Digital Secondary Control Architecture for Aircraft Application

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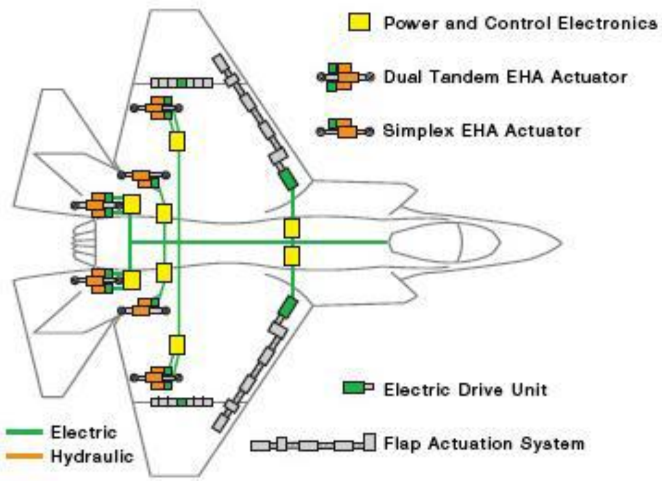
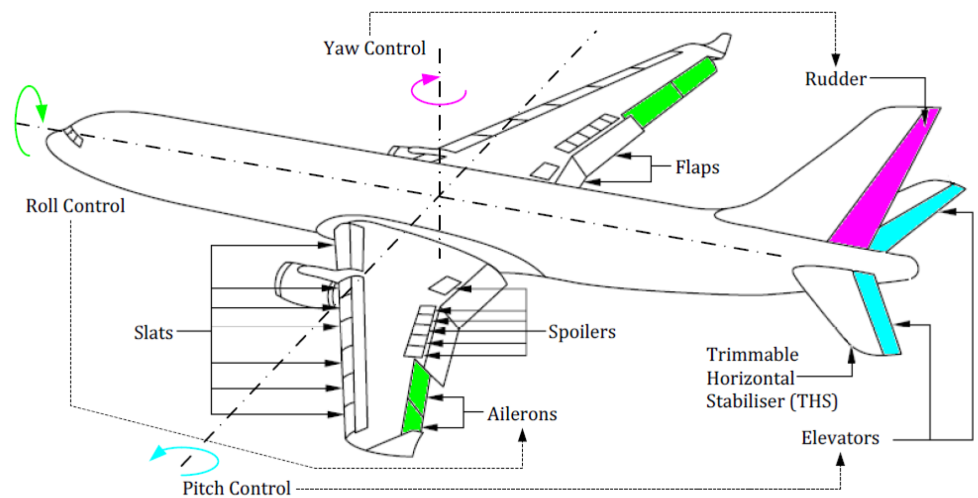
DFP15

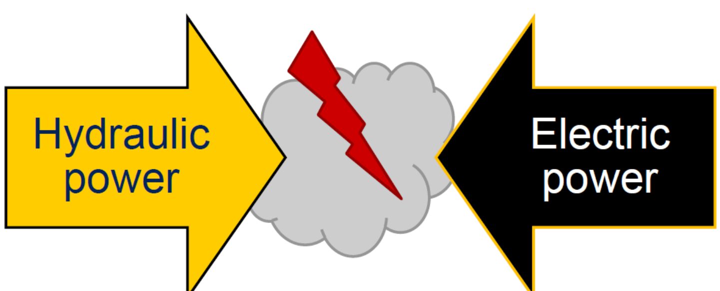
AIRCRAFT FLIGHT CONTROL SYSTEM



Moog Inc. (2010)



Wang, Lijian (2012)



"Hydraulics? Never heard of it!"
"Filthy, leaking"
"Difficult to assembly"

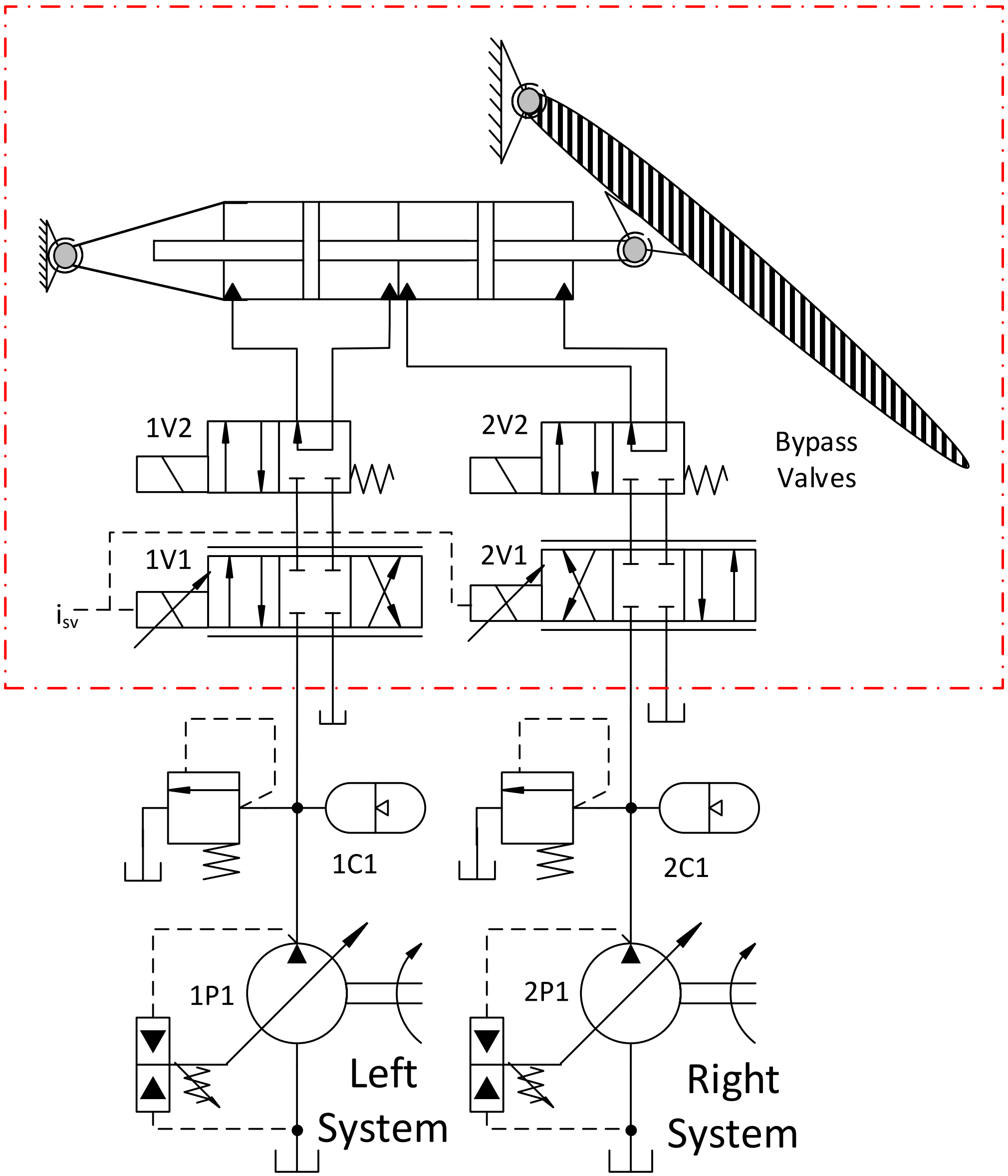
"Everyone knows it"
"Clean"
"Plug and play"

Lantto, Birgitta (2014)

Improve Efficiency

- Maintenance
- Reliability
- Performance
- Weight

Current System



External forces:

Maximum Range: ± ***70 kN;***
System mass: ***50 kg.***

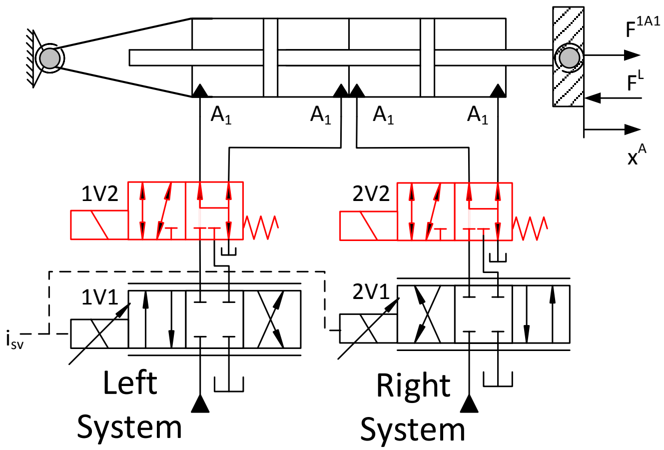
Supply pressure:

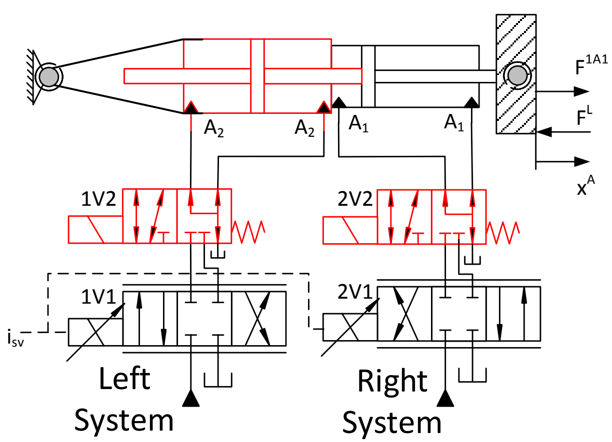
Maximum pressure: **350 bar**;
Middle pressure: **free to select**;
Minimum pressure: **20 bar**;
Tank pressure: **7,5 bar**.

Cylinder:

Minimum Area: **$10x10^{-4}$ m^2**;
Maximum Area: **20% more**;
Viscous friction: **2500 Ns/m;**
Static friction: **100 N**;
Kinematic friction: **70 N.**

Design with relatively few changes





Digital Concept

Digital Fluid Power

Digital Cylinders

Digital Motors

Secondary Control

Digital Flow Control Unit - DFCU

Switching Hydraulic System

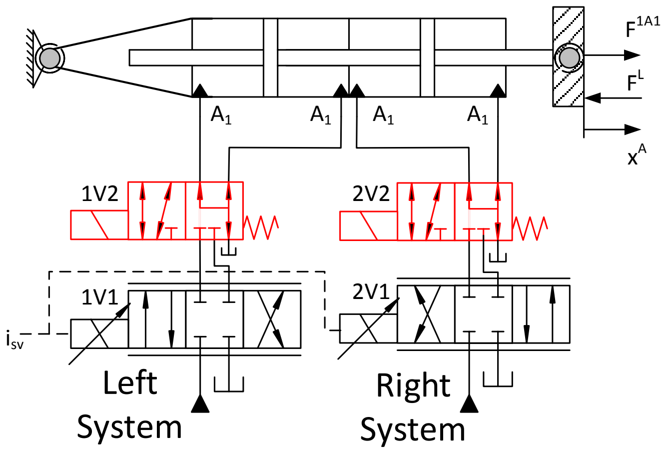
Digital Hydraulic Transformer - DHT

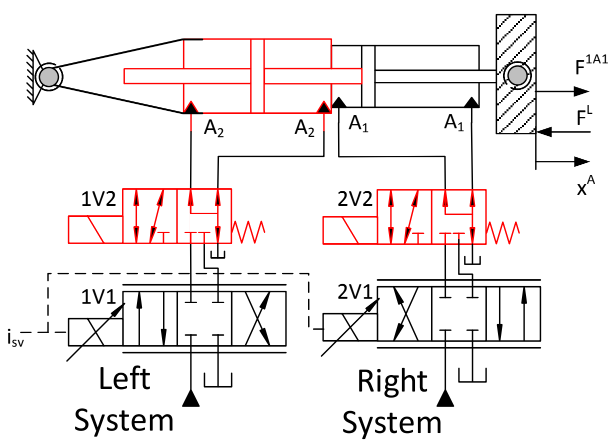
Digital Hydraulic Power Management System - DHPMS

Digital Pumps

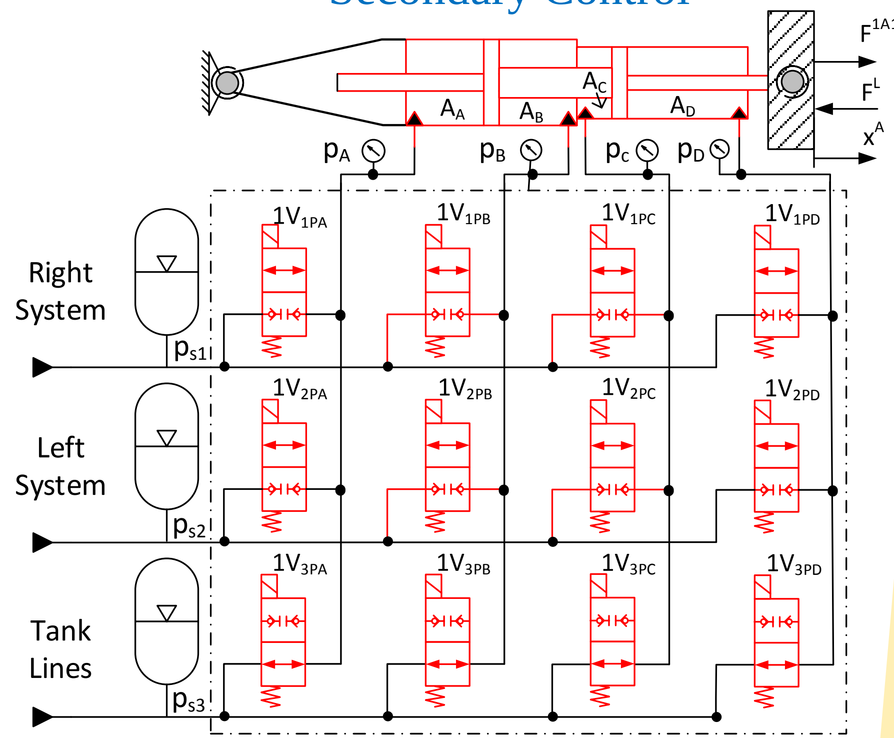
Digital Pumps in Closed Circuit

Design with relatively few changes





Digital Concept Secondary Control



Sizing of the cylinder

- Forces Distribution

$$n_{forces} = (n_{pressure})^{n_{chambers}}$$

$$n_{forces} = 3^4 = 81$$

Areas Rate

$A_A = 27x,$

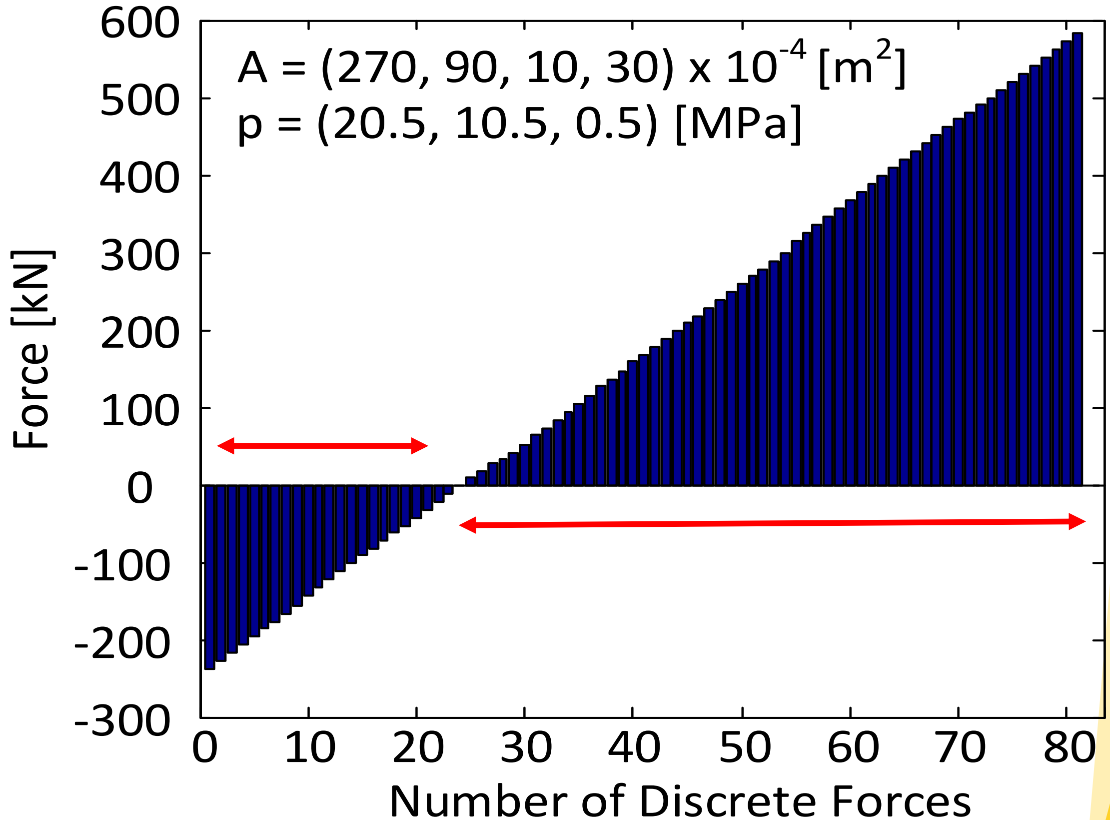
$A_B = 09x,$

$A_C = 03x,$

$A_D = 01x.$

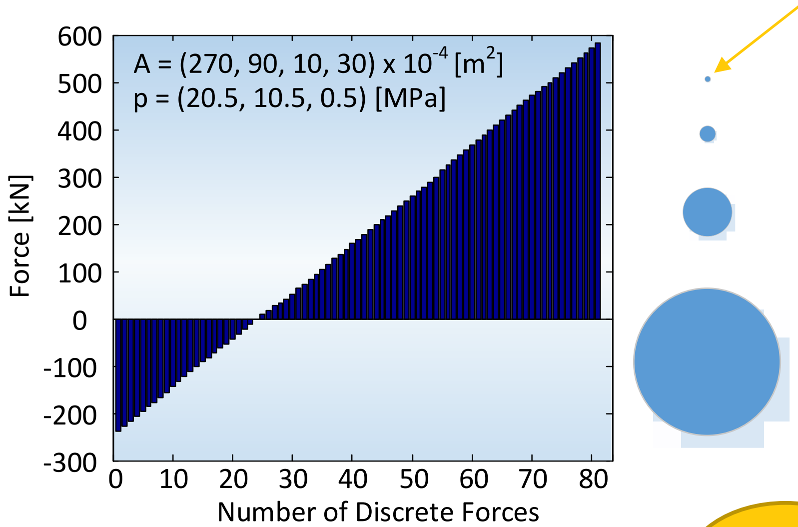
Pressures Rate

p_{S1} = 20.5 MPa;
p_{S2} = 10.5 MPa;
p_{S3} = 0.5 MPa

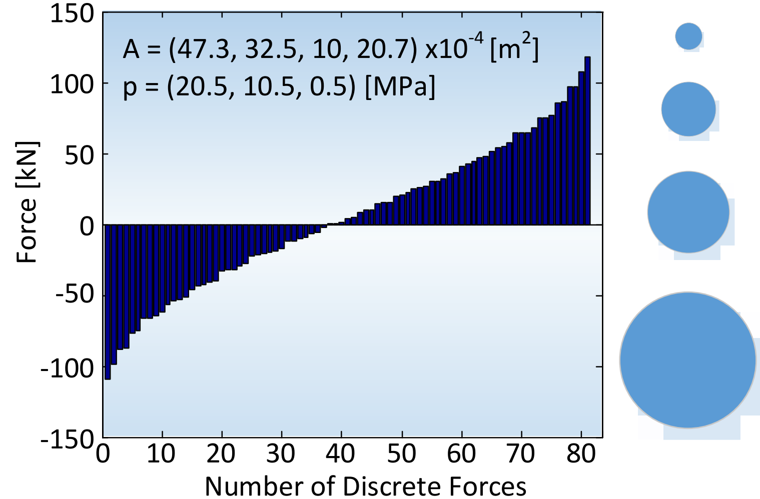


Sizing of the cylinder

27:9:3:1

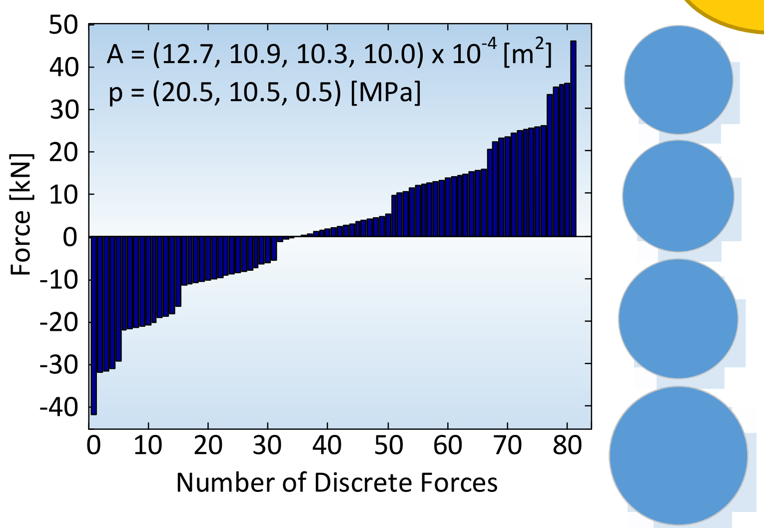


5:3:2:1

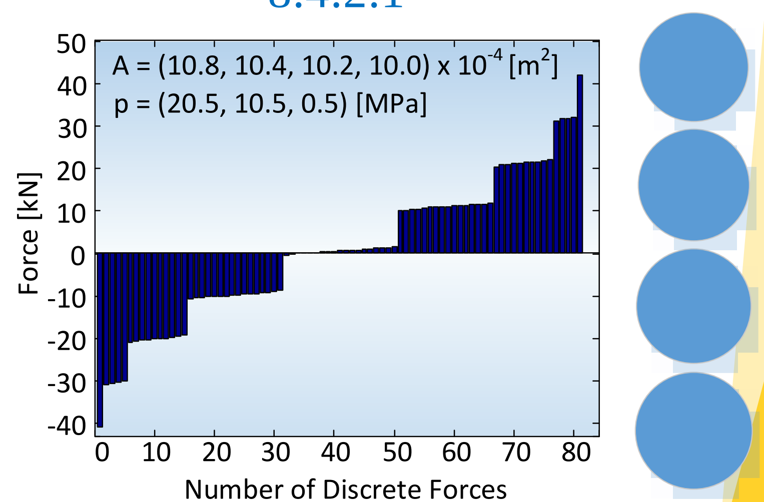


20%

¨27:9:3:1¨



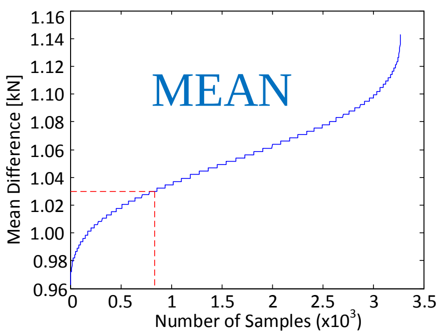
¨8:4:2:1¨

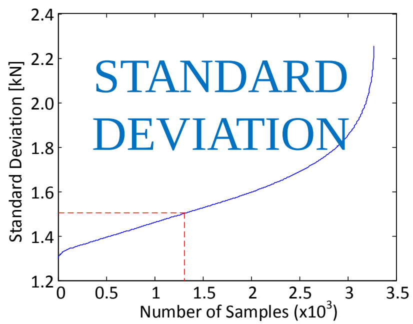


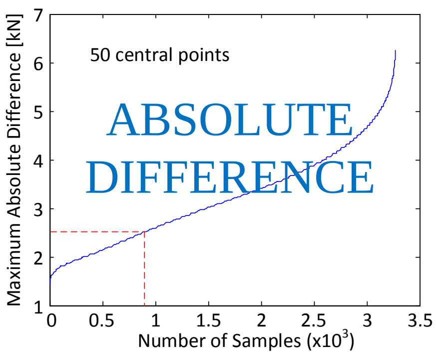
Step 01 – Areas combination

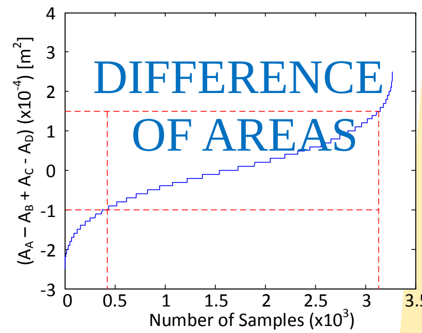
Inputs:

- Pressures: p_{s1} = 20.0 MPa ; p_{s2} = 13.5 MPa e p_{s3} = 0.75 MPa;
- Minimum area value: 10.0 x10^{-4} m^2;
- Maximum area value: 12.5 x 10^{-4} m^2;
- Increment in area value to search activity: 1x10^{-5} m^2;
- Magnitude for consider one force different of the other: 100 N.





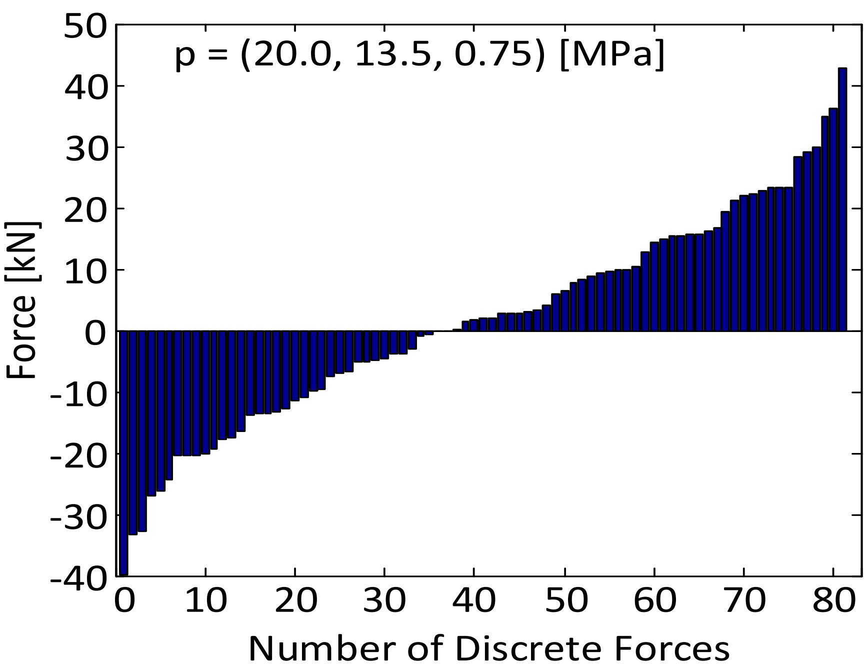


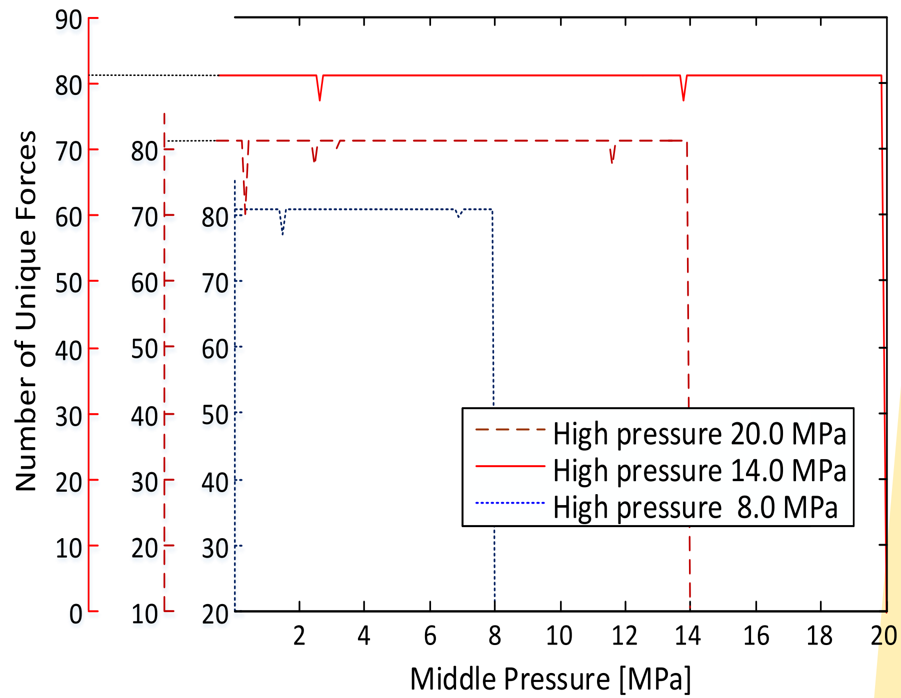


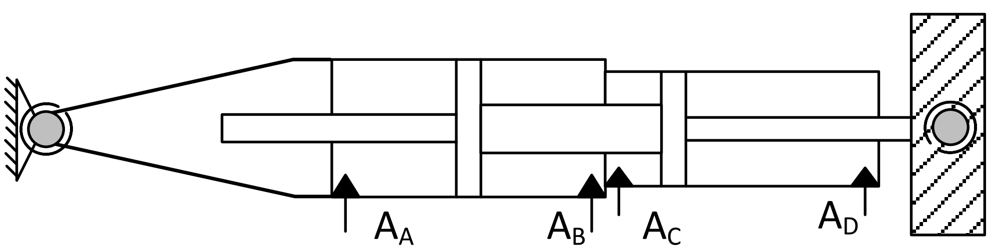
Filters:

- Minimum number of unique discrete forces: 80;
- Maximum mean: 1.03 kN;
- Maximum standard deviation: 1.5 kN;
- Maximum : 2.5 kN, for the 50 central forces;
- Minimum value for the difference of areas: -1x10^{-4} m^2;
- Maximum value for the difference of areas: 1.5x10^{-4} m^2.

Step 01 - Result







Areas: A_A = 12.1; A_B = 10.6; A_C = 10.0 and A_D = 10.1 (x10^{-4} [m^2])

Typical force levels

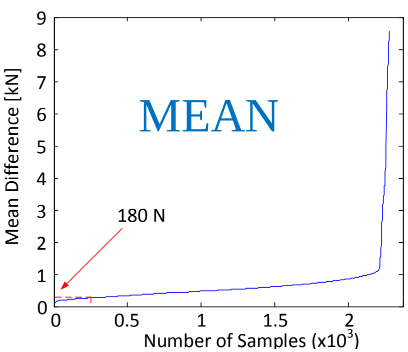
Surface	Takeoff/Landing	Ferry Flight	Dogfight/Turb. Flight
Military Aircraft			
Pitch	20%	10%	60% - 100%
Row	20%	10%	60% - 100%
Yaw	5%	5%	60% - 100%
Civil Aircraft			
Pitch	40%	20%	60% - 100%
Row	40%	20%	60% - 100%
Yaw	10%	10%	60% - 100%

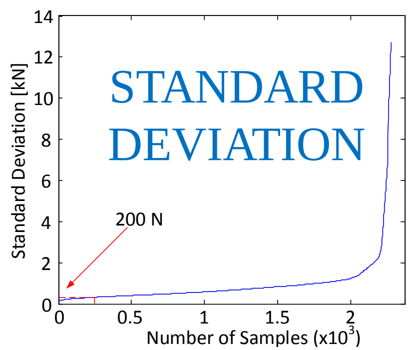
- 5% → 3.5 kN: (Rudder in takeoff movement)
- 10% → 7 kN: (Aileron in ferry flight movement)
- 20% → 4 kN: (Aileron in takeoff movement)
- 40% → 28 kN: (Elevator in takeoff movement)
- 60% to 100% → (42kN to 70 kN)

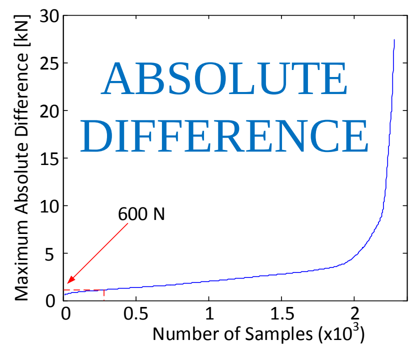
Step 02 – Operation points

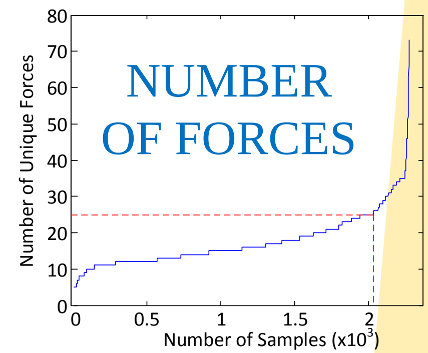
Inputs:

- Areas: $A_A = 12.1$; $A_B = 10.6$; $A_C = 10.0$ e $A_D = 10.1$ ($x10^{-4}$ [m^2]);
- Maximum force value: 3.5 kN;
- Minimum force value: -2.0 kN;
- Maximum working pressure: 35 MPa;
- Minimum working pressure: 2.0 MPa;
- Pressure of reservoir: 0.75 MPa;
- Increment in pressure value to search activity: 0.5 MPa.





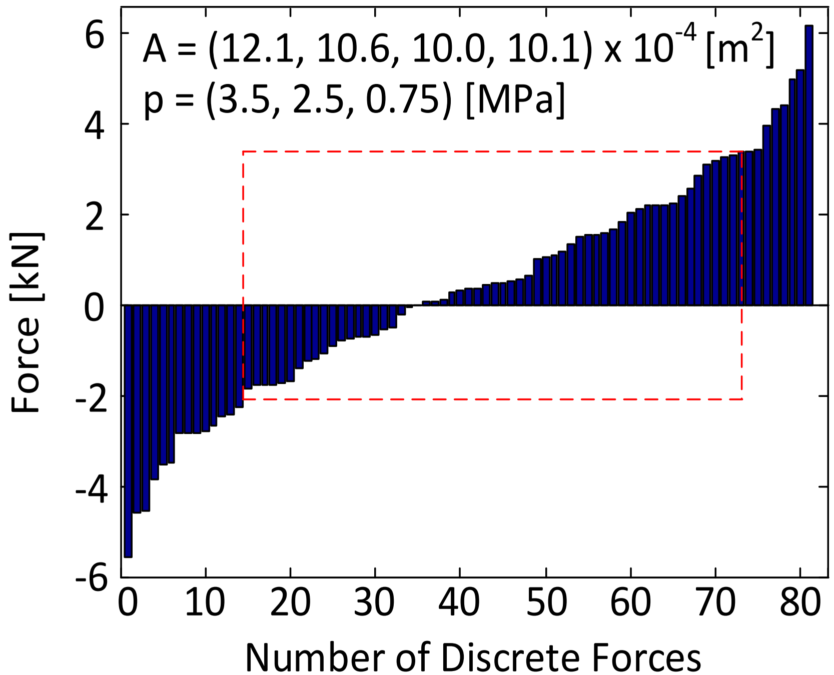


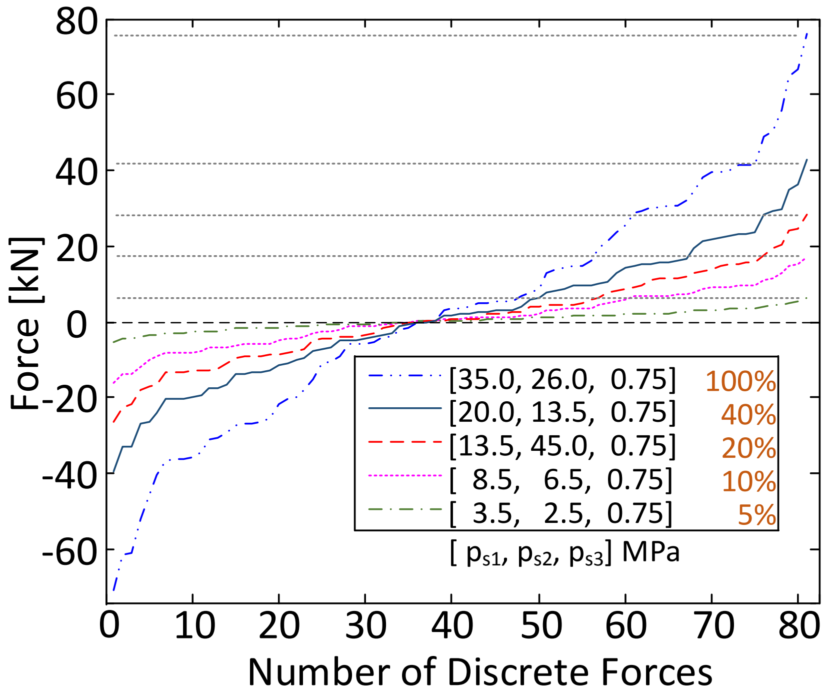


Filters:

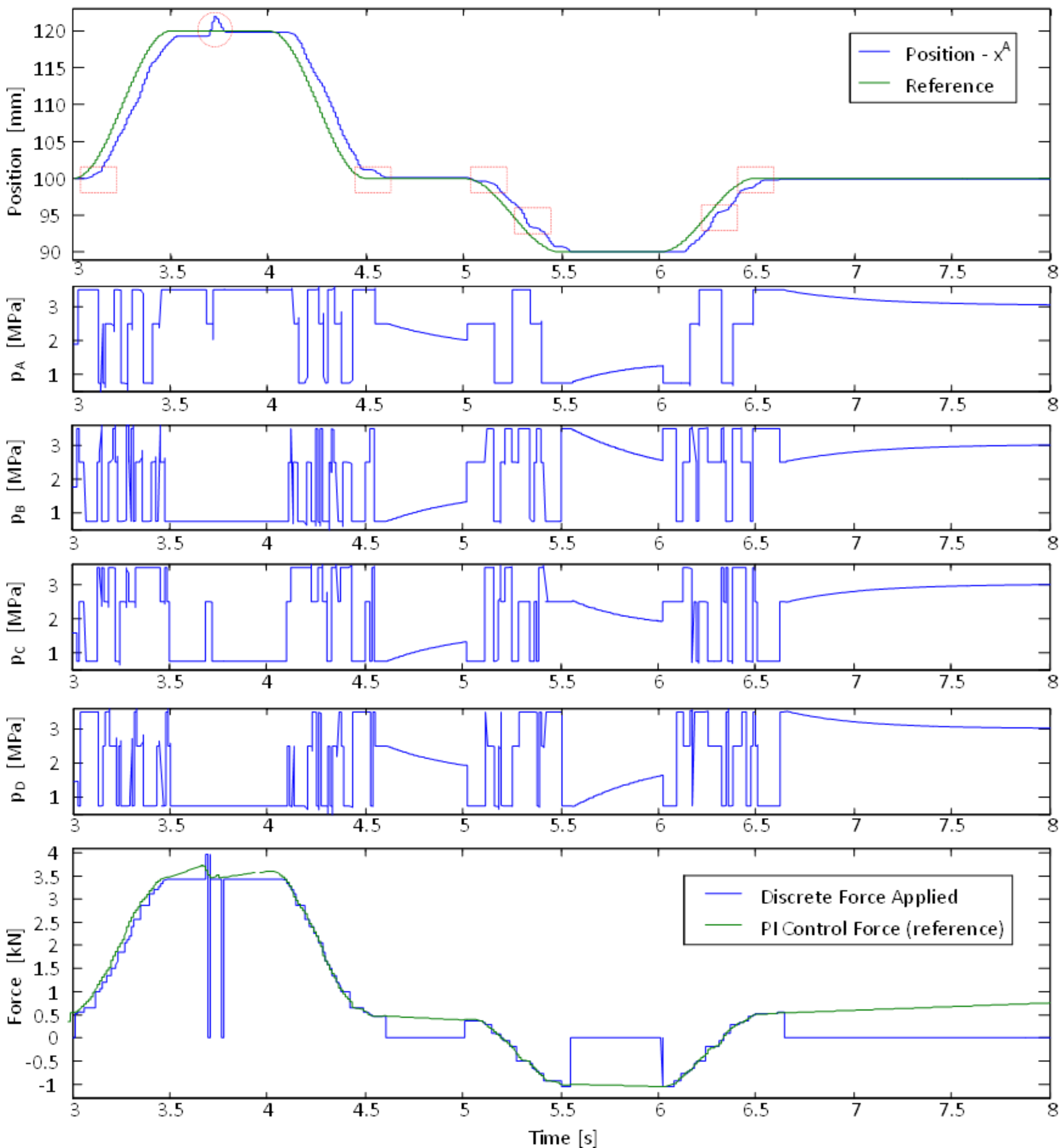
- Maximum mean: 180 N;
- Maximum standard deviation: 200 N;
- Maximum absolute difference: 600 N;
- Minimum number of unique discrete forces: 25.

Step 02 – Result

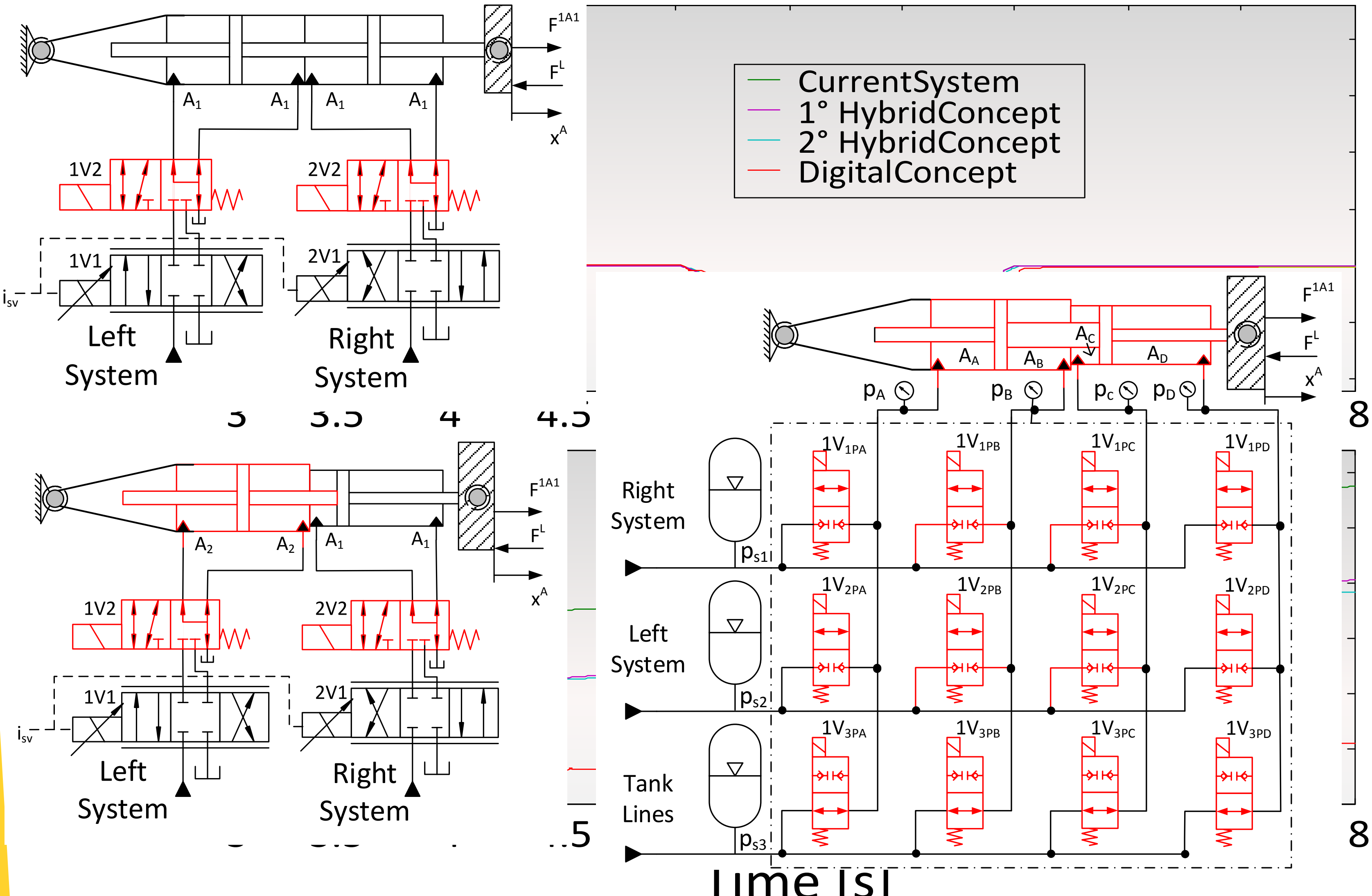




Simulation results



Energy efficiency



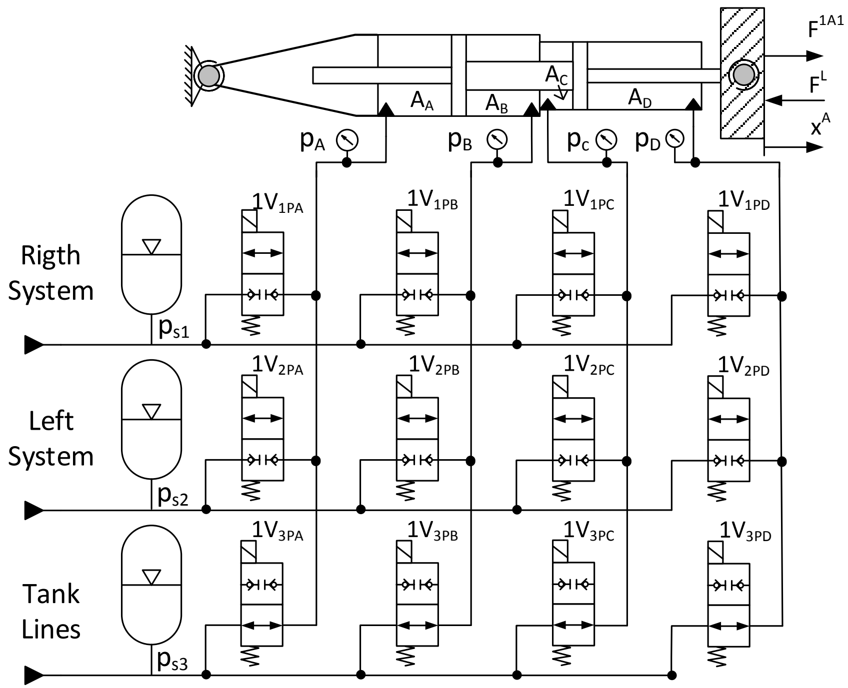
Conclusions

- It is possible to control a system using a combination of areas and pressures that does not provide an equidistant distribution for the discrete forces values.

- The digital technical efficiency was proven superior to the current system considered and hybrid proposals from an energy savings point of view
- However, more research, is needed, especially in relation to control and fault tolerance, to allow the technique to be used in aircraft

- One suggestion to address this challenge is to evaluate the possibility of using a smaller control surface to control the small variations of load and use the digital actuator for greater demands situations.

Failure cases



- If a valve has one closed failure, the system would still be able to generate 54 discrete force values (3^3x2^1), for each combination of pressure.
- If a valve has one open failure, which can be considered a failure in an actuator chamber, the system will operate with 27 discrete forces (3^3).
- If one pressure line fails, the number of discrete force will be reduced to 16 (2^4).

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