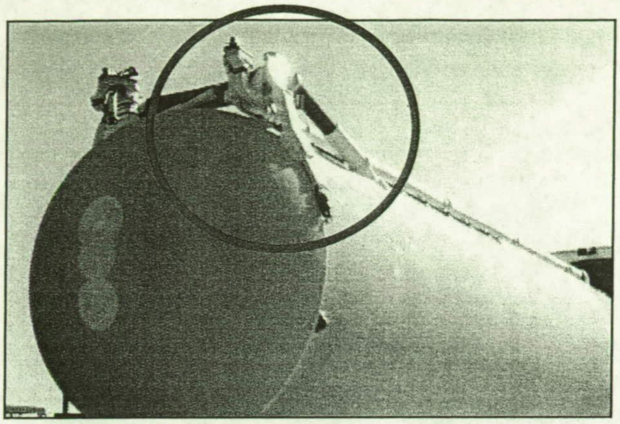

Figure 11. ET and Aft Right Tripod Support Structure

These assemblies were used to attach the Orbiter to the ET. See Figure 12.

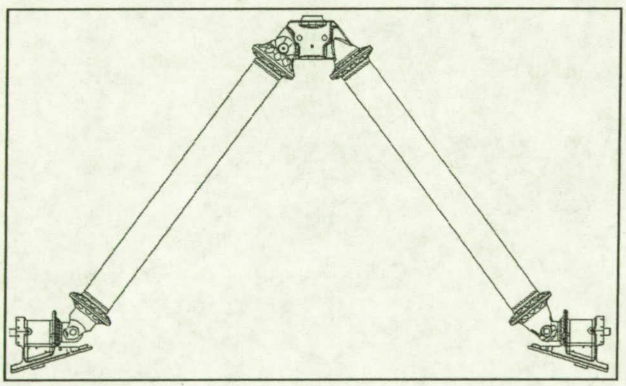

Figure 12. Orbiter/ET Attachment Assembly Hidden

III. Mathematical Presentations

An equation was used to create the shape at the bottom of the ET. This equation represents a variable radius curve. This dome curvature equation was obtained from a Lockheed/Martin drawing.

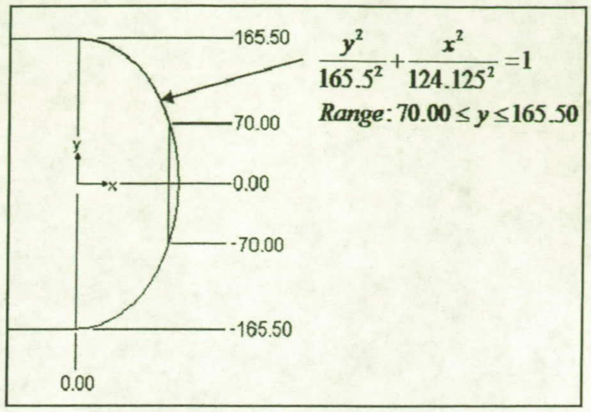

Figure 13. Dome Curvature Equation

For Pro/Engineer Datum Curves, equations must be expressed in terms of t, with t=0 being the start of the line, and t=1 being the end of the line. Since we want our curve to start at y=70 and end at y=165.5, we must adjust our t-values to cover this range:

$$y = 95.5t + 70 \quad (1)$$

Since we know our range of values in the y-direction, we must solve the curvature equation for X in terms of Y. See Figure 14.

$$\left(\frac{y^2}{165.5^2}\right)+\left(\frac{x^2}{124.125^2}\right)=1$$

$$\left(\frac{x^2}{124.125^2}\right)=1-\left(\frac{y^2}{165.5^2}\right)$$

$$x^2=\left(1-\frac{y^2}{165.5^2}\right)\left(124.125^2\right)$$

$$x=\sqrt{\left(1-\frac{y^2}{165.5^2}\right)\left(124.125^2\right)}$$

Figure 14. Solution for Curvature Equation

At this point, the dome curve can be entered into Pro/Engineer as a Datum Curve, expressed in three equations, in terms of x, y, and z. See Figure 15.

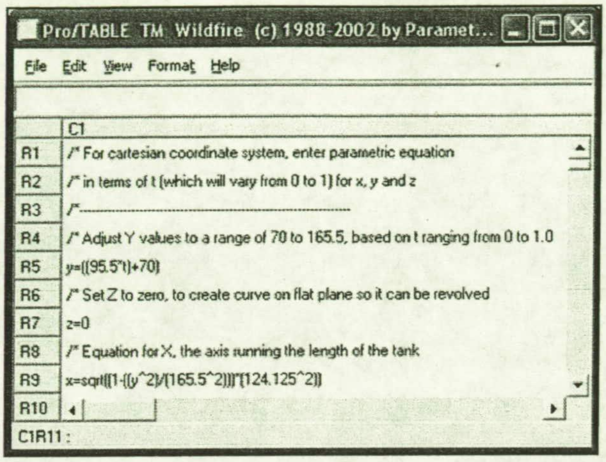

Figure 15. Pro Engineer Datum Curve

Once the curve has been created, a revolved protrusion, using the curve as its profile, creates an accurate model of the bottom end of the ET. See Figure 16.

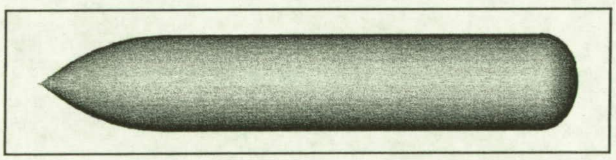

Figure 16. External Tank

IV. Results

The analysis of clearances involved comparing distances between the Orbiter/ET forward attachment and roller on the Orbiter umbilical door. See Figure 17.

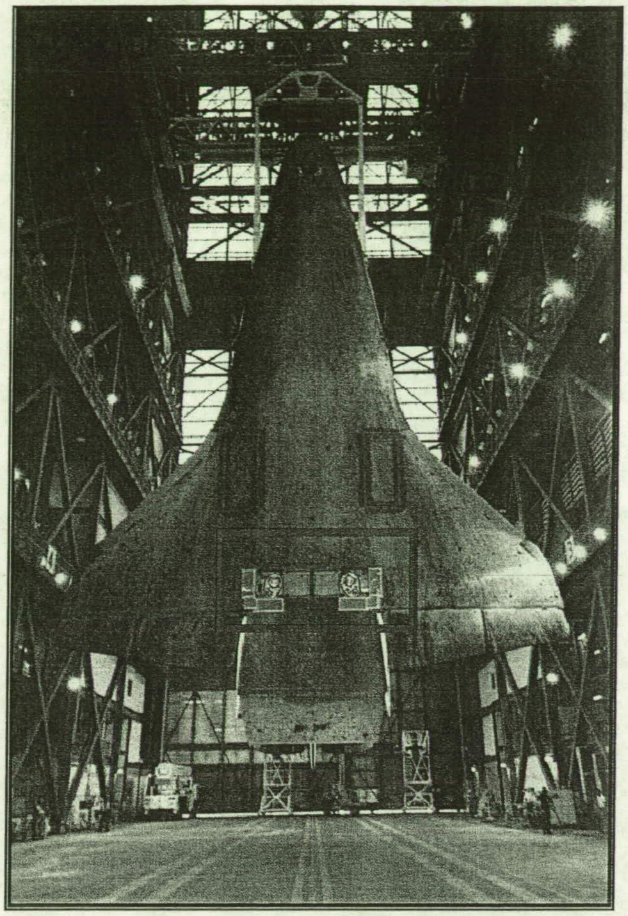

Figure 17. VAB, Orbiter, and Umbilical Doors

These distances were obtained using an assembly of 3-D solid models. A 2-D drawing was created to show these sizes. See Figure 18.

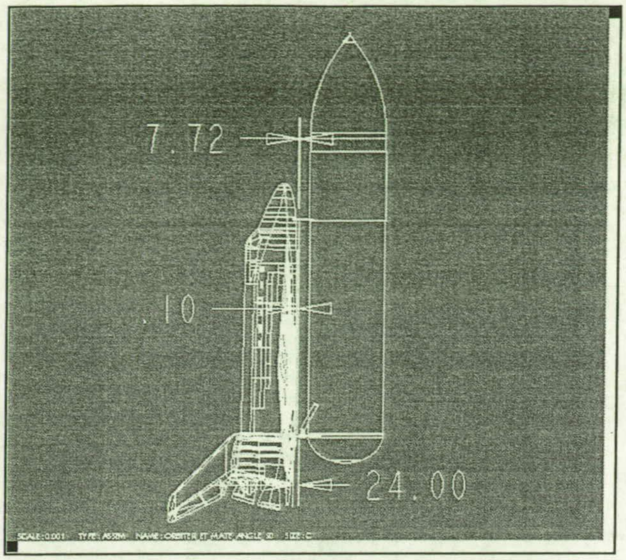

Figure 18. Hang Angle of 90 Degrees

The measured distances were compared with the Orbiter being hung at a 90° angle, then a 90° minus 30' angle. It was hoped that the Orbiter could be mated to the ET using a hang angle closer to 90°. See Figure 19.

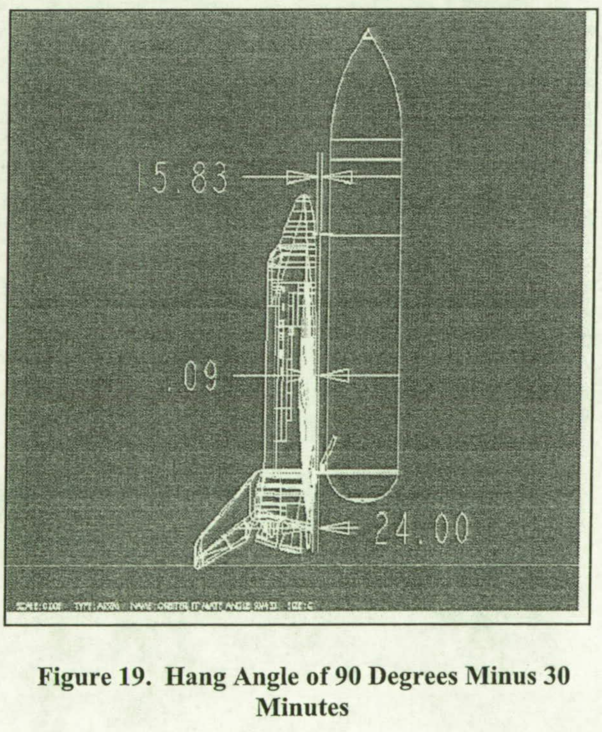

Figure 19. Hang Angle of 90 Degrees Minus 30 Minutes

It was found that a 30-minute arc angle change in Orbiter hang angle affected distance at the bipod strut to Orbiter yoke fitting (15.83 – 7.72) or 8.11 inches.

A 3-D model file library will be made available for engineering use. Information in this library has been translated into files that may be easily used. Models have been translated into formats that may be used for multiple purposes. All .prt and .asm files were translated into stl, stp, shrinkwrap, jpeg, and tiff formats. This provides a tessellation file for sterolithography, a neutral file that other programs could read, a compressed solid model file for handling large file size, an Internet picture file, and a print shop picture file. This 3-D solid model library will provide engineers with an additional tool for decision-making. This model depository will be made available using the IntraLink. The IntraLink is a file management system for the handling of parts, assemblies, and drawings.

V. Conclusions

Translation between various software platforms appears to be a problem. This is especially true when dealing with older 3-D models. Translation is best attempted using STEP and IGES files. These file formats represent the ISO and ANSI 3-D solid model data exchange standards.

There must be an assigned responsibility for maintaining a "master model" library. This group should have the duty of certifying solid model files. Their distribution should be in a read-only format. This read-only format file can then be used by manufacturing for creating machine code, engineering for strength analysis and decision making, or drafting for 2-D drawing creation.

We recommend that the software ProductView Express be downloaded from www.pct.com. It is available under free downloads at their web site. This web browser will enable engineers and Pro/Engineer "users and non-users" to view and manipulate Pro/Engineer parts, assemblies, and drawings.

The use of digital imaging must be researched since there is a large amount of 3-D modeling building that must be completed. This use of digital imaging should allow for the quick creation of 3-D models or refinement of detail. Digital imaging may be limited by large file size. See Figure 20.

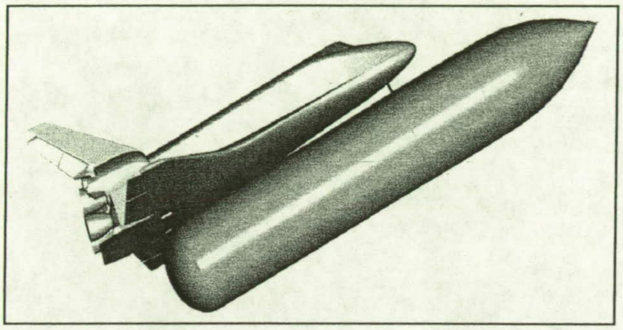

Figure 20. Orbiter/ET and Structural Interfaces

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