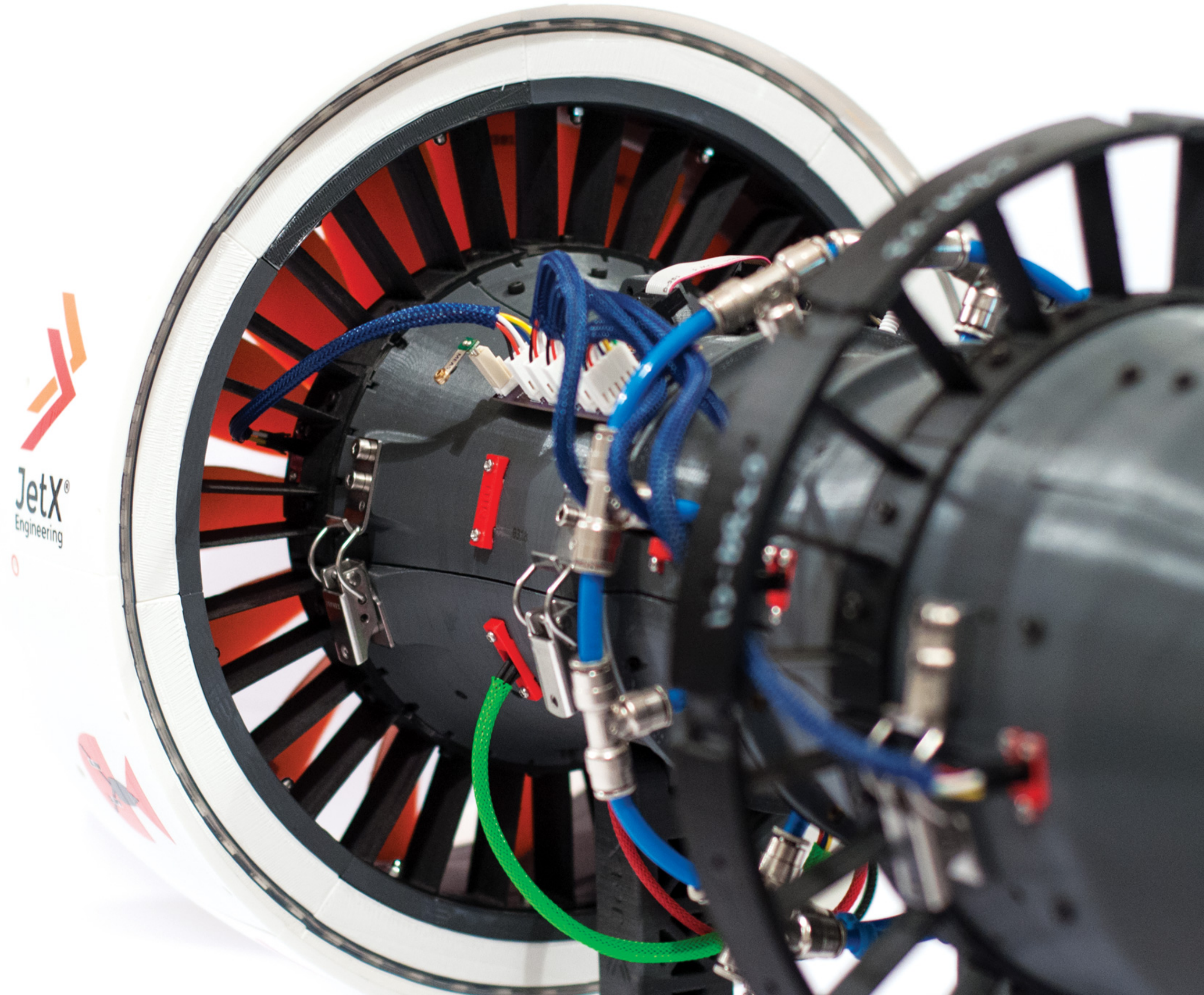
X-Plorer 1 EC

Operation & Maintenance Manual

Version 1



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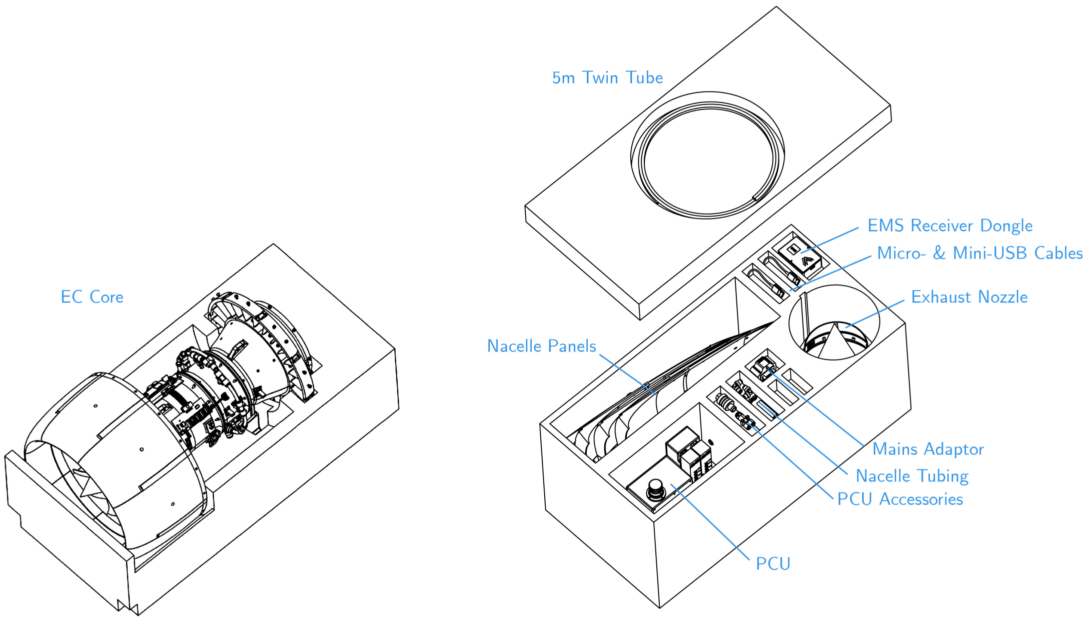
1. Getting Started

Welcome! It's great that you will be joining the growing community of users of JetX engines for educational and research purposes! We have put the following guide together to help you get up and running quickly as well as provide a lot of useful information on everyday operation and maintenance.

1.1 What's In The Box



The engine and auxiliary components are delivered in two boxes. In the first one labelled 'CORE' you will find:

- X-Plorer 1 EC core assembly

In the second one labelled 'AUX' you will find:

- 4x partially-assembled nacelle panels
- Exhaust nozzle sub-assembly
- Pneumatics Control Unit (PCU)
- EMS receiver dongle including USB cable
- 1x micro USB charging cable including mains adapter
- 5m twin 6mm OD pneumatic tubing

Both boxes are equipped with locks for safe storage and 2 sets of 2 keys are included. The keys can be used interchangeably between the two boxes.

1.2 Setting Up

Open the core assembly box and carefully remove the top half of the protective foam, setting it aside. Carefully lift the engine by the sides of the core near the pneumatic ring and place it on a flat and stable surface. The centre of mass of the X-Plorer 1 EC is located just behind the front stand and, as such, it is important not to lean on the front of the fan casing or nacelle.

The stands include mounting holes which can be used to secure the engine in place using M4 bolts. In the majority of operating conditions, mounting is not necessary and can be omitted.

1.2.1 Attaching The Exhaust Nozzle

From the AUX box lift the top block which contains the twin tube to gain access to the rest of the components. Carefully remove the exhaust nozzle sub-assembly, taking caution to not damage the protruding tubes and pins of the attached sensors.

! The tip of the exhaust cone is sharp! Take care to avoid injury during assembly or whilst it is in place.

Align it concentrically with the end of the turbine casing and slot over the lip. The airflow sensor should be positioned on the right lower quarter, looking from the back. Two red lines will indicate the correct position.

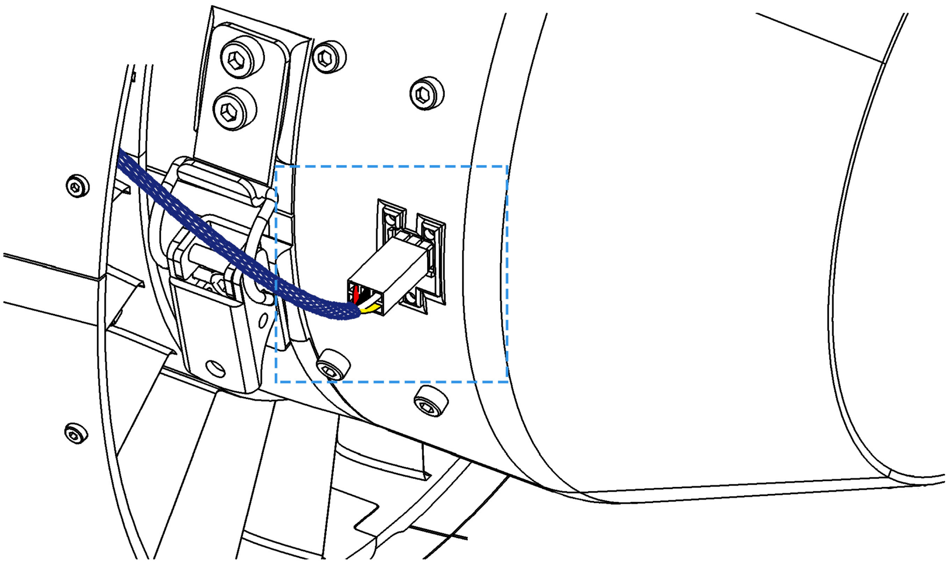
If needed, slightly adjust the rotation of the nozzle until the bolt holes are in alignment with the inserts in the turbine casing. The nozzle sub-assembly can be secured in place using 8 M3x6mm bolts, which are provided.

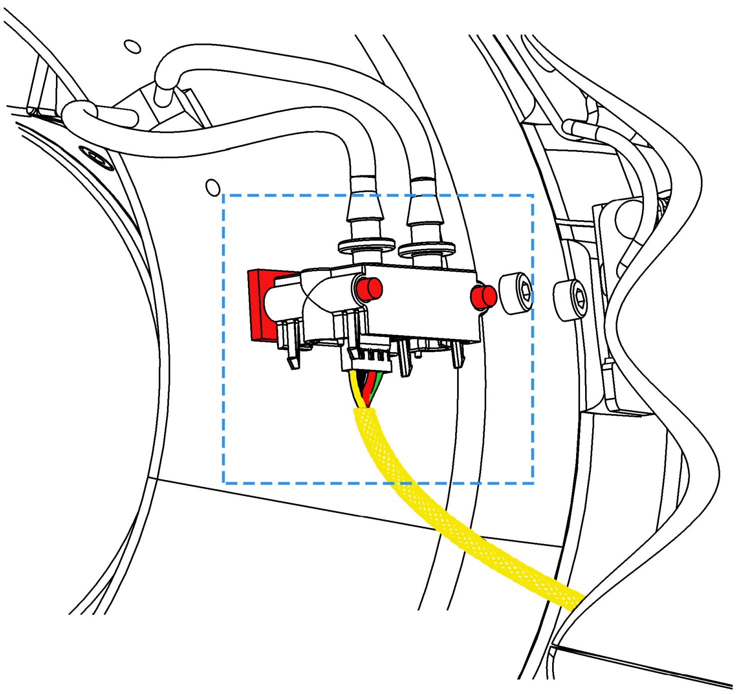
! Using bolts longer (not including the head) than the designated one (6mm) will prevent the rotation of the final stage of the turbine, potentially damaging it.

! Care must be taken when tightening the bolts as improper alignment and excessive force will damage the threaded inserts. If that occurs, remove the bolt and refer to the troubleshooting guide for the required steps before trying to insert the bolt again.

Connecting Exhaust Sensors

The exhaust nozzle comes with two sensors already attached; on the left, the fifth low pressure sensor is mounted with only the connecting pins protruding and on the right a differential pressure sensor attached to a Pitot tube to measure the airspeed of the core flow. The respective cables should be in close proximity to the sensors and can be connected as shown below:





1.2.2 Attaching The Nacelle

The nacelle is split into 4 parts for storage and transport; one part comes with electronics attached to it, one includes an opening for the pneumatic connections and the other two make up the top half of the nacelle.

Quarter 1 - Electronics

First, remove the quarter with the electronics attached to it and ensure you have clear access to the left side of the engine (as you look from the front). The panel sits right beneath the edge of the fan casing and outside the nacelle ring mounted around the turbine.

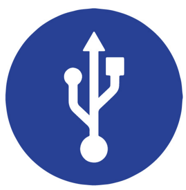
Take care to ensure that the black cable going from the LED ring to the core PCB goes into the dedicated slot first. The front of the sub-assembly should be only a few millimetres away from the bypass stators so that it can slide in place around the mounts. Carefully push the panel inwards so that it fits around the mounts and rests in place.

! If the panel does not go into position easily, do not force it and make sure the part is properly aligned.

Proceed to bolt the part in place, starting with the front section where 4 M2x18mm are needed for each quarter. Following that you can bolt the rear of the panel to the nacelle ring using 4 M3x8mm bolts. Please bear in mind that you might have to push the panel downwards for the holes to align properly, inserting the corresponding bolts until they reach the inserts. This is normal and is required before you attempt to tighten the bolts to ensure that the part is positioned correctly.

! Make sure the switch is at the **USB/OFF** position and the external USB cable is **disconnected** before making the following electrical connections.

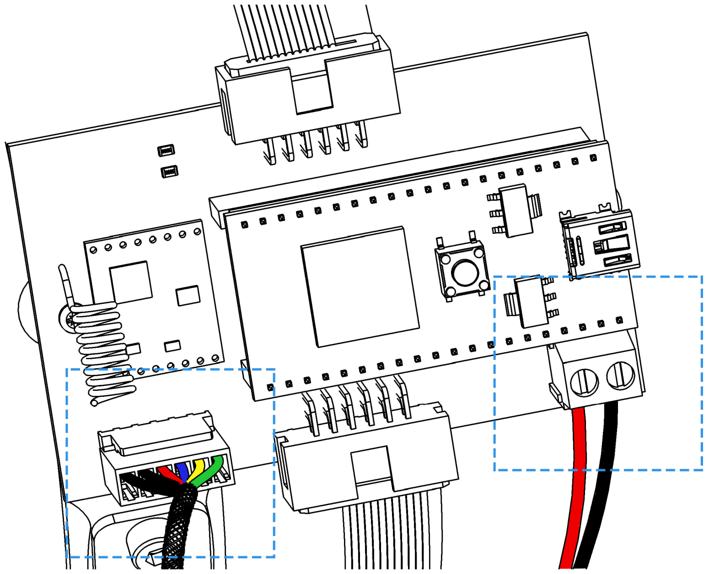
Power/Charging Port



USB-powered only. The battery is disconnected and unplugging the USB cable shuts the system down.

Hybrid USB/Battery-powered mode

Once the panel is secured in place, two connections need to be made with the main PCB. The 6-pin connector can be inserted in the respective header as shown below. Two power cables in the yellow sleeve need to be connected to the terminal block on the right of the onboard processor, as shown below. Using a flat head screwdriver tighten the cables in place.



Quarter 2 - Pneumatic Tubing

The second quarter includes a slot for the twin tubing to go through. For this part of the assembly you will also need:

- 1x 7.5cm long, 6mm OD twin tubing segment
- 1x tube spacer
- 2x push-in elbow fittings for 6mm tubing

All items can be found in the AUX box. If the spacer is already fitted, remove it before proceeding. Begin by inserting the twin tube through the nacelle slot. Once through, fit the spacer around the tubes until it reaches its resting place, or around 3cm from the edge. From the external side, insert the elbow fittings by pushing them over the tube ends. Move the entire tube so that the spacer is as close to the interior of the nacelle as possible.

Slide the panel into position and align the tubing with the fittings already on the nacelle ring. Push the twin tube from the outside with one hand, whilst holding the elbow fitting by the pneumatic ring until both tubes are firmly in place. If needed, readjust the position of the spacer. Bolt the panel in place in the same manner as the first quarter.

Quarters 3 & 4 - Top

The remaining panels can either be installed individually or pre-assembled to form the top half prior to joining it with the rest of the nacelle and the engine. Looking from the front, the panel with the University of Sheffield logo should be at the top right and the one with the rest of the logos on the top left. The two cannot be used interchangeably.

To join the two panels first, M2 bolts should be used with the following lengths (in order from front to back): 6mm, 5mm, 6mm, 4mm & 4mm. Once the top half is assembled, slide it over the nacelle ring and beneath the fan casing slot. You may have to loosen or remove the bolts outlined in blue and pull one of the bottom panels slightly outwards to allow correct positioning of the top half.

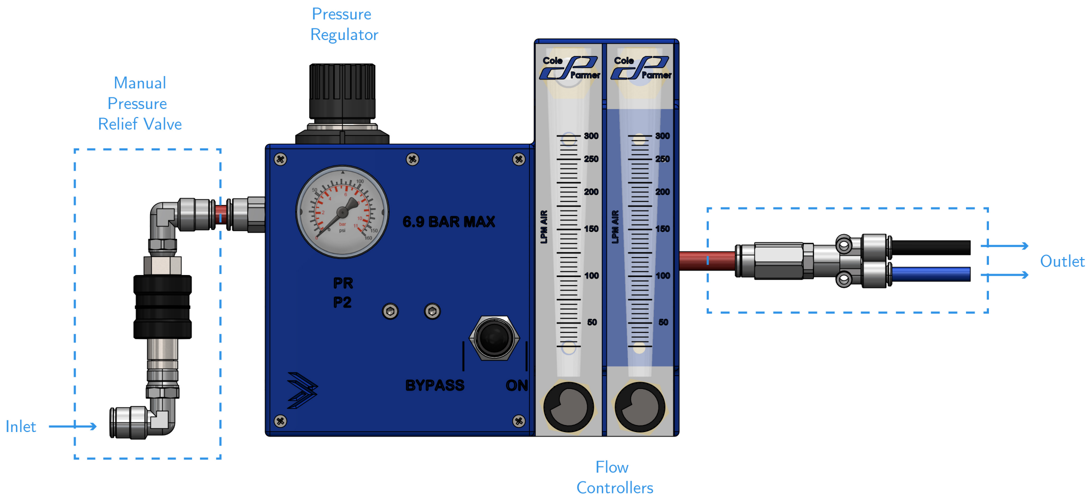
Once this is done, bolt the top half in position around the fan and the nacelle ring, making sure all parts have been secured in place.

1.2.3 Connecting the PCU

Remove the PCU and the provided tubing from the AUX box. You will need both a 5m twin tube segment and one 8mm OD spiral tube.

Connect the 8mm spiral tube and the manual pressure relief valve to the inlet, making sure the pressure regulator is set to low pressure (or rotate counter-clockwise fully), the control valve is in the idle position (in the middle) and the flow controller is fully shut (rotate clockwise to tighten). If you can't adjust the pressure regulator, make sure it is in the unlocked position by pulling the knob upwards.

Never disconnect pneumatic tubing before making sure that pressure has been relieved or is adequately low to eliminate the risk of sudden release resulting in injury.



Connect the twin tube splitter to the outlet tube, connecting the twin tube to it. Following this, complete the set-up by connecting the other end of the twin tube to the nacelle inlets. Finally, screw the control valve lever in place, once again making sure it is in the idle (middle) position.

1.3 Running the Engine

If there is nearby access to power, use the micro-USB cable and the mains adapter provided to connect it to the socket on the side of the nacelle. The on-board system will automatically turn on and you will see the status LEDs lighting up.

Remove the EMS Receiver unit from the AUX box, along with the mini-USB cable provided and connect to an available USB port. Open the JetX EMS application and check to see if the device is listed under a serial port (such as COM1). If you don't see any available port, click the refresh button and try again.

If this is the first time you are using an mbed-based device, you might have to install the respective serial port driver, available from the developer's website or our Users' Portal. Similarly, if this is the first time you are using the EMS application and your computer does not come with C++ Redistributable Packages for Visual Studio 2013 installed you will also have to install them from the developer's website or our Users' Portal.

The main window of the EMS application will provide you with an overview of the data collected. Once you are ready to test, click on the start button and data will shortly appear on the screen. This will also trigger the logging function, which will save the data to:

`/Documents/JetX/Logs/XP1EC`

once a test is completed and the stop button is pressed. This completes the quick set up as you are now ready to start the engine!

Although the fan exerts little suction, please adhere to the warnings displayed to make sure loose articles of clothing or light objects aren't caught.

On the PCU, make sure the inlet is pressurised and slowly start turning the regulator clockwise until a pressure of 6.9 bar is reached.

Do **NOT** exceed the pressure of 6.9 bar under the main flow line as this may cause the flow controller to shatter. If the bypass line is used, the pressure can be higher, but should not exceed 10 bar.

Never set the valve to **Bypass** at first unless you are aware of the inlet flow conditions and are certain that regulation is not required. Bypassing a sufficiently high flow of air can cause damage to the engine due to sudden discharge.

Once the desired pressure has been set, move the valve lever right to select the main flow line. You should hear a short hiss every time you connect the flow to a line and bring it back to idle as the valve is self-relieving. You can now slowly rotate the knob on the flow controller counter-clockwise which will allow air to start flowing to the engine. The shafts will start rotating and you should keep an eye on the monitoring screen for the testing conditions. Remember that at any time you can visually check the rotation of the LP shaft, but the HP shaft will be rotating at much higher speeds.

You are now ready to run the engine under various conditions, as well as view and record performance data!

1.4 Standby

If you are not going to use the engine soon, make sure the switch is at the **USB** position and remove the micro-USB cable from the built-in socket. Make sure the PCU is not under pressure and, when it's safe to do so, disconnect the inlet tube from the source.

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2. About the EC

The X-Plorer 1 EC is based on its predecessor, the X-Plorer 1. This iteration includes some key performance improvements. The EC has been manufactured with the intention of being used as miniature test rig for the testing of prototype electronic sensing and control systems at the University of Sheffield UTC.

This section will document the design of the EC in a bit more detail. It is intended that this section is referred to once at the start of your journey to provide some background information not covered in the quick start guide.

2.1 Specifications

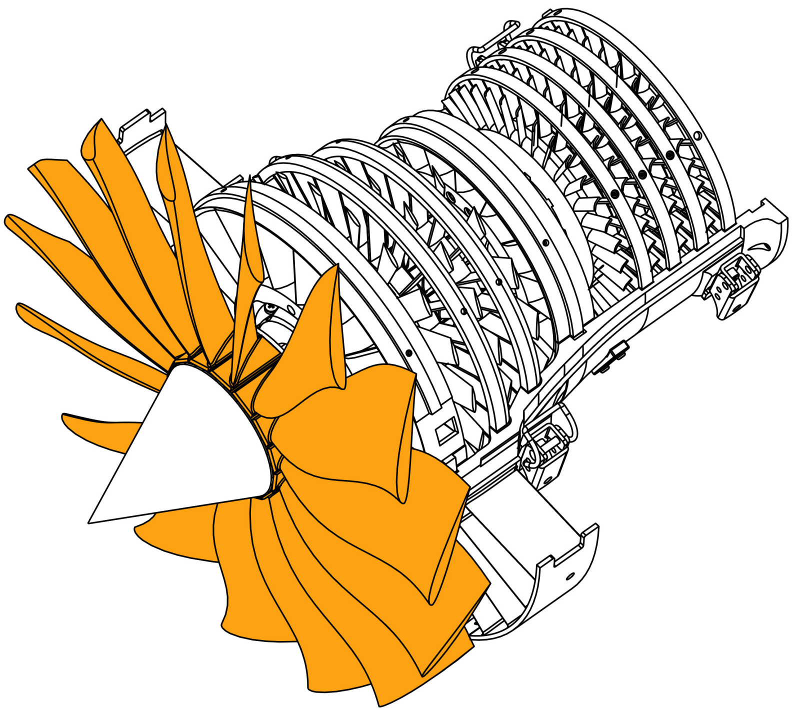
Type	**High-bypass turbofan**
Bypass Ratio	**5.0:1**
Spools	**2**
LP Stages	**3 (Compressor) - 3 (Turbine)**
HP Stages	**5 (Compressor) - 1 (Turbine)**
Static Thrust (Theoretical)	**2.99 kN**
Fan Diameter	**26.4 cm**
Total Length	**73.4 cm**
Gross Weight	**8.1 kg**
Manufacturing Method	**FFF (3D Printing)**
Total Parts in Assembly	**1432**
3D Printed Parts	**264**

2.2 Core Design Overview

2.2.1 Compressor

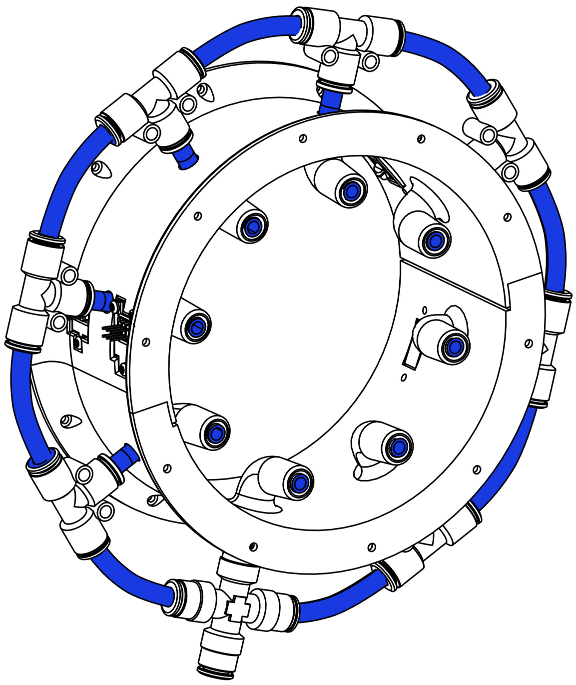
On the whole, the compressor design was largely carried over from that of the XP1. It is made up of three main assemblies; the fan with the outlet guide vanes, Low Pressure Compressor

(LPC) and High Pressure Compressor (HPC). One of the most visible changes made to the EC is the introduction of the new and improved second generation fan blade design. The flow that enters the core first encounters the LPC which consists of 3 consecutive rotor-stator pairings, known as stages. The LPC blades are connected to the LP shaft via the disk/hub, unlike each of the 5 HPC rotors which are manufactured as a single component, known as a blisk. These are mounted on the HP shaft which spins faster than the LP shaft.



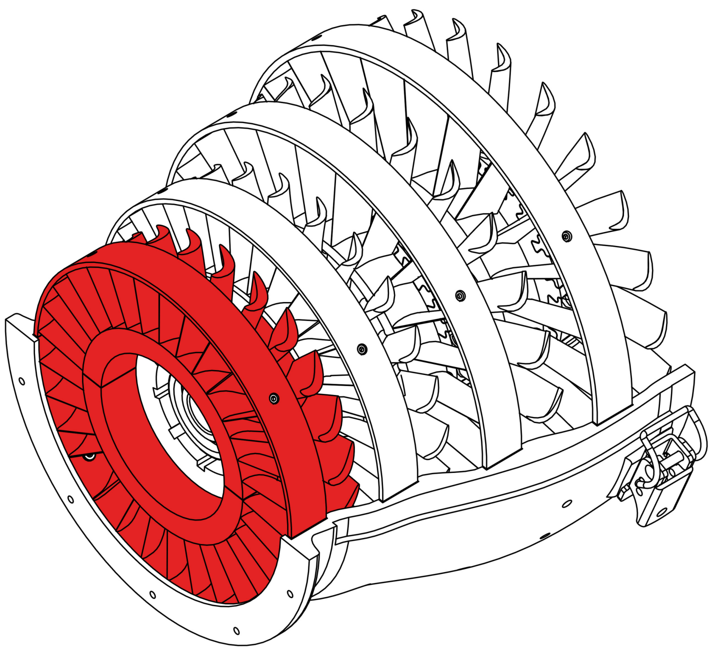
2.2.2 Propulsion Chamber

The majority of the energy required to drive the turbine is provided by an external compressed air supply. In this fireless engine model, a pneumatic ring with 8 nozzles takes the place of fuel injectors. This has been designed to allow the injection of air to be directed towards the first stage of the High Pressure Turbine (HPT). The addition of a second 6 mm OD pneumatic tube allows the EC to receive up to 500 LPM.



2.2.3 Turbine

The purpose of this assembly is to extract the power required to rotate the compressor. The turbine of the XP1 EC includes only a single-stage HPT. The 3-stage LPT drives both the LPC and the fan. The turbine contains similar components to the compressor. Like the compressor, the turbine has seen one important change; namely, the shift of a stage of the HPT to the LPT in order to increase LP shaft speed, relative to the HP shaft speed.



2.3 PCU

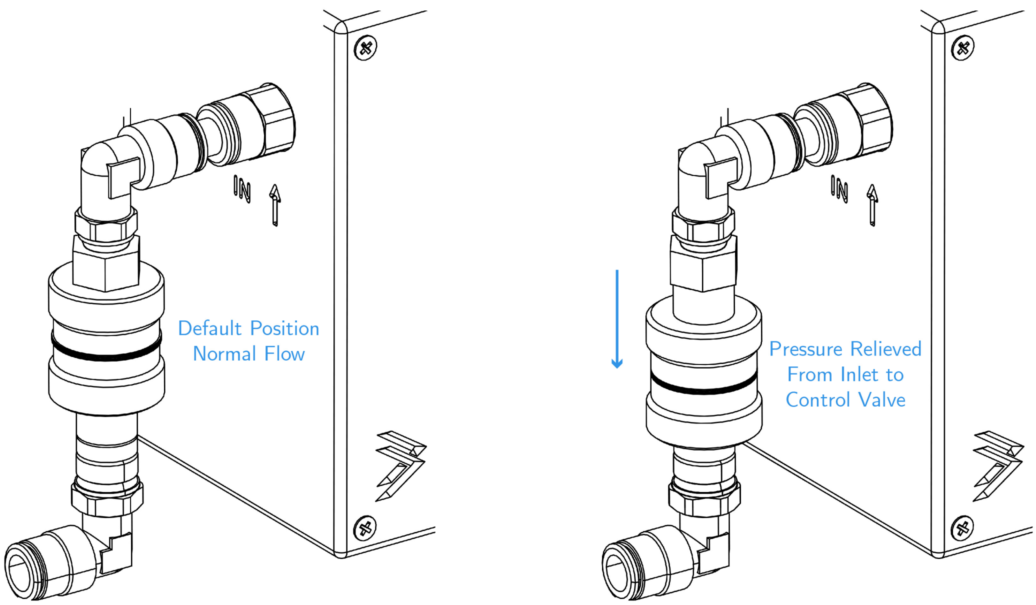
The Pneumatics Control Unit is the engine's control box and consists of a few tools that let you regulate a wide range of air supplies for monitored and safe operation of the engine. As with other components in the programme, the PCU design is largely similar to that of the one used for the X-Plorer 1 with three key differences:

- Increased flow rate capacity to 500LPM by replacing certain tubing segments with 8mm OD tubed and the use of a twin 6mm OD tube to the engine
- Replacement of the old branching set-up that used two separate flow regulators and combined them to a single 5-way, self-relieving valve
- Provision to use 2x 280LPM flow meters, providing a more economical solution to high flow rate control

These are changes that not only add to the testing capabilities but also make operation slightly faster and easier. This section will provide a quick but more detailed overview of the individual components and things to note while using the PCU.

Manual Relief Value

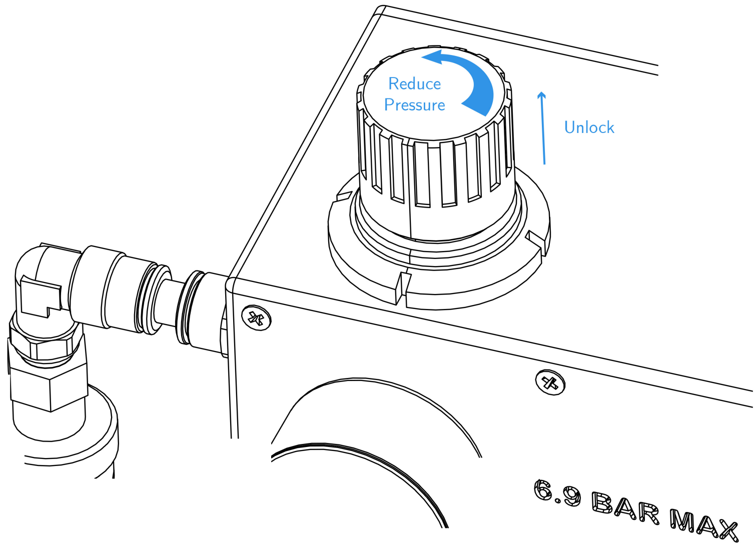
The PCU is ready to be connected to any 8mm OD pneumatic tubing and, prior to regulation, it can work with pressures up to 10 bar. The first component is located on the left-hand side of the unit and can be used during shutdown if required. The manual pressure relief valve has a cylindrical handle which is normally up for the closed position (allowing air to flow through the tube). To quickly de-pressurise the system from the inlet to the control valve, pull the cylinder downwards.



Pressure Regulator

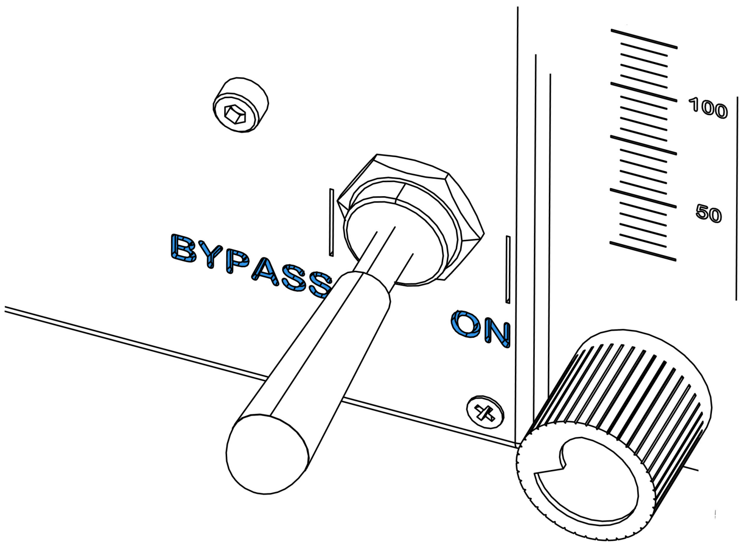
A pressure regulator is fitted next in line to reduce the pressure where required to acceptable levels for use with certain components. Its operation is fairly simple: rotating clockwise increases the pressure and vice versa; whilst pushing the knob down will lock the current pressure setting. The pressure setting depends on the subsequent use; if the flow meters are used then the pressure must not exceed 6.9 bar and if these are bypassed then a pressure up to 10 bar can be used, but it is advised to generally keep it under 8 bar.

A pressure higher than 6.9 bar in the main line may cause the flow meters to shatter.



Control Valve

The control valve has 3 positions; idle, main line & bypass line. When pressurising the system make sure the valve is in the idle/middle position and never use the bypass line first. The operation is equally simple, as you have to move the lever to the right to connect to the main line or to the left to connect the bypass line. The specific control valve installed is self-relieving with two sintered bronze silencers also installed. In order to use the current set-up and have a single output to the engine, a circuit selector is connected inside the PCU.



Flow Meter

Under the default operation mode, the flow meter is the final component in the PCU. The second version can accommodate 1 or 2 variable area flow meters with their own flow regulators. Turning the knob counter-clockwise will start releasing air through the meter and a metal floater will indicate the volume of air released to the engine per minute. Always increase the flow gradually until it reaches the desired level.

3. Electronics & Software

3.1 System Overview

The second and largely improved version of the Engine Monitoring System (EMS) builds upon its predecessor and addresses some of the key weaknesses identified during the testing of the X-Plorer 1. Overall the system contains:

- 12 integrated sensors
  - 2 infrared RPM sensors
  - 6 absolute MEMS pressure sensors
  - 1 radial glass thermistor for bearing temperature monitoring
  - 1 radial glass thermistor for battery safety monitoring
  - 1 differential pressure sensor coupled to a Pitot tube for airspeed measurement
  - 1 cantilever-type vibration sensor
- 2 ARM-based processors for data processing and transmission
- 2 RF transceivers for wireless communication
- 1 rechargeable Li-Ion battery for operational autonomy for up to 2.5 hours
- Fully integrated LED strip for system and power indications
- Improved data logging for more insightful performance tracking across the engine's lifetime
- Customised Graphical User Interface (GUI) for data visualisation and logging

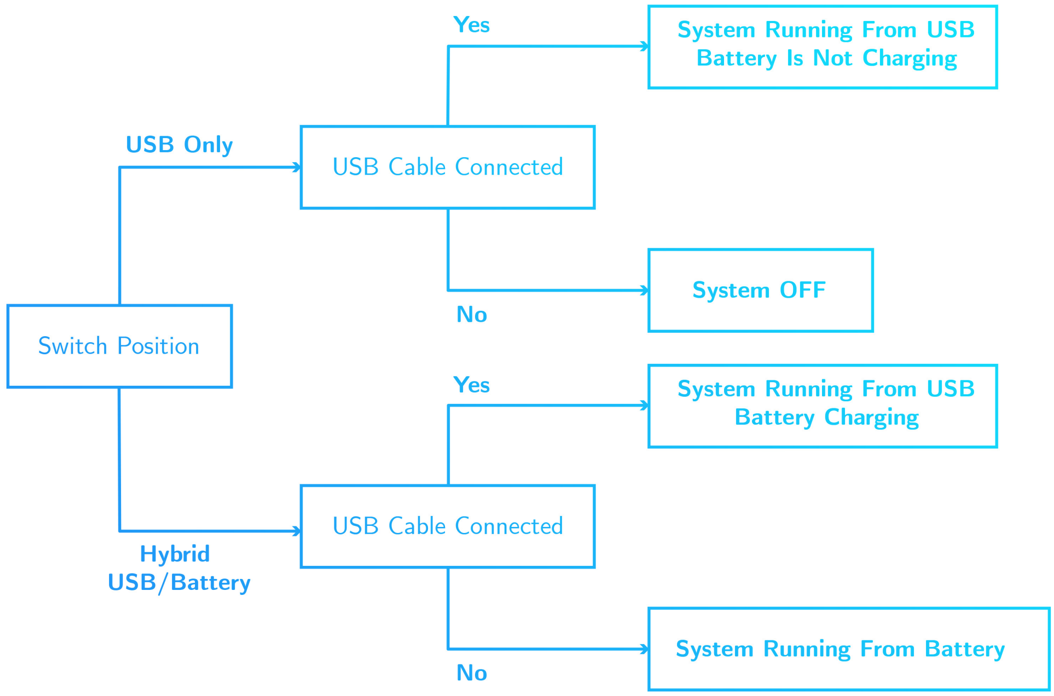
Operational Range

Sensor	Range	Normal Operation	Critical Level
Rotational Speed HP (RPM)	0 - >10,000	<1,000	>2,500
Rotational Speed LP (RPM)	0 - >10,000	<400	>900
Low Pressure (mbar)	0 - 1260	<300	>800
High Pressure (mbar)	0 - 5000	<300	>800
Temperature (°C)	-40 - 250	<50	>80
Airspeed (m/s)	0 - 12	<5	>10
Vibration (Hz)	0 - 42	<5	>15

These values should be cautiously used for reference and do not all represent the actual capabilities of the engine. Further testing is required to better understand some of the limits and the information will be updated accordingly.

3.2 Operation Modes

The on-board system can be powered both via mains or via the rechargeable battery installed on the nacelle. When in the **USB only** mode, the power cable needs to be connected for the system to run, but at this state, the battery is not being charged. Entering the **Hybrid/USB** mode coincides with intelligent power control which automatically selects the appropriate power source, as well as charges the battery whilst the rest of the system is powered by the USB cable. If set to hybrid mode, removing the USB cable results in a seamless transition to battery power and the system is ready to continue operation as before.



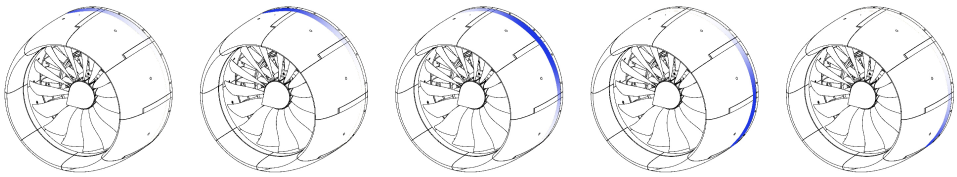
A full charge takes approximately 4 hours and should last for approximately 2.5 hours of use. When the LED strip indicates that the battery is low you should turn it off or connect it to a power source as soon as possible, ideally within 5 minutes.

3.3 LED Indications

3.3.1 Engine status related

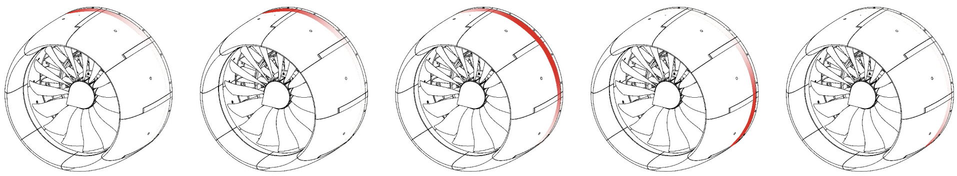
Idle & Running

Slow rotation in blue which responds to shaft speed.



Critical

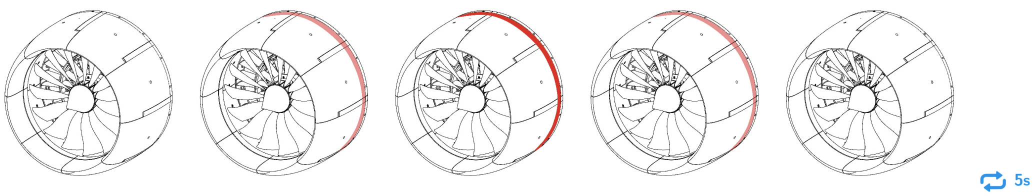
Rotation in red which shows that one of the critical levels from sensor data has been reached.



3.3.2 Power status related

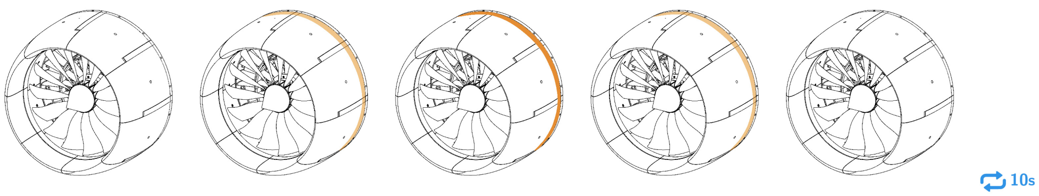
Low battery

Entire ring pulses red every 5 seconds.



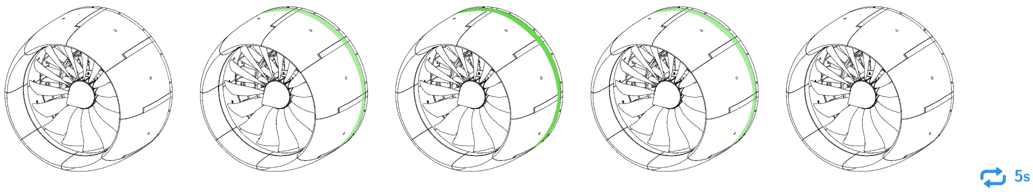
Charging in progress

Entire ring pulses orange every 10 seconds.



Charging complete

Entire ring pulses green every 5 seconds.

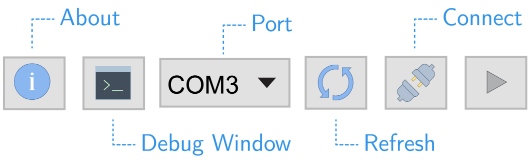


If the nozzle assembly is detached for maintenance, the critical warning will trigger due to the pressure sensor being disconnected.

A change of engine or power state is not instantaneously reflected on the LED strip. If you think something doesn't look right, wait for a few seconds to allow the system to update.

3.4 Using the GUI

Once the on-board system is up and running, you can plug in the EMS Receiver box to a USB port and open the application. In the drop-down menu, select the appropriate port and connect to the device.



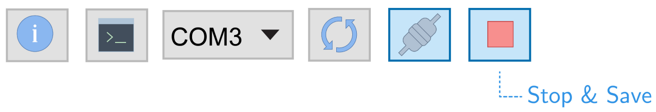
The main window provides an overview of all the data collected, including sensor data, lifetime usage and battery level. In the top left of the window the annotated schematic of the engine provides a quick way of reviewing all sensor data, the text of which also changes colour to highlight warnings or critical operation levels.

To start receiving and recording data for a test, press the start button at the top left of the window. Within 5 seconds data should start appearing on the screen. If that's not the case, try moving the receiver closer to the engine or away from obstructions.

The current transceiver does not have a equidistant range in all directions and can be sensitive to factors such as height and interference.

Once a test is completed stop the data acquisition. This will automatically save the log file to:

`/Documents/JetX/Logs/XP1EC`



Once finished, click disconnect and exit the software. When submitting a maintenance log for an issue related to performance or irregularities in the data, we would strongly encourage you to also attach the CSV generated for further review.

Notes

If the receiver is already connected and running while the engine is off, turning it on will result in some irregularities for the first few seconds. This affects arrays that are sent in packets and start from 0. Turning the on-board system on for a minute prior to a test can overcome this issue.

When switching between the charging and battery-powered states, a larger drop in the battery percentage can be observed which is normal. This stabilises after a few seconds.

3.5 Safety

The following are some basic safety precautions when handling the electronics system and are by no means exhaustive. Always take extra care when servicing.

Keep the engine away from liquids and open flames.

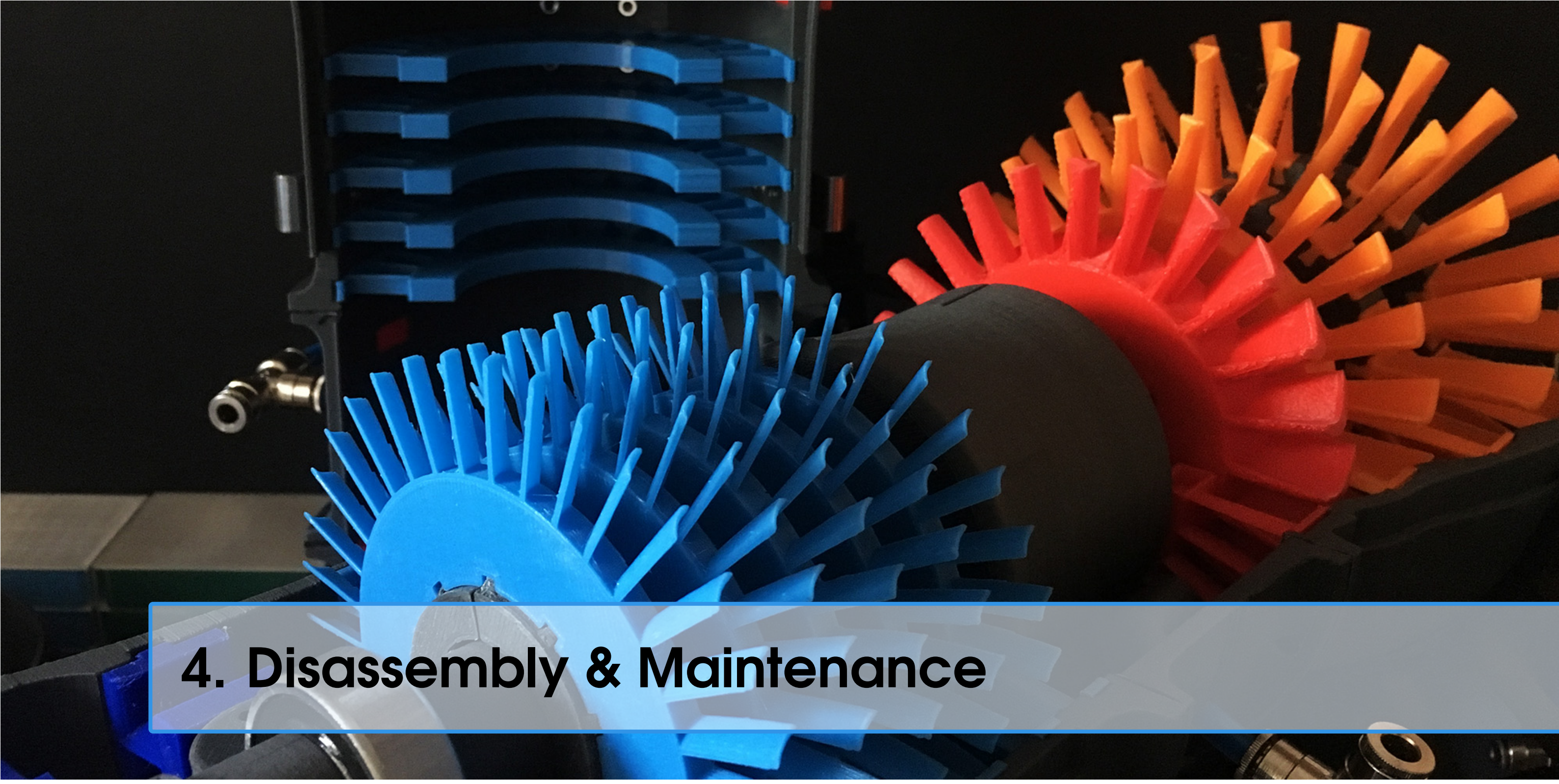
Always have safety equipment like a fire extinguisher, a basic first aid kit and a mobile phone nearby.

Do not touch exposed wires even if the system is off and ensure that exposed power cables never touch each other.

Disconnect all power sources before servicing or repairing any electrical component.

If the battery swells up, disconnect the power immediately and, when it's safe to do so, remove and dispose of it appropriately.

If any component heats up excessively, produces smoke, flames or a burning smell disconnect the power immediately.



4. Disassembly & Maintenance

Under normal operating conditions, the engine requires little maintenance. However, as a development product that has gone through a limited testing phase, continuous operation or experimentation with testing conditions are likely to end up in a scenario where a more thorough examination is required.

Furthermore, this section will be particularly useful when entering a stage of constructively interfering with the core to integrate new sensors or other devices.

4.1 Opening the Core

To open the core, you must first follow the reverse procedure described in the set-up section and get the engine to the same state as received in the transport box. This involves:

- Releasing and carefully removing the top half of the nacelle
- Releasing and carefully removing quarter 2, after removing the tube
- Disconnecting the power and signal connections from quarter 1 to the on-board PCB

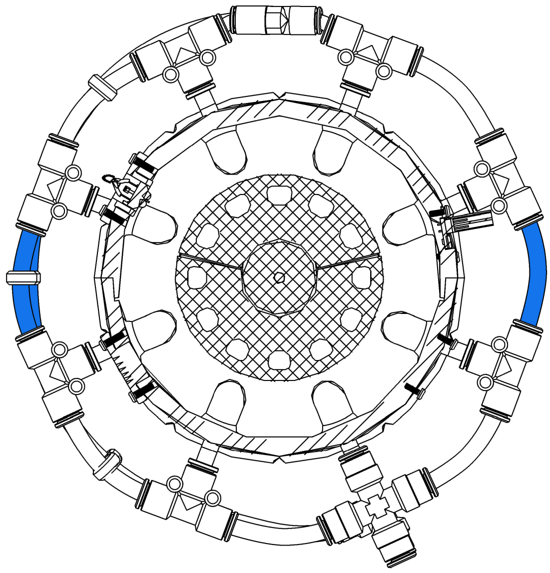
> ! It is advised to always disconnect the nacelle/on-board PCB cables from the on-board PCB end to allow for easier re-connection and assembly.

- Releasing and carefully removing quarter 1 of the nacelle
- Disconnecting the sensor cables from either side of the exhaust nozzle and
- Finally, releasing the nozzle assembly

These are the final steps that are necessary to be following every time the core needs to be opened:

Pneumatic Ring

Only the segments along the centreline need to be removed; one from the right and two from the left hand side. Push both ends of the adjacent fittings and remove the tube segments.



Fan Casing

M2 bolts join each fan casing part to its neighbouring segments. These connections are concealed under the nacelle parts that are not typically removed from the front of the engine, apart from the two along the centreline. These are outlined in red circles and should be fully removed using a hex driver before proceeding with the disassembly.

! If the original bolts are lost, only replace them with M2x4mm bolts. Using longer bolts may result in jamming and damaging the fan.

LED Strip

An LED strip runs around the edge of the nacelle behind the fan to provide feedback during operation and the power/battery status. Using a small screwdriver, carefully pull the edge of the strip near the front mount. Once you can hold it, slowly pull it working your way around the ring. You can just let it rest, as disconnecting it from the board is not necessary.

Release

You can now undo the toggle latches by pulling the lower handle outwards. As the latches are spring loaded, they may release fairly quickly once pulled slightly. Once all six latches have been undone, you can grab the top half from the front of the nacelle and the nacelle ring, pulling straight up.

4.1.1 Handling the Drivetrain

The drivetrain is made up of all of the rotating components, including disks, blades, blisks, shafts and bearings. Once the top half has been removed, the drivetrain can be easily lifted by grabbing both ends.

! When removing the drivetrain, make sure you lift both ends at the same time and maintain it level until all components are outside the core.

What to do with the drivetrain on disassembly depends on your end goal for that particular maintenance session. If you don't plan to make any modifications or adjustments to the drivetrain itself, you can remove it and temporarily keep it out of the way until your work is complete. To set it aside, rotate it by 90 degrees and slowly rest it on the turbine end on a level and stable surface.

! Never rest the drivetrain on its side, as this will likely damage or break certain parts.

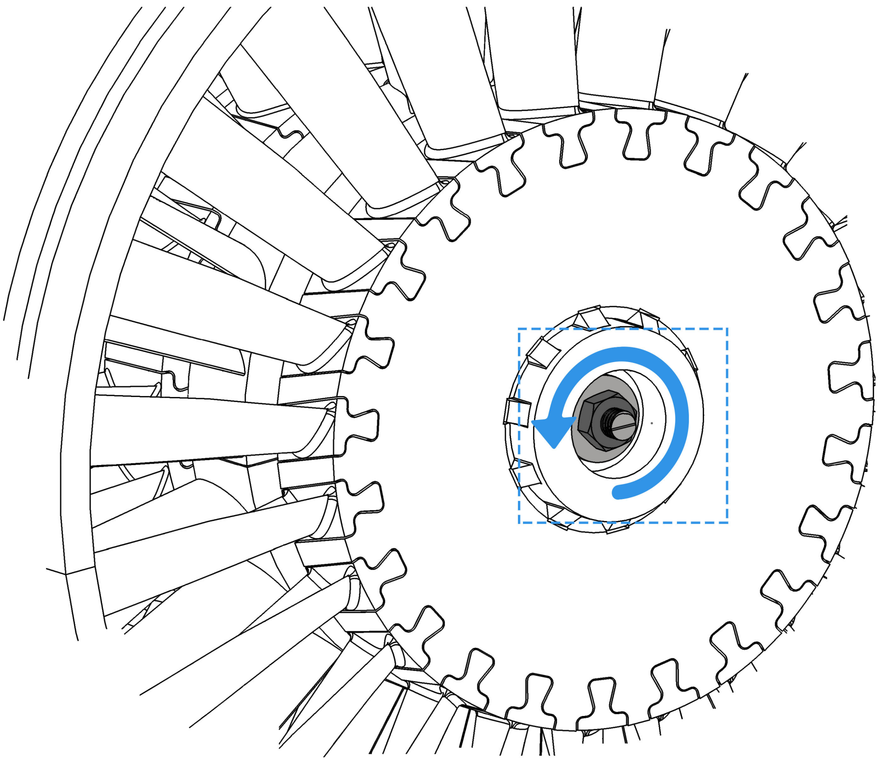
Alternatively, if this is a frequent occasion, you can email us to order stands that let it rest much more securely at the same points as the actual bearing carriers.

However, if you do intend to make modifications to the drivetrain, it is easier to remove the threaded rod while it still sits in the engine.

Removing the Threaded Rod

Using pliers or a spanner, undo the M4 nut situated in a small socket of the LP shaft at the rear of the turbine. Using a flat head screwdriver, turn the rod anti-clockwise until you feel it getting released from the concealed threaded insert that sits in the middle of the fan hub. Proceed to pull the rest of the rod out, which should be done without much force.

You can now lift the drivetrain as in the previous case and you will be able to remove individual segments of the shafts that will subsequently give you access to the respective disks and blisks.



Once the rod is removed, remember that individual sections might come off and get damaged. Exercise caution when handling the assembly.

In certain cases, it is more practical to remove the fan hub and keep the rest of the rod inside the shaft as you slide the shaft segments off the rest of the assembly.

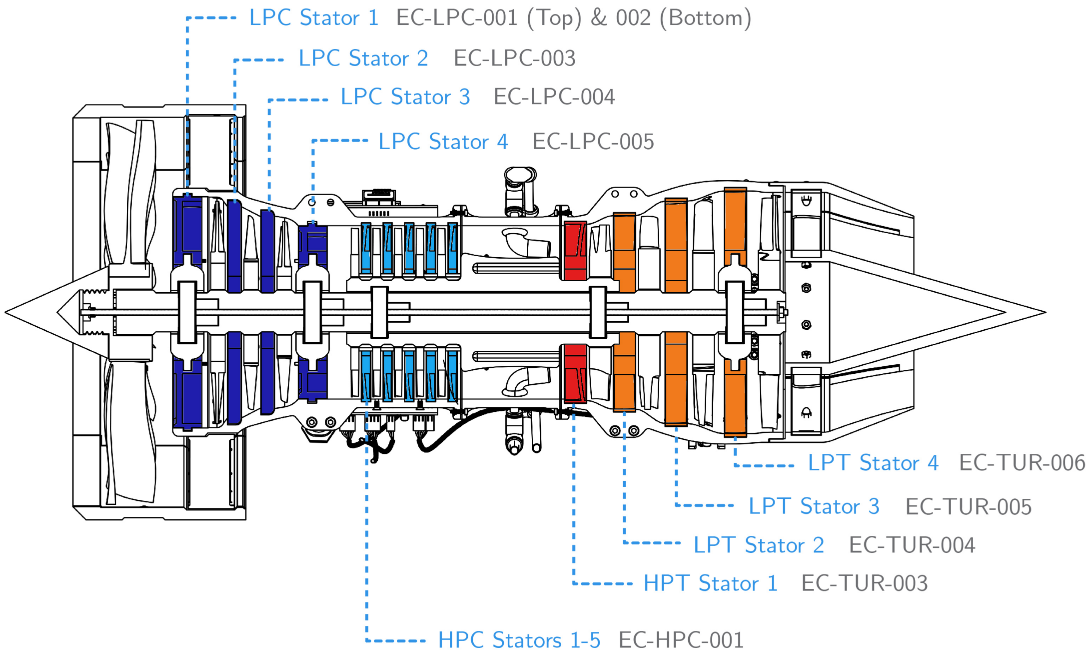
Re-inserting the Threaded Rod

Once maintenance is complete, slide the threaded rod through the shaft until it reaches the heat-pressed insert. Using a flat head screwdriver, screw the rod until its end sits 1-2 mm lower than the outermost edge of the shaft.

Add the washer and loosely tighten the nut. Using the screwdriver with one hand to prevent the rod from rotating and, preferably, using needle nose pliers tighten the nut by rotating it clockwise with the other hand.

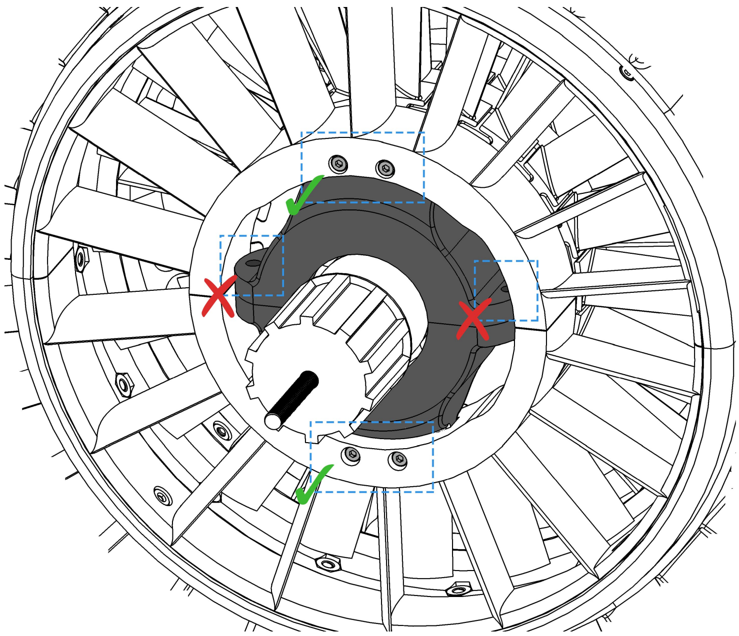
4.2 Replacing Stators

Any stator can be released by removing two M2 bolts that ensure correct alignment and secure attachment from the outside of the core casing. However, depending on which stage needs to be replaced, slightly different procedures need to be followed with varying degrees of difficulty.



Stator	Parts Affected
LPC Stage 1 (NGVs)	Requires removal of the following parts (in order of disassembly): section 1 of the nacelle (front), fan casing panels and outlet guide vanes
LPC Stage 2	None, but proximity to the OGVs may make complete removal of the bolts troublesome. Undo the bolts just enough to release the stator.
LPC Stage 3	None
LPC Stage 4	A cable runs along one of the blades of the bottom S4 stator and caution should be taken when removing the stator and the adjacent bearing carrier.
HPC Stages 1-4	Requires removal of the top two PCBs
HPC Stages 5	None
HPT Stage 1	None
LPT Stage 2	None
LPT Stage 3	None
LPT Stage 4	None

All stators come pre-assembled with heat-pressed inserts for mounting to the core casing and some also include inserts for mounting the bearing carriers. When removing a stator which houses a bearing carrier make sure you transfer the carrier over and secure it onto the stator.



When re-assembling, only bolt each carrier half to a respective stator. Do **not** bolt the bearing carrier half to each other. This connection can be used in an alternative configuration, which requires all stators to be removed at the same time as the drivetrain.

All stators go into dedicated slots. Once in place, use appropriately sized M2 bolts to secure the stator in place from the external side of the core casing. In certain cases, you might have to slightly pull the stator before inserting the bolts and proceeding to tighten the bolts, which will eventually pull the stator into its correct position.

! Never exert excessive force when tightening the stators in place. Difficulty may arise from improper alignment or damage to the threaded insert and may result in damage to the core casing or bolt slots.

Finally, bear in mind that some fine-tuning might be required to ensure the correct fit. Certain parts are produced without clearances for the optimum fit and might require filing. If that's the case, we recommend you use a high-quality Tamiya plastic modelling file or equivalent.

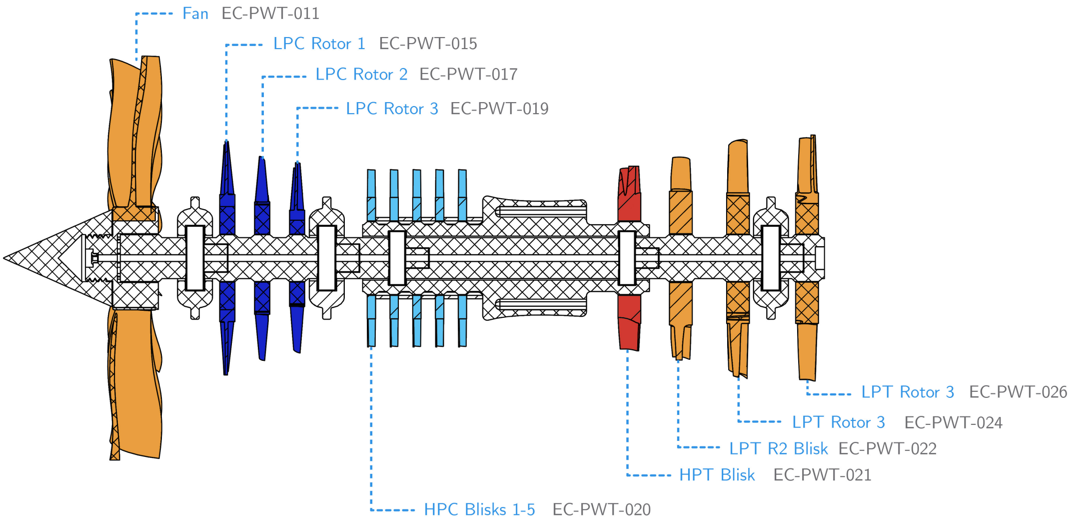
! Take caution if you use power tools such as a Dremel for filing, sanding or drilling 3D printed parts! If exposed for more than a couple of seconds, the friction will deform the part and may make it unusable.

Finally, you should check that the top half can freely close without any visible gaps from the side, after replacing stators and before lowering the drivetrain in place.

4.3 Replacing Rotors & Blades

All rotors can be replaced by removing the respective section of the LP shaft. Unless access is specifically required to section 4 of the LP shaft (which is fully concealed within the HP shaft), it is advised to keep the HP shaft partially assembled. The blisks attached to the HP shaft can still be released by pulling them from either end.

! Never assemble the LP shaft horizontally without the support of the threaded rod! The spline connections, particularly around the HP segment might become damaged or fracture.



Fan

With the rod removed or partially removed, pulling the nosecone will release the entire fan assembly. The nosecone is attached to the hub using a left-handed thread, so release it by rotating it clockwise. Using a flat head screwdriver, push the root of the damaged blade out against the resting shoulder. Once the part is about a third of the way out, pull it manually or using pliers. To insert a new blade, rest the hub onto a slightly elevated surface.

! Due to the curvature of the blades, the back of the hub does not rest on a flat surface. Do not attempt to insert a new blade unless the hub is slightly elevated and the rest of the blades are not touching the surface.

Get a new blade and make sure it is facing towards the right direction. Push it into the slot, so that it sits at least 1 cm below the top of the hub. Depending on the fit, you might be able to insert it all the way manually, but it is common to use a large hex key and a hammer to tap it into place.

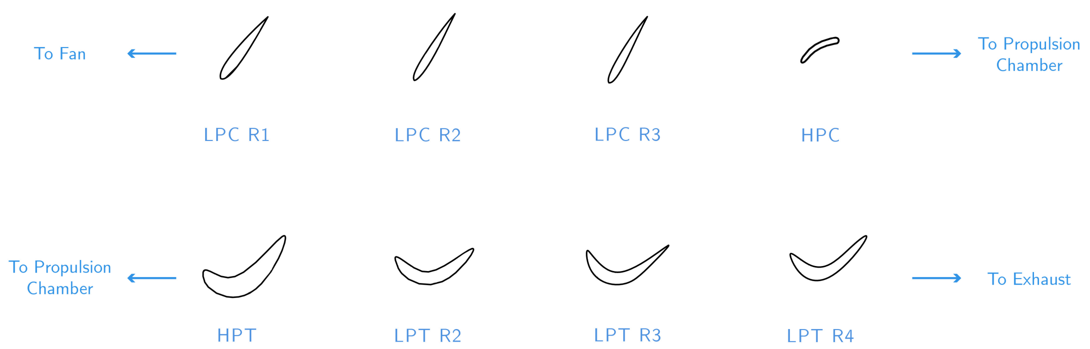
Make sure the edge of the root sits just beneath or level with the top of the hub and re-attach the nosecone. The hub can now be re-assembled to the rest of the LP shaft.

LPC Blades

Remove section 1 of the LP shaft to release section 2, where the LPC disks are attached. You can slide the disks over the shaft and remove any damaged blades in a similar fashion as before. For disks, the removal is even easier as the roots can be pushed from either end.

! Use a small but flat-headed tool like a hex tool to push blades out whether assisted by a hammer or not. Using a small screwdriver can result in the tip being embedded into the part as opposed to pushing it.

Pick the correct replacement part for the stage that you are repairing and insert it in the right orientation. Compressor blades are fairly thin and can be difficult to identify where the leading edge of the aerofoil is. Use the following diagram for guidance under close inspection.



Due to the cross between older hubs and newer blades, the fit might be a bit loose but adequate in operation due to the centrifugal loading.

HPC Blisks & HPT Blisk

To replace either the HPC or HPT blisks, the HP shaft has to be freed from the LP segment. Blisks can be easily removed from either side and replaced with the respective spares. Spacers of three different sizes are also available and can be used between HPC blisks to correct and adjust the spacing between them so that none of them interfere with the stators.

LPT Stages 2-4

Removing sections 5 and 6 of the LP shaft will provide access to the remainder of the stages. For the final two stages blades are attached to disks and can be replaced as described above. Blades with serial numbers 0304 (for stage 3) and 0434 (for stage 4) have a white dot marking which identified the rear face of the blade (i.e. facing towards the exhaust).

Finishing up

Once new blades are in place, put the blisk or disk assembly on the shaft segment and proceed to reassemble the drivetrain starting from section 6 (end of the turbine) and stack them with the help of the threaded rod. It might be easier to attach the fan hub once the drivetrain rests in the core.

Once positioned, you might have to gently move some stages to ensure they sit as perpendicular to the shaft axis as possible, making sure they don't collide with other parts. Some new blades might need to be filed for optimum fit.

! Do not file blade tips aggressively. This is likely to result in fracture at the root which can be avoided by holding the blade from the middle.

4.4 Mounts

The core is equipped with mounting points both above and below the core casing. By default, bottom mounts are used.

! The bolts attaching the mounts to the casing should not be tightened excessively to avoid introducing cracks at the roots. However, periodically check to ensure the nuts do not become loose.

4.5 Fatigue Life

We currently hold no fatigue data for engine sub-assemblies or individual parts and, due to the intricacies of simulating plastic 3D printed parts, we do not have any reliable estimates of fatigue life. Therefore, we would strongly encourage you to report all incidents and repairs through the online log, including failure that you might attribute to fatigue in the future.

4.6 Compressed Air Quality

Water and oil in the compressed air supply have not been previously considered as troublesome due to the short testing intervals in the past which did not reveal any related issues. However, as the testing frequency and session duration increase, these could cause issues to electronics located in the turbine, particularly in the first stages. As before, we encourage you to log such incidents so that we can keep track of them as well as address them in future iterations. However, as a general guide we advise the use of air filters, such as the Eliminizer Application Dryer before the air enters the PCU.

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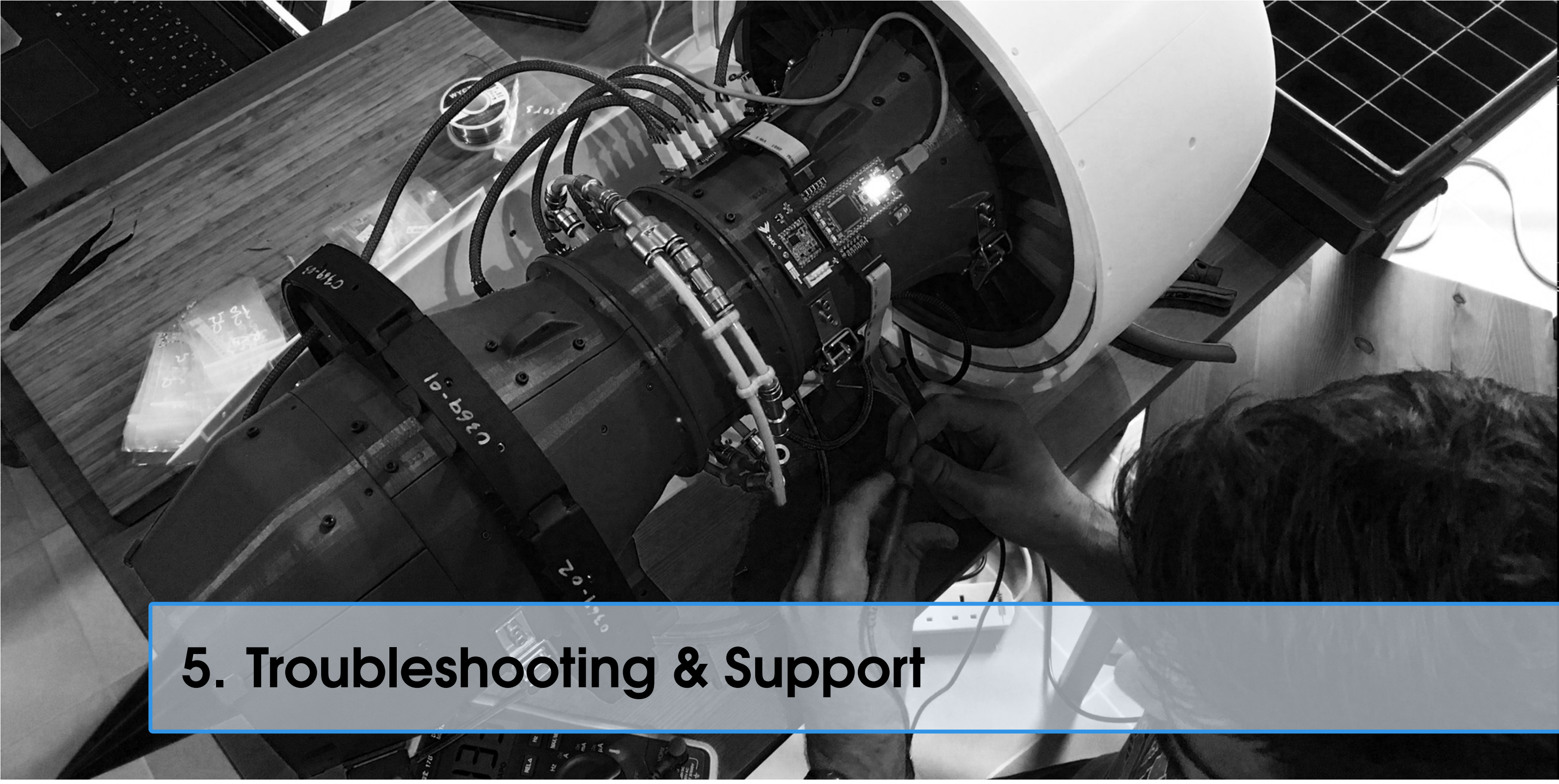

5. Troubleshooting & Support

This section includes a quick overview of common issues and suggestions on the steps that you should follow if that is the case. It is by no means exhaustive and we would like to hear from you if you are having difficulty with other components. This is both to help you to the best of our abilities as well as note any flaws for future improvement.

5.1 Common Mechanical Issues

5.1.1 Cross-threaded inserts

Issue Occasionally, when bolting into threaded inserts, the threads can become cross-threaded, causing the bolt to jam upon torquing.

Next Steps Carefully loosen the bolt until it is free from the threaded insert. At this stage, access to the reverse side of the insert is required in order to thread the bolt in the opposite direction to before. After completing this, the original direction of bolting can be attempted. Should cross-threading occur again, the insert needs to be replaced.

5.1.2 Jammed rotating assembly

Issue The rotating assemblies have ceased from rotating, whether during operation or through manual testing.

Next Steps If this should occur during operation, interrupt the airflow to the engine. Once stopped, or if the XP1 EC is already stationary, an external visual examination should be carried out. This should mainly focus on the fan blades (especially the tips) and the first few stages of the LPC, searching for objects inhibiting rotation through obstruction or entanglement. It may also be useful to inspect the LPT stages visible after removing the exhaust nozzle subassembly. If the issue remains unresolved, it is necessary to open the core. Once completed, a visual inspection of all compressor and turbine stages should be completed. If the source of the jam is still undetermined, gently attempt to rotate the HP and LP shaft independently. This will provide some insight as to where the interference is located. Should the matter persist, it may be necessary to further disassemble the drivetrain assembly, testing bearings. If that is the case you can get in touch with us for additional support.

5.1.3 Ingestion into/ejection from the engine

Issue Nearby objects being sucked into the engine and become stuck or leaving the engine again. Also the ejection of internal components of the engine due to failure.

Next Steps In this scenario, the first step is to halt the airflow to the engine until the EC is stationary. An external visual examination should firstly be carried out. Regardless of the outcome, it is then necessary to open the core to carry out an internal examination. In the case of an ingested object which has not been ejected, it is required to locate the object. Once located, an inspection for potential damage from the fan up to this point of the engine should be completed. If this was ejected, an inspection of all internal components is required to ensure that no visible damage has been caused. In the case of a damaged component, contact us for further advice.

5.1.4 Excessive vibration

Issue Oscillations resulting from the running of the XP1 EC due to critical frequencies or balancing issues.

Next Steps Should this be observed, take note of the rotational speed of both shafts and the flow rate. Reduce the airflow to the engine slightly to allow the rotational speed to decrease. If the problem has subsided momentarily, increase the engine back to the previously noted speed. If the oscillations reappear, with caution, quickly increase the flow rate by another 50LPM. Should the oscillations persist at this faster RPM, the engine speed should be brought down to below the noted speed. The engine is unstable above this velocity on account of manufacturing tolerances. Should the oscillations subside at this higher speed, it can be assumed that this was a critical shaft speed. The speed at this occurrence should be noted and fed back to us for comparison with design specifications. When operating the engine in future, care must be taken to avoid dwelling in the vicinity of this shaft speed.

5.1.5 Temperature warning

Issue The temperature warning for the bearings has been triggered.

Next Steps In this scenario, you should first bring the engine to a halt. Continue to log data, monitoring the temperature until it falls to room temperature. At this point, it is safe to open the core in order to perform a visual inspection. Particular focus should be given to bearings and bearing carriers as these are located closest to where the temperature sensor is positioned and could indicate a bearing failure. With that being said, all points where undesired contact of components can occur should be inspected, an example being the tip of blades with the core casing. Should any components appear warped or damaged from the temperature, a replacement component is required.

5.2 Common Electronic Issues

5.2.1 Wrong mode of operation

Issue A particular mode is selected and the output on the LED strip does not correspond to this.

Next Steps Firstly, the software can take a few seconds in order to update the modes. Wait for a few seconds before checking that the mode is still incorrect. Check to see if the indications on the processor board are lit and make sure no wires are loose or damaged. If it turns out that the EC is indeed in the wrong mode of operation, it is suggested that this is no longer used until this is addressed. Disconnect the engine from any electrical power supply (battery and mains) for at least 15 seconds before turning on again and checking if the problem is resolved. If not it might be helpful to log a maintenance entry and attach the latest CSV file from the GUI.

5.2.2 Battery not charging

Issue The XP1 EC has been plugged into a mains supply for at least a few seconds and the LEDs don't indicate that the battery is charging.

Next Steps Firstly, make sure that the USB cable is connected, the switch is set to hybrid and that the mains adapter is live. If the battery is still not charging, a reboot is recommended. Disconnect the engine for at least 15 seconds before turning on again and checking if the problem is resolved. You can always check the battery percentage through the GUI when the USB cable is unplugged. If this does not sort the issue, it is necessary to remove the top half of the nacelle, in order to check electrical wires and connections.

5.2.3 Not sending/receiving output data

Issue Information from the EC is not being logged on the computer with the receiver connected and the GUI open.

Next Steps Firstly, the correct drivers should be reinstalled to ensure these are not missing. These can be found on the Users' Portal. If this is the case, re-open the software window, select the correct COM port, connect and press the start button. If this fails to rectify the problem, it is suggested that a restart of both the computer and the engine is carried out.

5.3 Users' Portal

Authorised users for the X-Plorer 1 EC can request access through the academic liaison, who will need to forward your name and email to info@jet-x.org. An account will be created which will give you access to the Users' Portal at

`www.jet-x.org/users-portal`

On the portal, you will find useful information on existing features, as well as gain access to tools for maintenance logging and further support. A lot of the resources available, including software or even this manual, are periodically revised or updated and this is where you will be able to find the most recent versions.

5.3.1 Maintenance Log

The maintenance log is your tool to keep track of all repairs and incidents that can be reported or raised by any user and are kept for future reference. This way everyone can quickly save related information at any time, building a historical database of such events.

On the relevant page, you will find past repairs at the top and the submission form for new entries beneath that. Please submit as much information as possible and note that it takes up to 48 hours for entries to appear on the table above.

5.3.2 Software

The Software page grants you access to the current and future version of our three software binaries or executables, which include:

- EMS Software for sensor monitoring
- Code for the on-board processor
- Code for the receiving processor

In addition to these, you can also find copies of any supplementary software by third parties that might need to be installed depending on your system.

5.3.3 Spares Order

In this page, you will find a list of spares that can be ordered online and their cost. We can effectively reproduce any part of the EC, so if you need a part not listed at the time or one that requires modifications, please get in touch with us.