Pilot Control Loader System
For the Vertical Motion Simulator
at Ames Research Center

ADI APPLIED DYNAMICS INTERNATIONAL

A New Pilot Control Loader System for the Vertical Motion Simulator

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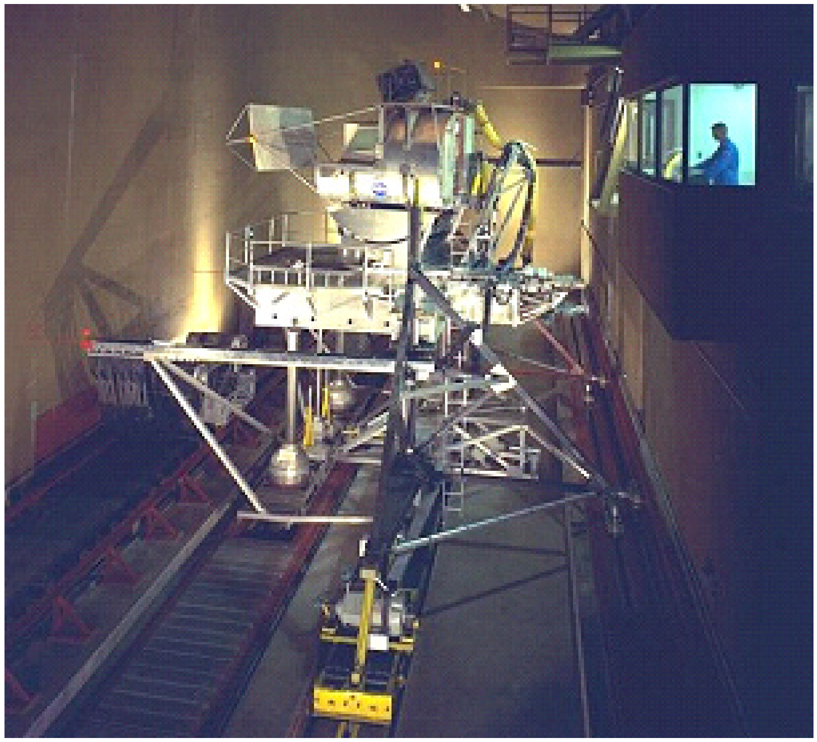
Introduction

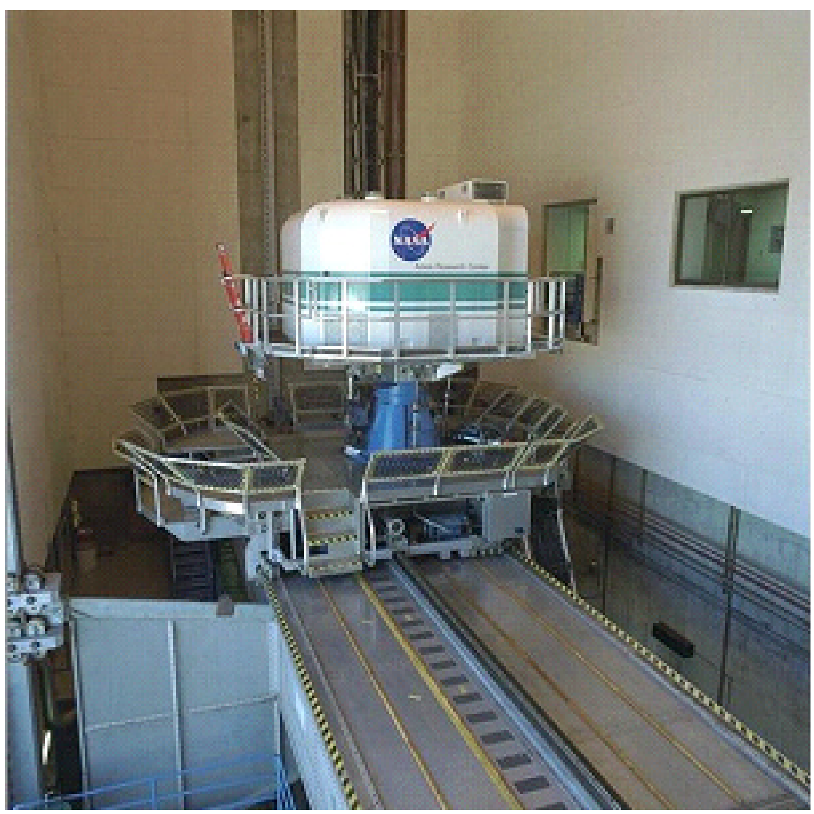
For over 40 years, Pilot Control Loader (PCL) characteristics at the NASA Ames Flight Simulation Laboratory were provided by analog computers. Only analog computers could provide the bandwidth and versatility needed to support complex flight simulation configurations using the McFadden electro-hydraulic PCLs. PCLs are used in everything from horse trailers (small roll-around single seat cabs) to stand-alone hexapods to large motion base systems. The first large motion base system was the S.01, more formally known as the Six Degrees-of-Freedom Motion Simulator, and it boasted a motion range of ± 9 feet for each X,Y, and Z axis. This was a general purpose motion simulator and used some of the very early McFadden PCL models.

Six Degree of Freedom Motion Simulator



Flight Simulator for Advanced Aircraft (FSAA)

The next large motion base system was the Flight Simulator for Advanced Aircraft (FSAA) capable of providing a motion range of ±3, ±40, and ±4 feet for the X, Y, and Z axes respectively. Its extreme lateral travel was widely used in transport aircraft simulation and employed a wide variety of McFadden PCLs, especially wheel and columns.



Vertical Motion Simulator (VMS)

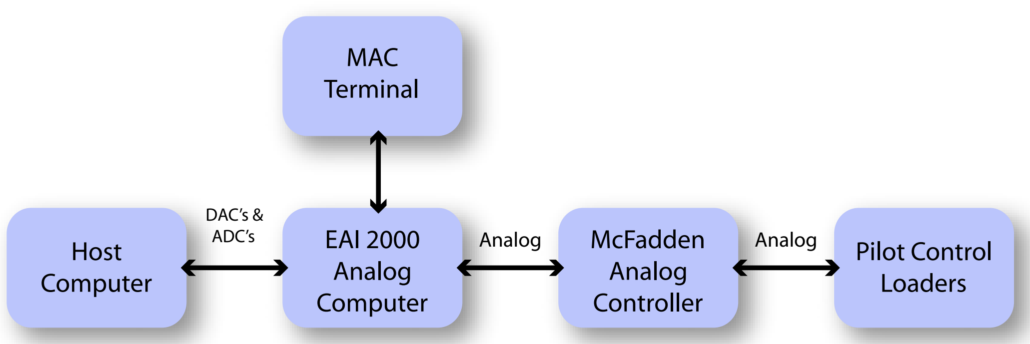
The FSAA was, in turn, replaced in 1980 by the current system, the Vertical Motion Simulator (VMS) which has a motion range of ±3, ±20, and ±30 feet for the X, Y, and Z axes respectively. The VMS uses what is probably the single largest collection of McFadden PCLs with over 31 assemblies for a total of 46 axes. These units include wheel and columns, fighter sticks (cyclics), collectives, hand controllers, rudder pedals, seat shakers, and custom devices. Because the VMS employs interchangeable cabs, the PCL systems used here needed to be flexible enough to meet rapidly changing requirements. The PCLs are routinely moved from cab to cab or to storage.

The availability of ever faster digital computers that use object oriented programs has finally led to the development of a digital system that meets the requirements of the VMS. The new system, implemented with an Applied Dynamics International (ADI) RTS real-time computer and Simulink, has added a flexibility that allows us to surpass the capability of the old analog systems. In fact, the Simulink program allows us to simulate every characteristic ever required in past VMS simulations. Furthermore, we've been able to overcome some old hurdles and add some impressive new features.

For information about the VMS, see: http://www.simlabs.arc.nasa.gov/vms/vms.html

Then... The Analog System

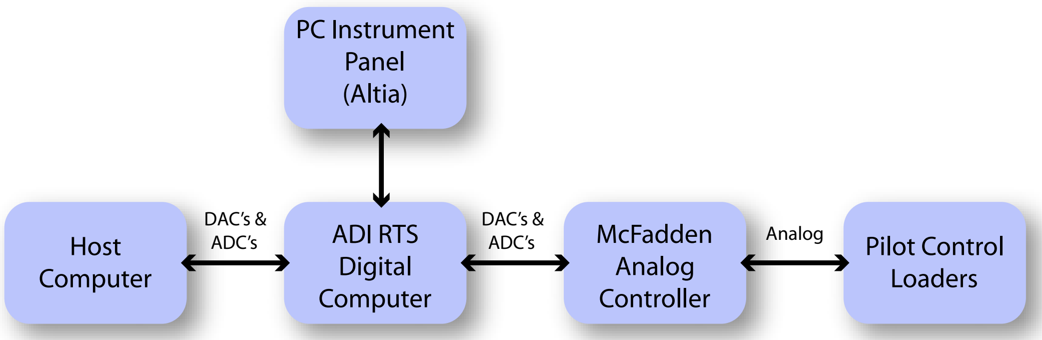
This system used a Mac Terminal to interface with an analog computer, a ±10 volt EAI 2000. Earlier systems used EAI 231R and EAI 8800 ±100 volt analog computers. The Mac Terminal allowed for setting the digital attenuators and integrator gains. It also provided readouts for some trunk lines, amplifiers, logic status, and so forth. Parameter settings, for determining PCL characteristics such as force gradient and damping factor, were provided either from the EAI 2000 or the host computer. Mechanical switches, located on the EAI 2000, were used to select from either source. The host computer set the parameters for the PCL via ±10 volt DACs and received feedback such as pilot force and control position/velocity via ±10 volt ADCs. The McFadden analog controller provided the interface to the pilot controls and closed the loop on PCL force (also referred to as the "pressure feedback loop"). It has been necessary in past simulations to "repatch" the analog computer, thus sacrificing some capabilities in order to simulate different characteristics.



Analog pilot control loader system

Now… The Hybrid System

This system uses a PC to interface with the Applied Dynamics Inc. Real Time Computer. A virtual instrument panel has been created using Altia FacePlate. This panel will be discussed in more detail later, but suffice it to say that this interface allows for setting all characteristics either locally (from the instrument panel) or externally (from the host computer). It also provides for readouts of all feedbacks and inputs (such as force command). When the instrument panel has been set to "External," the host computer controls all PCL parameters and interfaces to the ADI RTS via a SCRAMNet system. The McFadden Analog Controller is still required as the ADI RTS system isn't fast enough for closing the pressure feedback loop.



Hybrid pilot control loader system

Axis Control

The PC instrument panel, as illustrated in page 8, can provide control over a 4 axis PCL system and seat shaker. There are five columns of display, one each for roll, pitch, yaw, lift, and seat shaker. Each axis column has two columns of parameters. The column on the left shows parameters that can be entered from the instrument panel and the column on the right shows the parameter values sent by the host computer.

Parameter Control

PCL characteristics that can be controlled from either the instrument panel (see page 8) or the host computer are listed in the table below:

Force Limit	The upper force limit on the Force Command to the McFadden analog controller.
Damping	This is damping factor. A small amount of negative damping factor is allowed if compensation for the natural damping in the pilot control is needed.
Force Breakout	The force required to move the control from center.
Force Breakout Gradient	The force gradient for force breakout with an upper limit of 300 lbs/in. Force breakout occurs at the position trim position.

Parameters controlled from the instrument panel or host computer

Friction (Hysteresis)	The force required to keep moving the pilot control regardless of velocity or position. This is also referred to as hysteresis. Friction force applies outside of deadzone.
Stiction	The force required to initially move the control regardless of position, stiction is independent of the friction force and applies outside of deadzone.
Deadzone	The equivalent of mechanical free-play or deadband.
Deadzone Friction	The friction force that applies only to the deadzone region.
Deadzone Stiction	The stiction force that applies only to the deadzone region and is independent of the deadzone friction force.
Position + Stop	An electrical stop that applies only to the plus travel direction.
Position - Stop	An electrical stop that applies only to the minus travel direction.
Position Stop Gradient	The force gradient for the electrical stops with an upper limit of 300 lbs/in.
Position Trim	The centering position for the pilot control.
External Force	A force that is the equivalent to a pilot force.
11-Segment Force Gradient	A non-linear piece-wise approximation force gradient that uses 5 segments each in the plus and minus directions. An initial gradient is used for linear gradient applications. Gradients can be set up to 300 lbs/in.

Some of the parameters listed above are new, such as the 11-segment force gradient, stiction, and deadzone stiction.

What We Gained

It is not necessary to discuss all of the above parameters as most of them are well known and used in most pilot control loader simulations. However, friction and stiction stand out in this new program. For example, the new friction circuit is unconditionally stable. Implementing the analog friction circuit (which has been around since the 1960s) wasn't practical because of the small frame time requirements. The loop gain used in the analog circuit requires, at least, a digital program frame time of 20 microseconds. While it is possible to implement a digital integration algorithm that would be stable while using larger frame times, there are still undesirable side effects. All these problems are eliminated by avoiding integration algorithms. The resulting circuit also allowed creating a stiction circuit. The friction and stiction parameters are independent so that it would be possible, for example, to set in a value for stiction and zero for friction or any combination thereof. The same is true for the deadzone friction and stiction.

The 11-segment force gradient, using a piece-wise linear approximation circuit, is also available. Piece-wise linear approximations are nothing new. Analog computers have used DFGs (Diode Function Generators) with their bias and gain potentiometers from almost day one to simulate piece-wise linear approximations functions. However, all DFGs were time-consuming to set up and difficult to change. Changing a gain pot, for example, would affect all the gains or slopes that were normally set after that. The EAI 8800 analog computer provided a step up with their card-punched DFGs, but changes were still time-consuming. DFGs were not practical in an environment where it's necessary to move from one simulation to the next very quickly or make changes during a simulation. The new 11-segment force gradient uses a piece-wise linear approximation circuit that allows setting all breakpoints and gradients independent of each other. Changing the initial gradient, for example, will not affect the other gradients or breakpoints.

The PCL parameters that can be controlled from only the instrument panel (see page 8) include:

Parameters controlled from the instrument panel only

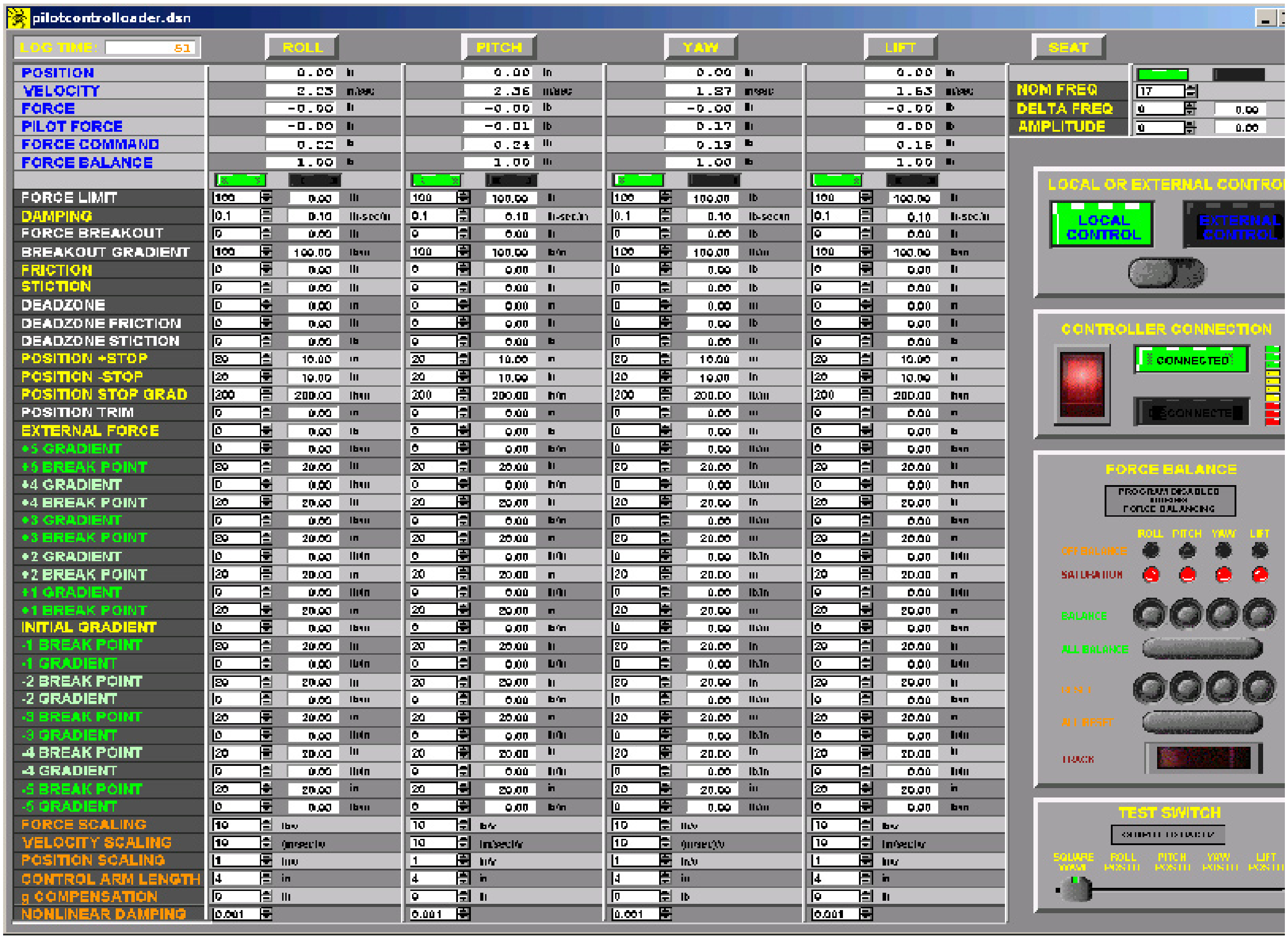
Force Scaling	A force scale factor that can be set from 5 to 20 lbs/volt.
Velocity Scaling	A force scale factor that can be set from 5 to 20 lbs/volt.
Position Scaling	A position scale factor that can be set from 1 to 2 in/volt.
Control Arm Length	The distance from the control axis pivot to the pilot grip point.
g Compensation	A force term used to scale the g compensation circuit for gravity nulling.
Non-Linear Damping	A damping term used only in the non-linear circuits. This is equivalent to the "tach cross-over" that is found in the McFadden analog controllers. When this setting is used, the McFadden tachometer cross-over circuit can be removed.

Scale factor (i.e. force, velocity, and position scaling) selection is included in the Simulink program so that it isn't necessary to rescale the DACs and ADCs each time a different pilot control is used (which would require recompiling). The scale factors used for the 2-axis hand controller are different than the scale factors used for the wheel and column or fighter stick. The scale factors are only set from the instrument panel and are not affected by the Local or External Control switch. Being able to change scale factors so conveniently allows the user to assign an axis to a different application. For example, the yaw and lift axis could be assigned to operate two sets of rudder pedals by simply setting in the scales factors for rudder pedals in both axes.

The gravity compensation (g compensation) is also not new to the simulation world but has not been used extensively in the past because of component limits on the analog computers. It is easy to implement such a circuit using Simulink and therefore has become a permanent part of the new program. This circuit compensates for the weight of the control, which can be quite significant in a wheel and column. It does not compensate for cab motion effects, but it is used to create a pilot force readout minus the gravity effect on the pilot control.

Instrument Panel Features

ADI's ADvantage real-time simulation framework enables user interfaces to be created and customized using Altia panels. The PLC Altia panel is shown below:



The following additional features are provided by the PCL Instrument panel:

Soft Turn On	One of the unique features of the Simulink program is the Soft Turn On program. The purpose of this program is to protect the pilot from transients while the Simulink program is being connected to the analog controller. By clicking on the Controller Connection switch, the Soft Turn On program brings full connection in 10 seconds. This is indicated by a vertical LED sequence bar indicator to the right of the Controller Connection button. Once full connection is made, a green LED bar indicator will light to indicate that the connection is complete.

Additional features provided by the instrument panel

Switch selectable between Local Control and External Control	A Local or External Control switch selects whether control is via the instrument panel (local) or via the host computer (external). An LED bar in each axis column shows which column of parameters is selected. A green LED bar is used for local parameters and a orange LED bar is used for host computer parameters. When the Local or External Control switch is clicked, control will toggle to the other connection (in this example, external) while the Simulink program is immediately disconnected and then restarted with the Soft Turn On program.
Readout of all inputs	All inputs for each axis, whether local or host computer, are on display.
Readout of all feedbacks	All feedbacks for each axis are on display. This includes position, velocity, total force, and pilot force.
Readout of all force commands	All force commands for each axis are on display. Force command is the Simulink program's computed force command that is sent to the McFadden analog controller.
Pushbutton force balancing	Pushbutton force balancing is another unique feature of this program. Initial force balancing is done on the McFadden analog controller and then from the instrument panel. A red LED indicator on the Force Balance panel will indicate when the force balance is more than ±0.02 lbs off. When a force balance is desired, simply pushing the axis button on the Force Balance panel will cause the program to temporarily disconnect while a force balance circuit takes control. The axis button will be backlit green while balancing is occurring. This takes 10 seconds and then the program is returned to normal operation in 2 seconds. All axis can be balanced simultaneous by selecting the All Balance button. The actual force offset is displayed in the readout section at the top of each axis column. Custom low drift pressure transducers and hydraulic oil temperature control has virtually eliminated force drift problems on the VMS PCLs. Of course, force balancing should only be performed when the simulation cab is level and the pilot has hands off the controls. The force balance circuits can be reset to zero by selecting the Reset button for each axis or by selecting the All Reset button for all axes if it is necessary, for example, to rebalance the PCL at the McFadden analog controller.

Additional features provided by the instrument panel cont.

Test Switch output	The Test Switch control at the bottom right of the instrument panel can be set to provide either a square wave output or a Simulink program position feedback signal for each axis on DAC 07. This allows for frame time checking or using the program position signal to cross plot against the force command for each axis. In this manner, frame time delay is avoided during cross plotting on an oscilloscope. For example, if the ADCs and DACs of the ADI RTS computer are sent to breakout boxes, a function generator (typically set to 10 Hz saw tooth) can be used to drive the ADCs for the position inputs for each axis. The selected axis position output on DAC 07 can be cross plotted against the force command for that axis on an oscilloscope to give a good confidence check on the operation of the program. Then the same setup, with the function generator set at a much lower frequency, can be used to create cross plots on a XY plotter. In short, stand-alone test capability was built into the Simulink program.

Special Features of the Program

The following special features are provided by the Simulink program:

- Rate control on all parameter inputs
- Minimum and maximum limits on all parameter inputs

All parameter inputs, whether from the instrument panel or from the host computer, have rate control limits. This allows for changing parameters during operation without triggering the safety circuits in the McFadden Analog Controller. The safety circuits are sensitive to large accelerations that step changes in parameter inputs could initiate. The rate limits are set high enough to make the input changes appear instant to the pilot but are also low enough to prevent safety circuit tripping. Dynamic changes can be made during PCL operation without having to build rate limit software in the host computer, as is currently the practice with the analog computer system.

There are also minimum and maximum limits on all inputs so that it is not possible to introduce inputs that are outside the range of operation for the Simulink program.

Advancements in Progress

True Pilot Force

A prototype circuit has been developed that gives the actual pilot force or the actual force at the grip handle. This circuit removes the gravity and cab motion effects to provide a true output of any force applied to the PCL grip. A demonstration circuit has been set up on the pitch axis of a wheel and column PCL.

Advancements in progress

New Analog Controller

A completely new analog controller has been designed that replaces the current McFadden analog controller. Each axis is reduced from 2 boards to a single board. A single chassis will contain 6 boards. Reference voltages are generated on each single board so that the boards may be moved between chassis without having to recalibrate. Much more versatility has been built into this new design, including more flexibility in checkout and frequency "tuning." The tuning circuits (phase lead and notch filter circuits) are moved to the forward loop to eliminate coupling with position and velocity feedback. A new bias and scaling circuit is used that only requires adjusting the bias and scale potentiometers once, not toggling between the two until both the bias and scaling are correct. At the same time, all scale and bias circuits have been desensitized so that adjustments aren't so touchy. A notch filter is included in the force feedback to remove the dither signal before the force signal is sent to the host computer. A new abort circuit eliminates the transients when returning to normal operation.

New Cab Control Panel

The cab control has been redesigned to provide a single button turn on. This button is simply held on until the controls are fully connected. During this time, the hydraulic pressure is brought up to full pressure and the abort circuits are allowed to clear. An indicator will light "System Ready" when the system is fully operational and the button can be released. Releasing the button before then will shut the system down, which includes shutting off the hydraulic pressure and forcing each axis into abort mode. An abort command from the analog controller will also cause the same effect.

New Status Panel

A display panel has been designed that is mounted in the same chassis rack as the new controller. The display shows the status of each axis and the cab control panel. It also displays which axis triggers an abort event.

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