Prototipo de palanca de gases para simulación aérea
(throttle prototype development)

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Summary
In the market there are a lot of throttles for simulation use with deficiencies in some aspects like non smooth axis and bad flight detents, the objective is to design and build the Throttle I always wanted to have.

With improved performance and characteristics of existing ones.

For that, it will be developed 6 systems:
- Stand→solid base for all the components.
- Axis→allow smooth rotation.
- Friction regulation→user can regulate the force needed to rotate the axis.
- Flight detents→ throttle has some fixed positions
- Grip→ user interface (hand)
- Position control→ system to track and transmit the axis/lever position

With the help of NX software and 3D printing, prototype will be design and manufactured, components will be tested and analysed for an optimal functionality. For a design structural optimization, using NX CAE (finite elements), a simulation model will be created and adjusted from physical test results. With that model, structural countermeasures can be analysed before any physical prototype.

1. Introducción
The throttle is a very important mechanism to control the thrust of the engines in the aviation world. From a little Cessna 172 to massive airbus 380 everyone uses it. In this project using advanced technologies like CAD modelling, simulations and 3d printing, it will cover the most of the development process for a prototype. From the initial concepts and ideas, test and experimentation to a physical prototype will be a large period of analysis, creativity and perseverance to make something from the scratch. Development methodology will be an important feature for the success of the product.
Design → test→ analyse→ resolve

2. Objectives
The purpose of this Project is to design and build a prototype of a throttle for flight simulation. As a user of flight simulators, I have observed that most throttles existing in the market have deficiencies in different aspects of their design in the axis mechanism that basically affect the precision of movement and the feeling of fluidity in the displacement and control compared to real flight professionals, other aspect to improve is the mechanism of the flight detents.

Secondary objectives are:
- Describe the control surfaces of a plane. Describes the throttle, types and functionality (real and sim). Analyse and describe the mechanicals problems that I have with other products. Connect the throttle to the computer flight sim and complete his functionality using Arduino and a potentiometer. Develop model simulation for prediction of structural behaviours of a 3D Printed component.

3. Methodology
Develop the design with the NX program. Build it with a PRUSA 3D printer. In the development process, design and construction are developed at the same level. Being necessary physical test approval to step to the next system. If the judgment of the test is negative, comprehensive analysis will be required for the adoption of a countermeasure to solve the corresponding issue.

The physical verification test will consist on: Check mechanical resistance, the correct assembly of the parts and its functionality. Systems will be judged and declared OK or NG, judgment criteria is defined by the experimentation.

The countermeasures can be of the following types: Post process measure (example file the edges), modification of 3D printing parameters such percentage of filling or detail. Or finally design / layout modifications Once the C/M is applied it will be tested and judged again. If it is declared OK, the design will advance to the next system, and then to the next until the completion of the assembly prototype.

Finally using NX CAE (finite elements), a structural simulation model will be created and adjusted from physical deformation test results. With that model structural countermeasures can be analysed before any physical prototype.

Fig. 1. Finished prototype assembly
4. Product definition

After many years involved in the aviation simulation, it was easy to define the characteristics, systems and functionality. The throttle would have the following functionalities, characteristics and properties:

1. The axis movement needs to be smooth with a fluid movement, for achieve that it will be used rolling bearings.

2. Force needed to move the throttle can be regulated via friction mechanism, user can regulate it via easy movement with one hand (user friendly).

3. Minimum throttle movement will be 90 degrees.

4. Throttle will have a flight detents mechanism with user adjustable stops and positioning.

5. Throttle will have an ergonomic grip with anti-skid surface.

6. Throttle position can be read with the more common flight simulations that will be achieve with a potentiometer linked to the lever with a gear mechanism. Potentiometer will be connected to an Arduino board; it will convert the analogue signal to digital. That will allow windows to read its position.

7. Throttle needs to be compact for use on desk table.

To achieve all these requirements, it will be developed 6 systems each one responsible to achieve each functionality (system and functionalities shown in figure 3).

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<th>Ref.</th>
<th>SYSTEM</th>
<th>FUNCTIONALITY</th>
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<td>STAND</td>
<td>Base for all the systems</td>
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<td>1.2</td>
<td>AXIS</td>
<td>Provide fluid movement to the lever</td>
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Table 1. Systems definition

5. Full assembly definition

As showed in the fig. 3 and table 1, throttle is composed by six systems, making a total assembly of 87 diferents components. Thirteen components are design, developed and manufactured inhouse with the prusa 3D printer. The rest of the components (74) are normalized (most made of steel), aquired from diferents suppliers.

For the design first I selected all the normalized components, and design the 14 inhouse so they can adapt to them. With this important rule is avoided the exasperant search of a normalized component with a rare dimensions.

6. (1.1) System Stand

The system 1.1 Stand is the base of all the other systems and components. Consist on 10 elements,only the component 111 “Body” is made in house. This element is particularly important, provides location for all the rest of the system. Initially is designed on parallel to the axis system, but it will be redesign every time the others systems need location for its components.

The body is attached to a wood plate with screws to provide a robust piece. During the develop proces, the legacy designed was affected with a high deformation on X axis, caused by the force of the shaft, that was discover on the physical test analysis. To solve that issue some structural reinforcement was added in the inferior part to improve the component stiffness, especially on the X direction.

To find and resolve issues like that on the initial digital phase, and for non waste printing time and material it was decided to develop a simulation model.
The system 1.2 Axis provides rotation movement to the lever. The system is composed by 16 components, only 5 of them are manufactured inhouse (122,128,127,1210).

The principal objective of all this system is to provide smooth movement with no interruptions. To achieve that was decided to use the rolling bearings layout recommended by SKF supplier, composed by axial and radial bearings.

This configuration will provide smooth movement even with the axial forces caused by the friction brake and the radial forces caused by the weight of the user arm.

Most of the products in the market, the movement of the lever is caused by axis lubricant.

The axis (1210) was decided to manufactured with 3D printing plastic so the tolerances were difficult to achieve.

In the physical test shaft was broked, that was caused for the stress during the assembly proces. To solve the issue the filling of the component was increased from 20% to 50%, increasing its durability and strenght.

For that reason and for a smooth result it was decided to use the radial rolling bearings NKI 15/20 [1] with a interior metal ring. Providing (metal-metal roll) and no (metal-plastic).

Axial bearing AXW20 [2] also contains rolling cage and it was selected for the same reason. When the system was physically tested also it was detected resistance rolling on the AXW20, after the analysis the conclusion was that the other side to the one with the rolling cage, was directly in contact with the not rectified plastic surface of the shaft. The countermeasures for solving the issue was to add the washer LS2035[3] also recommended for the supplier for conditions like this.

The length of the lever (128) was defined to generate an optimal momentum for best user precision but with a compact format for using in a table desk. Their bottom surface was redesigned to transmit the position to the potentiometer.

**Fig. 5. Component 111 high deformation on physical test**

**7.(1.2) System Axis**

**Fig. 6. System 1.2 Axis explosion view**

**8.(1.3) Friction regulation**

**Fig. 7 System 1.3 Friction regulation explosion view**

System 1.3 Friction regulation, provides an adjustable friction force to the shaft. The system is composed by 27 components, only 3 of them manufactured inhouse (133,139,1311).

The principal objective of this component is proportionate friction force to the shaft, for a user movement resistance.

That friction needs to be regulable with only one hand this is achieved with the (1311) brake wheel.

Most of the products in the market required a tool to adjust the required force.

The operation is easy rotating the brake wheel cause the thinening of the bolt, Presion originated by the brake (133) with the spring (135) against the shaft is liverated, so less force is required to move the lever.

If the wheel brake is rotated to the opposite direction the bolt is unthighten and that causes the increase of the presure between the brake and the shaft. More force is required to move the lever.

Bolts (138) regulate the maximum friction force of the system.

Springs (137) provide help for a uniform movement of the brake.
9.(1.4) System Flight detents

Fig. 8 System 1.4 Flight detents explosion view

System 1.4 Flight detents provides stop on the lever travel for the engine cut off and idle position. The system is composed by 23 components, only 3 of them manufactured inhouse (144, 1411, 1410).

The flight detent position can be move to every position on the lever travel thanks a guide on the component (1411).

Most of the products in the market had a fixed flight detents.

When the throttle is moved to the lower position the bolt (141) impacts to the cut off flight detent (1410) that position is idle detent. To exit from idle and enter in the cut off position it’s necessary to upper the flight detent lever and rotate the throttle to the cut off.

User can enter to the cut off position elevating the FD lever (144) to the upper position, moving the throttle to the lower position and then fitting the bolt (C141) inside the cut off flight detent (1410).

Flight detent Lever can move because of a guide consisting on a large hole (1411) and 2 bolts (141) with a little cylinder inside (142) that rotates when an upper force is applied. If no force is applied the spring return the lever to the lower position, not allowing the cut of position.

The mecanism provides a solid flight detent instead some of other products in the market. The stop is defined and not easy to escape from them with involuntary user movement.

10.(1.5) System Grip

Fig. 9 System 1.5 System 1.5 Grip explosion view

System 1.5 Grip, provides an optimal interface with the user and the lever. The system is composed by 1 component manufactured inhouse.

Grip is where the user will place his hand to move the lever, so it is required to have a good ergonomics. For that reason it is designed with and increased section from the small finger to the index.

The holes provides an anti-skid surface. Also trim on the back of the grip provides clearance for the location of the flight detent lever (144), making easy for user to pull the lever.

11.(1.6) Position control

Fig. 10 System 1.4 Flight detents explosion view

Control position system provides a way to define in which position is the lever at any time. The system is composed by 10 components, only 1 of them manufactured inhouse (167).

Position of the lever needs to be transmitted and be understood for the PC windows environment, for being used in any flight simulator on the market.

To achieve that the lever transmits their position mechanically with a mechanism of gears.

The bottom of the lever finish with a gear part. This part interacts with another gear (167) fixed on the potentiometer (166). So, the movement of the lever is transmitted to the gear(167) on the potentiometer. The position is in first step is transmitted mechanically and then transformed on a signal of voltage for the potentiometer.

As the potentiometer [5] has a rotation of 300 degrees and the lever 90 degrees, it wants to make a mechanical connection that achieve for 90 degrees of the lever 300 degrees on the potentiometer to have the maximum resolution

It uses a multiplier mechanism of gears 1=motor wheel, 2=driven wheel.

Legacy design of the gear(167) didn’t have the cilinder, only has the gear section. In physical test the vibration of the potentiometer causes the disconection of the gears.

Solution was put a cilinder to make the structure more rigid for avoiding potentiometer vibrations.
The potentiometer is fixed to the Body with a nut (C169) and a washer (168), the analogic signal of the potentiometer needs to be transformed to a digital protocol for windows work.

This protocol is (HID) (Human Interface Device), which will be driven by Microsoft between the USB device and the objective of establishing specifications that allow the development of compatible drivers with computers.

To transform the analogue signal (voltage) to a digital signal protocol (HID) is used an Arduino [4] (161) Leonardo board.

12. Development of a simulation model for the component C111

Legacy design for the Body component 111 had a big deformation on X axis (fig.5) when shaft is assembled, due to that issue a reinforcement was needed to improve stiffness specially in X direction.

To study structural behaviours, and for the application of countermeasures I decided to develop simulation model that predicts on early stages and future improvements the mechanical behaviour of particular components. That methodology can be exported to the rest of the components, to ensure quality design.

The simulations will predict the 3D printing structural behaviours (with a cell structure defined by filling parameter), with a NX CAD model (with solid sections instead cells structures).

Simulation objectives

1. Obtain the equivalent parameters for the component to develop a simulation as accurate as possible.
2. Use the simulation to understand the behaviour of the component and improve the design.

Physical Test

Test consists on apply a compression force with the sergeant tool to the component, on the X axis, simulating the force applied by the shaft, increasing the force and measuring the output distance D Test (mm).

The applied force is measured with the Force sensor via PC, an Arduino convert de analogue data of the strain gauge diode bridge to digital output (fig.11).
As seen in the fig. 3.15. If Poison ratio increases error respect test also increases, but if ratio decreases from 0.2 error also increases. Poison around 0.2 obtain the most accurate results.

![Simulation results, poison constant 0.2, Young variable](image1)

**Fig. 16 Simulation results, poison constant 0.2, Young variable**

As seen in the fig. 16. If Young moves away from 350 Mpa error increases. On 350Mpa, when more force is applied more precise is the model and less error.

![Simulation results comparison](image2)

**Fig. 17 results comparison (physical test vs simulation model)**

The most accurate model is achieved with a Young module of 350Mpa and a Poison ratio of 0.2. The results are very good with a little error basically when little force, less than 2.74Kg is applied.

This error can be from the measurements in the Physic test due a human error, sensitivity of the machine and others factors and it is negligible, in general terms, is a very accurate model.

The calculated properties of the model are not the material properties, are only variables to ensure the precision of the mathematical model, this is because the extra solid material from the NX CAD instead the real quantity of material from the 3D printed (20% cells), and the low accuracy of the mesh with Cetra 4 with a big element size of 10mm.

With the model now is possible to study the component and quantitatively with no physical object, know the behaviour, and study design modification.

**Countermeasure results**

To improve stiffness and have less deformation C/M reinforcement was applied at the bottom of the piece, now with the model without physical component can it know how is the improvement of this reinforcement.

![Countermeasure definition in component111](image3)

**Fig. 18 Countermeasure definition in component111**

The component with the C/M is average 41% more rigid than the legacy design Fig. 19.

![Stiffness comparison between legacy and counter measured component](image4)

**Fig. 19 Stiffness comparison between legacy and counter measured component**

13. **Conclusions**

The development of the throttle for simulation aviation has been a success, with improved characteristic compared to direct rivals. With the use of rolling bearings, very smooth movement is achieved compared to the most standard lubricated axis. An easy friction regulation provides the amount of force required for any user, its easy use with only one hand and no tool required, puts it one step ahead of its competitors. I selected this project because of my passion of planes world. It has been a large time of planning, study and work but it allowed me to go deeper and better understanding how a throttle works. But the most important thing is that it teaches me to how to develop a project from the scratch by my own. I applied a lot of knowledge that I learnt in the university and my professional work. It has been a large way where every issue that was appearing it was analysed and solved every time. This made me be more analytic and improved my skills and enginery knowledge. The final prototype has reached most of the objectives becoming a solid product. Analysing the product using the simulation process that I mentioned in this project we can get better version. The simulation model developed has exceeded my expectations, being very close to the real component behaviour. Now with that model, and using the same methodology, every plastic component can be analysed and improved before printing anything.
14. Agradecimientos
Quiero agradecer a mi familia todo su apoyo durante todos estos años, nunca dudando en que podría alcanzar mis metas.

A mi director de proyecto el Dr. en Ingeniería Industrial Hernan A- Gonzalez por su apoyo y guía en la realización de este proyecto.

References


