



CRANE CO. Hydro-Aire Inc. Technical Document Series

Brake Control System Stability Considerations

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Landing Gear Dynamic Stability

What Is Dynamic Stability, And Why Should I Care About It?

Most undergraduate engineering students have seen the classic black and white video of the collapse of the Tacoma Narrows Bridge, a frame of which is shown in **Figure 1**. Arguments continue about what design mistakes were made, but it is agreed that the culprit was resonance. Resonance is the sympathetic excitation of the resonant frequency of an object. It is not inherently bad-very few musical instruments would work without it. However, with aircraft structures, effort is usually made to control or avoid resonance.

A simple example of the good and bad of resonance is a child on a swing. If you push a child on a swing at the same frequency they are swinging, you get much better response! But if you continue to push with the same force "in synch" with their swinging, the amplitude will continue to increase until you reach some limiting factor, for example, the swing tips over!

There are several types of resonance in braking systems, including hydraulic system resonance, but the most serious kind is the fore and aft excitation of the landing gear, often referred to as "gear walk". The type of motion that takes place is shown in **Figure 2**. If the resonance is intense enough and/or lasts long enough, it can result in structural damage or even complete failures of the landing gear.

Aircraft main landing gear typically has a fore and aft resonant frequency that ranges from single digits to



Figure 1, An Example of Resonance, The Tacoma Narrows Bridge Collapse

as high as 40 Hz. One of the most important characteristics of a brake control system is how it manages the application of force to the gear to avoid this problem.

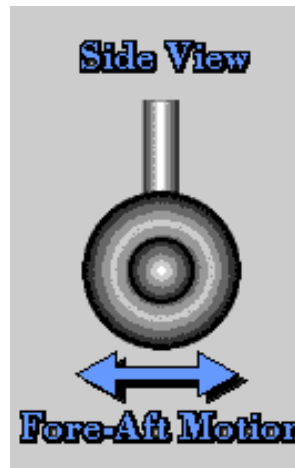


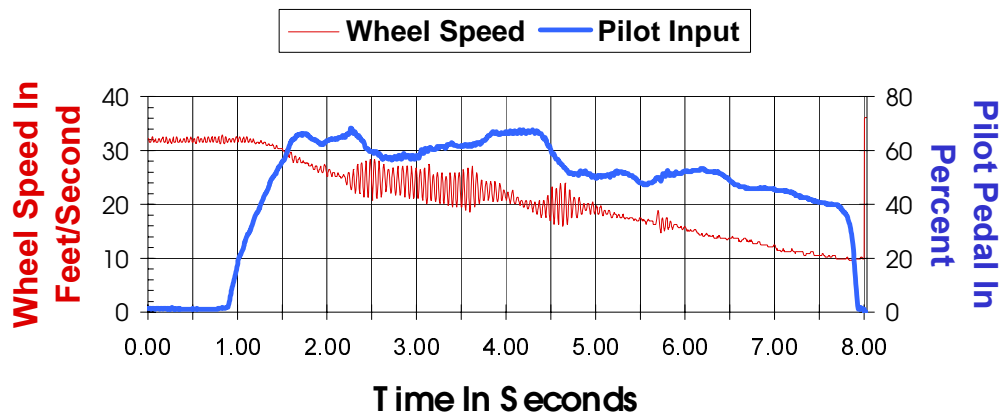
Figure 2, Gearwalk Motion

as the onset of a skid, and reduce brake pressure. Without the brake drag force, this allows the gear to move forward which makes the wheel appear to speed up, the controller reap-

Gear Resonance During Brake Control Testing

Figure 3 is an illustration of resonance using a non HydroAire brake control system. The gear motion fore and aft makes the wheel speed appear to speed up and slow down. As the wheel slows down, the controller will see this as the onset of a skid, and reduce brake pressure. Without the brake drag force, this allows the gear to move forward which makes the wheel appear to speed up, the controller reap-

Figure 3, Resonance Experienced During Aircraft Taxi Test





plies pressure, and the cycle repeats. When this cycling takes place at the resonant frequency of the gear, the amplitude is much higher because the gear “likes” to cycle at that speed. The cycling illustrated took place at taxi speeds, and could have been more serious if it had taken place at higher speeds.

How Not to Avoid Gear Resonance

The approach taken by some brake control manufacturers to this problem has been two-fold: First, filter out the resonance by using a notch filter, or Second, by slowing down the response of the entire control system so that control frequencies that could excite resonance is not encountered. Both methods can work but with serious drawbacks.

Controlling Gear Resonance by Notch Filtering

The idea of notch filtering is that the system cannot respond at the chosen frequency, and this will eliminate the resonance. One of HydroAire’s competitors very recently developed and provided a new system for an Air Force aircraft. A report of the flight test of this system is available on the Society of Experimental Test Pilots web site. The URL is:

http://www.netport.com/setp/Takealload_off.htm

The report describes problems with gear walk during the testing, and some of the problems with notch filtering as a solution. They found that the notch filter can be placed incorrectly in the control loop. They also found that the resonant frequency can change depending on loads, structural changes, etc., and what was thought to be a single resonance can actually be multiple resonant frequencies grouped closely together. The ultimate solution was a dual notch filter.

A problem not addressed by the dual notch approach chosen is that significant cycling can take place at harmonic and sub-harmonic frequencies which the notch filter(s) cannot eliminate. **Figure 4** is data from the testing of an-

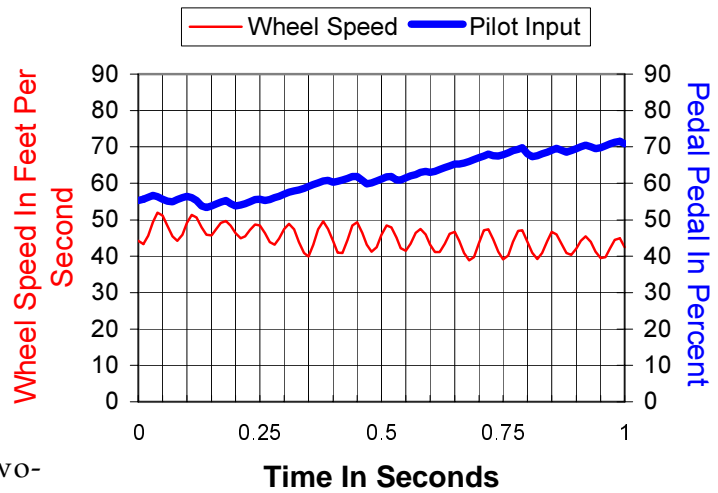


Figure 4, Oscillations at (Sub) harmonics of the Resonant frequency

other non Hydr-Aire controller.

Note that this test point is not maximum performance braking. The data demonstrates, as does figure 3, that gear walk can be encountered under conditions that are not part of the typical “flight test” where the emphasis is on maximum performance, and so may not appear until later, potentially after a system has been fielded.

The data shows that excitation of the gear at about 2/3’s of the resonant frequency (around 15 Hz) can cause significant cycling. Although this cycling was not structurally dangerous or extreme, it was objectionable to the pilot (who felt it as a low frequency vibration) and it had to be corrected.

Another problems is that resonant frequencies may change due to changes in rigging, materials, processes, or dimensions. A controller designed to just eliminate resonance at specific fixed frequencies will not be able to adapt to these changes.

Yet another drawback of the notch filter approach is that, like any filter, it will degrade the frequency response of the system and the system’s ability to respond to “real” skid activity. This has impacts for both braking performance and tire life. Because skids cannot



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be corrected as quickly, tire wear will increase due to deeper skids.

Brake life may also suffer due to the need to dump more pressure to correct the deeper skids, resulting in more chances for complete cycling of the brake.

Controlling Resonance by Slowing Response

There are brake control systems that don't have resonance problems because they respond too slowly to excite resonant frequencies. An example of this with another non Hydro-Aire system is shown in **Figure 5**.

The response of the system in cycling in response to skids does not exceed 10 Hz, avoiding resonant frequencies. The price that is paid for avoiding gear walk this way is also apparent in the data. The system cannot respond quickly to skids, and there is significant tire and pressure cycling. This results is significantly increased wear and tear on the tires (as they thrash in and out of skids) and the brakes (as brake pressure is released and reapplied). While there is no resonance, the cost to avoid it has been very high with extremely low operating efficiency and high component wear.

HydroAire Methods to Avoid Gear Walk (Instability)

The HydroAire approach to eliminating gear resonance is two fold. The combination of the two methods is very effective in eliminating the potential resonance problem. The other aspects of system design that aggravate gear walk (for example, a resonance of the hydraulics in the frequency range where gear walk takes place) are also addressed by these approaches.

First, the key is using a control method that manages the response of the gear through control of the brakes. Unlike the "notch filter" approach, this method does not depend on gear/brake/tire response remaining unchanged. It

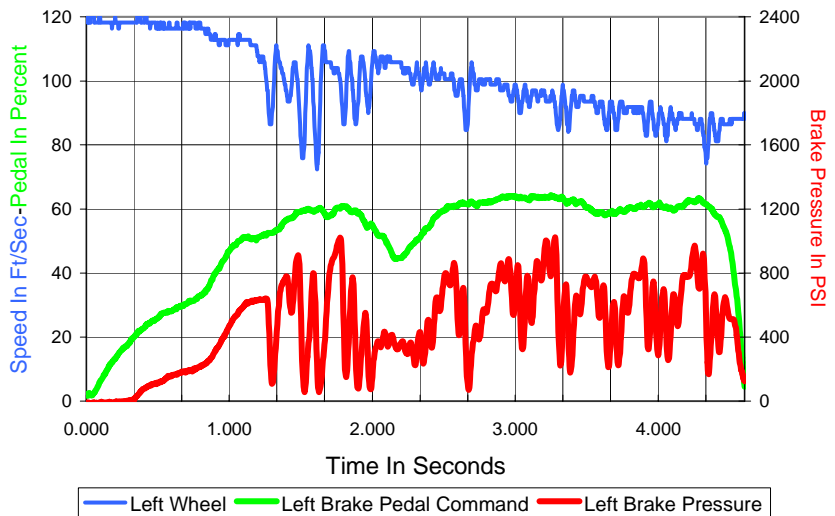
also avoids the problem of sacrificing brake control performance to obtain stability.

Secondly, HydroAire's validated Hardware in the Loop (HITL) simulation capability is used to study system operation under a very wide range of conditions-more than any flight test focused on maximum performance and safety could cover.

A block diagram of the HITL simulator is illustrated in **Figure 6**. The actual aircraft hydraulics, brake, and control electronics, are incorporated into the simulator. Gear models used range from a simple spring and damper to a complex six degrees of freedom model allowing modeling of complex gear characteristics.

The use of a control algorithm that actively damps out resonance, together with the validated simulation capability, assures that resonance phenomenon are not encountered on the aircraft either in flight test, or worse, during operational use. With their extremely broad experience base, HydroAire has had more experience, and more success, than any other brake control system supplier in avoiding landing gear instability (resonance) problems despite many challenges.

Figure 5, A Brake Control System Too Slow to Have Resonance Problems



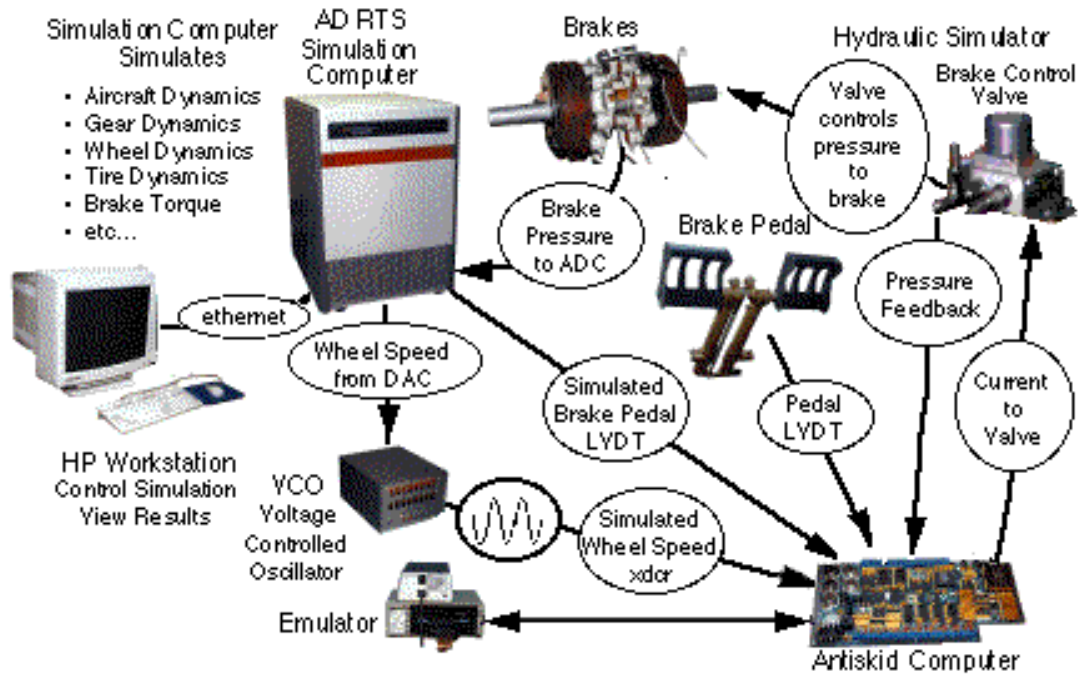


Figure 6, Functional Diagram of the Hydro-Aire Hardware In The Loop (HITL) Simulation System

Summary and Conclusions

Gear resonance is a serious consideration in brake control/antiskid system design. HydroAire has developed unique and effective solutions for prevention of the problem, and verification that the problem will not appear under conditions that flight testing may not cover. Hydro-Aire has also had success in "taming" problems where they were introduced by other components of the landing gear system.