

MODELLING AND SIMULATION OF AIRCRAFT LANDING GEAR RETRACTION AND EXTENSION SYSTEM

Souza Neto, José de Barros

Instituto Tecnológico de Aeronáutica – ITA
Pça. Mal. Eduardo Gomes, 50. São José dos Campos - SP
barros_j@yahoo.com

Villani, Emília

Div. Eng. Mecânica-Aeronáutica, Instituto Tecnológico de Aeronáutica – ITA
Pça. Mal. Eduardo Gomes, 50. São José dos Campos - SP
evillani@ita.br

Goés, Luiz Carlos Sandoval

Div. Eng. Mecânica-Aeronáutica, Instituto Tecnológico de Aeronáutica – ITA
Pça. Mal. Eduardo Gomes, 50. São José dos Campos - SP
goes@ita.br

Abstract. *Dynamic simulation is becoming increasingly important for the design of aircraft systems. Simulation makes possible to determine the operational features of a system or a component before building it. As a consequence development costs are drastically reduced. The main motivation for dynamic simulation is the need of optimizing the design of aircraft and reducing development costs.. In this context this paper approaches the problem of modeling the dynamics of a landing gear extension and retraction system. For this purposes concentrate parameter simulation (1D simulation) is used in the simulation software AMESIM. The purpose of the paper is to present the method used for specifying and building the landing system model. It analyzes the advantages and disadvantages of AMESIM when comparing with other software traditionally employed in the aeronautic sector, such as the MatLab/Simulink platform.*

Keywords: *Landing system, modeling, dynamic simulation.*

1. Introduction

Dynamic simulation is becoming increasingly important for the design of aircraft systems. Simulation allows the determination of the operational features of a system or a component before building it. As a consequence development costs are drastically reduced. The advantages of simulation are innumerable. In the preliminary phase of design, it provides the means for comparing different solution. It also allows the study of the system behavior when operating in dangerous situations or extreme conditions not always possible to achieve with physical models (Taylor, 2001).

Dynamic simulation is receiving increasing attention. The main motivation for dynamic simulation is the need of optimizing the design of aircraft and reducing development costs.

One of the key issues for the successful application of dynamic simulation is the simulation software. The choice of the simulation tool restricts the features that can be incorporated into the model, the results that can be obtained and how they are manipulated. Based on the simulation results, the system under design may be modified.

In this context this paper analyses the application of the simulation tool AMESim for aircraft systems and compares it with another well established computational tool, the MatLab/Simulink platform. It uses as a case study the problem of devising a good landing gear extension and retraction subsystem model, one which could be reliably used to assist in the product development/correction/improvement process. The conclusions obtained from the landing system use case are also compared with the ones resulted from an educational experiment made with students of the Aeronautic Engineering course at the Instituto Tecnológico de Aeronáutica (ITA).

This paper is organized as follows. The next section presents a brief description of the extension and retraction subsystem, the landing gear itself as well as accessory components. Section 3 introduces the software to be used as the modeling and simulation tool, its fundamentals, main characteristics and differences from MatLab/Simulink. Section 4 describes the modeling process and presents some examples of component modeling, giving the reasons that support the modeling choices. Section 5 rounds off the work presenting conclusions and future works.

2. The Landing Gear Retraction and Extension System

The landing gear system provides ground-rolling capability to the aircraft, thus enabling take-off, landing and taxi operations. The landing gear described in this paper is a retractable tricycle type hydraulically operated. It provides the structural support and shock absorber functions for safe transmittal of landing, taxiing and ground handling loads from the wheel axles to the aircraft structure.

The main landing gear retracts sideward and inboard into the wing and fuselage. It is hinged on the wing structure and fitted with wheels, tires and a brake system. The nose landing gear retracts forward into the nose wheel compartment. The nose landing gear is equipped with wheels and tires, which can be steered, and is hinged on the fuselage structure. Each landing gear contains one retraction actuator, to retract and extend each main landing gear, downlock springs, to ensure that the landing gear is locked when in its down position, and one downlock release actuator. The downlock springs ensure that the landing gear goes to the overcentered (down and locked) position, keeping it there when the landing gear is fully extended. The landing gear unlocking from down position is performed hydraulically by the downlock release actuators. Uplock boxes maintain the landing gear in the retracted position and are operated by hydraulic actuators.

The extension and retraction subsystem is composed of a hydraulic power circuit and an electrical control circuit. The landing gear is extended and retracted in normal operation via the landing gear control lever (located in the cockpit) and electronic control modules. There are two ways of deploying the landing gears in case of emergency: either using an electrical bypass (activated by an override switch) or a mechanical release system (activated using the free fall lever). There are several valves which make up the extension and retraction subsystem's hydraulic circuit, whose primary function is to control the flow as to perform its operations as intended by the control circuit. The aircraft hydraulic system provides power to the extension and retraction of the landing gear. A schema of the hydraulic circuit is presented in Figure 1.

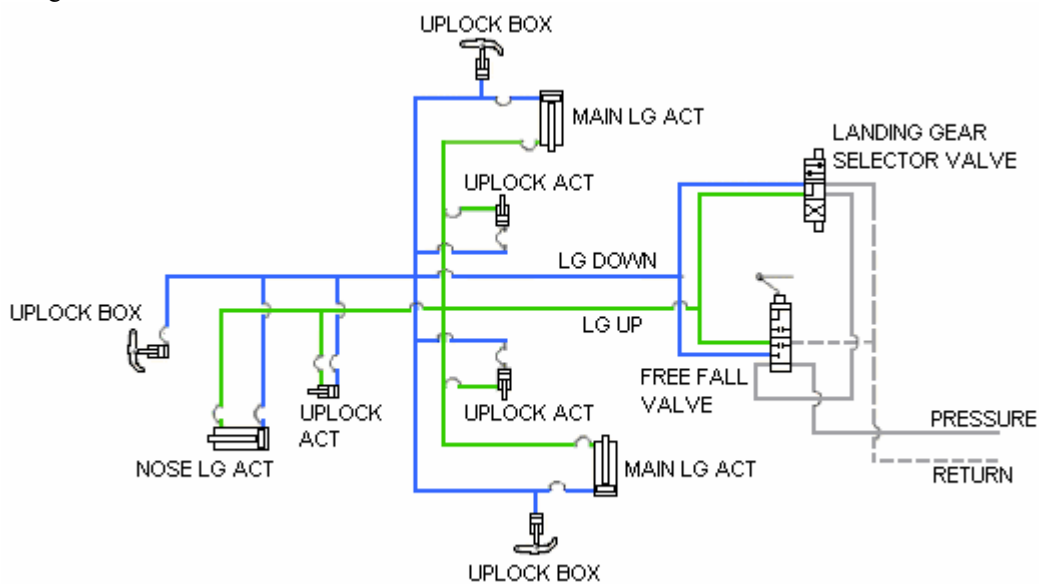


Figure 1 – Landing gear hydraulic circuit.

The extension hydraulic line is highlighted in blue (LG down line) in Figure 1, and leads to the extension chamber of the retraction actuators (the chamber opposite to the rod). Pressure coming from aircraft hydraulic system goes through the free fall selector valve (FFSV). The FFSV position is the same for normal extension and retraction. It works as a free passage for the pressure line. So the fluid goes directly to the landing gear selector valve (LGSV). For extension this valve communicates the pressure source with the hydraulic lines in blue.

During extension the downlock and retraction actuators have one of the chambers pressurized. They push for extension and pull for retraction. As the landing gear extends all retraction actuators and all uplock boxes are pressurized at the same time. The uplock box actuator has a small volume in comparison with the retraction actuator. The difference enables a very fast actuation of the uplock box, unlocking the landing gears before the retraction actuator action, which requires a bigger amount of fluid to push the landing gear for extension. The retraction hydraulic line is highlighted in green in Figure 1. The retraction side of all retraction actuators and all downlock release actuators are pressurized at same, and their joint action enables the retraction of the landing gears.

The crew commands landing gear retraction and normal extension by the landing gear control lever and emergency deployment by the free fall lever. In the case of the free fall lever, the gears will be extended by gravity and aerodynamic action, as the uplock boxes are actuated by cables mechanically attached to the free fall lever to unleash the gears.

Due to the limited space, only two components are detailed in this paper: the retraction actuator and the LGSV. Their modeling is used as testbed for analyzing the main features of the simulation tool AMESim.

The retraction actuator (Figure 2) is a double action type with internal restriction devices (snubbers). A restrictor valve and a directional restrictor valve are installed on the body of the snubbing valve. A check valve installed in the retraction port drives the outlet flow through two restrictors, whereas the inlet flow crosses the check valve nearly

unopposed. In the extension port the flow directional valve allows the outlet flow to leave unopposed, whereas the inlet flow must overcome two restrictions.

In the beginning of the extension the rod is in the retracted position. The extension port is fed with fluid coming from the LGSV. The fluid goes through two restrictors in the extension port, as the fluid trapped in the retraction chamber goes through two restrictors in the retraction port. The extension time is governed by these four restrictions. Before the piston stops, the snubbing valve installed on the retraction port starts operating, decelerating the rod and avoiding a bump. The restrictors control the retraction and extension times, while the snubbing device further reduces the rate of travel in the last portion of the stroke, delivering smooth deployments and stowages at end positions.

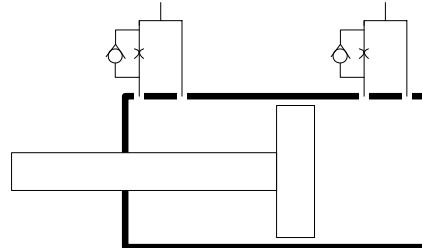


Figure 2 – Landing gear retraction actuator.

The LGSV (shown in Figure 1) is a four-way, three-position hydraulic valve, which enables extension, retraction and neutral conditions. It is fitted with two spring loaded solenoid valves, which command the spool position. It has four ports marked as follows: P – supply, R – return, LGU – landing gear up, LGD – landing gear down.

3. The simulation environment AMESIM

The AMESim (Advanced Modeling Environment for Simulation) package was developed by the French consulting company IMAGINE. It is a modeling and simulation tool tailored to model complex systems, often with a multitude and variety of parts. The software claimed to be well suited to the modeling of such systems because it allows the user to simulate without having to generate the mathematical model. The user's task is limited to generating the physical model instead. He needn't actually write and manipulate the equations; they're already embedded in the submodel chosen.

An AMESim model is composed of a set of interconnected components. The components are related to equipment, elements or physical phenomena of the system. AMESIM is based on the Bond Graph formalism (Karnopp et al, 1990). Each component has one or more ports, which are used to connect the component with other components of the system. The connection is based on the power flow: power and energy variables are used to consistently quantify the interaction among components, as illustrated for a mechanical system in Figure 3. One port is shown at which power flow is given by the product of force and velocity, $F \cdot V$, and another for which power is the product of torque and angular velocity, $T \cdot \omega$. These power-conjugate variables (i.e., those whose product yields power) along with those that would be used for electrical and hydraulic energy domains are summarized in Figure 3. Similar effort (e) and flow (f) variables can be identified for other energy domains of interest (e.g., thermal, magnetic, chemical). This basis assures energetically correct models, and provides a consistent way to connect system elements together. Behind each component an equation system models the component behavior.

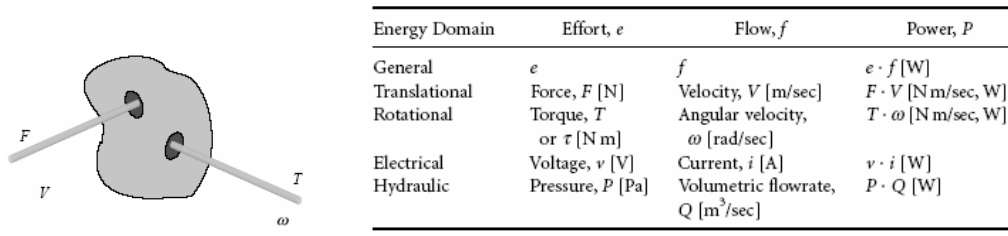


Figure 3 – Interconnection of system using power bonds.

AMESim was conceived after the multiport approach, as opposed to Matlab which utilizes the signal port approach.

In the signal port approach, a single value or an array of values are transferred from one component block to another in a single direction. This approach to simulation is basically a display of strong influences from the analog computer concept, good when the physical system behaves in the same way as the control system. However, problems arise when power is transmitted. Modeling of systems that transmit power requires exchange of information between components in both directions. In order to use a signal port approach in this situation, two connections must be made between the components where physically there is only one. It leads to a greater number of connections and means that even very

simple models involving power transmission look complex and unnatural. The excessive number of connections also gives rise to a greater probability of error.

In the multiport approach, by contrast, a connection between two components allows information to flow in both directions. This feature makes the system diagram much closer to the physical system. There are normally two physical quantities involved and the theory of power bonds provides a good theoretical background on the relationship between these quantities and the power transmitted. However, there is no limit on the number of quantities involved. There may be one quantity or three or more quantities. When there is only one quantity, the situation is the same as with signal ports. Thus signal ports can be thought of as a particular case of multiports.

The model on the right of Figure 4 employs the signal port approach: each bond communicates a single variable between components. For each power bond, two signal bonds and four ports are necessary to consistently connect the submodels of the valve, the actuator and the mass. In the signal port approach, used by software packages such as Matlab/Simulink, the user must explicitly determine all the bonds (the causality relationships) that make up the connections between the components and write down the equations for each component. Thus a low complexity model as the one depicted in Figure 4, will demand that the user explicitly define eight ports, corresponding to the four power bonds (two between valve and actuator, one between valve and reservoir and one between actuator and mass).

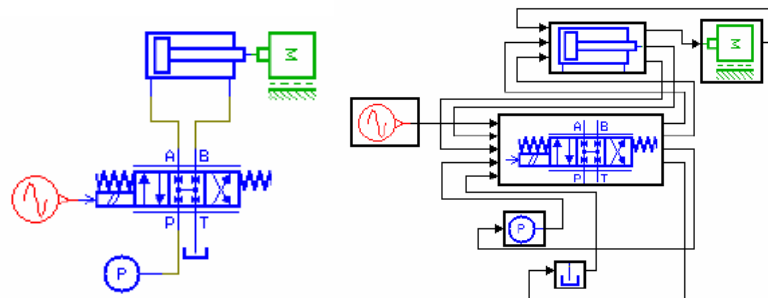


Figure 4 – The signal approach versus the multiport approach.

On the other hand, using the multiport approach, all the user has to determine are the bonds corresponding to the physical connections, and the component causality as well as the underlying equations will be automatically defined by the solver. Each component is fitted with one or more ports, each port allowing the flow of power between components, i.e., each port exchanges information both ways (in and out). The physical variables exchanged between ports have not only dimensions (as opposed to Matlab, where the variables are dimensionless) but also sense. In order to connect two ports, they must be totally compatible. There must be compatibility regarding the kind of variable as well as the sense in which these power variables flow. In other words, AMESim checks out on the coherence of the model being built beyond what is possible with Matlab.

Figure 5 is a typical example of component compatibility and incompatibility. The mass provides velocity and receives force. The spring provides force and receives velocity. These submodels inputs and outputs match, meaning that they can be connected. On the other hand, both springs provide force and have to be fed with velocity. The connection is impossible, and AMESim simply won't allow it to happen.



Figure 5 – Compatible and incompatible components.

A few additional points are worth mentioning, related to the comparison between AMESim and Matlab:

- Matlab requires deeper knowledge and physical insight to build the model. Due to the fact that the Engineer has to actually write down the equations and explicitly define each port and the causality relationships, there will probably be better understanding of the underlying physics, the phenomena that wield relevant influence and those that don't, the capabilities of the model (realms in which it returns accurate results) and ease of interpretation of the results. One will be able to assess the influence of each parameter on the simulation results. On the other hand there will be a tendency to simplify the model (because they're hard to build), perhaps mistakenly overlooking phenomena that should be accounted for.
- AMESim doesn't require the degree of knowledge that Matlab does, and complex models are easily, quickly put together and simulations run. AMESim allows the construction of complex models that would be impractical with Matlab. But the ease comes at a price, a certain loss of control: as a result there's greater difficulty in interpreting the results and no accurate idea of each parameter's influence.
- AMESim models are easy to build. The Engineer will therefore tend to build complex models with an enormous number of parameters that won't be easily or readily found. He may be tempted to accept the software defaults, without fully recognizing their influence.

- Although AMESim help documentation is supposed to convey the equations and assumptions behind the components, that information is not always available nor easily accessible.

4. Modeling of the Extension and Retraction System

The modeling process in AMESim can be organized in 4 steps:

1. Sketch: draw the model layout using the icons available from the AMESim component libraries.
2. Submodel: choose one of the submodels available for each component. Care should be exercised in matching the submodel complexity to the work at hand.
3. Parameters: enter the numerical parameters of the model. Data such as piston diameter, stroke, bulk modulus, spool diameter, leakage coefficient, friction coefficient, etc. must be collected. Depending on the complexity of the physical system and the submodels chosen this stage can be grueling.
4. Simulation: the step in which the simulation is actually run. Numbers such as simulation time, communication interval, tolerance and maximum integration step are to be determined.

In complex systems, such as the landing gear extension and retraction system, these steps are repeated many times and frequently it is necessary to return to the previous steps in order to correct the model. Moreover, in the case of hydraulic systems, the modeling process can encompass the building of new component models that are not available in the libraries, such as valves.

Another particular sensitive point for hydraulic systems is the design of the hydraulic connections. There are a number of submodels available for hydraulic lines. Each submodel has a different causality, i.e., different set of input and output variables. The lines connected to other hydraulic components have their set of available submodels limited by the connected component. According to the system design, the assignment of submodels may become impossible.

The model of the landing gear extension and retraction system is presented in Figure 6. The model developed herein focused on the extension and retraction subsystem, i.e. the hydraulics supporting the motion of the landing gear. The modeling of the landing gear structure, the mechanical hardware, the kinematics, is not included in this paper. Also, electrical components such as the landing gear control lever, weren't modeled. The emergency extension system is a complex arrangement of cables, pulleys and quadrants. These too were not included in the model unless as a force actuating the FFSV, again because the focus is on hydraulics.

In order to illustrate the modeling process, this paper details the modeling of the retraction actuator and the LGSV. The first one is modeled using a component from the Hydraulic library. The last one has no equivalent on the libraries. The model is then composed using basic elements of the Hydraulic Component Design library.

The retraction actuators are double chamber, single action, not spring loaded, linear hydraulic actuators. These characteristics lead to the obvious choice of the component depicted in Figure 6. The sub model associated with this component is HJ020, which includes pressure dynamics on both sides of the piston, viscous friction, and internal leakage between the chambers. The actual retraction actuators have four ports and are fitted with snubbing devices whose function is to render the retraction stroke faster than the extension stroke and to decelerate the piston + rod assembly when nearing the end stops. HJ020 models the end stops based on spring and damper rates. The actuator HJ020 plus OR003 (check valve and restrictor valve in parallel) account for the fact that the retraction stroke is faster than the extension stroke; the end of stroke deceleration is also taken into consideration.

The LGSV is a somewhat complex and specialized hydraulic valve and as such a readily available model unsurprisingly couldn't be found within the hydraulic and valve libraries. To work the way out of this situation it was necessary to build a customized valve using AMESim's Hydraulic Component Design library. The idea here is to replicate the physical arrangement of the LGSV, trying to be as accurate as possible. To achieve such a goal hydraulic valve building blocks were put together as it can be seen from Figure 6. Absolute motion blocks were always used, meaning that outer bodies are considered fixed. Spool blocks with annular channels are used where applicable. The solenoid valve is a standard Hydraulic Valve library component (HSV23_02), thus eliminating the need to build a new valve from the sketch. Its sole purpose is to drive the LGSV spool by means of hydraulic pressure. It is a two-position, three-way hydraulic valve. Normal position is maintained by a spring, whereas the other position is commanded by a solenoid. The component BAP16 is used to represent part of a valve where pressure and a spring force act on a spool and the body of the valve is fixed. The volume of the chamber formed by the body and the piston is computed from the displacement of the spool. This block imposes no restrictions regarding the spool displacement, but restrictions are provided by an attached submodel of the dynamics of a mass with end stops. There's no rod so the rod diameter is set to zero.

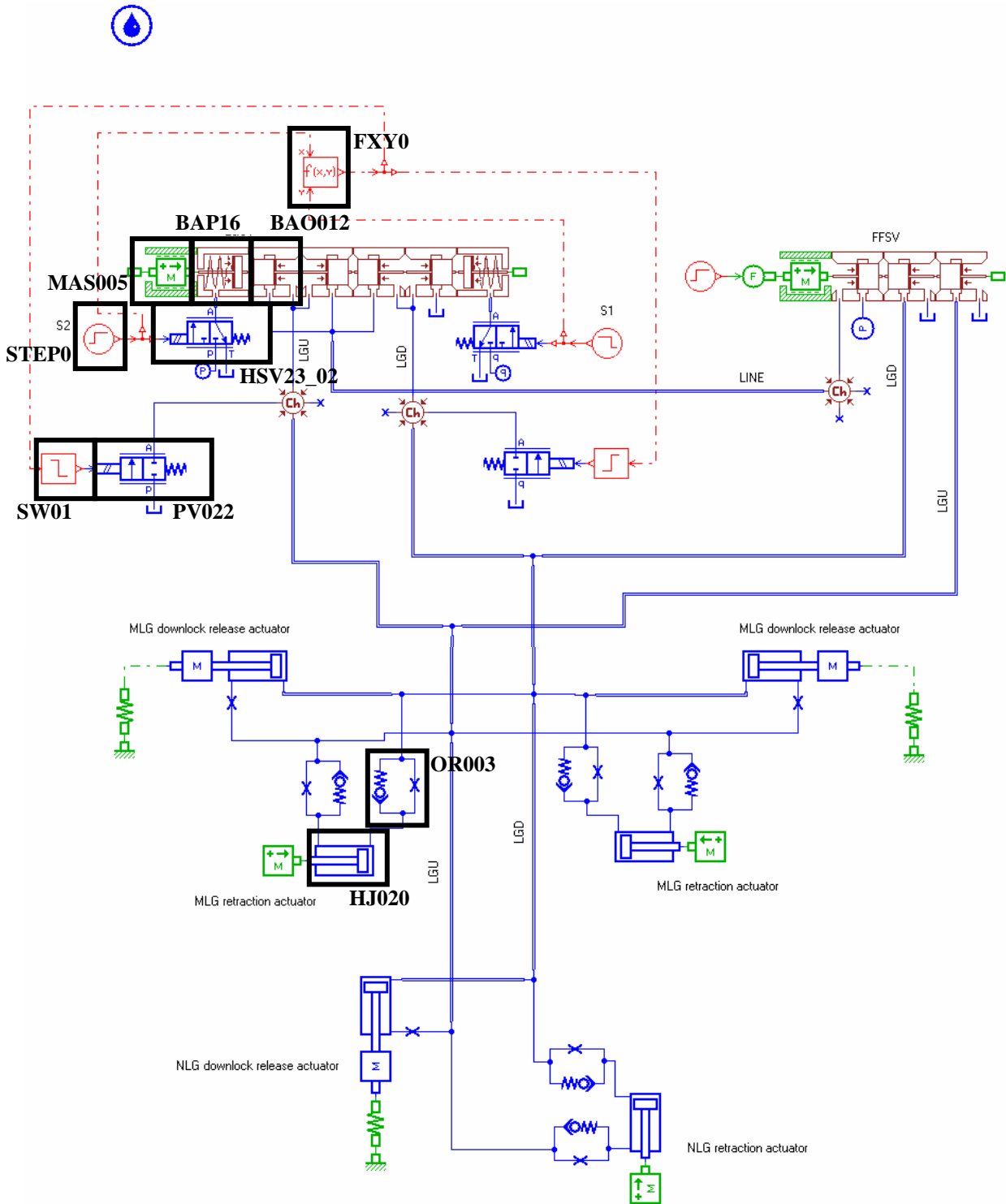


Figure 6 – Model of the landing gear extension and retraction system in AMESIM.

BAO012 represents the one-dimensional motion of an annular section valve without rounded edges and clearance between the spool and its sleeve (sharp edges). Pressure is entered for each hydraulic port and flow and volume are computed. The velocity and displacement of the spool are entered on one mechanical port and passed without modification to the other mechanical port. The net force on the spool is due to the pressure and the external forces in the mechanical ports. The displacement and velocity of the spool are supplied by the submodel attached to the left port of BAO012 (there are no restrictions on the displacement within BAO012, but restrictions may be provided by a submodel employing end stops such as an inertia submodel like MAS005). The opening is a variable related to this displacement by an offset. Sometimes it is useful to restrict the orifice area with a maximum value. This maximum area can be used to simulate the flow area adjacent to the orifice when the valve is wide open. The flow is corrected to take into account

the movement of the spool. When the valve is nearly closed, the flow is assumed to be laminar. The switch from laminar to turbulent flow is done using a continuity coefficient to avoid discontinuity between regions. The maximum orifice area is specified by the corresponding underlap position. This restriction is independent of any displacement restrictions applied by other submodels. In addition, the flow area is not allowed to exceed the annular area defined by the spool diameter and the rod.

For the solenoid valve submodel the majority of the parameters are default values, thanks to the fact that this submodel's AMESim help is quite unfriendly and incomplete. Explanations couldn't be found as to what exactly some parameters mean, leaving no choice but to rely on the software defaults.

To represent the LGSV central position, a 2 position 2 way control valve is employed. When both control signals are zero, the submodel PV022 springs into action, connecting the LGU and the LGD lines to return pressure. That's exactly what would happen to the real world valve because of the intervention of the centering springs. PV022 is a simple submodel of a 2 port 2 position proportional valve with pressure input at each hydraulic port and flow computed and output at both ports. The spool dynamics is modeled as a 2nd order system with natural frequency and damping ratio. The idea in this case is to eliminate as much as practical the dynamic effects of the valve, considering that such valve is not really present in a real aircraft system and its usage is merely a modeling artifice. Regarding the parameter values, trial and error was used to approach a step response (with step input) from the valve. The natural frequency and the damping ratio were manipulated so that such goals could be achieved. These are the only parameters which were modified, all the others being left at their defaults. The flow is modeled as in an orifice. Therefore a characteristic flow rate at maximum opening and a corresponding pressure drop have to be supplied.

Most of the valve control inputs are step functions. STEP0 is the submodel of a step rising to a user specified value at a user specified time. Submodel SW01 is employed to implement the 2-position 2-way valve logic. It generates an output that switches from high to low when the input is above a user supplied threshold. The output switches back to high when the input signal drops below the threshold. This submodel is used as a logical switch input to the 2-position 2-way valve controlling the selector valve neutral position. Its purpose is to reverse the output of a logical OR operation performed with the selector valve control inputs. The logic of the 2-position 2-way valve involves a logical OR operation, which is performed by the submodel FXY0. FXY0 applies a user supplied function to two signal inputs and the result is output on the third port.

It is important to highlight that the process of the modeling of the FFSV and LGSV has founded a number of difficulties. The first attempt was to reproduce the mechanics of an authentic valve putting together the blocks offered by AMESim's HCD library. The first valve to be modeled was the FFSV. The early ideas all gravitated around imitating the layout of the real valve: number of ports, what kind of line was attached to each port (pressure, return, service), number of internal chambers, internal channels, spool and rod details. The physical arrangement of the very first model definitely bore a close resemblance to its metal counterpart, though none of its proper workings could be reproduced. After some testing, it quickly became apparent that the valve didn't work as expected. There was the obvious need to try a different approach. At this point there was really no understanding of the how the blocks performed, only a misty notion brought up by their icons. The help documentation wasn't of much help either. A whole lot of time and testing elapsed before these building blocks discrete logic was thoroughly understood. The direction chosen was to replicate the function of the valve (its discrete logic) and then, only then, seek to replicate its physical arrangement by appropriately setting the parameters. Upon completion of the FFSV model, the time came to build the LGSV model. As one might expect, the second valve was much easier to put together than the first, after most of the necessary skills had been learned. One skill remained to be taken in, though. Unlike the free fall, the landing gear selector valve is a 3-position valve, fact that added considerable complexity to the task. To mimic the neutral position of the valve (in which both LGD and LGU lines are connected to return) took the employment of an artifice, a 2-position valve.

A lot of effort was put into obtaining an accurate model. Components and submodels were chosen so as to mimic a real system, approaching reality as much as practical. The parameters were gathered carefully (and there were plenty), from trusted sources. The great majority are from real applications, which adds up to the accuracy of the results. Numbers such as spring stiffness, restrictor valve orifice, etc, are very close to real elements. The LGSV and FFSV parameters were extracted from actual valve drawings, and the hydraulic lines lengths, diameters and materials from real hydraulic pipes routing diagrams.

After the modeling phase, the validation was organized in the following steps:

1. *Valve test*: the FFSV model was first tested isolated from the remaining system. The same approach was applied to the LGSV model.
2. *Actuation test*: actuation test is understood as the test of all the actuators, all the tubing, the nodes, snubber valves and restrictor valves, integrated. The LGSV and the FFSV were not included in the actuation test because they were already tested separately and will be tested again hooked to each other.
3. *Valve integration test*: this is the test of both Landing Gear Selector Valve and Free Fall Selector Valve hooked to each other, the way it is in real aircraft applications.

4. *Final test*: The final test is meant to encompass all the hydraulic components put together and working orderly as the Landing Gear Extension and Retraction Subsystem.

The landing gear extension and retraction subsystem model behavior as expected. Several aspects of its workings were exercised; several operational and functional tests were performed. All the components were individually tested and found to be performing accordingly.

Of course many faults and glitches were found when the model was put together. To debug the model, a fault isolation campaign was conducted. As mentioned, the components were tested individually and when found to be OK the scope of testing was expanded. The good components were attached to each other and the so-formed subsystem tested. This way, always working outwards to span more items, the testing got to the level where the whole LG extension and retraction subsystem could be tested.

The results dispensed by the model in the form of variable plots are consistent to what one would expect from a LG extension and retraction subsystem. To be reliable to the extent where it can successfully be used to develop aerospace products, any model would require some kind of validation from the test of reality and this is no exception.

4. Conclusions

This work resulted in the following conclusions about the simulation tool AMESIM:

- It is really easy to build complex model sketches with AMESim. The assignment of parameters and model debugging won't be easy, though.
- Since there are thousands of possible hydraulic component variants, all the necessary components for a given design won't always be available (that's expected for any simulation tool). If there's the need to resort to the HCD library, that will add a lot to the difficulty, even for the sketch mode, as it happened in the case of the LGSV and the FFSV.
- A certain loss of control (that doesn't feel good for aerospace applications) is likely to happen. As already talked about in Section 3, not having written the equations will not only make the simulation results harder to understand but will also make the influence of the parameters unclear.
- AMESim is a good tool for complex systems modeling, models that would be extremely difficult to implement with Matlab. But the user must bear in mind that the parameter gathering phase is indeed extensive research and that the debugging is time consuming beyond what would be expected. Some previous experience with the software is very helpful, to make up for the poor documentation and give a feeling about the more probable bugs. As with any modeling tool, for real systems some testing will be necessary to validate the model.
- AMESim can be a much better tool with better documentation. That will add greater power in understanding the workings of the components and in interpreting the simulation results. Better documentation will also save an enormous amount of debugging time. It will make the software more reliable by being more understandable.
- AMESim is great for educational purposes. It allows for quick buildup and simulation of simple systems, using the premier submodels and default parameters. It can be a source of great physical insight even for users in the industry.

Another work is the evaluation of the simulation tool by undergraduated students. Comparing the results, the following conclusion was obtained and complemented the conclusion of this work:

In (CONEM, 2005) the authors present the results of an academic project aiming at comparing MatLab/Simulink and AMESim. In this case, students of the 4th year of the ITA Aeronautics Engineering course where asked to model both on Matab/Simulink and AMESim different kinds of actuating system for aircraft control surfaces. The conclusions obtained from the academic project are similar to the ones obtained from the landing gear project. An additional conclusion is about the modeling of control systems. While Simulink model can incorporate control algorithms using blocks such as *function* and *s-function*, the same is not easily done in AMESim. So, an important point to consider when choosing the simulation tool is the complexity of the control system when comparing with the complexity of the controlled plant. Another point worth mentioning is about the resources provided by the tool for hierarchical modeling. In AMESim, hierarchical models are obtained by the definition of new submodels and components, which is a more elaborated process than the definition of subsystems in Simulink.

6. Acknowledgements

This work received financial support of the governmental agencies FAPESP, CNPq and CAPES.

7. References

- Botten, S.L., Whitley, C.R., King, A.D. "Flight Control Actuation Technology for Next-Generation All-Electric Aircraft." *Technology Review Journal — Millennium Issue*, Fall/Winter 2000.
- Chatzakos, P., Papadopoulos, E. "On model-based control of hydraulic actuators." *Proc. of RAAD'03, 12th International Workshop on Robotics*, Cassino, May 7-10, 2003.
- Faleiro, L. "Beyond the More Electric Aircraft." *Aerospace America*, AIAA, September 2005.
- Frischemeier, S. "Electrohydrostatic Actuators for Aircraft Primary Flight Control – Types, Modelling and Evaluation." *5th Scandinavian International Conference on Fluid Power, SICFP '97*, Linköping (Sweden), May 28. -30, 1997.
- Jensen, S.C., Jenney, G.D., Dawson, D. "Flight test experience with an electromechanical actuator on the F-18 system research aircraft." *Proc. of the 19th Digital Avionics Systems Conferences*, 2000.
- Karnopp, D.C., Margolis, D.L., Rosenberg, R.C. *System dynamics: a unified approach*. New York, NY: Wiley-Interscience Publication, 1990.
- Merritt, H.E. *Hydraulic Control Systems*. John Wiley & Sons. 1967.
- Taylor, J.H. "Modeling & Simulation of Dynamic Systems – a Tutorial." *Proc. of M2SABI'01 Conference*, Haifa, Israel, 2001.
- Bishop, Robert H. (Org.). *The Mechatronics Handbook*. Boca Raton: CRC Press, 2002.
- Franklin, G. F.; Powell, J. D.; Naeini, A. E. *Feedback Control of Dynamic Systems*. 4th. Singapore: Pearson Education, 2002.
- IMAGINE S.A. *AMESim a Brief Technical Overview*. Roanne,FR, 2000. (Technical Bulletin, no. 100).
- IMAGINE S.A. *Hydraulic Component Design Library: version 4.2*. Roanne, FR, 2004.
- IMAGINE S.A. *AMESim Help Files*. Roanne, FR, 2004.
- Lebrun, Michel; Claude, Richards. *How to create Good Models without writing a single line of code*. In.: *Scandinavian Intl. Conference on Fluid Power, 5th*, 1997, Linköping, SW. *Proceedings...* [S.l.: s.n.], 1997.
- Solutia Inc. *Skydrol: Type IV Fire Resistant Hydraulic Fluids*. St. Louis, MO, 2003. (Technical Bulletin)
- THE Lee Company. *Technical Hydraulic Handbook Release 10.3*. Connecticut: Engineeringtalk Editorial Team, 2003.

8. Responsibility notice

The authors are the only responsible for the printed material included in this paper.