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Research Article

Drive Systems for Landing Gears Numerically Simulated in AMESim Software

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This work presents two versions of landing gear drives numerically simulated. We follow to obtain the right driving sequence of the legs and doors and the estimation of the landing gear deploy and retract time. Although the studies in this paper do not exhaust all the aspects concerning landing gear hydraulic system functioning, these are useful in the design phase of the aircraft hydraulic systems. Regarding the landing gear hydraulic system, we highlight one version of the drive stall phenomenon. When the hydraulic feeding pressure decreases, it is possible that the forces developed by the hydraulic cylinders are enough to retract completely the legs. The landing gear remains in an intermediate position, and the aircraft cannot accomplish its mission safely. For a second version, logic command functions are synthesized using Karnaugh diagrams, and after that, the numerical simulation is accomplished to validate the solution. We used the AMESim software to perform numerical simulations.

1. Introduction

Landing gear system design implies many problems to study and solve. There are necessary detailed studies concerning strength, shock dumping, legs, and door drive for retractable landing gear. There is also a necessity to study the problem of emergency deploying of the landing gear. Also, recently, in the specialists' attention is the problem of the noise produced by the landing gear during the take-off and landing phases. We mentioned here only a few problems concerning landing gear design, not taking into account all the problems in landing gear design. In literature, there are many works concerning these subjects. In [1–3], we can find landing gear configurations. There are described landing gears for light aircrafts, for Unmanned Aerial Vehicle (UAV), but also for the airliner A 380. Luculescu and Prisacariu [4] and Pritchard [5] study the cinematic and dynamic of the landing gears. Actuators used for landing gears have different configurations, with studies concerning this problem being found in [6–9]. In reference [6], configurations and architectures are presented for different drives on "more electric aircraft", oriented on the transport aircraft drives. There are many compared configurations, and the advantages and disadvantages of each one are highlighted. We can notice the trend to replace classical hydraulic drives with electro-hydrostatic or electro-mechanical drives, aiming the elimination of the centralized hydraulic system. In reference [10], the authors present a study concerning dynamic loads in landing phase. Emergency deploying systems for landing gears are in [11]. Some emergency unlocking systems for the landing gear are presented. For many aircrafts, the emergency deployment procedure consists of unlocking the landing gear from retracted position, and then, the landing gear deploys upon its own weight. In [12–14], there is the analysis of the optimized design and landing gear load. Modern solutions for landing gear health monitoring are in [15]. Landing gear doors loads and landing gear noise reduction are found in [16] and [17], respectively. Frédéric et al. [18] present software testing methods for technical solutions used for landing gear construction. Numerical simulations using the AMESim software used for electro-hydraulic drives are in [19] and for landing gear drive system are in [20]. In [21] is presented a method to build a landing gear drive system in AMESim and are analysed the advantages and disadvantages of

AMESim comparing with other simulation software. In [22], the author performs a co-simulation for the nose landing gear system of Airbus 380. Mechanical system model is performed in ADAMS, and the hydraulic system model is performed in AMESim. Co-simulation techniques are highlighted in this work. In [23], the authors perform a landing gear system optimisation using Python script attached to AMESim simulation scheme. Authors follow to optimise the system movement speed using an intelligent optimisation algorithm. In [24], authors elaborate a simulation model in AMESim for a landing gear system, and using this model, they study the effect of common mode failures in the system. Pump leakage and low pressure in the hydraulic tank situations are considered. In [25], authors develop a simulation model in AMESim for the nose wheel steering system. Using this model, they study the steering system behaviour in normal and different fault conditions. As fault conditions, they consider the leakage of the steering actuator and leakage of electro-hydraulic servovalve. In [26], authors elaborate a simulation model for the aircraft leg shock absorber and study its behaviour. They compare numerical results with experimental results.

In this work, we study only the hydraulic drive system for the landing gear. We consider two versions widely used in practice. Training and light aircraft use mainly the first version, simpler and lighter. Big airliners use mainly the second version, more complex from the driving sequence point of view and heavier. We follow to make a modelling and numerical simulation for these systems using the AMESim software that offers important capabilities to simulate mechanic, pneumatic, hydraulic, and electric systems. Unlike some of the works referred above, we follow on the one hand to validate the solutions used for driving sequence implementation and on the other hand to highlight some problems that can appear in the landing gear drive functioning, such as stall phenomenon when hydraulic feeding pressure decreases. An original contribution that does not exist in the references is the synthesis of the logical functions that drive a large aircraft landing gear using Karnaugh diagrams and the validation of the logic using numerical simulation. Simulation schemes developed in this work can be completed in future works. Some elements were neglected in this paper, such as emergency deploying system or locking system on up and down positions.

The novelty of this paper consists of the implementation of simulation schemes for landing gear drives in AMESim and the validation of the studied solution by simulation with this software. This software tends to be widely used for complex systems simulations since it contains industrial validated mathematical models for implemented components. Using parametric and modularised mathematical modelling of the components, it results a versatile software, easy to use, and user-friendly. Many companies that develop systems in different domains already use this software in the design process. By this way, the confidence of results is high.

2. Landing Gear Drive for a Light Aircraft

Landing gear drive system, for a light aircraft, has a simplified configuration, in order to satisfy the functionality, but with a lower weight, corresponding to that aircraft. Details concerning landing gear hydraulic systems can be found in [27]. Aiming this, usually, the driving sequence has only two steps, as presented in Table 1.

On light aircraft, doors are smaller and remain open when the landing gear is down. It is considered that the door opening, when the aircraft is on the ground, does not present an important access to the aircraft's inside systems. Therefore, the open doors do not present an inconvenience.

Hydraulic drive system has a simplified configuration, to fit this situation. Main doors and legs have each one its hydraulic cylinder. For the nose leg, there is a hydraulic cylinder, and for nose doors, there is a lever system. When the nose leg reaches the superior position, drives the lever system, which closes the doors.

For the main legs, drive sequence implies two hydraulic cylinders—door and leg cylinders—and takes place as it follows. Gear down command feed simultaneous door and leg cylinders. Because the door cylinder is much smaller than leg cylinder, it fills faster with hydraulic liquid, and the door opens faster. Leg cylinder is bigger and fills slower, and so the leg deploys after the door opens and does not hit the door.

The problem to limit the leg movement speed appears in the landing gear deploying phase. In this phase, aerodynamic forces, leg weight, and hydraulic cylinder force tend to deploy the leg. From this reason, prevention measures are necessary, because the leg speed can be excessively high and can produce big shocks when the leg reaches the maximum open position. These great shocks can deform the airplane structure in that zone. Deploying speed is limited using flow limitation from the passive chamber of the hydraulic cylinder using a throttle.

Solution for deploying sequence does not fit with the retracting sequence. When the landing gear retracts, because the door cylinder is smaller, it fills faster, and the door closes before the leg completely retracts. This is not correct. In order to maintain the correct sequence, we used a supplementary distributor in the main door circuit. This distributor allows to feed simultaneously the door and leg cylinders in the deploying phase, but in the retracting phase, this distributor prevents door cylinder feeding before the main leg reaches the completely retract position. The command of this distributor can be electric by a micro-switch driven by the main leg when it reaches the completely retracted position. The command can be also mechanic, and the main leg hits the distributor rod when it reaches the completely retract position.

IAR 99 and other fighter airplanes use this solution to ensure landing gear drive sequence. We present this solution implemented in AMESim in Figure 1.

In Figure 1, we observe the hydraulic cylinders for the nose leg, for the left and right leg, and for the left and right main doors.

Legs cylinders drive by a crank-rod mechanism the corresponding leg. Legs cylinders retract the legs on the extension rod stroke. This solution offers a higher force and a higher moment to retract the leg. Door cylinder closes the door when it retracts their rod. Doors are very light, and

Table 1: Landing gear drive sequence for a light aircraft.

Gear down	Gear up
Open doors	Up legs
Down legs	Close doors

the moments produced by their weight are negligible with respect to the legs weight moment.

In order to simulate the moments produced by the legs weight when these are getting up, we considered a force applied on the leg. This force depends on the tilt angle of the leg. In the used version of the AMESim, there is not possible to simulate the weight effect, as it will be necessary. Therefore, we consider the angle made by the leg with the vertical direction, noted by φ; the moment produced by the leg weight with respect to its pivot is

$$M_j = -m_j \bullet g \bullet l \bullet \sin \varphi. \tag{1}$$

To obtain this variable moment in relation to angle φ, we used an angular position transducer that provides the angle φ, and using it, we determine the variable force applied on the leg

$$F_j = -m_j \bullet g \bullet \sin \varphi, \tag{2}$$

which produces the equivalent moment of the leg weight in the deploying or retracting phases. In Figure 1, we observe on each leg this ensemble composed of the position transducer, calculus block for the variable force, and the application device of this force on the mass that simulates the leg.

For the nose leg, there is another position transducer of the leg. Using this transducer, we simulate the functioning of the lever system that drives the nose doors. Nose doors are driven by the lever system only when the leg reaches a determined position, near the maximum up (see Figure 2). From that moment, door displacement is proportional to leg displacement, but doors displacement is more rapid so that, when the leg reaches the maximum up position, doors are closed. This process is simulated using a dead-band block that senses the leg displacement only after it reaches the position from which it produces the lever system drive. Further, we apply the displacement offered by the dead-band block to the lever that drives the nose doors by a spring with dumping.

We limited legs deploying speed by an ensemble consisting of a sense valve and a throttle. Such an ensemble named *shock dumper* in Figure 1 exists on each leg cylinder. In the retracting phase, hydraulic liquid passes through the sense valve with a small hydraulic resistance and feeds the hydraulic cylinder. In the deploying phase, hydraulic liquid returning to reservoir, from the passive chamber of the cylinder, is forced to pass through the throttle. By this way, the throttle limits the liquid flow and implicit limits the deploying speed.

Two distributors 3/2, one for each main leg, ensure the drive sequence for the main legs and doors. When the leg is maximum up, 3/2 distributor is engaged by the leg. By this way, the command from *command_distributor* feeds the up chamber of the door cylinder and initiates its opening. Hydraulic liquid from the passive chamber passes through 3/2 distributor in the up position and through *command_distributor* goes to reservoir. When the leg moves from the up position, it releases the 3/2 distributor, and this passes in the down position. Hydraulic liquid from the passive chamber of the cylinder can continue to pass through 3/2 distributor and sense valve back to reservoir. The main door opens completely before the leg deploys, due to the smaller dimension of its cylinder.

In the retracting phase, hydraulic liquid passes through the *command_distributor* and feeds in inverse sense the door cylinder. Passive chamber of the cylinder communicates with *command_distributor* and allows the hydraulic liquid to pass to reservoir. But the leg is deployed, and 3/2 distributor is in the down position and does not permit to feed active chamber. Liquid from pump cannot reach the passive chamber due to the sense valve. When the leg reaches the maximum up position, engage the 3/2 distributor and switch it on the up position. By this way, it feeds the active chamber, and the door is closed.

3/2 distributor simulation, during its commutation when the main leg reaches the up position, is possible with a position transducer placed on the leg cylinder rod. Using a function adequate choose, we obtain the output switch from 0 to 1 when the rod stroke is getting close to the maximum with a distance smaller than a value Δx. This function is

$$f(x) = \text{floor}\left(\text{abs}\left(\frac{x}{(c - \Delta x)}\right)\right), \tag{3}$$

where x is the rod stroke, c is the maximum stroke, and Δx is the distance from the maximum stroke when the switch produces. In the simulations performed in this work, we considered $\Delta x = 5\,\text{mm}$. It is necessary to use the function *abs* in Expression (3) because the cylinder with end stroke dumpers can reach negative displacement in AMESim, and in this case, function (3) behaves wrong, and the system behaviour is wrong implicitly.

Mathematical models of the scheme components are those implemented in AMESim and can be found in the *help* system of this software.

3. Numerical Values and Results of the Simulations for a Light Aircraft Landing Gear System

Numerical values for the components in Figure 1 are in Table 2 (adapted from [28]).

Pipes' diameters used in Figure 1 were between 8 and 12 mm and their length between 3 and 7 m. In the simulations, we noticed that these pipes' dimensions have a negligible influence in the system functioning. However, in order to obtain a difference between the legs movement speeds, we used three supplementary throttles in the left leg system. We produced by this way different speeds for the legs movement. We can notice these differences in Figure 3. These

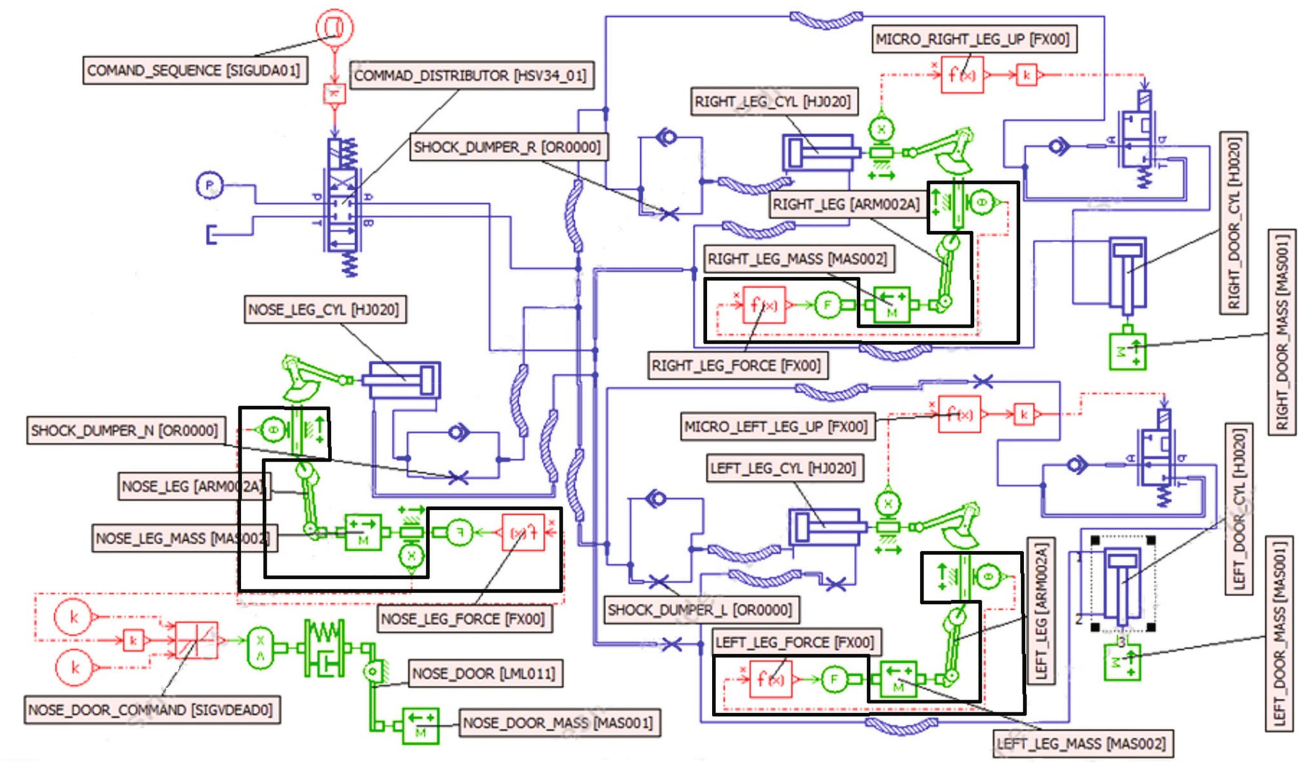


Figure 1: Landing gear drive system for light aircraft implemented in AMESim.

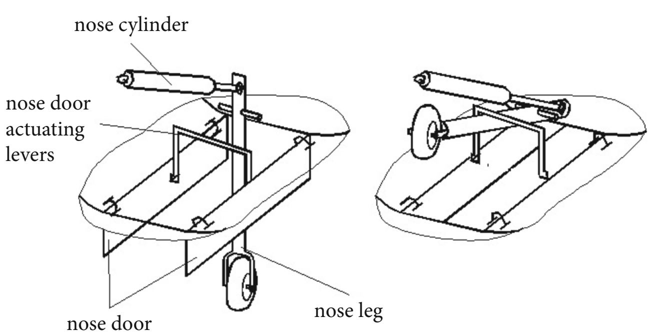


Figure 2: Nose landing gear for the first version.

differences are not necessary. Moreover, they can produce a slight airplane imbalance in the take-off and landing phases, but they are useful in the results presenting and performance assessment.

Graphs in Figure 3 present the behaviour of the systems. In each graph, on y-axis are marked the units the signals are measured. Signals presented in each figure are mentioned in the labels in each figure.

Command sequence consists of a period when the command signal of *command_distributor* switches from 0 value in neutral position to 1 value in the retracting phase (Figure 3(a)). This period lasts 10 seconds, from 60 to 70 seconds. Values on y-axis in this graph represent conventional values. 0 means neutral position, 1 means gear up, and −1 means gear down. By this way, it initiates the landing gear retraction. Behaviour of the right leg ensemble (leg and door movement) is presented in Figure 3(b). Values on y-axis in this figure represent displacements of the leg cylinder rod and door cylinder rod in m, from the position maximum retract (0 m). Leg cylinder extend their rods and retract the legs. Leg retracting at this feeding pressure lasts about 2 seconds. For the main doors, we notice they close after the corresponding leg reached the maximum up position, which means that the cylinder rod stroke exceeds 195 mm. Left leg system behaviour is presented in Figure 3(c). It is similar to the right leg system behaviour in Figure 3(b). Only a small difference in movement times appears due to the throttles provided in the system.

For the nose leg system (Figure 3(d)), we present the leg and door position measured in degrees from the maximum extended position. We notice the door movement begins after the nose leg exceeds approximately 70 degrees and finishes once the nose leg stops. Drive sequence is respected in this situation. Doors close after the complete leg retraction.

After 10 seconds, command signal switches again in 0, and hydraulic installation is passed in neutral position. Landing gear remains up. This period lasts from 70 to 80 seconds. After this period, command signal switches to −1, passing the *command_distributor* on the position corresponding to landing gear deploying. Main door cylinders extend very fast and open the doors in approximately 0.5 seconds, and main leg cylinders retract their rods and deploy the legs in approximately 2 seconds (Figures 3(b) and 3(c)). For the nose leg, the leg and door movement starts simultaneously, but the doors open in about 0.2 seconds due to the lever system, and nose leg deploys in about 2 seconds (Figure 3(d)). The drive sequence accomplishes correctly also in this case. First, the doors open, and then, the legs are completely deployed.

Table 2: Component's parameters in Figure 1.

Parameter	Value
Feeding pressure	210 bar
Main leg	
Length	1.5 m
Mass	300 kg
Main leg cylinder	
Piston diameter	63 mm
Rod diameter	35 mm
Stroke	195 mm
Crank	
Radius of crank	70 mm
Length of connecting rod	200 mm
Main door cylinder	
Piston diameter	25 mm
Rod diameter	12 mm
Stroke	100 mm
Nose leg	
Length	1 m
Mass	90 kg
Nose leg cylinder	
Piston diameter	40 mm
Rod diameter	25 mm
Stroke	95 mm

Figures 3(e), 3(f), 3(g), and 3(h) presented the pressures in the hydraulic cylinders, measured in bar, as it can be seen in the graphs. Significance of each curve is these graph results from the labels in the corresponding figure.

In practice, 4/3 *command_distributor* has two electromagnets, each one passing the spool from the neutral position to one extreme position—retract or deploy landing gear. Therefore, in practice, the command sequence would consist in switching from 0 to 1, the feeding of each electro-magnet at the corresponding moment. In AMESim, electric command distributors are implemented as servo-valve command. Spool displacement is proportional to command current value and sense switches by inversing the feeding current. From this reason, command sequence implemented here retracts the landing gear when the command signal passes from 0 to 1 and deploys the landing gear when the command signal passes from 0 to −1. From the drive sequence point of view, we can assess whether the simulated systems work well.

An interesting situation it is necessary to study is what happens when the feeding pressure decreases. As pressure decreases, at one moment, the hydraulic cylinders will not produce enough force to retract completely the legs. Decreasing gradually the feeding pressure, we noticed that at 55 bar feeding pressure, left leg does not retract completely. This situation is presented in Figure 4.

Command sequence in Figure 4(a) is the same as the sequence in Figure 3(a).

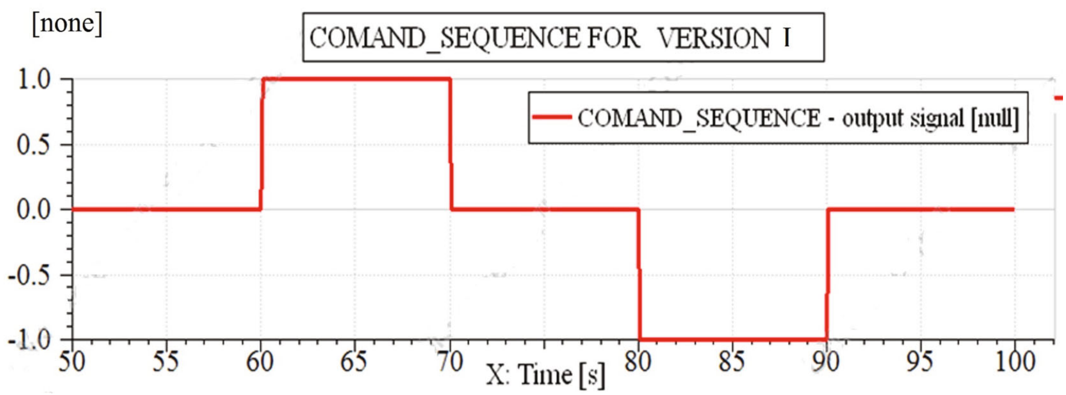
Figure 4(b) presents the behaviour of the right leg ensemble. The piston displacements for the leg cylinder and door cylinder, like in Figure 3(b), measured in m, are presented, each curve being specified by the corresponding label in the figure. In the retraction phase, right leg begins its movement, but due to the very low pressure in the system, retraction speed decreases. Right leg reaches the upper position at the limit of the 10 seconds the retraction command signal lasts. At that moment, door closes, and the right ensemble performs the retraction phase. In the deployment phase, right door begins its movement at the right moment, but due to the low pressure in the system, there is not enough flow. Right door stops for a moment, and the entire flow goes to the leg cylinder. However, right door opens before the right leg deploys completely. We notice here the slow motion of the leg and door, due to the low pressure in the system.

Figure 4(c) presented the behaviour of the left leg ensemble. Also, the pistons displacements for the leg cylinder and door cylinder, like in Figure 4(b), measured in m, are presented, each curve being specified by the corresponding label in the figure. The left leg does not reach the upper position in order to start the left door closing. Left leg remains near the upper position for the 10 seconds the command signal is up. When the command signal passes to the neutral state, left leg descends a little bit, and it deploys when the command signal passes to the down position. Left door remains open all the time, preventing the damages in the aircraft structure. We can also say this is a good behaviour in emergency situations when the hydraulic pressure in the system drops.

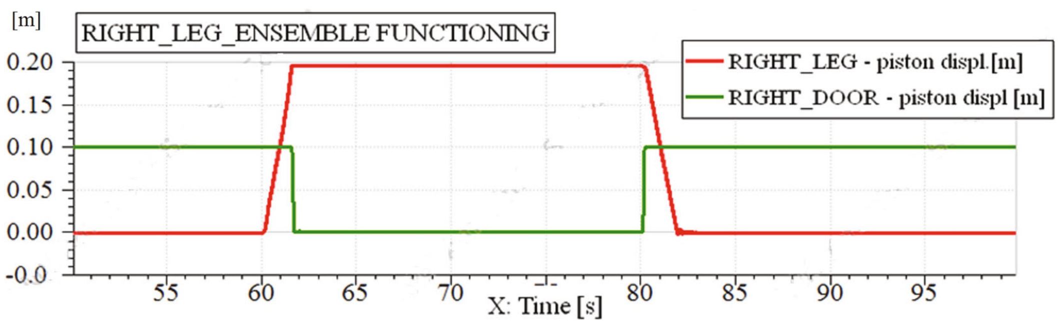
In Figure 4(d), we notice that the nose leg hardly reaches the upper position and closes the doors. We have here, like in Figure 3(d), the angular position of the nose leg and nose door, measured from the position completely deployed. Units in Figure 4(d) are degrees and the corresponding labels specify curves. Nose leg retracts after about 5 seconds and closes the nose door. In the deployment phase, nose leg descends first, and due to the hydraulic dumping decay, it produces some shocks when it deploys completely.

Big difference between the behaviours of the two main legs has the origin in the presence of the throttles introduced before, to create a difference in the movement of the main legs. If we remove the throttles, main legs will behave similar, and the stall pressure will be smaller with few bars. We proved that by using the simulation scheme, we could determine the stall pressure of the system. We can identify many other abnormal functioning situations using simulation scheme.

We have to notice that in the stall conditions, we considered only the effect of the leg weight. In the airplane flight, aerodynamic forces upon the legs can be important at the take-off speed. We can take into account these forces by adding in relation (2) the correspondent terms. Aerodynamic forces as a consequence have retraction time increase and deployment time decrease. Their behaviour is complementary to the weight force moment. When the landing gear is down, aerodynamic forces are relatively great, and the weight force moment is small. When the landing gear rises, aerodynamic forces decrease, and weight moment increases. Maximum aerodynamic forces can reach about 20% from the leg weight.



(a)



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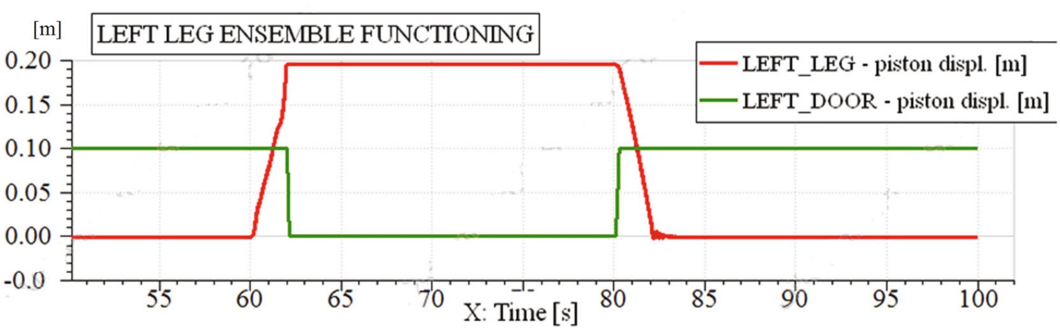
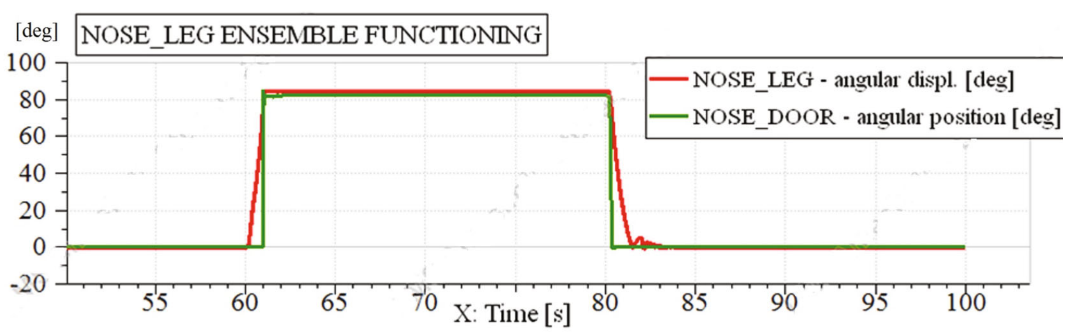
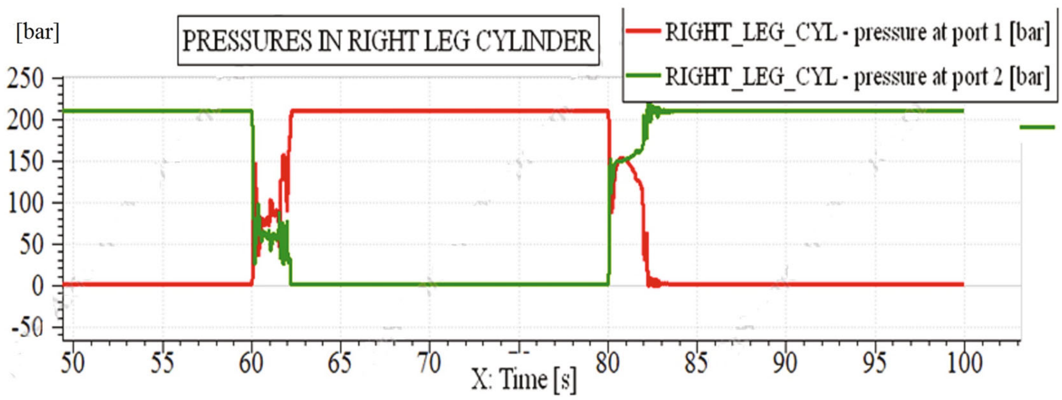


(c)

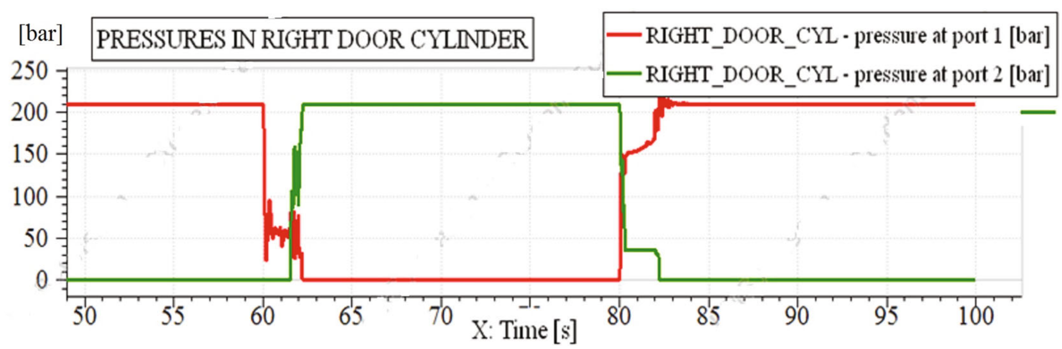


(d)

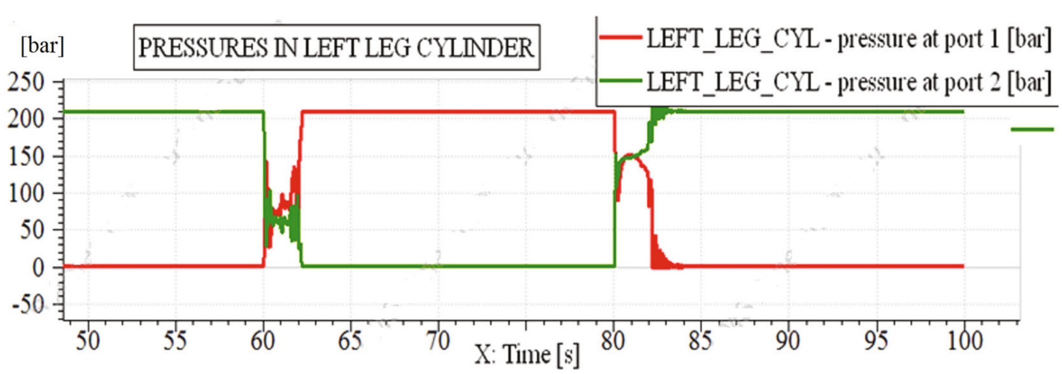
Figure 3: Continued.



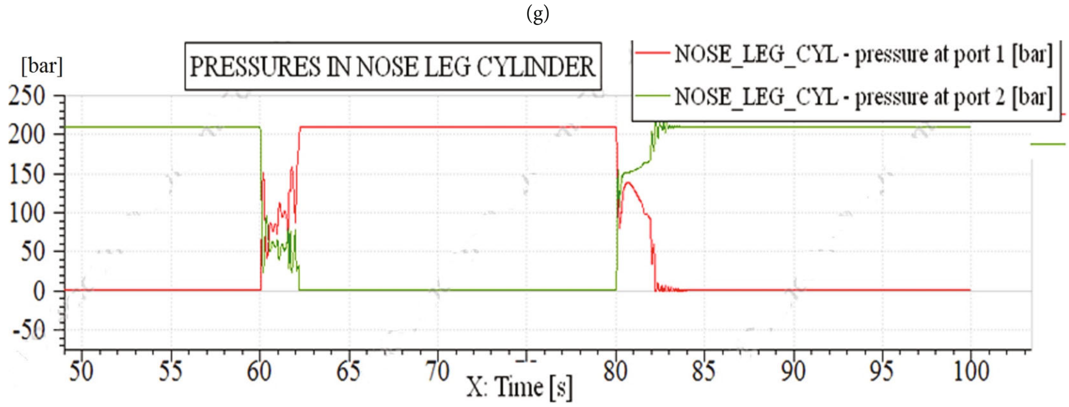
(e)



(f)



(g)



(h)

Figure 3: Simulation results for first version, feeding pressure 210 bar. (a) Command sequence for version I. (b) Right leg ensemble functioning - feeding pressure 210 bar. (c) Left leg ensemble functioning - feeding pressure 210 bar. (d) Nose leg ensemble functioning - feeding pressure 210 bar. (e) Pressures in right leg cylinder - feeding pressure 210 bar. (f) Pressures in right door cylinder - feeding pressure 210 bar. (g) Pressures in left leg cylinder - feeding pressure 210 bar. (h) Pressures in nose leg cylinder - feeding pressure 210 bar.

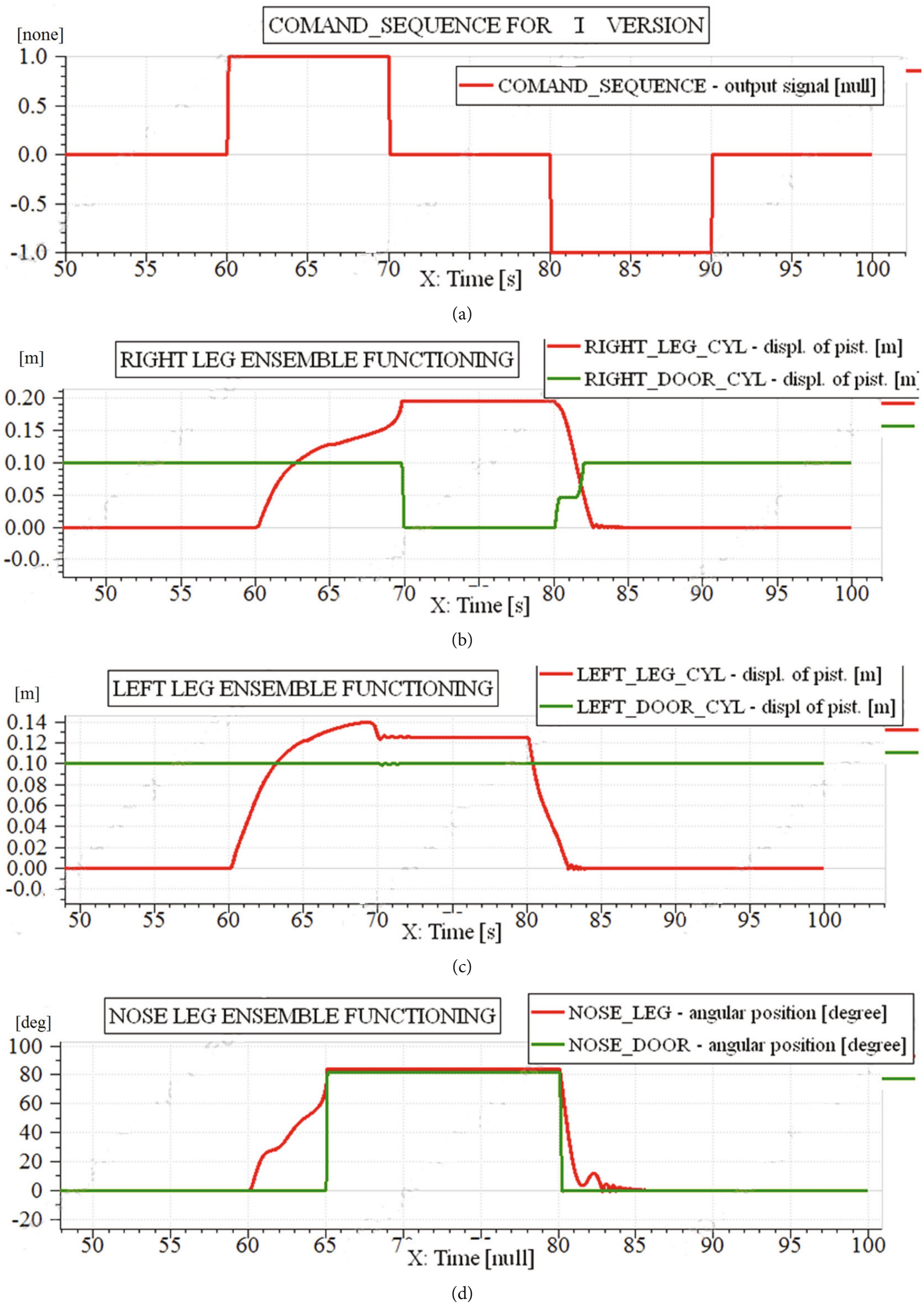


FIGURE 4: Simulation results for first version, feeding pressure 55 bar. (a) Command sequence for version I. (b) Right leg ensemble functioning - feeding pressure 55 bar. (c) Left leg ensemble functioning - feeding pressure 55 bar. (d) Nose leg ensemble functioning - feeding pressure 55 bar.

4. Landing Gear Drive System for an Airliner

At an airliner, landing gear doors are huge; therefore, when doors open, many inside installations are exposed. In order to protect these installations when the airliner is on the ground, the doors are closed. In order to provide the possibility legs remain deployed, there are some small doors, spring driven, that remain opened. In this situation, it is necessary to modify the drive sequence. Drive sequence for airliners is in Table 3.

Table 3: Drive sequence of the landing gear system of an airliner.

Deploy	Retract
Open doors	Open doors
Deploy legs	Retract legs
Close doors	Close doors

This sequence is more difficult to implement only by hydraulic devices, as in the previous version. It is more efficient to implement this sequence using logic functions, which command two hydraulic distributors—one distributor for legs drive and one distributor for doors drive. In the system, there are also some micro-switches, which sense the door and leg position. These end stroke micro-switches switch in "1" when the rod cylinder is near one of the end stroke at a distance smaller than a value Δx. We can know by this way if the leg is completely deployed or completely retracted, and if the door is completely open or completely closed.

Landing gear proposed in this paper uses "AND" logic functions, which determine the moments when all doors are completely opened or completely closed and when all legs are completely deployed or completely retracted.

For landing gear deployment, the sequence is the following:

-We command from the board panel the landing gear deployment. In this moment, doors distributor is commanded to open doors;

-Opening doors;

-When all doors are open, legs distributor is activated to deploy legs;

-Legs deployment;

-When all legs are deployed, doors distributor is activated to close the doors;

-Closing doors;

-When all doors are closed, both distributors pass in the neutral position.

By analogy, landing gear retraction sequence is the following:

-We command from the board panel landing gear retraction. In this moment, door distributor is activated to open doors;

-Opening doors;

-When all doors are open, the legs distributor is activated to retract legs;

-Legs retraction;

-When all legs are retracted, door distributor is activated to close doors;

-Doors closing;

-When all doors are closed, both distributors pass to the neutral position.

This version has the advantage that it uses only two hydraulic distributors, but if a leg or door is being blocked, due to the "AND" logic functions, the drive sequence will interrupt for all legs and doors. If one door or leg functions abnormally, all the legs and doors will fail.

A safer version, but it needs three distributors for the legs and three distributors for the doors, can independently drive the three systems—nose landing gear, left landing gear, and right landing gear. There will be three independent systems, which work after the same algorithm presented in this work. In this case, if one door or leg is being blocked, it will not interrupt the drive sequence for the rest of doors and legs. The "AND" functions are not necessary in this case.

The drive system in this case consists of three hydraulic cylinders, for the legs, driven by the same distributor and three hydraulic cylinders for doors driven by another distributor (see Figure 5). Functioning synchronization of the scheme is ensured by logic function implemented in the blocks SC_1, SC_2, SC_3, and SC_4. These logic functions have as inputs state signals provided by end stroke micro-switches mounted on the hydraulic cylinders and outputs command signals for the hydraulic distributors. End-stroke micro-switches are simulated using a position transducer mounted on the hydraulic cylinders rod and mathematical functions MDLR, MULR, MDLN, MULN, MDLL, MULL, MODR, MCDR, MODN, MCDN, MODL, and MCDL. The forms of these mathematical functions are presented in relations (3) and (4).

$$f(x) = \text{floor}\left(\text{abs}\left(\frac{(c-x)}{(c-\Delta x)}\right)\right). \tag{4}$$

Logical signals from the previous functions are passed through some "AND" logical functions. By this way, command distributors are engaged only when all the doors or all the legs fulfil a certain condition, e.g., doors opening starts when all legs are up, legs deployment starts when all doors are open, and so on. This version seems less safe than if separate distributors are used for eache leg and door. We use it here in order to verify the right behaviour of logical functions described in section 5 is enough. Practical implementation of the system can provide separate logical functions for each ensemble leg and door and separate command distributors for each leg and door; for a safer functioning, but generally on the airplanes, this version is not used.

Parameters in relation (4) are the same as in relation (3). Function (4) switches from 0 to 1 when the rod position is near the complete retraction with a distance smaller than Δx.

For this version, we study the possibility to obtain the drive sequence for legs and doors; therefore, we neglected the leg weight forces that produce resistant moments. Resistant moments on the legs and doors joints will produce only a delay in the leg and door movements in the retraction phase and a speed-up of their movement in the deployment phase. These delays and speed-ups are generally small and will not influence the behaviour of logical functions developed in Section 5. As consequence, in this case, we will be not able to determine the stall pressure for the drive using simulation of the scheme in Figure 5.

5. Synthesis of the Logic Functions for Distributors Command

For distributors command, we have to define logical functions, to ensure the drive sequence for the landing gear system. These logical functions have as inputs signals from the

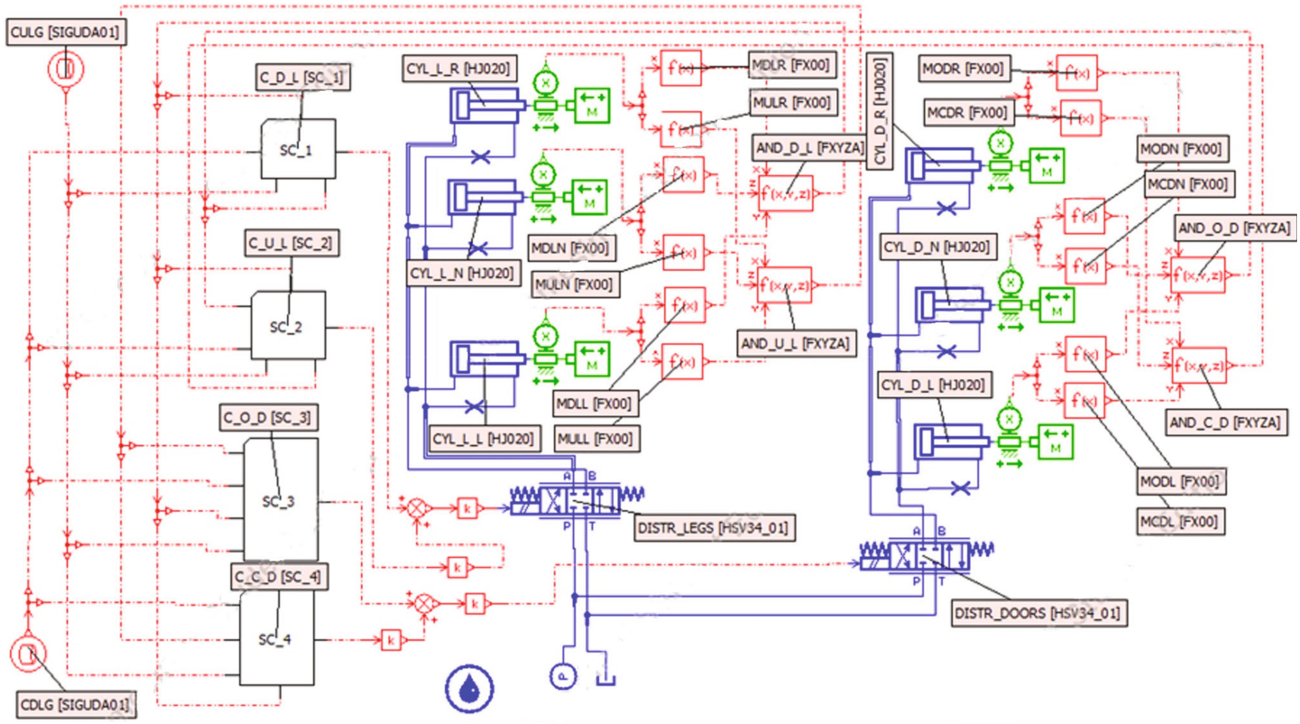


Figure 5: Drive system for an airliner landing gear.

Table 4: Logical signals in the airliner landing gear drive.

Phase	Step	CDLG	CULG	AUL	ADL	AOD	ACD	CDL	CUL	COD	CCD
Gear down	Gear is up, panel commands neutral	0	0	1	0	0	1	0	0	0	0
	Initialize gear down. Command gear down from panel, doors distributor switched to open	1	0	1	0	0	1	0	0	1	0
	Doors are opening	1	0	1	0	0	0	0	0	1	0
	Doors complete opened, initiate legs down	1	0	1	0	1	0	1	0	1	0
	Legs are getting down, doors command remains on open	1	0	0	0	1	0	1	0	1	0
	Legs complete down, initiate closing doors	1	0	0	1	1	0	1	0	0	1
	Doors are closing, legs command remains on legs down	1	0	0	1	0	0	1	0	0	1
	Doors complete closed, legs command remains on down until panel command gets on neutral. Doors command remains on close	1	0	0	1	0	1	1	0	0	1
	Gear down, panel command gets on neutral, doors and legs commands get on neutral	0	0	0	1	0	1	0	0	0	0
Gear up	Initiate gear down. Command to open doors.	0	1	0	1	0	1	0	0	1	0
	Doors are opening	0	1	0	1	0	0	0	0	1	0
	Doors complete open, command legs up	0	1	0	1	1	0	0	1	1	0
	Legs are getting up, doors command remains on open	0	1	0	0	1	0	0	1	1	0
	Legs complete up, command to close doors	0	1	1	0	1	0	0	1	0	1
	Doors are closing, legs command remains on up.	0	1	1	0	0	0	0	1	0	1
	Doors complete closed, legs complete up but panel command is not yet on neutral. Doors command remains on closed, legs command remains on up.	0	1	1	0	0	1	0	1	0	1
	Landing gear complete up, panel command gets on neutral.	0	0	1	0	0	1	0	0	0	0
Phase		CDLG	CULG	AUL	ADL	AOD	ACD	CDL	CUL	COD	CCD

Table 5: Von Karnaugh diagrams: (a) CDL command; (b) CUL command; (c) COD command; and (d) CCD command.

(a)

CDL		ADL, AOD, ACD							
		000	001	010	011	100	101	111	110
	000	X	X	X	X	X	0	X	X
	001	X	0	X	X	X	X	X	X
	010	X	X	0	X	0	0	X	0
CDLG, CULG, AUL	011	0	0	0	X	X	X	X	X
	100	X	X	1	X	1	1	X	1
	101	0	0	1	X	X	X	X	X
	111	X	X	X	X	X	X	X	X
	110	X	X	X	X	X	X	X	X

(b)

CUL		ADL, AOD, ACD							
		000	001	010	011	100	101	111	110
	000	X	X	X	X	X	0	X	X
	001	X	0	X	X	X	X	X	X
	010	X	X	1	X	0	0	X	1
CDLG, CULG, AUL	011	1	1	1	X	X	X	X	X
	100	X	X	0	X	0	0	X	0
	101	0	0	0	X	X	X	X	X
	111	X	X	X	X	X	X	X	X
	110	X	X	X	X	X	X	X	X

(c)

COD		ADL, AOD, ACD							
		000	001	010	011	100	101	111	110
	000	X	X	X	X	X	0	X	X
	001	X	0	X	X	X	X	X	X
	010	X	X	1	X	1	1	X	1
CDLG, CULG, AUL	011	0	0	0	X	X	X	X	X
	100	X	X	1	X	0	0	X	0
	101	1	1	1	X	X	X	X	X
	111	X	X	X	X	X	X	X	X
	110	X	X	X	X	X	X	X	X

(d)

CCD		ADL, AOD, ACD							
		000	001	010	011	100	101	111	110
	000	X	X	X	X	X	0	X	X
	001	X	0	X	X	X	X	X	X
	010	X	X	0	X	0	0	X	0
CDLG, CULG, AUL	011	1	1	1	X	X	X	X	X
	100	X	X	0	X	1	1	X	1
	101	0	0	0	X	X	X	X	X
	111	X	X	X	X	X	X	X	X
	110	X	X	X	X	X	X	X	X

command panel (CULG—command up landing gear and CDLG—command down landing gear) and signals from "AND" functions after micro-switches (ADL—and down legs, AUL—and up legs, AOD—and open doors, ACD—and close doors). Using these input signals, we obtain command signals for the distributors (CDL—command down legs,

Table 6: Parameters of the system in Figure 5.

Parameter	Value
Feeding pressure	210 bar
Main leg	
Mass	2000 kg
Main leg cylinder	
Piston diameter	80 mm
Rod diameter	56 mm
Stroke	500 mm
Main door	
Mass	50 kg
Main door cylinder	
Piston diameter	25 mm
Rod diameter	12 mm
Stroke	200 mm
Nose leg	
Mass	800 kg
Nose leg cylinder	
Piston diameter	63 mm
Rod diameter	35 mm
Stroke	500 mm
Nose door	
Mass	20 kg
Nose door cylinder	
Piston diameter	25 mm
Rod diameter	12 mm
Stroke	200 mm

CUL—command up legs, COD—command open doors, CCD—command close doors). We synthesize logic functions using Table 4.

For commands CDL, CUL, COD, and CCD synthesis, we use Von Karnaugh diagrams. These diagrams, for each command, are in Table 5.

The following logic functions are obtained based on diagrams in Table 5:

$$\mathrm{CDL} = \mathrm{CDLG} \times \overline{\mathrm{CULG}} \times \left(\overline{\mathrm{ADL}} \times \mathrm{AOD} + \mathrm{ADL}\right), \tag{5}$$

$$\mathrm{CUL} = \overline{\mathrm{CDLG}} \times \mathrm{CULG} \times \left(\overline{\mathrm{ADL}} \times \overline{\mathrm{AOD}} + \mathrm{AOD} \times \overline{\mathrm{ACD}}\right), \tag{6}$$

$$\mathrm{COD} = \overline{\mathrm{CDLG}} \times \mathrm{CULG} \times \overline{\mathrm{AUL}} + \mathrm{CDLG} \times \overline{\mathrm{CULG}} \times \overline{\mathrm{ADL}}, \tag{7}$$

$$\begin{aligned}\mathrm{CCD} = {} & \overline{\mathrm{CDLG}} \times \mathrm{CULD} \times \mathrm{AUL} + \mathrm{CDLG} \times \overline{\mathrm{CULG}} \\ & \times \overline{\mathrm{AUL}} \times \mathrm{ADL}.\end{aligned} \tag{8}$$

These logic functions were implemented in command blocks in Figure 5.

6. System Parameters and Simulation Results for Airliner Case

For the components in Figure 5, we used the parameters in Table 6 (adapted from [29]).

As in the previous version, pipes' dimensions had a negligible influence upon the results. In order to see a difference between the movement speed of the legs and doors, we used artificially some throttles in the scheme.

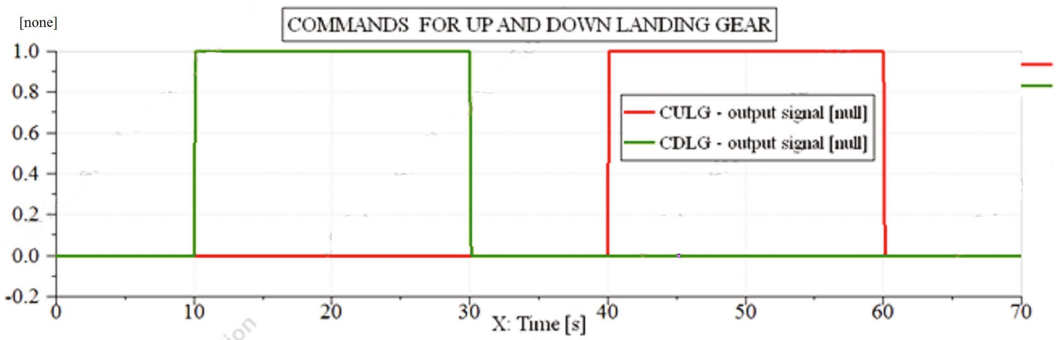
In Figure 6, we present the command signals from the board panel, command signals synthesized according to relations (5)–(8), and command signals applied effectively on the distributors and rods cylinders displacement. As in the previous version, distributors implemented in AMESim have a servo-valve type command. In order to obtain the command applied on the distributor, we made an inversion of the signals in relations (6) and (8), and after that, we added the signals in relations (5) and (7), respectively.

The command signals from the board panel switches are shown in Figure 6(a). Units are none because there are logical signals. Usually, the landing gear is commanded from a lever with three positions: "Landing gear UP", "Neutral", and "Landing gear DOWN". For the position UP and DOWN, there are two electrical micro-switches that close each one an electrical circuit, one for retraction and one for deployment of the landing gear. In red is the signal for landing gear retraction and in green is the signal for landing gear deployment. We considered here logical signals with values 0 and 1. Value 0 means that command is deactivated, and value 1 means that command is activated. These commands cannot be activated in the same time. First, we apply the DOWN command for landing gear deployment. This command closes one electrical circuit and starts the deployment sequence—green line in Figure 6(a). After the deployment sequence is finalized, the command is deactivated, and hydraulic installation is in NEUTRAL state. After 10 seconds in NEUTRAL state, UP command is applied (red line in Figure 6(a), another electrical circuit is closed and starts the deployment sequence. After this sequence is finalized, hydraulic system passes again in NEUTRAL state.

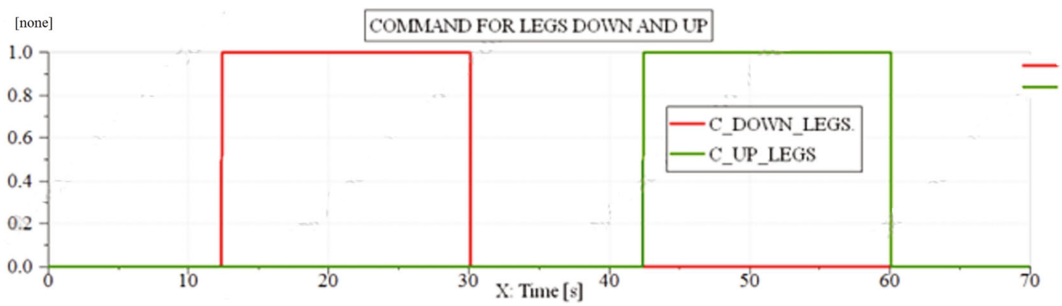
The commands for legs retraction and deployment are shown in Figure 6(b). These commands are not synchronous with the landing gear retraction and deployment, due to doors opening and closing. Behaviour of these signals results from the logical signals synthesized in Section 5. Red line is for legs deployment and green line is for legs retraction. Here are also logical signals with no units.

The command effectively applied on the legs distributor is shown in Figure 6(c). This distributor is implemented in AMESim with positive and negative values of the signal, there are not considered two electromagnets commanded separately. In order to command this distributor, we had to consider the deployment the legs produce on the positive command current of the distributor and the retraction produces on the negative command current of the distributor. Distributor command currents are +40 mA and −40 mA.

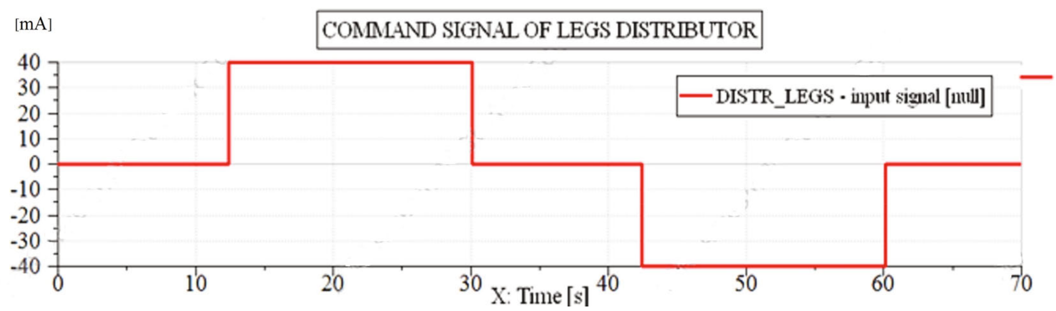
In Figure 6(d), there are logical command signals for the doors opening and closing. This signal variation is also obtained from the logical functions synthetized in Section 5.



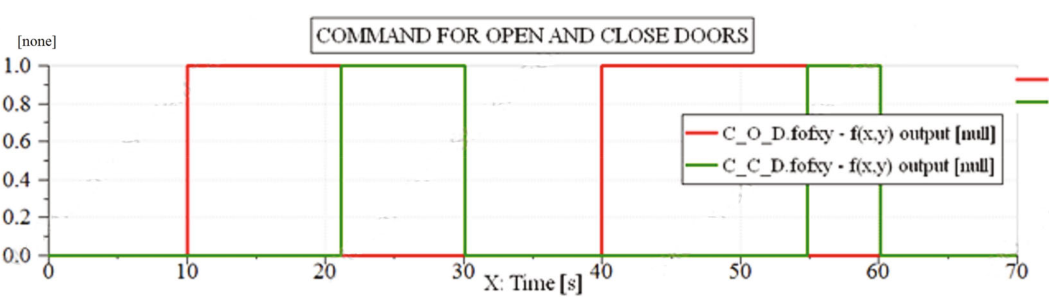
(a)



(b)

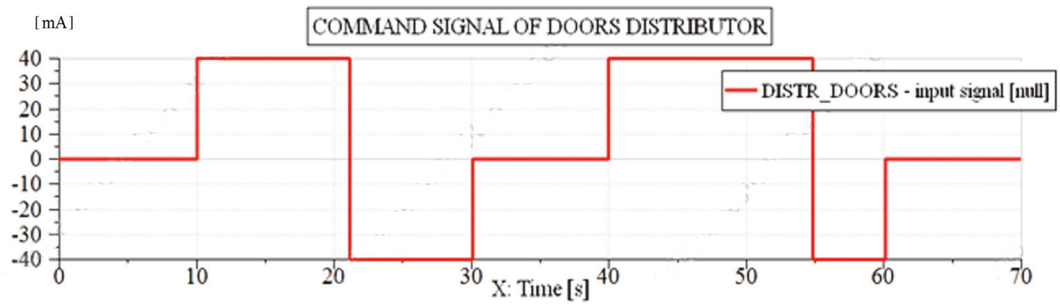


(c)

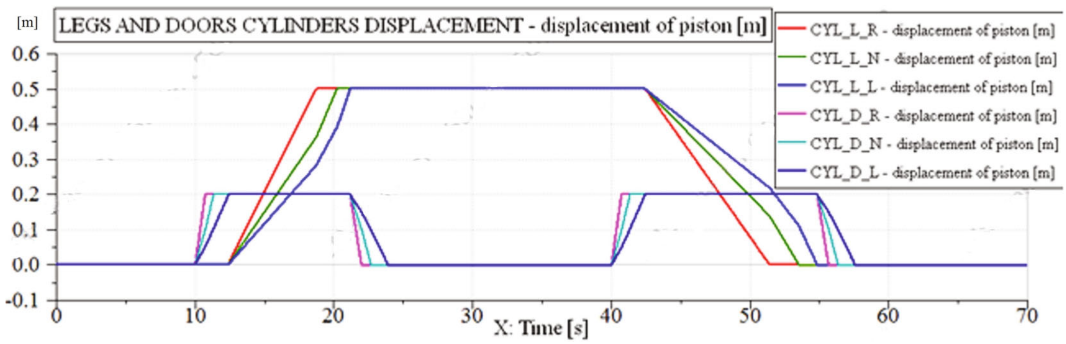


(d)

FIGURE 6: Continued.



(e)



(f)

Figure 6: Simulation results for the scheme in Figure 5. (a) Commands for up and down landing gear. (b) Commands for legs down and up. (c) Command signal for legs distributor. (d) Commands for open and close doors. (e) Command signal of doors distributor. (f) Legs and doors cylinders displacement.

The command effectively applied on the door distributor command is shown in Figure 6(e). This distributor works in the same manner as the leg distributor. Value of +40 mA is for doors opening and −40 mA is for doors closing.

Following cylinder movement in Figure 6(f), we notice that the drive sequence is respected. At landing gear deployment, the doors open first; when all doors are open, legs deploy; when all legs deployed, doors close; and finally, the installation passes on the neutral position. At landing gear retraction, first doors open; when all doors are open, legs retract; after complete retraction of the legs, doors close; and finally, the system passes on the neutral position. Synthesized signals fulfil the requirements, and we notice in Figure 6 their concordance with the other signals in the system.

For this version, we performed only simulation concerning the drive sequence for legs and doors. If we considered the forces upon the legs, as in previous version, we obtain a very complex scheme difficult to present in this work. We can simulate the stall of the system by completing this scheme with the correspondent elements we used in previous version, but this will be probably in another work.

For a more detailed study of the landing gear system, both for a light aircraft or an airliner, we can consider also other elements in the system as hydraulic and mechanical locks for up and down positions, wheel braking system when giving the retraction command, emergency drive system, hydraulic power source, and interaction with other aircraft hydraulic system. We can study all these problems in AMESim, but simulation schemes are huge.

7. Conclusions

Using the AMESim software, we can simulate complex aircraft systems. In this work, we presented two versions for landing gear drive: one simpler from the drive sequence point of view, used on light aircraft, and a second more complex, used for airliners.

We validated the drive scheme rightness for the studied versions, by numerical simulation in AMESim. Results are in concordance with the required drive sequence for each studied version.

We highlighted the drive stall phenomenon for the first version due to system pressure decrease. The stall pressure is 50 bar. When the system pressures decrease, hydraulic cylinders do not produce enough force to win the moments produced by the leg weight and aerodynamic forces. When the pressure decreases, hydraulic dump decay. So, it is possible end stroke shocks to appear, when the legs go down, even in the system are shock dumpers that work well when the pressure is normal.

We obtained logical function used to command distributors in airliner landing gear system fulfil the requirements. These logical functions have as input signals the command signals from the board panel and signals from end stroke micro-switches that determine position of the doors and legs, and the outputs are the command signals for the doors and legs distributors. Results of the simulations validate the correctitude of these functions.

In order to replace some features that are not yet implemented in AMSESim, we found solutions to use combination of existent elements and obtained the desired effects.

We replaced the end stroke micro-switches with position transducers followed by mathematical function to emulate micro-switches. We simulated the weight effect upon the legs with variable forces applied on the legs. These forces are function of leg tilt angle. The obtained results, with these simulation artifices, are in concordance with reality. These tricks proved to be correct and useful in the landing gear system simulation.

Using the AMESim software for future works, we intent to study aircraft landing gear systems in an extended frame to take into account locking systems, hydraulic sources, emergency drive, and interaction with other hydraulic systems.

Data Availability

The authors are willing to make available to those interested the results of the research presented in this article. Date used in this paper are from landing gear drive schemes used in practice.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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