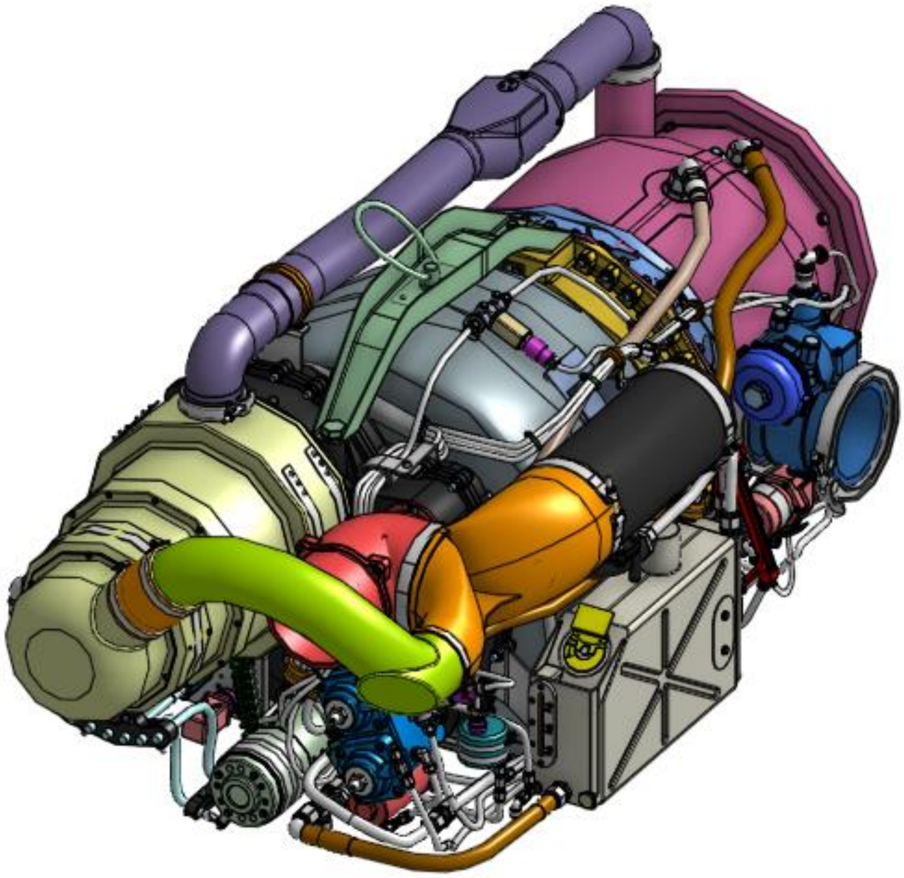

Internship report

Design of a testbed for an auxiliary power unit

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Abstract

This internship focused on the design and implementation of experimental setups in the field of aerospace propulsion and combustion. The main project was the development of a test bench for a Garrett GTCP85-98D auxiliary power unit (APU), which involved the design of a dedicated control panel, the integration of fuel and electrical systems, and the resolution of significant documentation inconsistencies. Through an iterative process combining schematic analysis, empirical pin testing, and successive redesigns, a functional control panel was built, and the APU was successfully started and operated under laboratory conditions.

A second project was carried out in parallel: the design of a large-scale Bunsen burner intended for combustion research and teaching.

Beyond the technical results, the internship highlighted the importance of prototyping, testing, and error correction, as well as the constant integration of safety considerations when working with high currents, combustible fuels, and hot exhaust gases.

Overall, the internship achieved its objectives by delivering functional experimental solutions and by strengthening my professional and technical skills. The outcomes provide added value for the laboratory, expanding its experimental resources, while also contributing to my development as a future engineer.

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Introduction

Context

This internship is part of the second-year internship (assistant engineer internship). Its main objective was to allow me to work in collaboration with experienced engineers while putting into practice the technical knowledge acquired during my first two years of training at ENSTA Bretagne. Passionate about engine problems applied to aeronautics, I first oriented my research towards leading companies such as Safran, Airbus and Arianespace, in the fields of thermal engines and material fatigue, in line with my AV specialty courses. However, as these companies did not offer internships at the bac+4 level, I chose to redirect my efforts towards the academic environment. It was in this context that I discovered the LICeM and AEROL laboratories at the University of Ljubljana, in Slovenia. After several discussions about possible internship topics with Mr. Igor Petrovic, a researcher at the AEROL laboratory, I was finally referred to Mr. Urban Zvar Baskovic of the Laboratory for Internal Combustion Engines and Electro-Mobility (LICeM). He offered me the opportunity to design and set up a test bench for an Auxiliary Power Unit (APU, a turbine generator). Seduced by the relevance and scientific interest of this subject, which was perfectly in line with my professional project, I immediately accepted. This is how I had the opportunity to do my internship in Ljubljana.

The lab and its missions

The LICeM laboratory has around thirty employees and is attached to the Faculty of Mechanical Engineering at the University of Ljubljana. Its infrastructure includes offices and an experimental workshop dedicated to research on internal combustion engines.

Faculty of Mechanical Engineering

The laboratory's main research themes cover a broad spectrum: internal combustion engines, electromobility, hybrid and electric powertrains, batteries, fuel cells, powertrain thermoregulation, cogeneration, alternative fuels, waste-to-energy, advanced concepts for ultra-low-emission combustion, as well as multi-scale and multi-domain numerical modeling of systems and components. The laboratory also conducts experiments/practical projects for students in the Faculty of Mechanical Engineering.

During my stay, however, the majority of the experimental work I witnessed focused on gas turbines.

Team

Upon my arrival, I was placed under the supervision of Dr. Urban Zvar Baskovic, assistant professor, who acted as my internship supervisor. A specialist in turbine engines, he supervised all of my work. We also shared an office with Mr. Anton Znidarcic, a specialist in fluid mechanics, who also supervised another French intern. The laboratory also had a technician, Mr. Jon Hauptman, responsible for general workshop maintenance and the installation of experimental equipment. I also collaborated with Mr. Ziga Rosec, a doctoral student working on a "flameless combustion" turbine, as well as with Dr. Samo Penic, assistant professor, who provided his expertise on the electrical component of the project. However, I did not have the opportunity to collaborate directly with the other members of the laboratory.

The work organization was as follows: I was left autonomous on the project, I planned my own tasks and had them validated by Urban during daily meetings and I could ask for help on technical subjects from other members of the laboratory as well as from external contacts working in aircraft maintenance.

Available infrastructures

The laboratory consists of two main areas: the offices and the workshop. Located in the basement of the Faculty of Mechanical Engineering, the workshop includes several functional areas. The first room is dedicated to storing engines, spare parts, and hardware. Other areas house various equipment, including machine tools (milling machine, drill press, etc.), a 3D printer, a welding station, and basic electronic components. At the center of the workshop is the test room, specially designed for conducting experiments on thermal engines. It is equipped with a test bench with a dynamometer, various engines and turbines, a ventilation system for extracting exhaust gases, and a high-capacity compressed air system, used in particular for starting the turbines. This room is isolated from the computer workstations by a window and a sealed door, thus ensuring the safety of researchers against gas emissions.

Constraints

As the sole project manager, I had to consider several constraints, primarily related to safety and budget. With the APU developing 224 kW of power, it was essential to implement preventive measures adapted to the fire risks and the significant heat generated by the machine. Financially, given the limited resources allocated by the Faculty of Mechanical Engineering, it was necessary to optimize spending: the majority of components were purchased from general suppliers, such as AliExpress or local DIY stores. Only aviation-grade oil had to be retained, due to the lack of a reliable alternative.

Furthermore, the limited number of available tools required the almost exclusive use of standard and easily accessible components (off-the-shelf components), which was the main technical constraint of this internship.

Stakes and objectives

Main project : APU testbench

Objectives

The main objective of the internship was to design an experimental device for the start-up and continuous operation of a turbine (Auxiliary Power Unit, model GTCP85-98D from Garrett) from a McDonnell Douglas DC-9 aircraft. This APU was installed on a large number of airliners from the 1980s to the end of the 1990s. Its two main functions are the power supply of the aircraft and the production of compressed air for starting the main engines. It is located in the tail of the aircraft.

GTCP85-98D in the faculty parking lot

The work initially involved an in-depth literature review, based on the analysis of maintenance manuals and technical procedures. It then included the design of an experimental setup allowing the integration of the APU on a mobile cart, coupled with the peripheral devices required for its start-up (fuel pumps, tank, oil pump, etc.), as well as the design of the missing electronic control system, essential for controlling the engine's start-up and operating phases.

Furthermore, the installation of pressure, temperature, and mass flow measurement instruments was to be completed to enable detailed monitoring of engine operation. These measurement systems relied on National Instruments hardware and the LabVIEW programming environment.

This test bench will be used during practical training sessions for students in the Faculty of Mechanical Engineering, as well as for pilot students.

The internship objectives could be broken down into a set of main tasks, structured as follows:

1. Study the APU maintenance manuals and technical documentation.
2. Identify the essential requirements for startup and basic operation.
3. Develop a conceptual diagram for integrating the APU into the laboratory environment.
4. Determine the necessary peripheral devices (fuel, lubrication systems, etc.).
5. Define the basic safety requirements for testing.
6. Identify the components essential for startup control (switches, relays, sensors).
7. Obtain official quotes from suppliers for their purchase.
8. Consider possible integration with National Instruments equipment.
9. Determine the essential parameters to be monitored (temperature, pressure, etc.).
10. Select suitable sensors and consider their integration with National Instruments equipment.
11. If the required sensors are not available in the laboratory, request official quotes from suppliers.
12. Develop a simplified interface for parameter monitoring (without full automation).
13. Set up basic data acquisition, preferably with simulated signals.
14. Write a summary of the results obtained, the system design, and recommendations for future work.
15. Provide a final report with a presentation of the project.
16.

However, some of these tasks were not completed.

Stakes

The challenges associated with this internship spanned several dimensions:

On a technological level, the project confronted entirely analog control systems with more modern approaches. The design and implementation of an auxiliary power unit (APU) raised questions about combustion modeling and the integration of control devices in a constrained experimental environment.

On a human level, the work required a genuine ability to collaborate within the team, to seek external contacts (particularly suppliers or specialists with technical documentation), and to demonstrate autonomy in solving practical and unforeseen problems.

The economic aspect was also a major challenge: costs had to be limited by reusing existing components, using inexpensive alternative solutions for electrical charging, and optimizing available laboratory resources.

Finally, the educational aspect proved equally important. The devices designed, whether the APU test bench or the Bunsen burner, are intended to become experimental supports for students and to enrich the laboratory's research work. Their value thus lies not only in the results obtained during the internship, but also in their potential for future use.

Second project : Bensen Burner

The goal here was to design a Bunsen burner with a suitable thermal power (3.5 kW) to be able to observe the molecules (e.g., HO and CH radicals) of the different stages of methane combustion using a specific camera. This Bunsen burner was to allow several types of combustion:

- Premixed mixture and laminar flow
- Premixed mixture and turbulent flow
- Non-premixed mixture and laminar flow
- Non-premixed mixture and turbulent flow

In addition, it was necessary to be able to preheat the mixture on demand using a resistor and to inject a variable amount of CO2 into the combustion chamber to simulate EGR.

Description of activities and results

APU : chronological description

Initial phase: framing and preparation (weeks 1 to 2)

The internship begins with a planning phase, including the creation of a Gantt chart and review of the technical documentation. Initial work includes:

1. Studying the APU maintenance manuals and technical documents
2. Identifying key requirements for startup and basic operation
3. Proposing a concept for integrating the APU into the laboratory
4. Identifying the necessary peripherals (fuel system, oil system, etc.)
5. Defining basic safety requirements for testing
6. Installing the peripherals

Provisional work schedule																			
Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Priority	%
Task	Deliverable																		
Litterature review																			
Study APU maintenance manuals and technical documeents	None																		0
Identify key requirements for startup and basic operation	List of requirements	ok																	0
Basic experimental setup design																			
Propose a conceptual design for placing the APU in the laboratory environnement	CAD model ? plan ? diagram ?		ok																0
Identify necessary peripheral devices (fuel system, oil system...)	List of peripheral devices with location and installation procedure on the APU		ok																0
Define basic safety requirements for testing	List of safety requirements		ok																0
Peripheral devices installation	Making sure evry device is available at LiCEM. If not, make an order. Installation of each device and checking the proper working				?														0
Simplified electronic control system plan																			
Outline key components needed for startup control (switches, relays, sensors) and obtain official prices quotes from suppliers for their purchase. Potential integration with national instruments hardware	List of key components with price and availability. Location and diagram for installation on the APU. List of steps for the starting procedure, including the peripheral devices		ok																0
Installation of control components	Making sure evry device is available at LiCEM. If not, make an order. Installation of each device and checking the proper working						?												0
Testing	Testing if evry component can work at the same time. I might have to place the APU in the laboratory environnement to see if a startup is possible. Test of the APU with Ziga						?												0
Basic measurement system selection																			
Identify essetial parameters to measure (temperature, pressure)	List of parameters																		0
Select suitable sensors and consider integration with national instruments hardware. If sensors are not available in the laboratory,	List of sensors with price and location,																		

Excerpt from the Gantt chart (provisional_work_schedule_for_the_APU.xlsx)

In this first part, the first deliverable was an Excel spreadsheet containing the APU characteristics: power, fuel consumption, heat output, exhaust gas flow, etc. Some of the values had to be calculated from the characteristics described in the maintenance manual, with simple assumptions (reagents in stoichiometric proportions, no friction losses, etc.). This spreadsheet is only intended to determine whether the test room is suitable for the operation of the APU; the accuracy of the calculations is therefore not essential.

Caracteristic	Value	Comment	Specs	
Output power	300Bhp (224kW)	At 40000 rpm		
Air bleed output	0,45 kg/s			
Nominal compressor speed	40000 rpm			
Nominal output speed	6000 rpm			
Weight		To verify		
Exaust gas Temperature	650°C (Max 760°C)			
Output electrical power	208V-83A-400Hz	Max value (208V constant)		
Input electrical power for starter motor	28V-300A DC			
Fuel consumption at nominal speed	59 kg/h = 16,4 g/s	Fuel : ASTM D1655-73	Fuel property	Value
			Density	0,8 kg/l
			Net neat of combustion	42 MJ/kg
			Flash point	38°C
			Freezing point	-47°C
			Air/fuel ratio	15/1
			Kinematic viscosity	8 mm^2/s
Air consumption at nominal speed	885 kg/h = 245,8 g/s = 737,5 m3/h	Stoechiometric ratio, air at 20°C		
Exhaust gas flow at nominal speed	2600 m3/h	Isobaric model used for calculation (perfect gases rule)		
Thermal efficiency at nominal speed	32,6%	Determined with previous informations		
Bleed air	3,5 bar-1,5 kg/s	at 250°C		
Heat release	464 kW	Determined with previous informations. A significant part of this heat goes into the exhaust.	Exhaust	254 kW
			Condution+convection+ radiation	210 kW

APU Characteristics (APU_caracteristics.xlsx)

From this stage, constraints arose: the APU produces approximately 2,600 m^3/h of gas at 650°C, while the laboratory's extraction system can only handle 580 m^3/h. Fuel tests will therefore have to be conducted outdoors.

An inventory of the components expected on the APU was also carried out during these first two weeks. Around sixty components were identified in the manual and their presence was verified.

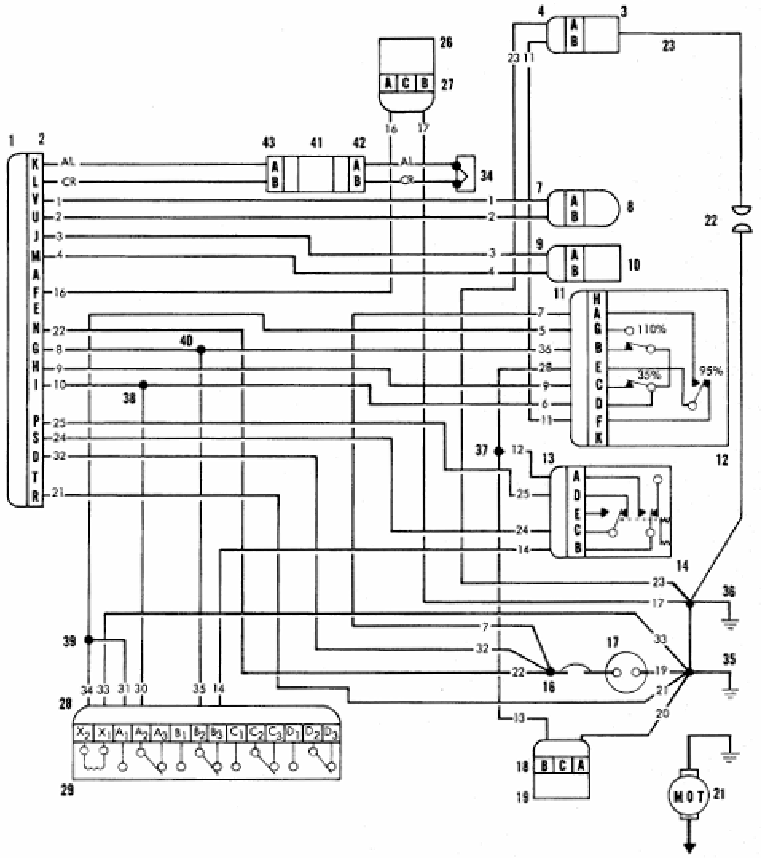
Sub-systems						
Name	Type	Components	Expected quantity	Real quantity	Type	Comment
Engine fuel and control	Automatic, electromechanical	Fuel control	1	1		
		Fuel pump	1	1	Gear pump	Fuel-lubricated, powered by the accessory drivetrain.
		Fuel governor	1	1	Centrifugal	Driven by the fuel pump
		Fuel filter	2	1	Paper cartridge	Low pressure and high pressure, just between the pump and the shutoff valve
		Fuel solenoid shutoff valve	1	1		
		Seal relief valve	1	1		Value : 1,7 bar
		Acceleration limiter	1	1		Between fuel filter, drain, and pneumatic tube
		Primary fuel manifold	1	?		I assume these components are there but I can't see them without disassembling the APU
		Secondary fuel manifold	1	?		
		Primary fuel nozzle	1	1		
		Secondary fuel nozzle	1	?		
		Combustion chamber	1	1	Can	
		Thermostat	1	1		Located in the exhaust manifold
		Plenum drain valve	1	Non connected		Might have to go back to the fuel tank
Ignition	Electromecanical	Ignition unit	1	1		
		Ignitor plug	1	1		
		Ignition lead	1	1		
		Starter motor	1	1		
Air circuit	Undefined	Ram air door	1	?		
		Nonram air door	2	?		
		Electrically driven actuator	1	?		Controlled by a switch located in the flight compartment
		Two-stage centrifugal compressor	1	1		
		Single-stage turbine	1	1		
Bleed air	Undefined	Load control valve	1	1		
		Pneumatic thermostat	1	1		
		3-way solenoid shutoff valve	1	1		
Engine controls	Master control pannel	Unknown	1	0		
Engine controls	External control pannel	APU shutoff switch	1	0		Also arms the fire extinguisher system
		Fire warning indicator	1	0		
		Fire warning horn	1	0		
		Agent bottle low pressure indicator	Unknown	0		
		Fire extinguisher discharge switch	Unknown	0		
Indicating	Undefined	Thermocouple	1	1		Temperature displayed in the flight compartment
		Compressor speed sensor	1	1	Tachometer gene	Speed displayed in the flight compartment as between 0-100%
		Available electrical power indicator	1	0	Light (Yes/No)	Located in the flight compartment

Extract from the component inventory (APU_caracterixtics.xlsx)

After the inventory, it became apparent that the APU control system was missing. The main task of this internship was therefore to design and manufacture a control panel to operate the APU.

Design and reception of components (weeks 3 to 4)

The third week was marked by the design of the wiring diagram and the receipt of the first ordered components. Indeed, I was able to contact Ian Bennett, from the website www.gasturbineworld.co.uk to ask him for the APU wiring diagrams. I found his contact through a YouTube video in which he was starting up a Garrett GTCP85-98C APU, similar to the GTCP85-98D we had in the workshop.



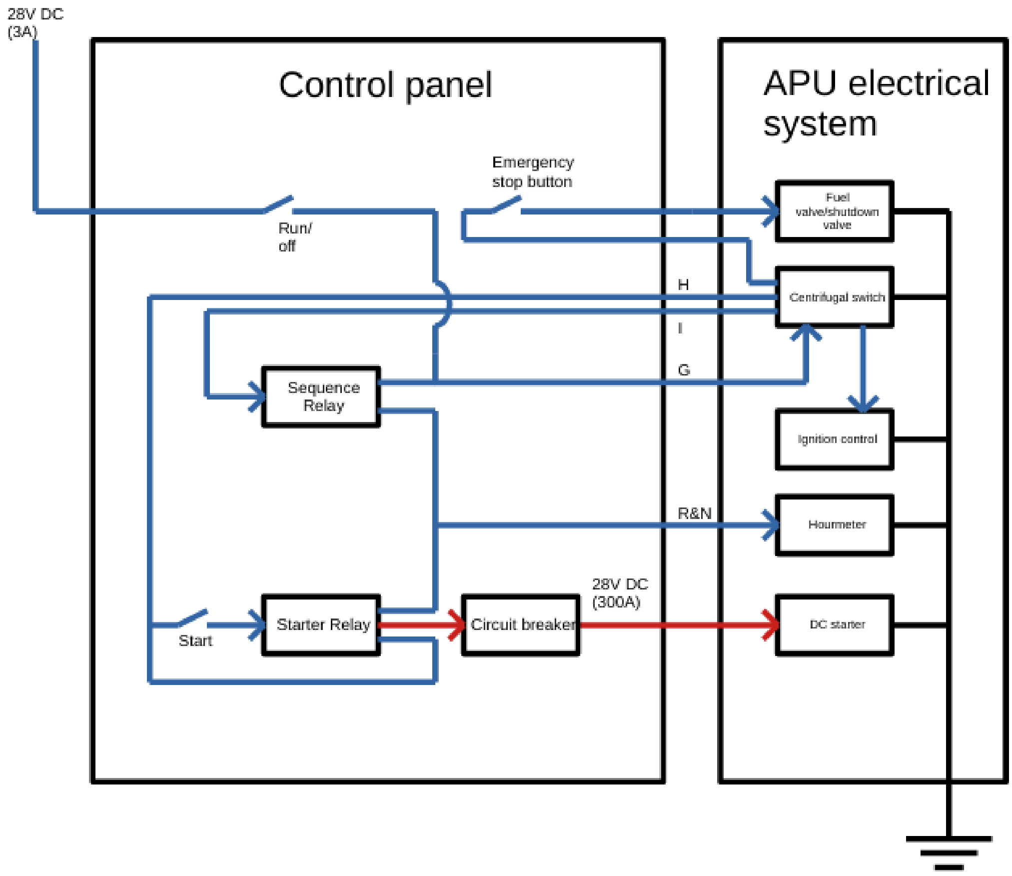
KEY TO FIGURE 101

* 1.	MAIN ENGINE CONNECTOR	21.	STARTER MOTOR
2.	ENGINE HARNESS CONNECTOR ASSY	22.	IGNITER PLUG
* 3.	IGNITION UNIT	*23.	IGNITION LEAD ASSY
4.	IGNITION UNIT CONNECTOR	26.	PNEUMATIC SOLENOID VALVE
7.	OIL THERMOMETER BULB CONNECTOR	27.	PNEUMATIC SOLENOID VALVE CONNECTOR
8.	OIL THERMOMETER BULB	*28.	LOCK OUT RELAY CONNECTOR
9.	TACHOMETER-GENERATOR CONNECTOR	*29.	LOCK OUT RELAY
*10.	TACHOMETER-GENERATOR	34.	THERMOCOUPLE
11.	CENTRIFUGAL SWITCH CONNECTOR	35.	GROUND TERMINAL
12.	CENTRIFUGAL SWITCH	36.	GROUND TERMINAL
13.	OIL PRESSURE SWITCH CONNECTOR	37.	SPLICE
14.	OIL PRESSURE SWITCH	38.	SPLICE
16.	CIRCUIT BREAKER	39.	SPLICE
17.	HOURMETER	40.	SPLICE
18.	FUEL SOLENOID VALVE CONNECTOR	41.	RESISTOR
19.	FUEL SOLENOID VALVE	42.	THERMOCOUPLE CONNECTOR
		43.	THERMOCOUPLE CONNECTOR

*CUSTOMER-FURNISHED.

GTCP85-98C Electrical Diagram

From the schematic provided by Ian Bennett, I was able to design a control panel for the APU. It is supposed to plug into connector (1) in the diagram above. The control panel contains various switches and relays to perform the APU startup sequence.



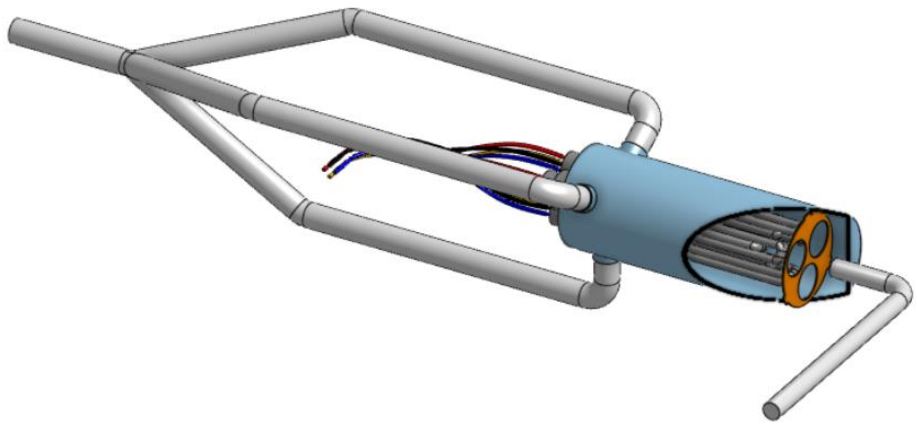
Electrical diagram of the APU control panel, first version

The sequence is as follows:

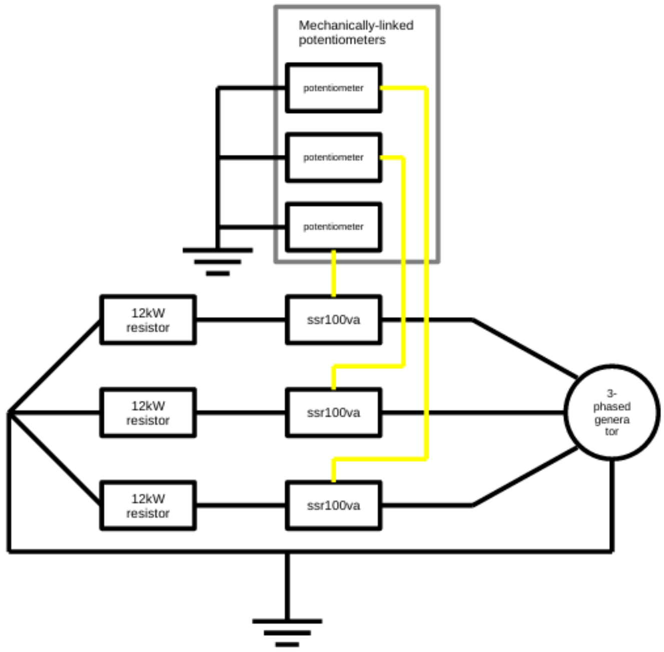
1. The "run/off" switch is closed, which energizes the APU's centrifugal switch.
2. The "start" switch is closed for a fraction of a second, activating the starter relay, which begins to rotate. This also activates the hour meter. The starter relay remains closed as long as it is energized by the centrifugal switch.
3. When the APU rotor reaches 35% of 40,000 rpm, the centrifugal switch performs several actions: activating the fuel valve, activating the spark plug, and deactivating the starter relay.
4. The APU gradually accelerates to 95% of 40,000 rpm. This speed is maintained by a governor associated with the fuel pump, which reduces the fuel injection flow when 100% of 40,000 rpm is reached. The flow returns to normal when the APU speed drops below 95% of 40,000 rpm.
5. When the run/off switch is opened, the centrifugal switch cuts off fuel injection. The centrifugal switch and the hour meter remain lit until the APU is completely shut down.

I decided to add an emergency stop button to the fuel valve. When pressed, this button cuts off the electrical power to the valve, placing it in the closed position.

At the same time, I began designing a system to dissipate the APU's electrical power with Samo. Indeed, the APU can generate approximately 36 kW of three-phase electrical power. We therefore began looking for water-cooled three-phase resistors. The power resistors considered to simulate an electrical load are expensive (approximately €400–500 each). Alternative solutions are being explored, such as the use of a three-phase motor coupled to a braking system or modulated boiler resistors. The latter solution will be chosen: zero-crossing TRIAC modules (ssr100va) will act as large transistors and will allow the resistive load (3 boiler resistors of 12kW each) to be varied using a potentiometer.



CAD modeling of three-phase resistive load



Wiring the resistors

Technical difficulties and incomplete documentation (weeks 5 to 7)

Construction of the control panel began. It was mounted on a spare box and incorporated switches secured with 3D-printed brackets.

Despite progress in the assembly, problems arose: the schematic provided by Ian Bennet corresponded to a different version of the APU (GTCP85-98C instead of the GTCP85-98D). This caused an inconsistency between the connector pins and the actual components.

A lengthy manual verification phase began, using a generator and a multimeter to test pin matching. Only four pins were identified with certainty. Obtaining complete documentation became a key challenge. Approaches were made to Honeywell Aerospace and Adria Tehnika, but without immediate results.

Slowdown period and additional activities (weeks 8 to 9)

Due to the document blockage, I am temporarily redirected to another project (Ziga's flameless turbine engine). I am carrying out minor work, such as installing pressure sensors or reinforcing the exhaust gas lines. No significant progress on the APU is possible at this stage.

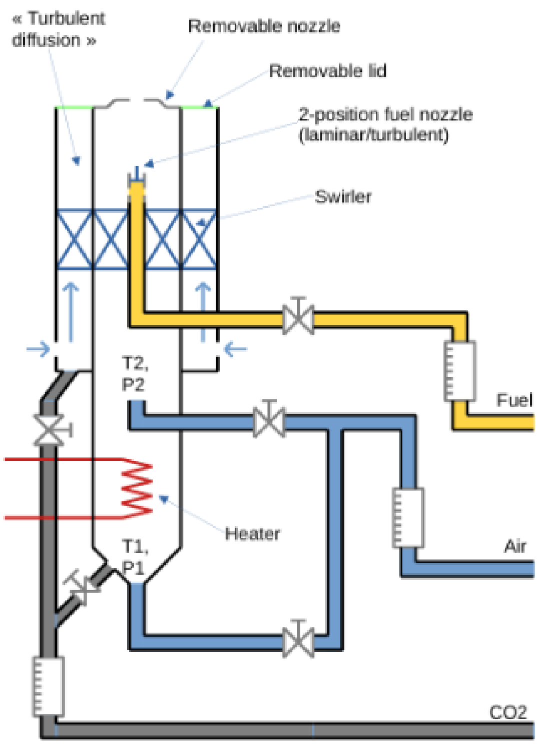
Burner Project Development (Weeks 10-11)

A new direction was taken: to design a large Bunsen burner for research and teaching.

The main specifications were:

- Ability to operate in premixed and diffusive regimes, in laminar or turbulent mode;
- Possible integration of flameless combustion;
- Addition of CO_2 to simulate exhaust gas recirculation (EGR).

The design was based on the requirement for a power output of approximately 3.5 kW to allow for camera observation of the radicals. Preliminary calculations were performed (air flow rates, butane flow rates, mixing speed).



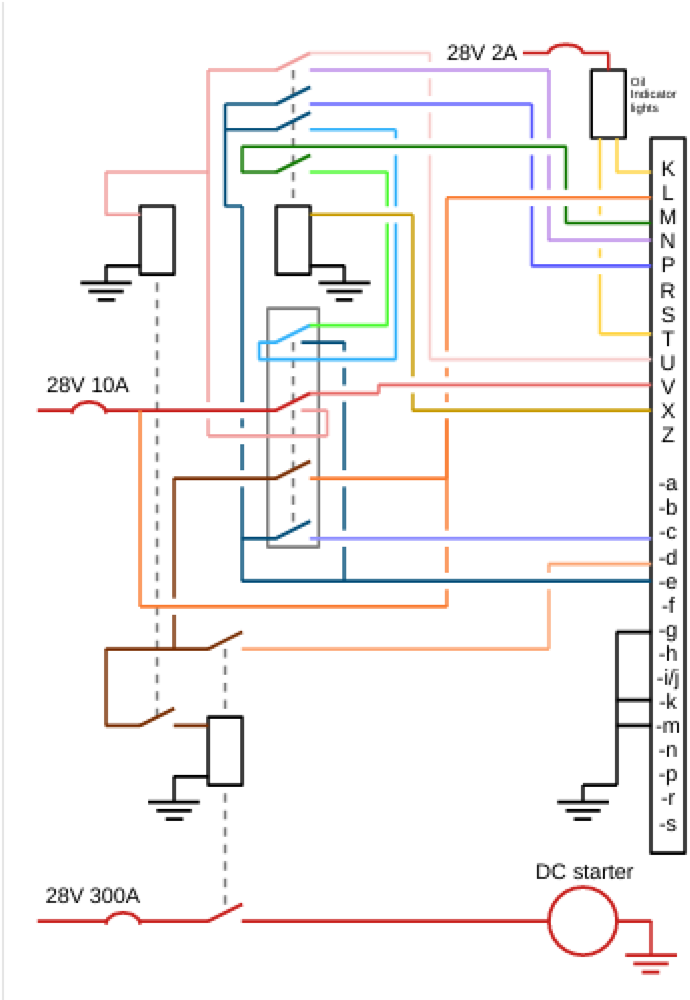
Bunsen burner diagram

A CAD model is then produced on Onshape, including variable-pitch swirlers. The burner must be assembled from steel tubes, hoses, and 3D-printed parts.

Resumption of the APU start-up project (weeks 12 to 14)

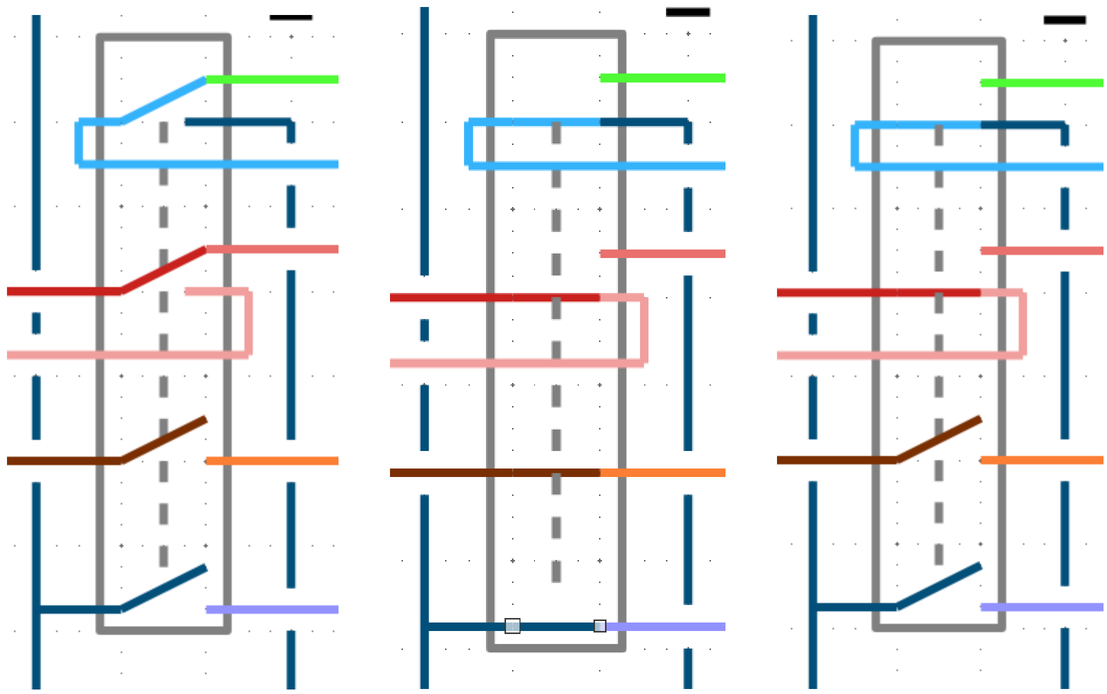
With the availability of a new manual corresponding to the GTCP85-98D, the APU project was relaunched. A new electrical diagram allowed the design of a functional control panel incorporating:

- Three relays and four switches (then the addition of a fourth relay),
- A 28V power supply for starting,
- A safety feature allowing automatic shutdown of the starter at 35% of maximum speed.



New control panel electrical diagram

This diagram is a partial replica of the control circuit found in the cockpit of the aircraft. However, a relay has been added (top left, pink circuit) to be able to stop the starter in case of emergency. The positions of the master switch (center, framed in gray) are as follows:



Master switch positions (in order: off/start/run)

Tests carried out (week 14):

Dry run: the starter engages but does not automatically shut off. The problem is identified as related to the absence of the non-ram door actuator (present on the aircraft but absent in the laboratory). An electrical simulation corrects this issue.

First test with fuel (diesel) on 08/12/2025: leak in the fuel circuit and battery voltage too low. This prevents the spark plug from igniting at the right time (35% rpm); it only ignites when the starter is manually turned off, resulting in flames and black smoke at the end of the test.

Black smoke from the exhaust

Test corrected on 08/14/2025: addition of a second battery, replacement of the oil, and correction of the leak, which allows for higher RPM and stable combustion. After unsuccessful tests, the APU ran continuously for 1 minute 15 seconds, without black smoke. I assume that the two unsuccessful tests had time to warm up the APU, facilitating combustion during the third test. However, white smoke appears during shutdown. Indeed, we were forced to shut down the APU by closing the fuel valve and not according to the standard procedure, which altered the air/fuel ratio and caused white smoke.

The test video is as follows: https://youtu.be/RJiwS3OH2Zs

This test constitutes the major result of the project: the demonstration that the APU can be started and operated under laboratory conditions.

Discussion and analysis

Technical skills acquired

One of the biggest challenges encountered during the internship was the mismatch between the available documentation and the actual version of the APU. The wiring diagrams initially provided corresponded to the GTCP85-98C model, while the lab equipment was a GTCP85-98D. This discrepancy made pin assignments unreliable and prevented straightforward wiring of the control panel. To address this, a trial-and-error approach was adopted: each pin was manually tested using a generator and a multimeter to establish the correspondences. However, obtaining documentation for the GTCP85-98D further contributed to the project's success.

The control panel itself had to be redesigned several times. Early versions revealed safety issues and malfunctions in the automatic startup sequence. Through iterative modifications, including the addition of relays, simulation of the non-ram door actuator (a simple electrical cable), and wiring adjustments, the panel gradually evolved into a functional and reliable system. This experiment illustrated the value of adaptive engineering: rather than seeking to design a perfect solution from the outset, incremental improvements allowed the system to reach operational maturity.

Another major technical challenge involved the design of a charging system capable of dissipating or converting the electrical power produced by the APU generator. Several solutions were explored in parallel: the use of high-power resistors (expensive and difficult to cool), the adaptation of a three-phase motor with a braking system (less expensive but mechanically complex), and the use of boiler resistors combined with electronic modules (a promising compromise between cost and controllability). This exploration highlighted both the economic constraints of the experimental setups and the need to creatively adapt existing technologies to the laboratory's needs.

Methodological lessons

From a methodological perspective, the internship highlighted the central role of prototyping, testing, and iterative error correction. Each stage of the work, from the initial wiring diagrams to the final assembly of the control panel, required successive trials, adjustments, and validations. This iterative approach proved more effective than seeking a definitive design from the outset, as it allowed for the gradual identification and resolution of unforeseen problems.

It is also noteworthy that the work schedule shown on the Gantt chart was not strictly adhered to: the entire LabView and instrumentation section was not completed due to lack of time.

The safety considerations inherent to the project were equally important. Working with an APU involved managing significant risks: fuel leaks that could cause fires or uncontrolled combustion, electrical currents of several hundred amperes during the startup sequence, and extremely high-temperature exhaust gases. These constraints required rigorous attention to procedures, careful inspection of each connection, and redundant protective measures. Beyond the technical results, the experience reinforced the need to integrate safety as a fundamental component of any experimental engineering project.

Added value for the laboratory

This internship made a concrete contribution to the laboratory's experimental capabilities. The successful operation of the APU demonstrated the technical feasibility of such equipment within the laboratory's constraints. This success lays the foundation for future experiments, whether for performance characterization, educational demonstrations, or research on combustion control and processes.

At the same time, the design of the large Bunsen burner created a versatile tool, adaptable to different combustion regimes (premixed, diffusion, laminar, turbulent, or flameless). Once built, it will provide a flexible platform for teaching and research, particularly for visualizing radical species and exploring advanced combustion concepts. Together, these two results enrich the laboratory's resources and open new avenues for experimental studies.

Conclusion

This internship allowed me to participate in two ambitious and complementary projects: the development of a test bench for the Garrett GTCP85-98D auxiliary power unit (APU) and the design of a full-scale Bunsen burner for combustion studies. Both initiatives were marked by technical challenges, methodological learning, and significant contributions to the laboratory's experimental infrastructure.

For the APU project, the internship began with planning, documentation review, and preliminary design of the control panel and piping. The lack of reliable documentation hampered progress, forcing the adoption of empirical methods such as manual pin testing with a generator and multimeter. Despite these obstacles, iterative redesign of the control panel and creative troubleshooting ultimately led to successful testing of the APU. This achievement not only validated the feasibility of operating the system under laboratory conditions but also laid the foundation for future experimental campaigns.

The Bunsen burner project opened up a complementary avenue of work. Its design required theoretical calculations of flow rates and mixing velocities, as well as CAD modeling of the structure and variable-pitch fins. Although its construction was not completed during the internship, the design deliverables represent a valuable asset for the laboratory: a versatile burner concept capable of supporting multiple combustion regimes, from premixed laminar flames to flameless combustion. This flexibility will allow students and researchers to visualize reactive species and study advanced combustion processes in a controlled environment.

Beyond these technical results, the internship provided me with important methodological lessons. It highlighted the value of prototyping, iterative testing, and adaptive problem-solving, as well as the absolute necessity of integrating safety considerations when dealing with high currents, fuels, and hot exhaust gases. The experience also highlighted the importance of teamwork, external communication, and self-reliance in overcoming technical obstacles.

In terms of added value for the laboratory, the internship provided a functional control system proving the APU's operability and a ready-to-implement burner design. These two contributions enrich the laboratory's experimental resources and create new training and research opportunities.

Finally, on a personal level, this internship was educational in several ways. It provided hands-on experience with electrical systems, combustion, and CAD design, while strengthening project management and troubleshooting skills. It provided a better understanding of real-world engineering constraints such as budget, documentation gaps, and safety, all essential factors in the profession. Most importantly, it helped clarify career ambitions by linking academic knowledge to real-world engineering challenges.

In conclusion, this internship successfully achieved its objectives, combining technical achievement and personal development. It represents a valuable step both for the laboratory, which now has new experimental tools, and for the student, whose skills and professional identity have been considerably strengthened.