DYNAMIC ANALYSIS OF ORION TEST FLIGHT ARTICLE MECHANISMS USING MSC.ADAMS SOFTWARE

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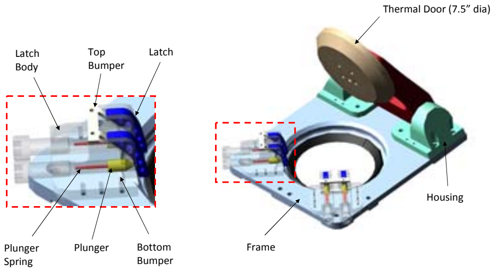
INTRODUCTION

The Orion crew module flight test article has two doors, which serve as openings for thermal and electrical controls to the vehicle prior to launch. Doors are required to close and latch during launch and will experience inertial loads in the range of eight to twenty two gs. The original design for the doors had many components not present in their final design. One of said components is the door damping mechanism, which was attached between the back of the doors and vehicle structure – its purpose being to control the doors' rate of descent. Omitting it brought about a sense of uncertainty in the latches' ability to catch the doors after rebounding from their door frames. The increased velocities and lack of information on the door-frame interaction prompted further tests and analysis.

ADAMS dynamics analysis software was used to simulate both thermal and electrical doors under the pair of thrust profiles that bracket the abort flight tests' acceleration environment: Ascent Abort 1 (AA-1) cold and Pad Abort 1 (PA-1) hot thrust profiles. Of particular concern is (1) the ability of the latches to catch the door after rebound and (2) the forces felt on the underside of the latches after rebound.

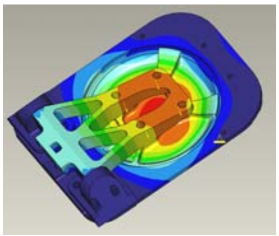
SETUP

After the solid model geometry was imported from Pro/Engineer CAD software, the components were assembled and constrained in ADAMS using translational- and rotational-type joints, as well as contact, or stiffness, parameters between components to limit travel. Motion of the assembly was then simulated under the pair of acceleration profiles. Several measures were set up to track such things as door tip velocity, door impact forces on the latches and frame, latch spring compression lengths, door-to-frame distance, and latching response time. This process was done for both thermal and electrical doors.



To ensure accurate contacts between the various moving components, a combination of Pro/Mechanica load/deflection analyses and hand calculations were used to estimate the relative stiffness between the interacting parts. The Pro/Mechanica approach took into account the structures' shape, interfacing surfaces, and mechanical properties to get an accurate set of load vs. maximum displacement data from which a stiffness value was calculated for each of the interfacing components.

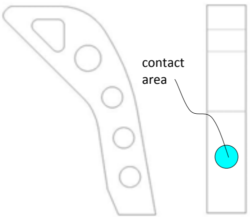
Door-to-Frame Contact



$P = Applied\ \ Load$
$d = Maximum\ \ Displacement\ (door\ \ center)$
$k = Contact\ \ Stiffness\ \ Parameter$

$$k = \frac{P}{d} = \frac{6000\ lbf}{8.456E-3\ in} = \underline{7.096E5}\ \frac{lbf}{in}$$

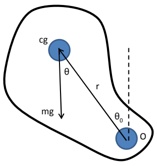
Plunger-to-Latch Contact



$$k_{eq} = \frac{1}{\frac{1}{k_{latch}} + \frac{1}{k_{plunger}}} = \frac{1}{\frac{1}{1.23E6} + \frac{1}{6.83E5}} = \underline{4.39E5}\ \frac{lbf}{in}$$

RESULTS

To ensure ADAMS is providing accurate results, one can compare the tangential velocity of the door prior to impact with the latches as measured in ADAMS to that calculated from the differential equation below. The velocity plays an especially important role due to kinetic energy's dependence on the square of the velocity. As can be seen, ADAMS falls within 1% of the analytical calculations:



$$\Sigma T_o = I_o \alpha$$

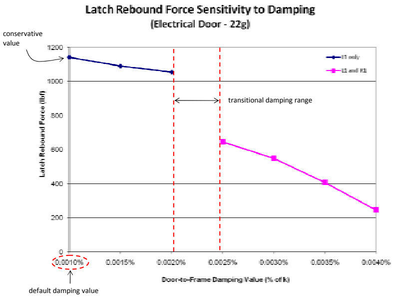
$$(mg \sin\theta) r = I_o \alpha$$

$$\alpha = \frac{d^2\theta}{dt^2} = \frac{mgr}{I_o} \sin\theta$$

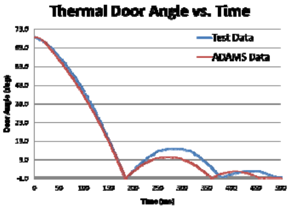
$$\boxed{\omega = \frac{d\theta}{dt} = \sqrt{\frac{2mgr}{I_o}(\cos\theta_o - \cos\theta)}}$$

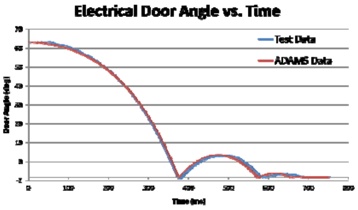
	θ (deg)	θ_o (deg)	r (inch)	a (gs)	V_{calc} (in/sec)	V_{model} (in/sec)	% diff (from calc)
Thermal	76.5	14.2	9.54	22	397	400	< 1%
Thermal	76.5	14.2	9.54	8	248	250	< 1%
Electric	77.5	15.6	13.1	22	494	490	< 1%
Electric	77.5	15.6	13.1	8	309	310	< 1%

ADAMS most accurately models contacts using a non-linear spring / damper system. An estimation of stiffness between the contacting bodies is required along with damping to determine how quickly energy is dissipated through the material or system after impact. To be conservative, damping was set as low as possible, such that minimal energy is dissipated during the interaction, thereby allowing the parts involved to move with maximum energy (i.e., velocity). This increases the magnitude of impact forces and decreases latch response times. However, there is the danger of being too conservative and reporting larger forces than the latches can handle. To get a feel of how sensitive the latch rebound forces are to door-to-frame damping, the following data was gathered for the electrical door (note: Individual latches in the left and right latch bodies are designated as L1, L2, R1, R2, respectively).



As can be seen from the sensitivity plot above, changing the damping value by only a few fractions of a percent can make a big difference in the forces felt on the underside of the latches. To help narrow down the damping value and other critical parameters, door angle vs. time data was gathered from a 1g drop test of both the thermal and electrical doors via a potentiometer installed on their hingelines.





Correlating the ADAMS models to this data helped narrow down more accurate values for damping, stiffness, friction, etc. However, it is important to note even under the most conservative of conditions, the doors are caught by the latches.