MINISTRY OF EDUCATION AND RESEARCH
National University of Science and Technology
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SUMMARY
PhD THESIS

Contributions to increase the performance of the nose landing gear of military school and training aircraft

Scientific supervisor,
Prof. univ. dr. ing. Nicolae IONESCU

- 2024 -

National University of Science and Technology POLITEHNICA of Bucharest

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Contribuții privind creșterea performanțelor trenului anterior de aterizare al avioanelor militare de școală și antrenament

Contributions to increase the performance of the nose landing gear of military school and training aircraft

PhD THESIS COMMITTEE

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Abbreviations

Item No.	Abbreviation	Meaning
1	AEM	Ethylene acrylic elastomers
2	AE-N/AG	Normal power signal from the aircraft power supply
3	AIDC	Automatic Identification and Data Capture
4	AJT	Advanced Jet Trainer
5	AH	Analytical Hierarchy

6	AMS	American Material Standard
7	AMT	Aviation Maintenance Technology
8	ANTISKID	The brakes, which employ a special computerized antiskid mechanism
9	APU	Auxiliary Power Unit
10	ARP	Aerospace Recommended Practice (NASA)
11	ASTM	American Society for Testing and Materials
12	BDI	International databases
13	BED	Electronic steering control unit
14	BUS	A BUS, in computing and digital technology, is an electronic pathway through which data can be transferred
15	C-2P	Two-position switch to select NORMAL steering or FREEWHEEL case
16	CAD	Computer Aided Design
17	CAE	Computer Aided Engineering
18	CAM	Computer Aided Manufacturing
19	CAx	Computer-aided technologies
20	CBI	Application for Patent of Invention
21	CFD	Computerized Fluid Dynamics
22	CGa	The forward limit position of the aircraft's Center of Gravity
23	CGp	The rear limit position of the aircraft's Center of Gravity
24	CPM	Core Process Module
25	DN	The landing gear is EXTENDED
26	DOT4	Brake fluid
27	DRESS	Distributed and Redundant Electro-mechanical nose wheel Steering System
28	EASA	European Aviation and Safety Agency
29	ECS	Environmental Control System
30	ED-004-3/2-NI	Three-way, two-position solenoid valve that switches from functional position I (NORMALLY CLOSED) to functional position II (OPEN)
31	EDA	European Defense Agency
32	EDSTAR	European Standards Reference System
33	EHA	Electro Hydrostatic Actuation
34	EMACC	European Military Airworthiness Certification Criteria
35	EMAR	European Military Airworthiness Requirement
36	EMCU	Electric Motor Control Unit
37	EMJAAO	European Military Joint Airworthiness Authorities Organization
38	EPDM	Ethylene propylene diene monomer
39	FAA	Federal Aviation Administration (USA)

40	FAM-B	Fuel commonly employed in Europe to test polymers that will be in contact with fuel
41	FCS	Flight Control Systems
42	FH	Flight Hours
43	FKM	Fluoro rubber material
44	FMECA	Failure Mode, Effects and Criticality Analysis
45	FOD	Foreign Object Damage
46	FTA	Fault Tree Analysis
47	FVMQ	Fluorosilicone rubber
48	GTB	Greater The Better
49	$H\infty$	$H\infty$ methods are used in control theory to synthesize controllers to achieve stabilization with guaranteed performance. To use $H\infty$ methods, a control designer expresses the control problem as a mathematical optimization problem and then finds the controller that solves this optimization.
50	HNBR	Hydrogenated Nitrile Butadiene Rubber
51	HOQ	House of Quality
52	Hp	High pressure
53	HVOF	High-Velocity Oxygen Fuel
54	INCAS	National Institute for Aerospace Development Research Elie Carafoli, Bucharest
55	IRM	Standard Practice for Rubber
56	KBE	Knowledge Based Engineering
57	LGS	Landing Gear Systems
58	LIFT	Lead-in-Fighter Trainer
59	LOF	Lift-off
60	Lp	Low pressure
61	LSI	Large Scale Integrated
62	LSS	Life Support System
63	MAA	Military Aviation Authority
64	MAWA	Military Airworthiness Authorities
65	MCE	Motor Control Equipment
66	MC-SH-N/LP	Pressure switch that signals normal hydraulic power supply from the aircraft's hydraulic system
67	MEA	More Electric Aircraft
68	MFV	Multi-Functional Valves
69	MIL	Military standard
70	MI-TA-C	AIRPLANE ON GROUND signal from nose landing gear micro switch

71	MI-TPD-C	AIRPLANE ON GROUND signal from right main landing gear micro switch
72	MI-TPS-C	AIRPLANE ON GROUND signal from left main landing gear micro switch
73	MPH	Miles Per Hour
74	MTBF	Mean Time Between Failures
75	MTTR	Mean Time To Repair
76	N/A	Not applicable
77	NA	Norm for aviation (Romania)
78	NAS	National Aerospace Standards (USA)
79	NASA	National Aeronautics and Space Administration (USA)
80	NLG	Nose Landing Gear
81	NMAA	National Military Aviation Authority
82	NTB	Nominal The Better
83	OEM	Original Equipment Manufacturer
84	OSIM	State Office for Inventions and Trademarks (Romania)
85	psi	Pounds per Square Inch
86	RDC	Remote Data Concentrator
87	RFID	Radio-Frequency Identification
88	SAE	Society of Automotive Engineers
89	TA	Nose Landing Gear
90	TC-P	Control transducer that measures the angle of rotation of the tiller shaft
91	TC-RA	The transducer that measures the steering angle executed by the moving assembly of the nose landing gear
92	TP	Main Landing Gear
93	TTP	Time-Triggered Protocol
94	TVR-RA	True ground speed transducer installed at the nose landing gear wheel
95	UP	The landing gear is RETRACTED
96	USAF	United States Air Force
97	VLE	The maximum speed that can be flown with the landing gear extended
98	VLO	Airspeed at which landing gear can be safely operated: extended or retracted

Foreword

The research-development on increasing the performance of the nose landing gear of military school and training aircraft marks the directions and motivation of the doctoral studies, presented in this doctoral thesis.

The doctoral program consisted of the conception, presentation, submission of examinations and scientific reports, detailing of the study, proposal and submission to OSIM of ten applications for invention patents, all approved by OSIM with the granting of patents, the creation and publication of eighteen presented scientific works at international scientific communication sessions, the creation and publication of a chapter, in English, published by the IntechOpen publishing house in England, as well as the elaboration of the present doctoral thesis that deals with the increase in the performance of the nose landing gear of military school and training aircraft.

On the occasion of the completion of the doctoral thesis, I sincerely thank the doctoral supervisor, Prof. univ. Dr. Eng. Nicolae IONESCU, POLITEHNICA Bucharest, for involvement, specialized guidance and constant support in the preparation of this doctoral thesis. His constructive suggestions and comments as well as communication provided an important contribution to the completion of this work.

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I also express my sincere gratitude to the Doctoral School of Industrial Engineering and Robotics, as well as to the entire organizing team from the National University of Science and Technology POLITEHNICA Bucharest.

I express my thanks to my family who supported me throughout the entire period of preparation, presentation and support of exams, scientific reports, deepening the study and for the elaboration of this doctoral thesis.

I hereby emphasize that I have completed this doctoral thesis through my direct analysis and development activity, based on reference scientific resources, in the collaborative environment of the Doctoral School of Industrial Engineering and Robotics and that of the National Aerospace Research and Development Institute "Elie Carafoli" - I.N.C.A.S. Bucharest.

Bogdan-Adrian I. NICOLIN

Introduction

The topic of the doctoral thesis "Contributions regarding the increase in the performance of the nose landing gear of military school and training aircraft" is a very important one, because, until now, the commanded steering has not been implemented in any military aircraft designed in Romania.

The landing gear of an aircraft is a support and running system during taxiing, take-off and landing operations. Each landing gear is equipped with shock absorbers that absorb and dissipate the energy of the landing impact or during taxiing on the runway in order to reduce the stresses transmitted to the aircraft structure. The main landing gear is equipped with a braking system for its wheels, and the nose landing gear gives the aircraft the ability to steering on the ground with the help of a nose gear wheel steering device. The landing gear supports the entire mass of the aircraft and ensures taxiing on the runway during take-off, landing and taxiing operations. To minimize the aircraft's aerodynamic drag during flight, the landing gear of military aircraft is always retractable.

The controlled steering is very important in all ground maneuvers of military aircraft, as it facilitates their movement during takeoff and after landing, including when parking in the open air or in covered hangars. In addition, the controlled steering enables fuel economy in all ground maneuvers of military aircraft.

For the reasons stated above, research has focused on the latest design methods, the latest materials, and a controlled steering system of the nose landing gear wheel.

* * *

The doctoral thesis is structured in two parts, with a total of 11 chapters. The first part of the doctoral thesis presents: the current state of research regarding the nose landing gear of military school and training aircraft; elements on the modeling and design of the nose landing gear of military school and training aircraft and conclusions on the current state of the modeling and design of the nose landing gear of military school and training aircraft. The second part presents the contributions regarding the performance increase of the nose landing gear of military school and training aircraft, respectively: the directions, the main objective and the research and development methodology of the steering device for the nose landing gear of military school and training aircraft ; the design of the steering servomechanism; the installation technology of the controlled steering device of the nose landing gear; calculation of the functional parameters of the steering device; experimental research of the hydraulic cylinder for cornering; simulation of the operation of the steering device; analysis of nose landing gear failure modes and risk mitigation measures.

The last chapter of the thesis summarizes the final conclusions and the main contributions regarding the increase in the performance of the nose landing gear of military school and training aircraft.

The doctoral thesis ends with the bibliography used by the author, which includes eighteen published scientific works and ten invention patents granted by OSIM.

Chapter 1. The current stage of research on nose landing train

1.1. The importance of developing military school and training aircraft

Romanian Army pilots currently use F-16 aircraft and will have F-35 aircraft in the near future. Both models of fighter aircraft benefit from controlled steering of the nose landing gear wheel. That is why it is very important that the Romanian-made school and training aircraft IAR 99 NG has this equipment, so that the pilots who train on it are used to this system when they fly the new common aircraft with the other NATO countries, i.e. F- 16 and F-35.

In addition, considering the conflict triggered by the Russian Federation by invading Ukraine, a conflict that is taking place very close to Romania's borders, it can be appreciated that any improvement brought to the military aircraft of the Romanian Army is of great advantage.

1.2. The role of nose landing gear

The landing gear is one of the critical subsystems of an aircraft, as the safety of the entire aircraft and its crew during take-off, landing and taxiing operations depends on it. The purpose of the landing gear on an aircraft is to provide a support and running system during taxiing, take-off and landing operations and is designed to absorb and dissipate the kinetic energy of the landing impact, thereby reducing the transmitted impact stresses to the aircraft structure.

The landing gear also facilitates braking of the aircraft using a main landing gear wheel braking system and provides directional control of the aircraft on the ground using a nose landing gear wheel steering device when the aircraft is on the ground and at speeds reduced displacement. On all military aircraft the landing gear is designed retractable to minimize the aircraft's aerodynamic drag during cruise flight.

1.3. Comparative analysis of some nose landing gear acting solutions

1.3.1. The role and importance of the action system

Military school and training aircraft of the Romanian army (IAR 99) and combat aircraft (IAR 93) are not equipped with a controlled steering system of the nose landing gear wheel, but other military aircraft produced in foreign countries have a steering system nose landing gear wheel drive.

The purpose of this paper is to define a new concept and wheel steering system for the nose landing gear of existing military school and training aircraft as well as for a new generation of military school and training aircraft to be designed at the National Institute of Research - Aerospace Development "Elie Carafoli" - INCAS Bucharest, called IAR 99NG (New Generation).

Chapter 2. Designing and homologation the nose landing gear

2.1. Conceptual design

The process of designing and integrating the nose landing gear into the structure of the military aircraft requires the knowledge of several engineering disciplines, such as aircraft structure, dynamics, kinematics, fluid mechanics, etc. The geometry, mission requirements, and operational requirements of the aircraft govern the landing gear configuration of a military aircraft [B04, D12, H02, L10].

The conceptual design of the node landing gear of a military aircraft begins with the preliminary calculation of the static and dynamic loads acting on the landing gear and is based on the following activities:

- Choice of number of wheels [B04, H02, L10];
- Choosing tire sizes from manufacturers' catalogs [B04, H02, L10];
- Establishing the type of shock absorbers [B04, H02, L10];
- Landing gear positioning [B04, H02, L10];
- Extension / retraction mode [B04, D03, H02, J02, L10, W08];
- Sizing of the compartment for the landing gear retracted into the fuselage [B04, H02, L10];
- Configuration of opening / closing doors of the train compartment in the fuselage [B04, H02, L10].

2.2. Detail design

In this phase, the detailed design of all components of the landing gear is carried out and a landing gear compatible with the other systems of the military aircraft is defined. The calculation of the static and dynamic loads [S17, W03] acting on the landing gear is updated and the selection of materials and the dimensioning of all the landmarks of the landing gear are carried out.

At this stage, a digital mock-up of the landing gear is developed, which is actually the 3D prototype of the landing gear on the basis of which the execution drawings of the component parts, sub-assemblies and the landing gear assembly are made [A03, A04, A07, A08, A09, B10, C02, C03, D04, D06, D13, E02, E03, F03, G06, G08, H01, H05, H06, J05, K01, K02, K04, K05, M07, R01, R09, R10, R11, S03, S05, S10, S12, S13, S15, U01, W03, Z06].

2.3. Homologation of the nose landing gear

The reliability of landing gear and landmarks is ensured by strict quality assurance requirements and the traceability of the manufacturing process of all Class I landmarks (required landmarks, of vital importance to the aircraft, whose removal from service in flight, takeoff or landing may result in structural destruction, loss of control of the aircraft or injury to personnel on board) according to NA 19500 [N29].

For the homologation of the landing gear for a military aircraft, three examples of the nose landing gear are manufactured and subjected to tests for homologation, as shown in figure 2.1:

- Specimen 1 is tested for operational shock and crash safety, Category B (the operational shock test verifies that the landing gear will continue to function to performance standards after exposure to shocks during normal aircraft operations, while taxiing, landing or when the aircraft encounters sudden gusts of wind in flight) [I03, M10, R13];
- Specimen 2 is subjected to endurance tests, i.e. 10000 stress cycles with the load equivalent to the normal landing impact force and must withstand without rupture or permanent deformation;
- Specimen 3 is subjected to a series of tests specified below.

Unless otherwise specified, all tests shall be performed under the following ambient conditions [I03, M10, R13]:

- Temperature: +15°C up to +35°C [I03, M10, R13];
- Relative humidity: maximum 85% [I03, M10, R13];
- Ambient pressure: 107 kPa to 84 kPa (equivalent to an altitude of -460 m to +1525 m) [I03, M10, R13].

If the tests are carried out under ambient conditions that differ from the values specified above, the actual conditions under which the tests were carried out will be recorded [I03, M10, R13].

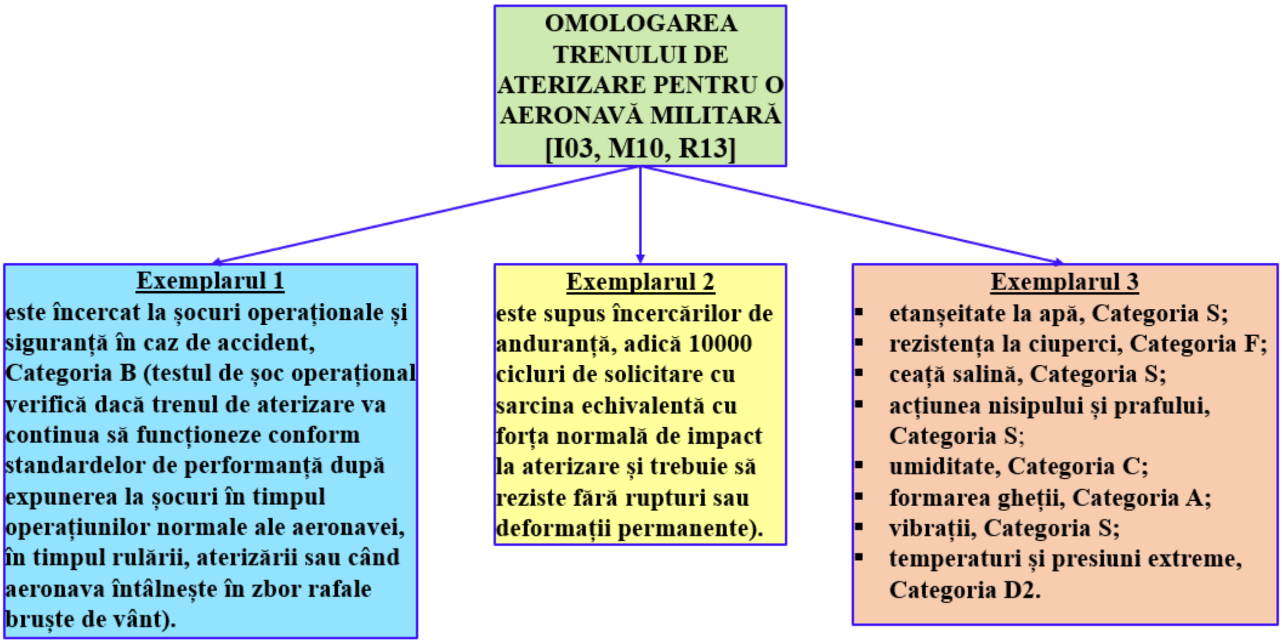


Fig. 2.1. Homologation of landing gear for a military aircraft

Specimen 3 is subjected to a series of tests in the order specified below [I03, M10, R13]:

- water tightness, Category S (this test determines whether the landing gear can withstand the effects of liquid water spray, water falling on the landing gear or the effects of condensed water) [I03, M10, R13];

- resistance to fungi, Category F (this test determines whether the materials of the landing gear are negatively affected by fungi in conditions favorable to their development: high humidity, warm atmosphere, and the presence of inorganic salts) [I03, M10, R13];
- to salt fog, Category S (this test determines the effects of prolonged exposure to a salty atmosphere or to salt fog under normal operating conditions on the landing gear) [I03, M10, R13];
- to the action of sand and dust, Category S (this test determines the resistance of the landing gear to the effects of blowing sand and dust in the air, at moderate speeds) [I03, M10, R13];
- to humidity, Category C (this test determines the ability of the landing gear to withstand natural humid or challenged atmospheres) [I03, M10, R13];
- on ice formation, Category A (the landing gear is mounted outside or in areas of the aircraft with uncontrolled temperature, where ice or frost may form due to condensation) [I03, M10, R13];
- vibration, Category S (these tests demonstrate that the landing gear meets applicable performance standards, including durability requirements, when subjected to specified vibration levels) [I03, M10, R13];
- to operational shock and crash safety, Category B (the operational shock test verifies that the landing gear will continue to function according to performance standards after exposure to shocks during normal aircraft operations, during taxiing, landing or when the aircraft encounters sudden gusts of wind in flight) [I03, M10, R13];
- at extreme temperatures and pressures, Category D2 (temperatures from -55^{o}C to +70^{o}C, ambient pressure: 11.6 kPa (equivalent to an altitude of 15240 m), respectively 101.32 kPa (equivalent to an altitude of 0 m) [I03, M10, R13].

The nose landing gear is considered homologated, if the three copies passed all the conditions of the tests to which they were subjected. The three specimens of landing gear that have been subjected to the homologation process are kept for a minimum of 2 years at the technical-economic unit that performed the homologation tests. After homologation the nose landing gear can be mass-produced and fitted to the aircraft for which it was designed.

Chapter 3. Conclusions regarding the current stage of modeling and designing the nose landing gear of military training aircraft

From the analysis of the current state of research on the nose landing gear of military school and training aircraft, important conclusions are drawn based on which the objectives and research directions detailed in chapter 4 are established. The study of the specialized literature demonstrates the existence of a relatively large number of works scientific studies addressing multiple aspects of the construction and operation of landing gear in general and the nose landing gear in particular for civil aircraft, military combat aircraft and military school and training aircraft. The nose landing gear of military school and training aircraft addressed in the PhD thesis is a complex system considered to be critical to the operation of the aircraft which, in order to perform its functions, must meet a large number of requirements, the most important of which are considered to be: to be retractable, to be robust, to have sufficient strength to take over loads on landing, to absorb shocks, to have as little weight as possible, to withstand large temperature variations, to allow damping of shimmy vibrations, to can be locked in the extreme positions etc.

Left-right differential braking and/or left-right differential acceleration of engines are used on many aircraft, including military school and training aircraft of Romanian production, but they are characterized by low accuracy, additional fuel consumption and give satisfactory results only when the aircraft has a low travel speed.

The installation of a controlled steering system on the nose landing gear complicates the constructive solution and requires structural adaptations and coupling to the aircraft's hydraulic system, but any constructive solution adopted must preserve the robustness of the undercarriage and, in general, comply with the above-mentioned requirements.

The study of specialized literature demonstrated that there are several trends regarding the construction of landing gear, the most important of which are: the tendency to increase the role of electric drive (the MEA concept), the attachment of electric motors to the main landing gear, the development of hydraulic drives, the use of electro Hydrostatic drives (EHA), the use of sensors and actuators, etc. Although in the literature these problems related to the construction of the landing gear are widely researched, a series of specific aspects regarding the effective construction of the controlled steering systems (constructive solutions, hydraulic resistance, free wheel-controlled wheel relationship, correlation of the travel speed with the angle of steering, system behavior in a complete cycle of the airplane taxiing → taxiing → takeoff → flight → landing → taxiing → taxiing) are less addressed.

Thus, summarizing the study on the current state of research on landing gear in general and the nose landing gear in particular, carried out in chapters 1 and 2, several conclusions can be formulated, of which the following are considered the most important:

- The landing gear of an aircraft is composed of the nose landing gear and two main landing gears. The landing gear is a complex system composed of structural elements, mechanisms, hydraulic components, electrical components, impact energy absorption and dissipation components, anti-shimmy devices and tire wheels.
- Additional attached components operating in conjunction with the landing gear may include the nose landing gear wheel steering system, main landing gear brakes, and electro-mechanical-hydraulic extension/retraction and landing gear locking mechanisms in the extended / retracted positions, and position sensors that signal the extended / retracted position of the train in the cockpit.
- The landing gear includes numerous components and sub-assemblies, and the structural elements support the very high stresses of the landing impact. The landing gear must withstand the weight of the aircraft during all phases of landing, take-off, landing and taxiing.

- The aircraft structure adjacent to the landing gear is designed with it, as it must provide attachment points for the gear, for the gear extension / retract mechanisms, for the extended / retracted locking mechanisms and position sensors that signal the extended / retracted position withdrawn from the train in the cockpit.
- The materials used to make the landing gear components must have high strength to support the weight of the aircraft at takeoff, when the military aircraft has a full load of fuel, crew, weapons, and ammunition, as well as the impact demands of landing.
- Landing gear materials must have good fatigue strength and protective coatings must withstand friction with airborne abrasive particles. The most used materials are high strength alloy steels and titanium alloys.
- Military aircraft generally have tricycle landing gear. The nose landing gear is placed in nose of the aircraft and the main landing gear is placed under the wings of the aircraft. If military aircraft are used on snow-covered terrain, then the landing gear is kept extended throughout the mission, and skis are fixed under the wheels.
- Landing gear, highly stressed component parts and subassemblies are part of NA 19500 Class I, i.e. parts or subassemblies of vital importance to the aircraft, the failure of which in flight, takeoff or landing may result in destruction of the aircraft structure, loss of control of the aircraft or injury to personnel on board.
- The landing gear provides a support and taxiing system for the aircraft during stall, takeoff, landing and for taxiing on the taxiways.
- Landing gear designers use modern design and analysis software tools to shorten design time and meet specification specifications.
- Landing gear manufacturers carry out theoretical and experimental research to incorporate the concept of MEA - More Electric Aircraft, for the drastic reduction of pollution during the manufacture and during the operation of the aircraft, but until now, the research results are used only in large commercial aircraft, as increased power sources on board aircraft and additional cooling of MEA components are required.
- A technical solution that combines electrical and hydraulic solutions is the EHA electro-hydrostatic actuation (Electro Hydrostatic Actuation) which includes electric motors, hydraulic pumps, and specialized actuators, governed by a common controller and its own software system. The EHA package has the advantage that it does not need hydraulic pipes and can be installed right next to the actuated object.
- None of the military aircraft of the Romanian army (IAR 93 and IAR 99, both designed at INCAS Bucharest) has a system for the commanded steering of the nose landing gear wheel. At low cruising speeds, these aircraft can steering by left-right differential braking. In flight, these aircraft change direction of flight by rotating the control surface called "rudder" mounted in the aircraft's vertical fairing by depressing the rudder pedals in the cockpit.
- Lack of controlled steering system, i.e. the current "freewheel" mode, means more fuel consumption for steering are not very accurate and anti-shimmy devices need to be installed.

- The Romanian Army has purchased F16 fighter aircraft and will purchase F35 fighter aircraft soon. These aircraft have a controlled steering system of the nose landing gear wheel.
- For the training of military pilots, a command steering system is required on the existing IAR 99 school and training aircraft, as well as on the future IAR 99NG school and training aircraft, both designed at INCAS Bucharest.
- The design of the nose landing gear is done in two distinct stages: the conceptual design in which the technical data about the aircraft is not fully known and the detailed design in which all the technical data are established and the execution documentation for the nose landing gear is provided.
- After the design and realization of the prototype, the nose landing gear is subjected to a special homologation procedure, whereby three copies of the product are manufactured and subjected to homologation tests.
- The nose landing gear is considered homologated, if the three copies passed all the conditions of the tests to which they were subjected, and the landing gear can be manufactured in series and can be mounted on the aircraft for which it was designed.
- The most important part of the nose landing gear with controlled wheel is the controlled steering actuation system, and as a component part of this system, the most important subsystem is the controlled steering device.

Chapter 4. The directions, the main objective and the methodology of research and development of the steering device for the nose landing train of military and training aircraft

4.1. Aspects regarding the situation of military aircraft produced in Romania

Based on the conclusions resulting from the analysis of the status, the following aspects regarding the situation of the aircraft produced in Romania regarding the increase in the performance of the nose landing gear of military school and training aircraft are:

- The Romanian army as a member of the NATO alliance has purchased F16 fighter aircraft and, soon, will purchase F35 fighter aircraft. These aircraft have a controlled steering system of the nose landing gear wheel, and therefore it is required that the military school and training aircraft that will be designed and manufactured in Romania be equipped with a similar system of controlled steering of the nose gear wheel of landing;
- None of the military aircraft of the Romanian army (IAR 93 and IAR 99, designed before 1989 at INCAS Bucharest) has a system for the commanded steering of the nose landing gear wheel; at low cruising speeds, these aircraft can steering by left-right differential braking, but the steering is not precise and involves more fuel consumption;

- For the training of military pilots, a controlled steering system is needed both for the existing IAR 99 aircraft, but especially for the future IAR 99NG school and training aircraft, which will be designed at INCAS Bucharest;
- Considering the conflict triggered by the Russian Federation by invading Ukraine, a conflict that is taking place very close to Romania's borders, any improvement made to the existing military aircraft (IAR 99) and future aircraft (IAR 99NG) of the Romanian army is a great advantage as they should be equipped with a controlled steering system of the nose landing gear wheel.

4.2. Research directions

The analysis carried out in the first three chapters regarding the current state of research and development of the landing gear of military school and training aircraft allows the formulation of research directions within the doctoral thesis, thus:

- Establishing the main subsystems of the nose landing gear of military school and training aircraft.
- Carrying out theoretical and experimental research on the design and experimental testing of the most important subsystems of the nose landing gear of military school and training aircraft manufactured in Romania.
- Sizing of the component elements of the nose landing gear of military school and training aircraft.
- Detailed design and testing of the most important part of the nose landing gear with controlled wheel, namely the controlled steering actuation system and, within it, the most important subsystem which is the controlled steering device.
- Determining the cornering stability conditions according to the aircraft's runway speed.

4.3. Research hypotheses

The research assumptions are based on the further development of the IAR 99 school and training aircraft and the production launch of the IAR 99NG aircraft in the near future.

4.4. The main objective of research-development activity

Taking into account the conclusions drawn from the analysis of the current state, as well as the directions of research and development regarding the increase in the performance of the nose landing gear of military school and training aircraft, it is established as ***the main objective of the doctoral activity***: **Redesign of the nose landing gear of military aircraft of school and training manufactured in Romania, having as its central element the research and development of a controlled steering system, in order to increase the performance of the train and create better conditions for the training of military pilots.**

It is proposed that this objective be achieved by structuring it into four ***specific objectives***:

- **OS1.** Detailed design of the most important subsystems of the nose landing gear, namely the controlled steering device and the controlled steering system;
- **OS2.** Determination of the constructive and functional characteristics of the nose landing gear;
- **OS3.** Simulation of the operation of the controlled steering device;
- **OS4.** Experimental validation of the results obtained through the conception, design and simulation of the steering control device.

4.5. Research and development methodology

The research-development methodology used in the doctoral thesis is subscribed to the realization of the main objective, the specific objectives as well as the formulation of future research directions.
Without being a goal, the applied methodology involves the implementation of original patented and/or patentable solutions, modeling and simulation, the realization of experimental determinations as a natural requirement of solving highly complex problems, imposed by the topic of the doctoral thesis.
To achieve the objectives of the doctoral thesis, a methodology compatible with the training of skills at level 8 of the European Qualifications Framework (EQF) and the National Qualifications Framework (CNC) [P07] was adopted. One of the fundamental aspects of the adopted methodology is the structuring of the doctoral thesis in two main parts, namely a first part in which the current state of achievements in the field of the topic is analyzed and a second part in which the author's contributions are detailed. In the first part of the thesis, a critical-constructive analysis of the current state was carried out in accordance with ensuring the cognitive dimension (knowledge) of learning outcomes [P07] which requires "systematic, advanced knowledge of concepts, research methods, controversies and new specific hypotheses" so that it is possible to "appreciate the state of theoretical and methodological knowledge as well as identify the knowledge and application priorities of the fields" and, on this basis, establish research directions.
Having the proposed objective, the problem of making a nose landing gear with controlled wheel, was divided into several stages corresponding to the chapters of the second part of the thesis, in which the author, through personal contributions, solves a series of specific problems to achieve the proposed objectives.

The second part of the thesis relates both to the proposed objectives and to ensuring the scientific level corresponding to the "Recommendation of the Council of the European Union of May 22, 2017, regarding the European Qualifications Framework for lifelong learning" [P07]. Thus, in this case as well, both cognitive aspects were considered through theoretical developments and the application of advanced methods, as well as those corresponding to the level of skills through "conceiving and carrying out original research, based on advanced methods that lead to the development of scientific knowledge and of research methodologies" [P07]. Finally, it should be mentioned that to achieve the objectives of the thesis, an interdisciplinary approach is needed in solving theoretical and practical problems.

All these aspects are structured in the second part of the work on several stages, as follows:

- Conception and detailed design of the main subsystem of the nose landing gear of the IAR 99NG aircraft, respectively the controlled steering device;
- Designing the hydraulic circuit of the controlled steering device;
- Establishing the conditions in which the controlled steering system ensures operation with controlled wheel and, respectively, free wheel and the theoretical-experimental research of all aspects related to the two operating regimes;
- Establishing a complete operating cycle: exiting the hangar, taxiing, take-off, training flight, landing, taxiing, parking in the hangar;
- Creating mathematical models regarding the relationship between the wheel steering angle, the control angle of the tiller and the running speed, in order to determine the stability conditions when steering;
- Designing the assembly technology of the ordered steering device as well as standardizing the assembly operations;
- Calculation of the constructive-functional characteristics of the nose landing gear by adapting existing methodologies in the literature, to the specific case of the IAR 99NG aircraft, based on the main characteristics imposed;
- Choosing tires using advanced multicriteria analysis methods;
- Calculation of the moment of friction at the steering using the most appropriate methods;
- Study of the kinematics of the controlled steering device;
- Simulating the operation of the controlled steering device in order to choose some characteristics of the hydraulic actuation cylinders, with the aim of achieving a compact and reliable construction under the conditions of external temperature and pressure variations, which require the entire aircraft;
- Creation of an experimental stand with the help of which to check the functional parameters of the hydraulic cylinders for cornering;
- Comparison of the simulation results with those obtained experimentally of the functional parameters of the hydraulic cylinders for cornering;
- Analysis of failure modes of the controlled steering system and establishment of risk reduction measures using advanced analysis methods.

Some elements of the previous landing gear (wheel fork, torsion arms, shock absorber, etc. - detailed in chapter 5) were taken from the IAR 99 aircraft (freewheel variant) and are not the scientific subject of the doctoral thesis. The previous freewheel landing gear, currently existing on the IAR 99 aircraft, has been modified and adapted to allow the installation of the new commanded steering system and some of its specific landmarks.

4.6. Limits of scientific research conducted in the doctoral thesis

The research carried out in this doctoral thesis is only valid for the characteristics of the IAR 99NG aircraft, but based on this research, the results can be easily adapted for other types of aircraft or for other military and civil applications, for which the implementation of the controlled steering system is desired: IAR 99, IAR 99 SM and IAR 99 TD.

Chapter 5. The conception and design of the ordered steering system

According to the research and development objective and methodology, detailed in chapter 4, the previous freewheel landing gear, currently existing on the IAR 99 aircraft, was modified and adapted to allow the installation of the new commanded steering system and specific landmarks of it on the new IAR 99NG school and training military aircraft. The redesign of the previous landing gear is based on the author's technical-scientific skills and competences both in gearless landing gear [N03] and in the construction and operation of military aircraft in general [N11, N13, N14, N15, N17, N18 – N28]. Nine of the author's ten patents [N21-N26, N27 – Annex II] are related to the development of the controlled steering landing gear which is the subject of this PhD thesis.

The yaw control system is a part of the nose landing gear that includes the yaw control device, linkages (such as the equal bending resistance bar), digital electronic yaw command and control (BED) block, sensors, circuit hydraulic, isolation and protection valves, overpressure valve, vent valve and other specific elements.

5.8. Designing and establishing the technical specifications of the ordered steering system

The nose landing gear, designed by the author, is presented in figure 5.22 and allows the aircraft to move in a controlled steering mode in all phases of movement, by rotating the mobile subassembly of the nose landing gear, with the help of a servomechanism, controlled by means of a block electronic steering command and control (BED), where the command signal is proportional to the control angle of the tiller in the cockpit.

The moving and maneuvering phases on the ground are carried out with the airplane powered by its own engine and the on-board systems functional, within the limits of normal parameters.

The steering system allows the aircraft to be maneuvered on the runway, with the propulsion engine stopped, with the on-board systems inoperative, but with the steering system in FREEWHEEL mode, by towing with suitable airport means.

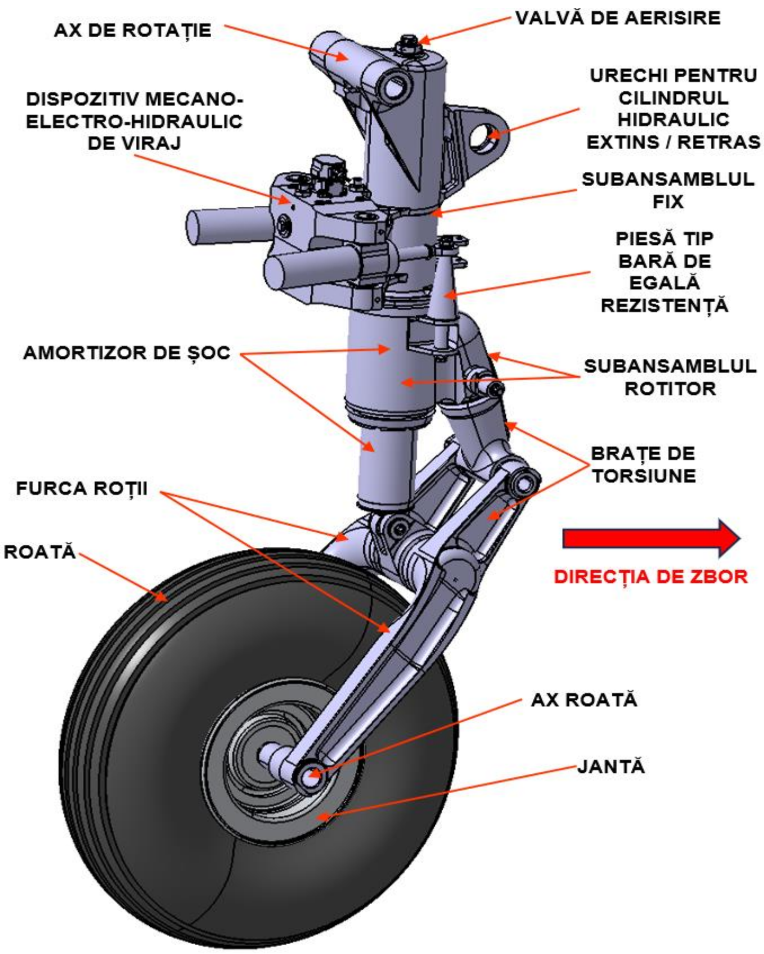


Fig. 5.22. The nose landing gear of the IAR 99NG aircraft

The controlled steering system of the nose landing gear, designed by the author, is shown in figure 5.23.

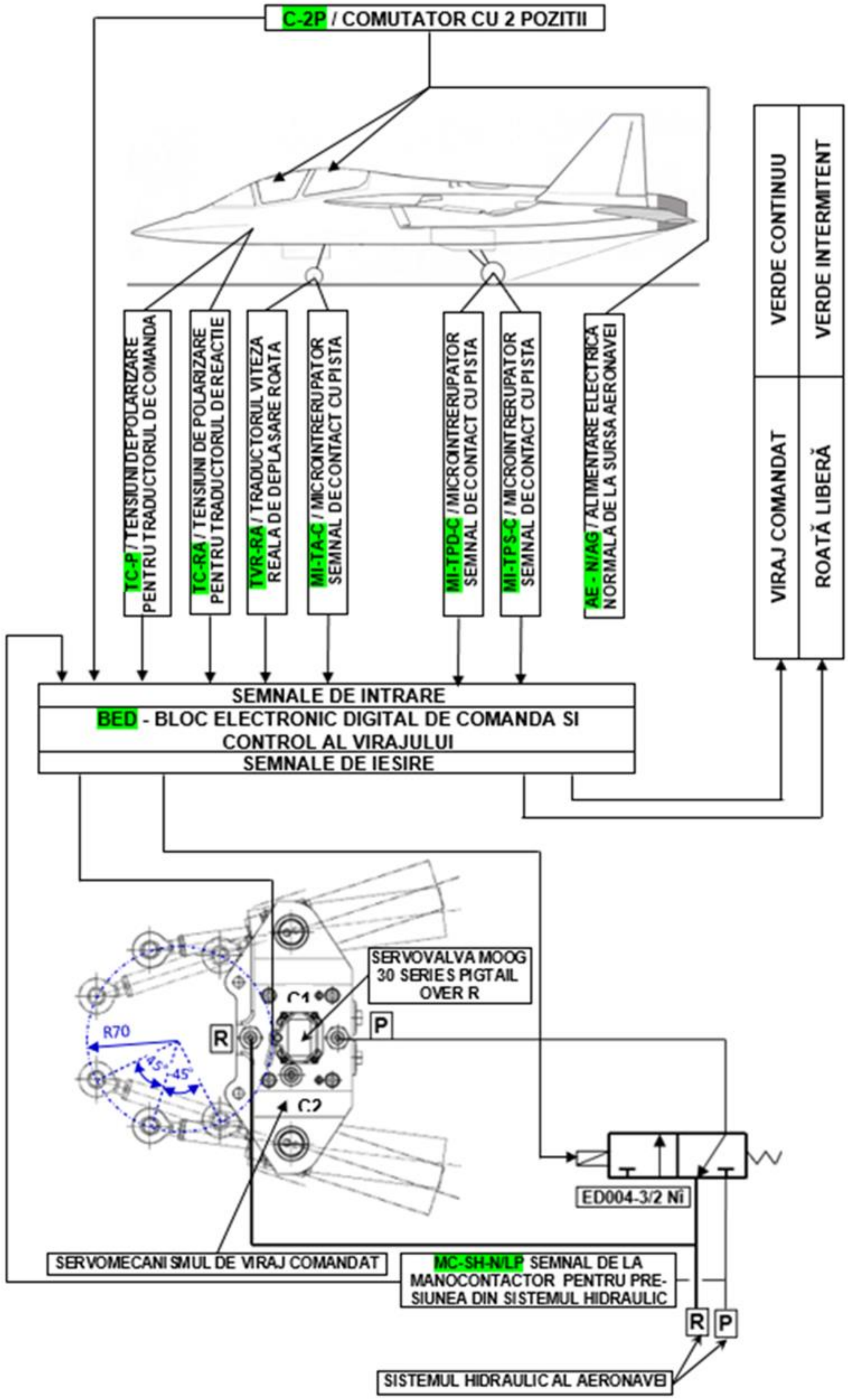


Fig. 5.23. Nose landing gear controlled steering system

The principal diagram of the hydraulic circuit for controlled steering is shown in figure 5.24, and the way of using the controlled steering system of the nose landing gear is shown in figure 5.25.

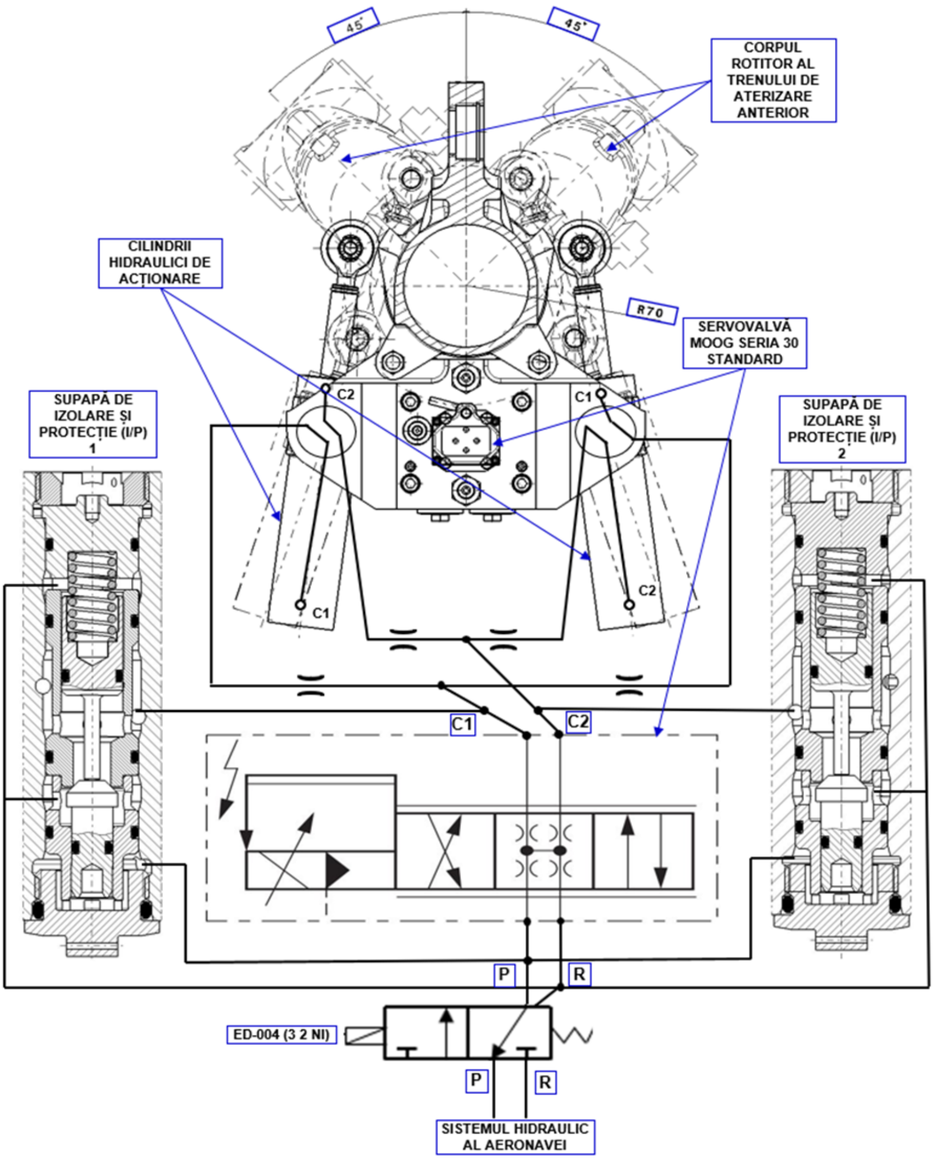


Fig. 5.24. Principle diagram of the hydraulic circuit for controlled steering

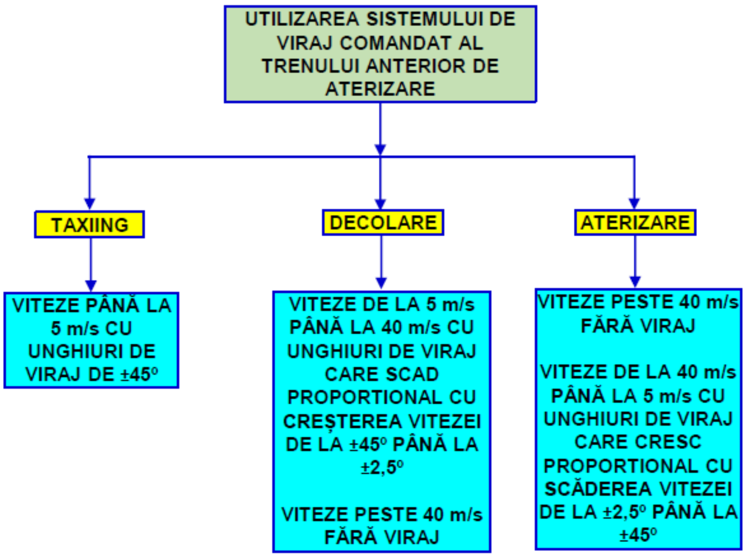


Fig. 5.25. How to use the nose landing gear-controlled steering system

In controlled steering mode, all the pairs of values (*V, γ*) located below the graph constitute the cornering stability zone. Practically, at speeds lower than 5 m/s the steering angle of the wheel *γ* can take the maximum value of 45^o. With the increase of the airplane's running speed, the steering angle of the wheel *γ* is more and more limited, reaching the maximum allowed value of 2.5^o at the speed of up to 40m/s. At speed values higher than 40 m/s, the nose landing gear wheel becomes FREEWHEEL and the variation of angle *γ* with speed *V* loses its meaning.

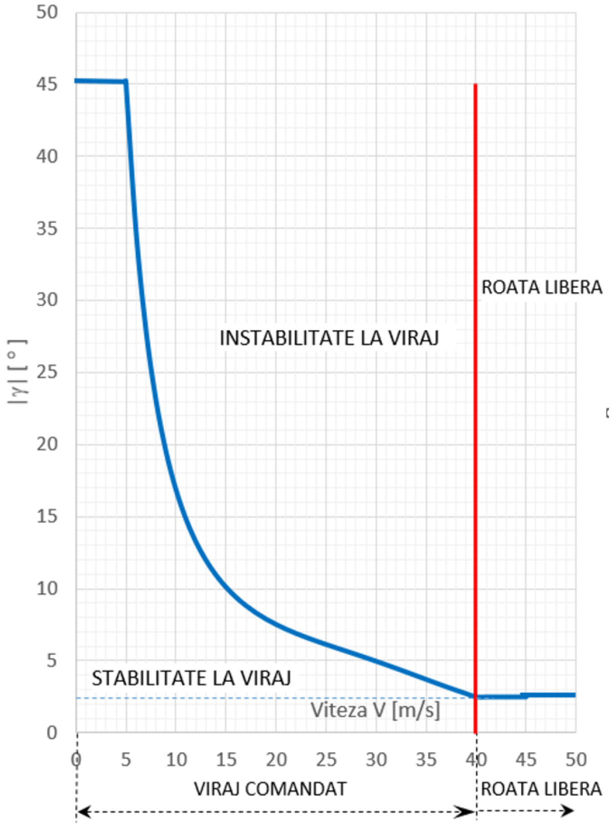


Fig. 5.31. Cornering stability curve

The steering stability equation, the steering stability curve and the steering stability zone are particularly important elements in the design of the steering control system and the entire nose landing gear of the aircraft.

Chapter 6. Contributions regarding the design of the assembly technology of the ordered steering device

6.1. General aspects regarding assembly

In the fifth chapter, the conception and design of the controlled steering system of the IAR 99NG aircraft (figure 5.23 and 5.24) was presented, which is composed of the digital electronic block of the steering command and control (BED), sensors, signal lamps and switches in the pilot cabins and from the electro-mechanical-hydraulic steering device (figure 5.1 and 5.2), consisting of the hydraulic block with the two hydraulic actuation cylinders.

The assembly technology of the ordered steering device is very important to guarantee the quality of the assembly of all the parts and sub-assemblies leading to a functional assembly according to the specifications of the author (designer). Since the design stage, technical solutions have been thought of to prevent wrong assembly, but nevertheless, it is necessary for the assembly technology to detail all the technical aspects of each assembly stage.

The technological activities of assembling the ordered steering device were divided into three distinct stages:

- **Stage 1.** Assembly of hydraulic actuation cylinders that have been designed as left-right interchangeable subassemblies, but have only one correct, constructively guaranteed installation position in the upper subassembly (§ 6.2).
- **Stage 2.** Assembly of the hydraulic block (§ 6.3).
- **Stage 3.** Assembly of the ordered steering device on the nose landing gear (§ 6.4).

At the end of each assembly step, the author presents an assembly diagram and the specific assembly cycle, and at the end the total time required for assembly is calculated.

6.5. Conclusions regarding the installation of the ordered steering device

The total time to assemble the ordered steering device is 355 minutes as shown in Table 6.1.

Table 6.1. The total time to assemble the ordered steering device

Nr.	Etapa de asamblare	Timpul necesar [minute]
1	Montajul cilindrilor hidraulici de acționare	160 (80 +80)
2	Montajul blocului hidraulic	125
3	Montajul dispozitivului de viraj comandat la trenul anterior	70
	Timpul total de montaj	**355**

Chapter 7. Contributions on the calculation of constructive-functional features of the landing gear

7.1. Calculating the features of the landing gear

Landing loads represent the greatest stresses on an aircraft's landing gear, particularly due to impact energy with the taxiway. Normally, the aircraft touches the taxiway with the main landing gear equipped with a braking system to reduce taxi speed. After reducing ground speed, the nose landing gear will touch the taxiway and the aircraft will continue to taxi with all wheels on the ground. The wheels of the landing gear, in contact with the taxiway, form a triangle called the stability triangle of the aircraft. The resultant of the forces acting on the aircraft (crosswind, landing on the side of the aircraft, with the main gear left or right, etc.) must be located inside the stability triangle of the aircraft. For the reasons stated above, it is necessary to calculate the landing loads and the positioning of the nose and main landing gear according to the position of the center of gravity of the aircraft and the weight of the aircraft.

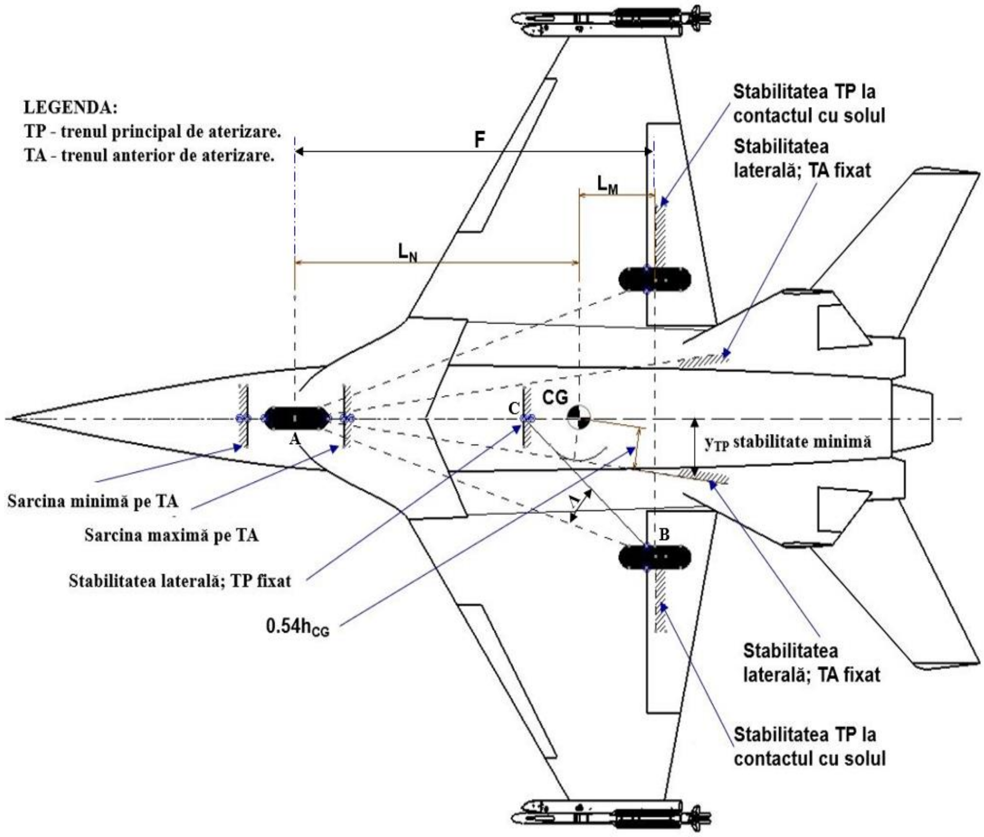


Fig. 7.4. Stability limits used when positioning trains [N04]

A summary of the above calculations is shown in figure 7.8.

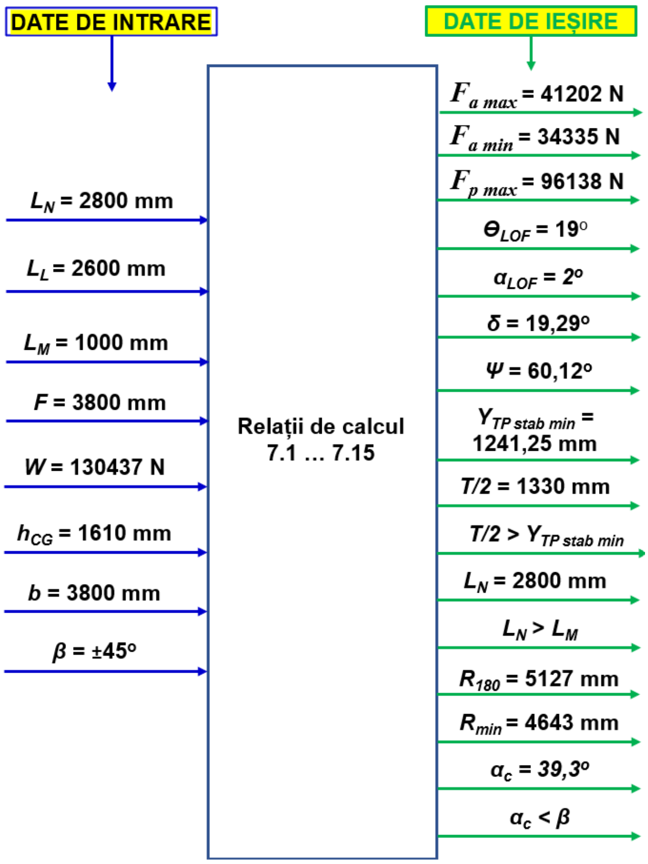


Fig. 7.8. Preliminary calculation of the landing gear of the IAR 99NG aircraft

7.2. Choosing the tires of the landing gear

7.2.1. The role and importance of tires

In both the military and civilian fields, tires are products of vital importance to the safety and smooth operation of aircraft. Aircraft tires have the following defining characteristics:

- are part of the landing gear of the aircraft;
- are the only parts of an aircraft that are in contact with the taxiway during parking, taxiing, take-off, and landing;
- support the entire weight of the aircraft during the afore mentioned phases;
- are very thermally demanding because they must withstand extreme weather conditions, i.e. all temperature variations of the ground, day, night, or depending on the climate zone where the aircraft is stationed or operates, and very low temperatures at high altitudes when the aircraft is in flight;
- must have very good resistance to friction (wear resistance) with the runway during landing, braking, and taxiing.

Another specific problem is that during the first moments of aircraft braking, until the peripheral speed of the tires becomes equal to that of the aircraft, there is sliding friction between the tires and the runway. That is why a lot of smoke is produced when the tires touch the road. After the peripheral speed of the tires becomes equal to that of the aircraft, rolling friction occurs which does not wear the tires as much as sliding friction [G09, M13, N10].

7.2.3. Choosing nose landing gear tires

The forces acting on the landing gear of the IAR 99NG aircraft were calculated in subchapter 7.1 and are presented synthetically in figure 7.8.

The Goodyear Military Tire Catalog is the only catalog that provides detailed information on tire construction, service rating, tread design, static loaded radius, deflated tire radius, aspect ratio and all tire rim information. From Section 4D, Type VII, based on preliminary screening [N10], an Aircraft Rib 18x5.5 tire is selected, with reference **185P4HG1**, Ply Rating 14, TL (tubeless), Rated Speed 239 mph (miles per hour), marked **TA1** and an Aircraft Rib 20x4.4 tire, part number **461B-3779-TL**, Ply Rating 14, TL (tubeless), rated speed 255 mph, rated **TA2**, both for the nose landing gear (TA) as shown in Table 7.1. Imperial units and the specific decimal separator, the point, are retained to avoid confusion.

Table 7.1. Tire and Rim Specifications (Imperial Units)

Denumirea caracteristicii	**TA 1**	**TA 2**	**Caracteristica Taguchi**
Size (Mărimea)	18x5.5	20x4.4	• NTB
Ply Rating (Numărul de straturi)	14	14	↑ GTB
Rated speed (Viteza nominală) (mph)	239	255	↑ GTB
Rated Load (Sarcina nominală) (lbs.)	6200	6500	↑ GTB
Rated Inflation (Presiunea de umflare) (psi)	215	265	• NTB
Maximum Braking Load (Sarcina maximă la frânare) (lbs.)	9300	9750	↑ GTB
Maximum Bottoming Load (Sarcina maximă la aplatizare) (lbs.)	18600	19500	↑ GTB
Static Loaded Radius (Raza la încărcarea statică) (Inch)	7.5	8.9	↓STB
Flat Tire Radius (Raza anvelopei dezumflate) (Inch)	6.3	8.10	↓STB
Aspect Ratio (Raportul de aspect)	0.869	0.901	• NTB
Rim size (Dimensiunea jantei) (Inch)	18x5.5	20x4.4	↓STB
Width Between Flanges (Lățimea între flanșe) (Inch)	4.25	3.50	• NTB
Specified Rim Diameter (Diametrul jantei) (Inch)	8	12	• NTB
Flange Height (Înălțimea flanșei) (Inch)	0.88	0.81	• NTB
Min Ledge Width (Lățimea minimă a marginii) (Inch)	1.50	1.28	• NTB

For choosing the optimal tire, it is very important to classify the 15 characteristics in the first column of Table 7.1 into the three categories established by Taguchi [A17]:

- Greater The Better – **GTB** (↑), for which the target value is theoretically infinite (or the highest competitor value) and the feature has a minimum acceptable value, $C \geq C_{min}$;
- Smaller The Better – **STB** (↓), for which the target value is theoretically zero (or the lowest value of competitors) and the feature has a maximum acceptable value, $C \leq C_{max}$;
- Nominal The Better – **NTB** (•), for which the target value is a well-established positive value, from which we must have as few deviations as possible, $C_{min} \leq C \leq C_{max}$.

The decision matrix for tire selection is presented in Table 7.12.

Table 7.12. The decision matrix

Tip anvelopă	**Pondere**	**TA1**	**TA2**
Maximum Braking Load	**0.386**	0.488	0.512
Maximum Bottoming Load	**0.249**	0.488	0.512
Rated Speed	**0.150**	0.485	0.515
Rated Load	**0.107**	0.488	0.512
Ply Rating	**0.054**	0.500	0.500
Size	**0.033**	0.527	0.473
Rated Inflation	**0.021**	0.552	0.448
Total / Scoruri decizionale	**1.000**	**0.493**	**0.507**

Based on the application of the Taguchi classification and the AHP multi-criteria analysis methodology, the TA2 tire was selected for the IAR 99NG aircraft, but the very close score obtained for the two tires shows that under certain conditions the TA1 tire can also be a viable option for the IAR aircraft's nose gear 99NG.

Chapter 8. Contributions on simulation of steering device operation

8.1. General aspects

The simulation of the operation of the controlled steering device was carried out using the SIMULINK module, part of the MathWorks MATLAB application. Because all the landmarks and subassemblies that define the nose landing gear and the nose wheel-controlled yaw device are fully defined, it is now possible and necessary to perform the simulations that allow them to be evaluated theoretically and experimentally.

The "Nose Landing Gear" assembly designed with the CATIA V5 CAD program comprises several sub-assemblies and a total number of over 180 individual landmarks.

Blocks are added to the rotational coupling between the fixed body and the rotating body (the one performing the steering movement) with the parameters of movement, changing the direction of the steering (left or right), converting the angular movement from radians to degrees and displaying angular values during the simulation, as shown in figure 8.7.

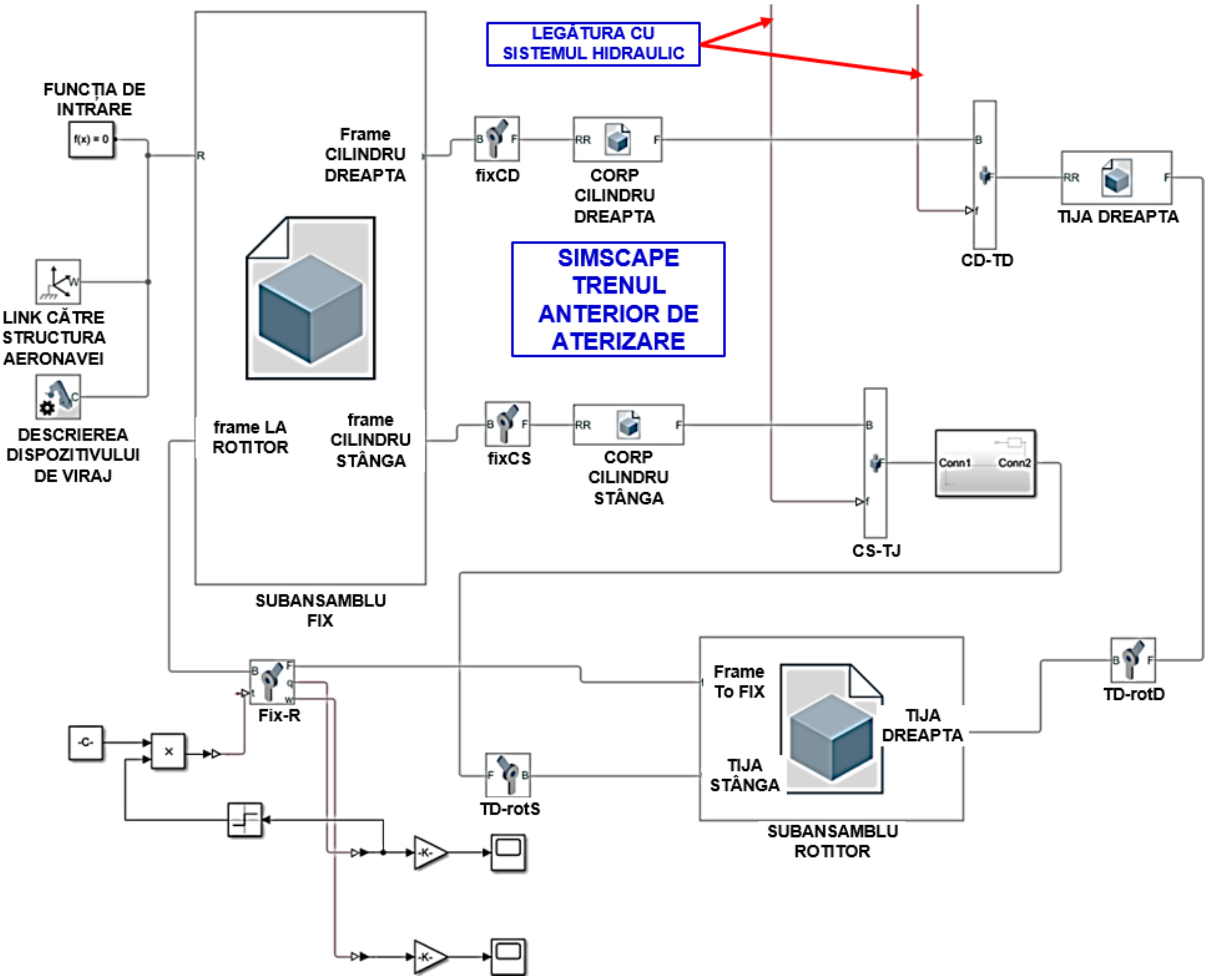


Fig. 8.7. Scheme of connection and conditioning of subassemblies in SIMSCAPE

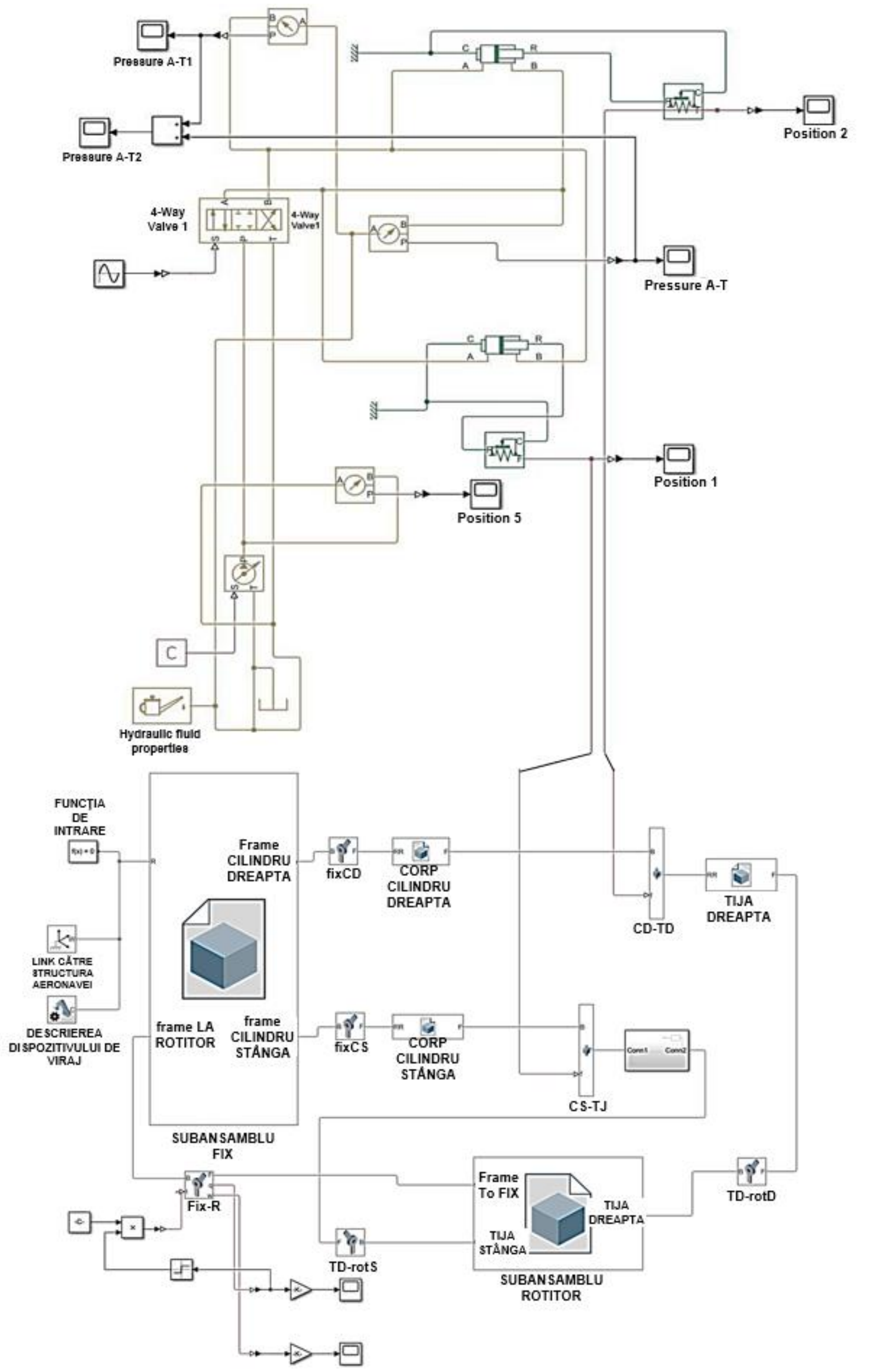


Fig. 8.9. The hydraulic supply circuit command, and control of the steering in SIMSCAPE

8.6. Presentation of the results of the simulation

The simulation demonstrated the correct operation of the nose landing gear assembly within the parameters used in the design, including the actuation system that includes the pair of hydraulic cylinders, as shown in figure 8.11.

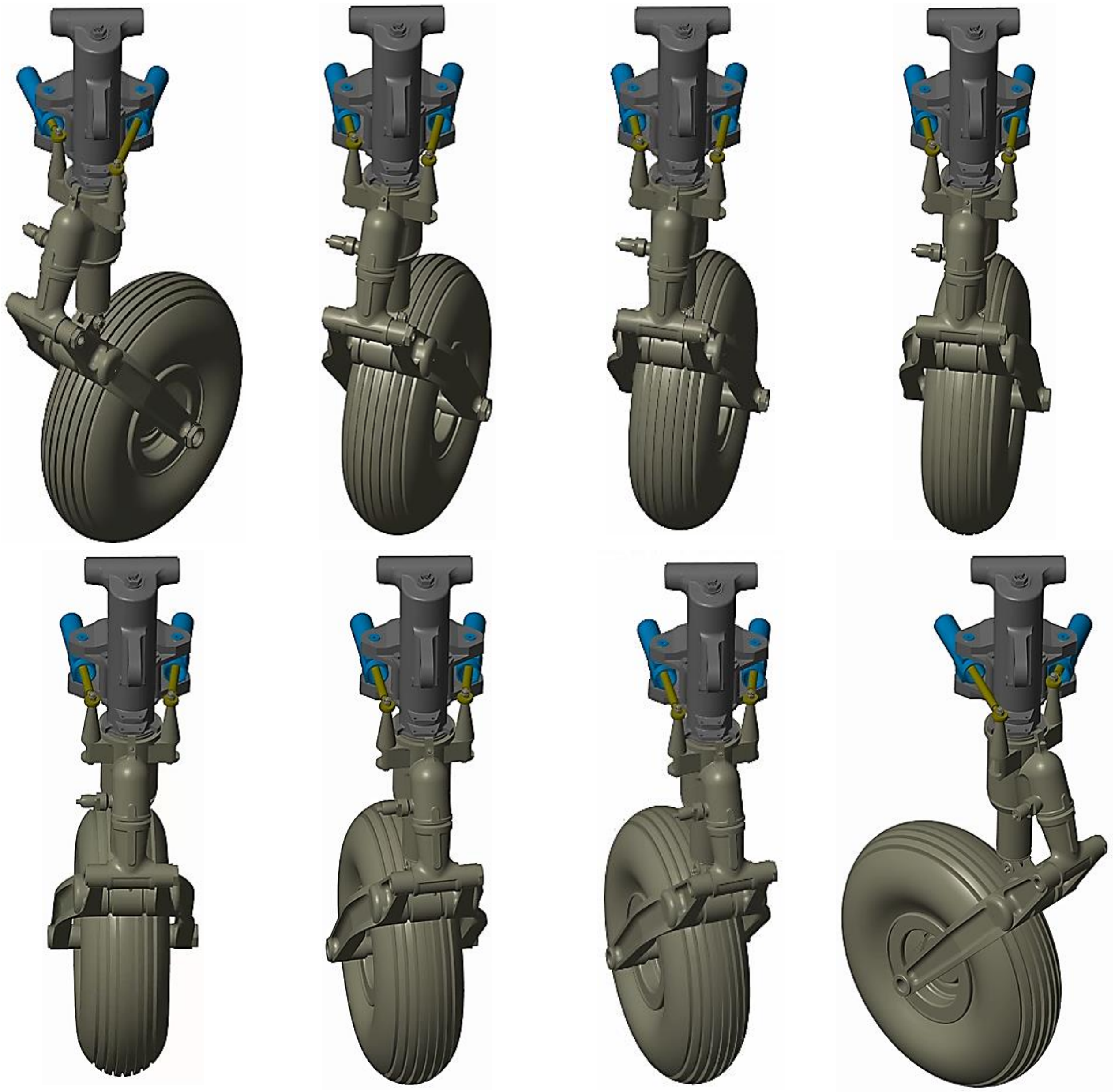


Fig. 8.11. Simulation of the operation of the nose landing gear

Also, based on the simulation, the average piston rod speed V_{mt}, the average expansion-retraction time t_m and the fluid temperature T_f were determined.

The simulation results for the two hydraulic steering actuation cylinders at hydraulic pressures of 15 MPa and 20 MPa are shown in Table 8.9.

Table 8.9. Simulation results for hydraulic actuation cylinders

Varianta de echipare	**Parametri înregistrați**			
	Presiunea hidraulică 15 MPa		**Presiunea hidraulică 20 MPa**	
T **M_f = 364,17 Nm** **A_T = 0,64 mm²**	V_{mt} - Viteza medie a tijei pistonului, mm/s	**15,783**	V_{mt} - Viteza medie a tijei pistonului, mm/s	**33,102**
	t_m - Timp mediu extindere-retragere, s	**7,127**	t_m - Timp mediu pentru o cursă completă stânga - dreapta, s	**3,591**
	T_f - Temperatura fluidului, °C	**20 - 21**	T_f - Temperatura fluidului, °C	**20 - 21**
	K_T	**1015,35**	**K_T**	**514,38**
D **M_f = 364,17 Nm** **A_D = 0,80 mm²**	V_{mt} - Viteza medie a tijei pistonului, mm/s	**19,930**	V_{mt} - Viteza medie a tijei pistonului, mm/s	**46,535**
	t_m - Timp mediu extindere-retragere, s	**5,544**	t_m - Timp mediu pentru o cursă completă stânga - dreapta, s	**2,390**
	T_f - Temperatura fluidului, °C	**20 - 21**	T_f - Temperatura fluidului, °C	**20 - 21**
	K_D	**635,52**	**K_D**	**273,57**
S **M_f = 364,17 Nm** **A_S = 1 mm²**	V_{mt} - Viteza medie a tijei pistonului, mm/s	**24,414**	V_{mt} - Viteza medie a tijei pistonului, mm/s	**53,380**
	t_m - Timp mediu extindere-retragere, s	**4,662**	t_m - Timp mediu pentru o cursă completă stânga - dreapta, s	**2,087**
	T_f - Temperatura fluidului, °C	**20 - 21**	T_f - Temperatura fluidului, °C	**20 - 21**
	K_S	**370,39**	**K_S**	**170,65**

The values obtained in Table 8.9 will be compared with those established based on experimental determinations in chapter 9.

Chapter 9. Contributions on the experimental determination of some features of hydraulic cylinders for steering

9.1. The purpose of experimental research

According to what is presented in the chapter. 7, the two hydraulic cylinders are interchangeable and act in tandem on the rotating body of the nose landing gear. To make the steering one of the cylinders expands and the other compresses, in a complex motion detailed in Chapter 7. Each hydraulic cylinder has a jacket inside it that is smooth on the inside $\boldsymbol{\emptyset 25_{0}^{0,033}(H8)}$, and with helical ducts outside it, acting as a hydraulic throttle (hydraulic resistance) for the compression (retraction) / expansion stroke of the hydraulic cylinder, with the aim of reducing the cornering angular speed in the safe range of angular speeds, to avoid oversteering aircraft, which can occur if the yaw rate is too high.
To carry out the experimental research, the author designed a stand presented in detail in subchapter 9.2. The experimental research was carried out with a hydraulic cylinder in which three types of interchangeable inner jackets were successively inserted, each with a certain profile of the helical channels (triangular, rectangular, and semicircular, according to those presented in chapter 8), so each with a specific hydraulic throttle (hydraulic resistance). The aim of the experimental research is to determine the displacement speed of the hydraulic cylinder rod according to the hydraulic throttle inserted through each type of inner jacket with helical channels. On the aircraft, during steering actuation, the speeds of the rods are correlated because they are mechanically linked to the rotating assembly of the nose landing gear as shown in figure 9.1.

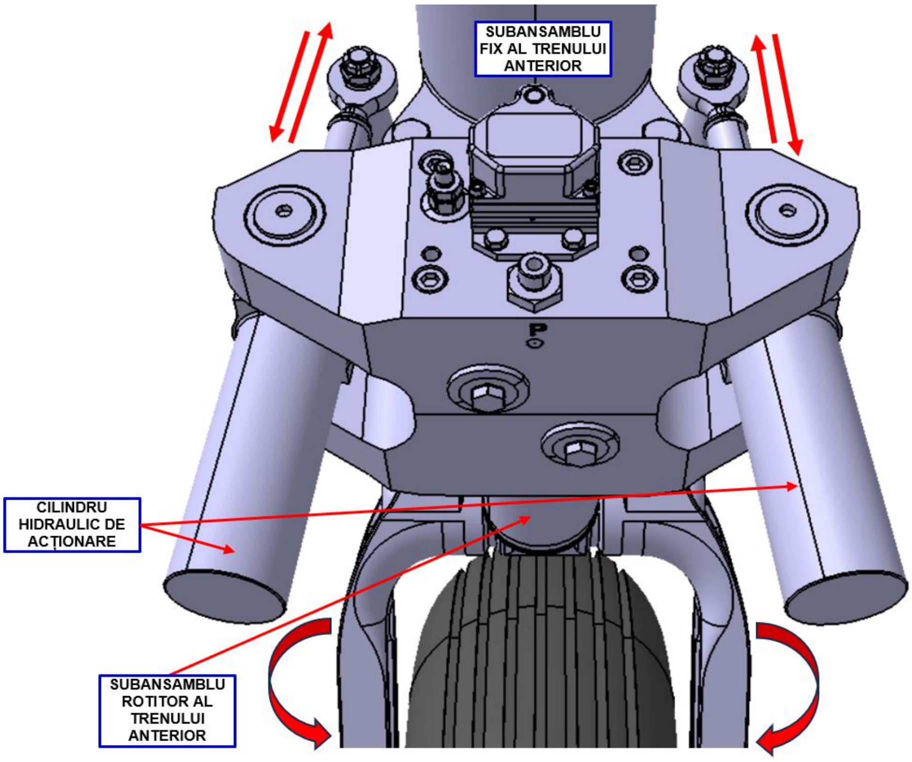
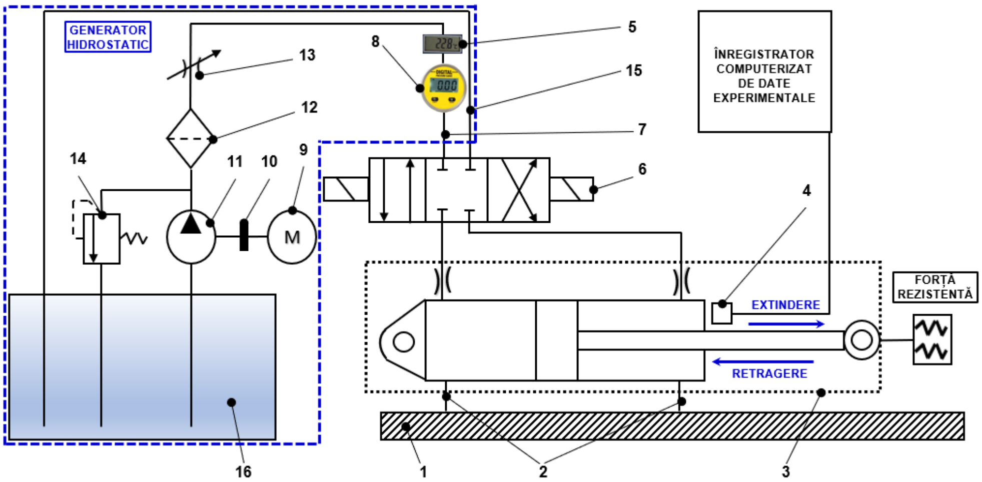


Fig. 9.1. Hydraulic drive for nose landing gear wheel steering

9.2. The conception and realization of the installation for experimental research

The scheme of the facility for experimental research designed and made by the author is presented in the figure 9.2.



1	Banc de încercări	9	Motor electric pentru antrenarea pompei
2	Suporți pentru cilindrul hidraulic	10	Cuplaj flexibil
3	Cilindru hidraulic cu drosel încorporat	11	Pompa hidraulică cu debit variabil
4	Traductor pentru viteza de deplasare a tijei cilindrului hidraulic	12	Filtru
5	Termometru digital sau analogic	13	Regulator de presiune
6	Distribuitor hidraulic cu patru căi și trei poziții, comandat electric 4/3	14	Supapă de siguranță
7	Conductă de presiune hidraulică (TUR)	15	Conductă hidraulică de RETUR
8	Manometru digital sau analogic	16	Rezervor pentru fluid hidraulic

Fig. 9.2. The scheme of the facility for experimental research

The installation for experimental research of the hydraulic cylinder for cornering is made up of:

- Test bench (1);
- Supports (2) for the hydraulic cylinder;
- Hydraulic cylinder with built-in throttle (3) subject to experimental research;
- Transducer for the displacement speed of the hydraulic cylinder rod (4);
- Hydraulic distributor with four ways and three positions, electrically controlled 4/3 (6);
- Simulator of the cornering force;
- Computerized recorder of experimental data, in real time;
- Hydrostatic generator.

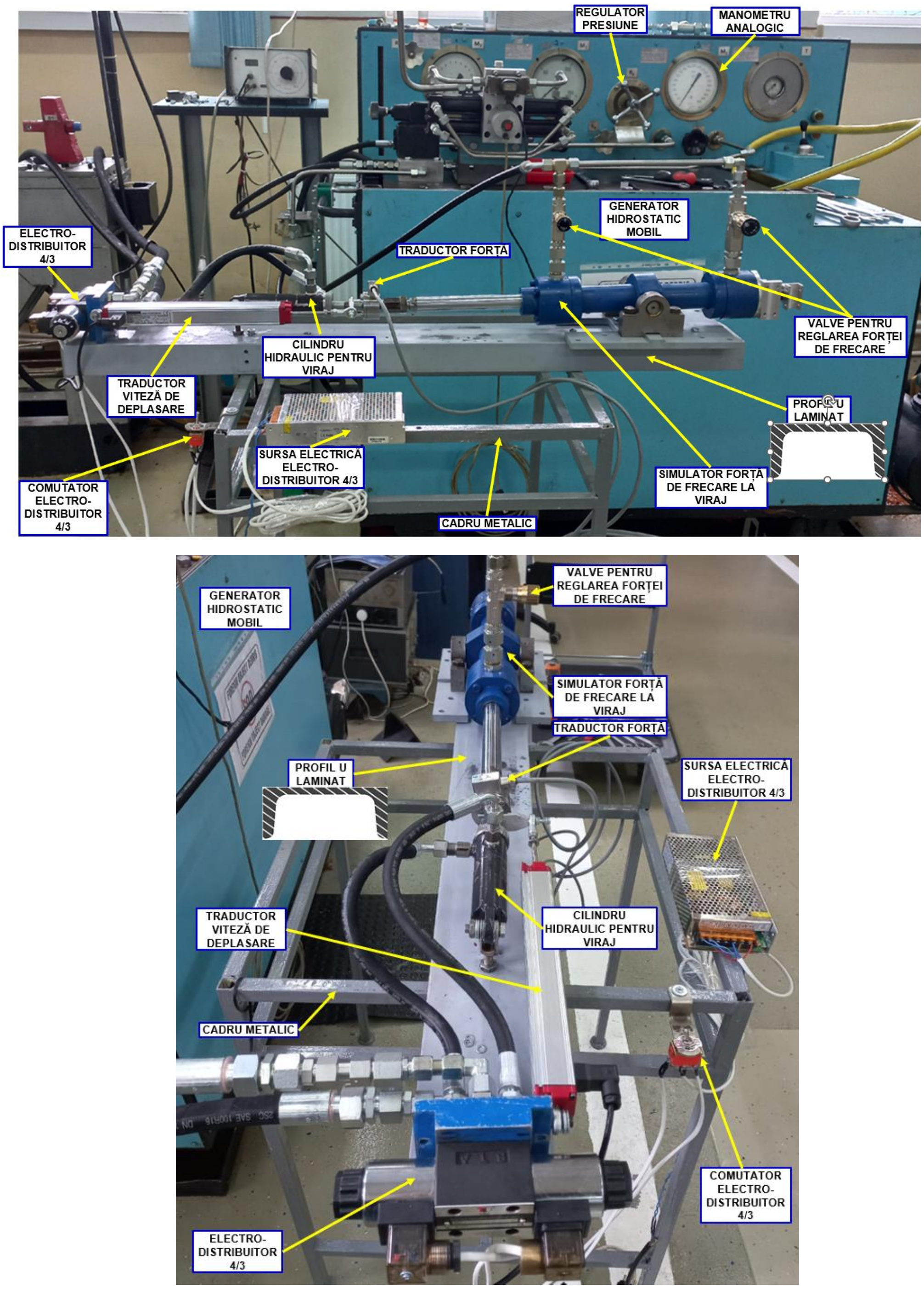


Fig. 9.6. Experimental research facility (side and longitudinal view)

9.4. Results of experimental research

The results of the experimental testing program are presented in Table 9.2.

Table 9.2. The results of the experimental testing program

Varianta de echipare	**Parametri înregistrați**			
	Presiunea hidraulică 15 MPa		**Presiunea hidraulică 20 MPa**	
T 3000 N $A_T = 0,64$ mm²	V_e - Viteza extindere, mm/s	19,0546	V_e - Viteza extindere, mm/s	38,1725
	V_r - Viteza retragere, mm/s	10,3637	V_r - Viteza retragere, mm/s	23,5283
	V_{mt} - Viteza medie a tijei pistonului, mm/s	**14,70915**	**V_{mt} - Viteza medie a tijei pistonului, mm/s**	**30,8504**
	t_m - **Timp mediu extindere-retragere, s**	**7,647**	t_m - **Timp mediu extindere-retragere, s**	**3,535**
D 3000 N $A_D = 0,8$ mm²	V_e - Viteza extindere, mm/s	25,2366	V_e - Viteza extindere, mm/s	59,243
	V_r - Viteza retragere, mm/s	12,8336	V_r - Viteza retragere, mm/s	29,6485
	V_{mt} - Viteza medie a tijei pistonului, mm/s	**19,0351**	**V_{mt} - Viteza medie a tijei pistonului, mm/s**	**44,44575**
	t_m - **Timp mediu extindere-retragere, s**	**5,8055**	t_m - **Timp mediu extindere-retragere, s**	**2,5025**
S 3000 N $A_S = 1$ mm²	V_e - Viteza extindere, mm/s	30,8601	V_e - Viteza extindere, mm/s	66,0898
	V_r - Viteza retragere, mm/s	14,2683	V_r - Viteza retragere, mm/s	32,5785
	V_{mt} - Viteza medie a tijei pistonului, mm/s	**22,5642**	**V_{mt} - Viteza medie a tijei pistonului, mm/s**	**49,33415**
	t_m - **Timp mediu extindere-retragere, s**	**5,0445**	t_m - **Timp mediu extindere-retragere, s**	**2,2585**

The extension V_e and retraction velocities V_r of the rod of the hydraulic actuation cylinder when steering are determined by deriving the distance traveled by the rod as a function of the time taken to make the move. On the computer display where the displacement-time parameters are stored (figure 9.6), the ends of the extension and retraction strokes of the hydraulic cylinder rod are selected, and the speed calculation was performed automatically.

The average extension and retract velocities V_{mt} of the steering actuation hydraulic cylinder rod were calculated for the case where the two cylinders act in tandem for steering as in figure 9.1, in which case the actuation speed is average, because for each left and right steering, one cylinder expands and the other compresses (the rod retracts).

Real-time recording of displacement-time parameters for hydraulic cornering cylinder equipped with sleeve (throttle) with helical channels of triangular section - A_T = 0.64 mm2, hydraulic pressure of 15 MPa and 20 MPa is shown in figure 9.11.

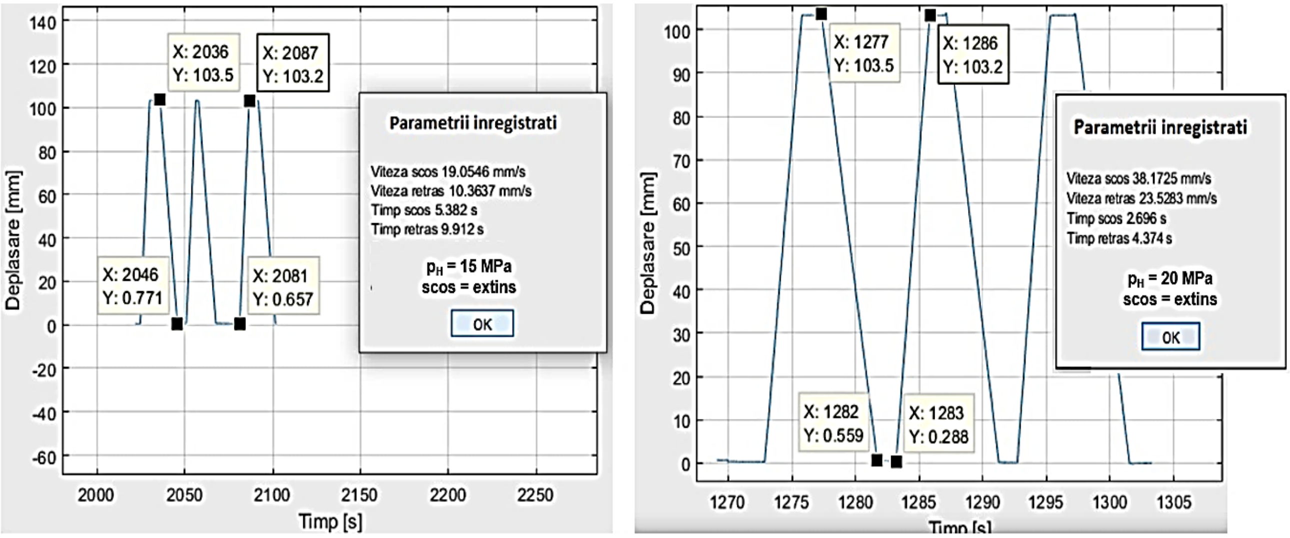


Fig. 9.11. Hydraulic cornering cylinder equipped with sleeve (throttle) with helical channels of triangular section - A_T = 0,64 mm^2

Real-time recording of displacement-time parameters for hydraulic cornering cylinder equipped with jacket (throttle) with helical channels of rectangular section - A_D = 0.8 mm^2, hydraulic pressure of 15 MPa and 20 MPa is shown in figure 9.12.

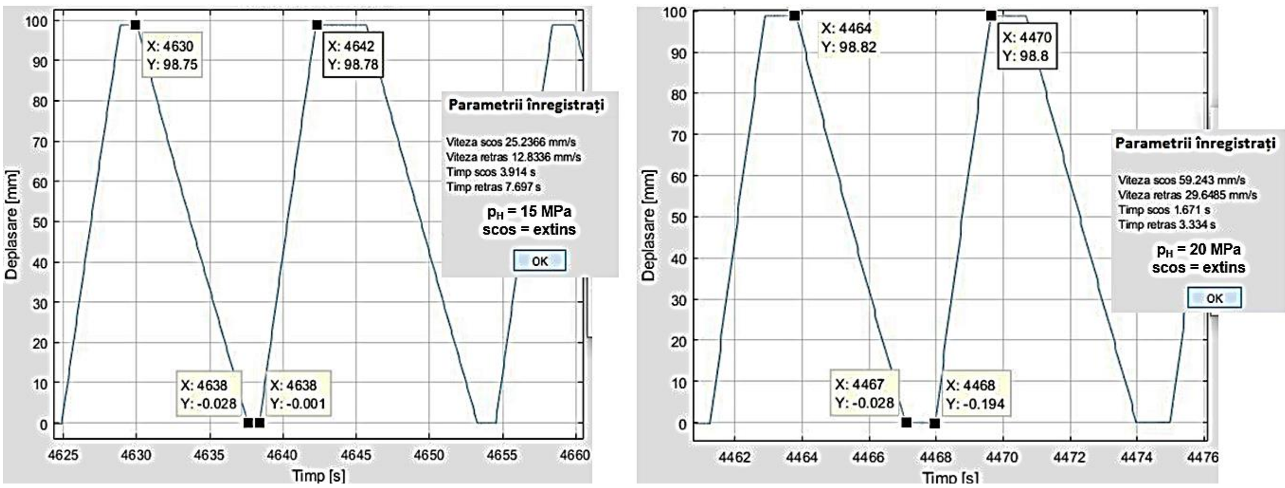


Fig. 9.12. Hydraulic cornering cylinder equipped with liner (throttle) with helical channels of rectangular section - A_D = 0,8 mm^2

Real-time recording of displacement-time parameters for hydraulic cornering cylinder equipped with sleeve (throttle) with helical channels of semicircular section - A_S = 1 mm^2, hydraulic pressure of 15 MPa and 20 MPa is shown in figure 9.13.

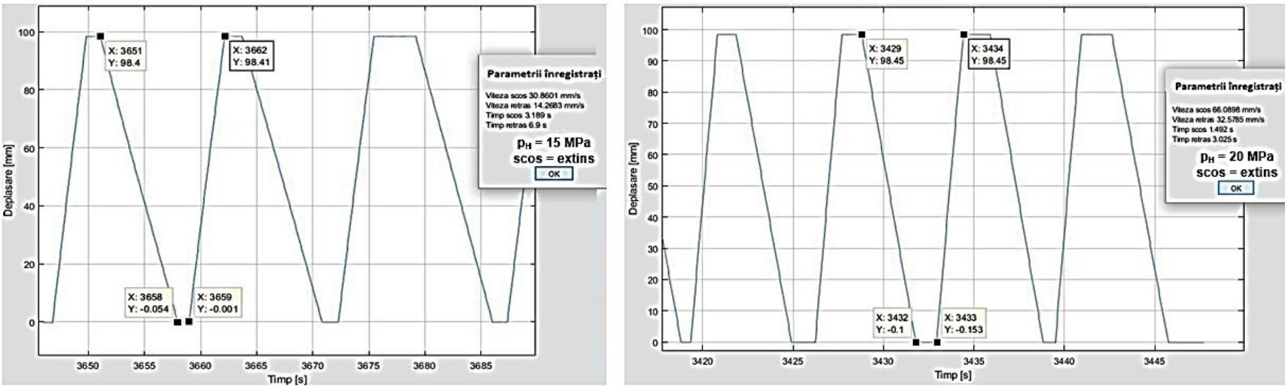


Fig. 9.13. Hydraulic cornering cylinder equipped with sleeve (throttle) with helical channels of semicircular section - A_S = 1 mm^2

The smaller the cross-sectional area of the helical channels, the lower the speed of the rod movement and, implicitly, the increase of the rod movement time. Also, rod travel speed is directly proportional to hydraulic pressure, and rod travel time decreases with increasing hydraulic pressure, as shown in Table 9.3.

Table 9.3. Synthesis of the results of the experimental testing program

Varianta de echipare	Parametri înregistrați			
	Presiunea hidraulică 15 MPa		Presiunea hidraulică 20 MPa	
T 3000 N A_T = 0,64 mm^2	V_{mt} - Viteza medie a tijei pistonului, mm/s	14,70915	V_{mt} - Viteza medie a tijei pistonului, mm/s	30,8504
	t_m - Timp mediu extindere-retragere, s	7,647	t_m - Timp mediu extindere-retragere, s	3,535
D 3000 N A_D = 0,8 mm^2	V_{mt} - Viteza medie a tijei pistonului, mm/s	19,0351	V_{mt} - Viteza medie a tijei pistonului, mm/s	44,44575
	t_m - Timp mediu extindere-retragere, s	5,8055	t_m - Timp mediu extindere-retragere, s	2,5025
S 3000 N A_S = 1 mm^2	V_{mt} - Viteza medie a tijei pistonului, mm/s	22,5642	V_{mt} - Viteza medie a tijei pistonului, mm/s	49,33415
	t_m - Timp mediu extindere-retragere, s	5,0445	t_m - Timp mediu extindere-retragere, s	2,2585

For the steering hydraulic cylinder equipped with the sleeve (throttle) with helical channels of triangular section - A_T = 0.64 mm^2, the average speed of the rod displacement is 14.70915 mm/s, at the pressure of 15 MPa, respectively 30 .8504 mm/s, at the pressure of 20 MPa, i.e. the maximum throttling among the three variants investigated experimentally.

For the steering hydraulic cylinder equipped with the sleeve (throttle) with helical channels of rectangular section - A_D = 0.8 mm^2, the average displacement speed of the rod is 19.0351 mm/s, at the pressure of 15 MPa, respectively 44 ,44575 mm/s, at the pressure of 20 MPa, i.e. the average throttling among the three variants investigated experimentally.

For the steering hydraulic cylinder equipped with the jacket (throttle) with helical channels with semicircular section - A_S = 1 mm^2, the average speed of the rod movement is 22.5642 mm/s, at the pressure of 15 MPa, respectively 49.33415 mm/s, at the pressure of 20 MPa, i.e. the minimum throttling among the three variants investigated experimentally.

In conclusion, for the steering actuation of the front landing gear wheel of the IAR 99NG aircraft, the medium version is preferred, i.e. the one with the hydraulic actuation cylinder equipped with a sleeve (throttle) with helical channels with a rectangular cross-section (equipment D), because the yaw rate is between the safe yaw limits of the yaw rate as in Table 7.14 and Figure 7.23 in Chapter 7.

9.5. Comparison between simulation results and experimental research

For the comparative analysis of the parameters resulting from the experimental research (Table 9.3) with the parameters obtained by numerical simulation (Table 8.9), it is considered that the most important parameters are the average speed of the piston rod V_{mt} and the average expansion-retraction time t_m.

The error ε was calculated taking the experimental values as a reference, based on the relationship:

$$\varepsilon = \frac{|E-S|}{E} \tag{9.1}$$

where E – represents the value obtained based on the experimental determination in chapter 9 and S – the value obtained by simulation in chapter 8.

Table 9.4. Comparison between simulation results and experimental research

Varianta de echipare	Parametri înregistrați	15 MPa			20 MPa		
		Experiment	Simulare	ε [%]	Experiment	Simulare	ε [%]
T A_T = 0,64 mm^2	V_{mt} - Viteza medie a tijei pistonului, mm/s	14,70915	15,783	7,31 %	30,8504	33,102	7,29 %
	t_m - Timp mediu extindere-retragere, s	7,647	7,127	6,80 %	3,535	3,591	1,58 %
D A_D = 0,8 mm^2	V_{mt} - Viteza medie a tijei pistonului, mm/s	19,0351	19,930	4,70 %	44,44575	46,534	4,69 %
	t_m - Timp mediu extindere-retragere, s	5,8055	5,545	4,48 %	2,5025	2,390	4,49 %
S A_S = 1 mm^2	V_{mt} - Viteza medie a tijei pistonului, mm/s	22,5642	24,414	8,19 %	49,33415	53,380	8,20 %
	t_m - Timp mediu extindere-retragere, s	5,0445	4,662	7,58 %	2,2585	2,087	7,59 %

Based on the centralized data in Table 9.4, it is calculated that, in the case of the average speed of the piston rod V_{mt}, the errors are between 4.69% in the case of channels with a rectangular profile (D) and 8.20% in the case of channels with a semicircular profile (S) , and in the case of the average expansion-retraction times t_m, an error variation is recorded between 1.58% for channels with a triangular profile (T) and 7.59% in the case of channels with a semicircular profile (S).

In the case of the average speed V_{mt}, the smallest error of 4.49% is recorded for equipment D (A_D = 0.8 mm^2).

The author considers these margins of error to be entirely acceptable given the multitude of factors that can influence values recorded through experimental research and simulation, respectively.
The errors determined in Table 9.4 are important in the case of adapting the results of the doctoral thesis for other types of aircraft, for sizing and simulating the operation of the system on the virtual prototype, to create a physical prototype as close as possible to the optimal solution.

Chapter 10. Contributions on analysis of nose landing gear failure modes and risk reduction measures

10.1. Choice of analysis method

One of the most important analysis methods to reduce failure risks is Failure Mode and Effects Analysis (FMEA), which was originally developed by the US military and used as a technique to assess the reliability and effects of equipment failures. However, the first important applications of the FMEA method are related to the development of the aerospace industry in the mid-1960s. FMEA is a methodology for systematically analyzing failure modes, prioritizing their importance, identifying system failure mechanisms, analyzing potential failure modes, and of the effects of these failures, followed by corrective actions, which are applied both in the conceptual stage and in the detailed design stage of the product. All approaches to FMEA methods in the scientific literature [B05, F07, G02, G03, I02, K03, N06, O02, Z02, Z03] converge to achieve three objectives, namely: the ability to predict the type of failure that may occur, the ability to anticipate the effects of the failure on system operation, and to establish steps to prevent the failure and its effects on system operation [B11, N06]. Due to these advantages, the FMEA method is frequently applied in the field of aviation [A10, C04, D11, F06], being used including by the author [N06].

10.8. Calculation of the Priority Risk Number (RPN)

To assess the risks and prioritize the removal of the causes of potential defects, the Risk Priority Number (RPN) is used, which is obtained by the product of three factors: the frequency of occurrence, the detection, and the severity of the effect, thus:

$$RPN = FREQUENCY\ OF\ OCCURRENCE \times DETECTION \times SEVERITY \quad (10.1)$$

For example, Table 10.4 shows how RPN was calculated for the first three parts (upper cylinder, piston rod and shock absorber). Similarly, the RPN was calculated for the other benchmarks, and the results were centralized in Table 10.5.

Table 10.4. Exemplu de calcul a RPN

Modalitatea de defectare	Frecvența de apariție	Detecția	Severitatea	RPN
Rupere/spargere	1	10	1	10
Rupere/spargere	1	10	1	10
Pierderea etanșeității	2	9	2	36

In general, using the priority criterion based on RPN, the priority order should be a function of failure mode with maximum RPN to minimum RPN. Most resources will be allocated to remove the cause of the potential defect with maximum RPN.

In Tables 10.4 and 10.5, column 10, the maximum RPN is 36 (higher than the maximum allowable value of 30), being specific to those parts or subassemblies of the front landing gear that include parts made of elastomers (sealing rings, tires, etc.).

10.9. Establishing measures and corrective actions

For determining corrective measures and actions, failure modes are ordered in descending order starting with the maximum value of the RPN. If the value of the RPN is greater than the accepted value (30), we impose corrective measures and actions to reduce this value. In this sense, the quality assurance department creates and transmits the necessary documentation regarding the recommended corrective actions, the way of materializing the corrective actions, as well as the nomination of qualified personnel to implement these corrective actions. Reducing the RPN value can be achieved by reducing the values of the three factors whose product gives this value, namely frequency of occurrence, detection, and severity.

No corrective actions are provided for the benchmarks and subassemblies in Table 10.5, column 11 that have RPN = 10. The corrective action for benchmarks and subassemblies in Table 10.5, column 11 with RPN = 36 > 30 is to enter the recommendations of the author (designer), Table 10.5, column 12, in the front landing gear assembly drawing, Table 10.5, column 13, which provides for the elimination of specific failure modes for parts and subassemblies that include parts made of elastomers.
These recommendations are:

- for the hydraulic shock absorber and for the ordered steering device: in the overall drawing it is specified "the replacement of the sealing rings after 8000 landings or after 8 years (whichever expires first)";
- For the tire: in the overall drawing it is specified "replacement of tires after 5000 landings or after 7 years (whichever expires first), in case of excessive wear or deep cracks".

10.10. Recalculation of the Priority Risk Number

If the RPN is above the established acceptable limit, corrective actions are required after application of which the RPN is recalculated. In the case of the FMEA Method for the design of the front landing gear, Table 10.5, columns 14 – 17, it was necessary to recalculate the RPN for the previously calculated values, which were greater than or equal to the maximum limit set RPN = 30. Thus for the three benchmarks for which corrective actions were introduced (hydraulic shock absorber, controlled steering device and tire), the frequency of occurrence was changed from grade 2 to grade 1 and, consequently, the RPN was recalculated to the value of 18 < 30 (Table 10.5).

10.11. FMEA method for nose landing gear design

Table 10.5 presents in detail the application of the FMEA method for the design of the front landing gear of the IAR 99NG aircraft, as presented above in subchapters 10.2 – 10.10.

10.12. Conclusions regarding the use of the FMEA method for design

The benefits of the FMEA method for the design of the front landing gear are to use the knowledge of the entire team involved in the analysis and design of the front landing gear of the aircraft in order to avoid design defects. The method used improves the quality, reliability and safety of the project and, implicitly, helps to increase the satisfaction and safety of the users of the product. It also reduces project development time, reduces design costs, and identifies risks and critical features for project quality.

The application of the FMEA method regarding the design of the front landing gear designed in the doctoral thesis allows the following conclusions to be drawn:

a. The low value of the RPN (below 30) for most of the benchmarks demonstrates the correctness of the solutions adopted in the design and assures us that no corrective actions are imposed on the project for these benchmarks/subassemblies;
b. The determination of exceeding the maximum threshold of the RPN for three points (the hydraulic shock absorber, the controlled steering device and the tire) allows the project to be improved by including some technical notes in the overall drawings, respectively: "the replacement of the sealing rings after 8000 landings or after 8 years (whichever expires first)" for the hydraulic shock absorber and the ordered steering device and "replacement of tires after 5000 landings or after 7 years (whichever expires first) in case of excessive wear or deep cracks" for the tire. These measures make it possible to restore the estimate of the frequency of occurrence of the failure from grade 2 to grade 1 and reduce the RPN from 36 to 18, which is thus within the maximum allowed limit of 30.

Table 10.5. Metoda FMEA pentru proiectarea trenului anterior de aterizare

Denumire reper sau subansamblu	Functia in cadrul trenului anterior de aterizare	Modul potențial de defectare	Efectul potențial al defectării	Cauza potențială a defectării	Condițiile existente					Acțiuni corective recomandate	Responsabil cu acțiunile corective	Rezultatele acțiunilor corective				
					Controale, încercări curente	Frecvența de apariție	Severitatea	Detecția	RPN			Acțiuni corective	Frecvența de apariție	Severitatea	Detecția	RPN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Cilindrul superior	Sistem de susținere și de rulare	Rupere / spargere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt	ing. Bogdan-Adrian Nicolin	Nu sunt	1	10	1	10
Tijă cu piston	Sistem de susținere și de rulare	Rupere / spargere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Amortizor hidraulic de soc	Absoarbe și disipează energia cinetică a impactului de aterizare	Pierderea etanșării	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	2	9	2	36	Coloana 13		În desenul de ansamblu se specifică înlocuirea inelelor de etanșare după 8000 de aterizări sau la 8 ani (care expiră prima)	1	9	2	18
Ax de rotație	Sistem de susținere și de rulare	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Urechi pentru cilindrul hidraulic	Extinderea și retragerea trenului de atrerizare anterior	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Dispozitiv de viraj comandat	Permite virajul aeronavei în timpul rulării la sol	Pierderea etanșării	Trece in regim ROATĂ LIBERĂ	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	2	9	2	36	Coloana 13		În desenul de ansamblu se specifică înlocuirea inelelor de etanșare după 8000 de aterizări sau la 8 ani (care expiră prima)	1	9	2	18
Came de aliniere	Permit alinierea rotii trenului anterior	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Brațul superior de torsiune	Amortizare la rularea pe pistă	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Brațul inferior de torsiune	Amortizare la rularea pe pistă	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Articulație cardanică	Sistem de susținere și de rulare	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Bolț articulație	Amortizare la rularea pe pistă	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Furca roții	Sistem de susținere și de rulare	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Axul roții	Suport pentru roată	Rupere	Catastrofic	Dimensionare și alegerea materialului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Jantă	Suport pentru pneu	Rupere	Deteriorarea trenului anterior	Spargerea pneului	Încercare la oboseală a prototipului (20000 cicluri)	1	10	1	10	Nu sunt		Nu sunt	1	10	1	10
Pneu	Sistem de susținere și de rulare	Spargere	Deteriorarea jantei	Suprasarcină	Încercare la oboseală a prototipului (20000 cicluri)	2	9	2	36	Coloana 13		În desenul de ansamblu se specifică înlocuirea pneurilor după 5000 de aterizări sau la 7 ani (care expiră prima), in caz de uzură excesivă sau fisuri adânci	1	9	2	18

Chapter 11. Final conclusions and main contributions on increasing the performance of the nose landing gear of military school and training aircraft

11.1. Final conclusions

Study of the current state of research and achievements regarding the front landing gear of military school and training aircraft, in general, and those related to the controlled steering system of the front landing gear wheel, in particular, as well as the research developed in the framework of the doctoral thesis allow the formulation of some final conclusions of the paper that can be summarized as follows.

1. Improving the performance of military school and training aircraft of the Romanian Army is a current research issue, technological developments in this direction being necessary and timely. Considering the military invasion of the Russian Federation in Ukraine, very close to Romania's borders, the author considers that any improvement to the existing military school and training aircraft (IAR 99, IAR 99SM), as well as future aircraft (IAR 99NG), of the Romanian Army is a great advantage. Equipping them with a controlled steering system of the wheel of the front landing gear allows future military pilots to train and acquire skills in using this system present on the existing F16 and F35 military aircraft, respectively, which will be acquired soon by the Romanian Army.
2. The military school and training aircraft of the Romanian Army (IAR 99 and IAR 99SM) do not have a system for the commanded steering of the front landing gear wheel, but at low travel speeds, they can steer by left-right differential braking, with the mention that steering is not very precise and requires more fuel consumption.
3. The controlled yaw system, designed by the author during his doctoral studies, allows performing controlled yaws of the front landing gear of military school and training aircraft and eliminating shimmy oscillations throughout operation. The author was actively involved in the theoretical and experimental research activity, starting in 2018, regarding the design of a controlled steering system for the IAR 99NG aircraft, which can be very easily adapted to the other military school and training aircraft (IAR 99 and IAR 99SM).
4. The landing gear is a complex system composed of structural elements, mechanisms, hydraulic components, electrical components, impact energy absorption and dissipation components, anti-shimmy devices and wheels with tires that are heavily stressed and belong to the class according to NA 19500, being items of vital importance to the aircraft.
5. Landing gear manufacturers are doing theoretical and experimental research to incorporate the MEA - More Electric Aircraft concept, but so far, the research results are only used in large commercial aircraft. A technical solution that combines electric and hydraulic actuation is the EHA electro-hydrostatic actuation (Electro Hydrostatic Actuation) which includes electric motors, hydraulic pumps, and specialized actuators, governed by a common controller and with its own software system.

6. The most important subsystem of the controlled steering system is the steering control device. For its design, original constructive solutions were used, patented by the author (patent granted by OSIM).
7. In the framework of the thesis, the cornering stability equation and the cornering stability curve were determined, respectively, which allow the delimitation of the cornering stability zone: at speeds lower than 5 m/s, the steering angle of the wheel γ can take the maximum value of 45^o and, with the increase of the aircraft's rolling speed, the steering angle of the wheel γ is more and more limited, reaching the maximum allowed value of 2.5^o at the speed of 40 m/s. At speed values higher than 40 m/s, the front landing gear wheel becomes a free wheel and the variation of the angle γ with the speed loses its meaning.
8. The assembly technology designed by the author establishes all the details regarding the assembly of the hydraulic actuation cylinders (author's patent), the assembly of the hydraulic block and the assembly of the controlled steering device.
9. Calculation of the main characteristic sizes of the landing gear of a military school and training aircraft, by adapting the existing methodologies in the specialized literature, to the specific case of the IAR 99NG aircraft, allowed the determination of the loads developed at landing, the position of the landing gear, the stability of the aircraft on landing, as well as setting the steering radius to 180^o.
10. For the pre-sizing of the steering actuators, the empirical method of determining the steering friction can be used, but for the detailed design it is necessary to use the analytical method.
11. The calculation of the actuation kinematics when steering with the system formed by the two hydraulic cylinders (patented solution) allowed the determination of the variation of the maximum active moment for the execution.

11.2. Main contributions on increasing the performance of the nose landing gear of military school and training aircraft

In relation to the current state and directions of research - development regarding the front landing gear of military school and training aircraft, it was established as the main objective of the research - development activity within the doctoral thesis: Redesign of the front landing gear of military aircraft school and training manufactured in Romania, having as its central element the research and development of a controlled turning system, in order to increase the performance of the train and create better conditions for the training of military pilots.

Other specific objectives of the research - development activity within the doctoral thesis consist of:

- Detailed design of the most important subsystems of the front landing gear, respectively the controlled turning device and the controlled turning system;
- Determination of the constructive-functional characteristics of the previous landing gear;
- Simulation of the operation of the controlled turning device;
- Experimental validation of the results obtained after the conception, design, and simulation of the controlled turning device of the front landing gear.

The relevant contributions regarding the research and development activity within the doctoral thesis, to achieve the main objective and, respectively, the specific objectives, in relation to the research and development methodology are the following:

- Conception and design of the electro-mechanical-hydraulic device for command and execution of the turn that includes the technical characteristics of the turning device (see § 5.2);
- The choice and integration of the MOOG servo valve that receives the electrical command from the cockpit and controls the hydro-mechanical execution of the turn (see § 5.3).
- The conception and design of hydraulic actuation cylinders with an inner jacket (throttle) to reduce the speed of movement when extending and retracting, thus reducing the angular speed of turning and determining their technical characteristics, through original solutions patented by the author (see § 5.4).
- Conception and design of the bars of equal bending strength that transmit the turning movement from the hydraulic actuation cylinders to the rotating subassembly of the front landing gear and the development of their resistance calculation (v. § 5.5).
- The design of special valves necessary for the operation of the controlled turning system, respectively: two isolation and protection valves, an overpressure valve and a venting valve (see § 5.6).
- The design of a sealing system and the establishment of all the characteristics of this system used in the electro-mechanical-hydraulic device for commanding and executing the turn (see § 5.4 and 5.7).
- Conception and establishment of the technical specifications of the controlled turning system for the front landing gear wheel; establishing the conditions under which the controlled turning system ensures operation with controlled wheel and free wheel, respectively, and the theoretical-experimental research of all aspects related to the two operating regimes; establishing a complete operating cycle: exiting the hangar, taxiing, take-off, training flight, landing, taxiing, parking in the hangar (see § 5.8).
- Creating mathematical models regarding the relationship between the wheel turning angle, the tiller control angle and the running speed and establishing, on this basis, the cornering stability conditions, as well as establishing the area and equation of the stability curve at turn (see § 5.8).
- Designing the installation technology of the hydraulic actuation cylinders and standardizing the installation operations (see § 6.2).
- Designing the hydraulic block assembly technology and standardizing the assembly operations (see § 6.3).
- Designing the assembly technology of the controlled turning device of the previous landing gear and standardizing the assembly operations (see § 6.4).
- The conception and use of a method for calculating the landing gear of a military school and training aircraft: the loads developed on landing, the position of the landing gear, the stability of the aircraft on landing and the determination of the turning radius at 180^{o} by adapting the

existing methodologies in the specialized literature, in the specific case of the IAR 99NG aircraft (see § 7.1).

- Conception and use of a tire selection method for the landing gear of a school and training military aircraft based on the application of the Taguchi classification and the AHP multicriteria analysis methodology (v. § 7.2).
- The design and use of two methods of calculating the turning friction moment for the front landing gear wheel for school and training military aircraft used in the sizing of hydraulic turning actuation cylinders (see § 7.3).
- Conception and realization of the calculation of the turning drive kinematics with two hydraulic cylinders for the front landing gear (patented solution) of military school and training aircraft (v. § 7.4).
- Conception and use of a method for calculating the functional parameters of the turning device of the front landing gear for school and training military aircraft (v. § 7.5).
- Calculation of the functional parameters of the controlled turning device of the front landing gear for school and training military aircraft using the Mathcad application and graphical analysis of the calculation results (v. § 7.6).
- Preparation for the import into SIMSCAPE of the functional subassemblies of the front landing gear (fixed and rotating) and the turning device designed in CATIA in the form of reduced 3D models (see § 8.2).
- Importing the functional sub-assemblies of the front landing gear and the commanded turning device, in the form of reduced 3D models in SIMSCAPE and then simulating with the SIMULINK application (v. § 8.3).
- Calculation of the hydraulic resistance of the inner liners (throttle) with different helical channels (T - triangular, D - rectangular and S - semicircular) for each constructive variant of the hydraulic actuation cylinders (see § 8.4).
- The design of the simulation program for the turn of the wheel of the front landing gear with the controlled turning device, with hydraulic actuation cylinders (see § 8.5).
- Processing the results of the previous landing gear wheel turn simulation (see § 8.6).
- Conception and construction of a stand for the experimental research of hydraulic actuation cylinders to validate the simulation results (see § 9.1 - § 9.2).
- The design of the experimental research program of hydraulic actuation cylinders successively equipped with three inner jackets (ducts) with different helical channels (T - triangular, D - rectangular and S - semicircular) (v. § 9.3).
- Realization of experimental research of hydraulic actuation cylinders (see § 9.4).
- Carrying out the comparative analysis of the parameters resulting from the experimental research with the parameters obtained by numerical simulation and the calculation of the percentage differences between the two determination methods (see § 9.4). The determined errors (4.69% for the average piston rod speed and 4.49% for the average expansion-retraction time, for ducts with a rectangular profile) are important in the case of adapting the results of the PhD thesis for other types of aircraft, for sizing and simulating the operation of the system,

on the virtual prototype to create a physical prototype as close as possible to the optimal solution.

- Analyzing the failure modes of the front landing gear, establishing risk reduction measures using advanced FMEA analysis methods for the project and improving the initial design by completing the documentation (see § 10).

* * *

The present doctoral thesis, through the approach, the theoretical and practical results obtained, develops the conditions for the research-development and production of a controlled turning system for the front landing gear of military school and training aircraft manufactured in Romania and for the realization of a front gear of high-performance landing like F16 fighter jets.

The scientific importance of this doctoral thesis is supported by the contributions made to the study, the theoretical-experimental research, and the calculation of some constructive-functional characteristics regarding the controlled turning system for the front landing gear of military school and training aircraft manufactured in Romania, which eliminates the shimmy phenomenon.

The practical importance of the doctoral thesis has as its basic element the fact that the research-development methodology, the models and means of work, the data and the actual results of the researches carried out represent a system - useful support for students, teachers, organizations, specialists, and organizations in the industry of Romanian aviation, as appropriate and can be easily adapted for other types of aircraft.

The problem of the controlled turn system for the previous landing gear of military school and training aircraft requires a research activity - continuous and analytical development, to determine the optimal solutions as technical, technological progress and the appearance of new materials require new, innovative solutions.

At the same time, the doctoral thesis opens new research directions, the most important of which are the following:

1. Adaptation of the controlled turning system, designed in the framework of the thesis, for other types of aircraft.
2. Development of a controlled turning system for the front landing gear of military aircraft, with electro-mechanical actuation.
3. Carrying out a comparative study between the electro-mechanical controlled turning system vs. electro-mechano-hydraulic.

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