# Project Number: 12241

## MOOG FLIGHT SIMULATOR – COCKPIT ASSEMBLY

| **Victor Calamaro**<br>Mechanical Engineer - Team Leader | **Nicholas Flanagan**<br>Mechanical Engineer - Team Member |
| --- | --- |
| **Rashaud Harvey**<br>Mechanical Engineer - Team Member | **Danielle Painter**<br>Mechanical Engineer - Team Member |
| **Michael Zona**<br>Faculty Guide | **Dr. Jason Kolodziej**<br>Faculty Champion |

**ABSTRACT**

MOOG wants to prove to potential customers that they can provide all components needed for "stick-to-tail" flight control capabilities. This is proven through a nonlinear six degree of freedom (6-DOF) aircraft simulation with multiple uses ranging from desktop, non-real-time engineering applications to real-time piloted simulation activities. The nonlinear simulation can be used for engineering analysis of flight control system failure modes to the implementation of a closed loop Ironbird simulation. A closed loop Ironbird simulation can include a cockpit with inceptors, visual displays, the flight control system with flight control computers that host the customer supplied control laws, the hydraulic or electro-hydraulic actuation system and the customer supplied aerodynamic model. The cockpit assembly team is responsible for all the work that needs to be done within the cockpit. Tasks include instrumenting the flight inceptors for the throttle, rudder pedals, & yolk, and mounting screens to display the gages virtually. Results were obtained through testing that concludes our product does indeed function as expected. The spring system provides the correct feedback that one pilot would expect to feel when controlling an actual airplane. The LVDTs generate a reading when either the throttle, yolk, or rudder pedals are being used. The display panel produces an image of the gages which are supplied through the flight simulation program.

**NOMENCLATURE**

LVDT: Linear Variable Displacement Transducer
"Stick-to-Tail" Capabilities: The capability for MOOG to provide everything required to instrument an aircraft from the pilots interaction (i.e. stick) to the movement of the flight surfaces (i.e. tail) and everything in between.

**INTRODUCTION**

MOOG would like to demonstrate to their customers that their system could produce "stick-to-tail" control capabilities. The project, which is a family of projects, was to design, build, and test a cockpit assembly system for application in a nonlinear closed loop aircraft simulation which provides the ability to predict an aircraft's flight path from time zero to time n based on pilot inputs and external disturbances. MOOG supplied a real plane cockpit to create the simulator. As the cockpit assembly team, our responsibility was all the work that needed to be done within the cockpit. We instrumented the yolk, throttle, and rudder pedals with a feedback system that allows the pilot to feel as if they were controlling a real airplane. We also designed a display panel equipped with two LCD screens to display virtual gages to the pilots. These gages included the altimeter, attitude indicator, airspeed

indicator, heading indicator, vertical speed indicator, and radio magnetic indicator.  Sound was included to provide a more realistic environment for the pilots.

## PROCESS

One of our team's responsibilities was to replace the existing dashboard and instrumentation with a new dashboard assembly that would house 2 monitors for display of the performance and navigation gauges to provide feedback to the operators of the simulation.

We discussed several options for the types of displays, the design of the dashboard and the methods for mounting and installation.  The design of the dash was based off of the monitors that were selected for the project. Through concept generation and functional decomposition, our team decided to purchase two Plye 15 inch, in wall mount, LCD, flat panel monitors with VGA and RCA input.  The monitors came preinstalled in a steel casing that had side flanges for mounting purposes.  Using Solid Works 3D modeling software, our team designed a prototype dashboard assembly that was compatible with the monitor casings.  The final design was generated through reverse engineering tactics.

Our challenge was to design and fabricate a new dash assembly that would fit perfectly in place and hold the monitors securely. We decided that the best way to ensure proper fit and location was to trace the outer geometry of the original front panel onto the new one; doing this also resulted in proper alignment of the plastic covering that went on top.  Two rectangular cutouts [15.35" x 11.81"] were located 5 inches from the left and right edges of the dash for the monitor casings to slide right in and be centered in front of each pilot. Our design is shown in Figure 1.
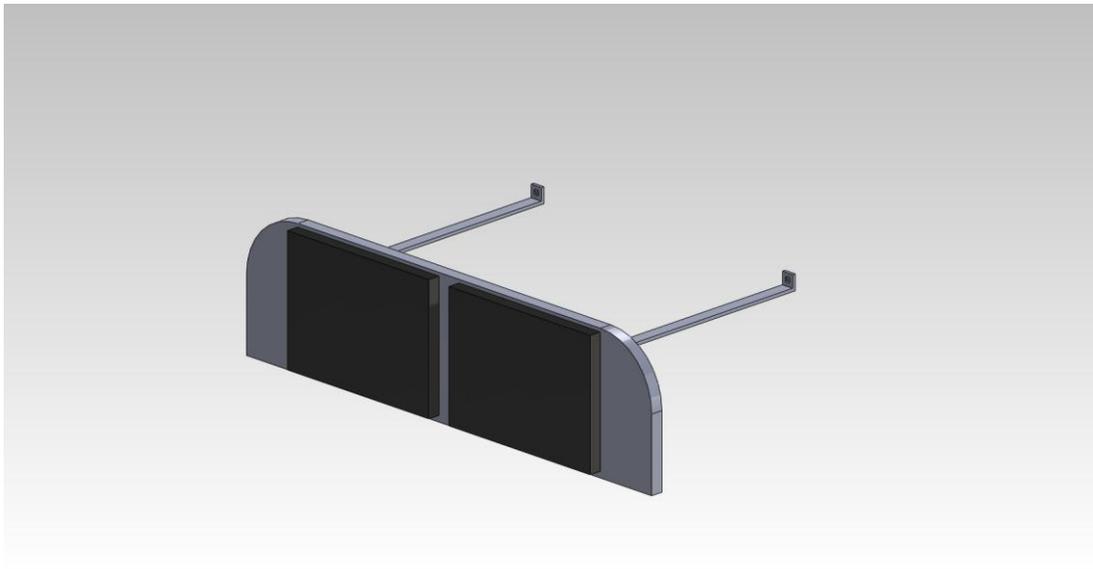


*Figure 1: Dash Design*

Given the nature of our task (having to fit the dash assembly to an already existing cockpit structure), a good portion of the design and fabrication was guess and check, and they took place simultaneously.  During this process, a series of brackets were conceptualized and machined to mount the face plate to the inner structure of the cockpit.  Three were placed along the bottom edge (connecting to the lower half of the existing dashboard), one on each side (connecting to the inner walls of the cockpit) and one at the top attached to a bracing rod that connected to the inner firewall of the nose.

All fabrication took place within the RIT engineering machine shop and each member of the team contributed to the machining processes for the components of the dash assembly.  Victor used a jig saw to form the outer contour of the face plate, and a mill to remove material for the rectangular cut outs designed for the monitors. Rashaud and I used the sheet metal sheer and the angle bender to cut and form the brackets, and Danielle drilled the holes for mounting and assembly.  All components were made from a 0.09" thick, multipurpose 6061 Aluminum alloy and fastened together with 10-24 machine screws.

At the onset of our project, we had a few ideas about how to measure the position of the flight controls. Some decisions that we had to make included whether measuring rotational motion or linear motion would be better for each flight control system (yoke, rudder, and throttle).

Mounting locations also had to be decided on.  To make these decisions we used a Pugh matrix that weighed cost, durability, accuracy, ease of installation and ease of maintenance.  We ultimately decided to use

LVDTs that measured the linear motion of the controls.  This decision was made because the LVDTs were the most accurate and was supplied by MOOG, so they did not cost anything.  They also allowed MOOG to easily source future sensors in the event of a failure or malfunction.  The linear motion was chosen because it allowed for the same mounting location for all of the controls as well as relatively easy access to all of the sensors (underneath the center console).

The LVDTs needed to be mounted securely in order to provide an accurate and consistent position signal to the software for the simulator.  First step in designing the brackets was brainstorming together as a group for possible mounting solutions and select the best idea.

We then designed the brackets with a CAD program, SolidWorks, and created an assembly that provided the viewer with a visual for our solution.  During the detailed design review, we presented this idea to our customer.  They provided us with some minor critiques and suggestions.  We took those suggestions and applied them to our design and then went ahead with construction.  Our final design is shown in Figure 2. Multipurpose aluminum was used to construct brackets to mount the LVDTs to the airplane cockpit.  The brackets were fastened with a nut and bolt and the LVDTs were affixed to the brackets with bolts and hose clamps.  The hose clamps were used to keep the round body of the LVDT from spinning and the bolt was placed on the end to keep the LVDT from displacing in the direction of the cable motion.  After the brackets were constructed and the LVDTs were connected to the cables securely, we tested them to make sure they were working properly.  Our test procedure was simple; we moved all of the flight controls and checked to make sure the LVDTs output a signal through the full range of motion.
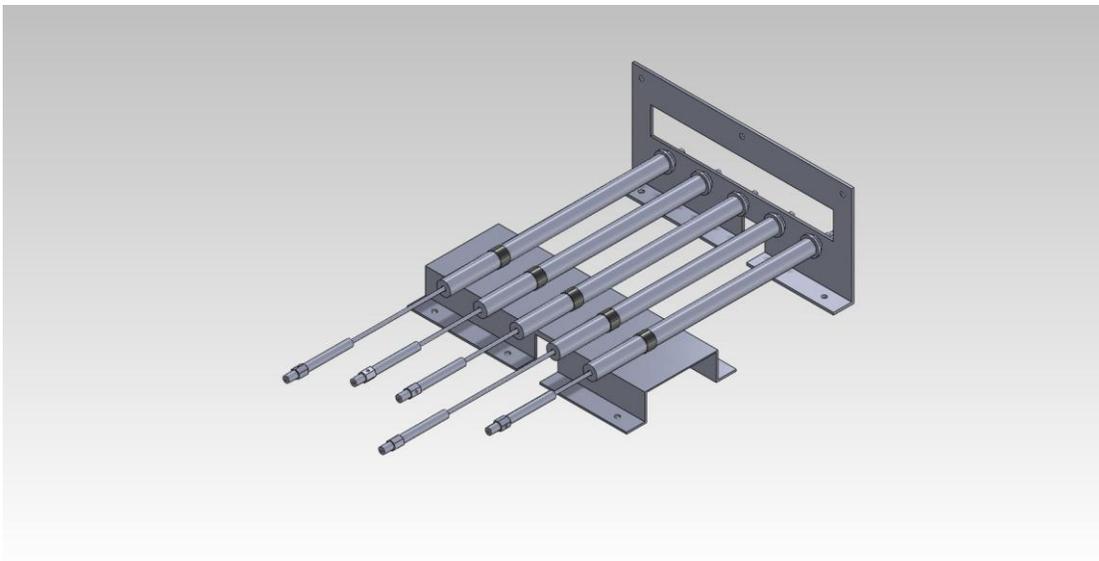


*Figure 2: LVDT Mounting Design*

The purpose of the feedback system was to provide realistic feel for the user operating the flight controls for the simulator.  After discussing methods for mounting the springs, our team decided to fasten them to the rear of the cockpit, using eye bolts.  These provided resistance on the flight controls for the operator.  Bolt holes were drilled into the rear near the attachment point of the wing and were aligned with the LVDT placement.  The springs were hooked onto the cables connected to the flight controls by cable clamps.  When adjustment of the cables and clamps was impractical, the position of the nuts and eye-bolts were adjusted to provide constant tension in the cables controlling the rudder and yolk.

## RESULTS AND DISCUSSION

The final result of the dash board assembly turned out very nice.  The assembly had a snug fit and was very sturdy once fastened to the frame of the cockpit.  The design allowed for the wiring to run under the dash and out of sight of the user.  Lastly, to maintain visual aesthetics and quality, we spray painted the fixture black to match the color of the plastic covering, monitor casings and lower dash structure.  This is shown in figure 3.
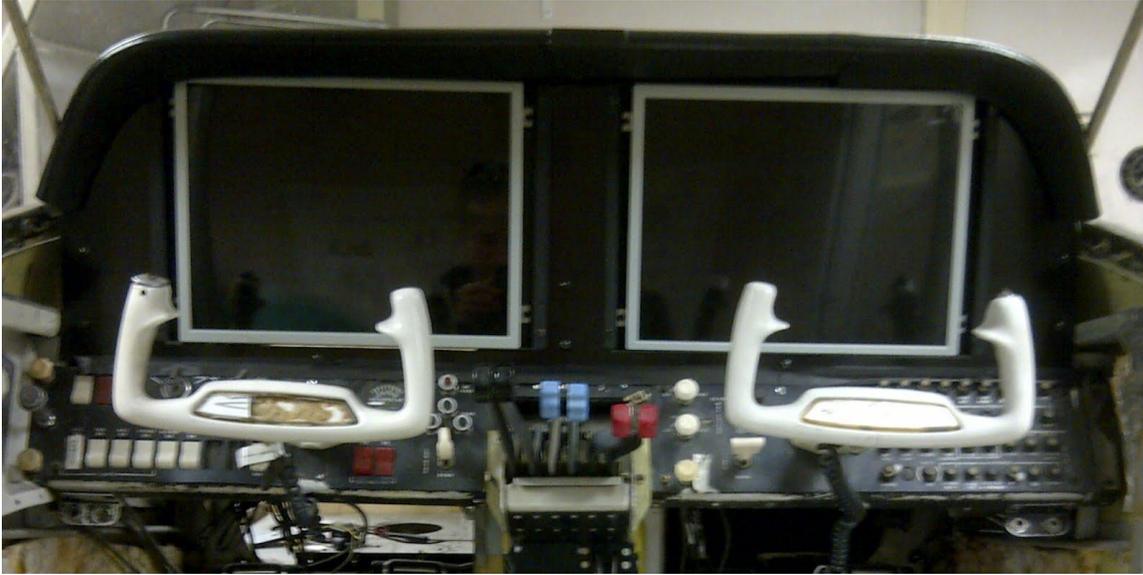


*Figure 3: Display Panel*

The LVDTs were mounted as shown in Figure 2.  An upright plate was used in the front to provide a means to stop the LVDTs from displacing in the line of motion.  A cutout was made in the plate to allow the cables from the flight controls to pass through without any interference. The other mounting point was on the horizontal plate. This plate utilizes hose clamps to connect to the round bodies of LVDTs and keep them from spinning. These plates firmly connected the LVDTs to the aircraft. The cables from the flight controls also needed to be connected to the LVDTs. This is shown in Figure 4.



*Figure 4: LVDT Connection System*

The large block screwed onto the end of the LVDT rod to provide a secure connection and the cables were wedged in between the notch in the block and the large washer.  The washer was tightened to ensure that no slipping occurred.  This ensured that the LVDT could move freely and would not impact the use of the flight controls in any way.  When the LVDTs were tested, they provided a clear and consistent signal, so our design worked as planned!

**Project P12241**

The success of the feedback system was best determined by the reliability and "feel" of the controls. For this we consulted Dr. Crassidis who was more familiar with active plane control surfaces. Proper operation also required constant tension in the controls of the feedback system during operation. The resistance provided to each cable was adjusted to ensure the rudder pedals and yolk would return to a neutral position when force is no longer applied by the user.

The feedback for the flight controls was provided by springs mounted to the back of the cockpit; this is shown in Figure 5. Larger trampoline springs were used for the rudder pedals since they are controlled with the operator's feet and smaller hobby horse springs were used on the yoke. No springs were used on the throttle.



*Figure 5: Spring Feedback System*

## CONCLUSIONS AND RECOMMENDATIONS

Overall, our project was a success. As our team went through the process of designing, planning, construction, and testing of this project we learned quite a lot. First of all, we learned a lot about each other. We learned the strengths and weaknesses of each team member. This allowed us to complete our work more efficiently. We also learned what our other team members enjoyed to do and what they did not. This was important for keeping everyone performing optimally. A happy team member does good work. Secondly, we learned a lot about the design process. When we actually constructed our design, it taught us how better to design components that actually need to be built. We also learned how space constraints affect your design. Implementing our design in the limited space given was very challenging. Third, we learned about the fabrication process. The fabrication of our design ended up taking longer than we anticipated. This lead to some scrambling in the last few weeks of the quarter but luckily we had planned for a cushion for just such an occurrence and we were still able to finish our project on time.

Looking back on our project, there were some things we may have done differently. We would have explored alternate mounting possibilities for the LVDTs. The mounting location chosen is definitely claustrophobic and lead to some major problems during the installation process. If this were an industry project with a longer time table, a fabricated box on the back of the cockpit to house everything would have been ideal. This would have given us all the space we could have needed and would allow for a more polished looking product. But, since our project will be covered up, looks don't matter much.

Our recommendations to other senior design teams would be to try to construct a prototype of your design as soon as possible. Even if it is just made out of cardboard, this allows you to get a much better sense of what you are actually working with. Also, when constructing a plan you should plan for delays. Try to identify the parts of your project that are most likely to cause delays and plan for them.

## ACKNOWLEDGMENTS

Dr. Agamemnon Crassidis [RIT Professor in Mechanical Engineering]: Professor with great background in flight simulators to get insight to narrowing concepts.
Dr. Mark Kempski [RIT Professor in Mechanical Engineering]: Professor with great background in wiring controls.
Michael Zona [Faculty Guide]: Guide who gave us great insight from the industry side.

# Requirements and Advice

## Construct an outline
A proper outline is the framework upon which a good paper is readily written.  In the process of making the outline, ideas are classified and thoughts are ordered into a logical sequence that is readily transformed into complete sentences.  In outline form, the sequence of the various items and the progression of thought can easily be adjusted and readjusted until the desired order is obtained.

## Length
**Your paper should not exceed 8 printed pages, all inclusive!**

**Style**. The chief purpose of the paper is to convey information to others, many of whom may be less familiar with the general subject than the author.  Care should be taken, therefore, to use simple terms and expressions and to make statements as concise as possible. If highly technical terms or phraseology are necessary, they should be adequately explained and defined. The use of the first person and reference to individuals should be made in a manner that avoids personal bias.  Company names should be mentioned only in the acknowledgments.

Papers should be concise. Long quotations should be avoided by referring to sources. Illustrations and tables are desirable but they should be kept to a reasonable level, especially considering the 8-page maximum length. Detailed drawings, lengthy test data and calculations, and photographs that may be interesting but which are not integral to the understanding of the subject, should be omitted.  Equations should be kept to a reasonable level.

## Originality
Only original contributions are accepted for publication. Under certain circumstances, reviews, collations, or analyses of information previously published may be acceptable.

## Accuracy
All technical, scientific, and mathematical information contained in the paper should be carefully checked.  SI units of measurement should be used. When U.S. customary units are given preference, the SI equivalent should be provided in parentheses or in a supplementary table.  Similarly, when preference is given to SI units, the U.S. customary units should be provided in parentheses or in a supplementary table.

## Headings
Headings and subheadings should appear throughout the paper to divide the subject matter into logical parts. Headings assist the reader in following your thought process and in forming a mental picture of the points of chief importance.

## Tabulations/Enumerations
It is often advantageous to put related items in tabular or enumerative form, one after the other, rather than simply running them into the text. This arrangement, in addition to emphasizing the items, creates a graphic impression that aids the reader in accessing the information.  It is customary to identify the individual items as (1), (2), (3), etc., or as (a), (b), (c), etc. Although inclusion of such elements makes the text livelier, care should be taken not to use this scheme too frequently, as it can make the reading choppy.

## Mathematics
Equations should be numbered consecutively beginning with (1) and including any appendices. The number should be enclosed in parentheses and placed on the right-hand-side of the equation. It is this number that should be referenced  within the text.  An example is shown below in Eq. (1).

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

Formulas and equations should be created to clearly distinguish capital letters from lowercase letters. Care should be taken to avoid confusion between the lowercase "l"(el) and the numeral one, or between zero and the lowercase "o." All subscripts, superscripts, Greek letters, and other symbols should be clearly indicated.

In all mathematical expressions and analyses, any symbols (and the units in which they are measured) not previously defined in nomenclature should be explained. If the paper is highly mathematical in nature, it may be advisable to develop equations and formulas in appendices rather than in the body of the paper.

## Figures

All figures (graphs, line drawings, photographs, etc.) should be numbered consecutively and have a caption consisting of the figure number and a brief title or description. The caption should be centered under the figure, using style "Figure Caption" This number should be used when referring to the figure in text. Figures should be referenced within the text as "Fig. 1." When a reference begins a sentence the abbreviation "Fig." should be spelled out (e.g., "Figure 1"). You may use single column figures or, if needed, the figure may span both columns.

Figures should be embedded electronically into your paper. Be sure to include the actual figure and not a link to another file. We will produce your paper from the electronic format that you provide. All photographs should be submitted as good quality jpeg or tiff files embedded in the Word file.

## Tables

All tables should be numbered consecutively and have a caption consisting of the table number and a brief title. The caption should be centered above the table, using style "Table Caption". The table number should be used when referring to the table in text.

Tables may be inserted as part of the text, or included on a separate page immediately following or as close as possible to its first reference, with the exception tables included in an appendix.

## Format

Papers must be submitted in Microsoft Word format. Your paper will be printed and prepared directly from your electronic media. Do not assume that any additional layout work will be performed, although we do reserve the right to make layout changes and editorial changes as needed to meet the publication turn-around time.

Check all page headings to be sure that dates and paper numbers are current. Also:
- Math expressions must be created using the Equation Editor supplied with Microsoft Word. Otherwise, the integrity of these special characters will be lost.
- All graphics should be embedded in the text file. Make sure the image is INCLUDED in the paper – not hyperlinked to a separate file.
- All Tables must be created using the Table utility provided with Microsoft Word. Tables created by use of the tab keys will not convert properly.
- No styling is necessary. However, inclusion of italics and roman script is necessary to indicate math and other special characters.
- Label the electronic file clearly as "*Pxxxxx project name*" and submit it to the program office.

## Copyright

The copyright statement at the bottom of the first page allows RIT (the MSD program) to print your paper and make it available electronically. The authors maintain the right to submit the paper for publication elsewhere. You will be asked to sign an "offer of a technical paper" document which grants RIT rights under Copyright law. If this document is not signed, your technical paper cannot be published.