Theme Park Applications of Dynamic Designer

by
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Abstract

This paper will outline the design and analysis process used to bring theme park animation to reality. The use of Dynamic Designer software and its importance to the analysis process will be shown through the use of projects currently in service.

Introduction

The intent of this presentation is to give you a look at the design process used in the entertainment industry and how the use of Dynamic Designer plays a role. I will give you a brief description of the equipment and the overall design process and highlight the significant changes in personal computing and how they are changing the way we do business. After explaining why I chose Dynamic Designer over other products, I will show you the analysis process for a two person arcade simulator that was put in service last month. I will finish with a quick description of a local project that just opened, but due to confidentiality issues, will not be displaying any printed results.

There are two main types of theme park animation in use today and they are Animated Props and Show Action Equipment. Animated props are defined as mechanical show elements that are intended to be seen by the theme park guest. Mechanisms that move an animated prop, or another mechanism, in and out of a show scene, but are never seen by the guest are categorized as show action equipment.

The Overall Design Process

The design process for a theme park attraction is iterative, and it starts with a concept conceived by an artist or show producer. The show producer will have a budgeted amount of money to build the attraction, which includes the design and development of buildings, support facilities, ride vehicles, and show elements. Factors such as ride length, ride speed, and the number of show scenes help determine how many guests per hour can be accommodated. During what is typically called the “blue sky” phase of a project, each animated scene is developed to the extent that the range of motion, power requirements, estimated weight, and cost can be estimated for each piece of equipment. Depending on the results of this first estimate, the overall show concept may be reworked and the design process started over. Situations like these emphasize the need for design and analysis tools that are easy to use.

PC Computing

Let me take a minute to put the current state of personal computing in perspective. In 1991 we used 386-33 computers with 120 meg hard drives and 4 megs of ram. Animation was developed in a 2-d environment. AutoCad 10 was the software package available and was considered to be state of the art compared to drafting boards, paper and pencil. Now a decent computer, outdated a month after purchase, has a 450 mhz Pentium II processor, 512 megs of ram, a 14 gigabyte hard drive, and 32 megs of video ram. These continuing advances in hardware are allowing small businesses to perform tasks that used to require a corporate owned mainframe computer.

Software technology has also changed dramatically as a result of hardware technology advances. No longer are designers working in a 2-d environment. There are several sophisticated 3-d packages on the market today. I use SolidWorks and Dynamic Designer for all of my projects now. I can develop a basic mechanism quickly to determine the preliminary operating characteristics. I can also change the design just as quickly as the project requirements change. The name of the game is to be flexible. Most projects are completed within a fixed number of hours allocated by the project, regardless of the number of iterations required.

Designing Animated Props and Show Action Equipment

There are two related criteria that influence the mechanical design process – stress and stiffness. When section properties are increased, stiffness increases and deflection and stress go down. Some design projects only require that an allowable stress limit be met for a given service life without serious consideration of deflection. These type of projects are usually static in design, and have dynamic requirements for wind and seismic loading only.

Structural analysis, required for reliability and safety, is only as accurate as the loads used for the analysis. For simple linear motion, hand calculations are usually sufficient. For complex, multi-axis high speed motion, the use of sophisticated computerized modeling techniques increases the accuracy of the analysis. Dynamic Designer, used in conjunction with SolidWorks, is well suited for animation analysis. Animated props and show action equipment are required to move at relatively high speeds with crisp response, generating significant dynamic loads. This type of motion requires a structure to be lightweight and rigid, while meeting service life requirements of 4.5 million cycles per year for 10 years. Structural fatigue is a major issue necessitating accurate load and stress analysis.

There are three basic steps to the design process. The first step is the actual design of the mechanism. The second step is the static and dynamic load analysis. Step three is the stress analysis.

Dynamic Designer is the tool of choice for accurate load analysis. Dynamic Designer runs “inside” of SolidWorks. Unlike other simulation programs which require manual entry of the masses and section properties, Dynamic Designer derives these values directly from the solid model. Every component in the model has mass that affects the dynamic loads generated during operation. You as the engineer or analyst do not have to calculate properties for each component in the mechanism, Dynamic Designer does it automatically. I consider this to be the single most important feature of the program because of the accuracy and time savings it provides, and was a major factor in my decision to purchase the software.

Animated props and show action equipment can be powered by several methods depending on the force required. Linear actuators, either hydraulic or pneumatic, are the most common. For continuous run applications electric motors are the way to go. Regardless of the type, Dynamic Designer has provisions for applying the power in an appropriate manner with respect to time.

A Completed Project

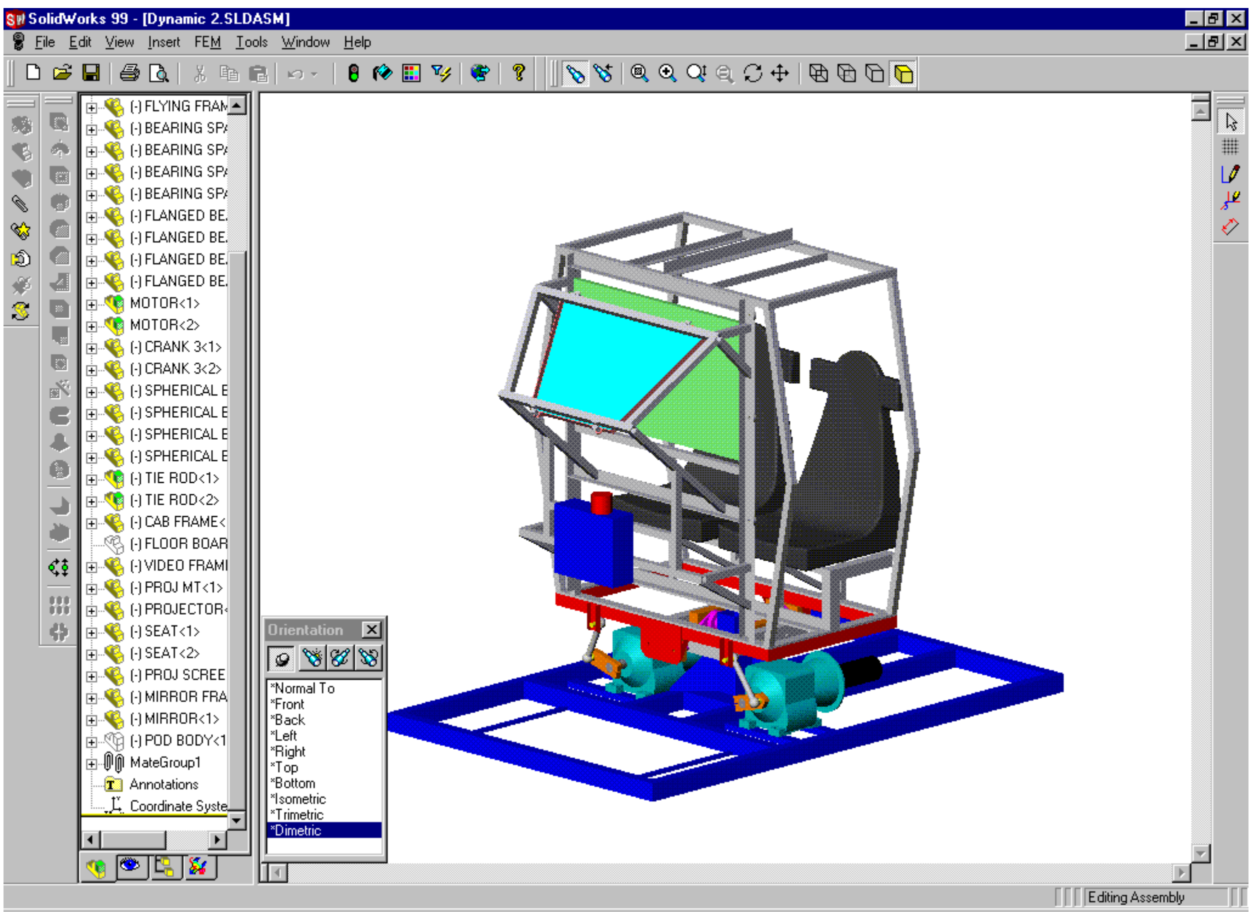


Figure 1 – Overall view of structure

The example I will use to demonstrate Dynamic Designer is a two axis electric motor driven arcade simulator. Originally built as single seat aircraft flight trainers, simulators and motion bases are now capable of transporting 40 people at a time on a virtual journey through space. They accomplish this with combinations of pitch and roll motion with sudden accelerations to give the sensation of movement. For these large mechanisms, linear hydraulic actuators operating at 5000 psi are required to deliver the force necessary to accelerate the cabs. Small arcade style simulators are typically powered by electric motors. Electricity is readily available and eliminates hazardous material problems associated with leaking hydraulic fluid. The short bursts of acceleration in these devices are often achieved through sudden starts and stops of the gearmotor, or in the game software.

The major components of this assembly are the base frame, gearmotors, flying frames, cab structure, and video frame including screen, mirror, and projector. For this project the client originally wanted the analysis completed for just the cab frame for two specific operating profiles; pitch and roll. These profiles, based on angular displacement of the body for a given time, were easily generated in Dynamic Designer by applying a motion profile to the output shafts of the gearmotors.

After running the simulation, I plotted data for each of the structural elements requiring analysis. I approach this process methodically, starting with the component where the force is generated and working my way through each successive component in the load path.

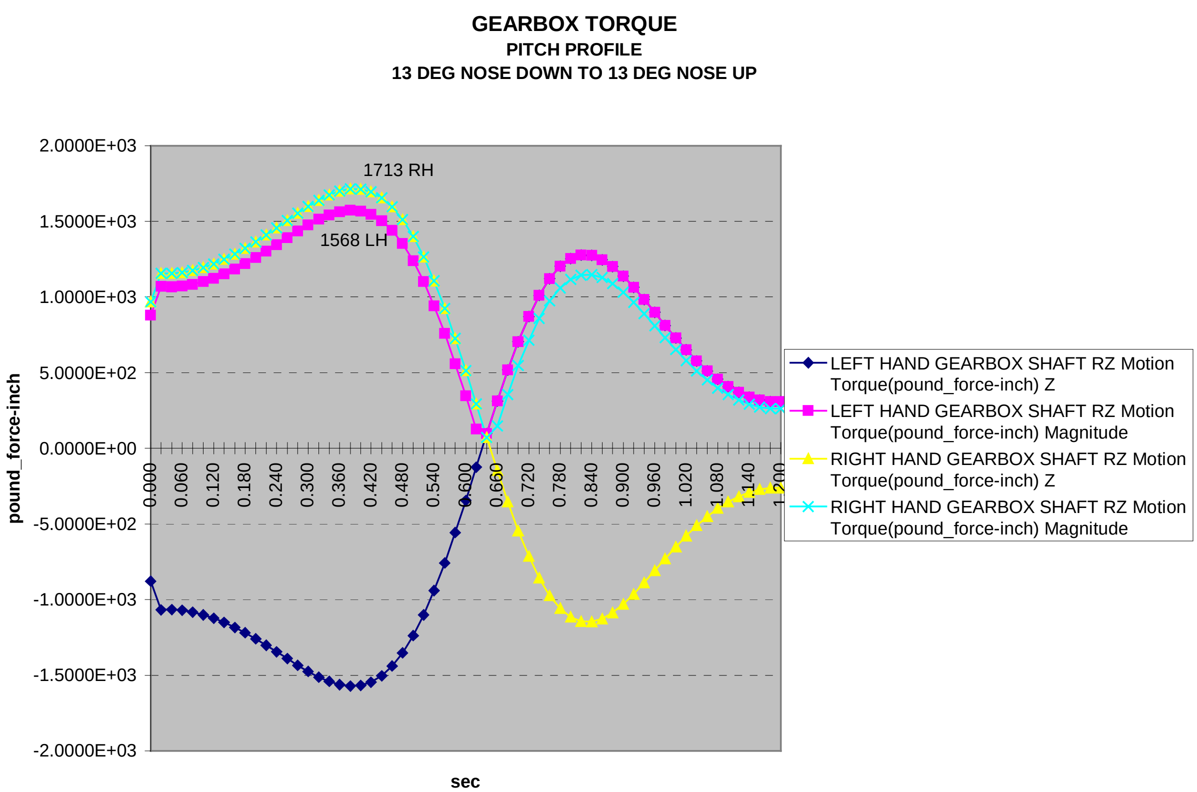
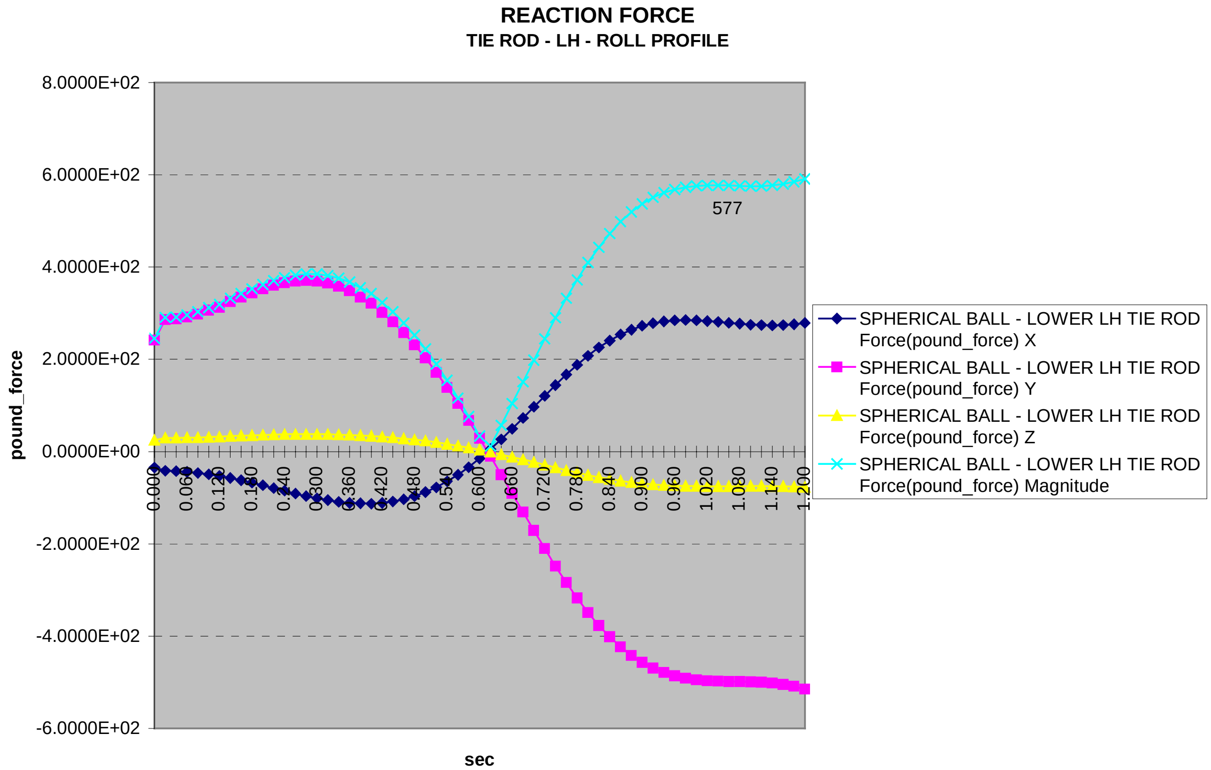


Figure 2 – Gearbox torque

Torque for the gearboxes is the first data plotted. The clients selection of the motor/gearbox combination can be verified and stress calcs can be completed for the crank arms including keyways.

By restraining the shaft, the components of force due to torque can be applied to the spherical ball. The resulting analysis shows that the stresses are highest where expected, which is in the keyway. Note that significant bending stresses are generated



on the surfaces of the crank arm relief cut.
Figure 3 – Tie rod reaction force

The next component in the load path is the Tie Rod. The Tie Rods connect the crank arms to the flying frames. When the cab is run through the full range of motion, the results of Dynamic Designer show that the components of force in the tie rods vary significantly. The tie rod was intended to be the “fusible” link in this design because it is the easiest component to replace should it break. It was important to size this correctly so it would be strong enough to meet the performance criteria but not so strong as to cause failures in other inaccessible places. I mention this because the entertainment industry is famous for “turning up the speed” once they see the potential of a mechanism. I have seen several cases where equipment was reported defective only to find out that the operators turned up the speed, thus increasing the dynamic loads and causing a structural failure.

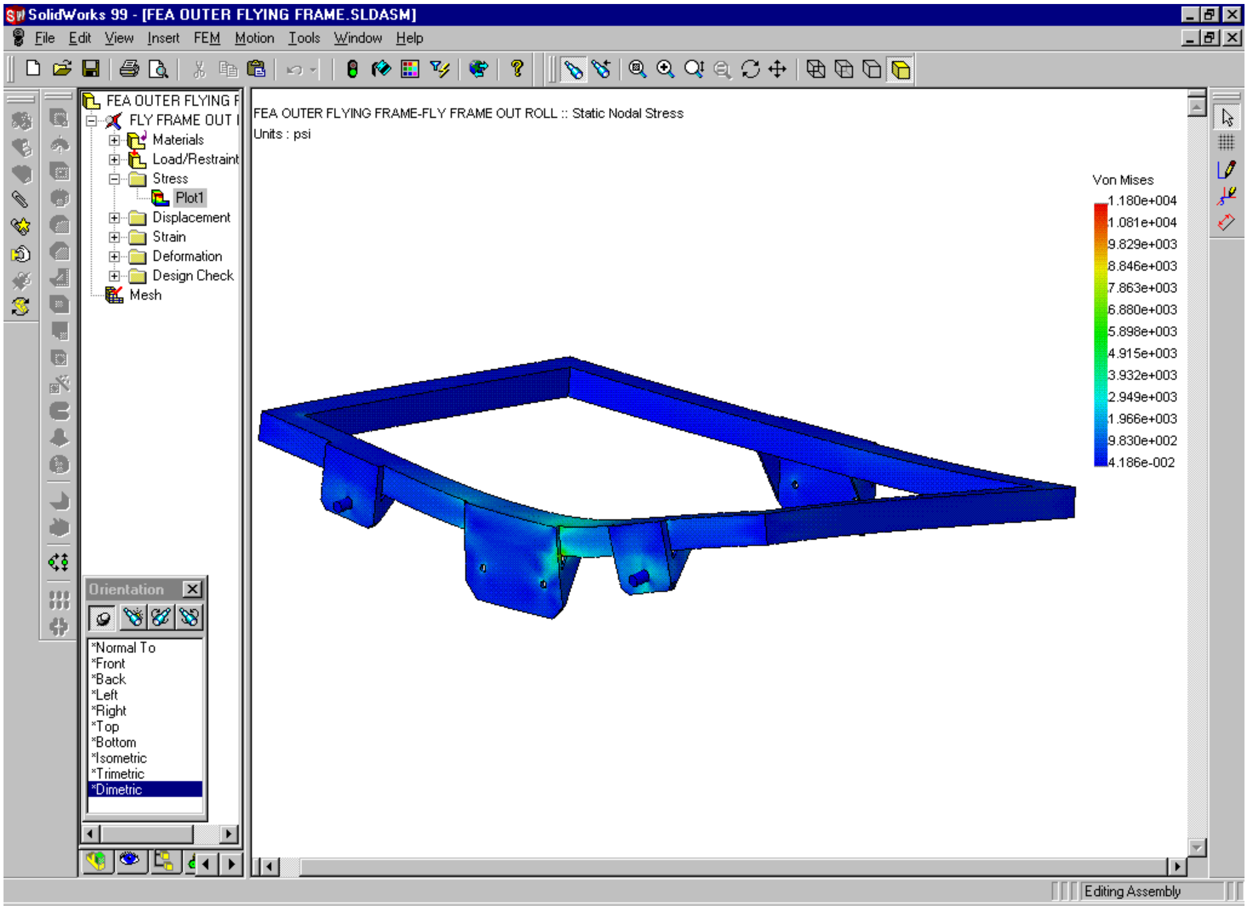


Figure 4 – Outer flying frame

The Tie Rods transfer load from the gearmotors to the flying frames. Really nothing more than an oversized universal joint, the flying frames support all of the moving components of the simulator. The only items of real concern here are the welds in the fittings that mount the spherical balls and flange mounted bearings.

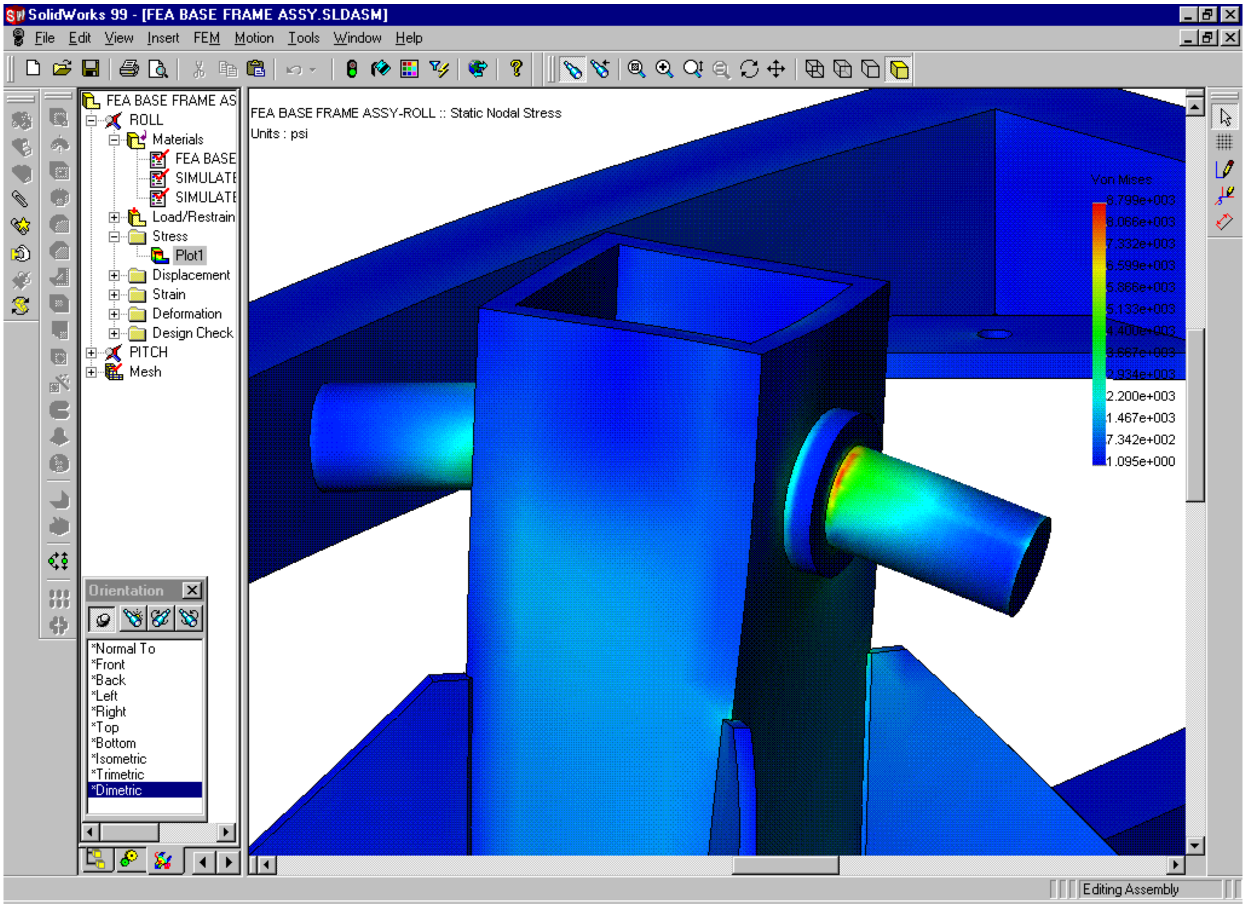


Figure 5 – Pivot shafts

The flying frames are connected to each other, and the base frame, by shafts. Although not in the original scope of work, these pivot shafts drew my interest because of their relative size in relationship to the rest of the mechanism. I re-ran the simulation and obtained the forces acting upon the shafts in the base frame. The finite element analysis indicated stress levels much higher than the allowable stress levels for fatigue set by the owner. I contacted the project manager with my findings and offered a new design. As it turned out, 29 bases had already been fabricated, and the client was not real happy to hear from me at the time. After the initial shock wore off, the client reworked the existing bases and the units have been operating safely and continuously.

Up to this point, all of the data extracted from the simulation has been reaction forces through hinged joints or parts. This has been done because the forces are applied through contact surfaces that are easily defined in SolidWorks for the finite element analysis.

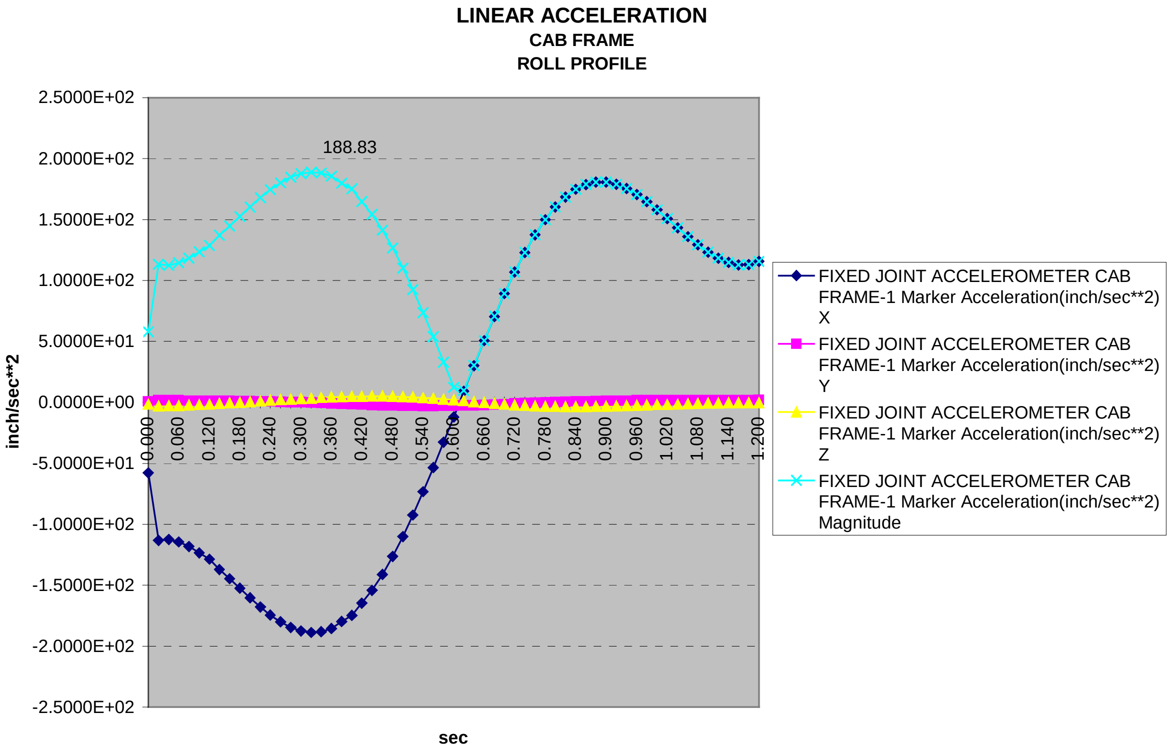


Figure 6 – Linear accelerations

The finite element analysis of the cab frame has to be completed using different techniques for applying the load. The major advantage of using SolidWorks and Dynamic Designer together is the ability to model all of the components as a complete assembly. When performing the finite element analysis, all of the miscellaneous components need to be removed so they are not included in the element mesh. The static weight of individual components are known and can be applied at their mounting points within the cab frame. The dynamic load on the cab frame is the result of mass times acceleration of the frame itself as well as the bolted on components such as the seat, door, body, and projection system. As a side note, the weight of the guests is accounted for by adjusting the weight of the seat assembly. The center of mass of the guest is reasonably close to the center of mass of the seat structure. To analyze the stresses in the cab frame due to the motion, a fixed joint is applied between the outer flying frame and the base of the cab frame. The fixed joint will “record” linear accelerations along the three primary axis. These accelerations can be applied to the structure using the gravity dialog box during the finite element analysis.

Figure 7 – Tipping

The final phase of the analysis was to determine if the simulator would tip over during normal operation as it wasn’t intended to be bolted to the facility floor. To do this, a ground plane was created and was selected to be the only fixed part in the simulation. The complete simulator assembly was identified as moving parts and connected to the ground plane with contact supports. The contact supports generate results in the simulation just like a load cell. As you can see, the loads are heaviest on the side the cab is leaning to initially, and then they reverse when the simulator cab is rolled to the other side.

Additional Projects

The motion simulator project that I have described is but one example of the use of Dynamic Designer in Theme Park design. Universal Studios recently opened several new rides in an area called Islands of Adventure here in Orlando. One ride is themed after the movie Men In Black.

I was involved in this project with two separate clients. The first client was developing the ride vehicle and asked me to simulate the lapbar release mechanism. This mechanism is triggered by a computer controlled linear actuator mounted to the facility, and is triggered when the vehicle stops at the end of the ride. The linkage is complex because it runs through the vehicle chassis and terminates at the latching mechanism mounted below the seat support structure. I was able to model the linkage in SolidWorks, operate it with Dynamic Designer, and perform the finite element analysis. The client, overworked and understaffed, was using SolidWorks to model the entire vehicle. When we completed the lapbar mechanism, the client simply added my solid model of the mechanism to the overall assembly.

The second project for MIB was the analysis of several animated figures. One in particular, the Tailgate Alien, is one of my favorites. The concept is very simple. You as the guest in the vehicle see a two legged alien standing alongside the track. It appears to be smiling at you when, for some unknown reason, you shoot it. As it turns out, what you shot was the tail end of the figure. The head and torso rear up glaring at you in disbelief. The structural supports running up through the legs were geometrically complex and required an accurate load and stress analysis. The rotating body was mounted to a shaft driven by a pneumatic linear cylinder. I created a model of the finished assembly, ran the simulation, and was able to size the cylinder based on the force data. Also of interest was the speed of the cylinder which affects the life of the rod seals. This was a simple project, but really fun due to the effect it has on the guest during the ride.

Summary

That concludes my presentation. I have given you a brief look behind the scenes in theme park animation and how Dynamic Designer is playing an important role. Through the use of solid modeling techniques and virtual prototyping, I am able to help my clients meet stringent safety and reliability requirements in a cost effective manner.

Thank you for your time today. I would be glad to answer any questions.