Integrated Landing Gear System

Retraction/Extension Analysis Using ADAMS

H. Zhang, J. Ning, and O. Schmelzer
Messier-Dowty Incorporation
574 Monarch Ave.
Ajax, Ontario
Canada L1S 2G8

Key Words: Landing Gear, Retraction, ADAMS

INTRODUCTION

In recent years a clear trend has developed in the aerospace industry towards the procurement of integrated systems from major suppliers (ref. 1). In this process, Messier-Dowty became a provider of integrated landing gear systems who is responsible for supplying a certifiable landing gear system and providing all the system level performance analysis. The aircraft landing gear system retraction and extension performance analysis is part of the certification requirement. The landing gear system is an integrated system which consist of the landing gear structure, the complicated door motion mechanism, locking mechanism, landing gear control module, and the interface between the landing gear system and the hydraulic system. A comprehensive landing gear system model is thus required to evaluate the system level performance. The modeling of such an integrated system using ADAMS provides a satisfactory solution to this challenging requirement and results in the saving of the system development time and a cost reduction for system level testing.

In this paper, the dynamic performance of the landing gear system during retraction and extension operations is examined under various aircraft speeds and hydraulic fluid temperatures using ADAMS. The landing gear structure, the aircraft hydraulic system and flight control functions are combined in an integrated aircraft landing gear system model which provides a fairly accurate estimation of the landing gear system motion characteristics, hydraulic flow requirements, and load information.

Modeling Methodology

The dynamic performance of the landing gears during normal retraction and extension operations is examined under various aircraft speed and hydraulic fluid temperature conditions. A three gear model is integrated with the aircraft hydraulic system to simulate the real flight conditions (with side slip) and to account for overall landing gear system dynamic flow distribution.

The landing gear system has been modeled to include all the loads on gears/doors with the actuator forces developed based on the dynamic hydraulic fluid flow rates. The gear/door loads include aerodynamic forces, gear/door weight and inertia, joint friction, and uplock/downlock impact loads. The hydraulic system pressure losses include the pump, control valves, pipeline (including bends) and speed control restrictors pressure losses. These pressure losses are functions of hydraulic flow rate and fluid viscosity (hence the fluid temperature).

Dynamic simulations are performed using ADAMS, which allows a model to be constructed graphically with actual gear geometry and with joints having the same degrees of freedom as they do in the physical system. Masses and rotational inertia are attached to the parts to represent their dynamic properties. External loads such as gravity and aerodynamic loads are applied to the model to duplicate the actual loading situation. As this is an integrated system analysis, pressure losses across various components are calculated based on their location on the flow path. A series of force balance equations and hydraulic pressure loss equations are embedded in the model to calculate the force at retraction actuators and the pressure drops across various components of the system during the gear retraction/extension process based on the instantaneous fluid flow into and out of the retraction actuators. The time history of the gear movement is then obtained. The simulation results can then be presented and motion of the landing gears can be graphically animated. The graphic representation of an integrated landing gear system model is shown in Figure 1. (with nose gear aft door wire-framed for clarity).

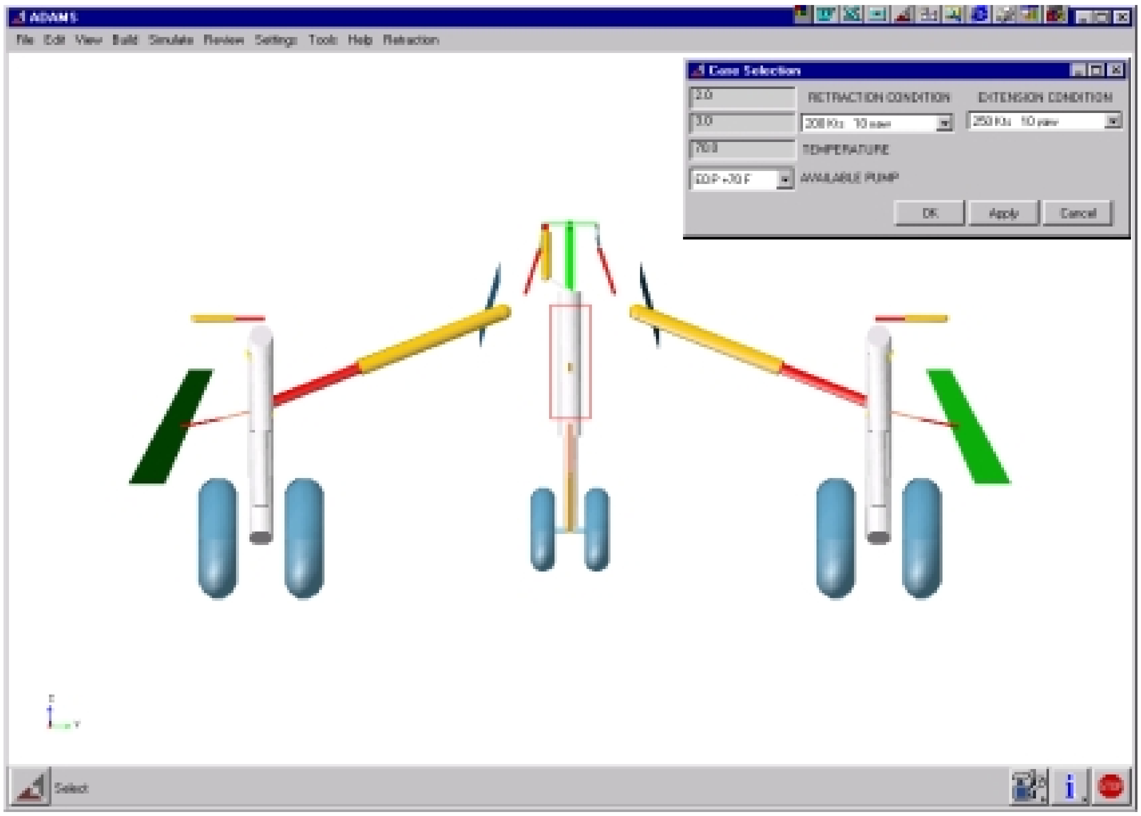

Figure 1 Integrated Landing Gear ADAMS Model

LANDING GEAR SYSTEM RETRACTION/EXTENSION ANALYSIS

System Description

The objectives of the landing gear system retraction/extension analysis are to verify that the landing gear system retraction/extension meet the performance requirements under various gear operation conditions and to provide load information on actuators, door links, and major joints. The landing gear system has to meet the retraction/extension time requirement based on the available pump flow. The load of the door mechanism during the retraction and extension process has to be determined by simulation to size the links.

The landing gear system referred herein consists of a nose landing gear (including two hydro-mechanically driven forward doors and an aft door attached to the gear), two main gears (with outboard doors attached to them), gear locking mechanism, hydraulic subsystem (including an engine driven pump, a priority valve, a selector valve, a control valve manifold), retraction actuators (with in-port or in-line restrictors), and associated hydraulic pipelines. The hydraulic circuit of an integrated landing gear system is shown in Figure 2.

System Supply and Return Pressures

The landing gear system is usually powered by an engine driven pressure compensated piston pump of aircraft hydraulic system. The nominal pump supply pressure is 3000 ±50 psi. The pump pressure – flow characteristics is interpolated using spline and built into the ADAMS model. The system return pressure at selector valve is also built into the dynamic model.

Hydraulic Line Pressure Drop

The pressure drop in the landing gear hydraulic lines is based on the assumption that the fluid flow state inside the pipe line be either laminar (Reynolds number < 2000) or turbulent flow. A switch based on the Reynolds number is used in the model for the calculation of the pressure loss. The pressure drop equation is expressed as follows (ref. 2):

$$
\begin{aligned}
p_{pipe\_in} - p_{pipe\_out} &= \frac{64}{Re}\frac{L_{pipe}}{d_{pipe}}\frac{v^2}{2} \qquad Re \le 2000 \qquad Laminar \\
p_{pipe\_in} - p_{pipe\_out} &= \frac{0.3164}{Re^{1/4}}\frac{L_{pipe}}{d_{pipe}}\frac{v^2}{2} \qquad Re > 2000 \qquad Turbulent
\end{aligned}
\tag{1}
$$

where v is the fluid velocity inside the pipe, d_{pipe} is the pipe inner diameter and L_{pipe} represents the hydraulic line length. The hydraulic pipe lengths are true lengths which do not include the bends and “T” heads. The pressure losses due to bends and the “T” heads depend upon the number and angles of the bends and “T” heads in the system. As a conservative measure for the system simulated in this paper, their effect have been accounted for by introducing a line length correction factor. Thus the effective line length is used in the dynamic modeling with the following expression:

$$L_{effect} = f_{bend} \times L_{pipe} \tag{2}$$

Pressure Drop for Speed Control Orifices

The pressure drop for speed control orifices are calculated based on the turbulent flow pressure drop calculation (ref. 3). The formula is expressed as follows:

$$Q_{orifice} = c_d A_{orifice}\sqrt{\frac{2}{\rho}(p_{in} - p_{out})}\, sign(\dot{x}_{act}) K_{viscosity} \tag{3}$$

where c_d is the flow coefficient, p_{in} and p_{out} represent pressures of hydraulic flow into and out of that orifice, $sign(\dot{x}_{act})$ takes care of the flow direction, and $Kviscosity = f(\mu, \Delta p)$ is a viscosity compensation factor, which is viscosity and pressure dependent. Its value can be determined based on the viscosity-temperature curve and the *Kviscosity*- pressure drop curves found in ref. 4.

Fluid Compressibility under Actuator Snubbing

When landing gear moves into the up and locked position, the aerodynamic load diminished, tending to speedup the gear movement. To reduce the dynamic impact load on the gear uplock and minimize the vibration, the retraction actuator is often designed with end stroke snubbing mechanism. As hydraulic fluid inside the actuator being compressed, its pressure increased sharply, forcing fluid be squeezed out of the snubbing chamber through snubbing orifice. The resulting resistant force (braking effect) will slow down the gear movement. The pressure change due to the fluid compressibility is described as follows (ref. 3):

$$dp = -\frac{\beta_e}{V_0 - AS} dV = -\frac{\beta_e}{V_0 - AS}(A \times dS - q_{snubbing}) \tag{4}$$

where V_0 is the initial volume of fluid to be compressed, $\beta e = f(T, p)$ is the fluid bulk modulus, which is temperature and pressure dependent. $q_{snubbing}$ represents the fluid being squeezed out of the snubbing chamber through snubbing orifice. It can be calculated using Eq.3.

Hydraulic Force Acting on Retraction Actuators

The force acting on the retraction actuator can be expressed as follows:

$$F_{retract} = A_{Act\_in} p_{Act\_in} - A_{Act\_out} p_{Act\_out} \tag{5}$$

where A_{Act_in} and p_{Act_in} are area and pressure at the pressure supply port, while A_{Act_out} and p_{Act_out} are area and pressure at the pressure return port of the retraction actuators, respectively.

Joint Frictions

The friction moment applied to joints is defined as follows:

$$M_{friction} = f_{friction} F_{joint} \times \frac{D_{joint}}{2} \tag{6}$$

where $f_{friction}$ = 0.2 for static and 0.05 for dynamic, is the joint friction coefficient, F_{joint} is the radial joint load resolved from the ADAMS program, and D_{joint} is the pin rotating diameter for that specific joint.

Aerodynamic Loads

Aerodynamic loads acting on the main and nose landing gear and the attached doors under the limit speed are provided by airframe manufacture based on the aircraft CFD model. These aerodynamic load data are interpreted and implemented in dynamic retraction/extension model. For aerodynamic loads under the speed other than the limit speed, the following formula is used in the model.

$$Load_{xkts} = Load_{ref} \left(\frac{V_{xkts}}{V_{ref}} \right)^2 \tag{7}$$

Hydraulic Fluid Viscosity, ν_T

The fluid viscosity is a function of the fluid temperature which can be expressed as (ref. 4)

$$\nu_T = \nu_0 e^{-\alpha T} \tag{8}$$

For the type of hydraulic fluid Skydrol 500B-4, the viscosity curve is given in ref. 4. and its polyfit given as follows:

$$\nu_T = 125.5910 \times e^{-0.0258T} \tag{9}$$

Restrictor Sizes

For the main landing gear, the retraction speed is controlled by an annulus side port orifice (L3). A fixed orifice (L2) inside the control manifold is used to compliment the retraction speed control. The head side fluid flow freely to the return port to reduce the possibility of fluid clog. For the nose landing gear, the retraction speed is controlled by head side orifices (N1, N3) and complimented by an annulus side orifice (N2). The main gear extension speed is controlled by an in-line orifice (L1) built in the control manifold. the pressurized fluid flow is routed to both sides of the side brace actuator via a run-around valve. The flow circulation reduces the flow demand on the hydraulic pump during gear extension. The annulus side orifice (L3) is used to compliment the extension speed control by limiting the pressure difference between the head side and the annulus side of the side brace actuator.

The speed control restrictor sizes are represented by “lohm rate” introduced in Lee restrictor handbook (ref. 4). The relation between the restrictor diameter and the “lohm rate” can be expressed in the following equation (ref. 4):

$$lohm = \frac{0.76}{d_{restrictor}^{2}} \tag{10}$$

The speed control restrictors have been sized to meet the landing gear system required retraction and extension time. By properly design and tuning of the speed control restrictors, the cavitation or over pressurization inside the actuators can be prevented during landing gear retraction and extension process.

LANDING GEAR RETRACTION EXTENSION SIMULATION

Features of The Dynamic Model

The landing gear dynamic model is fully parameterized such that the changes in gear structure geometry can be readily incorporated into model which will update the part and joint orientation and force alignment accordingly. Hydraulic components (valve, pipe, and orifice) are parameterized such that the size and location of the components can be easily redefined or relocated to perform the parameter study. IF statements are used to limit the minimum pressure along flow paths to sense the fluid chamber cavitation.

A dialog box is created to facilitate the simulation under various aircraft airspeeds, side slips, and temperature conditions (ranging from –40 °F to +160 °F). Different temperatures can be set at pump, pipe line, and retraction actuators to reflect the real flight conditions. The pressure drop across these components are then corrected using temperature compensation factors.

This dynamic model is also used to examine the lock mechanism impact load and door linkage load under various flight conditions up to cruise and dive speeds. Impact functions and bi-stop functions are used in the dynamic model with appropriate gear and lock segment stiffness to simulate the impact.

Retraction and Extension Analysis Results

The landing gear system retraction and extension performances under two distinctive flight conditions and fluid temperatures are shown in Figure 3 and Figure 4. The results indicate that the landing gear system retraction and extension time requirement can be achieved through the optimum design of the speed control orifices. The maximum required hydraulic pump flow can be determined based on the system flow output. The airspeed plays a very important role on the landing gear retraction performance. From Figure 3, it is seen that with side slips, a certain degree of asymmetry occurs during the main landing gear retraction process due to the difference of aerodynamic loads applied on right hand and left hand main gear/doors. Variation of the fluid temperature has a significant impact on the landing gear system retraction time, because the pressure drops across the hydraulic components and along the hydraulic lines increase dramatically for highly viscous fluid. Since the main and the nose gears use same hydraulic power source, the movement of the one gear will affect the movement of other gears. This is particularly true under low temperature operation where the hydraulic pressure is high enough to bring main gears up while, with this pressure, the nose landing gear actuator force is not able to overcome the resisting aerodynamic load. As shown in Figure 4, at 200 kts limit retraction airspeed under low fluid temperature (-20 °F), the nose landing gear barely stalls at the start of the gear retraction process. It picks up the speed after main gear retraction are finished. A much longer gear retraction time is observed under such low temperature condition.

During gear extension, air loads on gear and doors help pulling gear down. Thus, an increase of the airspeed speeds up the extension of the landing gear system. Within certain operating temperature range, variation of the fluid temperature has less significant impact on the landing gear system extension time (comparing with the gear retraction) since high hydraulic pressure is not needed to extend gears. Nose gear is simply forced down by air loads and main gear will experience a certain degree of asymmetry under flight conditions with side slip. For the nose landing gear, the speed control orifices provide a braking effect during gear extension. Pressure in the head side of the nose gear retraction actuator could go fairly high. To prevent over pressurization of the retraction actuator, the complimentary speed control orifice (N2) is sized to restrict the incoming flow pressure as low as possible during extension but not cause cavitation inside the retraction actuator.

CONCLUSION

From this investigation, it has been learned that the utilization of ADAMS offers a great deal of benefit for the integrated landing gear system simulation. Similar retraction and extension models have been used by Messier-Dowty on other projects and simulation results demonstrated very good correlation with the LGSTR (Landing Gear System Test Rig) and flight test data. ADAMS allows a model to be constructed graphically with complicated gear and door mechanism and with joints having the same degrees of freedom as they do in the physical system. A series of force balance equations and hydraulic pressure loss equations are embedded in the model to calculate the force at retraction actuators and the pressure drops across various components of the system during the gear retraction/extension process based on their location on the flow path and the instantaneous fluid flow into and out of the retraction actuators. The parameterization tool allows user to perform parameter and design study with ease, The dynamic pressure and load information obtained from the dynamic simulation can be confidently used in the stress analysis, resulting in the saving of the system development time and cost reduction for system level testing and performance verification. The time history of the gear/door movement and the dynamic flow from the simulation will provide information for actuator sizing and the hydraulic system configuration.

REFERENCES

1. L. Dacko, R. F. Darlington, P. Van Roon, D. Shindman, Integrating Aircraft Landing Gear Systems, SAE Conference, 1999
2. Robert W. Fox, A. T. McDonald, Introduction to Fluid Mechanics, John Wiley & Sons Incorporation, 1985.
3. Herbert E. Merritt, Hydraulic Control Systems, John Wiley & Sons Incorporation, 1967.
4. The Lee Company, Technical Hydraulic Handbook, Release 10.0, 1996.

Nomenclature

$A_{orifice}$	Speed control orifice area
A_{act_in}	Actuator area at pressure port
A_{act_out}	Actuator area at return port
c_d	Flow discharge coefficient for turbulent flow
d_{pipe}	Hydraulic pipe line internal diameter
$d_{restrictor}$	Speed control orifice diameter
D_{joint}	Joint bearing diameter
f_{bend}	Pressure drop factor for bends and T heads
$F_{retract}$	Retraction actuator load
F_{joint}	ADAMS resolved joint load
L_{pipe}	Hydraulic pipe line true length
L_{effect}	Hydraulic pipe line equivalent length
$Load_{xkts}$	Aerodynamic load at specified airspeed
$M_{friction}$	Joint friction moment
p_{in}	Orifice input pressure
p_{out}	Orifice output pressure
P_{pipe_in}	Pipe line input pressure
P_{pipe_out}	Orifice output pressure
$Q_{orifice}$	Flow rate of speed control orifice
Re	Reynolds number
$\dot{x}_{act}$	Retraction actuator velocity
βe	Fluid bulk modulus
ρ	Fluid density
μ	Fluid absolute viscosity
ν_T	Fluid kinematic viscosity

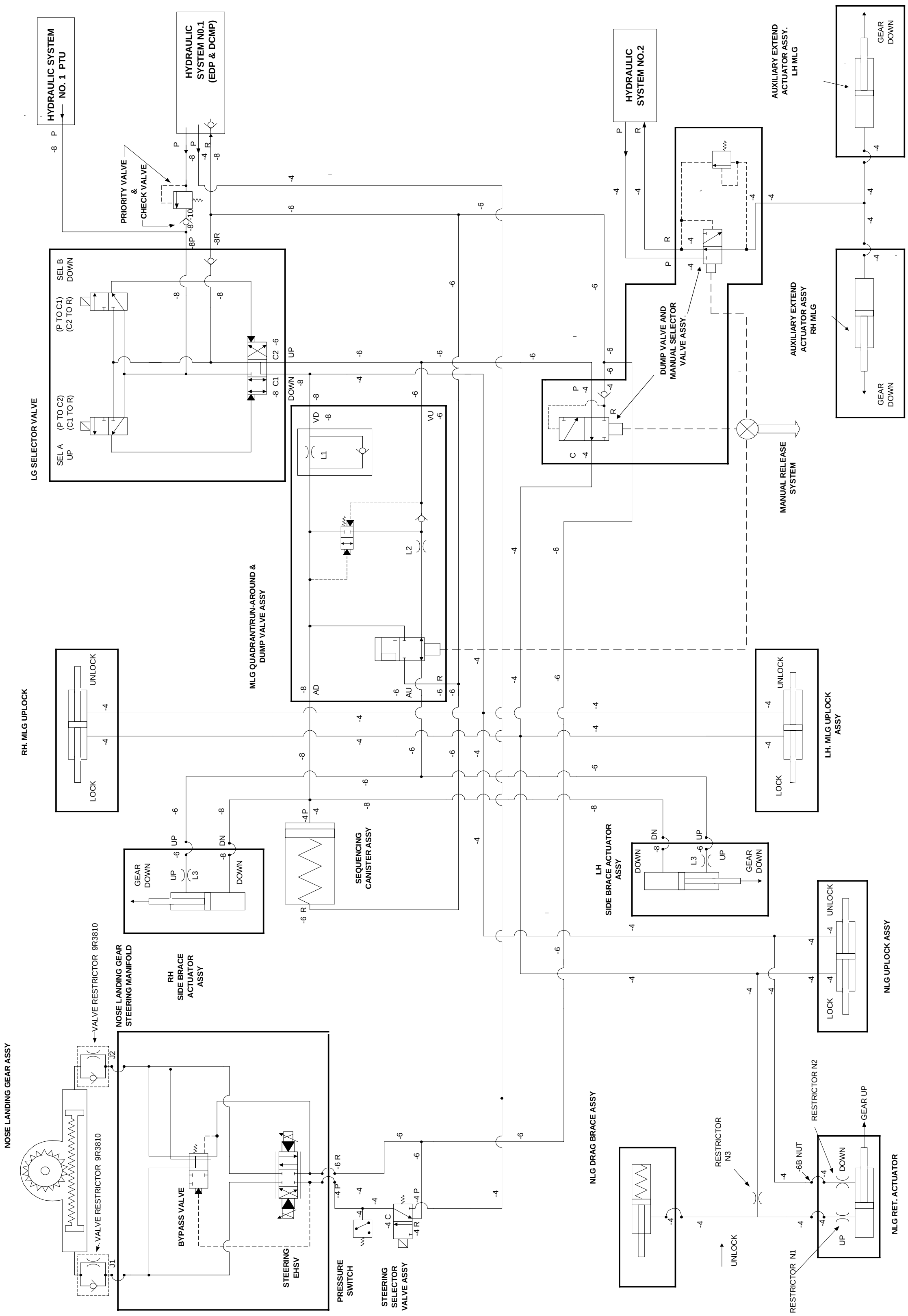

Figure 2 Integrated Landing Gear Hydraulic Schematic

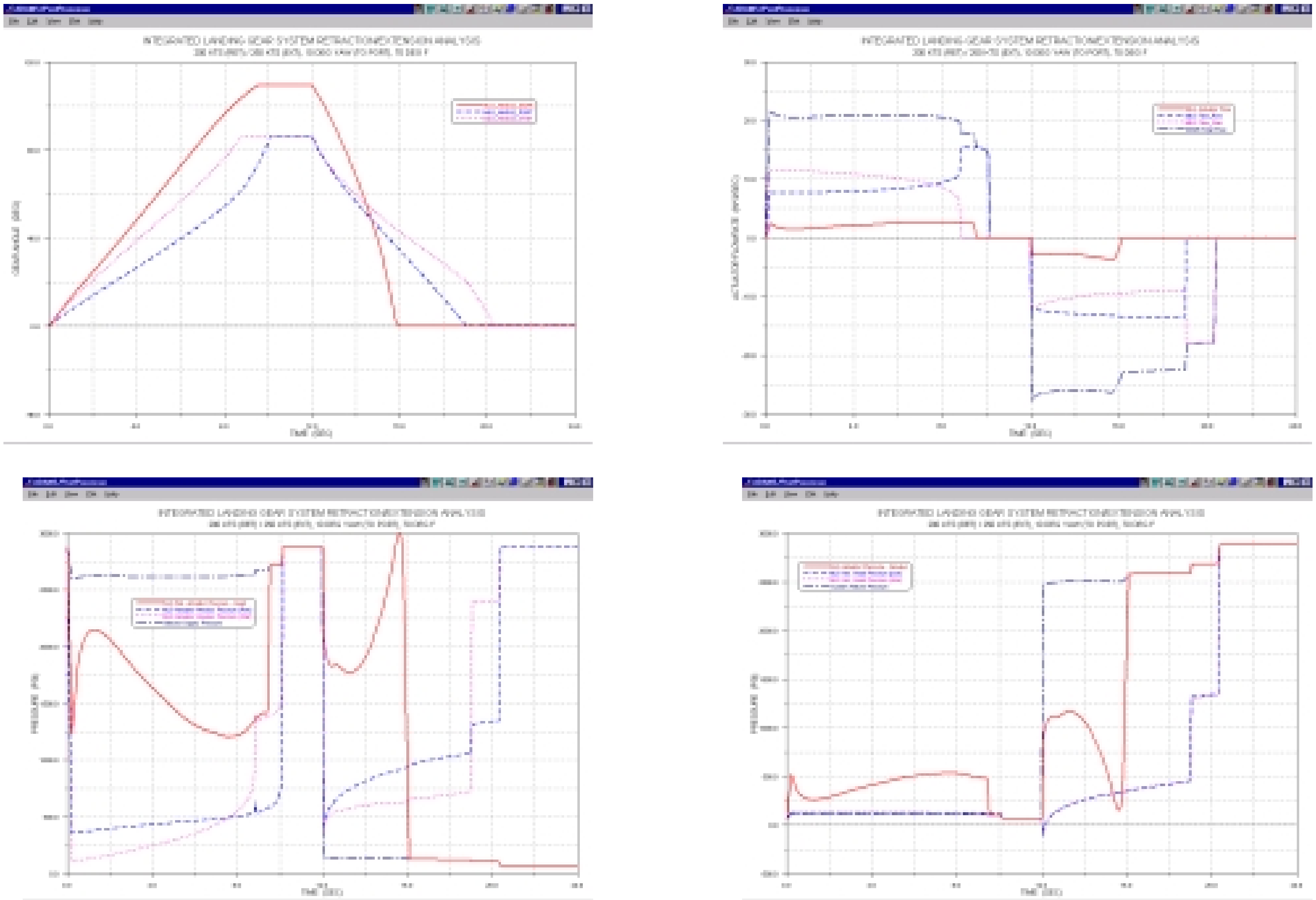

Figure 3 Landing Gear System Retraction/Extension – Normal Temperature

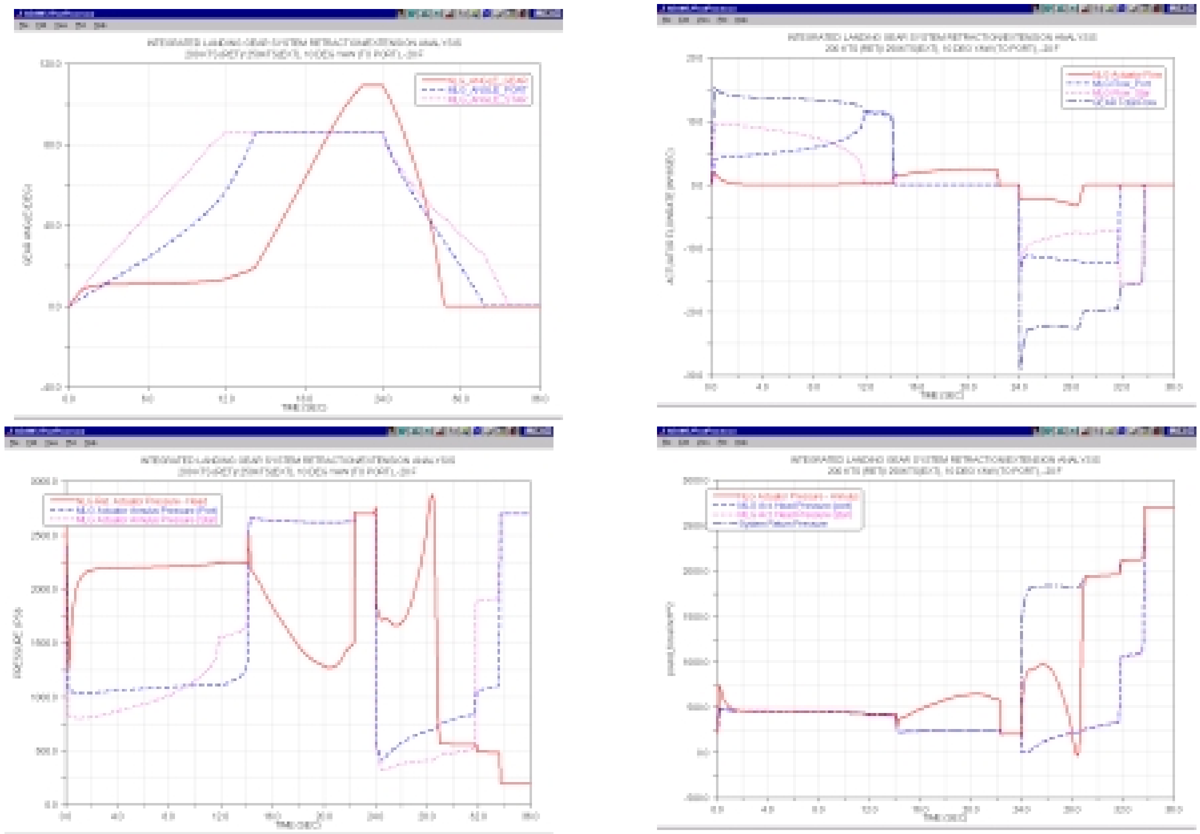

Figure 4 Landing Gear System Retraction/Extension – Cold Temperature