H.G. Engineering

CSI AEROSPACE

VIRTUAL PROTOTYPING OF A WHEELCHAIR LIFT FOR THE DISABLED FITTED TO A CL-600 CHALLENGER AIRCRAFT

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NOMENCLATURE:

ADAMS®	"Automatic Dynamic Analysis of Mechanical Systems" by Mechanical Dynamics Inc., 2301 Commonwealth Blvd., Ann Arbor MI 48105
ANSYS®	"Analysis Systems" by ANSYS Inc., Southpointe 275 Technology Drive, Canonburg, PA 15317
CSA	Canadian Standards Association
FAR Part 25	Federal Aviation Administration (USA) Code of Federal Regulations, Aeronautics and Space, Part 25 – Airworthiness Standards: Transport Category Airplanes.
JAR25	Joint Aviation Authorities Committee (Europe), Joint Airworthiness Requirements – Large Airplanes

ABSTRACT

The concept and goal of virtual prototyping is to develop a mechanical product as an integrated system entirely using computer methods thus avoiding the necessity of building engineering model prototypes and instead to proceed directly to production hardware. This particular paper refers to mechanical/structural systems which are subjected to any kind of mechanical loading/force or velocity/acceleration input. The example (Figure 1) we shall use to demonstrate the approach is the wheelchair lift design of SIDDHIS Aviation Design Inc. of Dorval, Quebec. This product is designed to provide the Canadair Challenger series of aircraft with the ability to board and deplane a disabled passenger and wheelchair with a combined weight of 180 kg (396 lb). The wheelchair lift is a new product and has been sold and is fitted to a Canadair Challenger CL600 aircraft. This first optimized high strength aluminium chairlift prototype used the ADAMS/ANSYS virtual prototyping strategy and was fitted to its intended aircraft with the only minor modifications to some detail parts being required during the acceptance testing prior to delivery and installation.

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1.0 INTRODUCTION

Virtual prototyping is the new collective name given to the design process which uses computer aided engineering to avoid the manufacturing of initial prototypes. A considerable amount of virtual prototyping work has already been accomplished both in the aircraft industry and also in the automotive sector for crash simulation, vehicle dynamics, brake noise and road performance etc. For clarity, the following paper will limit discussion of the method as it was applied to the mechanical/structural behaviour of a wheelchair lift for the handicapped. This aeronautical product was recently designed and manufactured by SIDDHIS Aviation with analytical support provided by CSI Aerospace. The wheelchair lift is a mechanical system fitted onto a Canadair Challenger aircraft and is used to board and deplane a disabled passenger in a wheelchair.

This is of particular social interest as well as technical. It is gratifying to be part of an industry involved in caring about others with special needs. The history of this project involved initial interest from a foreign private customer who partially provided funding for a preliminary working prototype. This prototype lift was fabricated in mild steel to demonstrate functionality and acted as a convincing sales tool to a customer not conversant with simulation technology. The construction of this steel prototype is in conflict with virtual prototyping strategy but it needs to be stated clearly that this activity occurred before the virtual prototyping option was identified as an available approach. The steel lift geometry design drawings only, were used as the starting point to the virtual prototyping process which resulted in the first high strength aluminium design being manufactured as the actual production prototype lift which has now been delivered and fitted to a CL600 Challenger aircraft. The procedure sets forth a useful cost saving approach for the development of new mechanical systems products.

2.0 TECHNICAL DISCUSSION

2.1 General

Since the introduction of matrix methods of structural analysis (later called finite element methods) in 1952[1,2,] the accuracy of stress analysis prediction has increased with each passing decade. This, combined with the automated dynamic analysis of motion systems developed since 1965[3] has produced a combined computer solution for accurate mechanical system design and analysis simply not possible previously. A virtual prototype is a computerised representation of the product in lieu of a physical hardware representation of the product. This has led to the concept of virtual prototyping as applied to mechanical/structural systems. This enables a mechanical/structural product to be developed from the designer's initial idea directly to the production design with confidence and without the need for expensive and disposable preliminary working prototype hardware to prove the design. Of course, the extent to which this methodology can be applied, will vary from industry to industry and from product type to product type and from customer to customer. In the high technology aerospace sector, which already has an in-depth understanding of computer aided engineering, the confidence exists which makes for virtual prototyping strategy being a readily acceptable approach.

The SIDDHIS Aviation wheelchair lift design was developed into a virtual prototype using the ADAMS® and ANSYS® computer codes to arrive at loads and deflections (stresses) respectively.

The product was designed to satisfy Transport Canada-Aviation Airworthiness Manual Chapter 525, United States FAR Part 25 and European JAR25 airworthiness standards for transport category airplanes together with and the CSA standard for "Elevating Devices for the Handicapped" CAN/CSA-B355-94 which required a Factor of Safety of 5.0 during operation. The design was mainly stiffness driven for user comfort, which conveniently complemented the large factor of safety requirement required to meet strength criteria and to substantiate compliance with the above requirements. The lift was proof tested to 1.25 times operating loads during commissioning.

The included drawings, force and velocity diagrams and contour stress plots indicate the analytical work required to establish loads for later verification of product integrity through finite element stress analysis and classical stress calculations.

For clarity, the loads analysis and deflections (stress) analysis are described separately below, even though each is performed in a logical interaction with each other.

2.2 Operating Loads Simulations

In the present discussion context, the virtual prototype consists of a mathematical model of the mechanical system, capable of simulating actual operating conditions. Transient dynamic loads and kinematics parameters are correctly determined by simulating the full motion behaviour of the mechanism.

The virtual prototype of the wheelchair lift was built and simulated using ADAMS®, Rev. 9.04. ADAMS® (Automatic Dynamic Analysis of Mechanical Systems) is a general purpose program that simulates complex multi-body mechanical systems undergoing large non-linear displacements by solving the first order Euler-Lagrange equations of motion. Non mechanical sub-systems, i.e. electrical, control, pneumatic, hydraulic, etc., can also be incorporated into the model within the ADAMS® environment.

The wheelchair lift consists of two simple four-bar mechanisms driven by two hydraulic actuator cylinders. In a typical simulation the lift with passenger is moved from rest on the ground to the aircraft cabin floor level in 20 seconds. The cylinder is actuated by applying the full fluid flow rate of 1.82 in^3/sec (for 2 cylinders) in 0.5 seconds and shut off in 0.1 seconds at the stop position.

All the transient aspects of the motion, such as actuator initial pressure build-up and consideration of flexible arms are taken into account. For the present dynamic analysis purposes a 2-D model was deemed sufficient.

The 2-D model incorporates rigid bodies, flexible parts, revolute and fixed joints, contact surfaces, friction and hydraulic subsystem. Figures 4 shows the ADAMS® model for the wheelchair lift mechanism. All the main constituent parts and joints connecting them are represented.

A simple hydraulic subsystem consisting of an actuator cylinder driven by a compressible fluid flow is added to the model. The basic equation used in the formulation of the hydraulic subsystem is:

{ EMBED Equation.3 }

where:
β - fluid bulk modulus of elasticity
p - fluid pressure
ρ - fluid density

See Reference 4 for further model details.

The arms were modelled using flexible beam elements from the ADAMS® library. The ADAMS® beams use the Timoshenko beam formulation.

The calculated hydraulic fluid pressure curve is shown on Figure 5. A pressure surge of 2026 psi at t = 0.36 seconds is predicted. Note also the transient oscillations when fluid flow is shut off.

The outboard and inboard reactions at the aircraft cabin floor are shown on Figure 6. The maximum peak loads are +3363 lbf and –2751 lbf at the O/B and I/B attachment pairs respectively. Each point (fore and aft) is half of these values respectively. Likewise other joint loads an kinematics parameters time response can be extracted from the model simulation.

More accurate results can be obtained by including other components in the hydraulic system model such as pump, accumulators, directional valves, pressure control valve, hose line and flow control valves. However, it was conservative to omit these effects in this application.

2.3 Environmental Loads Consideration

In addition to operating loads of 2.2, the lift must withstand ground gusts. These forces are considered as lateral loading excitations and the structure is designed for wind gusts to an upper limit of 50 mph. Beyond this structural limitation, the lift is deemed inoperable in an outside environment and boarding or deplaning shall be performed inside a hanger or by other means.

2.4 Finite Element Stress and Dynamics Analysis

The mechanism components of the lift were idealised as an assembly of beam elements with rotational freedom at the pin joints in the plane of operation (X-Y) using the ANSYS® finite element code. The base support and platform were represented as plate element assemblies. The local floorbeams and intercostal reinforcement members where included in the model also. The maximum loading geometry configuration occurs in the fully extended position just as the platform leaves the ground fully loaded with wheelchair and passenger. (Figure 2) The ANSYS® code uses the displacement method approach to finite element method solution which eventually became the industry standard after the landmark paper by Turner[5] et al in 1956.

It is noted that the dynamic shock input from the ADAMS® solution at start-up is minimal. Refer to Figure 6 which shows reaction forces versus time. A start time ramp of ½ second was input as the requirement followed by 20 second constraint velocity profile to a stop time ramp (at minimum loads) of $^{1}/_{10}$ second. This relatively slow ramp-up time is realistic for passenger comfort and coincided within the time and deflection required to take up the combined loaded lift deflection of 2" as predicted in the finite element solution using ANSYS®.

The element section properties and nodal geometry for the initial design (steel model) where input as the starting point. These determined the initial bending moments and end loads in the elements. These main elements where then optimized with 7075-T6 aluminum alloy machined components using the same internal loads to produce consistent combined stresses throughout the structure, within practical manufacturing constraints. The working stress level of ultimate strength divided by five was used to satisfy the CSA Standard. After one or two minor changes to avoid local crippling or long wave buckling, the sizing was complete and the ANSYS® model was run again to produce final bending moments (Figure 7) and end loads. It was important that deflections were small and that the natural frequency was acceptable. The first resonant frequency is low at 1.84 Hz in the side sway mode at the fully extended position with maximum loading. This is acceptable as the damping is significant and this particular mode is not excited by normal operational forces. The maximum vertical deflection is 2" which is not evident during operation due to ground reaction support. The CSA requirement for safety factor of 5 proved to be very compatible with this low deflection effect. The factor of safety of 5 refers to normal maximum operational loads which in this case also includes the potential maximum ground gust loads as a combined loading case.

2.5 Detail Design and Analysis of Components

It was determined in the first iteration of the finite element model that a high bending moment and rotational deflection occurred at the end of the lower arm due to the load offset of the platform (Figure 2). The geometry was changed to include a diagonal folding link (Figure 4). This created a more efficient structure by eliminating the bending moment at the end of the lower arm which effected a weight saving and an increase in stiffness. The ADAMS® model was then modified to include the geometry and include structural flexibility.

The wheelchair platform was a removable folded design which was treated separately and analysed by classical manual methods. Similarly, all bearing components, fork and lug ends of the lower and upper arms, bolts and pins were analysed by classical manual methods.

2.6 Final Design Modifications

During the initial design phase it was proposed to use high performance composite journal type bearings. These bearings proved to be unsuitable in this application and were replaced with traditional press fit phosphor bronze bushings reamed to size for minimum clearance. After this minor change during pre-delivery bench testing, the lift was fitted and commissioned on the aircraft without incident.

3.0 CONCLUSIONS AND FUTURE POTENTIAL

It has been shown that for mechanical systems analysis, including hydraulic system performance, that in terms of mechanical operation, structural stiffness, hydraulic pressure, cylinder size, orifice configuration and flow rate that these parameters can be assessed analytically using ADAMS® or a similar code. Stress prediction can also be predicted with confidence by well proven finite element methods such as ANSYS®. So with these combined strategies, virtual prototyping of any structural/mechanical system can be achieved.

It is interesting to note that sophisticated space hardware design has typically proceeded through preliminary and critical design reviews supported by breadboard models sometimes, then to engineering models, qualification models and to eventual flight hardware. Perhaps, future confidence in analysis would allow the design to proceed directly via virtual prototyping to the qualification model. In future aircraft design, the continued increased confidence in finite element methods backed up with detail stress and damage tolerance (fracture mechanics) analysis may allow that only the overall fatigue specimen airframe be physically tested to predicted flight spectra with virtual prototype models being sufficient in lieu of static testing.

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Figure 1 Production Prototype – System Extended

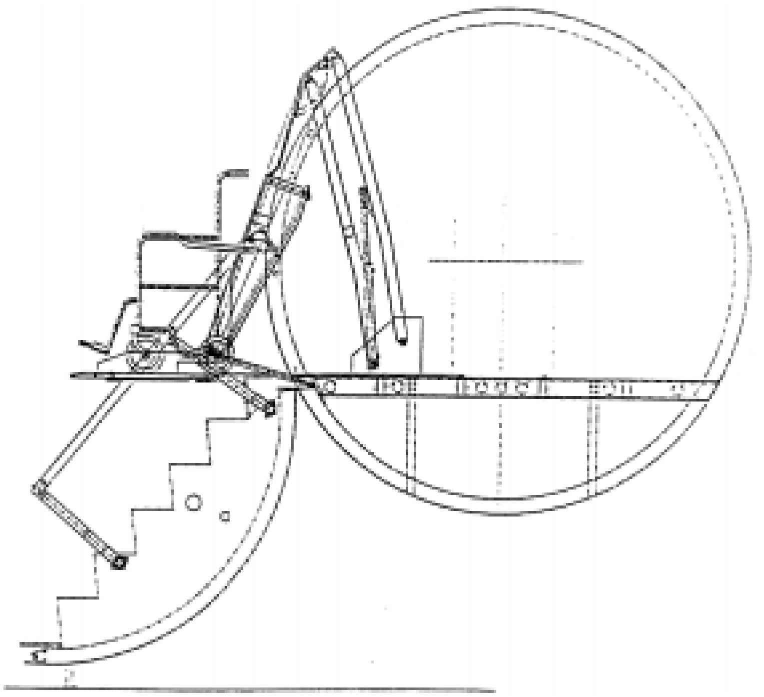

Figure 2 **Initial Design – System Retracted**

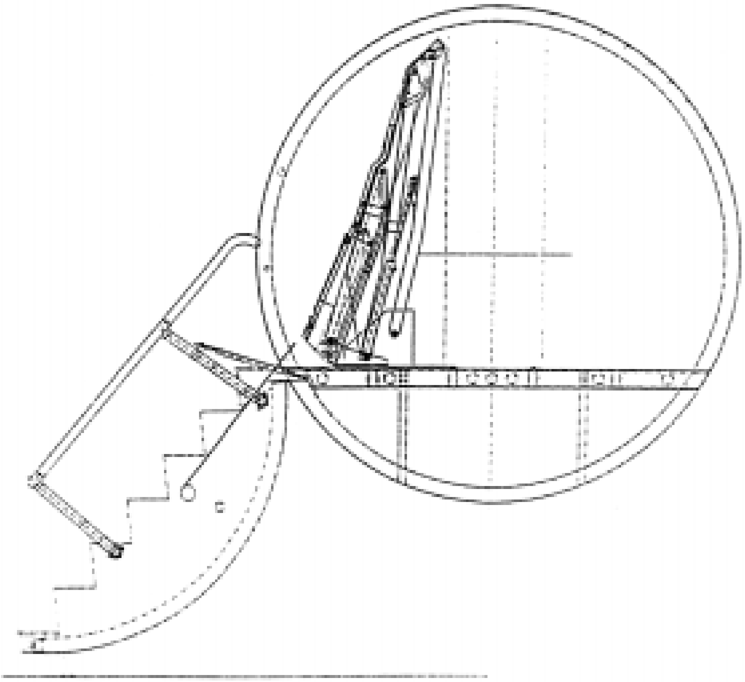

Figure 3 **Initial Design – System Folded**

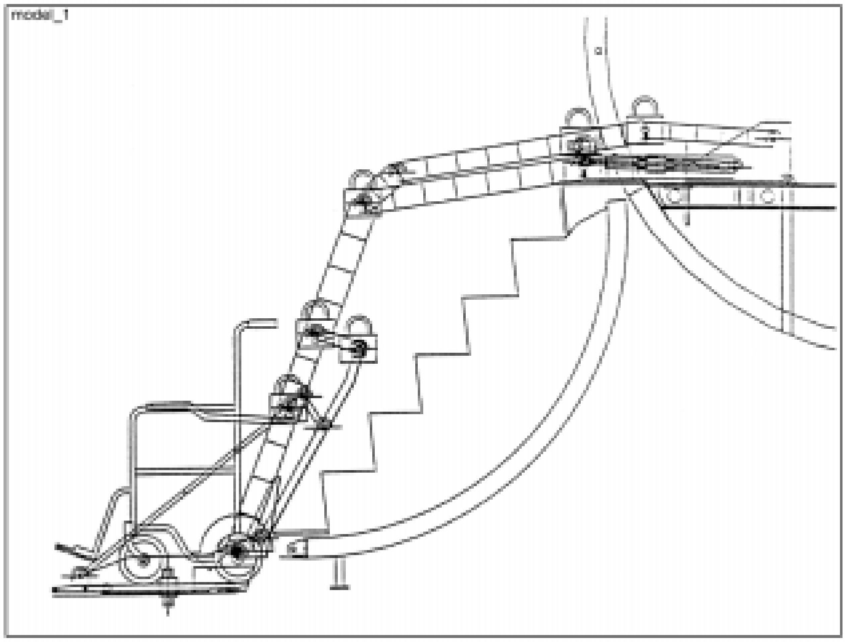

Figure 4 Final ADAMS Model – System Extended

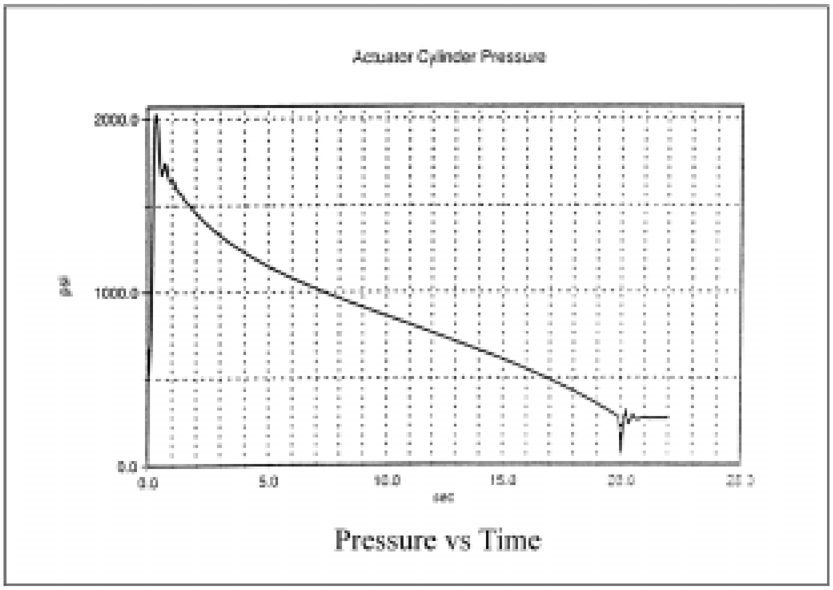

Figure 5 Actuator Cylinder – Pressure Versus Time

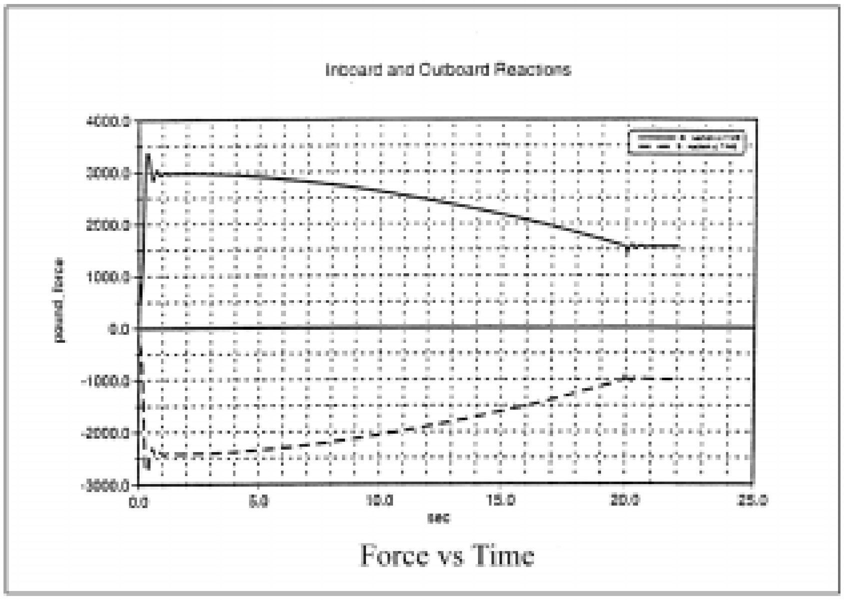

Figure 6 **Inboard of Outboard Support Reaction – Force Versus Time**

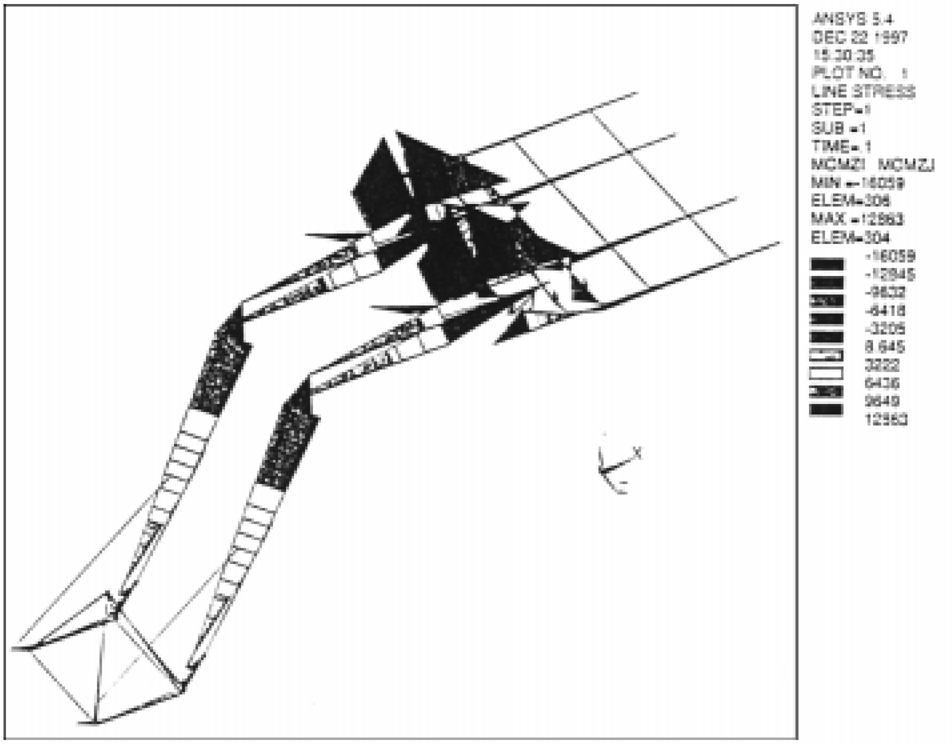

Figure 7 **F.E. Static Analysis: M_z Bending Moments – System Extended**

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