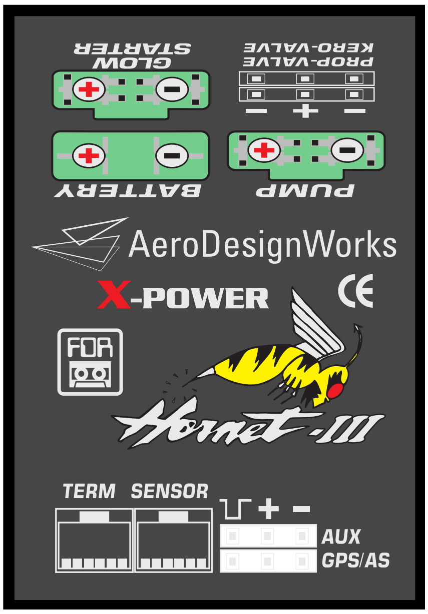
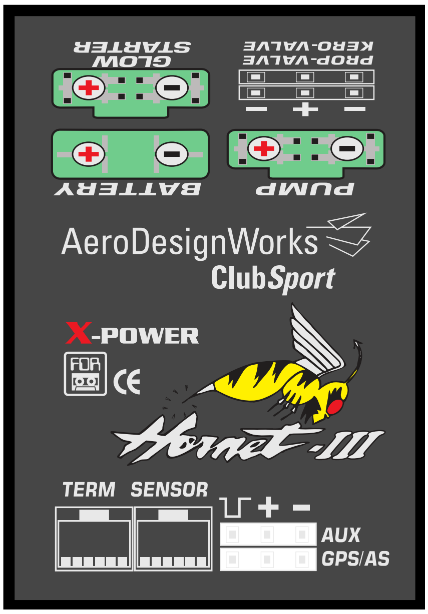
AeroDesignWorks





HORNET-III manual
Firmware v3.0

AeroDesignWorks GmbH
Wankelstr. 57
D-50996 Köln
Germany

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Contents

1 Introduction

The HORNET-III is an engine control unit (ECU) for model jet turbines, originally developed and produced by ProJET electronic components GmbH, Fuchsmühl, Germany. Its home builder version (still distributed by ProJET) can be used for engines of a wide range of manufacturers. All HORNET-III variants have the following features in common:

- ECU settings accessible via Ground Support Unit (GSU).
- Engine can be started using standard fuel or an auxiliary gas.
- Controls an analogue (brushed) fuel pump.
- RPM sensor can be optic or magnetic (Hall).
- Dynamic throttle response depending on the temperature and RPM sensor signals.
- Fail-safe mode in case run time errors (e.g. one or both sensors fail and other errors).
- Support for connecting to a GPS module.
- Support for a smoker valve.
- Communication with XBee modules for saving telemetry data.

After acquiring the BF Turbines product line in 2017, AeroDesignWorks GmbH purchased the HORNET-III firmware source code together with a license to use, modify and redistribute the firmware in 2018. The goal was to be able to make modifications for the BF range of engines. AeroDesignWorks and ProJET continue to work together on the hardware, but starting in 2021, AeroDesignWorks distributes their HORNET-III ECUs with a new firmware starting at version v3.0.

- All HORNET-III ECUs sold by AeroDesignWorks only work with our own range of model jet engines.
- As they are configured for a fuel start, we no longer provide information on using an auxiliary gas.
- The firmware version v3.0 brought some changes that affect the end user and hence a long overdue update to the manual.

ProJET developed a HORNET-III capable of powering and controlling brushless fuel pumps called HORNET-III-BLC (Brushless Controller), which uses different hardware and cannot be used with analogue fuel pumps. There are some notable differences, which will be mentioned in the manual where appropriate.

1.1 Hardware information

The HORNET-III is powered by an Atmel Atmega2560 processor, which has 256 KB of program memory and 4 KB of EEPROM to persistently store settings. The EEPROM has an unlimited amount of read cycles and a limited but large (100,000+) amount of write cycles per byte.

- The maximum supported battery voltage is $12.8V$ for continuous operation.
- The receiver input supports 5 cells with a maximum voltage of $7.5V$ and a minimum pulse amplitude of $2.7V$.
- The fuel pump can be supplied with a current of $10A$ for continuous operation, with peaks of $20A$ for up to $0.2s$.
- The starter can be supplied with a current of $10A$ for continuous operation, with peaks of $20A$ for up to $0.2s$.
- The glow plug can be supplied with a current of $10A$ for continuous operation, with peaks of $20A$ for up to $0.2ms$.
- The fuel valves can be supplied with a current of $0.25A$ for continuous operation, with peaks of $0.5A$ for up to $1s$.

1.2 Liability and limited warranty

By using this product, you agree to hold AeroDesignWorks GmbH free from any form of liability for damage or injury, direct or indirect, resulting from using this product. As AeroDesignWorks GmbH cannot supervise the proper installation and operation of the jet engine, the electronic components and the radio controller, the end user is responsible for all of this.

The product comes with a 24 month limited warranty from the date of purchase. It applies only to defects (material or operational) present at the time of purchase. It does NOT apply to improper handling, normal wear, overloading or damage due to use of incompatible accessories.

2 Components and connecting

For operating a model jet engine, the following components need to be connected to the HORNET-III:

1. A Ground Support Unit (GSU).
2. An I/O board (with LED and buzzer).
3. RPM and temperature sensors together with an amplifier.
4. A fuel pump.

   HORNET-III: Analogue pump, e.g. the AeroDesignWorks B100F and B140F ship with HP-Tech ZP30725F pumps, while the B300F ships with an HP-Tech ZP48031 pump.

   HORNET-III-ClubSport: Brushless pump, e.g. the AeroDesignWorks B140F ClubSport ships with an HP-Tech BZP21L40 pump.
5. A battery for power supply.

All new AeroDesignWorks model jet engines ship with these accessories except for the battery. How these components are connected is shown in Figure 1a.

Note that there are two fuel valves for the two fuel lines labeled *KEROSENE* and *IGNITION* on the engine. These valves and their fuel lines refered to as *main* and *ignition* in this manual.

2.1 Ground support unit

The usage of the GSU is covered in Section 4.

2.2 I/O board

The I/O board can (and should be) placed between the GSU and the HORNET-III. It can be kept in the model will use the LED and the speaker for feedback.

LED

1. **Green:** Engine is off.
2. **Orange:** Engine is in standby mode and ready to accept the starter signal from the RC.
3. **Red:** Engine is running in automatic mode.

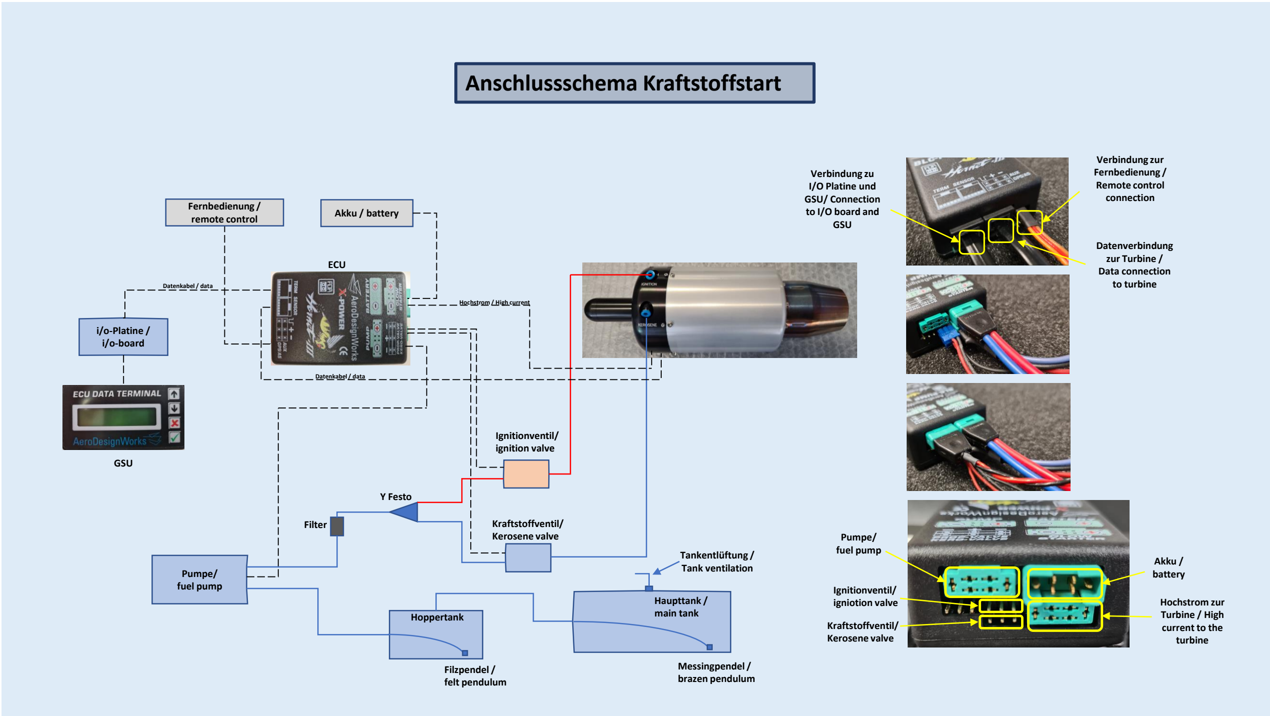
Speaker

1. **Short beeps:** ECU starting.
2. **Long beep:** Engine is starting.
3. **Sequence of short beeps:** Error message: Low battery voltage, temperature sensor failure or glow plug failure

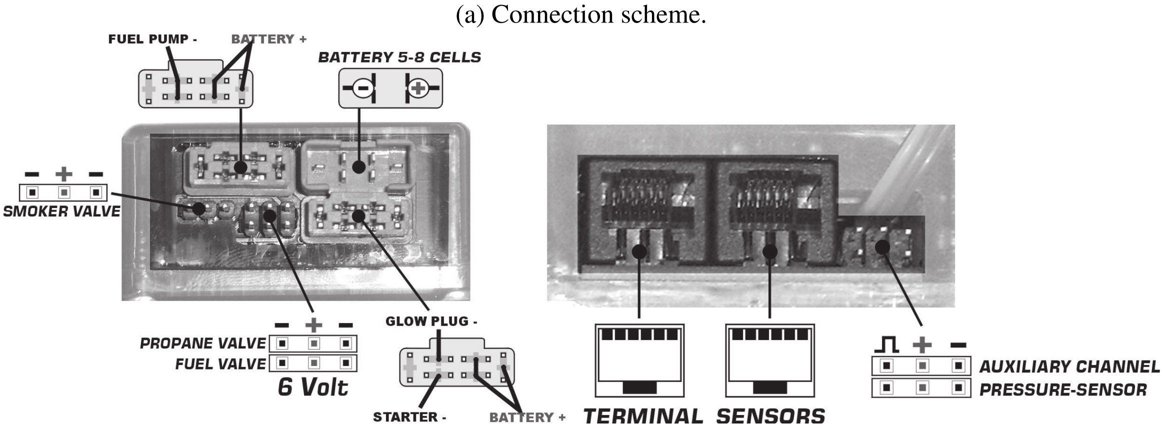
When the engine is off, the button can be pressed to operate the fuel pump (e.g. if there is a lot of air in the fuel lines).

WARNING

Be careful not to flood the engine with fuel!



(a) Connection scheme.



(b) ECU connectors.

Figure 1: Connecting the HORNET-III.

2.3 Fuel system

The overall reliability of the jet engine system depends on a well-made fuel system. New AeroDesignWorks model jet engines ship with high quality components (fuel pump and valves, connectors, . . .). If you need to make adjustments or exchange components, some suggestions are:

- Use a high quality fuel pump like the ones shipped with the corresponding AeroDesignWorks jet engines.
- Use fuel valves of high quality.
- Use a hopper tank with felt pendulum in front of the main fuel tank(s).
- Do not use fuel filters directly before the fuel pump.
- Use a fuel feed line with the largest possible diameter.

2.4 Power supply

Since all components (like glow plug, starter, valves, fuel pump) are supplied by a single battery, its capacity should be sufficiently high ($\geq 2500mAh$).

WARNING

Carefully monitor the battery voltage, especially during and after the first few flights, as a low battery voltage can be fatal e.g. to maintaining a sufficient fuel flow.

Disconnect the battery from the ECU if it is not operated for several days.

2.5 GPS module

A GPS module can be connected to the corresponding outlet on the ECU. It does not need to be configured via GSU. The GPS data is available in the corresponding menu (see Section 4.5.4) or can be transmitted by a telemetry module.

2.6 Telemetry module

A telemetry module can be connected. It is placed between ECU and I/O board and usually comes with an integrated battery. It needs to be configured via GSU in the corresponding menu (see Section 4.5.3).

3 Engine operation overview

This is summary of how the ECU controls various stages during the engine operation to better understand the following section about using the GSU (Section 4). The details about how the ECU controls the engine and the various settings can be found in 5.

3.1 Engine operation modes

The ECU define several modes of engine operation, which can be controlled by the RC (see Section 5.2).

1. **Off:** The engine is off. Settings can be adjusted via GSU (see Section 4). The engine can then be put into standby mode using the RC. In standby mode, the ECU accepts a starter signal from the RC and commences the autostart sequence.

2. **Autostart:** The engine goes from standby mode to operation mode and idle RPM by performing several steps like pre-heating, switching on the burner, fuel ignition and finally increasing the RPM (see Section 5.3).

   When using an analogue (brushed) pump, there is also a phase called *auto calibration* (see Section 5.4), which is needed to determine some characteristic voltages for specific fuel flows and RPM. This is due to brushed pumps slightly differing in their operation characteristic.

   A HORNET-III-ClubSport with brushless pump does not need the auto calibration because all brushless pumps of the same model have the same operation characteristic (with only negligible differences).

3. **Automatic:** The engine is running. The ECU responds to the RC's throttle position, which can govern thrust or RPM or any linear combination between these two characteristic curves (see Section 5.2). It automatically adapts the fuel flow to match the user's input, depending on the RPM and temperature sensors and monitoring both signals to ensure a safe operation of the engine (see Section 5.5). Telemetry is transmitted (if using a telemetry module). It is possible to turn off the engine and going into *cool-down mode*.

4. **Fail-safe:** If the ECU recieves errors from the RC during the *Automatic* phase (e.g. no signal or signal errors), it switches to *fail-safe mode* if it is configured (see Section 5.6). After a user-defined delay, fail-safe mode is activated for up to $10s$ and the ECU assumes a prescribed throttle position.

5. **Cool-down:** After the ECU shuts down the engine, the starter will hold the start RPM for several seconds to allow the engine to cool down. The ECU automatically switches to *off* afterwards.

3.2 Differences in operating behaviour between HORNET-III and HORNET-III-ClubSport

As mentioned in the introduction, the ProJET HORNET-III and HORNET-III-BLC use different hardware, but the same firmware (as of writing, the firmare version is 2.8). Most notably, they use the same code for controlling the pump's behaviour and require auto calibration (see Section 5.4).

To better leverage the brushless pump's quicker response and the fact that different pumps of the same model have the same operating behaviour (pump voltage and flow at a specific pressure) up to negligible differences, AeroDesignWorks modified the firmware of the HORNET-III-ClubSport. This new firmware is designated v3.0.

The AeroDesignWorks HORNET-III-ClubSport uses *a priori* knowledge of the pump's characteristic curves and also employs a PI controller for controlling the fuel flow to match the user's throttle input (and thus RPM).

The result is a much more responsive feel of the jet engine. A comparison of measurement data can be found in Figure 2. This was done with the same engine by only changing the ECU and fuel pump between measurements.

- **nrpm**: The normalised RPM, where 0 corresponds to idle and 1,000 to full RPM (in the case of the B140F 130,000).

- **Controller signal**: This corresponds to the normalised throttle position, where 0 corresponds to idle and 1,000 to full throttle.

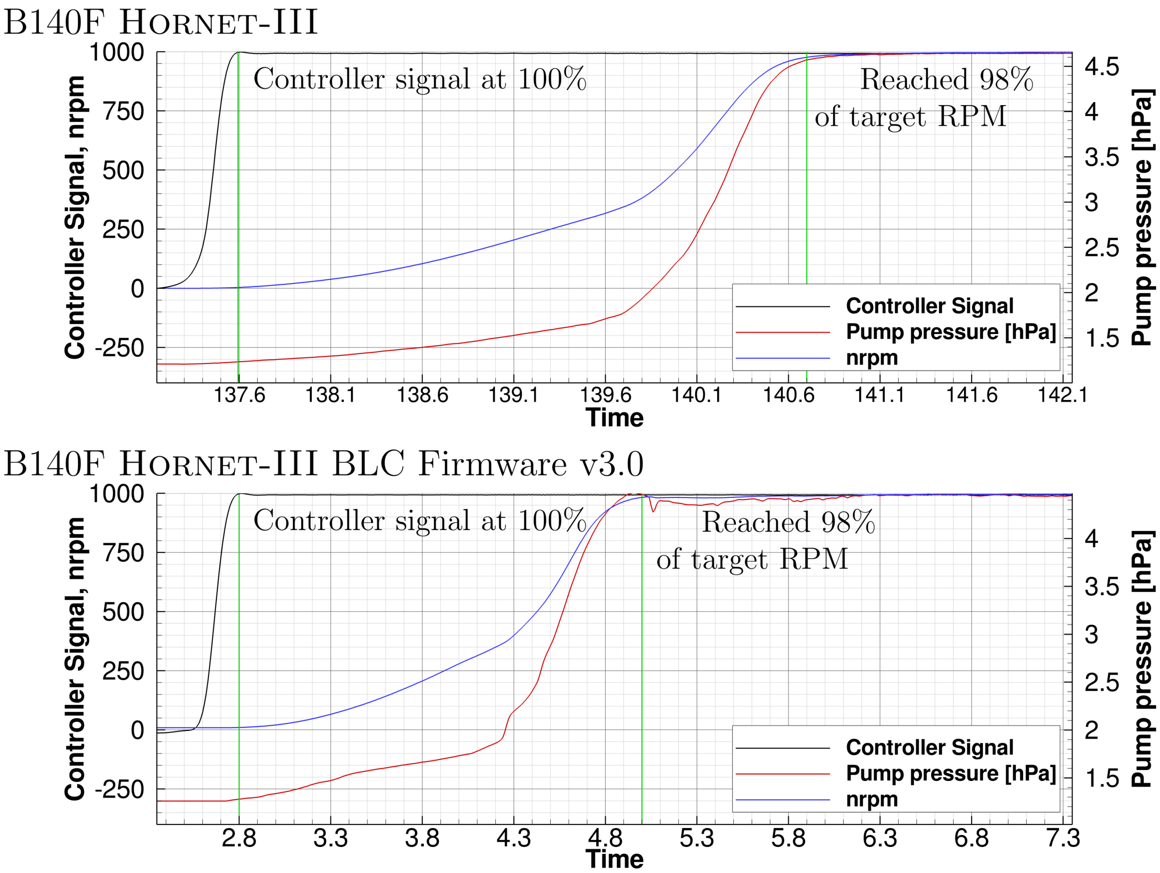


Figure 2: Comparison of measurement data: B140F with Hornet-III vs. B140F ClubSport with Hornet-III-ClubSport.

- **Pump pressure**: This is plotted to visualise how quickly the pump reacts.

As the engine has to slow down the acceleration towards maximum RPM to prevent overshoots, we measured the time from the controller signal assuming its maximum value to the engine reaching 98% of the maximum RPM (note the vertical green lines in Figure 2). With this definition of the acceleration phase, the Hornet-III-controlled engine took $3.1s$, while the Hornet-III-ClubSport-controlled engine took $2.1s$. The pump pressure curve is not as smooth as for the Hornet-III-controlled engine, as the pump reacts more quickly and the PI-controller is more aggressive.

4 Using the Ground Support Unit (GSU)

The GSU is a small terminal with an LCD with two lines and 16 characters each and four buttons (up ↑, down ↓, escape ✘ and enter ✓).

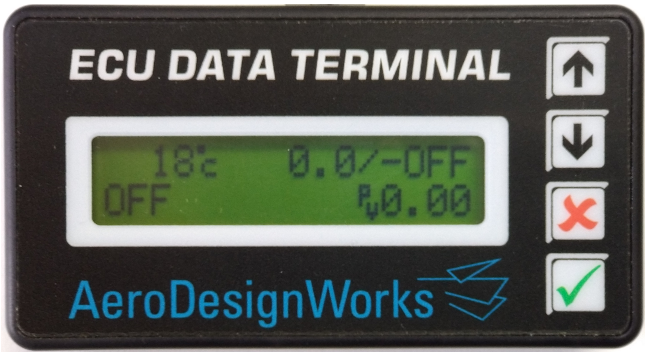


Figure 3: An AeroDesignWorks GSU.

WARNING

Do not permanently install the GSU in the aircraft model, as the LCD might have a negative impact on the RC's range!

Regardless, the GSU can be used to change ECU parameters while the engine is running.

- The menu can be navigated up (↑) and down (↓), sub menus can be entered (✓) and left (✘).
- Values can be adjusted up (↑), down (↓), saved (✓) or discarded (✘). Changes to values are written to the EEPROM automatically upon saving them.
- When the engine is in *standby* mode, the start sequence can be initiated by simultaneously pressing up (↑) and escape (✘). This might be needed if one HORNET-III is used to simultaneously control more than one engine.
- The expert menu can be unlocked by simultaneously pressing and holding up (↑) and down (↓), see Section 4.5.6.

4.1 Power on messages

After starting the ECU, some messages will be displayed on the GSU. The startup procedure will also produce some messages.

1. ECU and firmware version, e.g

   ```
   HORNET-III CS E
   V3.0 2021-10-22
   ```

   In this example, a HORNET-III-ClubSport is used and its expert mode is unlocked, signified by the last character `E` on the first line.

2. The engine that was connected last, e.g.

   ```
   005 AEROD.WORKS
       B140F
   ```

   The three digit number is the model ID of the engine.

These messages will be repeated if the GSU is removed and reconnect, or if it is connected after the initial startup procedure. The following messages are printed by startup routines and will not be displayed again if the GSU is reconnected.

3. Connection to GPS module: The ECU will try three times before giving up

```
CONNECT TO GPS
TRY 2/3 FOUND.
```
or
```
CONNECT TO GPS
NO GPS MODULE
```

4. Connection to XBee module: This ECU will only try to connect to an XBee module if it was configured during an earlier start. In this case, the GSU will display

```
INITIALISE XBEE
OK
```
or
```
INITIALISE XBEE
FAILED
```
if the previously configured module was not found.

5. Connection to engine:

```
CONNECTING TO
ENGINE...   :000
```
The last three digit number is the number of failed connection attempts. If you see something other than `000`, there might be a problem with one of the cables. When the connection is successful, the GSU will display e.g.

```
CONNECTED TO
#4711 TYPE: 005
```
In this example, the successfully connected to an engine with serial number `4711` of type `005`

6. Result of RPM check:

```
RPM CHECK
    OK
```
or
```
RPM CHECK
FAILED
```
This checks the full throttle RPM currently set against the maximum value and limits the full throttle rpm if an inconsistency is detected.

4.2 Status screens

The HORNET-III will by default display its first of six status screens. The default behaviour is that up (↑) and (↓) switch between the screens, enter (✓) opens the main menu (see Section 4.5) and escape (✘) returns to the first status screen.

1. Standard status screen.

```
TEMP.  THR./rRPM
STATUS    PvVOLT
```
e.g.
```
  20°C   0.0/-OFF
 OFF       Pv0.00
```
where `TEMP.` is the measured exhaust temperature, `THR.` is the throttle position, `rRPM` is the relative RPM (in %), `STATUS` is the engine status (see Section 4.3) and `PvVOLT` is the fuel pump voltage in V. If there the throttle signal is outside the limits stored by learning the RC timing (see 4.5.2) the message `-FAIL` is displayed instead of the relative RPM.

2. Last run termination status.

```
LAST RUN
RUN_STATUS
```
where `RUN_STATUS` is a run termination status (see Section 4.4).

3. Last run minimum and maximum values. On this screen, enter (✓) cycles between the different values:

   Pump voltage

   Temperature

   RPM

   Fail-safe information, e.g.

   ```
   FS_COUNT: 0x
   FS-TIME: 0s
   ```

   In this example, the fail-safe program was never invoked, so the total time spent in the fail-safe program is 0*s*.

4. Battery status. Shows the battery voltage and a visual indicator. The values used for determining the battery status can be configured in the main menu (see Section 4.5).

5. Fuel status. Shows the fuel level with a visual indicator.

   WARNING

   There is no way to accurately measure the fuel level, so it is calculated from some predefined values (e.g. fuel flow at idle speed, fuel flow at full speed) and some user supplied values (the fuel tank size).

   These values can be configured in the main menu (see Section 4.5).

4.3 Engine statuses

Table 1 contains all engine statuses the GSU can display. Most statuses are related to the various stages of the autostart process (see Section 5.3) and are given in the order they are displayed during a successful startup procedure.

Status	**Description**
`OFF`	Engine is is off, can be switched to `standby` by moving the throttle first to *neutral* and then to *full* (see Section 5.2.2).
`STANDBY`	Engine is ready to receive the start sequence: Move the throttle from *full* position to *off* position. If the throttle is then set to *full* position within three seconds, the ECU will initiate the *autostart* sequence (see Section 5.2.2).
`PROP IGNIT`	Engine ignition using auxiliary gas. Not relevant for AeroDesignWorks engines.
`BURNER ON`	Burner is on for the engine start using fuel.
`FUELIGNIT`	Ignition sequence for engine start using fuel.
`FUELHEAT`	After fuel ignition, the engine will heat up using constant RPM and pump voltage.
`RAMP DELAY`	The starter will increase its RPM, but the fuel flow will be kept constant.
`RAMP UP`	The engine will increase its RPM to idle speed by increasing the pump voltage and thus the fuel flow.
`AUTO`	Engine is operating in automatic mode.
`SLOWDOWN`	Engine is turning off, waiting for RPM to go to 0.
`COOLDOWN`	Engine is turned off, cooling down with constant RPM from the starter after reaching 0 RPM briefly.

Table 1: Engine statuses displayed on the GSU.

As engines using an analogue (brushed) fuel pump need an additional auto calibration phase, they have additional engine statuses (see Table 2).

Status	Description
`WAIT ACC`	Waiting for the acceleration to stop (nearing `STEADY`).
`STEADY`	Waiting for the RPM to stabilise (at idle or calibration speed).
`CAL IDLE`	The ECU tries to find the correct pump voltage for idle RPM.
`CALIBRATE`	The engine accelerates to calibration RPM and waits for the RPM to stabilise.
`GO IDLE`	The engine drops back to idle RPM.
`PVOLT DELAY`	Pump voltage increase was too high during auto calibration, delaying further acceleration.
`TEMP DELAY`	Exhaust temperature increase was too high during auto calibration, delaying further acceleration.

Table 2: Additional engine statuses for engine setups with analogue (brushed) pumps displayed on the GSU.

4.4 Termination statuses

Table 4 contains all statuses with which a run can be terminated that are not related to the auto calibration (see Section 5.4) needed only when using an analogue (brushed) fuel pump, which are found in Table 3 (also see Section 5.4).

Status	Description
`CALIBRATION FAILURE`	The RPM during auto calibration was more than 5,000 RPM off target.
`FLAMEOUT DURING CALIBRATION`	Exhaust temperature went below 250 °C which indicates a flameout.
`FELL BELOW MIN. CAL. RPM`	The RPM dropped below the acceptable limit during calibration.
`MAX. CAL. VOLT. EXCEEDED`	The maximum fuel pump voltage allowed was exceeded without reaching the required RPM.
`CALCULATED MAX. PUMPVOLT. EXCEED`	The calculated voltage needed for maximum RPM exceeds the maximum voltage (see Section 5.4).
`CAL. PLAUSI FAIL dV MIN-CAL <0.2V`	The voltage difference between idle and calibration speed is less than $0.2V$, which indicates an error during calibration.
`CAL. PLAUSI FAIL dV CAL-MAX <0.6V`	The voltage difference between calibration and maximum speed is less than $0.6V$, which indicates an error during calibration.

Table 3: Run termination statuses related to the auto calibration displayed on the GSU.

If an error is encountered during auto calibration, the engine will go to status `SLOWDOWN` and power down.

4.5 Main menu

The main menu is accessed from the status screen by pressing the enter (✓) button on the GSU. It has five regular sub menus and the expert menu, which is locked by default because it exposes many parameters which are outside the scope of normal user adjustments should only be changed by a qualified person (see Section 4.5.6).

4.5.1 Run time settings

This sub menu contains settings that affect the engine at run time, see Table 5.

4.5.2 User adjustments

This menu contains adjustments the user needs to make at least once, and some of them at the beginning of each session (e.g. the ambient temperature), see Table 6.

Status	Description
WITHOUT ERRORS	No error was encountered during the last run.
FAILURE THROTTLE PULSE	The RC's throttle pulse failed, possibly bad signal reception or loss.
RPM SENSOR FAILURE	Failure of the RPM sensor, either no signal or errors detected.
TEMP SENSOR FAILURE	The temperature sensor reported implausible values and might be malfunctioning.
EXCEEDED MAXIMUM RPM	The engine went over its hard maximum RPM limit, possibly due to a configuration error or faulty RPM sensor.
FELL BELOW MINIMUM RPM	The engine went below its hard minimum RPM limit, possibly due to a configuration error or faulty RPM sensor.
MAXIMUM TEMP EXCEEDED	The exhaust temperature exceeded 800 °C for an extended period of time.
FLAMEOUT DURING RUN	The temperature fell below 200 °C, indicating a flameout.
FLAMEOUT DURING FUEL HEAT	The temperature fell below 200 °C, indicating a flameout. Might be due to an interrupted fuel supply (e.g. air bubbles).
FLAMEOUT DURING RAMP UP	The temperature fell below 200 °C, indicating a flameout. Might be due to an interrupted fuel supply (e.g. air bubbles).
RPM < 2,000 DURING FUEL HEAT	The engine could not reach the required RPM. May be due to a broken starter or a jammed engine.
RPM < 5,000 DURING RAMP UP	The engine could not reach the required RPM. May be due to a broken starter or a jammed engine.
BATTERY VOLTAGE TOO LOW	The battery voltage fell below the limit set by the user in the main menu (see Section 4.5).
FUEL PUMP FAILURE	The fuel pump exceeded the maximum voltage allowed by the ECU, most likely because it could not meet the fuel flow required for the RPM requested by the user. This indicates a blocked fuel line or pump.
FAIL SAFE TIMEOUT	The ECU remained in fail-safe mode longer than the user allowed to classify as a successful run (see Section 5.6).

Table 4: Run termination statuses displayed on the GSU.

Learning RC Timings

The three throttle positions (see Section 5.2) and the RC switch function (if any) must be set.

1. `THRO. LO/TRIM LO`: The *off* position. Move both throttle and trimming to minimum.
2. `TRIM TO MAXIMUM`: The *neutral* position. Keep throttle at minimum and move the trimming to maximum.
3. `THROTTLE MAXIMUM`: The *full* position. Move throttle to maximum and keep the trimming to maximum.
4. `SET SWITCH LO`: The switch's *off* position.
5. `SET SWITCH HI`: The switch's *on* position.
6. Sanity check for the throttle positions and the RC switch positions (if any) as they must be distinguishable. If the check fails,the RC functions are disabled to avoid starting the engine with malfunctioning controls.

4.5.3 System and periphery

This sub menu settings for the system and periphery devices (see Table 7).

	Menu item	Description
1.1	RPM FULL THR.	The full throttle RPM. Can be set lower than the default value, e.g. to limit the resulting thrust and / or fuel consumption.
1.2	RPM IDLE	Can be lowered slightly or increased from the default setting, e.g. in extreme ambient conditions.
1.3	ACC/DEC DYNAMIC	Can be set to FAST, MEDIUM (default) or SLOW to adjust the engine's responsiveness to the throttle position.
1.4	THROTTLE CURVE	The throttle position can govern the RPM, the thrust, or a convex combination of the Two, Here, the fraction of the nonlinear part corresponding to the thrust can be set. 0% means the throttle position governs the RPM, 100% that it approximately governs the thrust. A combination of the two (20% - 70%) is recommended for better control at both low and high RPM (see Section 5.2.3).
1.5	PUMP VOLTAGE START	Adjusts the fuel pump voltage during startup. If it is set too low, the autostart program may fail due to a fuel shortage. If it is set too high, excess fuel might extinguish the combustor or even produce an open flame in or after the thrust nozzle!
1.6	FAILSAFE PROGRAM	Adjust the FAILSAFE DELAY, FAILSAFE TIMEOUT and FAILSAFE THROTTLE (see Section 5.6).

Table 5: Entries in the RUNTIME SETTINGS menu.

	Menu item	Description
2.1	LEARN RC TIMING	The RC timings must be learned, see Section 4.5.2.
2.2	SET AMBIENT TEMPERATURE	The ambient temperature should be set at the beginning of each session as functions and safety checks depend on it.
2.3	BATTERY VOLTAGES	Set the voltage at which the battery is considered empty or full here. This is important for the battery warning.
2.4	FUEL CONSUMPTION	Set the fuel flow at fuel pump voltages $1V$ and $2V$ and the fuel tank size here.
2.5	RC SWITCH FUNCTIONS	The RC switch can be set to NO FUNCTION, ON/OFF SWITCH (to replace the trimming, see Section 5.8.1) or SMOKER VALVE (see Section 5.8.2) here.

Table 6: Entries in the USER ADJUSTMENTS menu

	Menu item	Description
3.1	LANGUAGE	Switch between English and German (Deutsch).
3.2	ENGINE STATISTICS	Show engine statistics using up (↑) and down (↓) keys, such as the connected engine type, firmware version, total run time, serial number, manufacturing week and year and the total number of revolutions.
3.3	TELEMETRY MODULE	Here the telemetry sampling rate can be set between $0/s$ (off) and $10/s$ and a com channel between 1 and 9 can be chosen.
3.4	RESET TO DEFAULTS	The ECU can be reset to factory defaults, overwriting all user adjustments.

Table 7: Entries in the SYSTEM AND PERIPHERY menu

4.5.4 GPS and airspeed value

In this sub menu, data from the GPS module (if any) can be displayed by using the up (↑) and down (↓) keys on seven screens. Enter (✓) has no function in this sub menu, and escape (✘) returns to the main menu.

1. LA, LO: Latitude and longitude.
2. U, C: UTC time and GPS fix status (NOK for *not OK*, OK for a valid GPS position, 3D for a valid 3D GPS position) in the first line, current movement direction in degrees and number of satellites in use (should be about seven in most circumstances).

3. `GPS V, GPS ALT`: Current GPS ground speed in $\frac{km}{h}$ and altitude in m.

4. `DISTANCE R, X, Y`: Travelled ground distance, travelled distance longitudinal, travelled distance latitudinal.

5. `G MAX R, G MAX V`: Maximum ground distance from the take off point in m and maximum ground speed in $\frac{m}{s}$.

6. `G MAX ALT, G MIN ALT`: Maximum and minimum altitude in m.

7. `IAS, MAX IAS`: Indicated airspeed and maximum indicated airspeed in $\frac{km}{h}$.

Keep in mind that ground speed and air speed can differ significantly.

4.5.5 Test functions

This menu gives access to various test functions to manually operate connected devices (fuel pump, valves) or to query sensors (RPM, temperature, RC), see Table 8).

	Menu item	**Description**
5.1	`FUEL PUMP`	Pressing enter (✓) enters a sub menu where the fuel pump's voltage can be adjusted using the up (↑) and down (↓) keys. Pressing enter (✓) then starts the fuel pump and escape (✗) aborts. This program can only be used when the engine is *off*.
5.2	`GLOW OUTPUT`	Pressing enter (✓) enters a sub menu where the glow plug's voltage can be adjusted using the up (↑) and down (↓) keys. Pressing enter (✓) then turns on the glow plug and escape (✗) aborts. This program can only be used when the engine is *off*.
5.3	`IGNIT. FUEL`	Pressing enter (✓) switches the valve from `OFF` to `ON` and vice-versa.
5.4	`FUEL VALVE`	Pressing enter (✓) switches the valve from `OFF` to `ON` and vice-versa.
5.5	`SMOKE VALVE`	Pressing enter (✓) switches the valve from `OFF` to `ON` and vice-versa.
5.6	`RC TMNG. THR`	Shows the RC signal for the throttle position.
5.7	`RPM SENSOR`	Shows the RPM sensor's signal.
5.8	`TEMP SENSOR`	Shows the temperature sensor's signal.
5.9	`STARTER TEST`	Pressing enter (✓) once enables setting the starter's voltage using the up (↑) and down (↓) keys. Pressing enter (✓) again switches the starter to *on*. Pressing escape (✗) aborts and / or switches the starter to *off*.

Table 8: Entries in the `TEST FUNCTIONS` menu

WARNING

Fire hazard! Be careful not to flood the engine with fuel using the fuel pump test (`5.1`).

4.5.6 Expert menu

The expert menu is locked by default. Its unlocking can be triggered by pressing and holding the up (↑) and down (↓) keys and the releasing them simultaneously. A four digit number is the unlock challenge. The expert menu is unlocked if the user enter the correct input for the unlock challenge by using the up (↑) and down (↓) keys. Enter (✓) confirms the unlock code, while escape (✗) returns to the main menu without completing the unlocking process.

```
CODE : 8144
INPUT:  127
```

WARNING

The expert menu has access to parameters outside the scope of normal use of the ECU. These values should only be adjusted by qualified personnel! Therefor, the expert menu is not explicitly documented here. If you feel that you need to change settings that are not accessible through the normal menus, please get in touch with our support at `turbines@aerodesignworks.com`.

4.6 Necessary settings before starting

At the start of each session (i.e. before the engine's first start of the day), the GSU should be used to set the ambient temperature (Section 4.5.2) as several safety catches and functions depend on a correct temperature.

As the RC timings are stored persistently, it is not strictly necessary to learn the RC timings again if nothing has changed in the hardware. Nevertheless, many users do this before their first flight of the day.

5 Engine operation details

5.1 Radio Control (RC)

Only one channel is needed for the RC's throttle signal. With the throttle channel, the engine can be started, controlled and shut down. The additional channel available (labeled `AUX` on the housing, see Figure 1a) can be used by connecting an auxiliary input patch cable (1-to-1) and can be configured either for digital trimming or a smoker valve (see Section 5.8).

The throttle channel's timings must be learned using the GSU (see Section 4.5.2), while the auxiliary channel does not need this as it can only have the states `ON` and `OFF`.

5.2 Throttle positions

The ECU recognises three throttle positions.

5.2.1 Defined positions

1. **Off:** Both throttle and trimming are set to minimum. Engine is off.
2. **Neutral:** Throttle set to minimum and trimming is set to maximum. Corresponds to idle RPM.
3. **Full:** Both throttle and trimming are set to maximum. Corresponds to maximum RPM and thrust.

If the RC uses digital trimming, the additional auxiliary channel (see Section 5.8) can be configured in the corresponding menu via GSU (see 4.5.2).

5.2.2 Starting, running and stopping

1. **Off to Standby:** When the engine is in *off* mode, move the throttle first to *neutral* and then to *full* position. This will put the engine into *standby* mode.
2. **Start:** When the engine is in *standby* mode, move the throttle from *full* position to *off* position. If the throttle is then set to *full* position within three seconds, the ECU will initiate the *autostart* sequence.
3. **Running:** After successfully completing the *autostart* sequence, the ECU puts the engine in *automatic* mode. In this mode, a throttle position between *neutral* and *full* controls the engine's RPM and thrust.
4. **Stop:** When the engine is running, it can be stopped by moving the throttle to the *off* position. The ECU will shut down the fuel pump and run the cool-down sequence before switching the engine to *off* mode.

5.2.3 Throttle curve

The throttle position on the RC will command a certain engine RPM. The *neutral* setting will always correspond to idle RPM, while the *full* setting will always correspond to the maximum RPM. Between these two settings, it is a matter of personal preference and control whether the throttle position should command the engine's RPM, the thrust, or a convex combination of the two functions describing this.

There is an approximately cubic relation between thrust and RPM: $F \approx a \cdot (RPM)^3$ with $a \in \mathbb{R}_{>0}$. This means that

- If the throttle position commands the RPM, the thrust near full RPM becomes hard to control, as e.g. 90% RPM correspond to 72.9% thrust (see Figure 4b, the line corresponding to $c_1 = 0$). If an analogue controller is used, this means that almost 30% of the thrust is governed by only 10% of the lever stroke!
- If the throttle position command the thrust, the RPM near idle become hard to control for the same reasons, as 10% of the thrust already correspond to $\approx 46.4\%$ of the full RPM (see Figure 4a, the line corresponding to $c_1 = 1$).

For these reasons, it is very useful to use a convex combination of these relationships as the throttle curve to avoid the RPM or thrust to react too sensitively to the throttle position at either end of the range.

Assuming the throttle position is mapped to $[0,1]$ such that *off* corresponds to 0 and *full* corresponds to 1, we get the target relative RPM function as

$$r:[0,1]\to[0,1], r(s)=(1-c_1)s+c_1\sqrt[3]{s}. \quad (1)$$

As our throttle position will only be between *idle* and off, we need the linear mapping

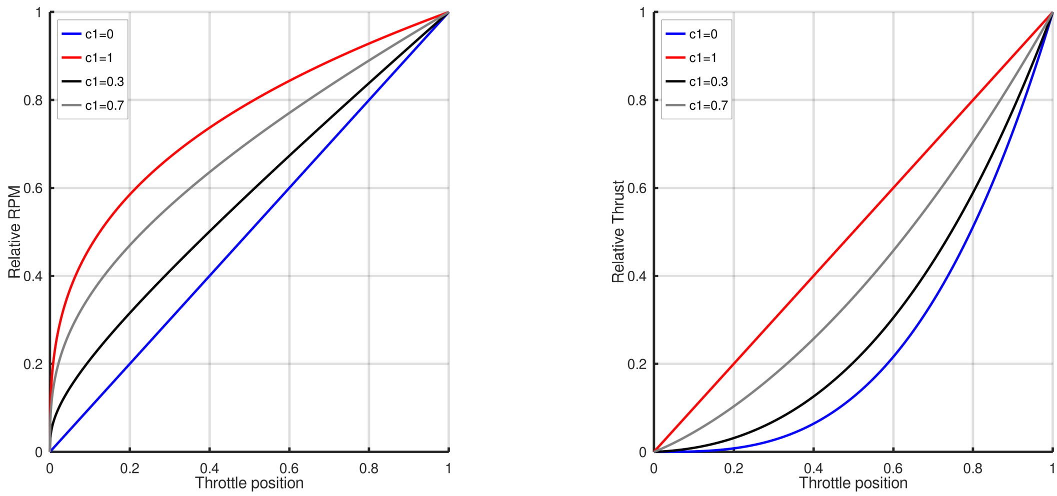
$$\tau:[0,1]->[0,1], \quad \tau(t):=at+b, \quad (2)$$

with $b:=\frac{RPM_{idle}}{RPM_{full}}, a:=(1+b)^{-1}$.

Now we can get the true RPM as a function of the relative throttle position $t\in[0,1]$, where 0 corresponds to *neutral* and 1 corresponds to *full*

$$R:[0,1]\to[0,1], R(t)=RPM_{idle}+r\circ\tau(t)(RPM_{full}-RPM_{idle}). \quad (3)$$

This way, $R(0)=RPM_{idle}, R(1)=RPM_{full}$ and R is a convex combination of a linear function and a root function in between.



(a) Relative rpm over relative throttle for different values of c_1.

(b) Relative thrust over relative throttle for different values of c_1.

These convex combinations (the grey and black lines corresponding to $c_1=0.3$ and $c_1=0.7$ in Figures 4a, 4b) result in throttle curves that are easier to control at both low and high RPM.

5.3 Autostart

The autostart sequence can be triggered when the engine is in *standby* mode. The sequence is as follows (with statuses as given on the GSU, also see Table 1).

1. `BURNER ON`: The glow plug is switched on for 8s. The starter slowly increases the engine's RPM.
2. `FUEL IGNIT`: Modulation of the starter fuel valve and starting of the fuel pump. Upon successful fuel ignition (exhaust temperature exceeds 150 °C), transition to `FUEL HEAT`.
3. `FUEL HEAT`: Transition from ignition to main line fuel supply. The burner is still supplied with fuel while the main fuel line valve is opened. The starter's voltage (and thus the RPM) is increased slowly.
4. `RAMP UP`: The engine's RPM is increased by increasing the main fuel line's flow rate. The starter and burner are switched off at the configured RPM, respectively.

After the completion of the autostart sequence, the engine is running at idle RPM. If a HORNET-III with analogue (brushed) pump is used, the ECU will then execute the auto calibration (Section 5.4). If a HORNET-III-ClubSport is used, the engine will be in automatic mode (see Section 5.5) and ready to go!

5.4 Auto calibration

A HORNET-III with analogue (brushed) pump needs to perform this step for a sufficiently precise guess of the pump's voltage for full RPM for a correct throttle response until the correct voltage is known.

The reason for this is that the brushed pump's characteristic curves are not entirely consistent and may differ between between devices of the same model, or even due to different ambient conditions. Brushless pumps do not have these inconsistencies up to negligible differences and do not require auto calibration.

The auto calibration sequence consists of the following steps.

1. Starting at idle RPM, the engine accelerates to the *calibration* RPM.
2. After reaching the calibration RPM, the ECU waits for the RPM, fuel flow and pump voltage to stabilise.
3. The engine then drops back to idle RPM.
4. Now that the pump voltage is known for idle and calibration RPM, an educated guess for the correct pump voltage for full RPM can be made.

After completing the auto calibration, the engine will be in *automatic* mode (see Section 5.5).

5.5 Automatic mode

This is the standard mode of engine operation and will display as `AUTO` on the GSU. If a HORNET-III with analogue (brushed) fuel pump is used, the engine will run in mode `AUTO*` (automatic, pump voltage for full RPM not yet known) until reaching full RPM once.

- The RPM between idle and full RPM is controlled by the user's input.
- This is achieved by an RPM and temperature dependent fuel flow.
- Telemetry data is transmitted if a telemetry module is connected and configured.
- Temperature and RPM are monitored by the ECU, as are the battery voltage, the RC signal and the fuel pump voltage.
- In case the RC signal is lost or outside acceptable ranges, the ECU will switch to *failsafe* mode (Section 5.6).

5.6 Fail-safe mode

If the RC signal is lost, the ECU will switch to *fail-safe* mode, which can be configured in the corresponding menu via GSU (see Section 4.5.1). By default, the fail-safe mode is off, meaning the engine will shut down if the RC signal is lost.

- `FAILSAFE DELAY`: The time (in *s*) the ECU will operate normally if the RC signal is lost before switching to fail-safe mode. *Setting this to 0 will deactivate the fail-safe mode*.
- `FAILSAFE TIMEOUT`: The time (in *s*) the ECU is allowed to operate in *fail-safe* mode. After this time, the engine will shut down by stopping the fuel pump. The default is 0, meaning instant shutdown.
- `FAILSAFE THROTTLE`: The throttle position the ECU assumes in *fail-safe* mode. Default is 0, so the engine will go to idle speed.

If the fail-safe program was activated and for how long it ran during the last engine run can be found on a status screen via GSU (see Section 4.2).

5.7 Cool-down mode

After the engine came to a standstill after turning off, the starter will cool the engine until the measured temperature is below the corresponding threshold.

5.8 Auxiliary channel

For using an additional smoker valve, it is possible to connect an AUX input patch cable to the HORNET-III.

5.8.1 Using the auxiliary channel to replace the RC's trimming

The auxiliary channel can be configured to replace the trimming using the GSU menu (see Section 4.5.2), e.g. if the RC uses digital trimming.

- `ON` replaces the maximum trim setting.
- `OFF` replaces the minimum trim setting.
- Leave the RC's trimming at maximum when using this switch function.

5.8.2 Smoker valve

Alternatively, the auxiliary channel can be used to operate a smoker valve. The valve will open if the measured temperature exceeds 300 °C and close if the reported temperature is below.

The smoker valve can be manually operated via GSU for testing (see Section 4.5.5).

6 Contact and support

If you encounter any problems with one of our products or require support, please contact AeroDesignWorks via

- telephone: +49 (0) 221 / 98 43 11-50
- email: `turbines@aerodesignworks.com`

7 Changelog

Firmware version 3.0

- Two different models: HORNET-III, HORNET-III-ClubSport.
- Support for using brushless fuel pumps with the new HORNET-III-ClubSport.
- Major overhaul of the GSU menu structure.
- As the hardware for the flight recorder is no longer manufactured, the flight recorder feature had to be dropped.
- Notable bug fixes:

  The maximum RPM for the B300F could not be re-adjusted to 105,000 after lowering it. This has been fixed.

  When the GSU was used to modify values, the user could not discard the changes. Pressing escape prevented the values from being written to the EEPROM, but the modified values were active until the next restart of the ECU. This has been fixed so that pressing escape restores the unmodified values from the EEPROM, while enter stores the modified values in both RAM and EEPROM.

8 Acknowledgements

We want to thank ProJET electronic components GmbH for the excellent cooperation over the years and in developing new products. We also want to thank our fearless test pilot J. Jungnischke for taking the new HORNET-III-ClubSport out for its first flights.

Thank you for your attention!

Your team at

AeroDesignWorks

AeroDesignWorks GmbH
Wankelstr. 57
D-50996 Köln
Germany

Telefon: +49 (0) 221 / 98 43 11-50
Telefax: +49 (0) 221 / 98 43 11-02

https://aerodesignworks.com
turbines@aerodesignworks.com