UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Study of the use of lunar materials to produce rocket propellants

Document:
Appendix

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Degree:
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BACHELOR FINAL THESIS

APPENDIX

Study of the use of lunar materials to produce rocket propellants

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Bachelor's Degree Thesis in Aerospace Vehicle Engineering

Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa
Universitat Politècnica de Catalunya

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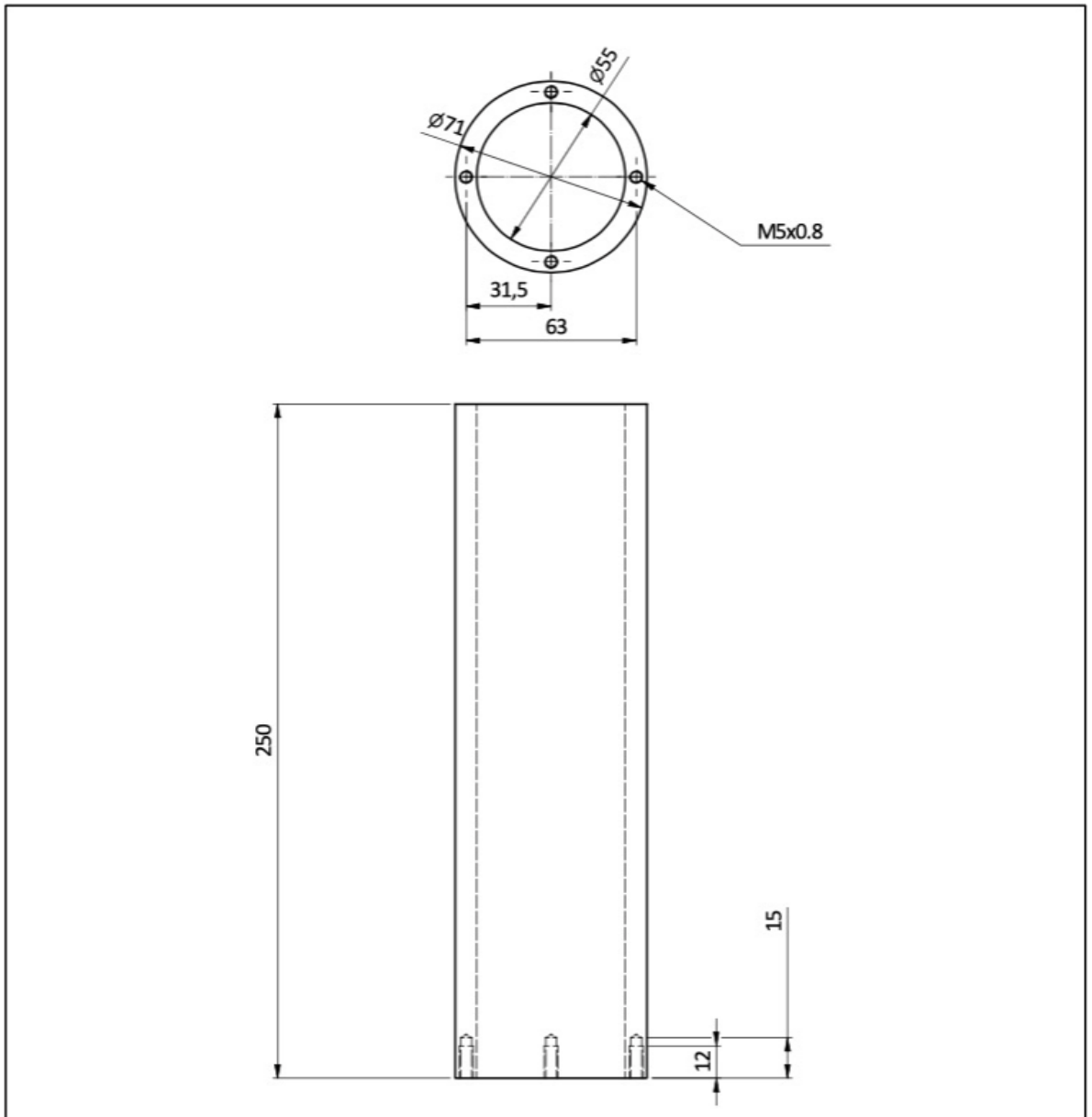
Appendix A

Drawings of rocket engine components



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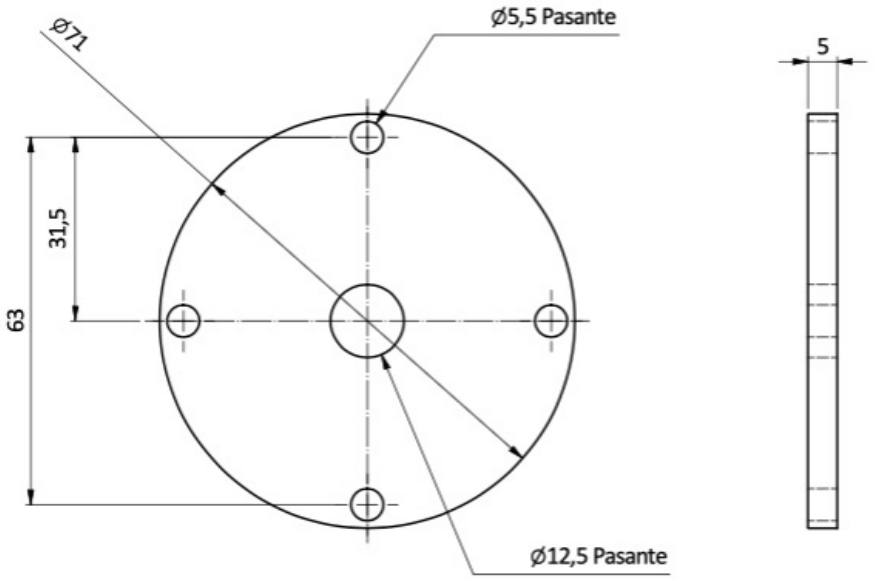

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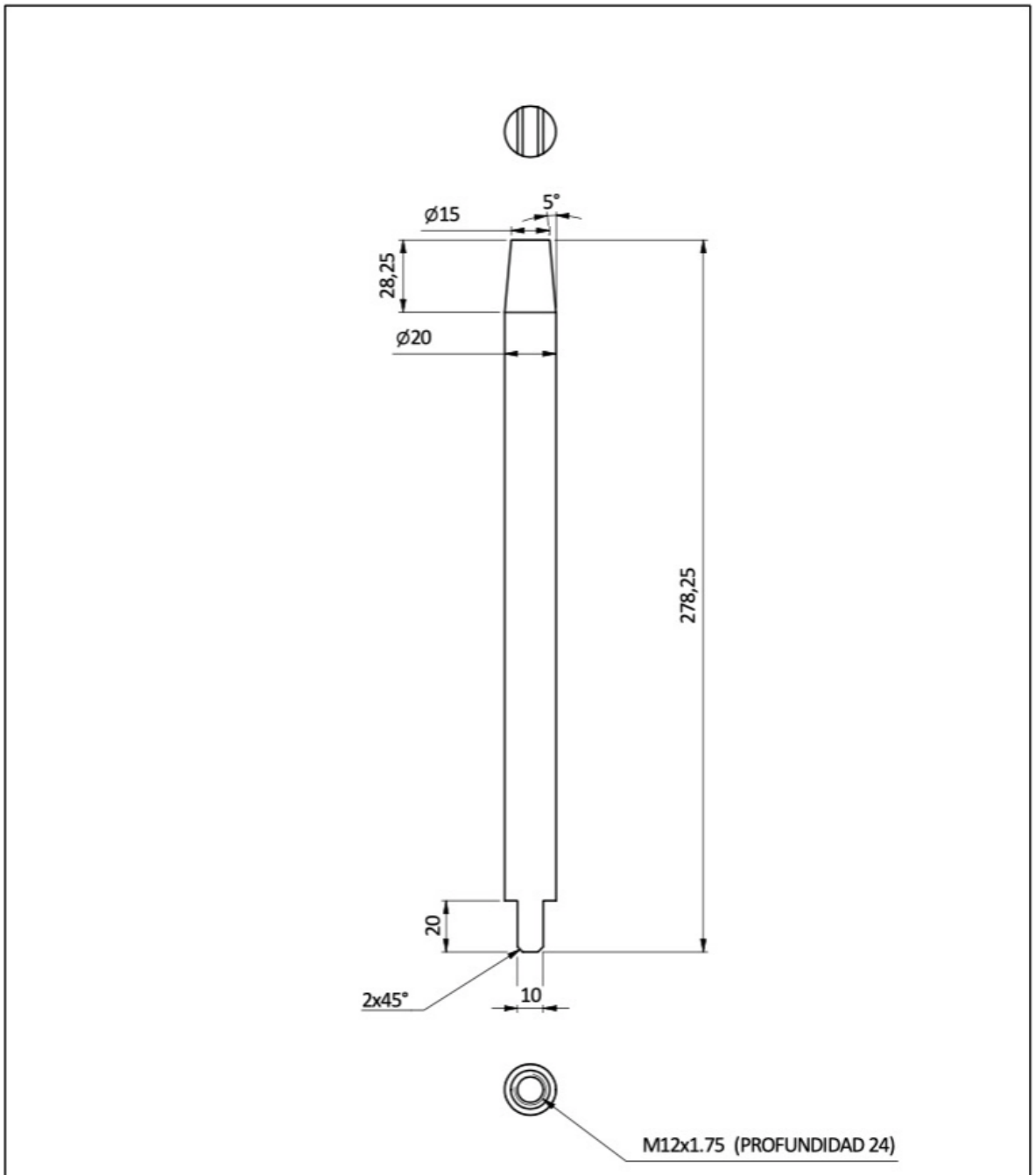

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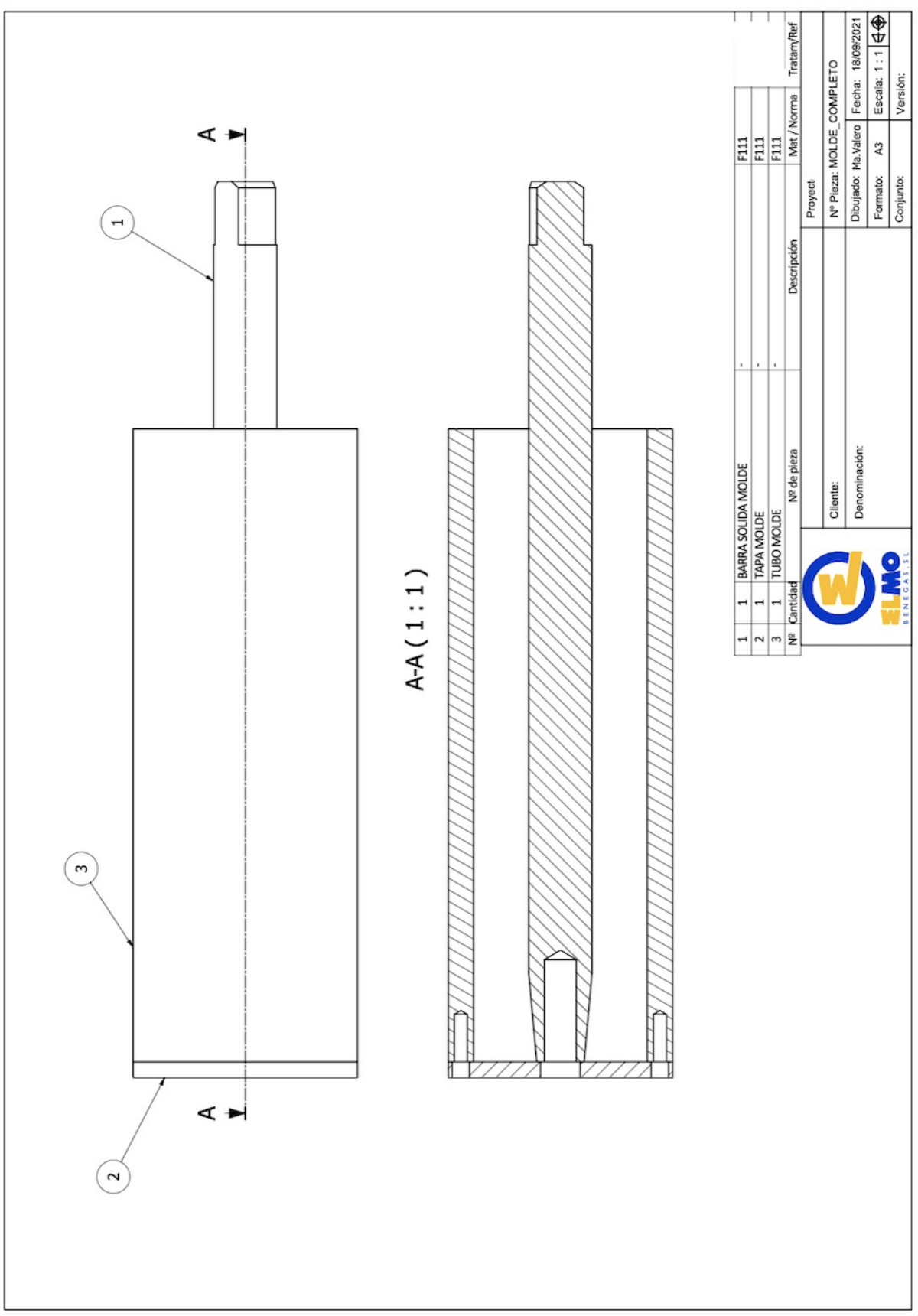
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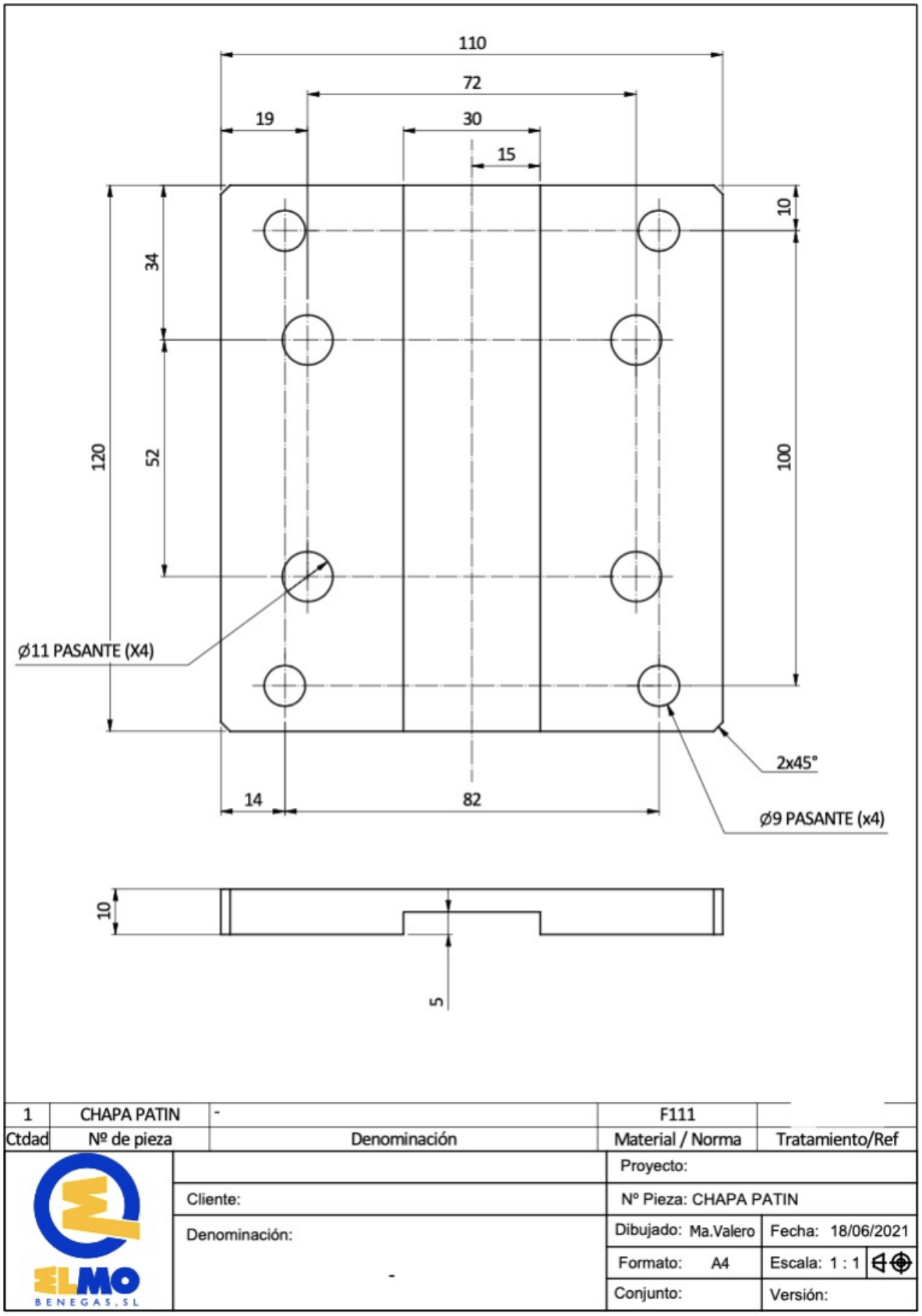

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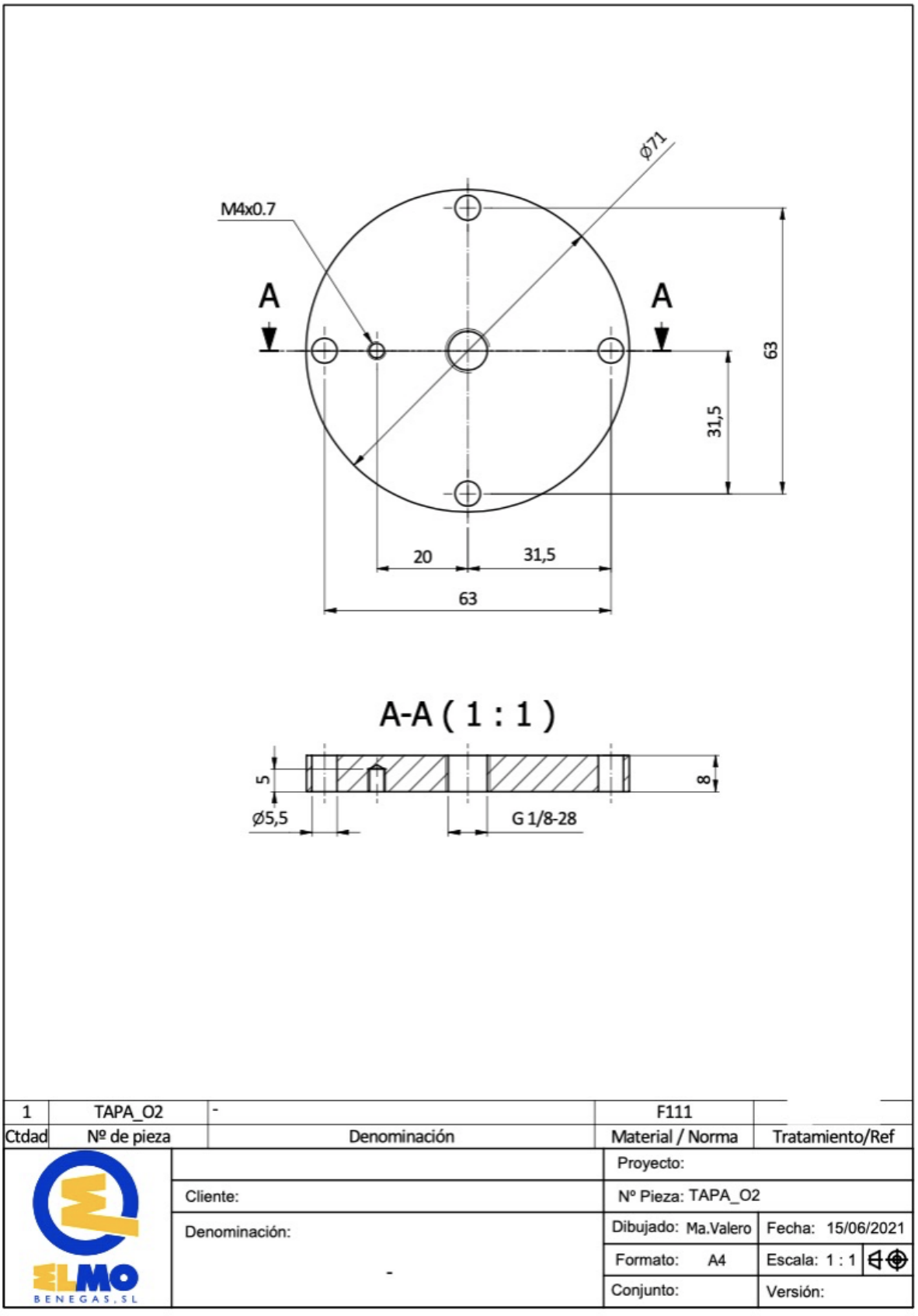

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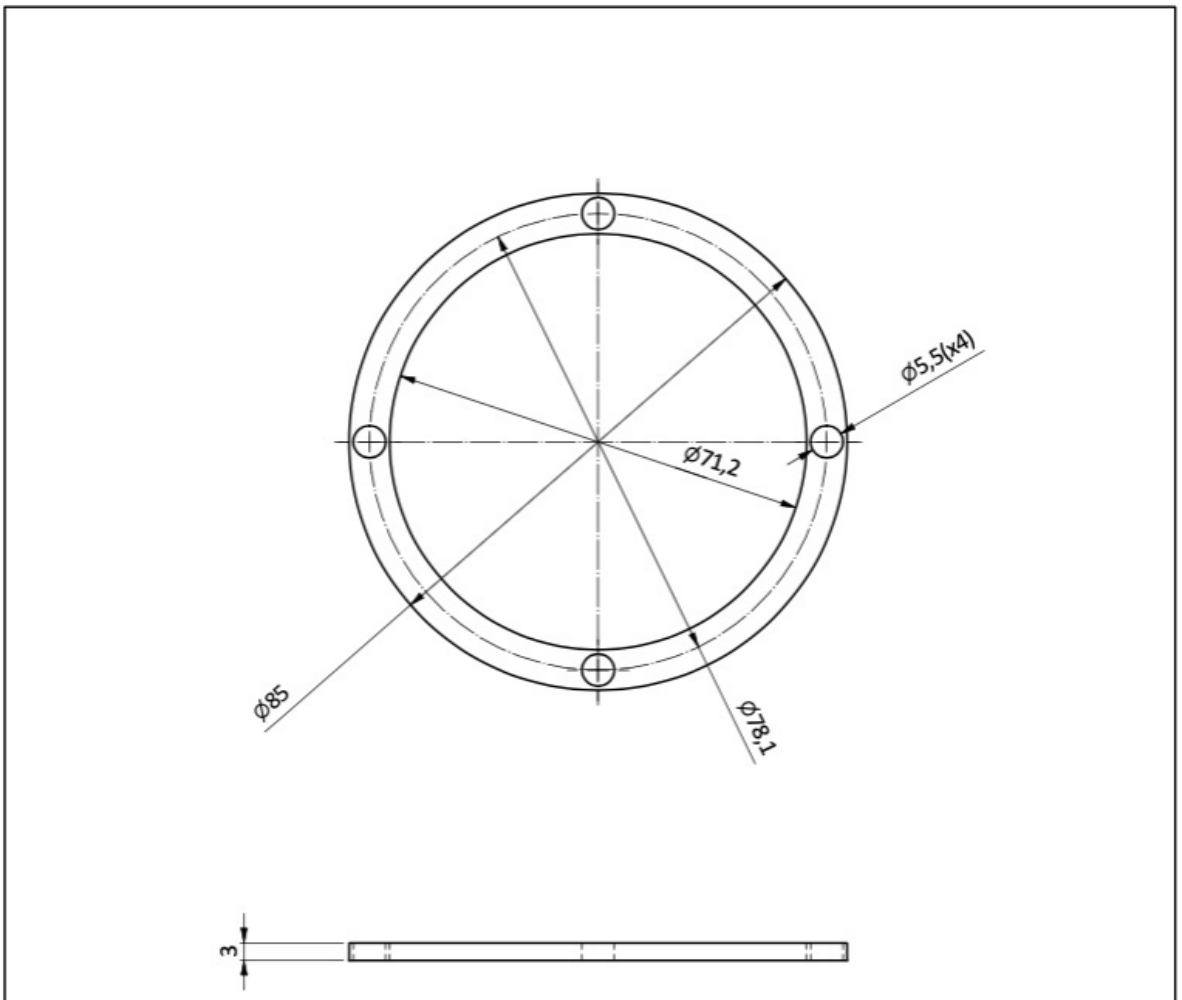

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ELMO BENEGAS, SL

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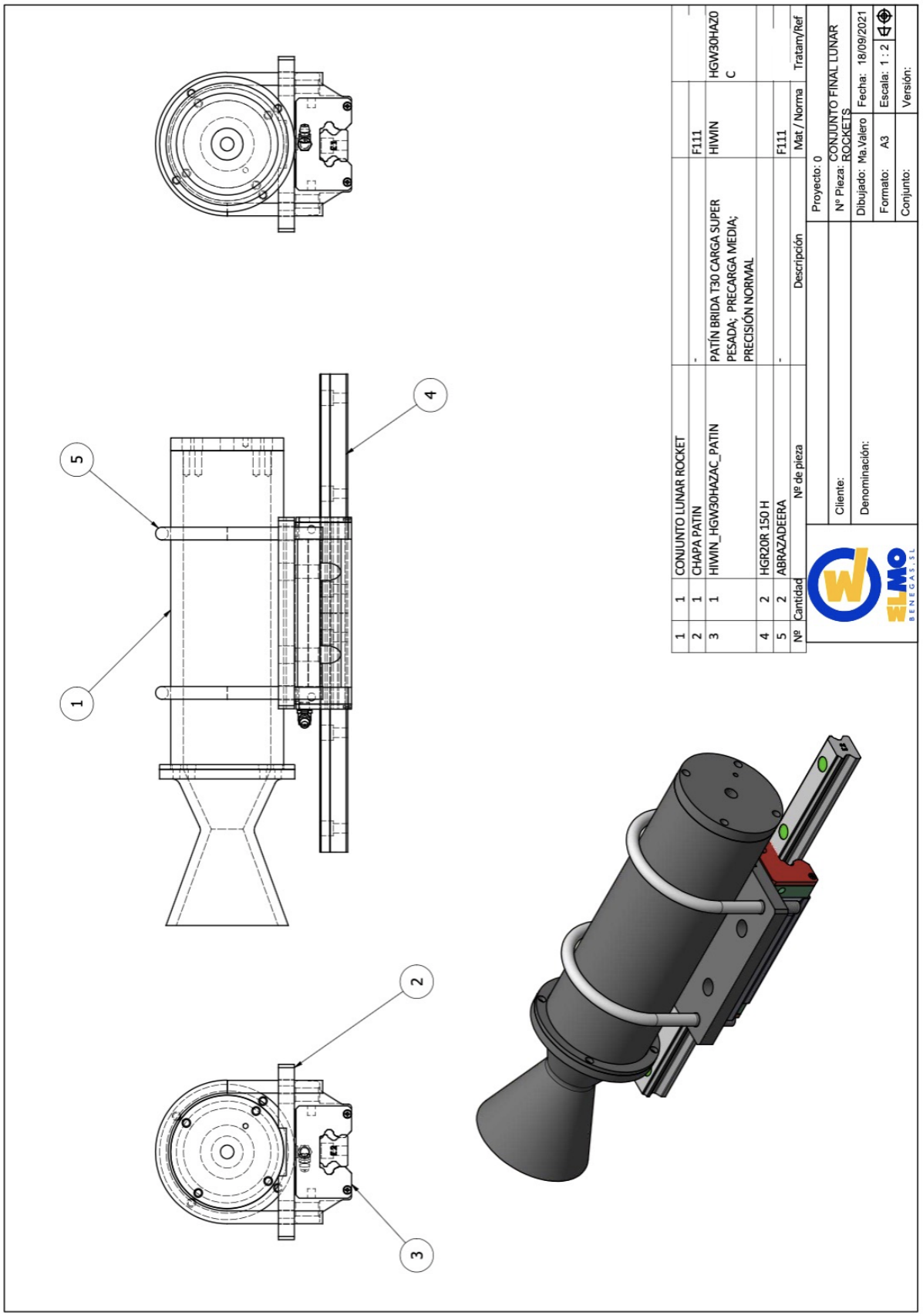
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4 2 HGR20R 150 H - F111
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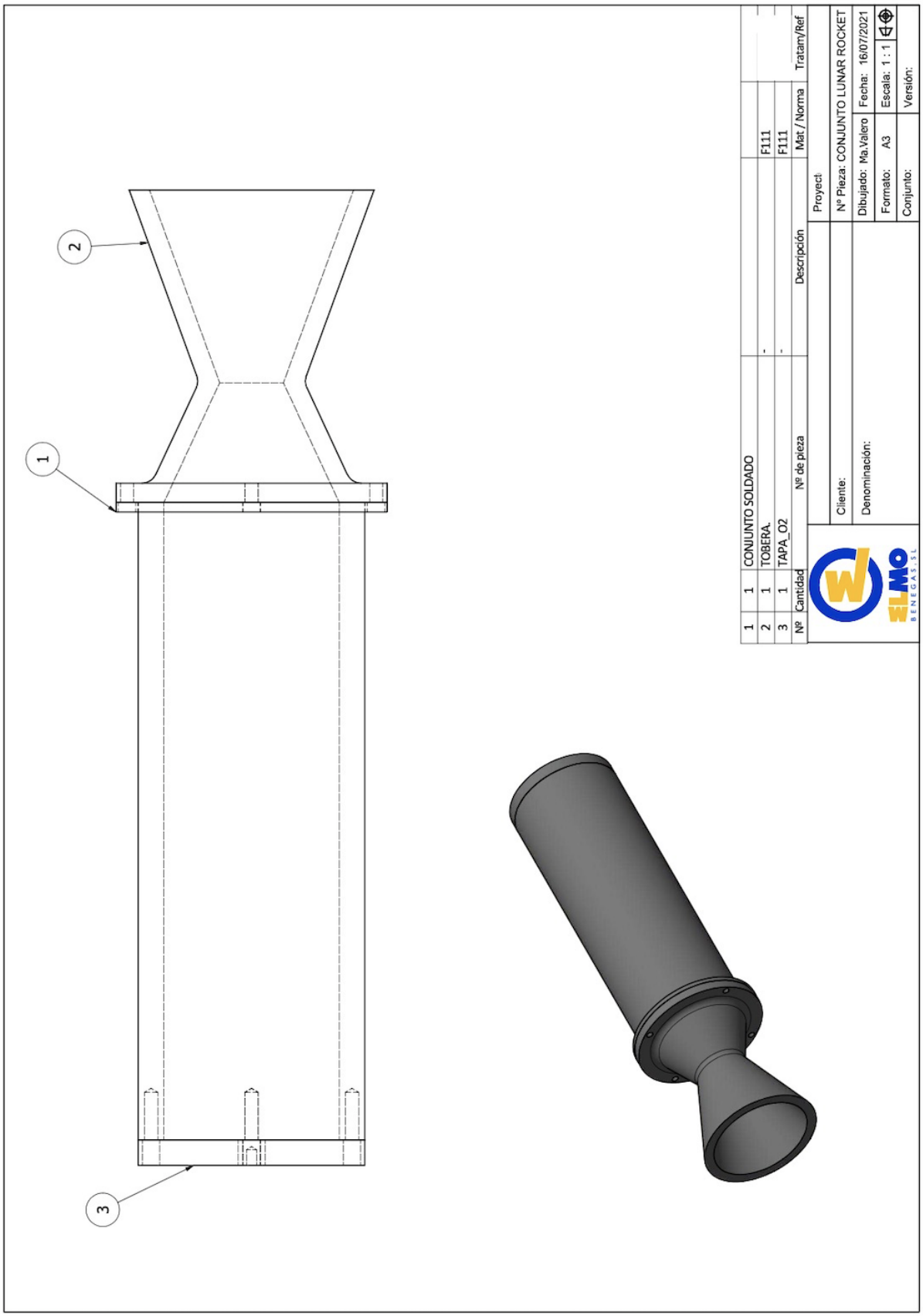
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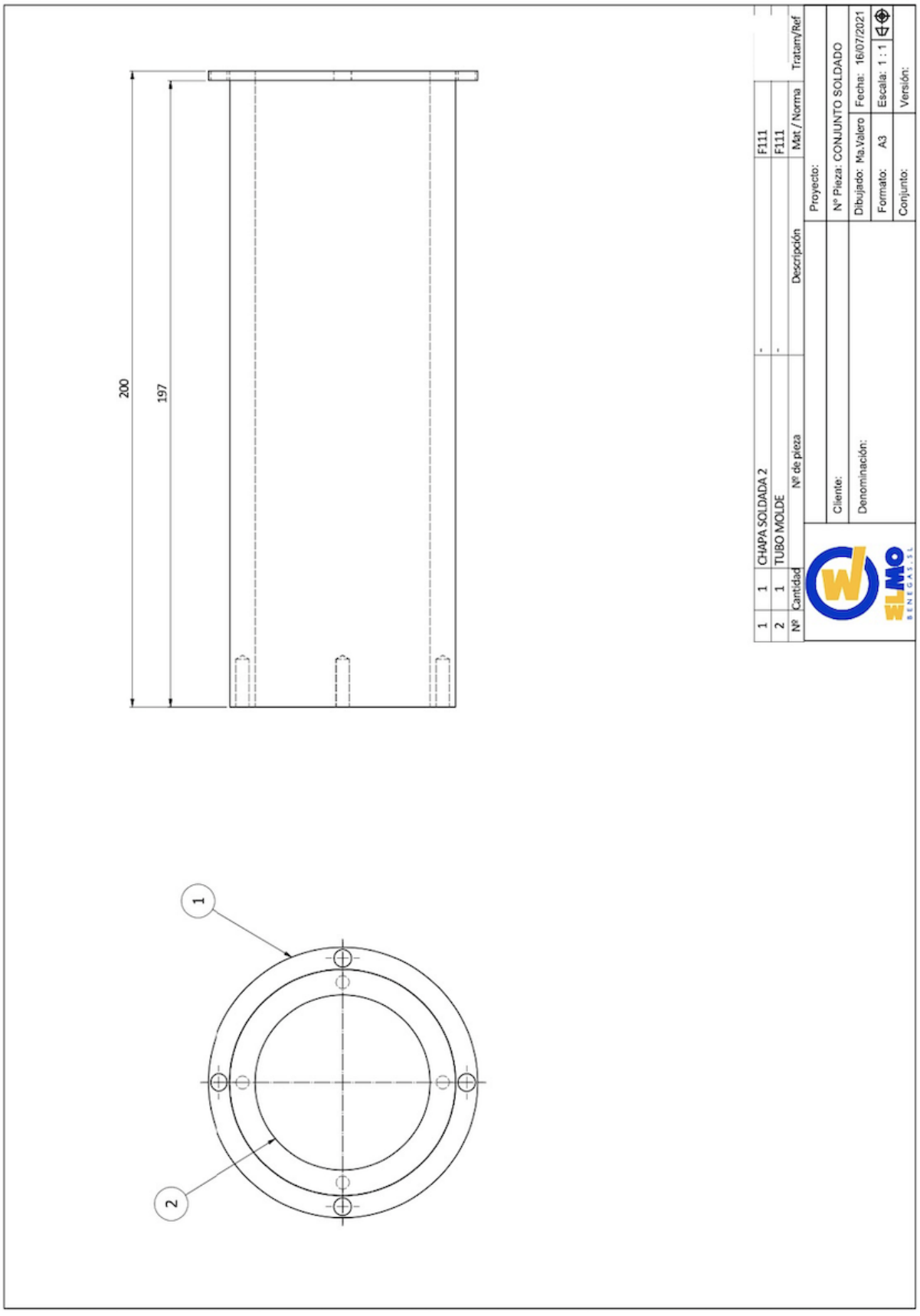
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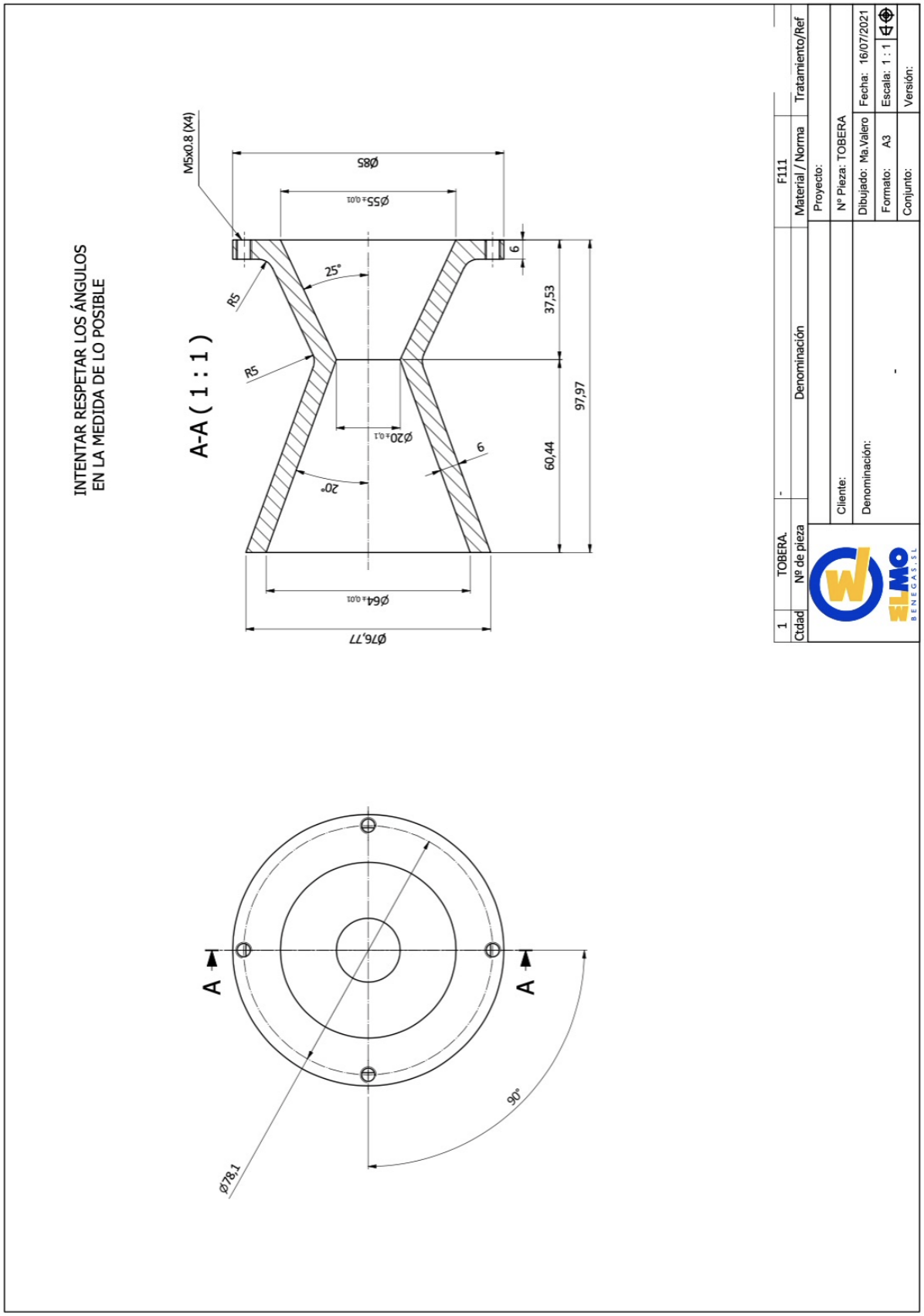
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EN LA MEDIDA DE LO POSIBLE
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Material / Norma
Tratamiento/Ref
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BENEGAS,SL

Appendix B

TSTP

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Study of the use of lunar materials to produce rocket propellants

Test Specifications and Test Procedures

University Name: Universitat Politècnica de Catalunya (UPC)

Date: 28/09/2021

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1. Document Scope

This document defines the tests and procedures to perform the ignition and propulsive characterization tests of the fuel composed only of lunar material.
Both the ignition test and the propulsive performance test must be performed in a controlled environment with plenty of ventilation. The test setup is described below.

Three basic components are necessary for the ignition test: the combustion chamber, the test bench and the ignition system. However, it is also necessary to take into account several safety elements such as tongs that withstand high temperatures for handling hot material, high temperature resistant gloves, protective goggles and non-flammable clothing. An oxygen tank will also be needed to provide the oxidizer to the combustion chamber in order to produce the combustion

For the propulsive characterization test four main elements will be necessary: the rocket engine composed by the combustion chamber and the nozzle, the test bench, the ignition system and a balance to measure the thrust generated by the propellant. As in the first part, the oxygen tank and the safety elements will also be necessary.

2. Ignition test

2.1. Test Description and Objectives

This test consists of an ignition test of the combustion between aluminum and oxygen. The purposes are to recreate the reaction in a combustion chamber designed to see how the system acts, to study its behavior to see its controllability using a constant flow of oxidant and to check that the material selected to manufacture the combustion chamber containing it withstands the duration of the experiment without deforming due to the heat and stresses of the reaction.

2.2. Test Requirements

The main requirements of this experiment are as follows:

- The material from which the combustion chamber is constructed must withstand high temperatures to ensure that the reaction can take place.
- The test bench must allow a rectilinear movement.
- The reaction must be ignitable with an external ignitor.
- It must be ensured that the aluminum is covered by an outer layer to protect the reaction environment.
- A material is needed as a base for the test bench in order to protect the surface where the experiment is performed from possible burns.
- Handling of the components should be done using safety elements during and after the test.

2.3. Test Organization and Schedule

The test at least requires three operators:

- Test runner responsible to perform the test following procedures.
- An operator in charge of opening and closing the oxygen valve.
- Quality member to note the results.

The test is composed mainly by two phases:

- Test bench setup
- Execution of test steps

2.4. Test Set-up

Mold Assembly

First it is necessary to place the cover with the central through hole and to fix it to the end of the combustion chamber delimiting tube. The cover is fixed to the pipe with M5 metric screws. Once in place, the bar that will act as the inner cavity of the grain is inserted and fixed with an M10 metric screw through the cover. All screws have been fastened using wrenches suitable for the specified screws.

Before starting the test, it is necessary to use this setup in order to create the propellant grain. Then the test is carried out using the test bench setup below.

Test bench with the combustion chamber

For this test the cover with the threaded hole for the insertion of the male fitting for the insertion of the oxidizer into the end of the combustion chamber is placed and the linear guide and the necessary fasteners for fixing the combustion chamber to the linear guide are added.

It is necessary to insert washers between the screws that are in the cover and the cover itself. They are grower washers and their purpose is to maintain axial tension with their spring effect between the nut and the fixed part.

For this assembly, both nuts and bolts have been fixed with wrenches. An inlet fitting with male thread G 1/8 and with the other end in the form of a spigot to allow the union of a conduit through which the oxygen will be introduced and the tube of the combustion chamber to avoid leaks is already placed on the cover.

A methacrylate plate is placed as the base of the test bench, acting as an additional barrier in case of high temperature residues coming out of the reaction, in order to protect the surface where it is carried out.

2.5. Step-by-Step Procedure

The following table presents the different steps that have to be done in order to execute this test.

TSTP – Ignition Test (IT)

Date:

Location: UPC – Campus Besós

Activity description: Test to recreate the reaction in a combustion chamber designed to see how the system acts.

Operators:

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-IT -010-010	Perform mold configuration	Mold assembled as expected		If passes the mold is performed			
TSTP-IT -010-020	Insert the aluminum foil in the mold to obtain the propellant grain leaving approximately 30mm of margin in order to ensure a safety zone for later ignition	To achieve the desired geometry of the propulsive grain		If passes the mold is filled with aluminum foil			
TSTP-IT -010-030	Removing the aluminum grain from the mold	To obtain the propulsive grain		If passes it is obtained the propellant grain			
TSTP-IT -010-040	Prepare the set-up for the ignition test	All set-up must be mounted as detailed		If passes the set-up is done			
TSTP-IT -010-050	Place the test bench on an elevated surface to facilitate handling	The test table is placed on a high surface.		If passes the test bench will be placed on an elevated surface			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-IT -010-060	Introduce the aluminum grain into the combustion chamber	To have the combustion chamber with the aluminum grain inside it		If passes the combustion chamber will be with the propulsive grain inside			
TSTP-IT -010-070	Place the oxygen tank near the test bench	The oxygen tank should be close to the test bench		If passes the oxygen tank will be placed near the test bench			
TSTP-IT -010-080	Connect a rubber hose to the tank outlet and to the combustion chamber inlet fitting	The combustion chamber must be connected to the oxygen tank by means of the rubber hose		If passes the oxygen tank will be connected to the combustion chamber			
TSTP-IT -010-090	Set-up the ignition system. The welding equipment is connected to the power supply and then the positive terminal is connected to the electrode and the negative terminal to the base of the linear guide	The ignition system must be ready for use		If passes the ignition system will be ready for use			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-IT -010-100	Open the tank valve	The oxygen tank should be opened to allow the flow of oxygen to the combustion chamber		If passes, the flow of oxygen will arrive from the oxygen tank to the combustion chamber			
TSTP-IT -010-110	Place the electrode of the ignition system at 150A inside the combustion chamber and establish contact with the aluminum grain	To ignite the propulsive grain		If passes the combustion will be started			
TSTP-IT -010-120	Remove the electrode from the combustion chamber and switch off the ignition system	The combustion should be stable and the ignition system must be turned off		If passes the combustion will be stable and the ignition system will be off			
TSTP-IT -010-130	Separate from the combustion mechanism at least one meter away	Maintain a safe distance from the combustion mechanism		If passes we will be at least one meter away from the propulsion system			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-IT -010-140	Close the oxygen valve when the combustion is completed	The flow of oxygen to the combustion chamber is cut off		If passes there will be no more oxygen flow through the combustion chamber			
TSTP-IT -010-150	Allow the mechanism to cool	Bring the propulsion system to room temperature		If passes the propulsion system will be at room temperature			
TSTP-IT -010-160	Disassemble the combustion chamber to analyze results	To be able to analyze results		If passes it will be possible to see the debris inside the fuel chamber			

3. Propulsive performance test

3.1. Test Description and Objectives

The objective of the propulsion performance characterization test is, once the objectives of the first part have been met, to verify that the reaction exhaust gases are able to produce thrust when compressed by the nozzle and thus validate its propulsive quality. If thrust is produced, it will be quantified using an Arduino chip programmed as a scale. Another objective of this second part is to study the results to draw a conclusion on the propulsive characterization of the aluminum formation reaction.

3.2. Test Requirements

The main requirements of this experiment are the same as for the ignition test with some additions:

- The material from which the combustion chamber is constructed must withstand high temperatures to ensure that the reaction can take place.
- The test bench must allow a rectilinear movement.
- The reaction must be ignitable with an external ignitor.
- It must be ensured that the aluminum is covered by an outer layer to protect the reaction environment.
- A material is needed as a base for the test bench in order to protect the surface where the experiment is performed from possible burns.
- Handling of the components should be done using safety elements during and after the test.
- The inner walls of the nozzle must be protected so that the ignition system can reach the propellant grain without getting caught.
- The balance that measures the thrust must be calibrated prior to performing the test.
- A portable device will be necessary to observe the test results.

3.3. Test Organization and Schedule

The test at least requires four operators:

- Test runner responsible to perform the test following procedures.
- An operator in charge of opening and closing the oxygen valve.
- An operator in charge of calibrating the scale and of putting it into operation.
- Quality member to note the results.

The test is composed mainly by two phases:

- Test bench setup
- Execution of test steps

3.4. Test Set-up

Mold Assembly

First it is necessary to place the cover with the central through hole and to fix it to the end of the combustion chamber delimiting tube. The cover is fixed to the pipe with M5 metric screws. Once in place, the bar that will act as the inner cavity of the grain is inserted and fixed with an M10 metric screw through the cover. All screws have been fastened using wrenches suitable for the specified screws.

Before starting the test, it is necessary to use this setup in order to create the propellant grain. Then the test is carried out using the test bench setup below.

Test bench with the combustion chamber

The assembly of the propulsive performance test is very similar to that of the ignition test; however, a welded plate is added to the combustion chamber in order to later add the nozzle.

Therefore, adding the nozzle at the end of the welded plate and the cap for the introduction of oxygen at the other end, the new combustion chamber with nozzle is obtained. The screws used to connect the nozzle to the combustion chamber are ALLEN head M5 metric screws, since only an ALLEN wrench could be used for screwing due to the difficult geometry of the nozzle.

As for the ignition test the cover with the threaded hole for the insertion of the male fitting for the insertion of the oxidizer into the end of the combustion chamber is placed and the linear guide and the necessary fasteners for fixing the combustion chamber to the linear guide are added.

Also, it is necessary to insert washers between the screws that are in the cover and the cover itself. An inlet fitting with male thread G 1/8 and with the other end in the form of a spigot is placed on the cover to allow the connection of a conduit through which the oxygen will be introduced and the combustion chamber tube to avoid leaks.

A ceramic plate is placed as the base of the test bench, acting as an additional barrier in case of high temperature residues coming out of the reaction.

The thrust is made with a load cell and an Arduino chip. It has been specially programmed for use in this test. This cell will be placed in front of the test blench. In order not to damage the balance, the combustion chamber cover has been modified by adding a threaded hole in order to insert a 40 mm long screw so that the head of the screw is the point of contact with the load cell in case of movement.

3.5. Step-by-Step Procedure

The following table presents the different steps that have to be done in order to execute this test.

TSTP – Propulsive Performance Test (PPT)

Date:

Location: UPC – Campus Besós

Activity description: Test to verify that the reaction exhaust gases from the alumina reaction are able to produce thrust when compressed by the nozzle and thus validate its propulsive quality.

Operators:

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-PPT -010-010	Perform mold configuration	Mold assembled as expected		If passes the mold is performed			
TSTP-PPT -010-020	Insert the aluminum foil in the mold to obtain the propellant grain leaving approximately 30mm of margin in order to ensure a safety zone for later ignition	To achieve the desired geometry of the propulsive grain		If passes the mold is filled with aluminum foil			
TSTP-PPT -010-030	Removing the aluminum grain from the mold	To obtain the propulsive grain		If passes it is obtained the propellant grain			
TSTP-PPT -010-040	Weight all the components of the set-up	The components of the set-up must be weighted		If passes all the components of the set-up will be weighted			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-PPT -010-050	Prepare the set-up for the propulsion performance test without the nozzle	All set-up must be mounted as detailed but without the nozzle		If passes the set-up is done but without the nozzle			
TSTP-PPT -010-060	Place the test bench on an elevated surface to facilitate handling	The test table is placed on a high surface.		If passes the test bench will be placed on an elevated surface			
TSTP-PPT -010-070	Introduce the aluminum grain into the combustion chamber	To have the combustion chamber with the aluminum grain inside it		If passes the combustion chamber will be with the propulsive grain inside			
TSTP-PPT -010-080	Attach the nozzle to the combustion chamber	The complete set-up for the propulsion performance test must be mounted as detailed		If passes the final set-up is done			
TSTP-PPT -010-090	Protect the inside of the nozzle with black adhesive tape	The surface inside the nozzle must be protected so that the electrode does not get stuck		If passes the surface inside the nozzle will be protected from the ignition system			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-PPT -010-100	Place the balance to measure the thrust in front of rocket engine	The scale must be in front of the fuel chamber		If passes the scale will be located in front of the fuel chamber ready to take test measurements			
TSTP-PPT -010-110	Place a 40 mm screw into the new threaded hole in the cover and align it with the load cell	The screw will be placed in the threaded hole and aligned with the load cell		If passes the 40mm will be placed in the threaded hole of the cover			
TSTP-PPT -010-120	Place the oxygen tank near the test bench	The oxygen tank should be close to the test bench		If passes the oxygen tank will be placed near the test bench			
TSTP-PPT -010-130	Connect a rubber hose to the tank outlet and to the combustion chamber inlet fitting	The combustion chamber must be connected to the oxygen tank by means of the rubber hose		If passes the oxygen tank will be connected to the combustion chamber			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-PPT -010-140	Set-up the ignition system. The welding equipment is connected to the power supply and then the positive terminal is connected to the electrode and the negative terminal to the base of the linear guide	The ignition system must be ready for use		If passes the ignition system will be ready for use			
TSTP-PPT -010-150	Open the tank valve	The oxygen tank should be opened to allow the flow of oxygen to the combustion chamber		If passes, the flow of oxygen will arrive from the oxygen tank to the combustion chamber			
TSTP-PPT -010-160	Place the electrode at of the ignition system at 150A inside the combustion chamber and establish contact with the aluminum grain	To ignite the propulsive grain		If passes the combustion will be started			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-PPT -010-170	Remove the electrode from the combustion chamber and switch off the ignition system	The combustion should be stable and the ignition system must be turned off		If passes the combustion will be stable and the ignition system will be off			
TSTP-PPT -010-180	Separate from the combustion mechanism at least one meter away	Maintain a safe distance from the combustion mechanism		If passes we will be at least one meter away from the propulsion system			
TSTP-PPT -010-190	Close the oxygen valve when the combustion is completed	The flow of oxygen to the combustion chamber is cut off		If passes there will be no more oxygen flow through the combustion chamber			
TSTP-PPT -010-200	Allow the mechanism to cool	Bring the propulsion system to room temperature		If passes the propulsion system will be at room temperature			

Step ID	Instruction	Expected	Actual	Pass/Fail Criteria	Passed[Y/N]	Time	PA
TSTP-PPT -010-210	Disassemble the combustion chamber to analyze results	To be able to analyze results		If passes it will be possible to see the debris inside the fuel chamber			
TSTP-PPT -010-220	Re-weigh all the components of the set-up	The components of the set-up must be re-weighted		If passes all the components of the set-up will be weighted			