

# FLIGHTZOOMER

## 1.5.1

# MANUAL

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## 2 Document change log

### Version 1.5.1

- September 15, 2015: Added FMS generic operations with line keys and scratchpad.
- September 15, 2015: Added that aerodynamics need to be considered when attaching the sensor device.
- March 23, 2016: Corrected, revised and restructured

## 3 Disclaimer

While FlightZoomer offers fantastic features, the following operations rules must be strictly followed:

- The FlightZoomer system is intended for hobby usage only.
- Be familiar with the operation of RC aircraft having 1kg flying weight or more.
- Use FlightZoomer only aboard a proven configuration of RC equipment, airframe, flight controller, motors, propeller, battery and ESCs.
- Operate FlightZoomer strictly within the safety boundaries of any other onboard components.
- Operate FlightZoomer strictly within the boundaries of any local regulatory statute.
- Fully respect any disclaimer and safety note which is associated with any other onboard or controlling component, such as RC radio and equipment, telemetry radios, autopilots

## 4 FlightZoomer in a nutshell

### 4.1 What can you do with FlightZoomer?

FlightZoomer is a smartphone-based system which can be used to navigate, track, control and record the flight of remote controlled model aircraft, especially fixed wing planes and multicopters. A special emphasis is laid on the implementation of the systems, pilot control interface and procedures of a real airliner cockpit.

FlightZoomer is supplementary to an existing setup consisting of an RC aircraft (which can be a multicopter or an airplane), a flight controller and an RC transmitter. The smartphone therefore operates as a companion computer to the flight controller and autopilot, such as a Pixhawk.

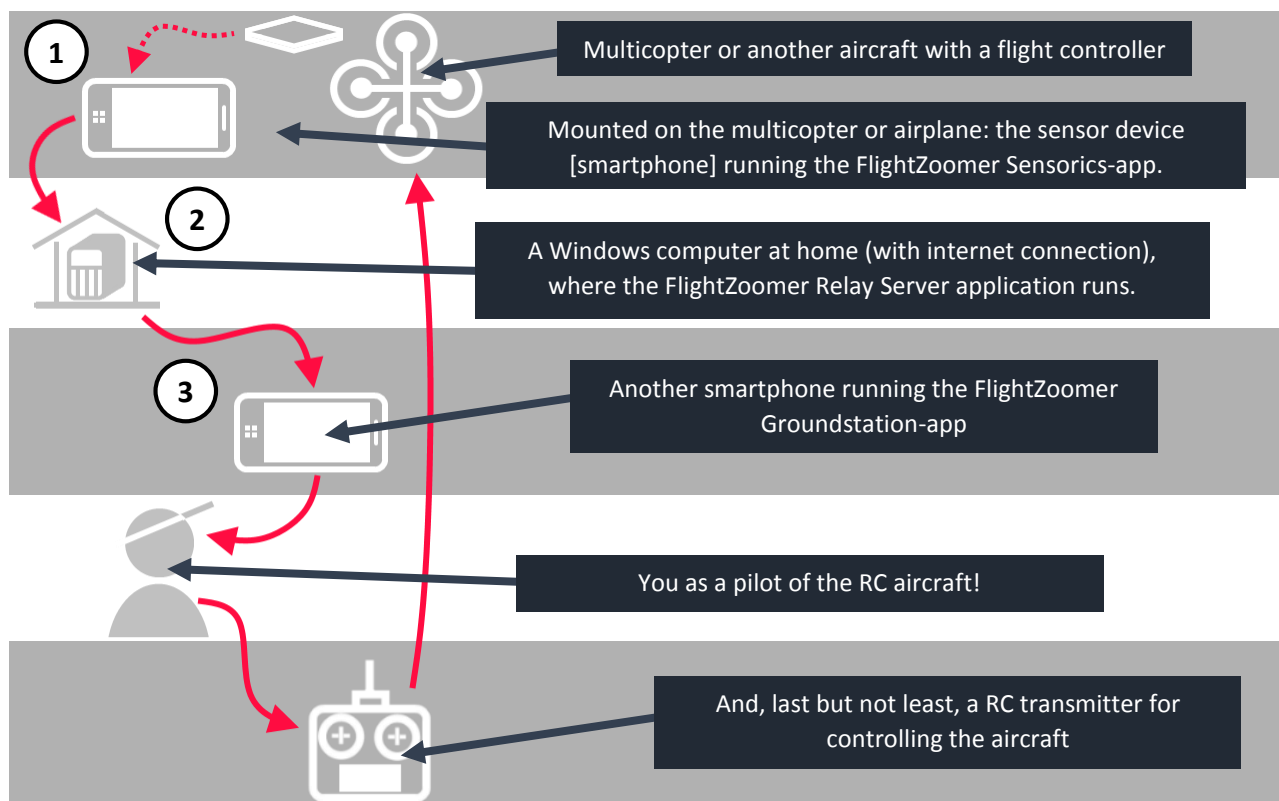
There are many use cases covered with the first version of FlightZoomer:

- Transmission of sensor data from an onboard smartphone to a ground-based smartphone groundstation via cellular network: so your control and telemetry range is virtually unlimited!
- The source of flight sensor data preferably is the flight controller (connected via MAVLink): Get the highest available accuracy!
- The phone offers an additional motion sensor set which can be used (though by far not as accurate): Get a fully redundant second sensor stack!
- Provide a display to the pilot showing the position of the aircraft on a moving map: so you can navigate, guide, track and even locate lost copters!
- Display speed, altitude and attitude to the pilot: so you get the information like in a real cockpit!
- Allows the pilot to navigate the aircraft based on self-created flightplans: prepare, plan and execute routes like real pilots do (according to instrument flight rules)!
- Even scale RC aircraft just look visually like their originals but are flown with control systems that bare no similarity with their real world counterparts: operate your RC aircraft using an avionics suite user interface (UI) that reproduces the cockpit of the Boeing 787 Dreamliner!
- Synthetic voice to guide the pilot along the flightplan: experience guidance from a simulated co-pilot!
- Enables navigation based on a simulation of standard radio navigation aids: create your own airspace with airports and NAVAIDS!

- Instrument Landing System (ILS) offering the full set of real world instruments including the beeping at the outer, middle and inner markers: capture and follow the glideslope performing precision approaches with your RC aircraft!
- Let the camera of the onboard device record images or videos of the flight: put that smartphone camera to work!
- Provide extensive flight telemetry/logging capabilities: dig into structured data for post flight analysis and email to your instructor/mentor...or make available to a governing agency
- Flight replay feature: show your friends at any time, how your cockpit looked during a flight!
- Flight simulation feature: induce simulated flight movements (altitude, course, speed and vertical speed) to explore the capabilities of the groundstation in your living room!
- Testpilot feature: let the system automatically measure some of the required flight performance parameters!

## 4.2 System overview

The following diagram shows FlightZoomer's control loop over all interfaced subsystems:



FlightZoomer consists of three components:

1. The **FlightZoomer Sensorics device**. This is a Windows Phone® device, mounted on a RC aircraft. It is connected over Bluetooth to the MAVLink communications of the flight controller. The device must have a cellular data connection (EDGE, 3G, 4G or LTE), which is critical to enable the communications path from onboard the aircraft over cellular data network to the internet.

2. The relay server. This is a PC at home (or alternatively in the cloud with a service provider such as MS Azure) on which the **FlightZoomer Relay Server** application runs. The relay server connects the FlightZoomer Sensorics and the FlightZoomer Groundstation devices over the Internet.
3. The **FlightZoomer Groundstation device**. This is also a Windows Phone® device, which is used as display and touchscreen interface for the pilot.

The principle is very simple: Overall FlightZoomer is a pure software solution that fully relies on off-the-shelf hardware.

Regarding the **FlightZoomer Sensorics** app: This app runs on the aforementioned smartphone “Sensorics” device. The app receives all flight parameters in real time from the flight controller via the MAVLink interface and transmits flight parameters or “telemetry” via cellular network to the Relay server, which then forwards the data in near real time to a second smartphone device, which runs the FlightZoomer Groundstation app and acts as a groundstation.

### 4.3 The apps

The flowing Figures show the main user interfaces of the three apps that constitute FlightZoomer.



FIGURE 5.2 FLIGHTZOOMER CONSISTS OF, FROM TOP TO BOTTOM; THE SENSORICS APP, THE RELAY SERVER AND THE GROUND STATION APP.

## 5 Functional aspects

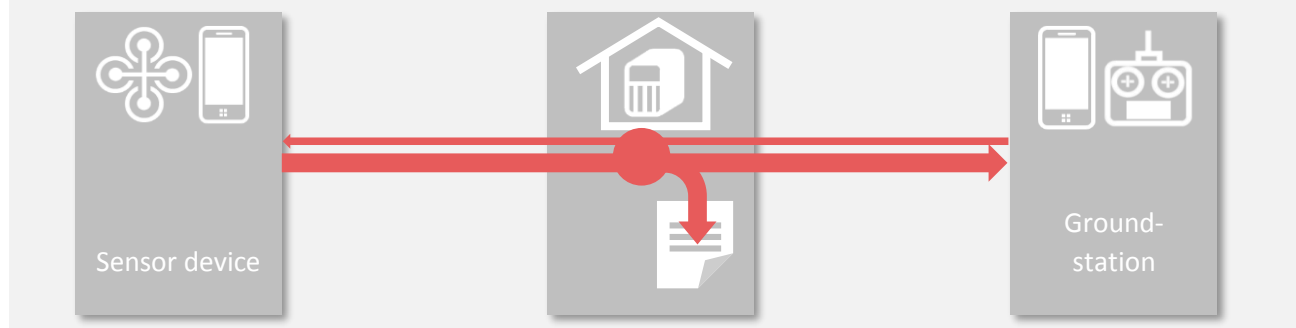
### 5.1 System requirements

- FlightZoomer is a sole software solution which currently runs on Windows Phone® 8.1 (the apps) and Windows 7 or higher (the relay server).
- The devices on which the software runs are off-the-shelf devices.
- The typical latency of FlightZoomer's control loop is not bad (0.03 to 0.13 seconds, on average about 0.08 seconds) but...
- Occasional latency spikes prohibit controlling the RC aircraft without additional stabilization. Thus the RC aircraft must be equipped with a MAVLink based flight controller (APM, Pixhawk, AUAV X2,...). The flight controller must offer predictable and reliable flight characteristics.
- The onboard device can be mounted on the aircraft in any attitude that is suitable for safe carriage, either internal or external (there is a geometry capturing sequence to measure and calibrate the actual attitude).

## 5.2 Operations scenarios

There are many operations scenarios which serve different purposes and use cases.

### 5.2.1 Normal operation

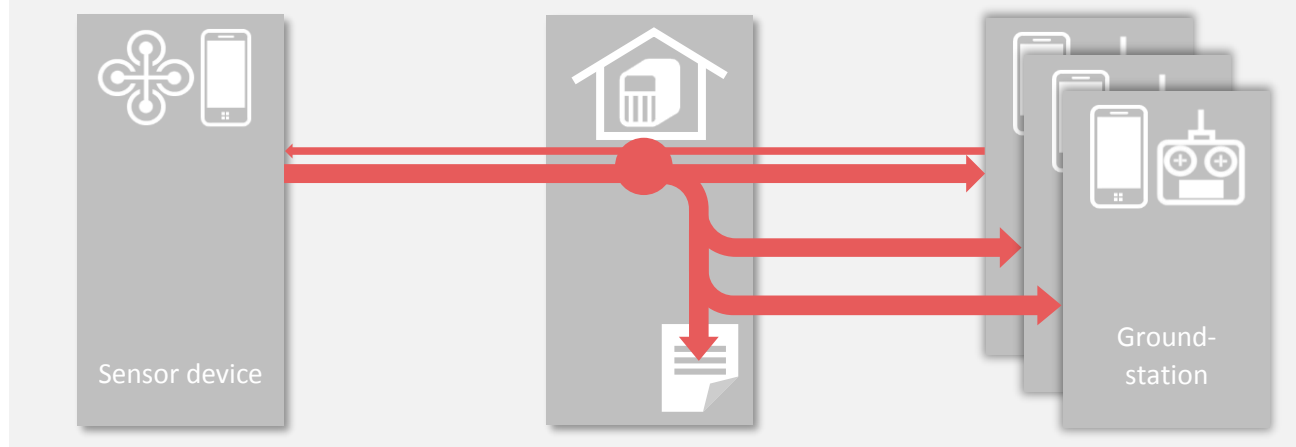


During normal operation the sensor device transmits flight sensor (compass, IMU etc) and location data to the relay server. The data is then forwarded to the groundstation.

In the opposite direction certain commands can be sent from the groundstation to the sensor device and on to the aircraft.

The aircraft flight sensor and location data are automatically written into a flight-logfile on the relay server as soon as the sensoric system switches to flight locked (armed) mode (see chapter 5.4).

### 5.2.2 Normal operation, multiple groundstations



Supplementary to the normal operation scenario, additional groundstations can connect to the relay server. This allows observing flights from multiple devices. So you can virtually fly your wife or your friends while piloting your RC aircraft! Regardless where they are on the world! Another safety feature of multiple ground stations enables airspace control authority to log-in to your server, with permission, and watch your flight mission progress, knowing where your unmanned aircraft is in relation to manned aircraft.

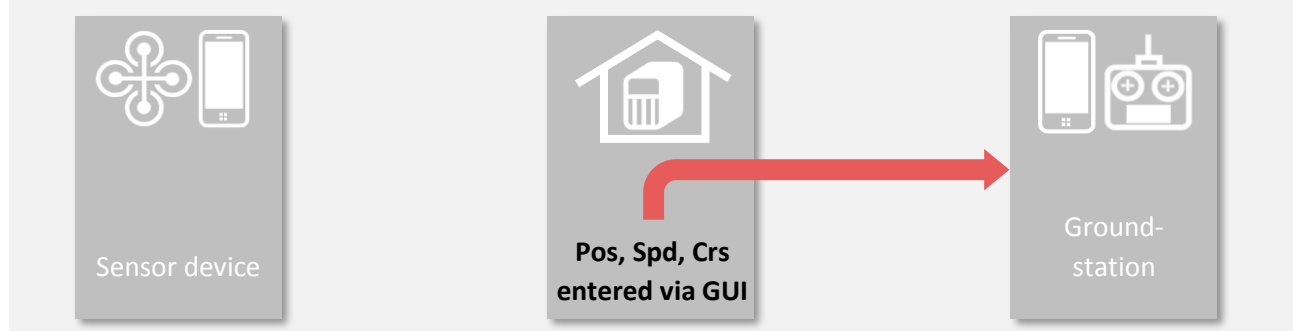


### 5.2.3 Replay file operation



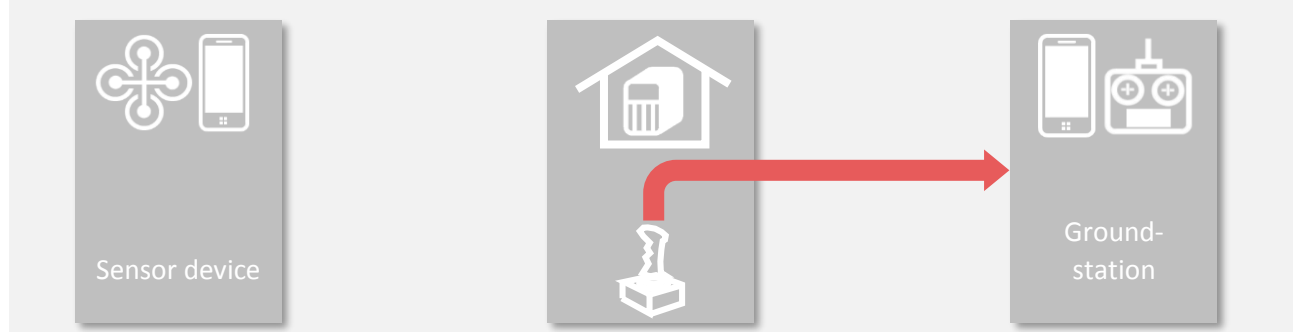
The flight logfiles, which were recorded while flying, can be used later to replay the flight in real time. This allows repeating earlier flights for analysis, training or demonstration purposes.

### 5.2.4 Simulated operations



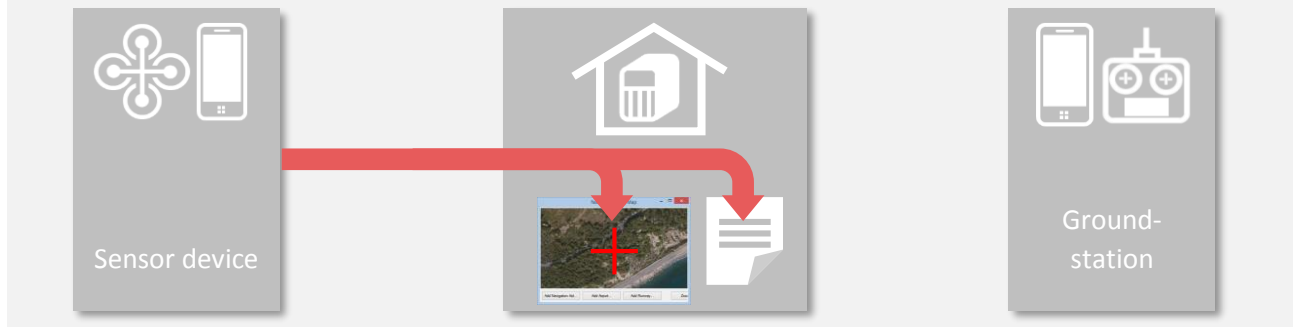
Beside the option to replay logfiles from earlier flights, the flight parameters (location, speed, course and altitude) can also be generated directly by providing these parameters on the relay server GUI. This enables injection of events to simulate very precise flight movements; again for training purposes and system familiarization.

### 5.2.5 Simulated operation, with joystick



The input for the flight simulation can also come from a standard joystick, which is connected to the relay server. This enables training and inspection of the features of the groundstation that is nearly as realistic as flying with the real model.

## 5.2.6 Live position



The last operations scenario enables observation and tracking of the sensor device position directly on the relay server. Again, a feature for those who stayed at home to monitor flight progress. Technically, this capability feature can be used as a secondary aircraft flight telemetry data stream albeit using the sensoric device onboard IMU and GPS as the source instead of the aircrafts sensors.

## 5.3 Network connectivity

### 5.3.1 Principle

Between both apps and the relay server, bi-directional UDP connections are established. While the relay server is just listening for (and responding to) incoming messages, the two apps need to initiate the communication.

The user therefore needs to provide UDP connectivity between the phones and the PC where the relay server runs. This might involve usage of DSN services, firewall configuration and port forwarding configuration. How this is actually being done is described in chapter 6.2.

The backward channel from the relay server to the smartphone apps does not need to be configured, because the relay server just responds to the sender of the incoming messages.

The UDP port number on which the relay server is listening for incoming messages is statically configured with 57778. Both phones connect to this port and are differentiated by the relay server based on their respective endpoint.

### 5.3.2 Control over the preferred network

#### 5.3.2.1 FlightZoomer Sensorics-app

The FlightZoomer Sensorics-app enables selection of the preferred connectivity path, whether via cellular or WIFI network interfaces (switching on the connection either with the app's CELLULAR or the WIFI button).

Setting the network preference just means that the operating system will pick the preferred network interface type if more than one are available. Without preference the operating system would just pick the best available network. And if only one network is available, the device will establish connectivity using that network interface in all cases. Independent of the selected network interface, the FlightZoomer Sensorics app will display which network type is being used.

While flying, cellular network connectivity should be selected as preference. The WIFI option on the other hand allows setting up local communication between the sensor device and the relay server at home without burdening the mobile data plan. This can be used for testing purposes and to download videos from the device (if FlightZoomer Sensorics is used to record videos, the only way to download them is the built-in download functionality).

#### 5.3.2.2 FlightZoomer Groundstation-app

The FlightZoomer Groundstation-app will always automatically connect to the relay server with cellular network preference. There is no option to choose the network type preference. The assumption is that the Groundstation is “mobile” outside of WiFi coverage where the pilot is controlling the aircraft flight.

## 5.4 State Models

The whole system has three end-to-end modes:

- Idle
- Connected
- Flight Lock

These three modes reflect the **state** of the communication between the FlightZoomer components. In all three modes the source of the transmitted sensor data can either be the MAVLink, the phone’s sensors or both.

#### **Idle-mode:**

The app on either smartphone has been started but not yet connected to the relay server.

#### **Connected-mode:**

The connection from either of the smartphones to the relay server has been established. In this state all the sensor data is forwarded from the sensor device to the groundstation device. Flight preparations are best accomplished in connected mode.

#### **Flight Lock-mode:**

Once flight preparation is complete, and immediately before taking off, the devices need to be switched into the Flight Lock-mode. This prevents further user input on the touchscreen of the FlightZoomer Sensorics device and starts recording the flight data on the relay server. In addition, the camera starts recording a video or taking images, see section 7.1.9).

If the sensor device is mated with the flight controller (which is typically the case) the Flight Lock-mode goes along with the armed state of the aircraft’s throttle. These two states are kept in sync automatically in both directions:

- Whenever the flight controller is brought into armed state (e.g. via RC transmitter), the FlightZoomer Sensorics-app detects it and switches automatically into the Flight Lock-mode.

Likewise, if FlightZoomer is brought into the Flight Lock-mode (e.g. using the respective button on the groundstation), the flight controller is thereby commanded to switch into armed state.

## 5.5 Sensor data via MAVLink

The onboard FlightZoomer Sensorics app offers two sources for sensor data:

- From the flight controller via a MAVLink connection
- From the phone's own sensors

Up to FlightZoomer 1.5 only the phones sensors were considered, which led to rather large errors and unreliable accuracy (sometimes good enough, sometimes insufficient, especially the GPS). With FlightZoomer 1.5 a Bluetooth interface was incorporated to easily mate a MAVLink capable flight controller with the onboard smartphone.

With that setup the following data source options/priorities are supported:

	Data source priority	Description
1	Phone always	Mode if no MAVLink connection is available (e.g. low tech devices, flight controller does not support it).
2	Weighted priority	Reserved for future use; currently not implemented. This mode is intended to blend the two sources based on estimated errors per parameter including the ever increasing error due to passed time since the last data was received (reward the source with more frequent updates).
3	Flight controller unless failed	Clear preference for MAVLink, unless the MAVLink stops providing fresh data (e.g. due to technical outages in the Bluetooth connection). This is the recommended option.
4	Flight controller always	Never mind the phone and its sensor stack. If the Bluetooth proves to be trustworthy enough, the phone's sensors can be ignored altogether.

As explained in section 1 the accuracy of flight controller sourced data generally is excellent and should be preferred whenever possible. Using FlightZoomer without MAVLink is not impossible but seriously restricts the usability of the system.

### 5.5.1 MAVLink requirements

FlightZoomer is using a number of MAVLink packets to extract relevant sensor data. These can be broadcasted from the flight controller to the onboard smartphone via Bluetooth using preconfigured streams.

The following table shows the required streams, the relevant packets and the recommended rate to transmit them (per second):

Stream	Recommended rate per second	Contained packets/ used packets	Used by FlightZoomer
RAW_SENS	10x	- RAW_IMU - SCALED_IMU2 - SCALED_PRESSURE - SENSOR_OFFSETS	X
EXT_STAT	1x	- SYS_STATUS - MEMINFO - MISSION_CURRENT - GPS_RAW_INT - NAV_CONTROLLER_OUTPUT - POWER_STATUS	X  X
RC_CHAN	2x	- SERVO_OUTPUT_RAW - RC_CHANNELS_RAW	X X
POSITION	5x	- GLOBAL_POSITION_INT	X
EXTRA1	5x	- ATTITUDE - SIMSTATE (SITL)	X

Using a baud rate of 57600 easily supports the recommended packet rate. Using the default baud rate of 9600 of an out-of-the-box HC-06 Bluetooth device however would not support the aforementioned frequencies.

## 5.6 Navigation data

FlightZoomer emulates the structure and elements of a real air space. There is a navigation database, consisting of navigation aids (radio beacons), airports and runways, which can freely be defined wherever you like.

Navigation data is used to fly the RC model in a controlled manner. There are a number of possibilities: capture simulated radials of radio beacons, follow glideslopes of a simulated ILS (Instrument Landing System) or create flightplans and fly any predefined route at will.

The system does not need real radio equipment to implement these features. A navigation aid is nothing but a data record, which consists typically of an ID, a location and a frequency. If a simulated navigation receiver on the groundstation is tuned to the frequency of a navigation aid, the groundstation cockpit displays will simulate the appearance of the real instruments based on the aircraft location, the navigation aid location and some other parameters.

FlightZoomer stores the navigation data in a database that is located on the relay server. Any groundstation which connects to the relay server will automatically download and import a copy of the navigation data.

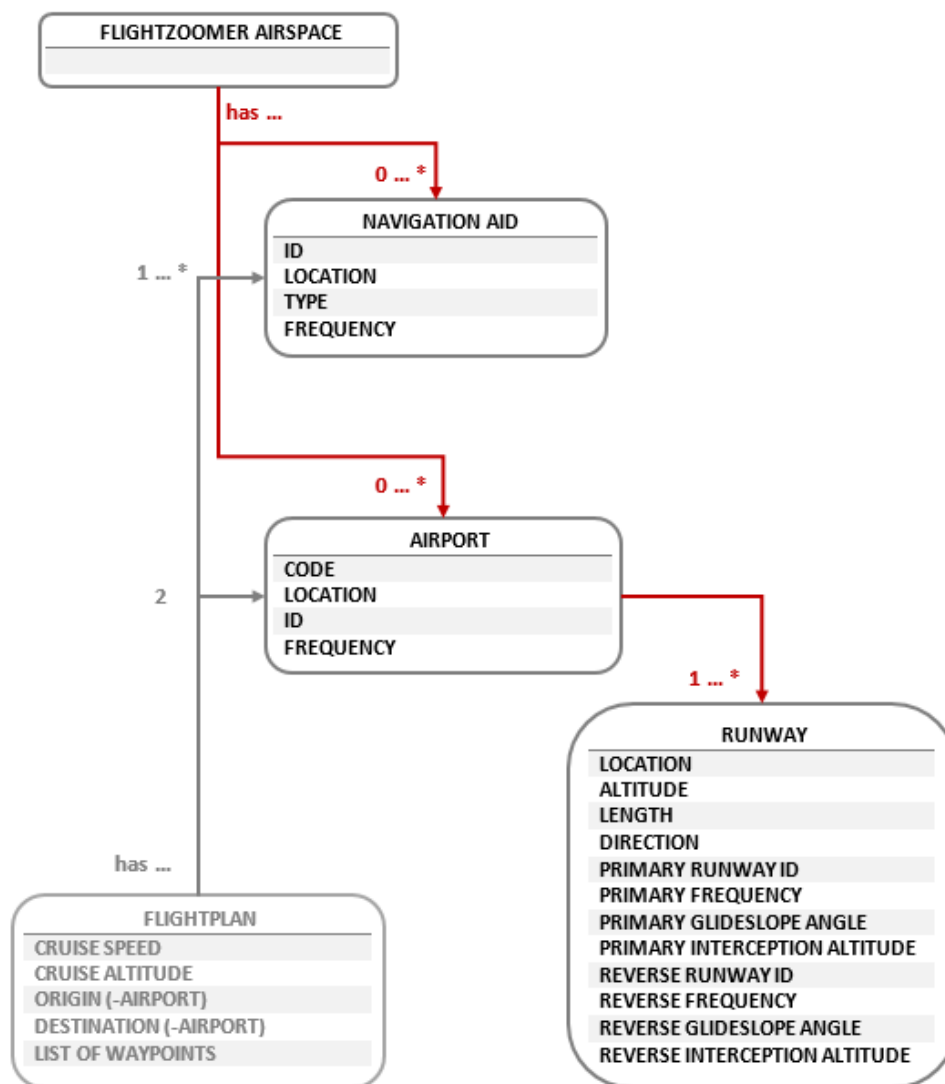
The creation and modification of navigation data is done with the FlightZoomer Relay Server application. The application has convenient features for that purpose (see 7.2.7). Creating navigation aids and airports is one of the preparation steps. With the present version 1.5 it is not possible to add navigation aids (=waypoints) on the fly during flight operations.

The navigation database consists of text files (ending with \*.txt) which are located in the following folder on the relay server:

	What	Folder
1	Navigation aids	C:\ProgramData\FlightZoomer\Navigation.Navaids
2	Airports (and runways)	C:\ProgramData\FlightZoomer\Navigation.Airports

Navigation data generated within the Relay Server application is stored in two files named nav aids.base.txt and airports.base.txt. Other \*.txt files can be added manually in the two folders and will be incorporated automatically into the navigation database. Due to technical limitations for downloading the files to the groundstation the total size of all the \*.txt-files must not exceed 10kB.

The following diagram shows the navigation data model (with the relationship to a flightplan):



## 5.6.1 Navigation aid

Navigation aids are points on the landscape, which are used to determine the position of the aircraft and are also used as waypoints for flight routes.

In controlled airspace (manned) aviation there are three basic types of navigation aids:

1. Non-directional beacon (NDB): The ID for NDBs have three letters. This type of radio beacons is mostly obsolete nowadays. They operate at low frequencies and don't provide inherent and precise directional information. FlightZoomer does not model NDBs.  
More information can be found here:  
[http://en.wikipedia.org/wiki/Non-directional\\_beacon](http://en.wikipedia.org/wiki/Non-directional_beacon)
2. VHF Omnidirectional Range (VOR): The ID for VORs has three letters. VORs are still in use in aviation today. They offer exact measurements of the radial on which the aircraft is located. A subtype are VORDMEs which additionally offer a distance measurement. Tuning to a single VORDME enables unambiguous determination of the current position.  
More information can be found here:  
[http://en.wikipedia.org/wiki/VHF\\_omnidirectional\\_range](http://en.wikipedia.org/wiki/VHF_omnidirectional_range)
3. Fixed geographic coordinates (GPS FIX): The ID for GPS FIXs has five letters. These are fixed positions which were defined to support airways and flight paths without the need to install ground based radio beacons. They far outnumber VORs in most airspaces. As they don't emit any radio signals they can only be used for aircrafts which can determine their location autonomously. Due to GPS and other advanced systems this is almost always the case today.

FlightZoomer implements the VOR, VORDME and GPS FIX navigation aid types.

A navigation aid has the following properties:

Element		Purpose
1	ID	The ID identifies a certain navigation aid and needs to be distinct within the whole navigation database. It consists typically of 3 to 5 uppercase letters (3 letters for VORs and VORDMEs and 5 letters for GPS FIXs). FlightZoomer does not restrict the character count however so any desirable ID can be assigned to navigation aids (and thus be displayed on the navigation display). The ID is mandatory.
2	LOCATION	The location is also mandatory and defines the geographic coordinates. It consists of longitude and latitude.
3	TYPE	The possible types are VORDME, VOR and GPS FIX. The first would offer distance measurement and radial capturing, the second only radial capturing and the third could not be used for radio navigation but only for flightplans. However, there is currently no different behavior implemented for each of these, so each type would represent a VORDME (with the small exception, that leaving away the frequency would emulate a GPS FIX).
4	FREQUENCY	The frequency is used to tune to a certain navigation aid. It also needs to be distinct within the whole navigation database. The frequency property is not mandatory and can be left empty. In that case the navigation aid emulates a GPS FIX and would not be useable for radio navigation. But frequency can still be used for flightplans.

## 5.6.2 Airport

Airports can be placed freely on the landscape. They are needed as origin or destination for flightplans and can also be used to fly ILS approaches.

Airports are a composite data structure including common properties in their data model as well as a list of runways, which are described in the next chapter.

An airport typically also has a radio navigation aid. The data model thus has properties for the airport navigation aid ID and frequency.

In FlightZoomer the code of airports follows the guidelines from the ICAO (although the airport codes you define will never be visible outside your simulated UAS flight area!). In the real world of manned aviation, the ICAO defines the airport codes for any airport worldwide. ICAO codes have four letters as opposed to the IATA codes having three letters. The first or the first and the second letter stand for the country and are defined statically (see this map [ICAO countries prefix map](#)).

An airport has the following properties:

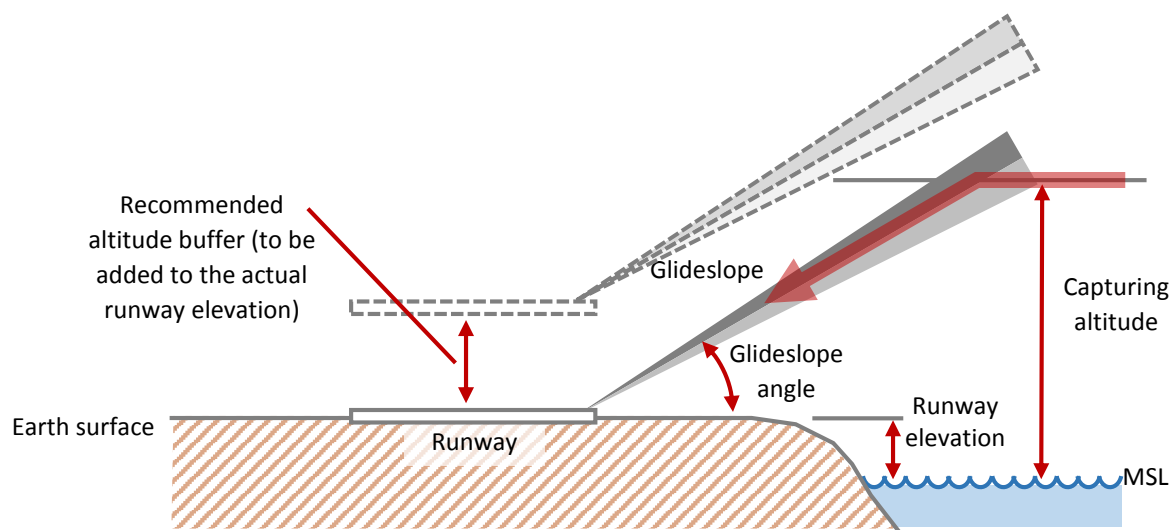
	Element	Purpose
1	CODE	The CODE identifies a certain airport according to the ICAO scheme and needs to be distinct within the whole navigation database. It consists of 4 uppercase letters. FlightZoomer does not restrict however the character count so any desirable name can be assigned as CODE to an airport (and thus be displayed on the navigation display). The CODE is mandatory.
2	LOCATION	The location is also mandatory and defines the geographic coordinates of the airport navigation aid. It consists of longitude and latitude.
3	ID	The ID identifies the radio navigation aid which is located on the airport. The description for ID in the chapter before does apply here as well.
4	FREQUENCY	This property defines the frequency of the navigation aid which is located on the airport. The description for FREQUENCY in the chapter before does apply here as well.

## 5.6.3 Runway

Runways can also be placed freely on the landscape but they need to be assigned to an airport. Runways support flying ILS approaches.



An ILS approach is defined by the following parameters (in red):



Additional properties not shown in the diagram is the runway direction.

A runway has the following properties:

Element	Purpose
1 LOCATION	The location is mandatory and defines the geographic coordinates of the center of the runway. It consists of longitude and latitude.
2 ALTITUDE	Altitude of the runway in meter above sea level. It is one possibility to define the actual altitude of the runway. Due to the somewhat limited vertical accuracy of the system, it is recommended however, to define the runway altitude 5...10 m higher. This would give some safety buffer to safely complete suboptimal approaches.
3 LENGTH	Length of the runway in meters.
4 DIRECTION	Direction (primary) between 0° and 360°. The reverse direction does not exist as an attribute but is derived from this property.
5 PRIMARY RUNWAY ID	The ID of a runway is formed by the first two digits of the direction (e.g. direction = 73° -> ID = 07, direction = 157° -> ID = 16) Parallel runways are suffixed with L, R or C: L for left, R for right and C for center (e.g. 28L and 28R).
6 PRIMARY FREQUENCY	The next three properties are optional and describe the ILS approach to the primary runway direction. If the navigation receiver on the groundstation is tuned to this frequency, deviations from the ILS glideslope will be indicated on the primary and navigation displays. Like the frequency of any navigation aid, each ILS frequency needs to be distinct within the whole navigation database.
7 PRIMARY GLIDESLOPE ANGLE	The primary glideslope angle is the vertical angle between glideslope and the earth surface. While real ILS typically have 3° glideslope angles, for multicopters 20° is recommended and for

		fixed wing planes maybe 5°..10°. This property is only required if a frequency has been specified.
8	PRIMARY INTERCEPTION ALTITUDE	The interception altitude in meters is the altitude at which the final approach ideally begins. In reality this altitude is 2000' to 3000' above the runway. For FlightZoomer the interception altitude typically would be defined 50m to 70m above the runway.
9	REVERSE RUNWAY ID	The ID of the reverse runway is formed by the first two digits of the opposite direction (e.g. direction = 73° -> opposite direction = 253° -> ID = 25, direction = 157° -> opposite direction = 337° -> ID = 34). Parallel runways are differentiated as described under PRIMARY RUNWAY ID.
10	REVERSE FREQUENCY	The next three properties are also optional and describe the ILS approach to the reverse runway direction. If the navigation receiver on the groundstation is tuned to this frequency, deviations from the ILS glideslope will be indicated on the primary and navigation displays. The frequency of the reverse runway ILS must not only be different than the frequency for the primary direction but also distinct from any other ILS or navigation aid frequency.
11	REVERSE GLIDESLOPE ANGLE	The reverse glideslope angle is the vertical angle between the reverse glideslope and the earth surface. For details see PRIMARY GLIDESLOPE ANGLE.
12	REVERSE INTERCEPTION ALTITUDE	The interception altitude in meter is the altitude, at which the final approach ideally begins. For details see PRIMARY INTERCEPTION ALTITUDE.

## 5.7 Units of measurement

FlightZoomer is strictly based on SI units except in the presentation layer of the groundstation. SI units are meter and kilogram. The following table shows how units of measurement are used:

	App	Usage	Parameters	Supported units (display units on the groundstation)
1	FlightZoomer Sensorics	Various screens	Distances, lengths, altitudes	m
			Speeds	m/s
			Angles	degree
2	FlightZoomer Relay Server	Screens, logfile and navigation data	Distances, lengths, altitudes	m
			Speeds	m/s
			Angles	degree
3	FlightZoomer Groundstation	Various screens	Distances, lengths, altitudes	m (ft)
			Speeds	m/s (km/h nm/h Mph)
			Vertical speeds	m/s (ft/s)
			Angles	degree

Legend:

m = Meter; m/s = Meter per Seconds; ft = Feet; km/h = kilometer per Hours; nm/h = Nautical Miles per Hours (= knots); mph = (statute) Miles per Hours.

## 5.8 How does it work

A detailed functional description would exceed the reasonable scope of this document. Therefore, the following diagram depicts the ingredients (technologies/algorithms/formulas), which have been used or have been under consideration for FlightZoomer:



## 6 Installation

### 6.1 What hardware do you need?

Related to FlightZoomer operations:

Component	Required equipment	Specifications	Mandatory	Recommended
FlightZoomer Sensorics	Windows Phone 8 or higher device	- Mobile plan with 3G data plan	X	
		- Supports Bluetooth		X (highly)
		- Compass sensor		X
FlightZoomer Groundstation	Windows Phone 8 or higher device	- Mobile plan with 3G data plan	X	
		- Support Bluetooth		X
		- 6" display is preferred		X
FlightZoomer Relay Server	PC or Server with Windows 7 or higher, located at home or	- Internet connection	X	
		- High availability/ unattended operation	X	

	alternatively in the cloud		
Stabilizing unit	Flight controller; FlightZoomer has been tested with the APM/Pixhawk derivative AUAV X2.	- Support stabilized flight	X
		- Ardupilot based	X
		- Support fully redundant failsafe (e.g. RETURN-TO-LAUNCH -mode)	X
		- Offer MAVLink connectivity using the APM variety	X (highly)
MAVLink bridge	Bluetooth transceiver HC-06 or compatible (e.g. from 3DR or Ebay)	- The UART side must be compatible with the flight controller	X (highly)
		-	

Not related to FlightZoomer itself you need as a minimum, the following equipment:



Component	Required equipment	Specifications	Mandatory	Recommended
Aircraft	RC airplane or multicopter	- Fully equipped in flyable condition without FlightZoomer	X	
		- Unproblematic handling		X
		- Electric propulsion		X
Radio system	Radio transmitter and receiver	- Possibility to command constant yaw		X
		- Possibility to command constant pitch		X

## 6.2 Prepare the FlightZoomer Relay Server

### 6.2.1 Shall it run in the cloud or at home?

The relay server principally can be operated unattended. For the normal operation scenario (see chapter 5.2) the relay server needs to be started and that's it.

There are two possibilities to run the FlightZoomer Relay Server application.

1. On a cloud-based virtual machine		
2. On your own PC (at home).		

We recommend using the cloud option because of these advantages:



- You do get a DNS service out of the box. If the relay server runs at home, an extra DNS service needs to be provided.
- The UDP port forwarding requirement can be implemented in a common and easy way.
- Access on the virtual machine is easily possible from the phone. This means that the relay server can be accessed from any place (e.g. from the outdoor location where you are flying). This is normally not needed, but in some cases it could turn out to be advantageous (e.g. if you forgot to launch the application at home).

Disadvantages of a cloud based relay server would be:



- There is a fee for a cloud based virtual machine (VM). There are price models however, which charge per operating hour, which means that per flight the price would only be some cents.
- Cloud dependency.

The following lists shows the steps needed to prepare the relay server:

One-time installation steps:

Step		
Select a virtual machine provider	X	
Create a virtual machine instance	X	
Provide DNS capabilities		X
Configure port forwarding		X
Install the FlightZoomer Relay Server application	X	X
Open the firewall for the required ports	X	X

Recurrent preparation steps:

Step		
Start the virtual machine	X	
Access the virtual machine (from a PC and from a smartphone)	X	
Shutdown the virtual machine after usage	X	

More details about any of these steps in the following chapters.

## 6.2.2 Select a virtual machine provider

This step is needed for:



While there are tons of VPS providers in the Internet, it is recommended to run the FlightZoomer Relay Server application on Microsoft Azure. Other providers often focus on virtual Linux boxes while FlightZoomer requires a virtual Windows machine. It is paid per usage hours so the fees for FlightZoomer purposes are really very moderate. The following guidelines describe the usage of an Azure virtual machine.

### 6.2.3 Create a virtual machine instance on Microsoft Azure

This step is needed for:



First a Microsoft Azure account needs to be opened. Login into Azure from this page. If you don't have a Microsoft account yet, click on *[signup up now](#)* first (but you should already have one if you have set up your Windows Phone devices properly):

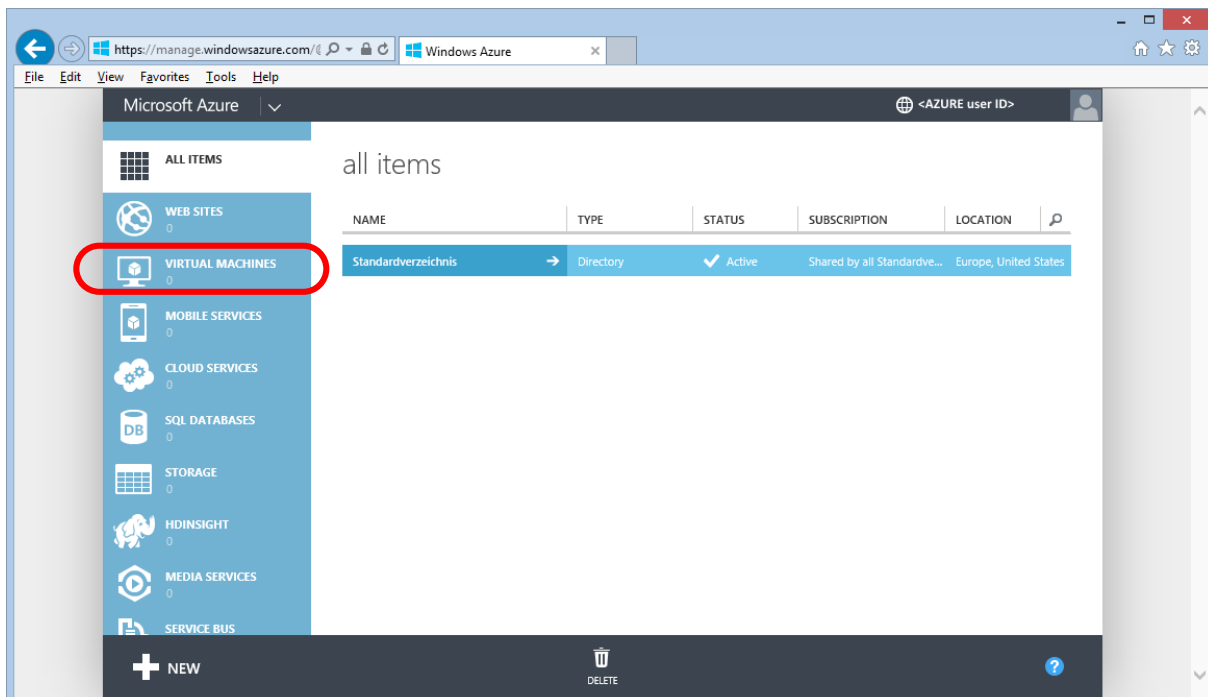
[Azure login](#)

After that the following steps are needed:

#### Step 1: Go to the Management Portal

Here you can see all items that you have created so far...

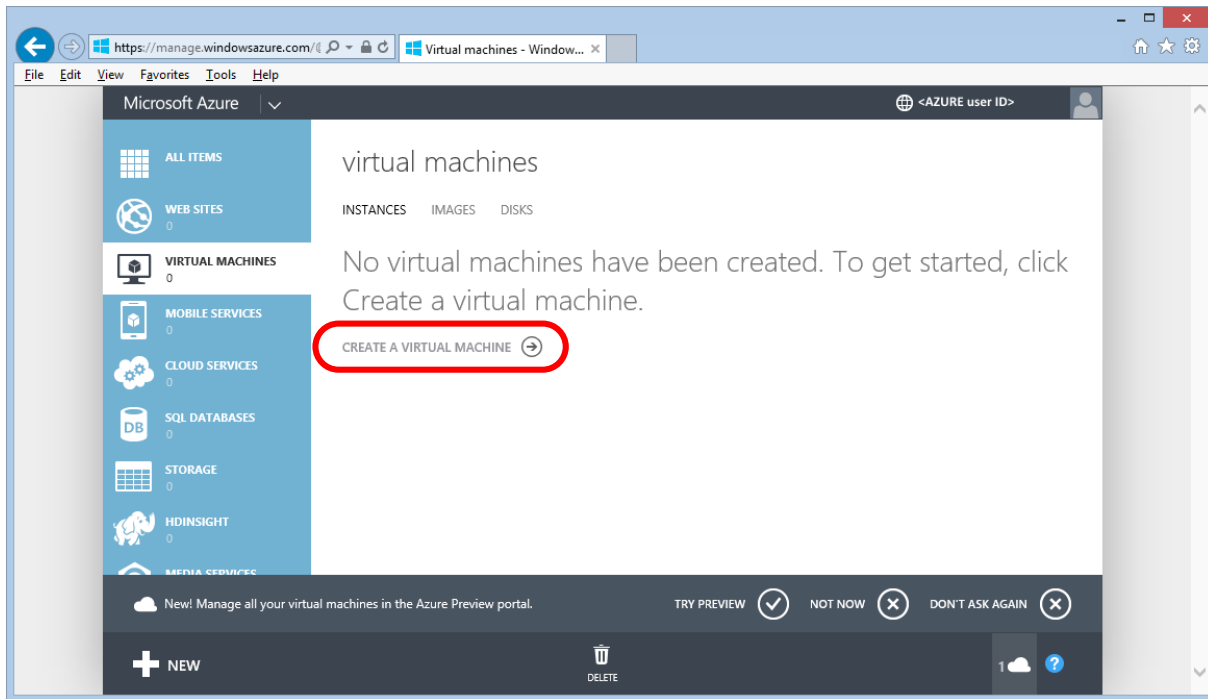
Now click on VIRTUAL MACHINES on the left hand menu bar





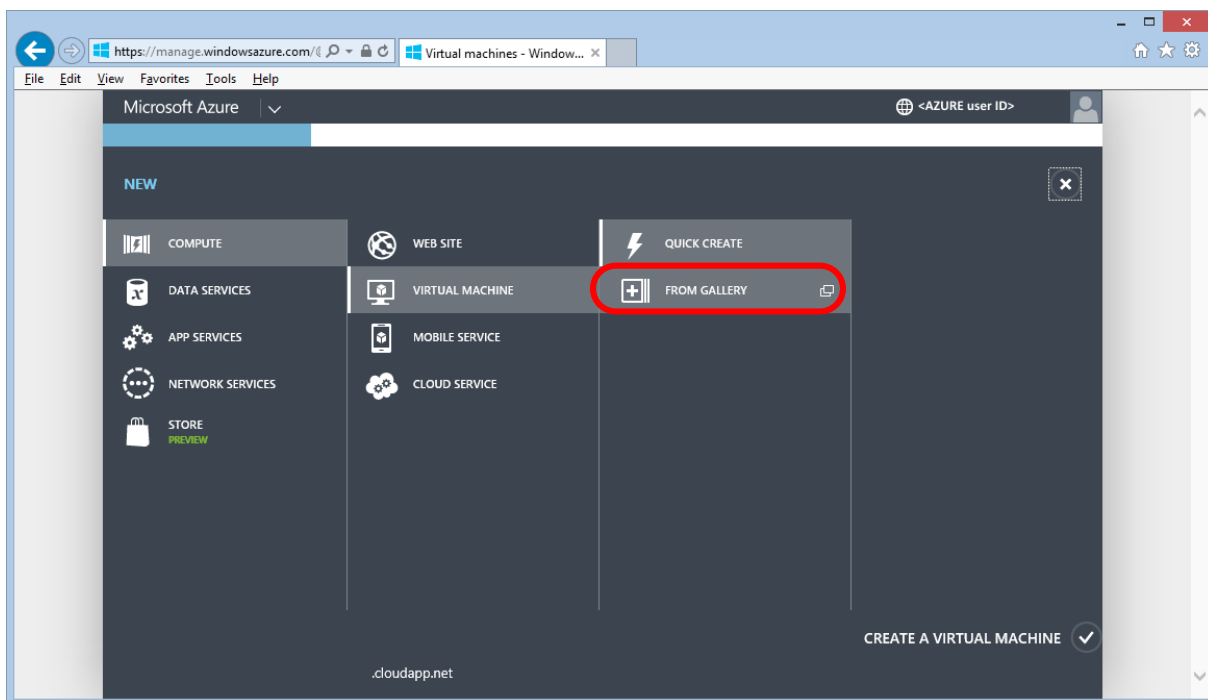
## Step 2: Virtual machines screen

Here you can create a new virtual machine. Click on the red-marked link to do that:



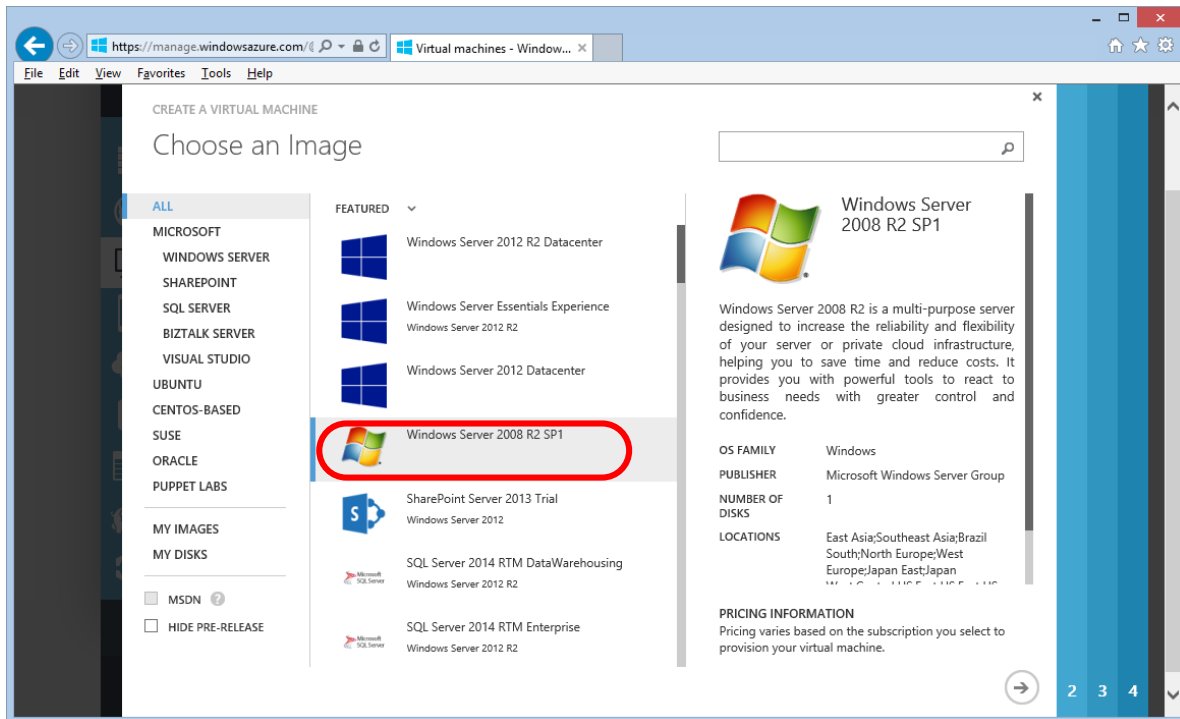
## Step 3: Create new virtual machine screen

Here select *COMPUTE* > *VIRTUAL MACHINE* > *FROM GALLERY*



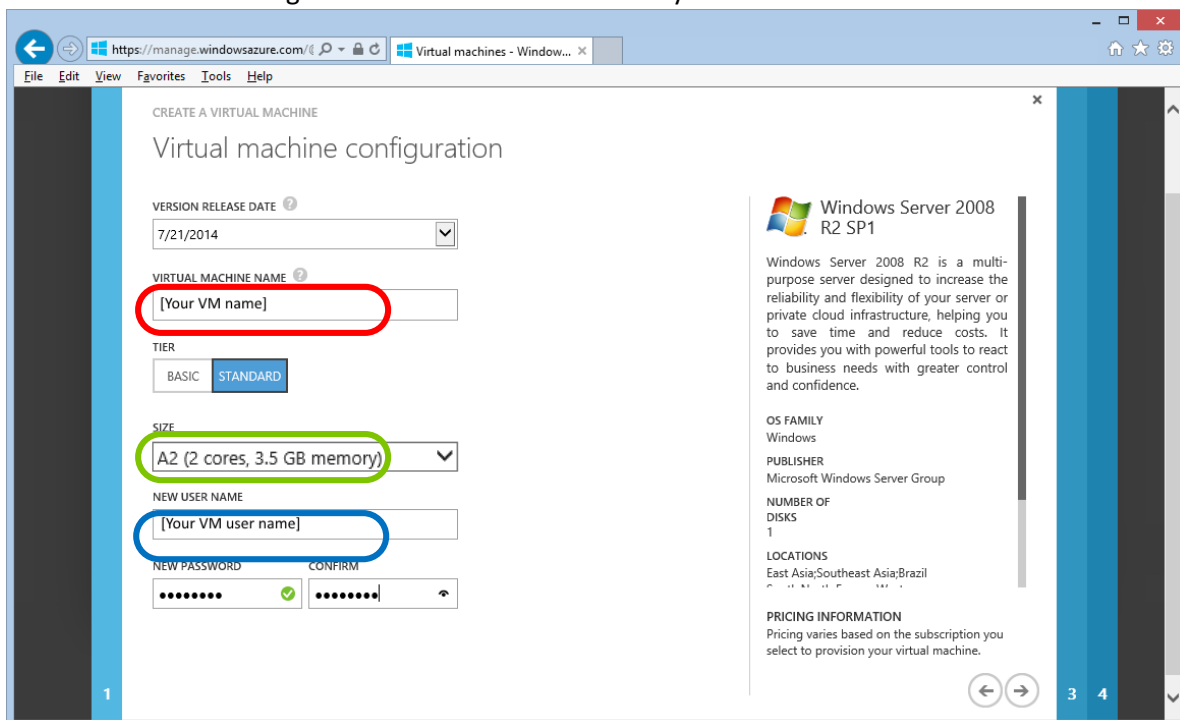
## Step 4: Image selection screen

From the various options choose Windows Server 2008 R2 SP1. It is good enough by far for our purposes:



## Step 5: Configuration screen I

Provide a name for the virtual machine (red box), the machine size (green box) and a user name, for later login purposes (blue box). Note the specified names for later usage. Also provide a password for the user, which will be used to login from now on. This user is only created on the new virtual machine:



A remark regarding the machine size: it is recommended to choose A2 or higher

## Step 6: Configuration screen II

On this page the public name of the virtual machine (red box) and the UDP port forwarding are specified. Here the DNS name must be kept ready for later usage. Also select the region which is located the closest to places you usually fly (yellow box). Also add an endpoint as shown in the blue/green boxes:

CREATE A VIRTUAL MACHINE

### Virtual machine configuration

CLOUD SERVICE ?  
Create a new cloud service

CLOUD SERVICE DNS NAME  
[Your VM DNS name] .cloudapp.net

REGION (AFFECTS CLOUD INFRASTRUCTURE NETWORK) ?  
West Europe

STORAGE ACCOUNT  
Use an automatically generated storage account

AVAILABILITY SET ?  
(None)

ENDPOINTS ?

NAME	PROTOCOL	PUBLIC PORT	PRIVATE PORT
Remote Desktop	TCP	AUTO	3389
PowerShell	TCP	5986	5986
FlightZoomer	UDP	57778	57778

ENTER OR SELECT A VALUE

Windows Server 2008 R2 SP1

Windows Server 2008 R2 is a multi-purpose server designed to increase the reliability and flexibility of your server or private cloud infrastructure, helping you to save time and reduce costs. It provides you with powerful tools to react to business needs with greater control and confidence.

OS FAMILY  
Windows

PUBLISHER  
Microsoft Windows Server Group

NUMBER OF DISKS  
1

LOCATIONS  
East Asia; Southeast Asia; Brazil

PRICING INFORMATION  
Pricing varies based on the subscription you select to provision your virtual machine.

The information on this page is all that you need for connecting both the Sensorics- and the Groundstation-app to the relay server. In both apps you would enter the Network Address on the add relay server screen according to this pattern:

[Your VM DNS name].cloudapp.net : [Public Port]

FLIGHTZOOMER SENSORICS

## add relay server

Name  
[Define name of relay server]

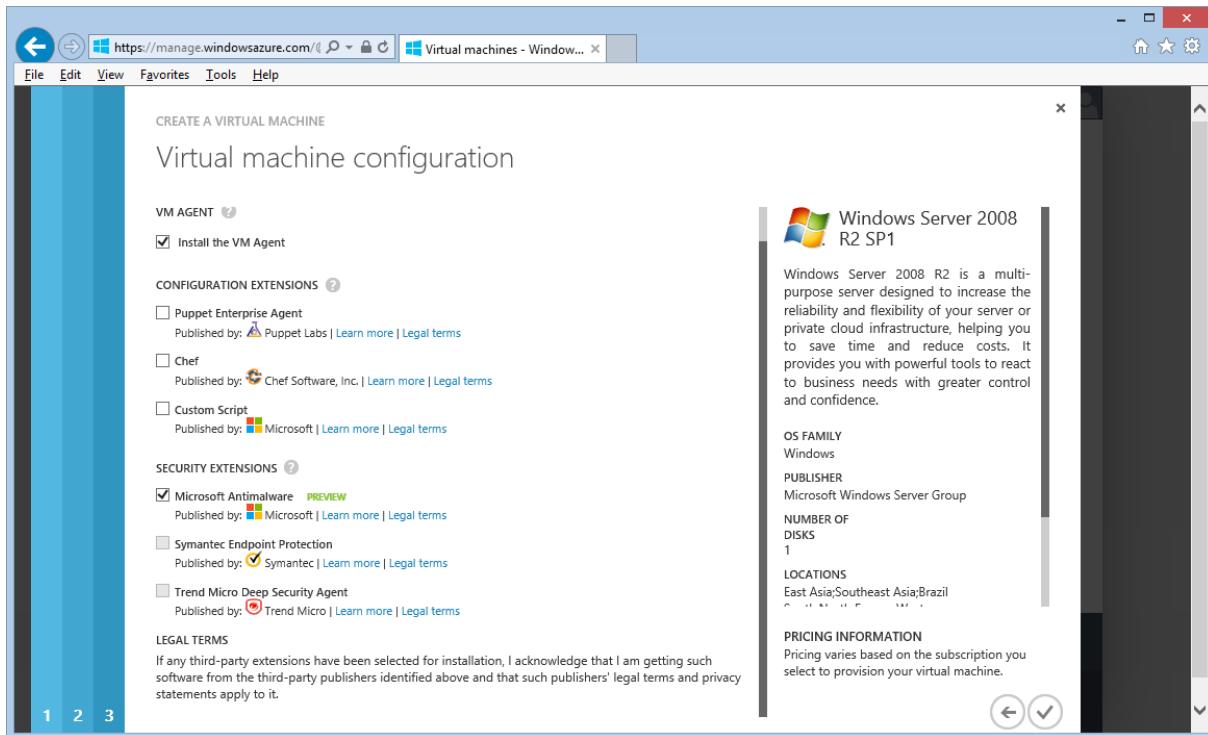
Network Address  
[Enter URL or IP Address]

Save Cancel

**User hints:**  
The name of the Relay Server can be chosen freely by the user. It will be made available in the dropdown box on the main page.  
The address can be IPv4 or IPv6 or a URL.  
Ports need to be separated by a ':' from the address part.

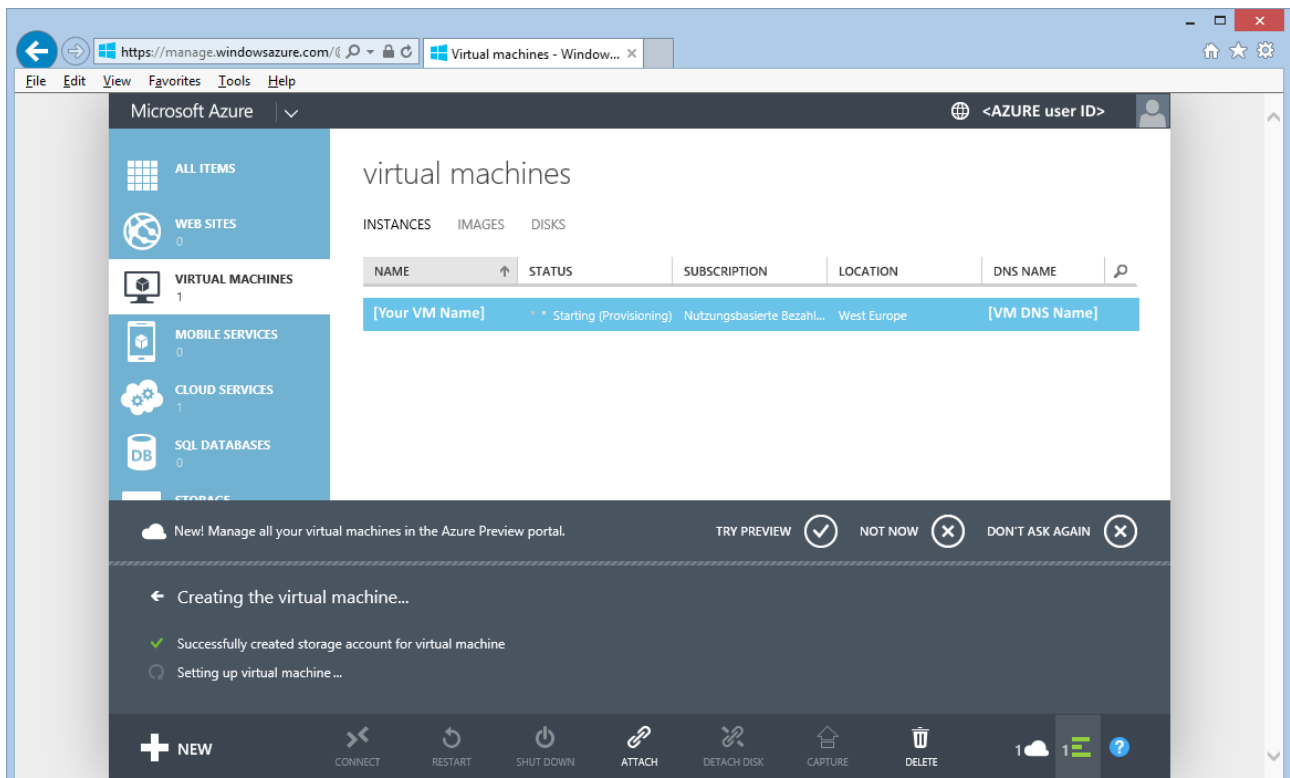
## Step 7: Configuration screen III

Here just pick the suggested options and finalize the order with the button on the right hand bottom:



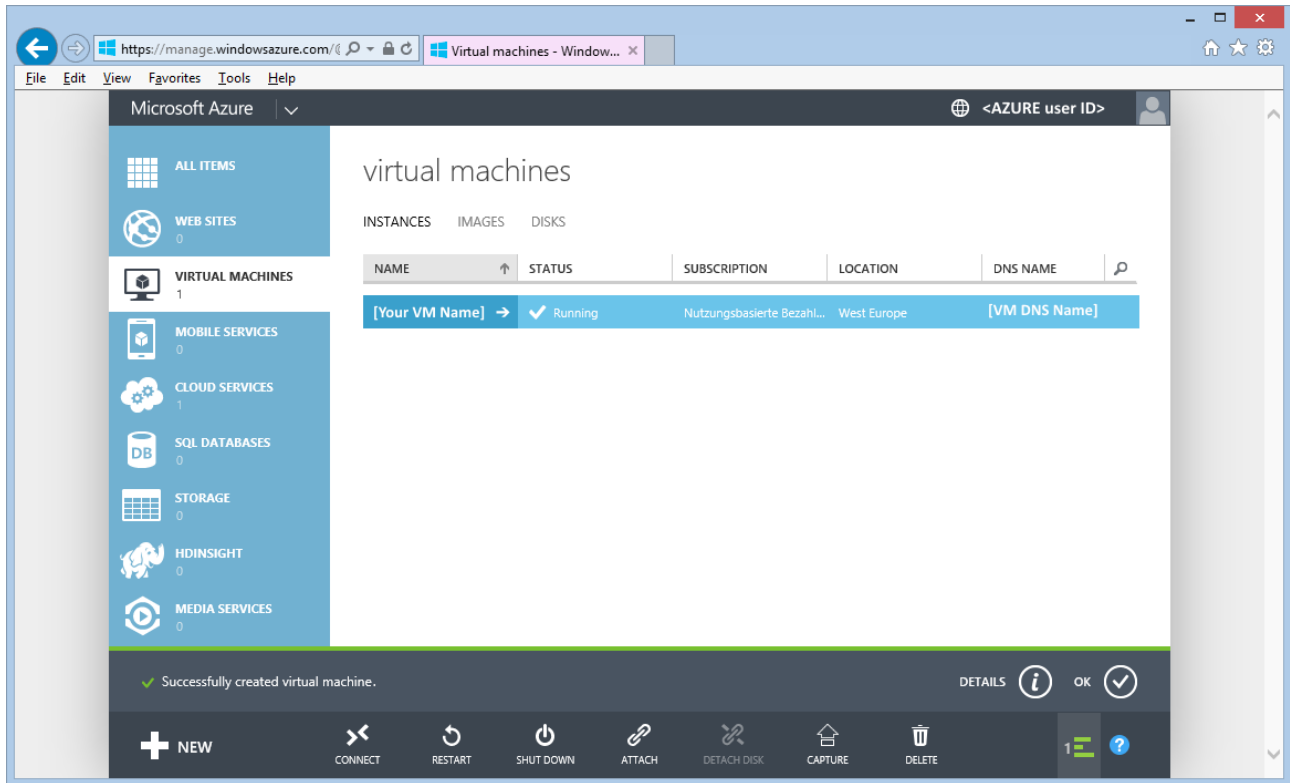
## Step 8: Virtual machine screen, creation status

On bottom of this screen you can see the virtual machine creation progress. After creation, the VM will be running:



Here the virtual machine has been created successfully and is running. At this point there are two options:

- Connect to the instance using a Remote Desktop Client (RDP Client) -> go to chapter 6.2.9
- If you are not using the VM at the moment, switch it off avoiding charges -> go to chapter 6.2.10



After creating the virtual machine for the first time, it is already running. In case you do not continue, don't forget to shut down the virtual machine as described in chapter 6.2.10.

## 6.2.4 Provide DNS capabilities

This step is only needed for:



While using the Azure based virtual machine, the DNS service is already available out of the box.

If you are using a PC at home, you will need to configure a DNS service accordingly.

The DNS serves the purpose, that the relay server can be reached from any point in the Internet via a public name (like google.com is a name that can be reached from anywhere in the internet). Actually the public name will resolve to the public IP address of your internet router or modem. Reaching the relay server from the router is explained in the next chapter.

The public name of your relay server needs to be entered as relay-server network address in both the Sensorics- as well as the Groundstation-app.

DNS services require a DNS provider and some configuration in your router that the actual public IP address of your home endpoint gets reported to the provider.

There is a large variety of DNS providers. Some of them have been free, but no longer are ([dyndns](#)), some are pseudo-free ([noip](#)) and some are really free ([FreeDNS](#)).

Setting up DNS services requires these steps:

1. Pick a suitable DNS provider
2. Get an account
3. Set up everything as explained by the DNS provider in your modem/router.

## 6.2.5 Configure port forwarding

This step is only needed for:



While using the Azure based virtual machine, the port forwarding is already available out of the box.

If you are using a PC at home, you need to configure your internet router accordingly.

What basically is needed, is that UDP messages reaching your public home IP address are forwarded to the PC, where the relay server application runs.

The method, how to do that differs from router to router. Therefore, the required settings are only shown here exemplarily for the Fritzbox 7390 Router:

### Step 1: Overview page for the port forwarding feature:



The screenshot shows the Fritz!Box 7390 web interface. The browser address bar shows <http://192.168.188.1/>. The page title is "FRITZ!Box 7390". The user is logged in, with links for "FRITZ!Box Login", "FRITZ!NAS", and "MyFRITZ!".

The left sidebar contains a menu with the following items: Overview, Internet, Online Monitor, Account Information, Filters, Permit Access (selected), MyFRITZ!, Telephony, Home Network, WLAN, DECT, and System.

The main content area is titled "Permit Access" and has several tabs: Port Forwarding (selected), Storage, FRITZ!Box Services, Dynamic DNS, and VPN.

Below the tabs, there is a text block: "Computers connected to FRITZ!Box are safe from unauthorized access from the Internet. However, for certain applications such as online games or the eMule file sharing program, it must be possible for other users in the Internet to access your computer. Such connections are made possible by enabling port forwarding."

Below this text is a table titled "List of Ports with Port Forwarding Enabled":

Enabled	Name	Protocol	Port	to Computer	to Port	
<input checked="" type="checkbox"/>	FZRDVServer1	UDP	57778	LP0006-LAN	57778	 

Below the table is a button labeled "New Port Forwarding".

Below the table is a checkbox labeled "Allow changes to security settings over UPnP".

Below the checkbox is a text block: "Devices and applications that support UPnP can be used to change security settings in the home network automatically, such as the FRITZ!Box port forwarding rules. For reasons of security, only enable this option if you really want to allow incoming connections from the Internet."

At the bottom of the page are four buttons: Apply, Cancel, Refresh, and Help.

## Step 2: Detail page for the relay server port forwarding:

The screenshot shows the FRITZ!Box 7390 web interface. The browser address bar shows <http://192.168.188.1/>. The page title is "FRITZ!Box 7390". The user is logged in as "FRITZ!Box Login". The left sidebar contains a menu with "Overview", "Internet", "Filters", "Permit Access", "MyFRITZ!", "Telephony", "Home Network", "WLAN", "DECT", and "System". The "Permit Access" option is selected. The main content area is titled "Port Forwarding" and contains a form for editing port forwarding. The form has a checkbox "Port forwarding enabled for" which is checked, and a dropdown menu "Other applications". The form fields are: Name: "FZRDVServer1", Protocol: "UDP", From port: "57778" through port: "57778", to computer: "LP0006-LAN", to IP address: "192.168.188.10", and to Port: "57778". The form has "OK", "Cancel", and "Help" buttons. At the bottom right, there are links: "View: Advanced", "Contents", "Manual", "Newsletter", and "avm.de".

However, this screen looks on your router, you need to configure UDP port forwarding from the listening port 57778 to the IP address and port 57778 of the PC, where the relay server runs upon.

At this point there is a public URL pointing to your house (see the chapter before) and a port forwarding to connect the public network endpoint with the relay server. The related parameter can be used to connect both the Sensorics- and the Groundstation-app to the relay server. In both apps you would fill in the *Network Address* according to this pattern (on the *add relay server*-screen):

[Your public DNS name] : 57778

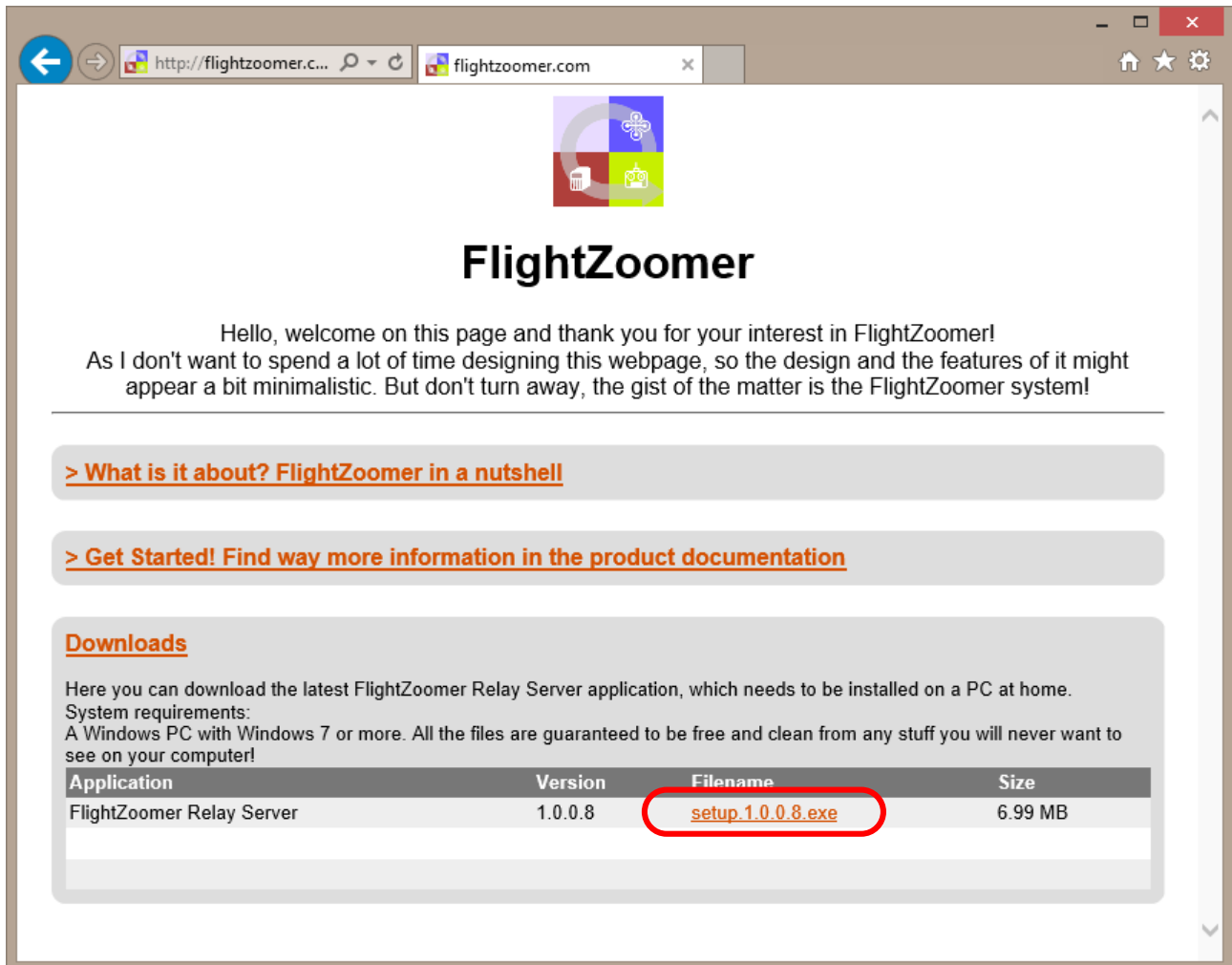
The screenshot shows the "add relay server" screen in the FLIGHTZOOMER SENSORICS app. The screen has a black background with white text. The title is "add relay server". There are two input fields: "Name" with a placeholder "[Define name of relay server]" and "Network Address" with a placeholder "[Enter URL or IP Address]". The "Network Address" field is highlighted with a purple oval. Below the input fields are "Save" and "Cancel" buttons. At the bottom, there is a red box with white text containing "User hints:" and instructions: "The name of the Relay Server can be chosen freely by the user. It will be made available in the dropdown box on the main page. The address can be IPv4 or IPv6 or a URL. Ports need to be separated by a ':' from the address part."

## 6.2.6 Install the FlightZoomer relay server application

This step is needed for:



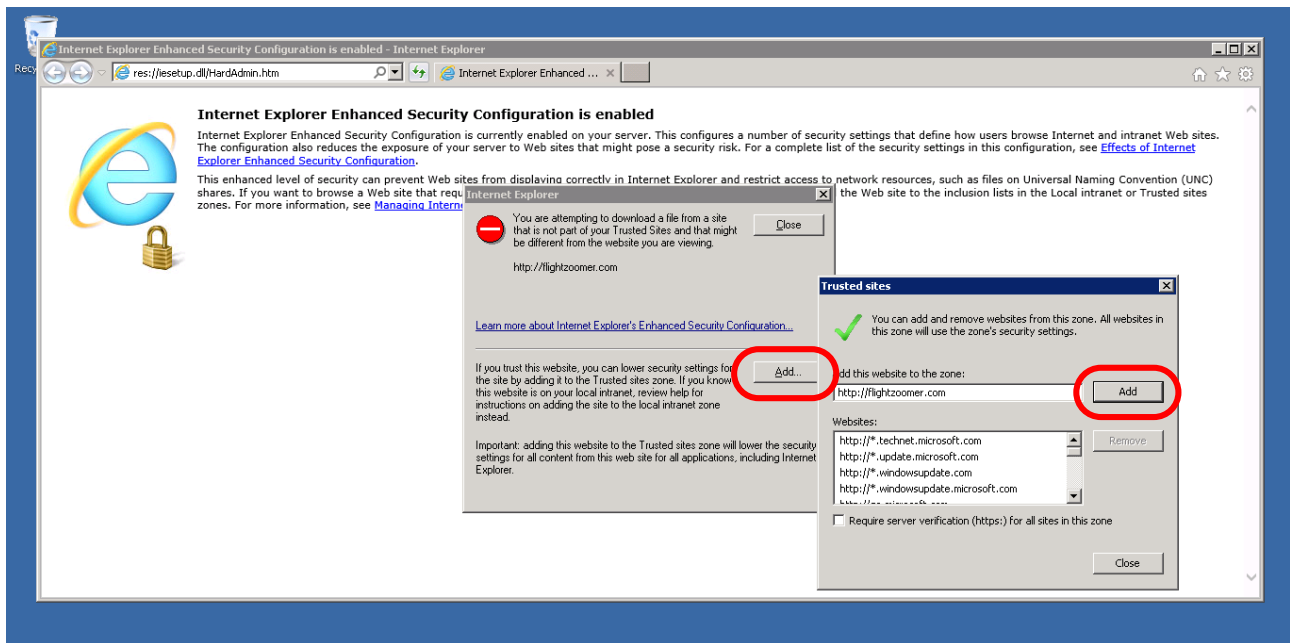
**Step 1:** Go to <http://flightzoomer.com/downloads.html> and download the latest version of the FlightZoomer Relay Server application:



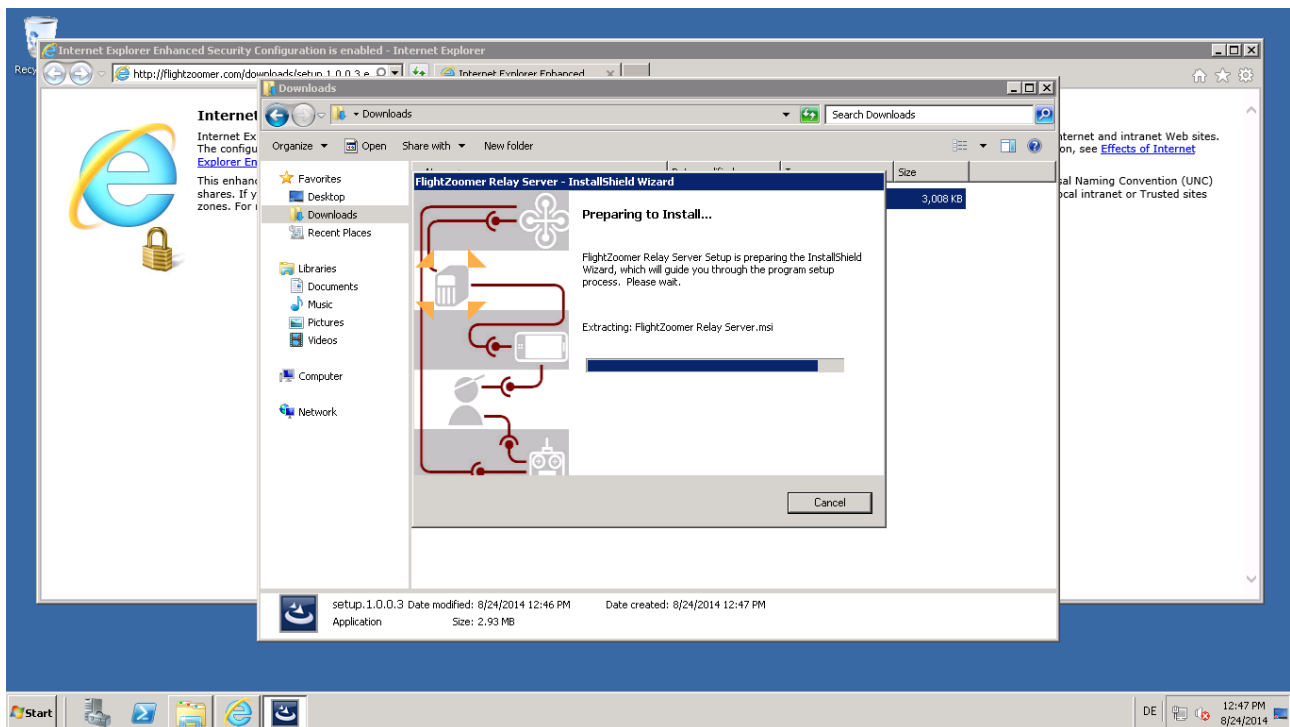
**Step 2:** Add flightzoomer.com to the list of trusted websites (only on  )

When the download link from flightzoomer.com is clicked, a warning pops up. Add flightzoomer.com to the trusted websites as shown. The reason for this is that the operating system on the virtual machine is not plain vanilla Windows but the Server version which has higher security standards.





### Step 3: Download the setup file and run it:



## 6.2.7 Open the firewall for the required ports

This step is needed for:



In this chapter there are two sections. The first describes opening the firewall on your PC at home and the second shows how it is done on the virtual machine.

### 6.2.7.1 Opening the firewall on your PC at home

This task is very easy: when the FlightZoomer Relay Server application is started for the first time, the following pop up window will appear. Allow communication with the suggested networks and click on “Allow access”:



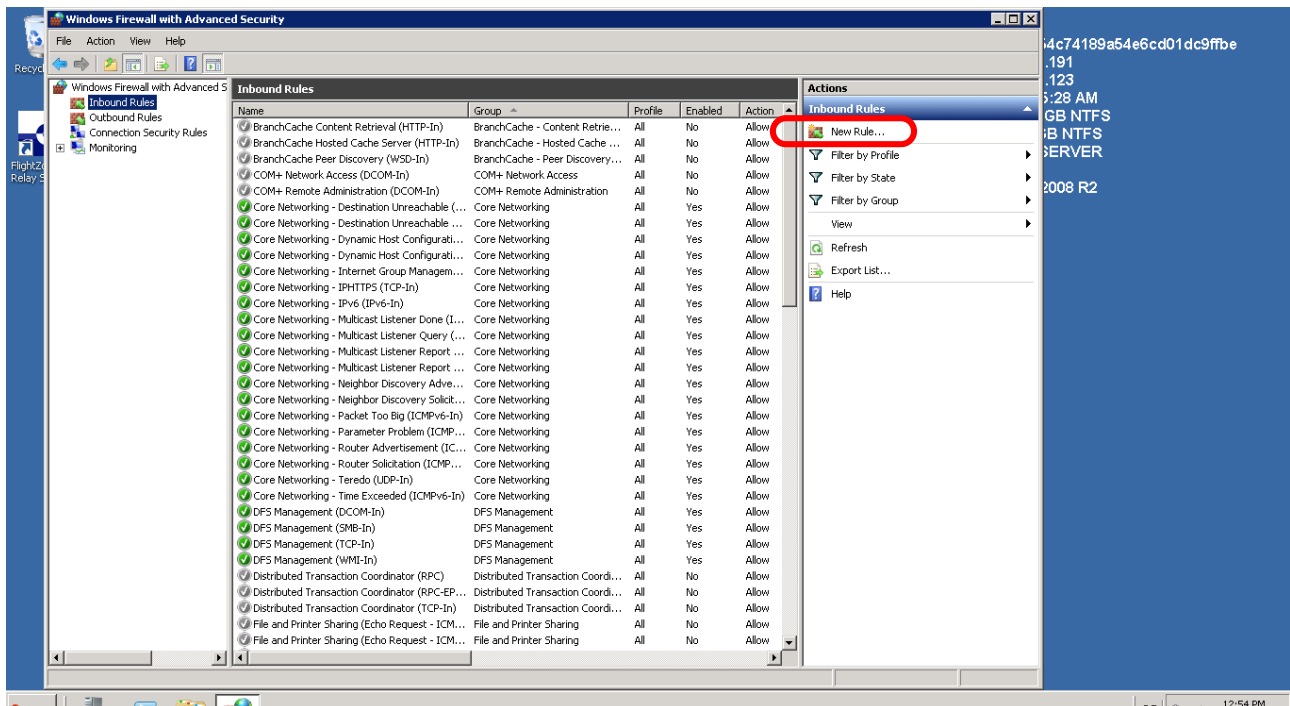
### 6.2.7.2 Opening the firewall on the virtual machine

As the virtual machine operates a Windows Server operating system, the default security settings are higher. Therefore, the following steps are needed:

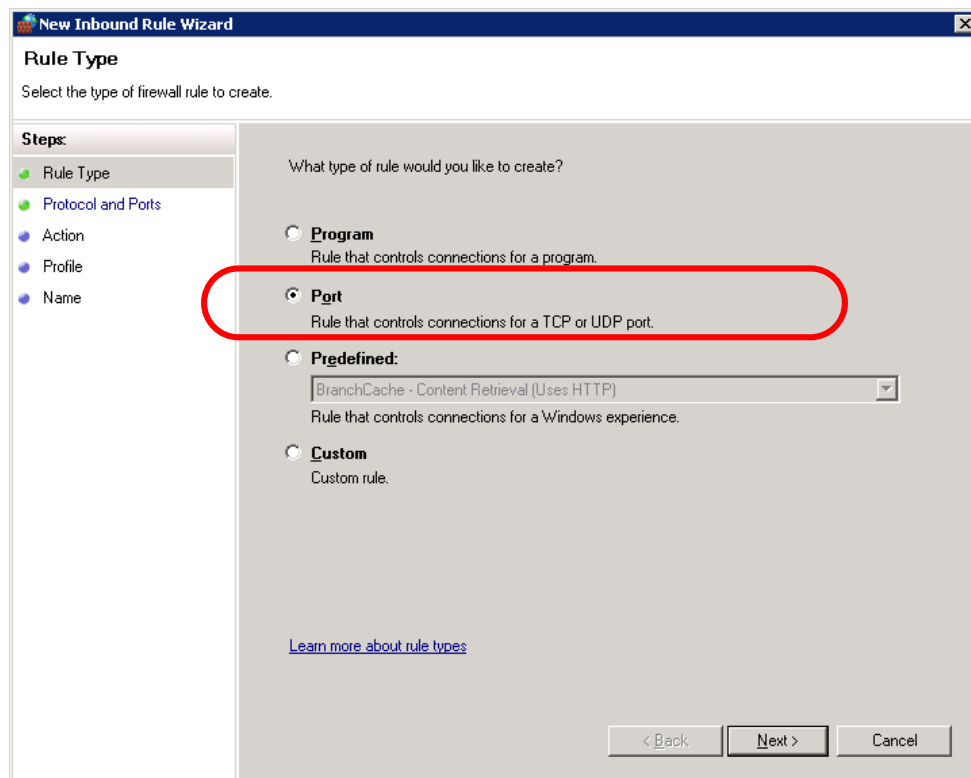
**Step 1: Click on the *Windows Start*-button and write “*firewall*”**

**Step 2: Open *Windows Firewall with Advanced Security***

### Step 3: Create a new rule



### Step 4: Select Port as firewall rule type



## Step 5: Enter the options for the firewall

The screenshot shows the 'New Inbound Rule Wizard' window, specifically the 'Protocol and Ports' step. The left sidebar lists the steps: Rule Type, Protocol and Ports (selected), Action, Profile, and Name. The main area contains the following options:

- Does this rule apply to TCP or UDP?
  - ☐ TCP
  - ☒ UDP
- Does this rule apply to all local ports or specific local ports?
  - ☐ All local ports
  - ☒ Specific local ports:

Below the 'Specific local ports' input, there is a small text example: 'Example: 80, 443, 5000-5010'. At the bottom right, there are three buttons: '< Back', 'Next >', and 'Cancel'. A link 'Learn more about protocol and ports' is also present.

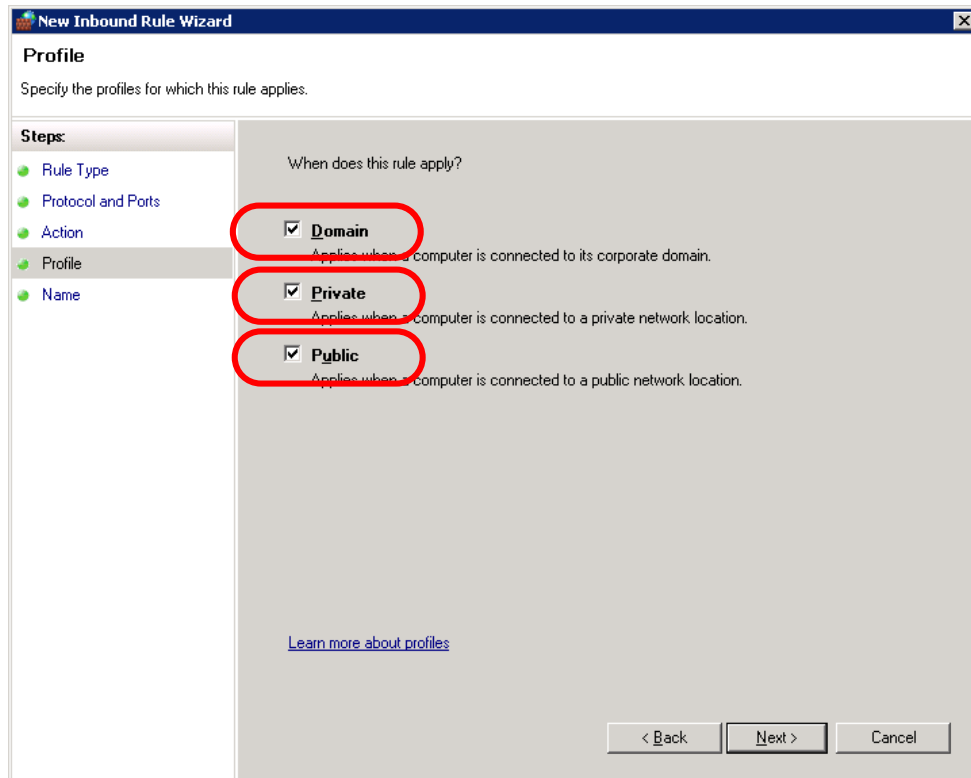
## Step 6: Allow the connection

The screenshot shows the 'New Inbound Rule Wizard' window, specifically the 'Action' step. The left sidebar lists the steps: Rule Type, Protocol and Ports, Action (selected), Profile, and Name. The main area contains the following options:

- What action should be taken when a connection matches the specified conditions?
  - ☒ Allow the connection
    - This includes connections that are protected with IPsec as well as those are not.
  - ☐ Allow the connection if it is secure
    - This includes only connections that have been authenticated by using IPsec. Connections will be secured using the settings in IPsec properties and rules in the Connection Security Rule node.
    -
  - ☐ Block the connection

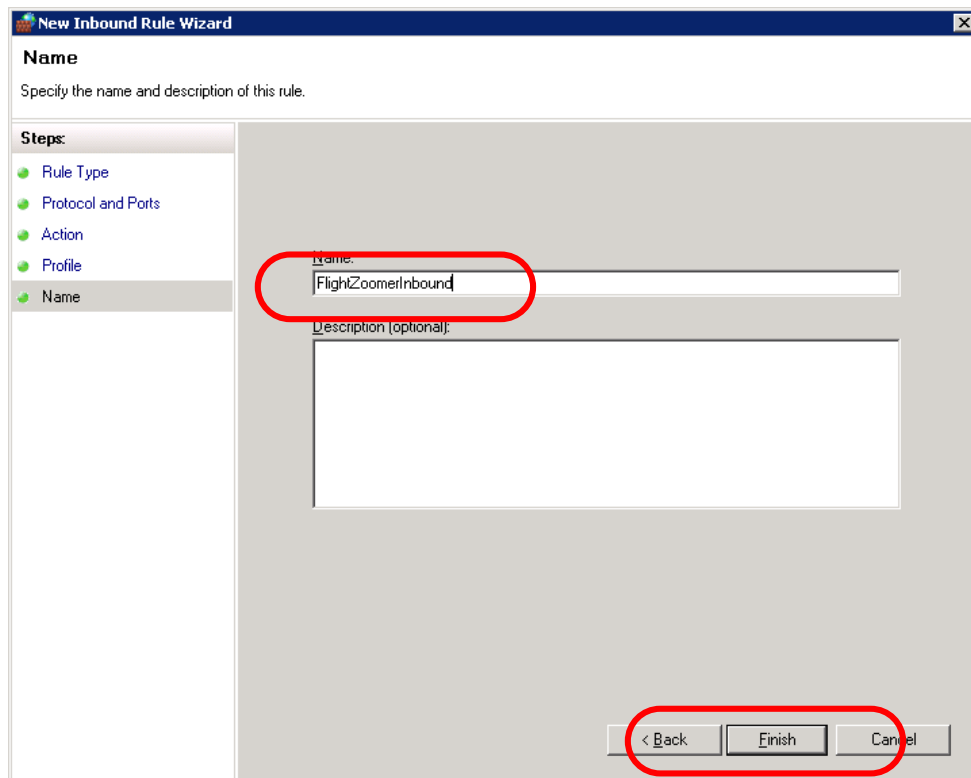
At the bottom right, there are three buttons: '< Back', 'Next >', and 'Cancel'. A link 'Learn more about actions' is also present.

## Step 7: Let this rule apply always



The screenshot shows the 'New Inbound Rule Wizard' window at the 'Profile' step. The left sidebar lists the steps: Rule Type, Protocol and Ports, Action, Profile (selected), and Name. The main area is titled 'When does this rule apply?' and contains three checked options, each circled in red: 'Domain' (Applies when a computer is connected to its corporate domain.), 'Private' (Applies when a computer is connected to a private network location.), and 'Public' (Applies when a computer is connected to a public network location.). At the bottom right are buttons for '< Back', 'Next >', and 'Cancel'.

## Step 8: Define the name of the rule (only for displaying purpose). Click on Finish afterwards.



The screenshot shows the 'New Inbound Rule Wizard' window at the 'Name' step. The left sidebar lists the steps: Rule Type, Protocol and Ports, Action, Profile, and Name (selected). The main area is titled 'Specify the name and description of this rule.' and contains a 'Name:' label with a text box containing 'FlighZoomerInbound', which is circled in red. Below it is a 'Description (optional):' label with a large empty text area. At the bottom right are buttons for '< Back', 'Finish' (circled in red), and 'Cancel'.

## 6.2.8 Start the virtual machine

This step is needed for:



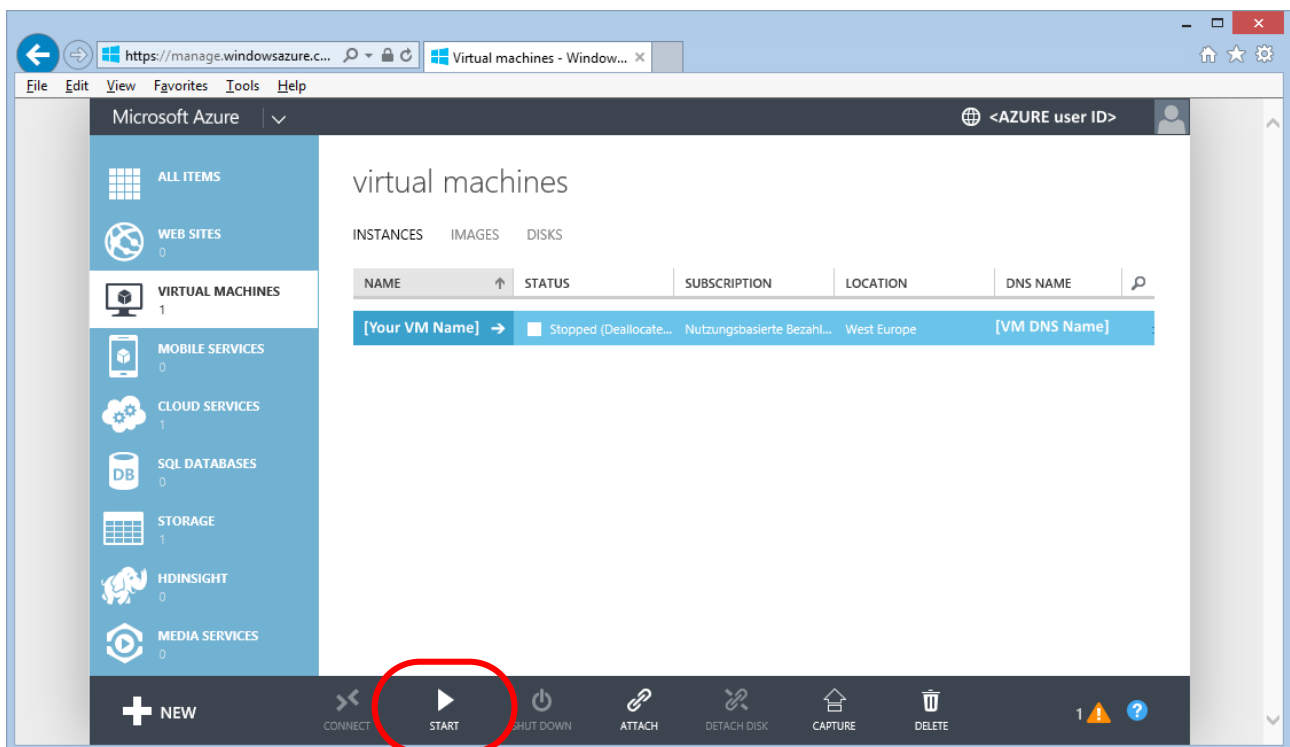
After creating the virtual machine for the first time, it is already running. If that is the case, skip this chapter and continue with the next chapter. Otherwise follow these steps, to start the virtual machine:

Step 1: Log first into your Azure Management site under <https://manage.windowsazure.com>

Step 2: Then enter the Portal at the top right.

Step 3: Click on *VIRTUAL MACHINES* in the menu on the left.

Step 4: The virtual machine can be started as shown on the following screen. Wait until *STATUS* shows *RUNNING* (this can take several minutes):



## 6.2.9 Connect to the running virtual machine

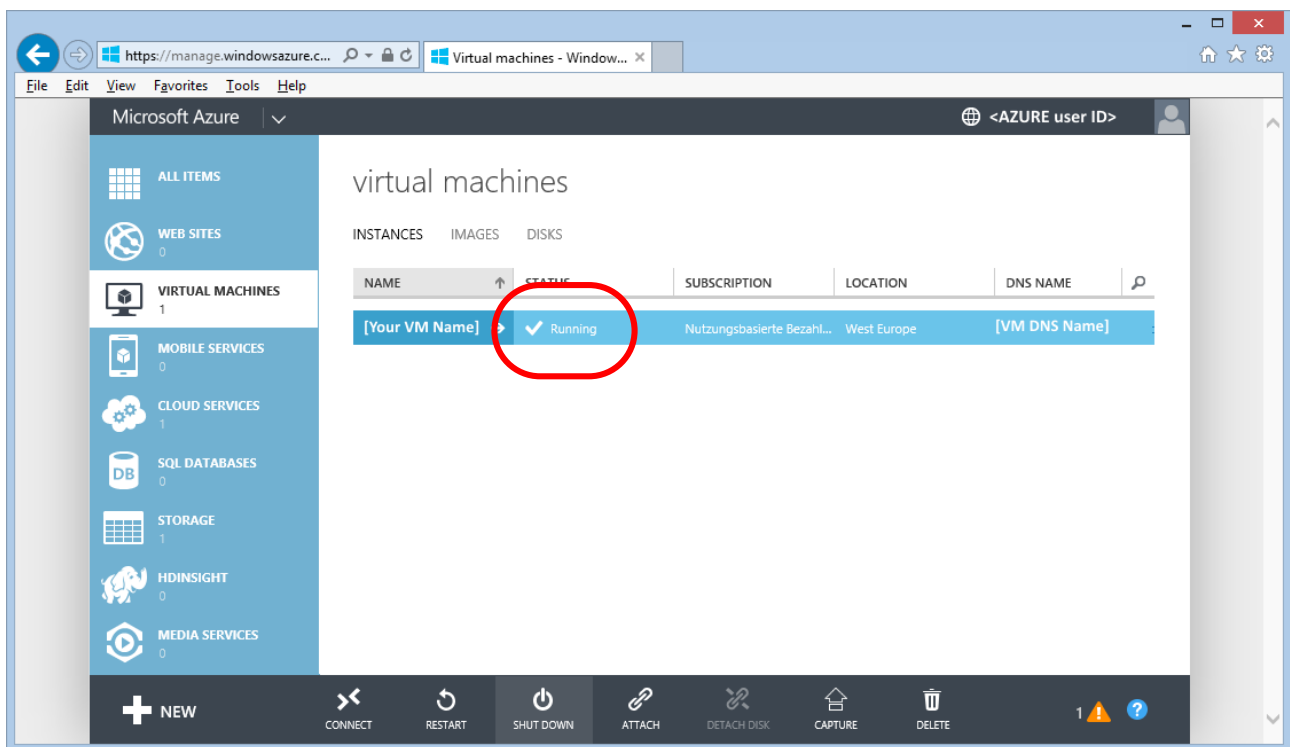
This step is needed for:



Like a real PC is accessed by taking a chair and sitting in front of it, a virtual machine needs to be accessed. For that purpose, there is a program which is available on any Windows PC. This program is called Remote Desktop and allows to see the desktop of the virtual machine, as if you would sit in front of it.

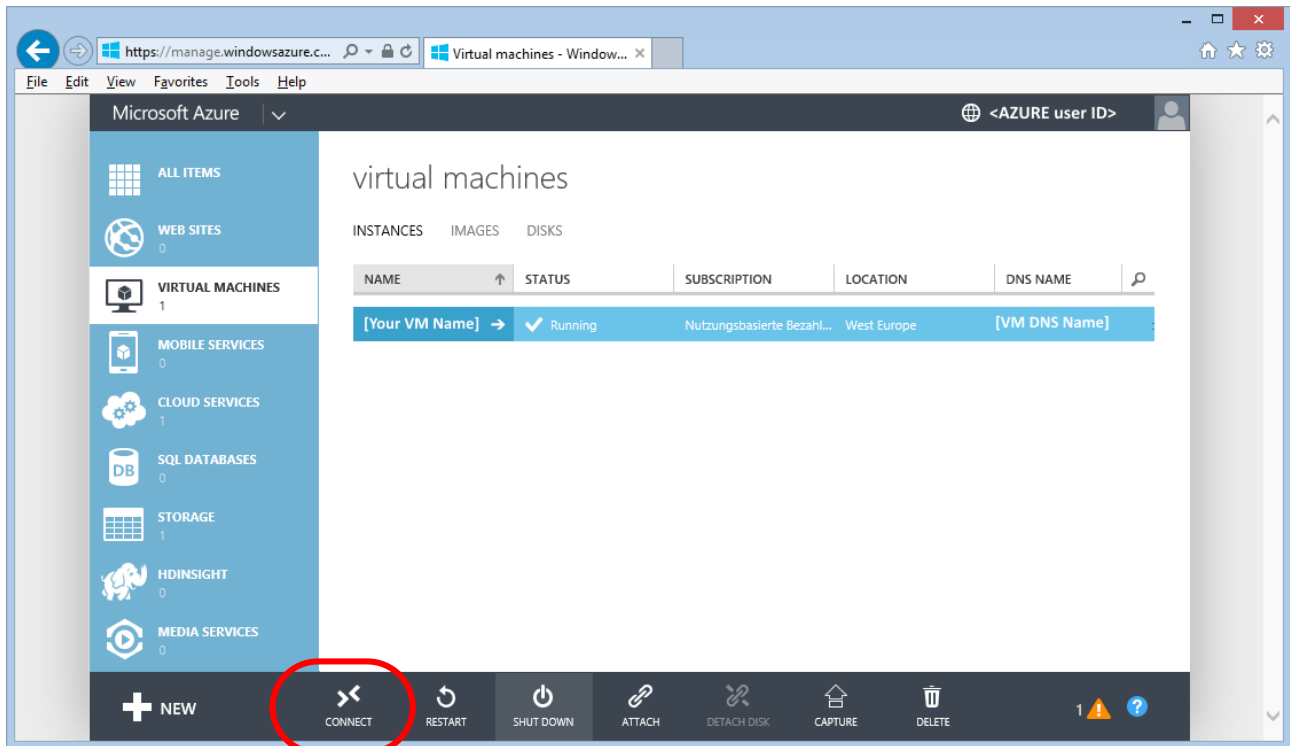
In this chapter there are two sections. The first describes accessing the virtual machine from a desktop PC and the second shows how it is done via the phone.

Precondition is that your virtual machine shows the status RUNNING in the Azure Management site console (<https://manage.windowsazure.com>):

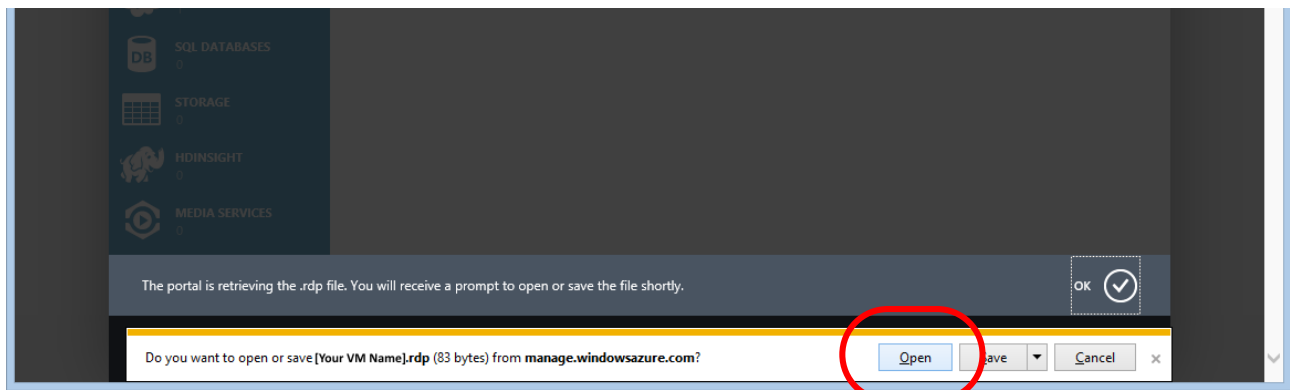


## 6.2.9.1 Accessing the remote machine from your PC

### Step 1: Connect to the running virtual machine by clicking on the **CONNECT**-button

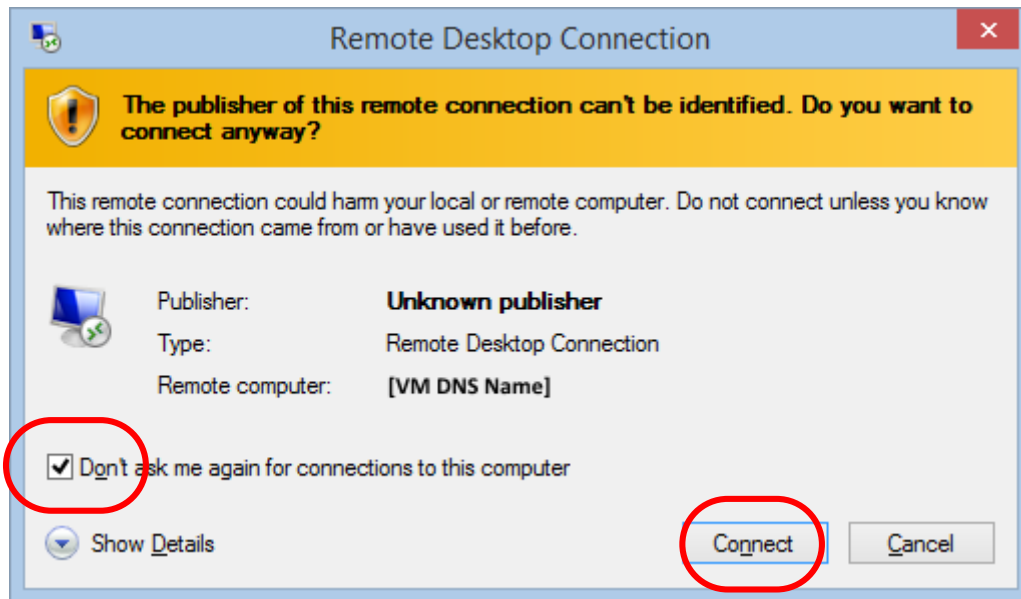


### Step 2: Click on Open to launch the downloaded \*.rdp file



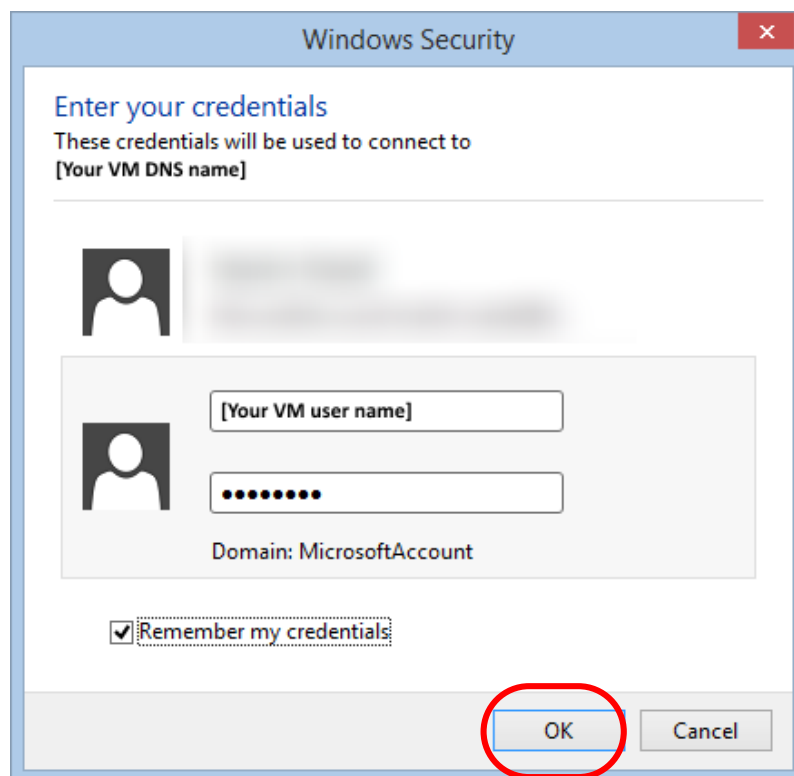


**Step 3: Select the checkbox “Don’t ask me again for connections to this computer” and press Connect**

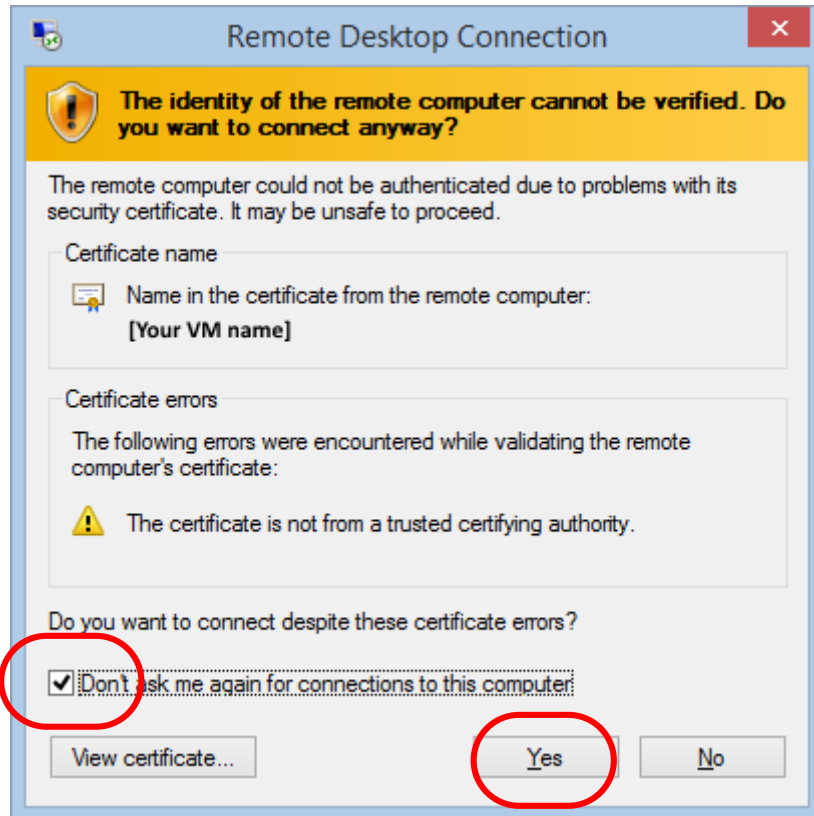


**Step 4: Enter the user credentials of the virtual machine as defined, when the VM was created**

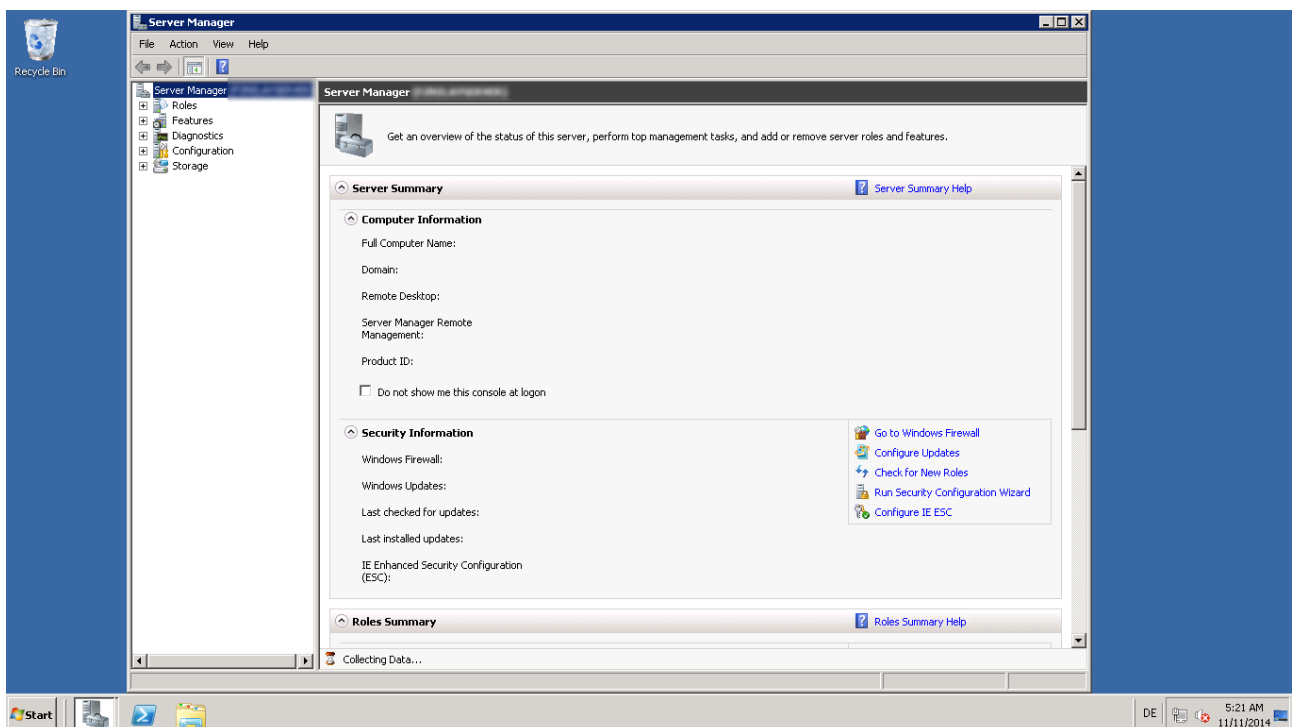
Here the user credentials need to be used that you have entered during Step 5 in chapter 6.2.3.



### Step 5: Confirm that you trust the remote computer

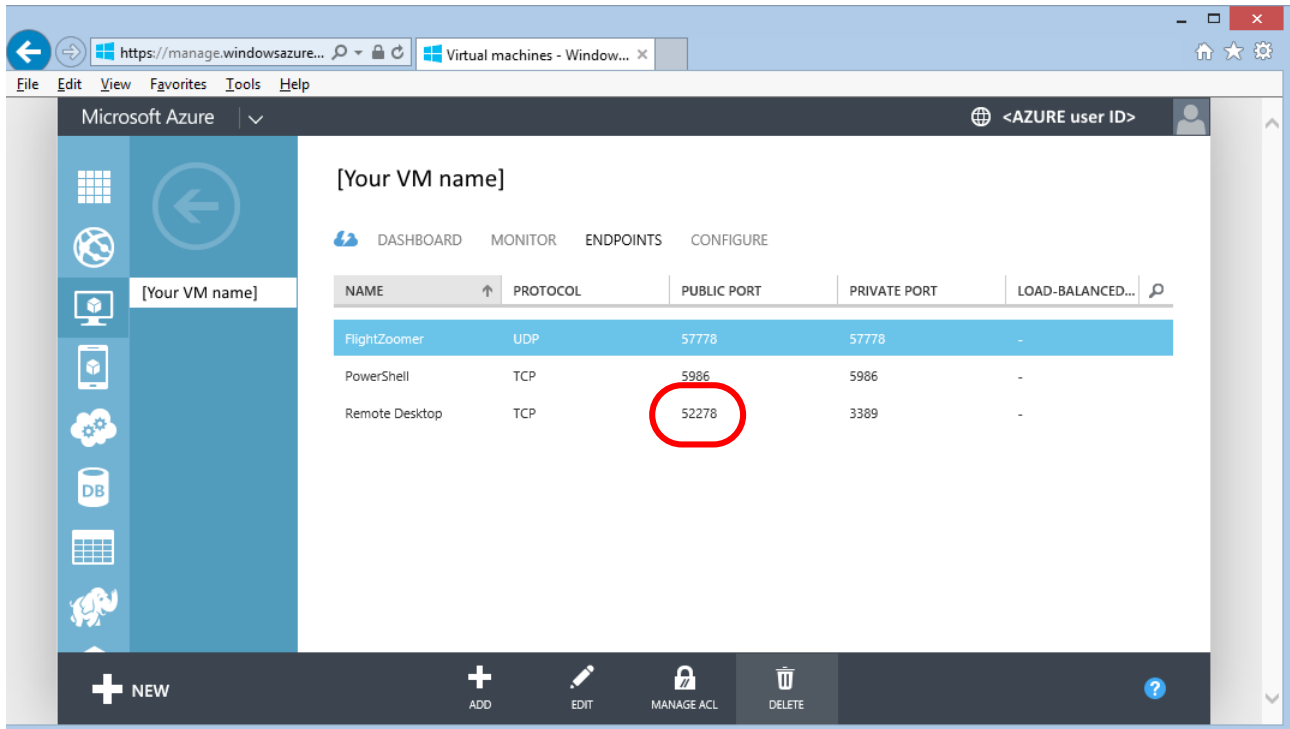
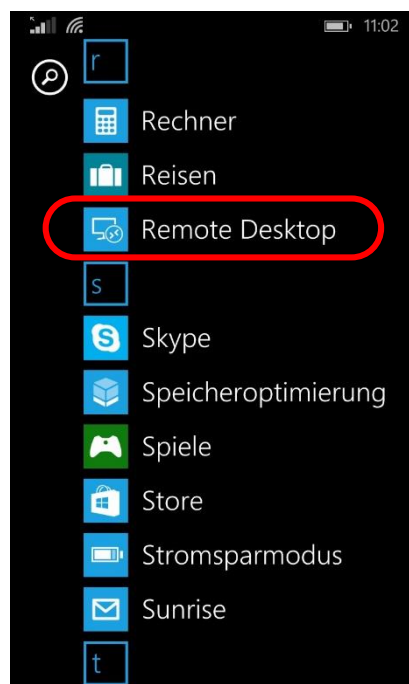


### Step 6: At the end you see the Azure desktop of the virtual machine:



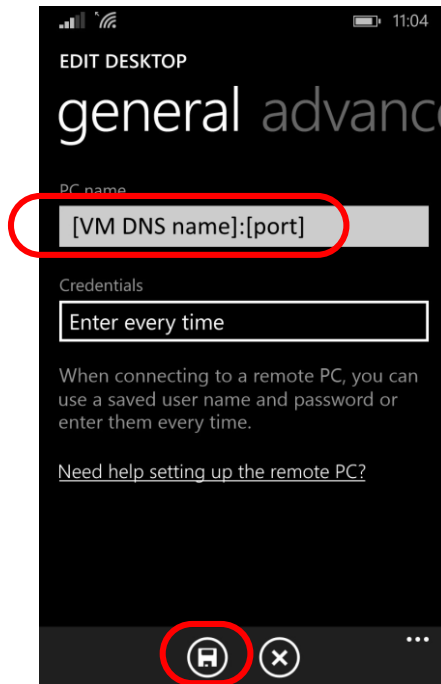
**Step 1: Figure out and note the port needed for the remote desktop connection**

Navigate to the following page on the Azure Management site by clicking on *VIRTUAL MACHINES* -> [your VM] -> *ENDPOINTS*. Note the *PUBLIC PORT* for Remote Desktop connectivity:

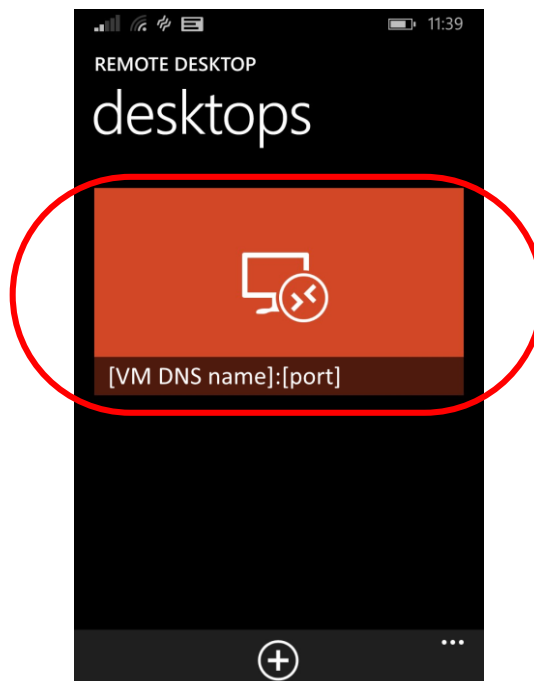
**Step 2: Install the free app REMOTE DESKTOP from the Store and start it**

**Step 3: Press on the + button to create a new connection as follows**

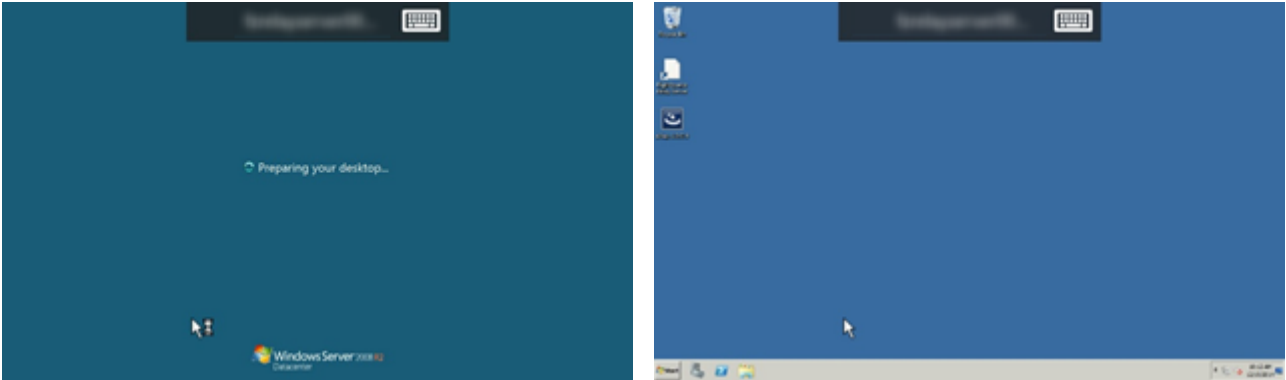
Enter the VM DNS name and the noted port from step 1 into the PC name textbox, separated by a colon. Save the connection afterwards.



**Step 4: After that connect to the server**



### Step 5: Et voila, there is your relay server, accessed from the phone

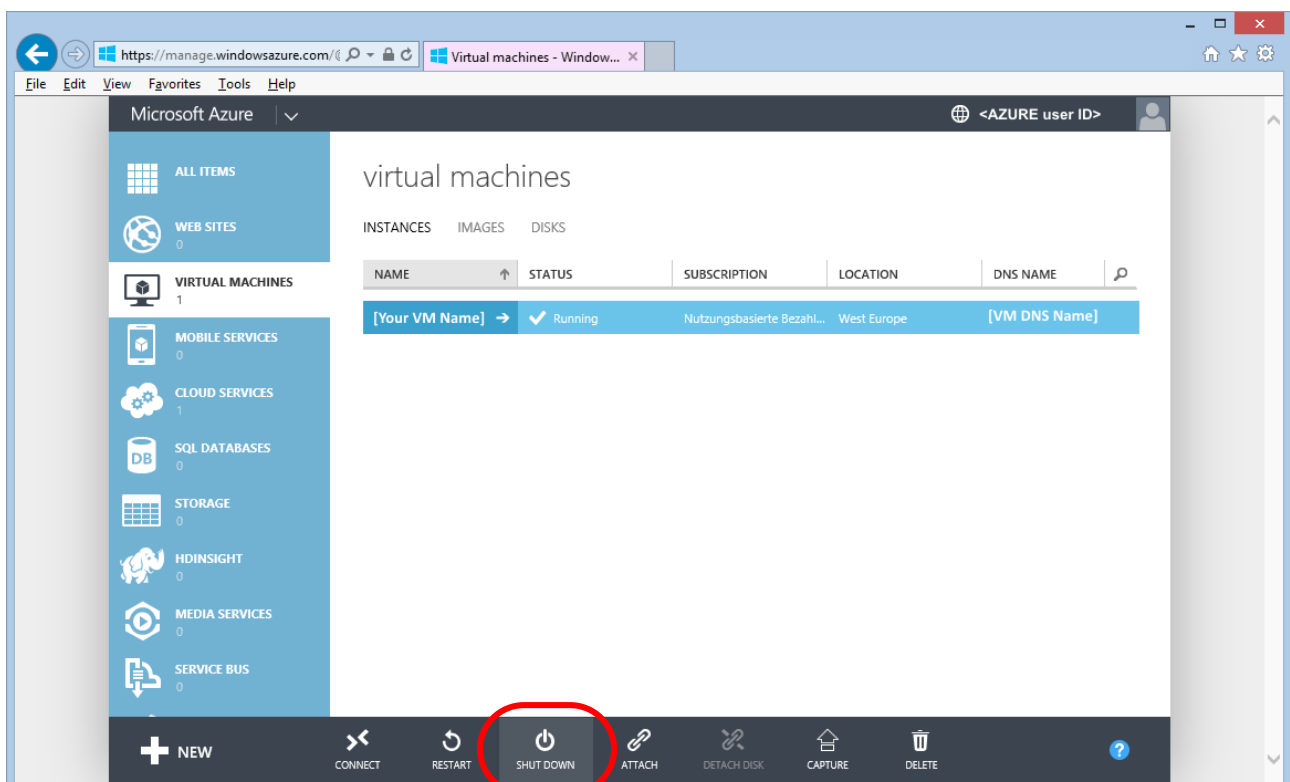


### 6.2.10 Shutdown the VM after usage to minimize charges

This step is only needed for:



In order to avoid charges don't forget to shut down the virtual machine after the work is done:



## 6.3 Prepare the FlightZoomer Sensorics-app

### 6.3.1 Attach the sensor smartphone

This chapter explains how the sensor smartphone needs to be mounted on an RC aircraft or copter. There are some things that need to be considered, some things that don't need to be considered and some things that depend on user preferences.

To be considered:

- The smartphone needs to be mounted detachable (in order to remove the device for compass calibration).
- Provide lightweight, yet sturdy installation.
- Provide as much clearance as possible to other electrical components.
- The smartphone needs to stay in a fixed relative attitude vs. the aircraft/copter.
- The position of the smartphone potentially affects the aerodynamics of the aircraft/copter (due to the form factor of the device). This is especially valid for multicopters at high speeds. Positions in front of the center of gravity have a negative impact on the stabilization. While all the examples in the following *best practices*-chapter have worked at fairly high speeds ( $\sim 20$  m/s), the ideal position would be like a trailing horizontal stabilizer, which is tilted to become aerodynamically neutral at the max forward pitch angle (of the copter).

Not to be considered:

- The actual attitude of the smartphone relative to the aircraft/copter.
- It is not necessarily required that the touchscreen of the smartphone is accessible while the device is attached.

Dependent factors:

- If you intend to use the camera of the smartphone to create inflight footage or images (see chapter 7.1.10) stick to these guidelines:
  - The smartphone needs to be fitted with unobstructed camera vision.
  - Keep vibrations away from the smartphone. Google "copter" and "vibrations".

#### 6.3.1.1 Best practices

The following images show some solutions for attaching smartphones successfully to multicopters.

A very successful approach was to fix only the back cover of the phone, so the phone itself could easily be detached from the copter. Note also that the phone becomes aerodynamically neutral when the copter pitches forward:



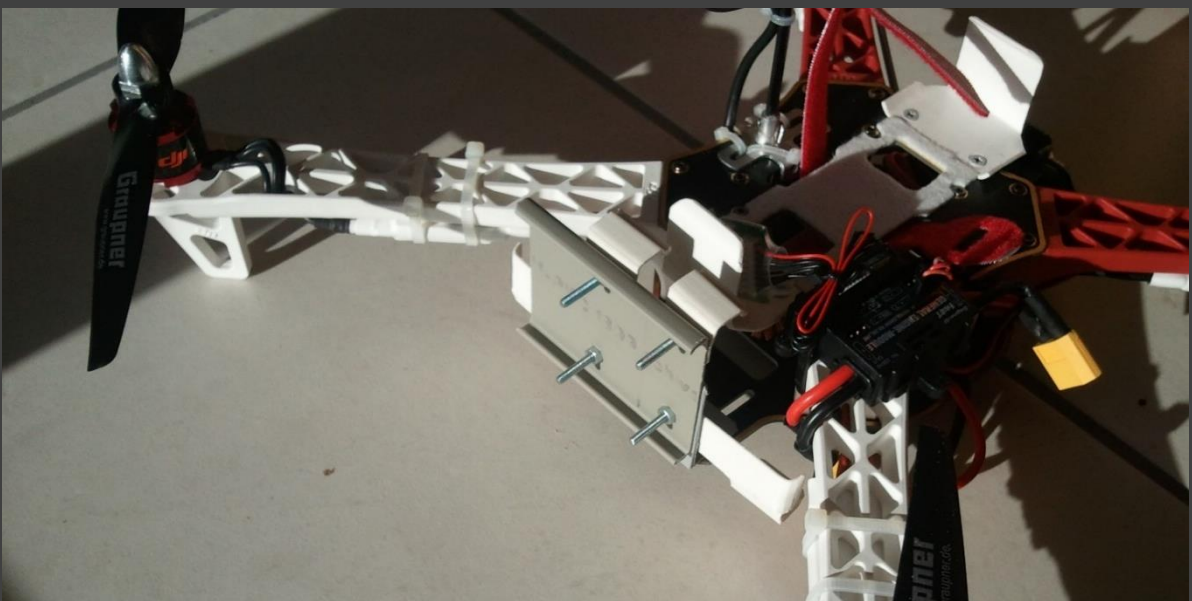
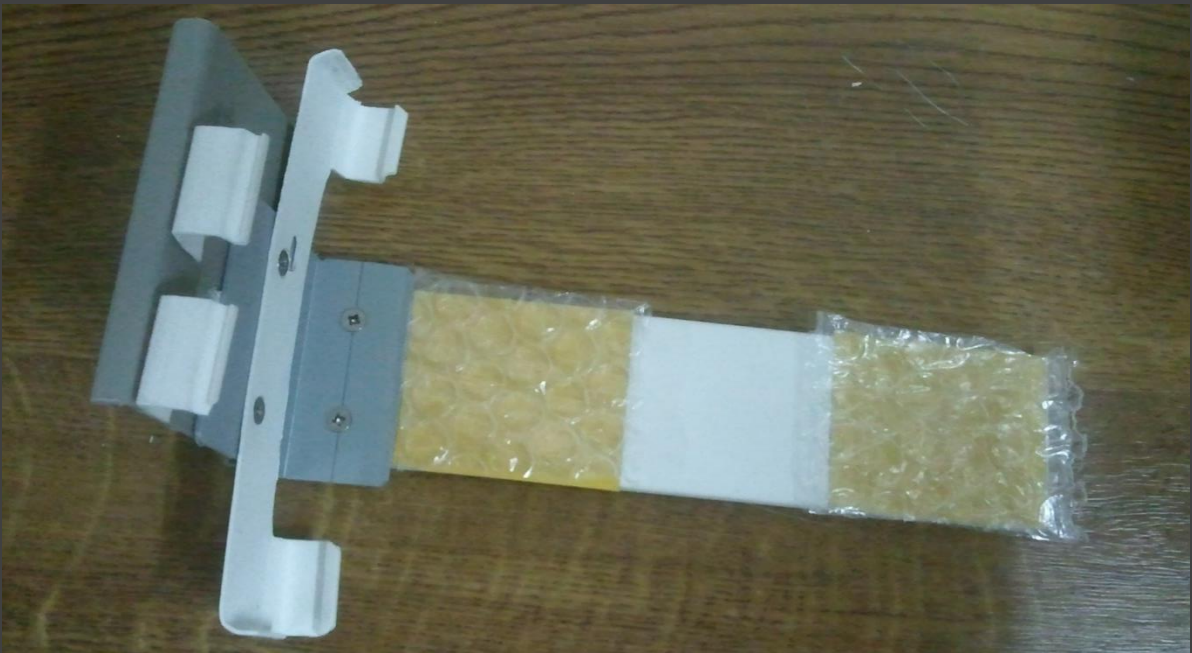


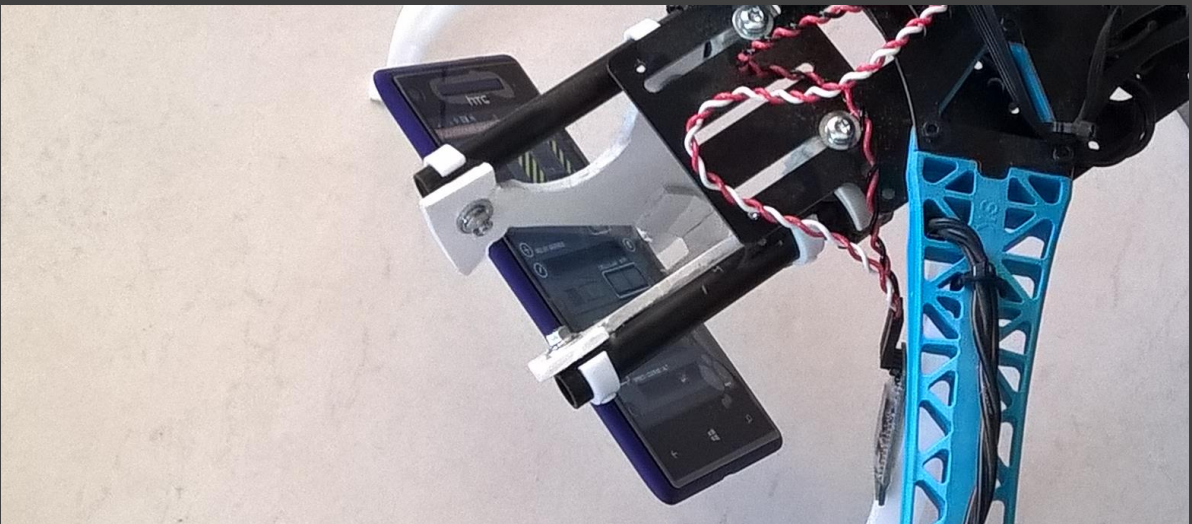
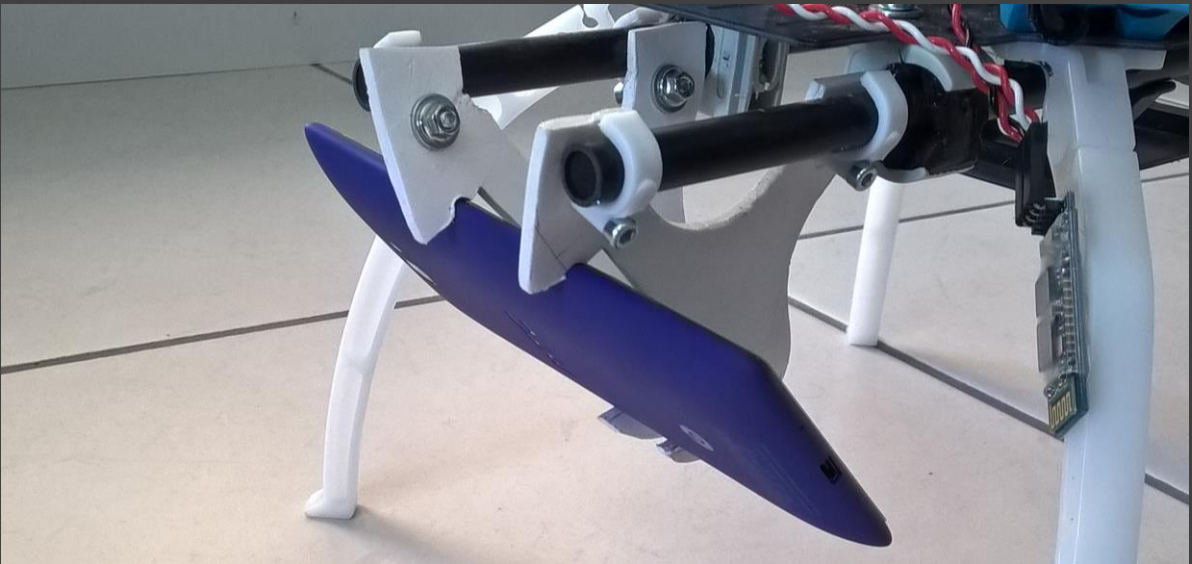
Another example where the back cover is fixed on the copter and the phone itself is just clipped onto the back cover:





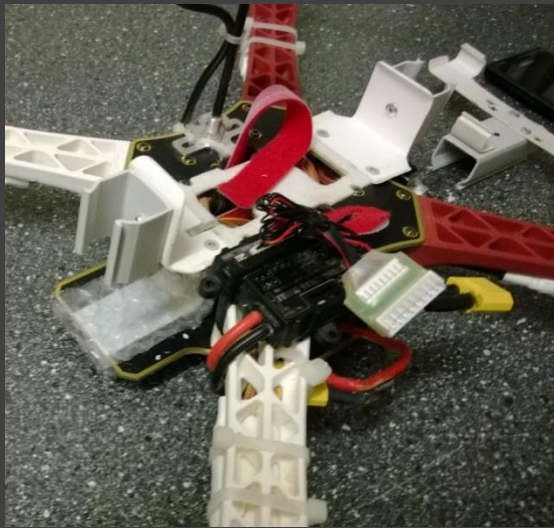
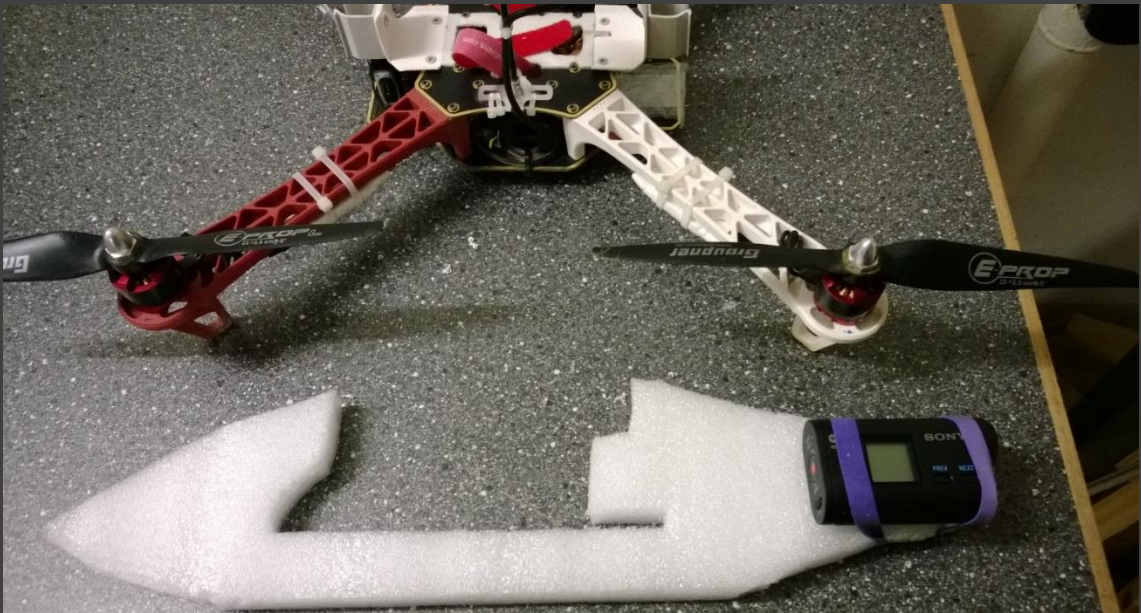
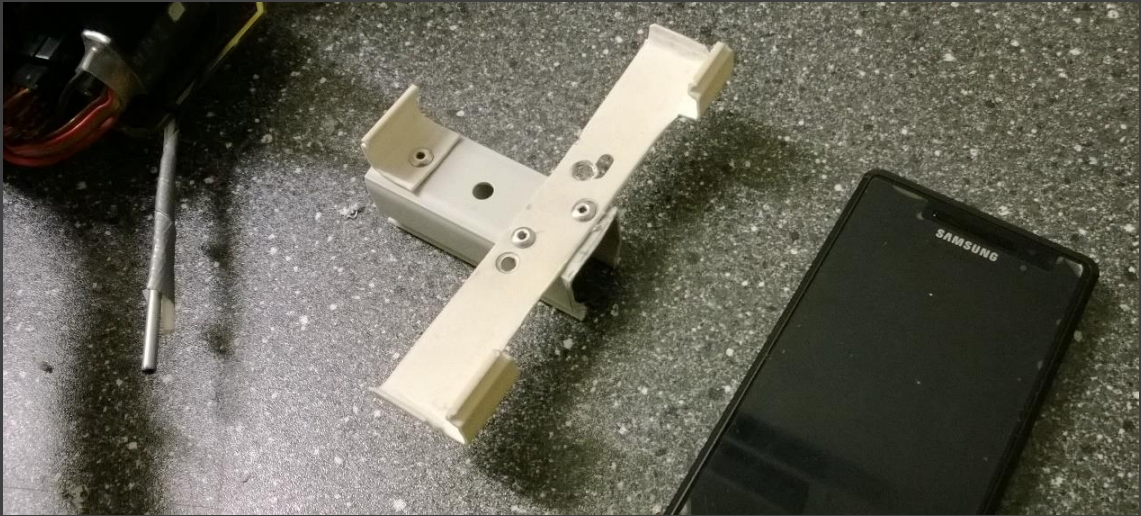
The first two designs are not suitable to use the camera of the phone. The next two designs have a front-mounted phone which allows using the camera:







Another design:



### 6.3.2 Install the app

The FlightZoomer Sensorics app can easily be loaded on any device from the store. Just enter “flightzoomer sensorics” in the search textbox.

### 6.3.3 Install and configure MAVLink connectivity

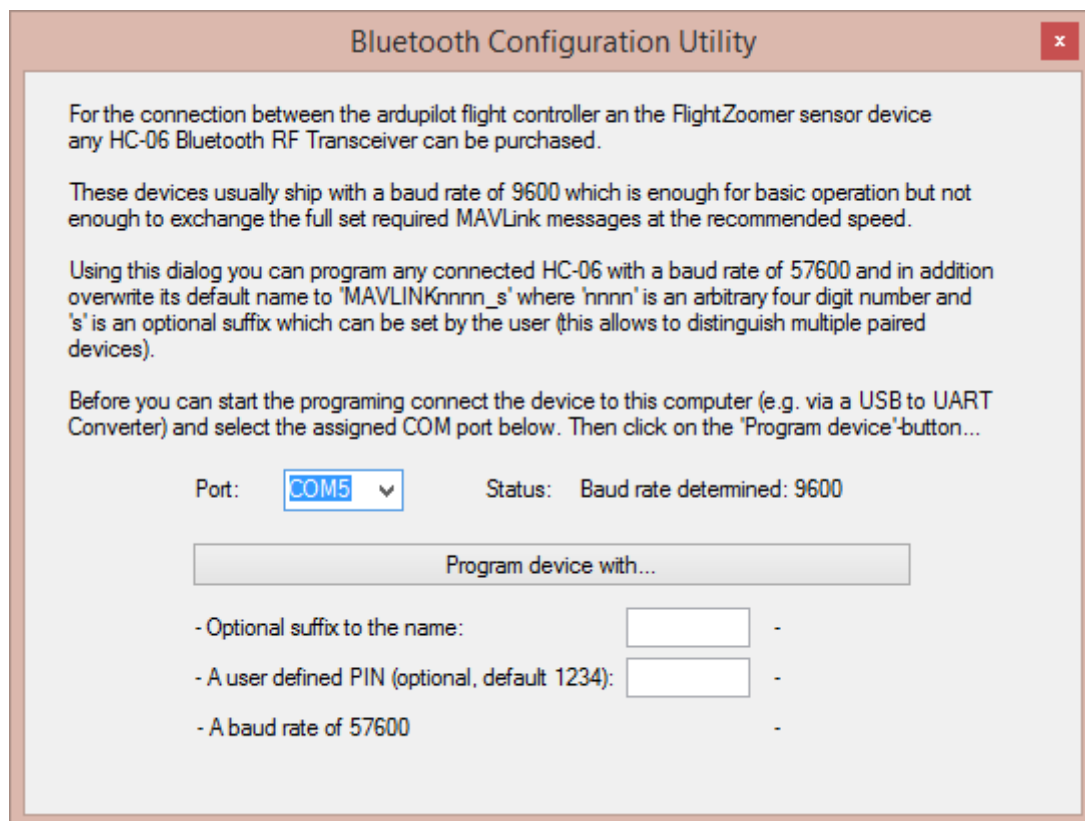
In order to mate the onboard smartphone to the Ardupilot based flight controller a HC-06 Bluetooth transceiver needs to be used. This device can be purchased from 3DR or in many other online shops (e.g. on Ebay).

The following steps are needed to accomplish MAVLink connectivity between the flight controller and the onboard smartphone:

#### Step 1: Configure the Bluetooth transceiver to the recommended baud rate of 57600

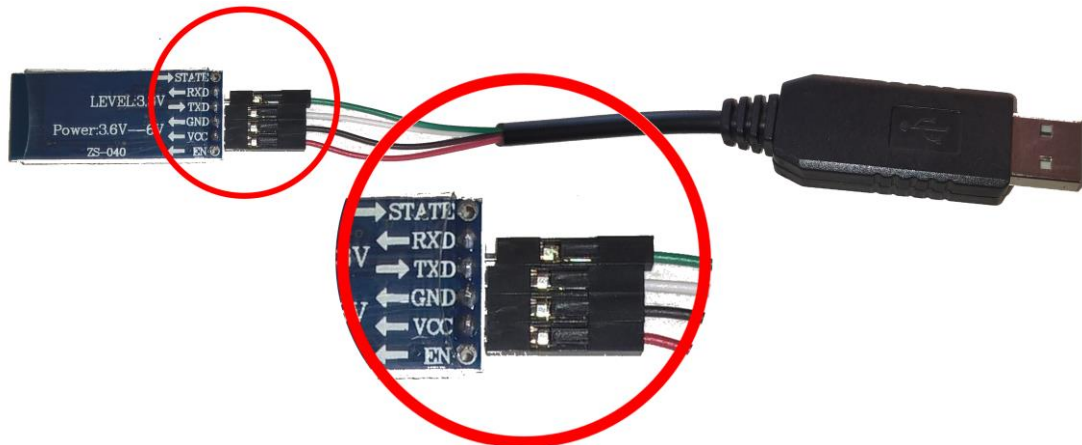
While the 3DR device comes already configured at 57600 baud, other HC-06 devices typically have the default baud rate of 9600. As 9600 is not enough for the recommended MAVLink packet update rates, it is recommended to change the configuration of the transceiver accordingly.

For this purpose, the Relay Server application has a special utility to automatically overwrite the configuration parameters of a HC-06 Bluetooth transceiver with the correct values:

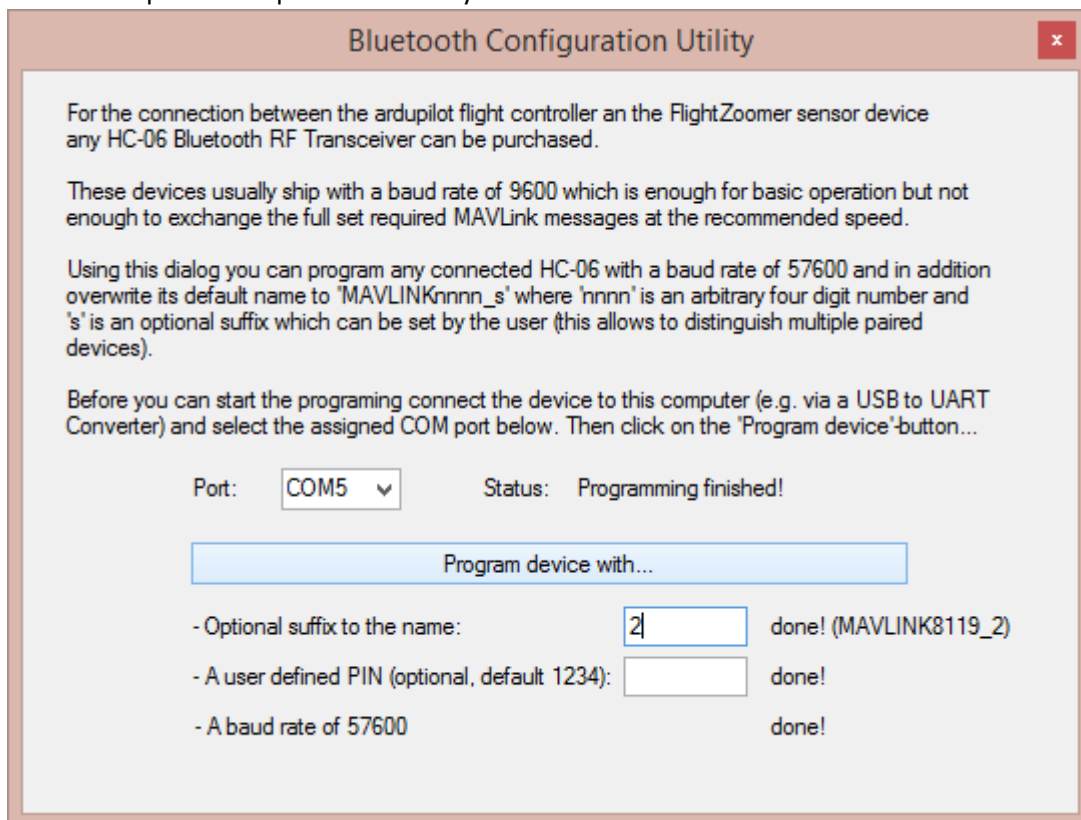


Perform the following actions to re-program the HC-06 device:

- Connect the HC-06 with the computer using a typical USB to RS 232/UART Adapter (as offered for Arduino) like shown on this image:



- Open the Bluetooth programming utility from the Relay Server main window by clicking the button *Bluetooth Configuration Utility....*
- Confirm that the correct COM port is shown in the *Port* dropdown box (or select it otherwise).
- The current baud rate will automatically be determined!
- Choose whether you want to add a one-character-suffix to the name and choose a PIN code (or leave it at 1234).
- Click on the button *Program device with...*
- Once all steps are completed the utility looks like this:





## Step 2: Connect the Bluetooth transceiver to the flight controller

For this step the documentation of the flight controller needs to be consulted. The following wiki page shows the connection for the APM and the PIXHAWK:

<http://copter.ardupilot.com/wiki/common-optional-hardware/common-telemetry-landingpage/common-mission-planner-bluetooth-connectivity/>

For the Arsov AUAV X2 the Bluetooth transceiver needs to be connected with the USART3 (SERIAL2) on the front side. The following diagram shows the respective pins. Always connect the Rx pin on one side of the connection with the Tx pin on the other side (and vice versa):

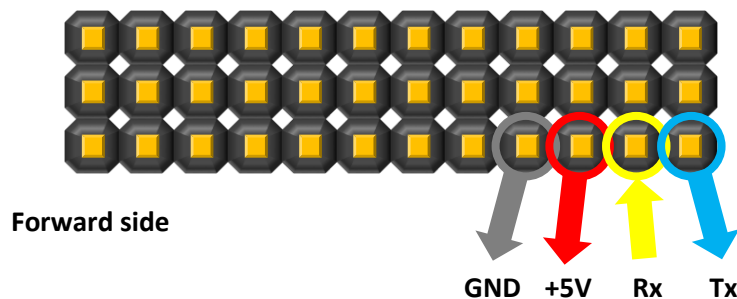


FIGURE XX ARSOV AUAV X2 BLUETOOTH CONNECTION

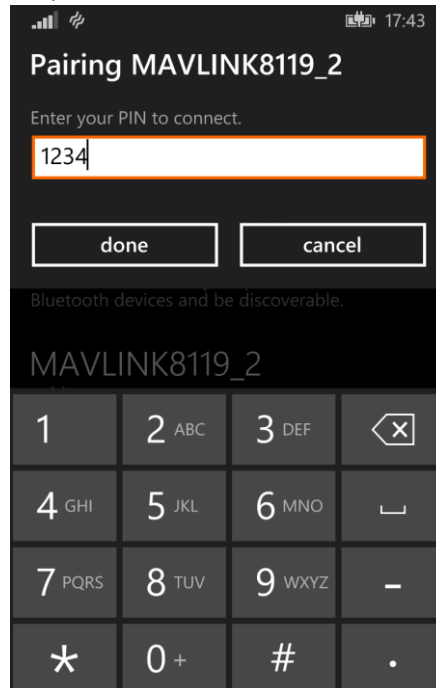
## Step 3: Pair a new Bluetooth transceiver with the phone

This steps needs only to be done once for each particular HC-06 Bluetooth transceiver:

1. Power up the new transceiver until the red LED blinks.
2. On the phone open the *Settings* > *Bluetooth* screen.
3. Turn Bluetooth on if not yet done.
4. Select the new device in the list (identify the device with the name as generated in step 1 above) and press *tap to pair*:



5. Enter the PIN as also defined in Step 1 above:



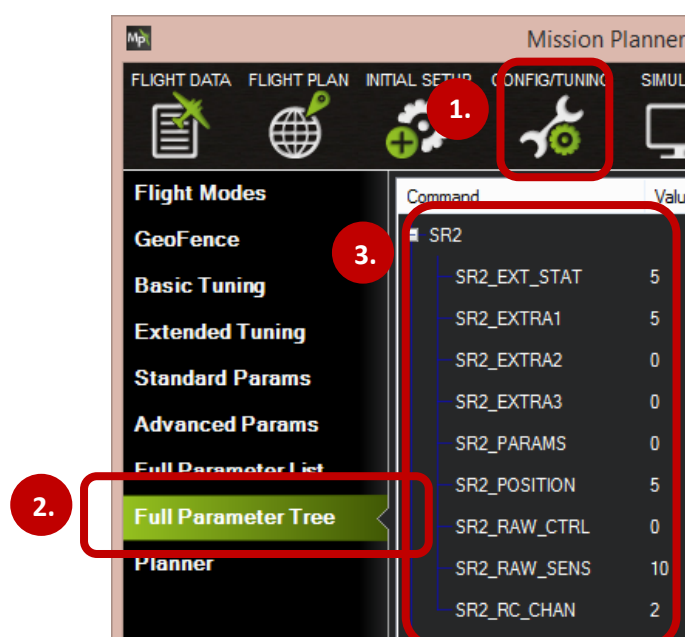
6. Finished! From now everything can be done in the app.

#### Step 4: Configure the flight controller to feed the required MAVLink packets

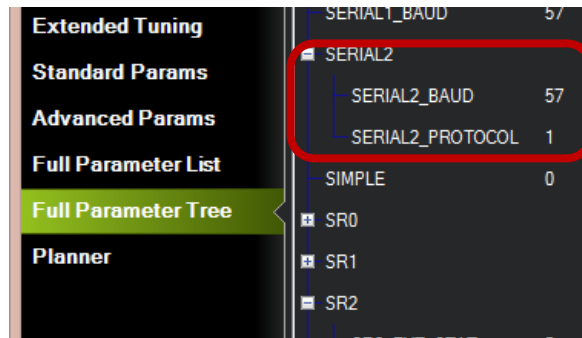
As the last step the flight controller needs to be configured to stream the required packets at the recommended rate.

Consult chapter 5.5.1 to understand the exact set of packets which are needed.

Use the Ardupilot Mission Planner to set the SRx-parameters rates as follows (x stands for the chosen serial port):



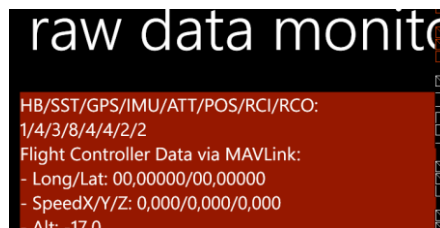
Also set the baud rate of the serial port which feeds the Bluetooth transceiver to 57600 and the protocol to '1' (GCS MAVLink):



### Step 5: Test the configuration

Run the FlightZoomer Sensorics-app and the flight controller. Mate the app with flight controller and check whether the MAVLink Status LED turns solid green after some time.

Also consult the raw data screen, to check the rate of the received MAVLink packets:



The first two lines show how many relevant packets have been received in the last second. The legend shows the order of listed packets and needs to be decoded as follows:

HB = HEARTBEAT/SST = SYS\_STATUS/GPS = GPS\_RAW\_INT/IMU = RAW\_IMU/ATT = ATTITUDE/  
POS = GLOBAL\_POSITION\_INT/RCI = RC\_CHANNELS\_RAW/RCO = SERVO\_OUTPUT\_RAW

#### 6.3.4 Prepare the app

Once the device is fitted to the aircraft/copter and the app is loaded on the device, the initial setup can take place. The initial setup is very easy and consists of these three steps:

1. Configure the relay server (see chapter 6.2).
2. Configure the MAVLink connection to the flight controller (see the chapter before)
3. Geometry capturing (see chapter 7.1.8). With this step the actual attitude of the device relative to the aircraft is measured.
4. Optionally choose options for the inflight camera (default = off, see chapter 7.1.10).



## 6.4 Prepare the FlightZoomer Groundstation-app

### 6.4.1 Attach the device to the RC transmitter (optional)

While it is possible to keep the groundstation device loosely it is much more convenient, if the device is attached to the RC transmitter, so you have enough “hands” to hold everything properly.

A good and proved solution would be to buy a cheap case for the device and attach the case to the handle of the RC transmitter. Be inspired by the following images!



### 6.4.2 Install the app

The FlightZoomer GroundStation app can easily be loaded on any device from the store. Just enter “flightzoomer groundstation” in the search textbox.

### 6.4.3 Prepare the app

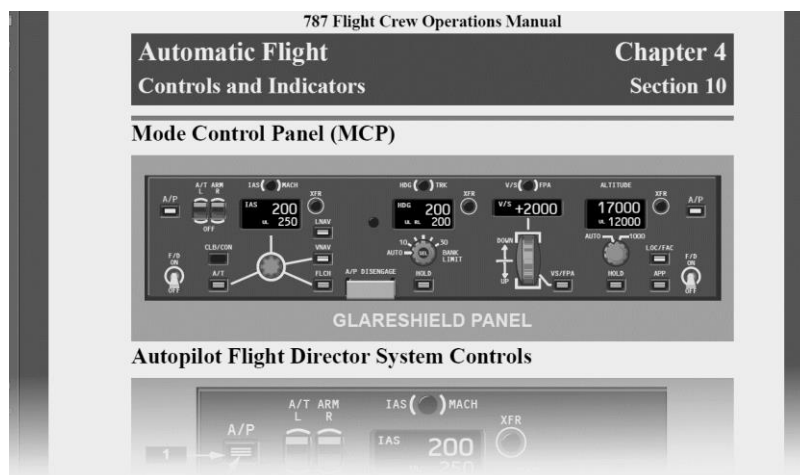
The preparation for the groundstation is even simpler than for the onboard sensor device and has only one step:

1. Configure the relay server (see chapter 7.3.3). This is done exactly the same way as for the Sensorics-app.
2. Additionally, the standard turn rates can be configured. Alternatively, these they can be gained by the flight test feature (the system measures the turn rate automatically while steady turns are flown by the (test-)pilot...

### 6.5 Prepare the RC system

While it is possible to use with FlightZoomer with a regular RC system without modification, the flying experience and the realism can be greatly enhanced if the RC transmitter is configured adequately to simulate the behavior and autoflight systems of real aircraft.

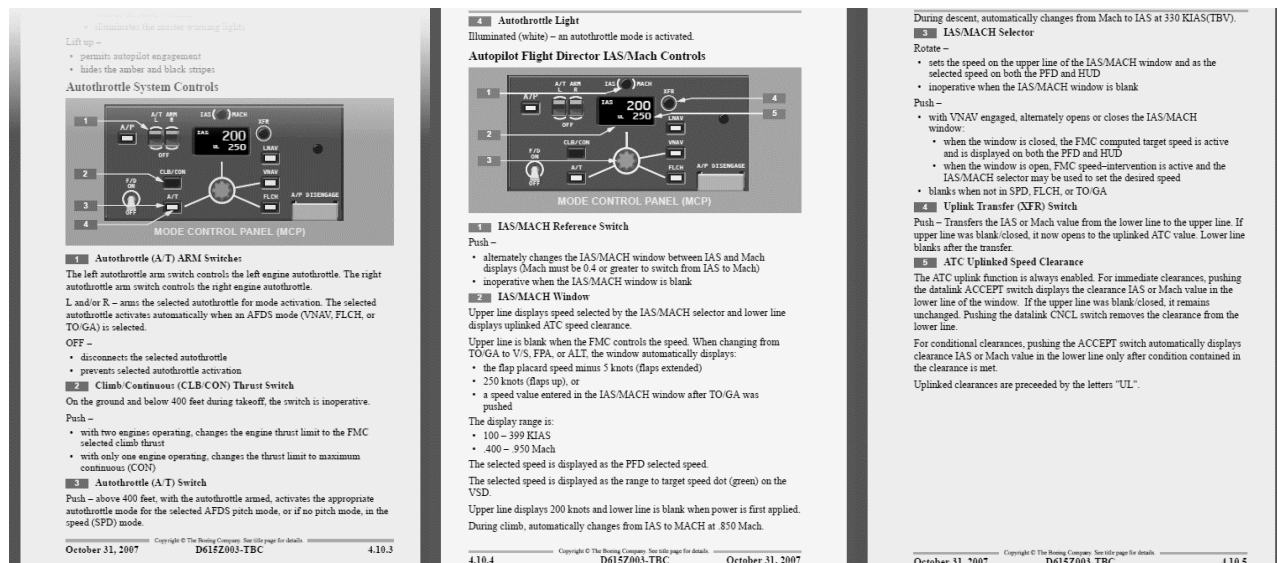
As FlightZoomer is modeled after the Boeing 787 Dreamliner, let's first have a look at the original Boeing documentation, which explains the autopilot of the mighty 787. The following extract shows the glareshield panel of the autopilot:



The panel looks rather complicated but the meaning of each control is quite understandable if we dig a bit deeper in the next chapters.

## 6.5.1 Speed hold/autothrottle mode

The following extract from the original manual explains in detail the controls of the autothrottle and speed controls (IAS/MACH = the two speed modes):



The autothrottle can work in several ways but the simplest mode is the speed (SPD) mode. In this mode the desired target speed is dialed in using the IAS/MACH Selector (Nr. 3 in the middle image, the value is shown in display Nr. 2). Pressing the A/T switch (Nr. 3 in the left image) the autothrottle starts controlling precisely the thrust to maintain the target speed.

This procedure currently can't be simulated with FlightZoomer but a similar behavior can be achieved by configuring the RC transmitter as follows (using a multicopter):

By mixing a configurable proportional control to the pitch channel, constant pitch-angles can be applied (while the channel's stick stays untouched). At a constant tilt angle, a multicopter will establish a constant speed (wind effects aside). So a certain target speed can be set by turning that control until the reported speed matches the desired target speed.

## 6.5.2 Constant turn mode

Another possibility which greatly improves the usability and the precision of FlightZoomer operations is the provision of constant turn rates by configuring the RC system accordingly. FlightZoomer uses a constant value as the expected turn rate for the calculation of turn radiuses, route length & duration and the turn countdown timer. The expected turn rate can either be set manually or measured automatically with the flight test feature. This behavior again matches real aircraft like the Boeing 787 Dreamliner which also have a standard 3°/second turn rate.

As a constant and consistent turn rate is hard to achieve manually (with the yaw/rudder channel) it is recommended to implement this capability also with the RC transmitter (this again makes only sense using a multicopter).

There are two recommended ways to achieve that:

1. By mixing two configurable switches (ideally spring loaded) to the rudder channel, constant turn rates can be commanded (while the channel's stick stays untouched). For a typical multicopter this might require to mix +10% to the yaw channel if the turn-right-switch is actuated and -10% if the turn-left-switch is actuated. A turn rate of about 6°/second proved to be quite good for RC modeling purposes.

Or alternatively:

2. Use the dual rate feature to have either the full travel or only +/- 10%. The second, reduced control travel will be used for constant, gentle turns and shall be made available by an external switch. This way the normal rudder stick can be used.

### 6.5.3 Example

The following image shows how a RC transmitter has successfully been configured to support constant speed and constant turn rate operations with multicopters:



## 6.6 Prepare the navigation database

One important step for preparing FlightZoomer is the creation of a suitable navigation database. This task is done with the Relay Server application as described in chapters 7.2.6 to 7.2.9. The underlying knowledge for the navigation database is described in chapter 5.6.

Some tips how to setup the navigation database:

- Creating the navigation database means that you already have a clear vision what kind of flights you want to do.
- Wherever you wish to have waypoints for your routes place a VOR or a GPS FIX. You can cover the whole landscape with as many navigation aids as you want.
- Place airports that have real (rural) roads are aligned parallel to your runway. You don't need real landing strips, especially with multicopters. This means that you can defined touchdown points virtually everywhere (the reason is that realistic accuracy does not permit spot-on landings solely based on the FlightZoomer ILS).

- One airport typically is enough because RC aircrafts usually land where they took off!

## 7 System Reference

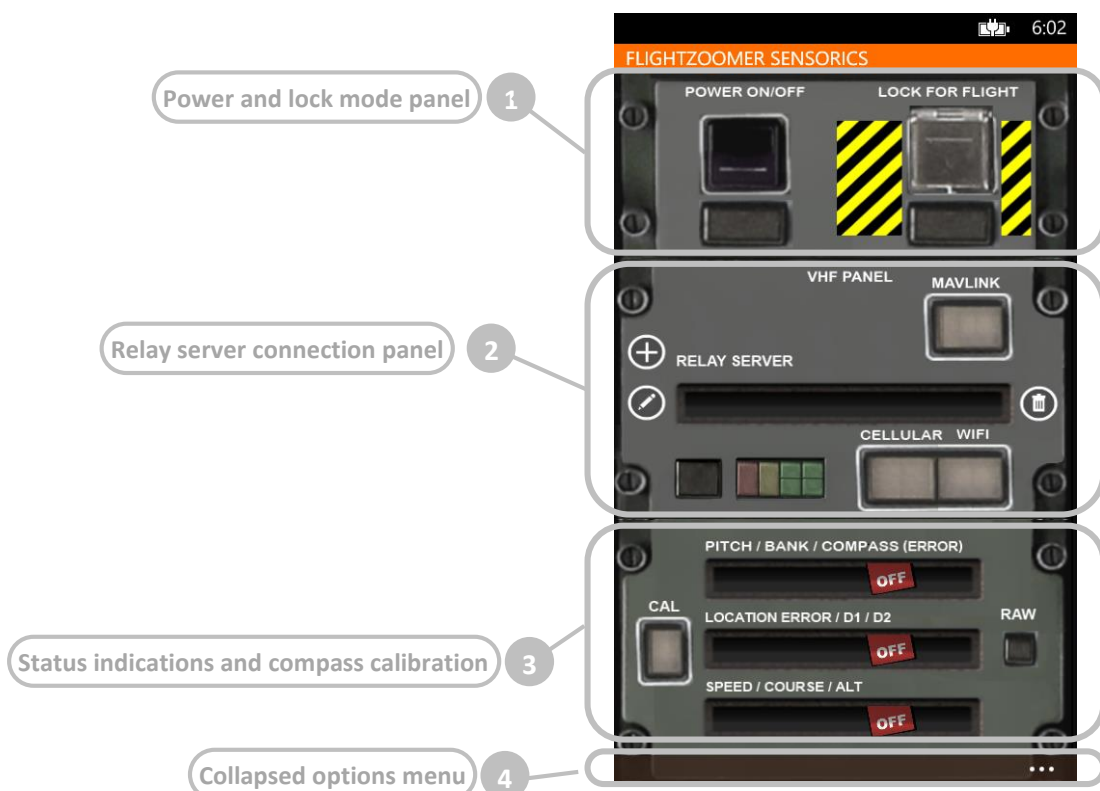
### 7.1 FlightZoomer Sensorics-app

The FlightZoomer Sensorics-app runs on a smartphone, which is mounted aboard an RC aircraft. The app collects sensor data from the smartphone's internal sensor suite and transmits them to the groundstation (via relay server).

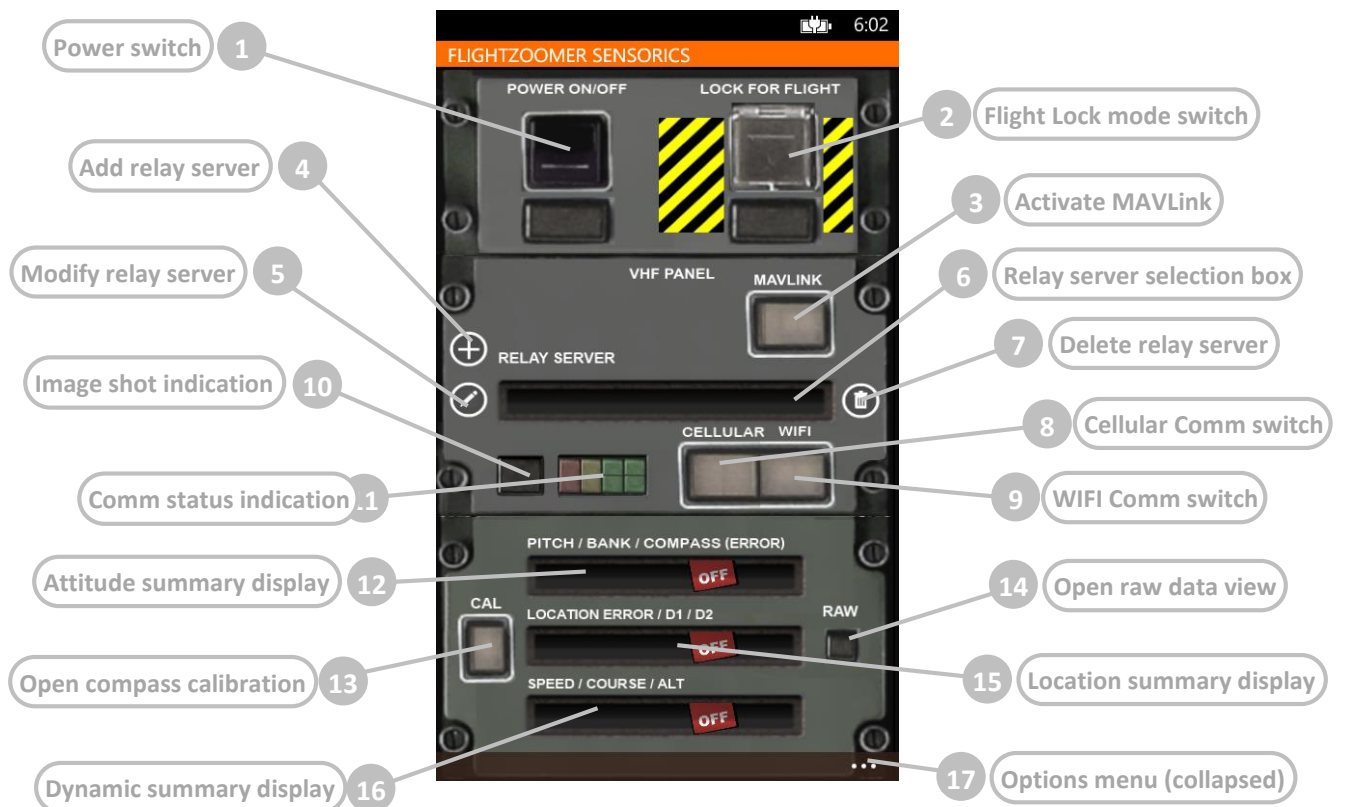
The app is rather simple. The main features are:

- Configure and control the connection to the relay server.
- Calibrate the compass.
- Send sensor and location data as a constant feed to the relay server.
- Raw data view.
- Geometry capturing (capture the attitude of the device aboard the aircraft).
- Configuration of the video or image recording.

#### 7.1.1 Main screen – overview



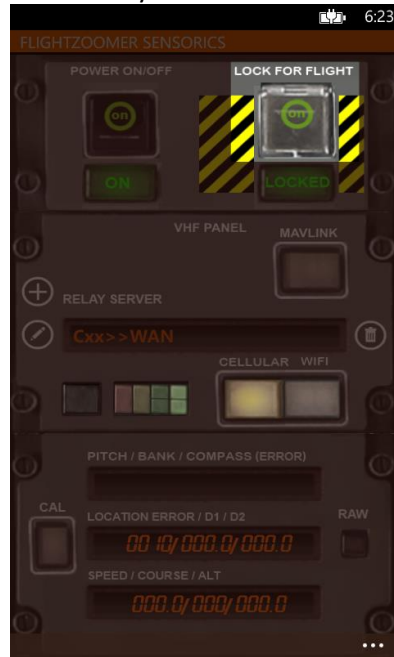
## 7.1.2 Main screen – detailed view



Element	Purpose
1 Power switch	Switches on the whole system
2 Flight Lock-mode switch	<p>The button cap is simulated so pressing it three consecutive times toggles the Flight Lock-mode to locked and by pressing it another three times back to unlocked (see chapter 5.4). The first tap raises the cap, the second actually actuates the switch and the third closes the cap again. This sequence protects the system from unintended mode changes. The Flight Lock mode transition sequence looks as follows:</p> <p>The transition sequence back to unlocked:</p> <p>In locked mode an overlay mask is laid over the whole screen. As a result, any user input is blocked on the entire touchscreen. Only in the area around the Flight Lock-mode switch there is a cutout in the overlay mask (allowing a transition back to the unlocked mode).</p>





The overlay mask looks as follows:



Alternatively, the locked mode can also be commanded from the groundstation.

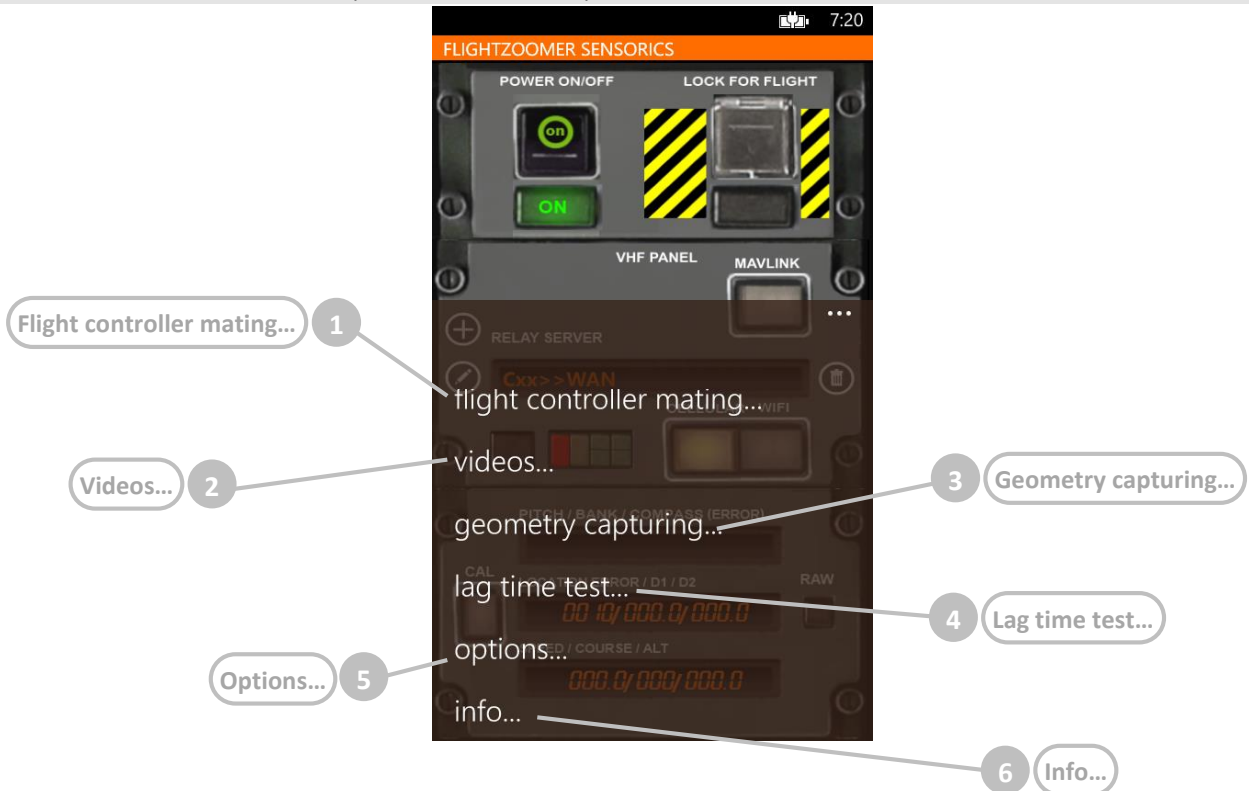
3	Activate MAVLink	<p>This button switches on the MAVLink connection to the flight controller. The button is two-color lighted to indicate the state of the MAVLink connection.</p> <p>Using this button will try to establish a connection to the Bluetooth device which was successfully connected the last time. This requires the first-time user to use the <i>flight controller mating</i>-screen to pair, select and connect a particular device. Multiple devices can also be managed on that screen.</p> <p>The color of this button has the following meaning:</p> <table><tr><td>[none]</td><td>MAVLink switched off</td></tr><tr><td>[yellow]</td><td>MAVLink is being switched on</td></tr><tr><td>[green]</td><td>MAVLink switched on</td></tr><tr><td>[green, blinking]</td><td>MAVLink switched on, some packets are missed</td></tr></table>	[none]	MAVLink switched off	[yellow]	MAVLink is being switched on	[green]	MAVLink switched on	[green, blinking]	MAVLink switched on, some packets are missed
[none]	MAVLink switched off									
[yellow]	MAVLink is being switched on									
[green]	MAVLink switched on									
[green, blinking]	MAVLink switched on, some packets are missed									
4	Add relay server	<p>The app allows configuration and storage of an unlimited number of relay servers. This button opens a menu to define and add a new relay server. A relay server definition is a combination of a plain text name, a URL (or an IP address) and a port number.</p> <p>Pressing on the button opens the screen described in chapter 7.1.4.</p>								
5	Modify relay server	<p>This button opens a menu to modify the relay server displayed in the selection box.</p> <p>Pressing on the button opens the screen described in chapter 6.2.</p>								
6	Relay server selection box	<p>This selection box shows the currently selected relay server. The box is empty as long as no relay server has been defined.</p> <p>After the connection to a relay server has been established, one of the following prefixes are added to the text in the selection box, which indicate the currently active interface type and the network quality:</p> <p><b>2.5G&gt;&gt;</b> <b>3G&gt;&gt;</b> <b>3.5G&gt;&gt;</b> <b>WIFI&gt;&gt;</b></p>								
7	Delete relay server	<p>This button deletes the relay server which is displayed in the selection box from the list of stored relay servers.</p>								

8	Cellular Comm Switch	<p>This buttons switches on a cellular connection to the selected relay server. Precondition is the selection of a relay server, which has been configured using a public URL or IP address.</p> <p>A given relay server definition consisting of a public URL or IP address can be used to create both a cellular or a WIFI connection. With the cellular Comm switch you can enforce a WAN (internet) connection if both networks types are available. If there is only one network type available, the operating system will automatically pick the available one.</p> <p>The button becomes lighted while the connection is switched on.</p>
9	WIFI Comm Switch	<p>This buttons switches on a WIFI connection to the selected relay server. There is no precondition for the relay server definition. Ideally you would choose an IP address or URL which points to the local network.</p> <p>Contrary to the Cellular Comm Switch the WIFI Comm Switch allows setting the network preference to WIFI if both network interface types are available. This might be useful to download videos, while the device is connected to the relay server in the same LAN (over WLAN).</p> <p>The button becomes lighted while the connection is switched on.</p>
10	Image shot indication	<p>This light toggles between illuminated and dark each time an image has been shot (with the camera fixed interval image recording feature).</p>
11	Comm status indication	<p>These LEDs indicate the operation status of the relay server connection. The LEDs are arranged in four columns:</p> <ul style="list-style-type: none"> <li>[1] Error indication - red</li> <li>[2] Transient state or warning indication - orange</li> <li>[3] Even message sent successfully - green</li> <li>[4] Odd (alternate) message sent successfully – green</li> </ul> <p>In addition, [3] and [4] above are split into an upper and lower half. During normal operation the odd and even message sent indications toggle on and off alternately (green light jumps from [3] to [4] to [3] to [4]...)</p> <p>If 10 messages have been sent in a row without successfully receiving a single response message, either [3] or [4] start toggling between the upper and lower half.</p> <p>This gives an indication that the connectivity might be impaired (messages are still sent, but a roundtrip seems to be no longer possible).</p>
12	Attitude summary display	<p>This text box shows the current pitch, bank and compass angle at any time. In brackets the compass error is shown.</p> <p>This display can be used to verify the result of a geometry capturing run. The OFF flag disappears as soon as attitude and compass data is available.</p>
13	Open compass calibration	<p>This button opens the compass calibration screen. It is illuminated if the current calibration is insufficient.</p> <div style="display: flex; align-items: center;">  <div style="margin-left: 10px;"> <p>The compass is calibrated. The compass accuracy is equal or smaller than 20° (degrees)</p> </div> </div> <div style="display: flex; align-items: center; margin-top: 10px;">  <div style="margin-left: 10px;"> <p>The compass needs to be calibrated. This is required frequently and must be checked prior each take off.</p> </div> </div> <p>Pressing on the buttons opens the screen described in chapter 7.1.5.</p>
14	Open raw data view	<p>This button opens the raw data screen. Pressing on the buttons opens the screen described in chapter 7.1.6.</p>



15	Location summary display	<p>This text box shows the status and summary of the location determination sensor suite. During normal operation the following numbers are displayed (in one line):</p> <p>[current location determination error in meter]/  [East/West offset in meter from the initial location]/  [North/South offset in meter from the initial location]</p> <p>During GPS initialization or in case of localization errors one of the following texts might be displayed (horizontally scrolling):</p> <p>&gt; <i>Device localization is switched off in this app, FlightZoomer does not work.</i></p> <p>&gt; <i>Device localization is not supported on this device, FlightZoomer might not work.</i></p> <p>&gt; <i>The GPS is not activated, please switch on the GPS.</i></p> <p>&gt; <i>The GPS is being initialized.</i></p> <p>&gt; <i>Currently the GPS is not able to extract the position.</i></p> <p>The OFF flag disappears as soon as location data is available.</p>
16	Dynamic summary display	<p>This textbox shows the current speed, track and altitude in meters per second, degrees and meters.</p> <p>The OFF flag disappears as soon as location data is available.</p>
17	Options menu (collapsed)	<p>Pressing on the collapsed menu symbol will show the full menu (see next chapter).</p>

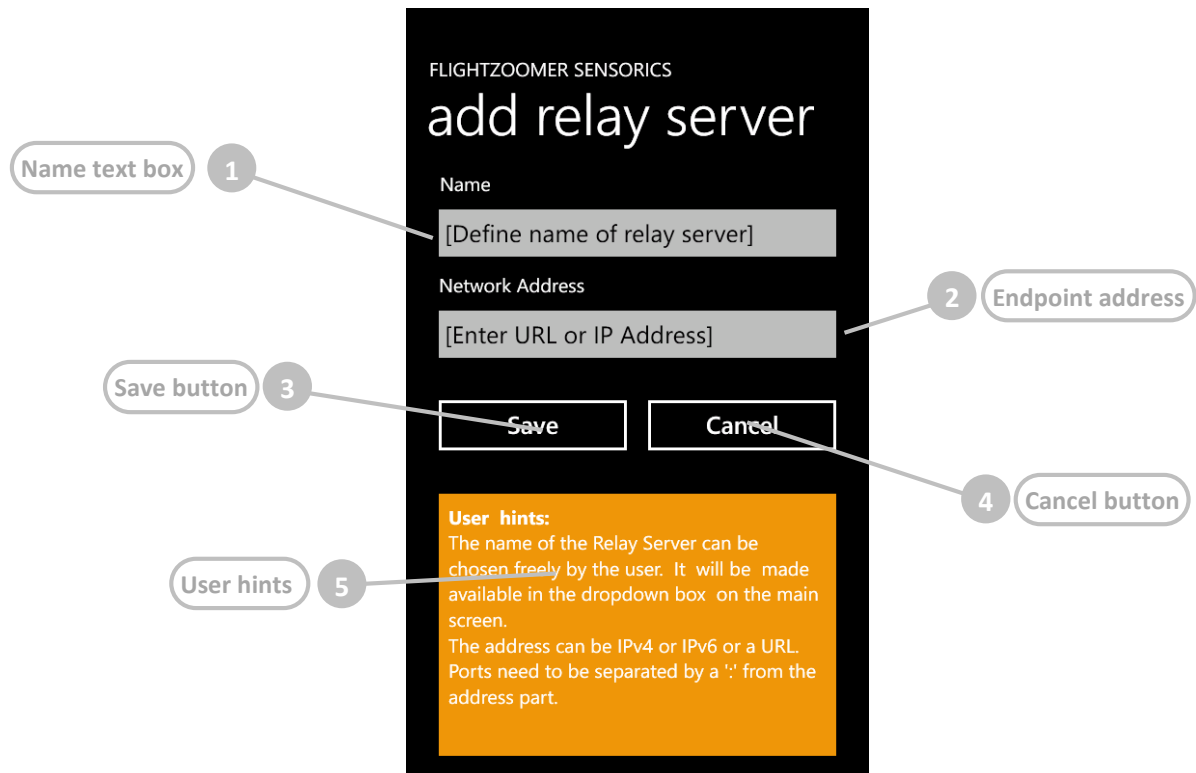
### 7.1.3 Main screen – options menu expanded



Pressing on the right corner at the bottom, the jump menu appears. This menu offers the following commands:

Element	Purpose
1 Flight controller mating...	This menu opens the <i>flight controller mating</i> -screen (see chapter 7.1.7).
2 Videos...	This menu opens the video screen, where recorded videos can be watched, deleted and also downloaded to the relay server.
3 Geometry capturing...	This menu command opens the screen, where the geometry of the attached device on the aircraft can be captured (see chapter 7.1.8).
4 Lag time test...	This menu opens the <i>lag time test</i> -screen, where the complete lag between the sensor device and groundstation can be measured for each transmitted package (see chapter 7.1.9).
5 Options...	This menu command opens the options screen (see chapter 7.1.10).
6 Info...	This menu command opens the info screen, which shows the version, the build date and links for support purposes.

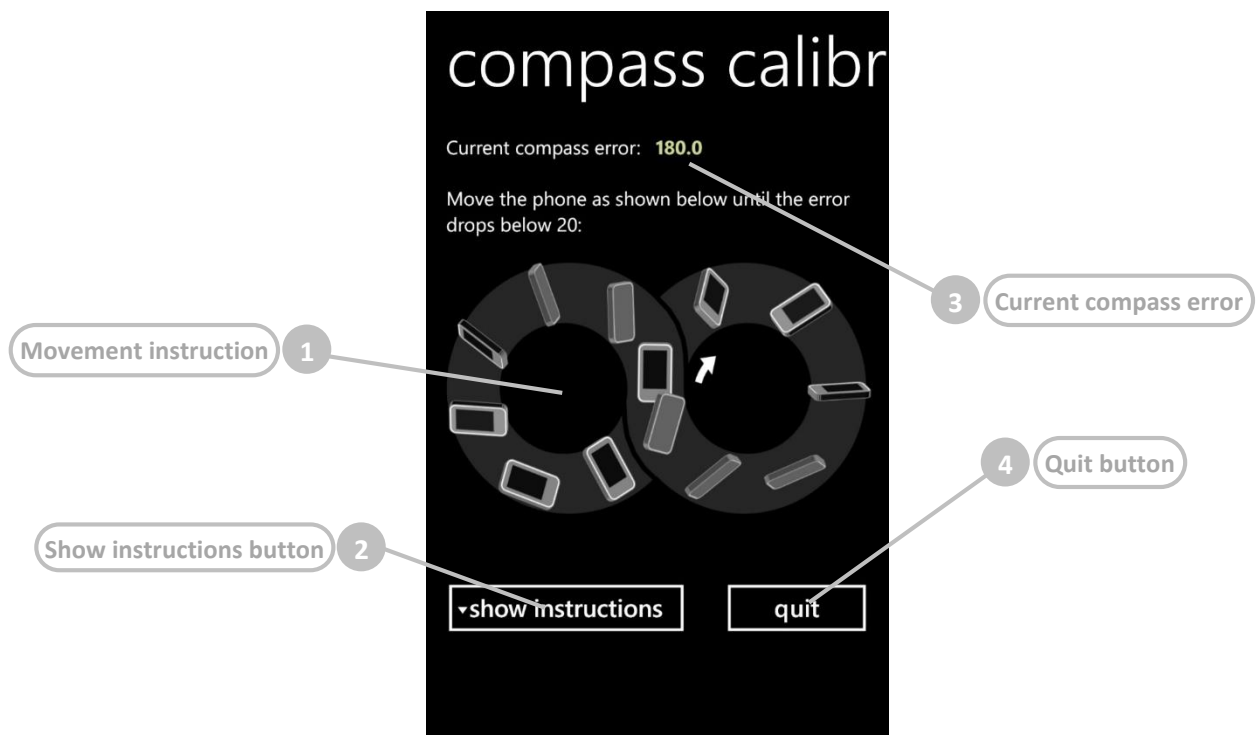
## 7.1.4 Add/modify relay server screen



This screen is shown in order to add or modify a relay server.

Element	Purpose
1 Name text box	This text box allows definition of the relay server name. The name of the relay server can freely be chosen by the user. It will be available in the selection box on the main screen.
2 Endpoint address	This text box allows definition of the IP address (IPV4 or IPV6) or a URL for the relay server. In addition, the destination port can be specified (if it is missing, 57778 is taken as default). If specified, the port must be separated by a colon-character (:) from the IP address/URL. (ie: 10.1.3.4:57778) The FlightZoomer Sensorics App will connect to this endpoint when building up UDP connectivity with the relay server.
3 Save button	Store the definition/changes.
4 Cancel button	Leave this screen without saving the definition or modification.
5 User hints	Usage and instruction summary

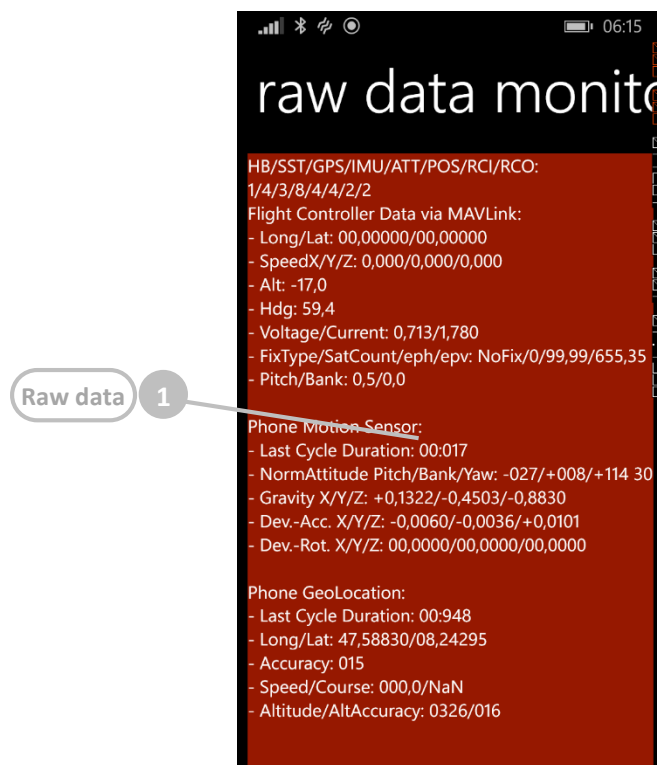
## 7.1.5 Compass calibration screen



This screen is shown while the compass is going to be calibrated. After the screen is displayed the device needs to be rotated in all three axes as shown. Take the device in one hand and fluidly trace a figure 8. This movement needs to be continued until the compass error will become less than 20°. At the moment when this happens the device will vibrate for 100ms.

Element	Purpose
1	Movement instruction This image shows the movement and rotation, which is needed to calibrate the compass.
2	Show instructions This buttons opens detailed further information: <div data-bbox="558 1314 1056 1960" data-label="Image"> <p>The screenshot shows a detailed instructions screen. At the top, there are two buttons: 'hide instructions' and 'quit'. Below them, the text reads: 'If the calibration can't be completed successfully consider the following points:'. This is followed by a list of four points: '- Choose an outdoor location to run the calibration.', '- Shutdown the phone and remove/reinstall the battery before trying the calibration again.', '- Repeat the 8-movement a number of times. Move steady, quick and excessive.', and '- Consult internet videos to see real life examples of the calibration, e.g. the following links. Especially consider the second example, that shows an alternative movement:'. At the bottom, there are two links: 'Instruction video 1' and 'Instruction video 2'.</p> </div>
3	Current compass error Store the definition/changes.
4	Quit button Leave this screen.

## 7.1.6 Raw data screen



This screen shows the raw data. The output of each and every sensor as well as everything related to the MAVLink connection is shown in real time.

This feature can be used for system monitoring purposes and for trouble shooting.

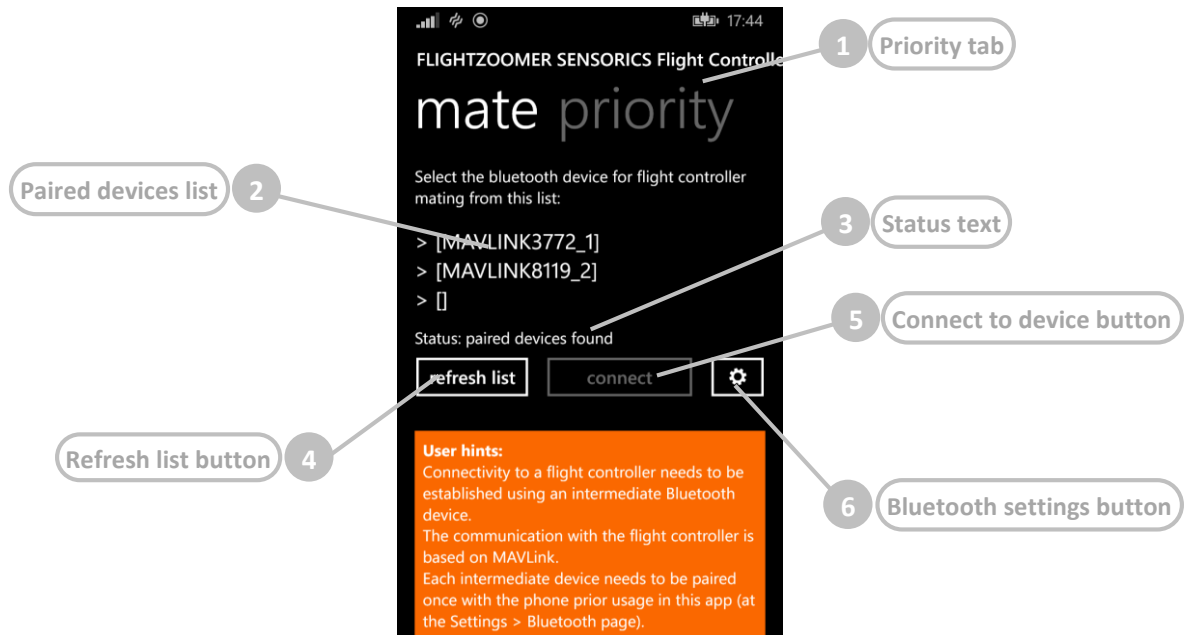
Leave the screen with the BACK button of the device.

Element	Purpose
1 Raw data	Shows the output of sensors used by the app.

### 7.1.7 Flight controller mating screen (MAVLink connection)

From this screen the Sensorics-app can be connected to a HC-06 Bluetooth transceiver, which provides MAVLink connectivity with the flight controller. The screen offers the capability to connect to a particular Bluetooth transceiver for the first time, select one among multiple devices and display detailed status information.

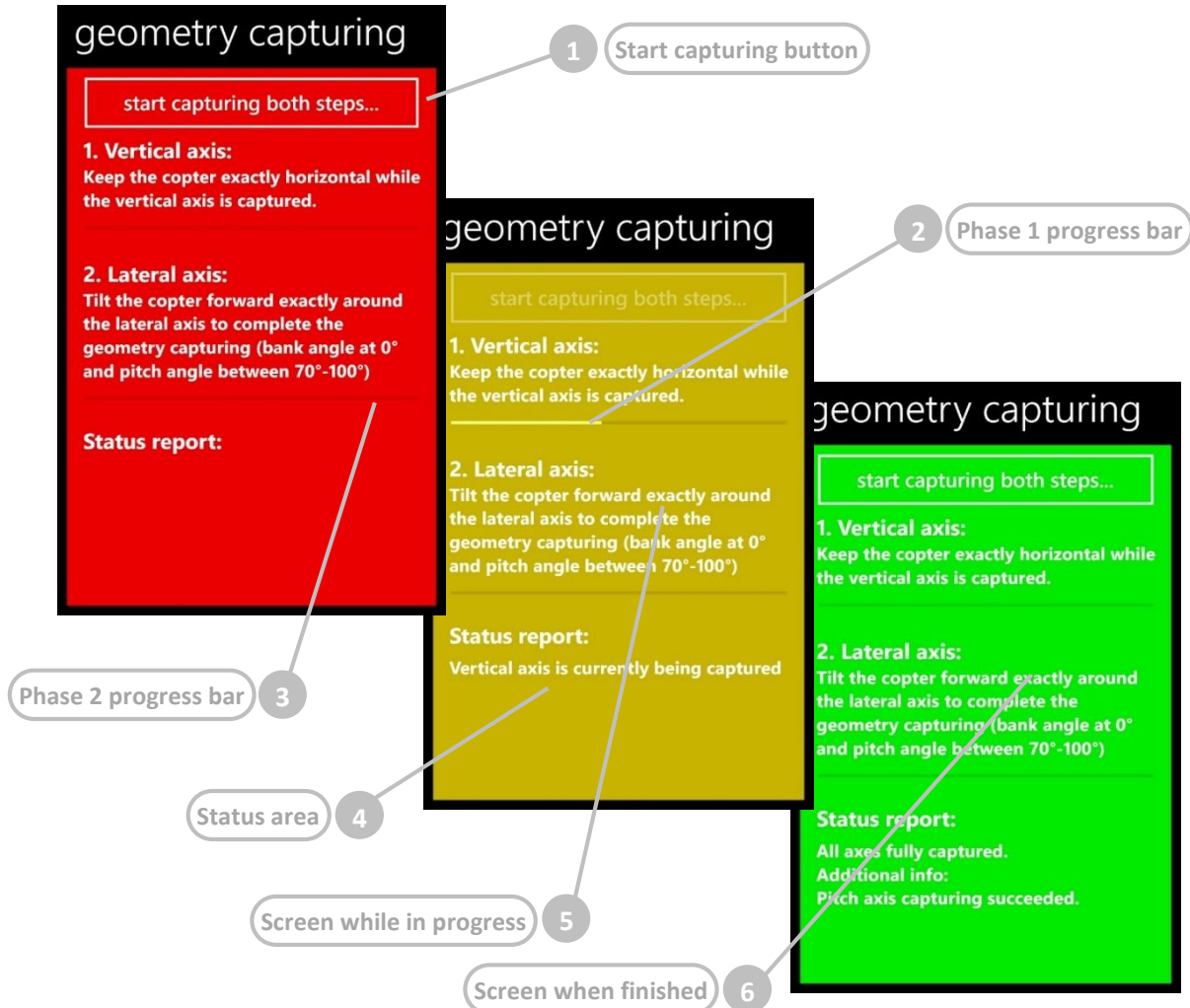
Whenever a connection is established successfully, the respective transceiver is stored. The stored transceiver is also used whenever the *Activate MAVLink*-button is pressed on the main screen. Provide a unique naming convention for each Bluetooth transceiver for each aircraft.



Element	Purpose
1 Priority tab	Opens the second pivot screen where the sensor source priority can be configured. For details about the four options consult chapter 5.5:
2 Paired devices list	List of all the paired Bluetooth devices. The list shows the name of each Bluetooth device (which is either HC-06 or LINVOR per default or MAVLINKnnnnn_s if the transceiver was configured using the <i>Bluetooth Configuration Utility</i> of the Relay Server-application).
3 Status text	The status text shows the connection progress. The following states are possible: <ul style="list-style-type: none"><li>- Searching for paired devices</li><li>- No paired devices found</li><li>- Paired devices found</li><li>- Paired devices found, connecting...</li><li>- Connected with device</li><li>- Connected with device, MAVLink available</li></ul>
4 Refresh list button	With this button the list of paired devices can be refreshed at any time.
5 Connect to device button	By pressing this button, a connection to the selected device in the list can be established. The button is only enabled if one item in the devices list is selected.
6 Bluetooth settings button	Pressing this buttons opens the device's Bluetooth settings.

## 7.1.8 Geometry capturing screens

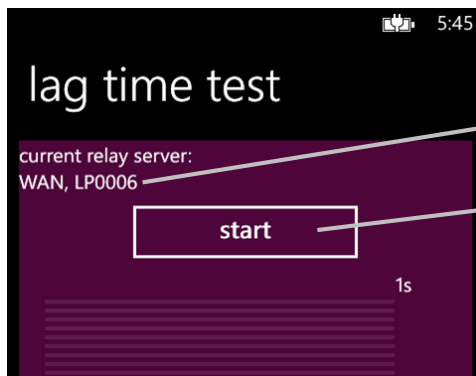
The geometry capturing is needed to measure the attitude of the device as it is mounted on the aircraft. Each time the position relative to the aircraft changes the geometry needs to be captured again. (eg. You decide to change the mount for the device to downward aim the camera)



Element	Purpose
1 Start capturing button	This buttons initiates a geometry capturing sequence.
2 Phase 1 progress bar	The aircraft needs to be kept exactly horizontal during the first phase of the measurement. The phase 1 takes 20 seconds. During that time the average gravity vector is measured and stored.
3 Phase 2 progress bar	After the first phase is completed tilt the aircraft forward by about 90° during the second phase to complete the measurement. It is less important that the aircraft is pitched exactly 90° forward than doing so exactly around the lateral axis (which goes from left to right). In fact, any pitch forward angle starting from 0° is valid and does not affect the measurement.
4 Status area	The status area displays information about the progress and the outcome.
5 Screen while in progress	During measurement execution the screen becomes yellow.
6 Screen when finished	After measurement completion the screen becomes green.

## 7.1.9 Lag time test screen

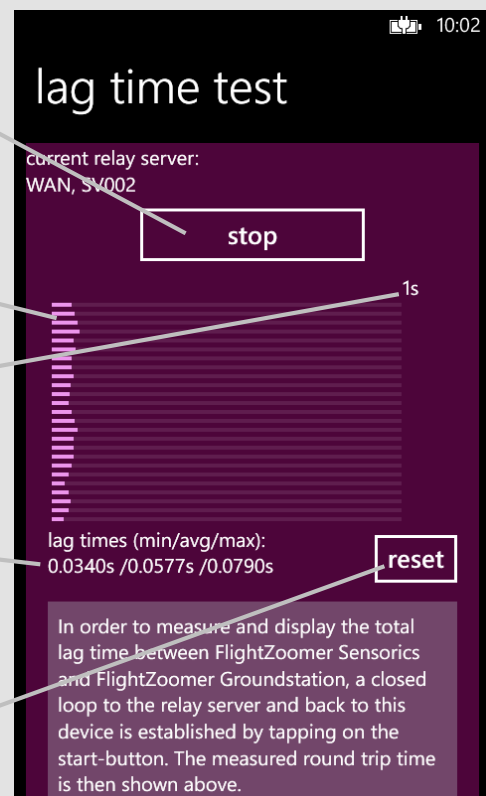
Switched off:



1 Relay server connected via active connection

2 Start button

While the test runs:



3 Stop button

4 Lag time bar per package

5 Lag time scale

6 Minimum/average/maximum values

7 Reset button

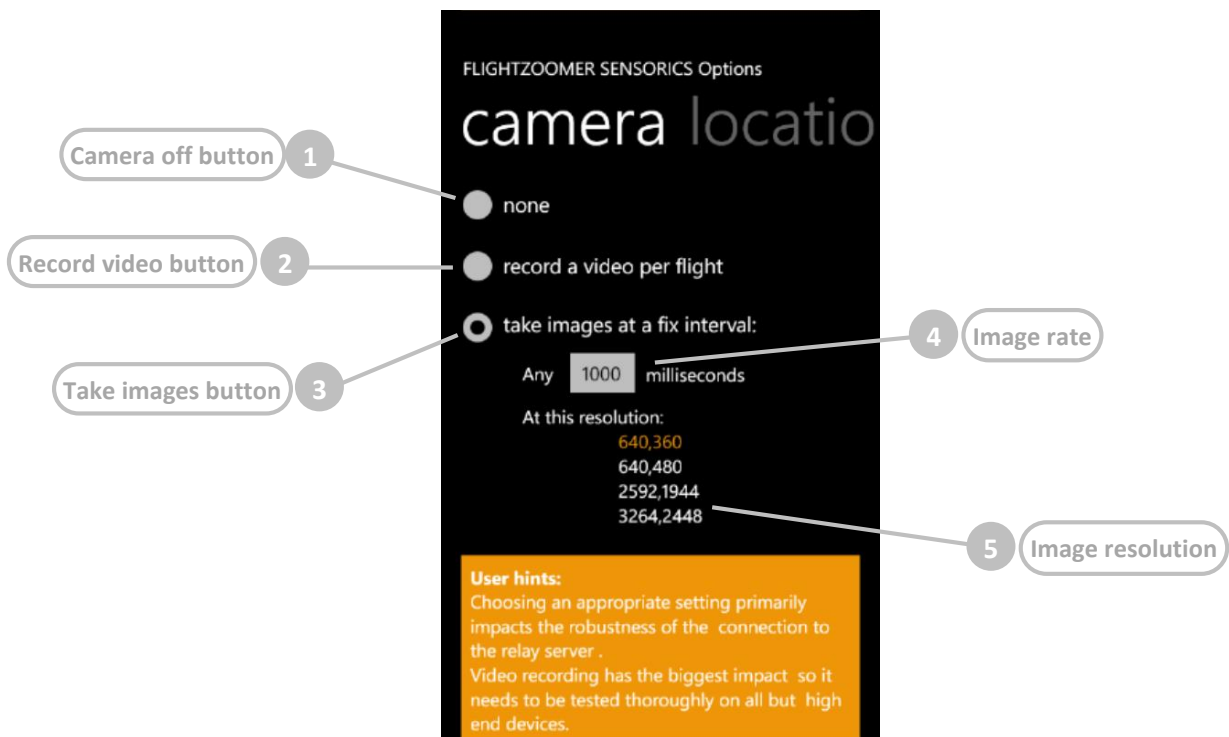
The lag time test measures and displays exactly how long it takes for each single transmitted packet over the entire communication route from the sensor device to the groundstation device. This test is accomplished solely by the Sensorics-app and the relay server. The Groundstation-app is not needed. Once the test is started, a second connection from the sensor device to the relay server is established which is used to simulate the complete end-to-end connection.

Element	Purpose
1 Relay server connected via active connection	This text label shows the relay server to which the currently active connection is built up. If no connection is activated, the label shows "Not connected". In that case starting the lag test is not possible.
2 Start button	With this button the lag test is started. After pressing on the button, a second connection to the relay server is established and



		the time for the whole roundtrip of each transmitted package is measured and displayed.
3	Stop button	This button stops an ongoing lag test.
4	Lag time bar per package	For each received package the length of the lag time bar changes in order to reflect the overall transmission time. There are 25 bars so after 25 received packages the bars are reset and the animation of the lag time starts again from the top.
5	Lag time scale	The scale of the time lag bar means that full width matches 1 second.
6	Minimum/average/maximum values	This text labels shows the shortest, the longest and the average observed time lag. The labels are updated as long as the lag test runs.
7	Reset button	With this button the minimum, average and maximum values can be reset and in addition a new lag test session can be triggered.

### 7.1.10 Camera options screen



The camera options screen defines the usage of the camera while in Flight Lock mode. Choosing an appropriate setting primarily impacts the robustness of the connection to the relay server. Video recording has the biggest impact so it needs to be tested thoroughly on all but high end devices.

Element	Purpose
1 Camera off button	Switches off the camera.
2 Record video button	Switches on video recording.
3 Take images button	Switches on image capturing at a fixed interval.
4 Image rate	This number determines the image capturing interval in ms (1000 = 1s).
5 Image resolution	This list allows selection of the desired image resolution.

## FlightZoomer Relay Server Application

The FlightZoomer Relay Server application is a rather simple single-screen application. It mainly controls the operations scenarios, which are explained in chapter 5.2.

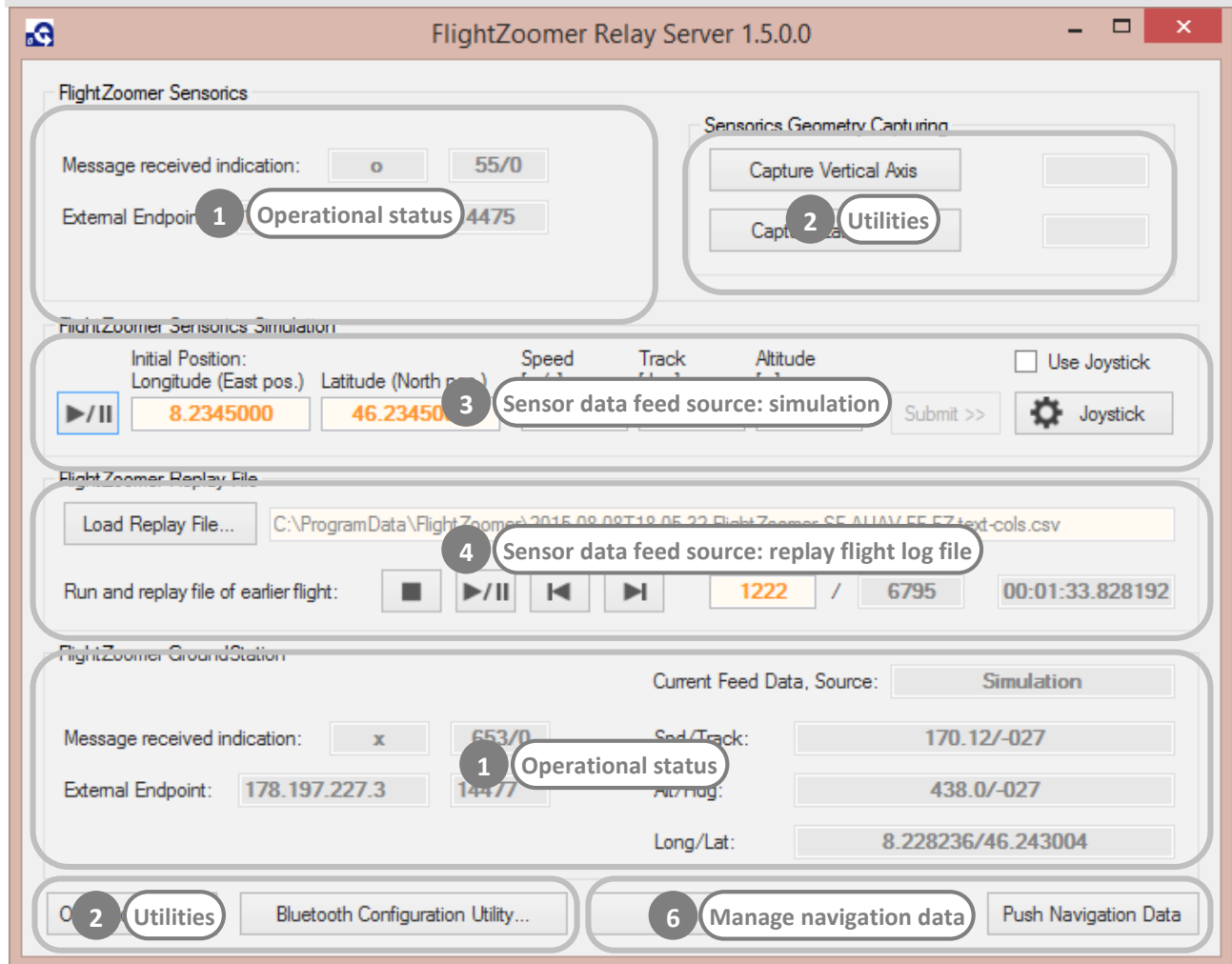
For normal operation the application just needs to be started and that's it. The application runs unattended and will just route incoming sensor data to as many groundstations as connected. The data feed towards the groundstation can come from the sensor device, from the flight simulation feature or from the replay file feature. There is only one restriction: The data feed can only come from one source at a time. Additionally, as soon as data is incoming from the sensor device, the other sources (sim, replay) are deactivated.

Other features are:

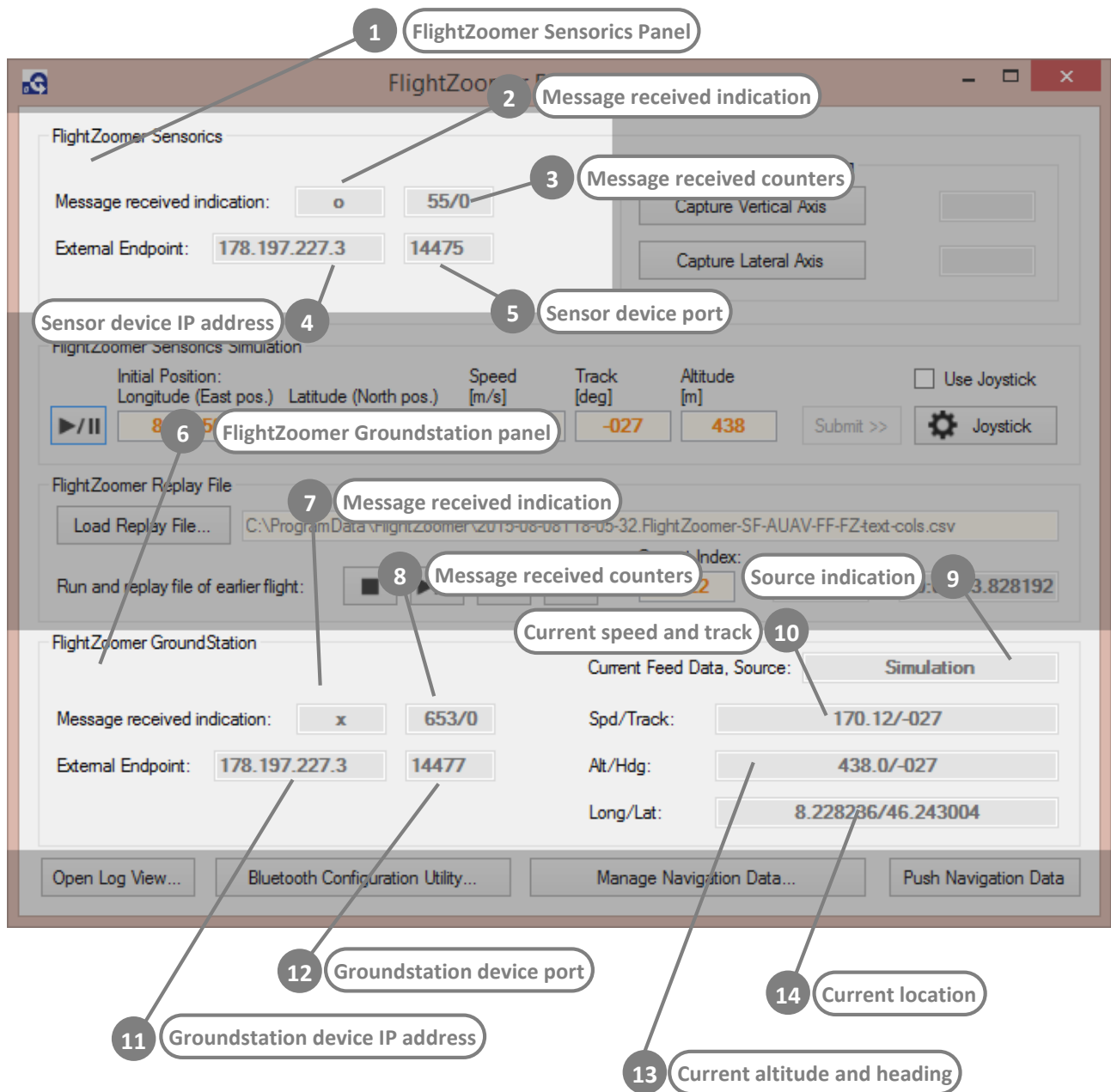
- Operational status indication.
- Automatically store sensor data into the flight log file as soon as the Flight Lock mode is activated.
- Flight simulation based on specified parameters or alternatively on joystick input.
- Replay earlier flight log files.
- Manage navigation data.
- Program HC-06 transceivers with the Bluetooth configuration utility.

## 7.2 FlightZoomer Relay Server desktop application

### 7.2.1 Main screen – overview



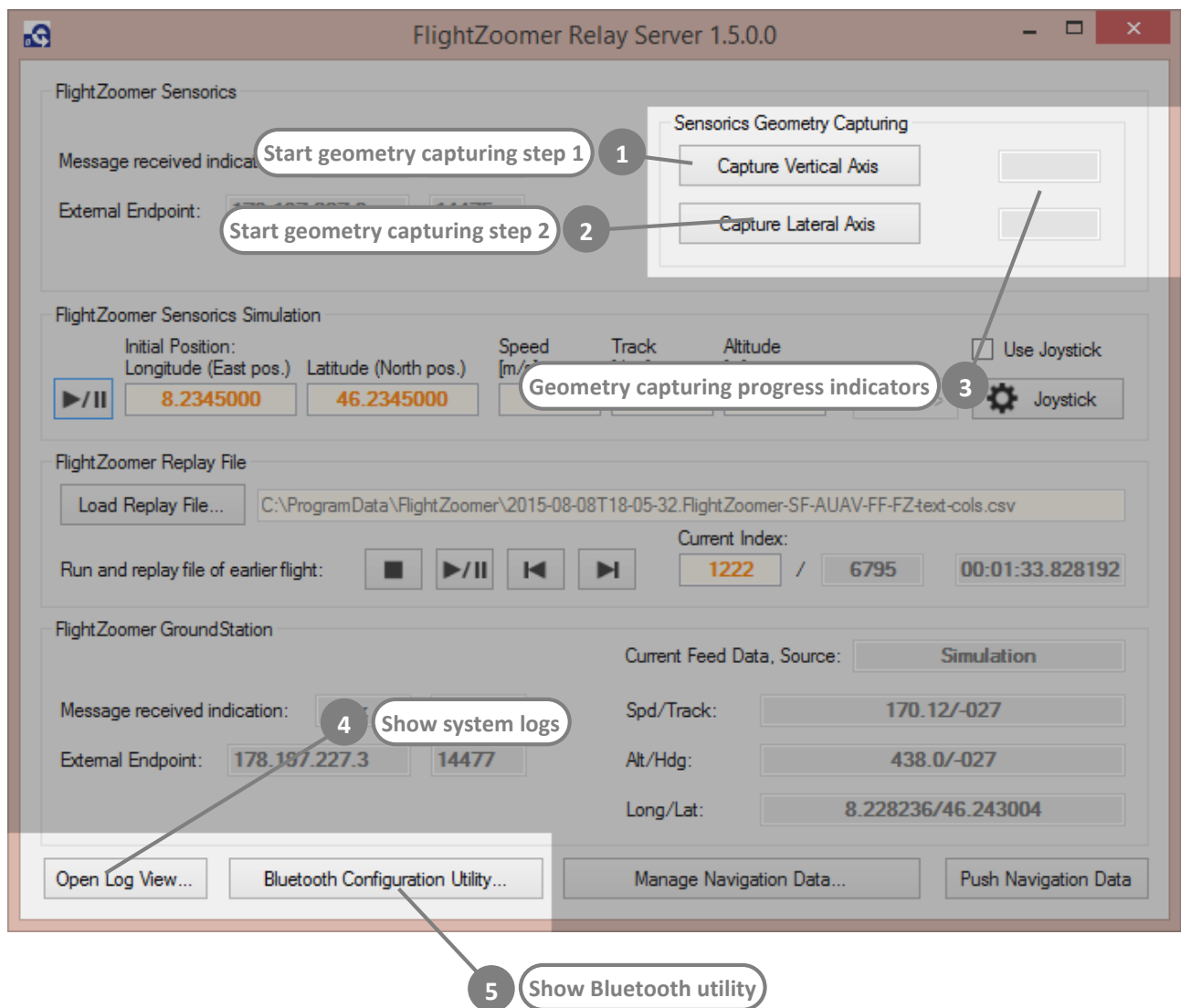
## 7.2.2 Main screen – operational status



Element	Purpose
1 FlightZoomer Sensorics Panel	Section that covers the connection to the sensor device.
2 Message received indication	Indication which toggles between “x” and “o” with each received message.
3 Message received counters	Sensor device message counter. Behind the slash sign the current number of non-sensor-data messages is shown.
4 Sensor device IP address	IP address from which the sensor device is sending messages.
5 Sensor device port	IP port from which the sensor device is sending messages.
6 FlightZoomer Groundstation panel	Section that covers the connection to the groundstation device.
7 Message received indication	Indication which toggles between “x” and “o” with each received message from a groundstation.

8	Message received counters	Groundstation message counter. Behind the slash sign the current number of non-sensor-data messages is shown.
9	Source indication	Indication that shows from where the current sensor data feed towards the groundstation is coming from. The following sources exist: <ul style="list-style-type: none"> <li>- From Sensorics</li> <li>- Simulation</li> <li>- Replay File</li> </ul>
10	Current speed and track	Indication of the speed and track (course over ground) as currently sent to the groundstation. Units are m/s and degree.
11	Groundstation device IP address	IP address from the groundstation device.
12	Groundstation device port	IP port from the groundstation device.
13	Current altitude and heading	Indication of the altitude and heading as currently sent to the groundstation. Units are m and degree.
14	Current location	Indication of the longitude and latitude as currently sent to the groundstation. Units are degrees.

## 7.2.3 Main screen – utilities



Element	Purpose
1 Start geometry capturing step 1	Alternatively, to the menu option in the FlightZoomer Sensorics app, the geometry capturing can also be launched from the relay server application. This buttons initiates the first step (during which the aircraft needs to be kept horizontal). See also chapter 7.1.8.
2 Start geometry capturing step 2	This buttons initiates the second step of the geometry capturing sequence (during which the aircraft needs to be tilted forward). See also chapter 7.1.8.
3 Geometry capturing progress indicators	Progress indications in seconds for each of the two geometry capturing steps.
4 Show system logs	This button opens the log view pop up window.
5 Show Bluetooth utility	This buttons opens the Bluetooth configuration utility as described in chapter 6.3.3.

## 7.2.4 Main screen – simulated sensor data feed

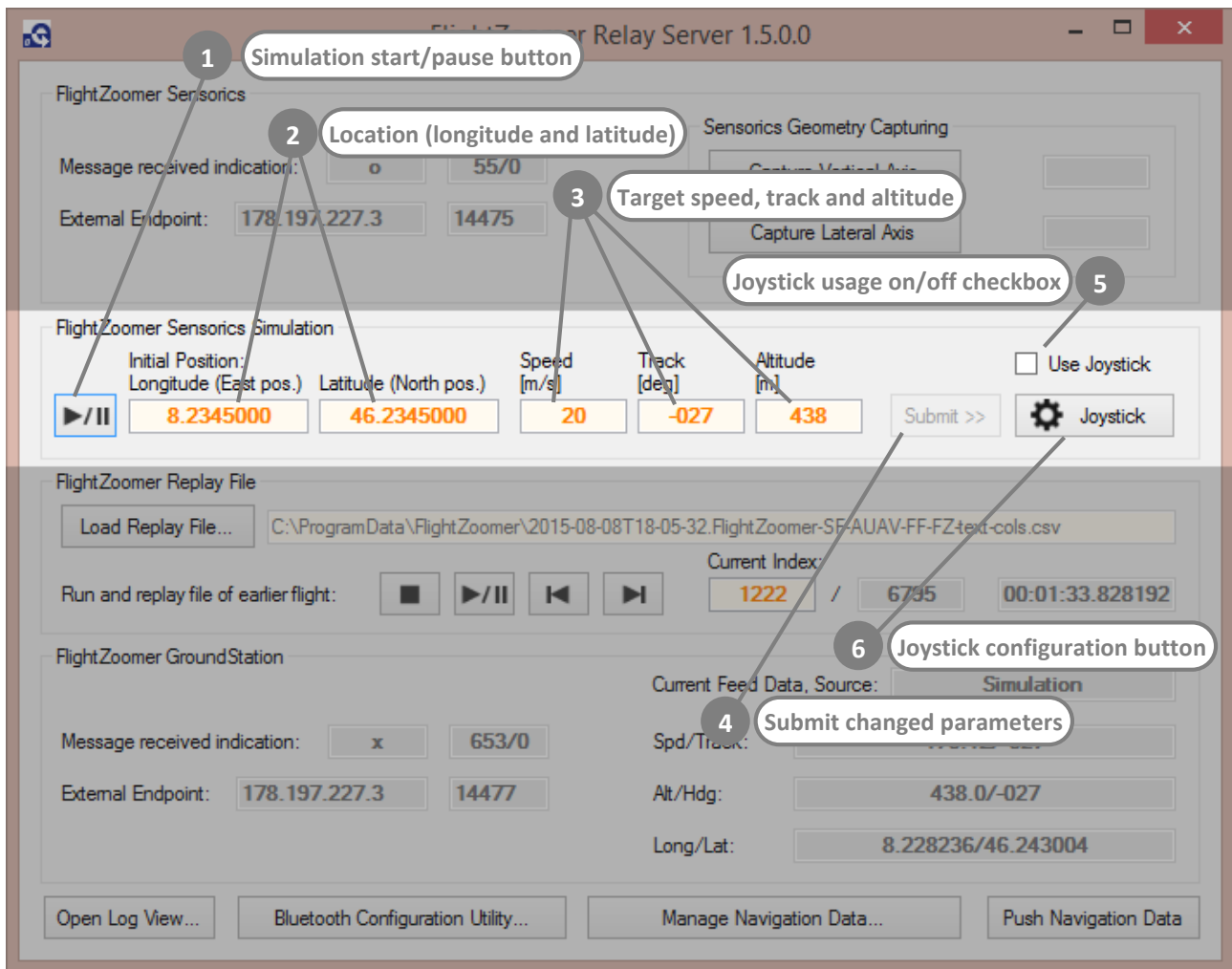
This feature allows injecting any desired flight parameter to simulate aircraft movements for training and demonstration purposes. Using this feature only the groundstation is needed (to “see” what’s going on) while no sensor device is required (in fact the simulation is switched off as soon as real flight data from a sensor device is received).

The simulation is based on longitude/latitude for the (initial) position, the target speed, target track and the target altitude. Additionally, small attitude variations are induced, which add realism.

The initial location (Longitude/Latitude) can be entered by the user before starting the simulation.

The simulation provides following flight parameters:

	Parameter	Purpose
1	Location	Updated every second, derived from the simulated flight trajectory.
2	Speed	Updated by the simulation. Parameter of the current simulated flight trajectory.
3	Altitude, vertical speed	Updated by the simulation. Parameter of the current simulated flight trajectory.
4	Track/heading	Updated by the simulation. Parameter of the current simulated flight trajectory.
5	Pitch	Updated by the simulation. Derived from speed.
6	Bank	Updated by the simulation. Derived from track changes.
7	Horizontal accuracy	Constant value of 2m.
8	Vertical accuracy	Constant value of 5m.



Element	Purpose
1 Simulation start/pause button	This button starts or stops the flight simulation. Therefore, clicking on this button switches off the replay file functionality if it was running). While running, the simulation stops immediately and automatically if data from a sensor device is received.
2 Location (longitude and latitude)	The location can be defined while the simulation is paused. Once the start button is clicked , the textboxes become disabled because the updated locations will steadily be generated by the simulation feature.
3 Target speed, track and altitude	These parameters define the flight trajectory, which the simulation uses. Depending on these parameters each second a new location is calculated. Derivatives as speed acceleration/deceleration ( $\Delta$ speed), yaw rate ( $\Delta$ track) and vertical speed ( $\Delta$ altitude) are calculated adequately to capture changed target values. If any of the target values is updated while the simulation is running, the Submit>>-button becomes enabled. The changed target value will only become effective once the Submit>>-button is clicked.
4 Submit changed parameters	This button allows enables changing target values for speed, track or altitude. More than one changed target value can be activated by one click on the button.



5	Joystick usage on/off switch	Alternatively, the joystick can be used to simulate the flight trajectory. This checkbox activates reading the primary four joystick axes to determine the following four trajectory properties: speed-forwards, speed-sideways, $\Delta$ track and $\Delta$ altitude. Prior to joystick usage the joystick needs to be configured.
6	Joystick configuration button	With this button the joystick configuration popup window can be opened.

### Joystick configuration popup window

With this popup window the joystick can be configured:

Joystick Configuration

Select a device as joystick: Gam

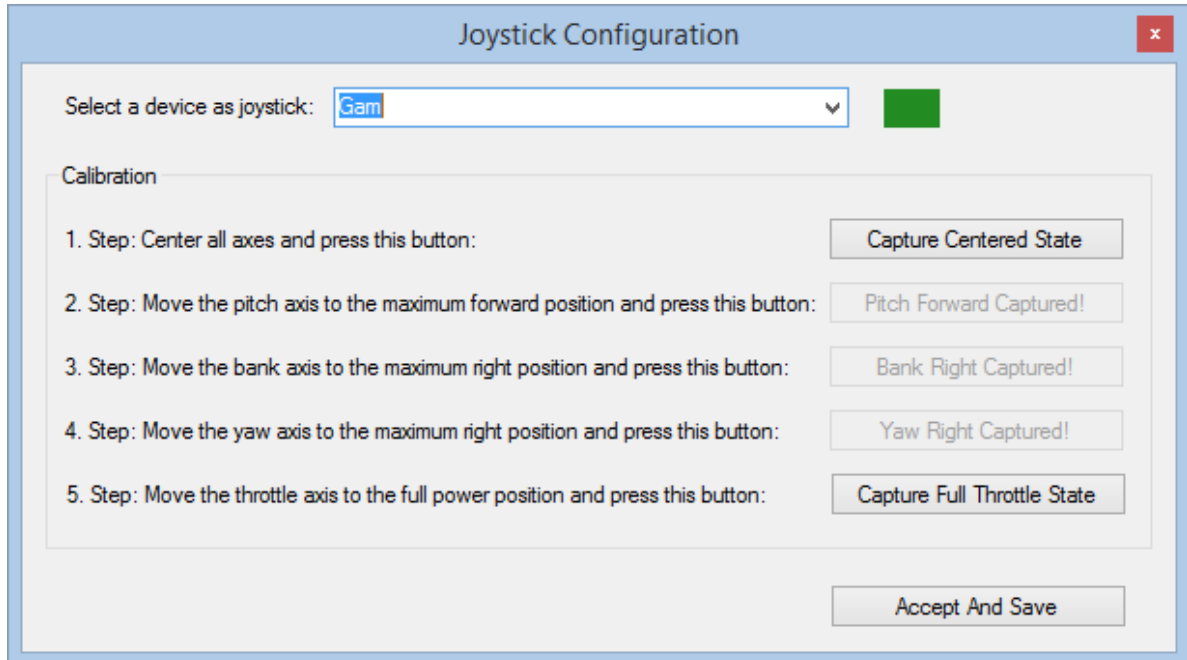
Calibration

1. Step: Center all axes and press this button: Capture Centered State
2. Step: Move the pitch axis to the maximum forward position and press this button: Capture Pitch Forward State
3. Step: Move the bank axis to the maximum right position and press this button: Capture Bank Right State
4. Step: Move the yaw axis to the maximum right position and press this button: Capture Yaw Right State
5. Step: Move the throttle axis to the full power position and press this button: Capture Full Throttle State

Accept And Save

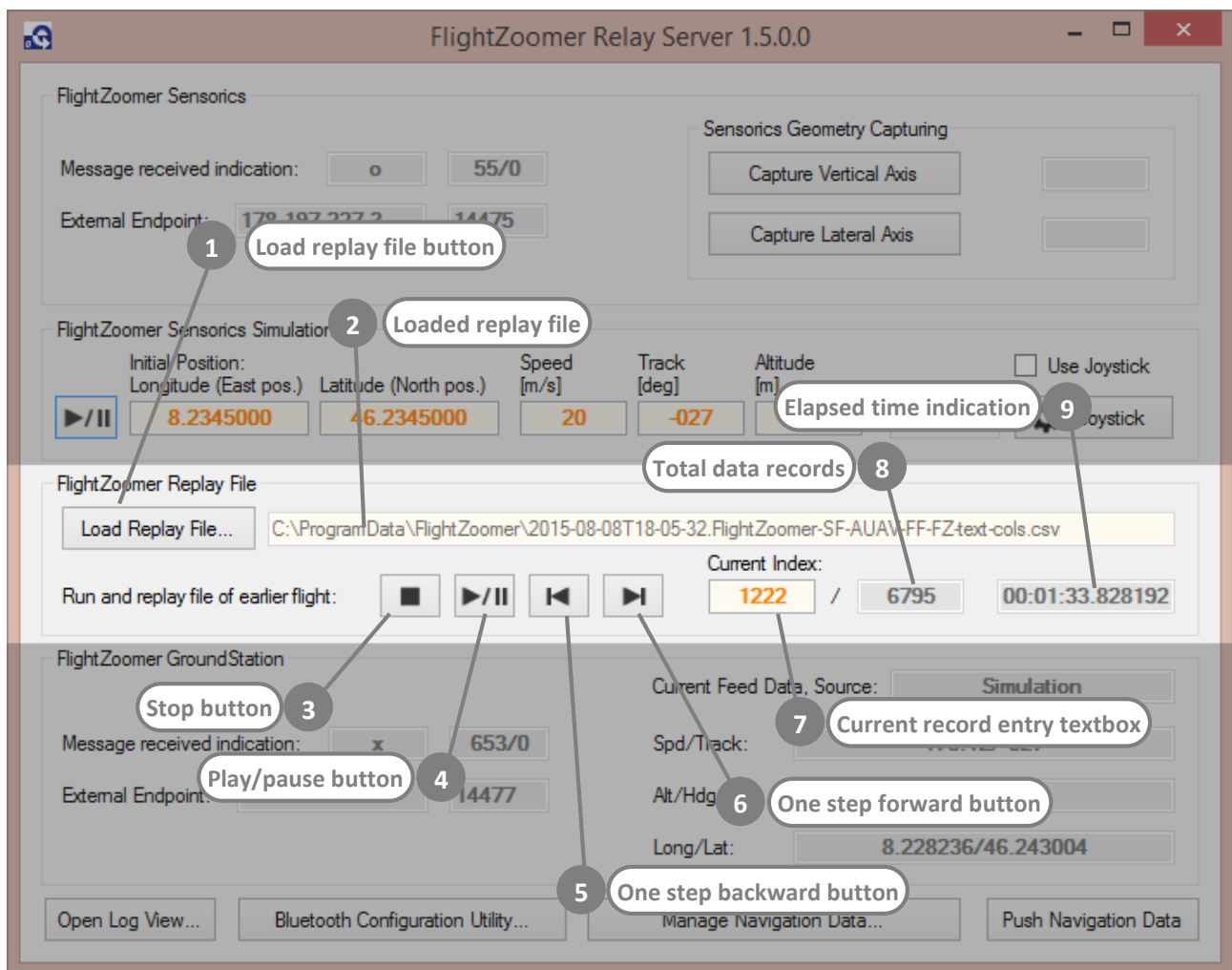
The following procedure is needed to configure all the axes:

1. First select the joystick in the drop down box.
2. Follow the instruction of Step 1 until Step 5 and press the respective button to define and measure each axis.
3. After the pitch, bank and yaw axis have been defined (Step 2 to Step 4) the minimum configuration has been reached and the red indicator at the top becomes green:



4. The throttle (Step 5) can be defined optionally. This allows to use joysticks with only three axes. The limitation is lack of altitude control.
5. At any time, the whole procedure can be reinitiated by capturing the centered state again.
6. Once calibration is complete, click on the "Accept And Save"-button.

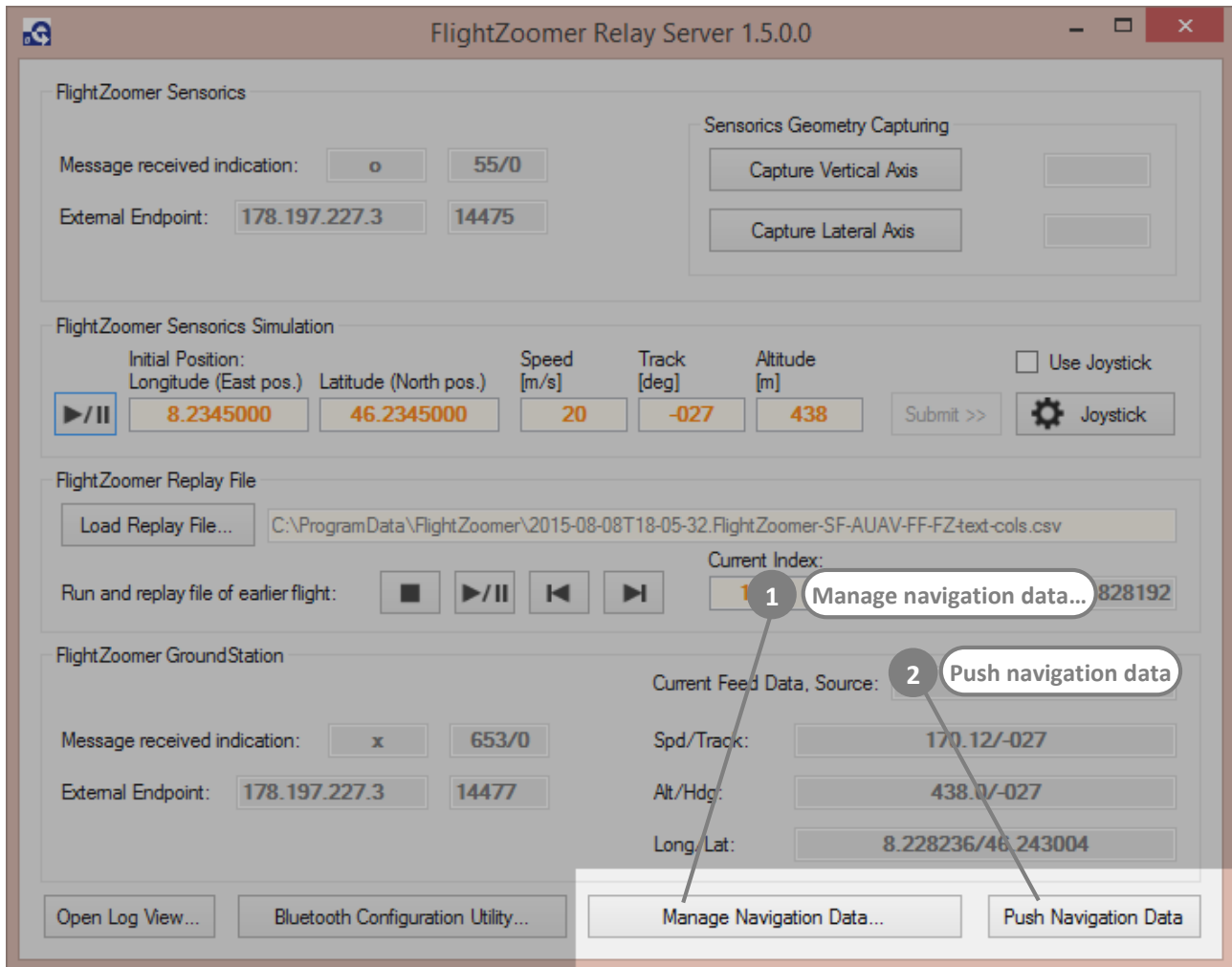
## 7.2.5 Main screen – replay flight from log file



Element	Purpose
1 Load replay file button	This button opens a file selection popup window which allows selecting a flight log file from an earlier flight.
2 Loaded replay file	This read-only textbox shows the path and name of a loaded flight log file.
3 Stop button	This button stops the playback and resets the current index.
4 Play/pause button	Start playback of the loaded flight log file. Repeated clicks toggle between playing back and paused.
5 One step backward button	Allows single step backward movements while the playback is stopped or paused. The current record and the elapsed time indication will be updated accordingly.
6 One step forward button	Allows single step forward movements while the playback is stopped or paused. The current record and the elapsed time indication will be updated accordingly.
7 Current record entry textbox	Allows to specify the exact record number while the playback is stopped or paused. The elapsed time indication will be updated accordingly. Playback will continue exactly at the specified record.
8 Total data records	This read-only textbox shows the total number of data records in the loaded file.

9	Elapsed time indication	The elapsed time indication shows the duration since the beginning of the replayed file.
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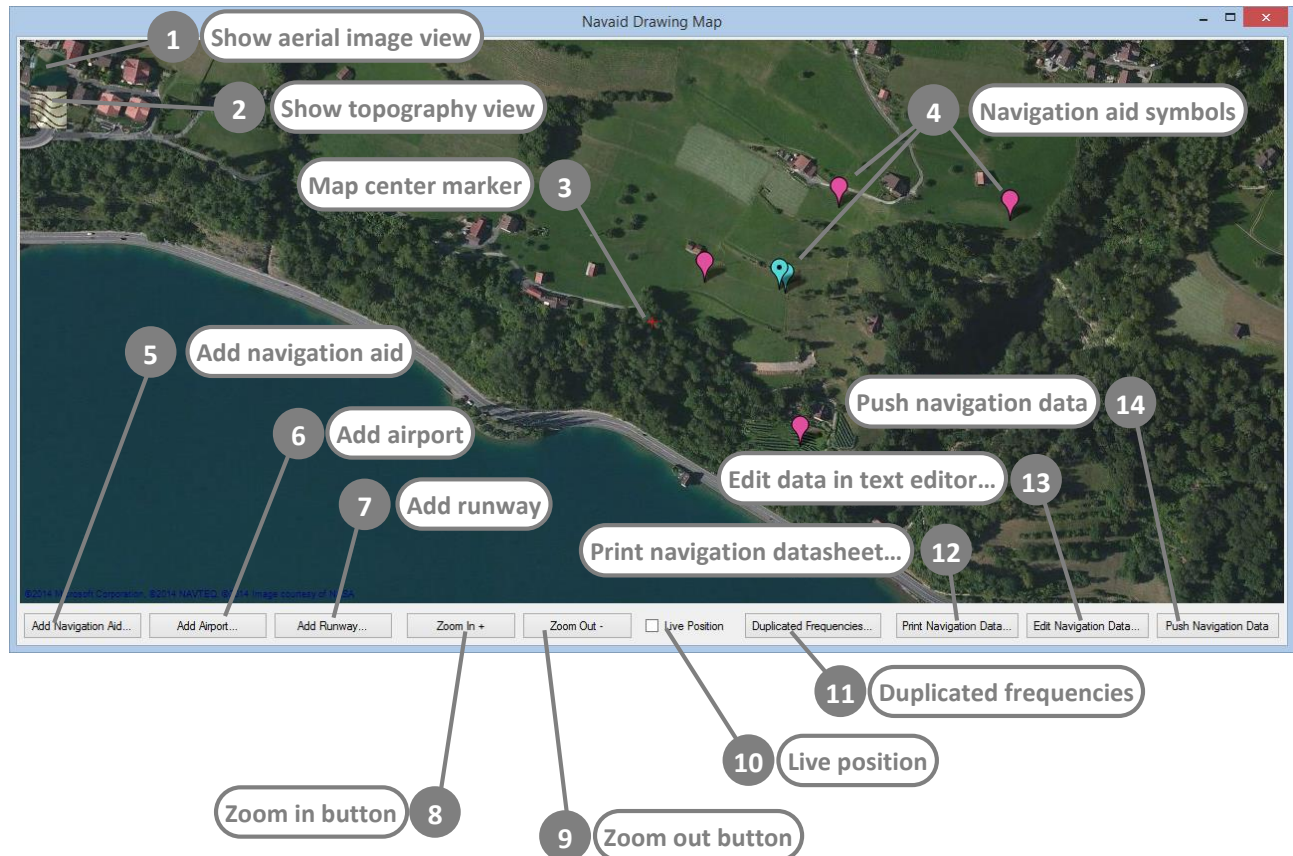
## 7.2.6 Main screen – navigation data






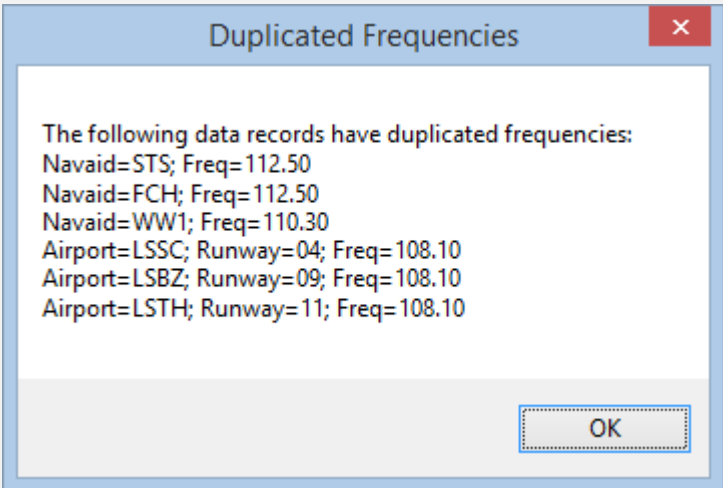
Element	Purpose
1 Manage navigation data	This button opens a popup window which allows management of the navigation data (create, update or delete navigation aids, airports or runways).
2 Push navigation data	Forces updated navigation data to be sent to the groundstations.

## 7.2.7 Navigation aid drawing map – overview

With this popup window the navigation data is managed. Navigation aids, airports and runways can be added, updated or deleted. Details about the navigation aids data model can be found in chapter 5.6.

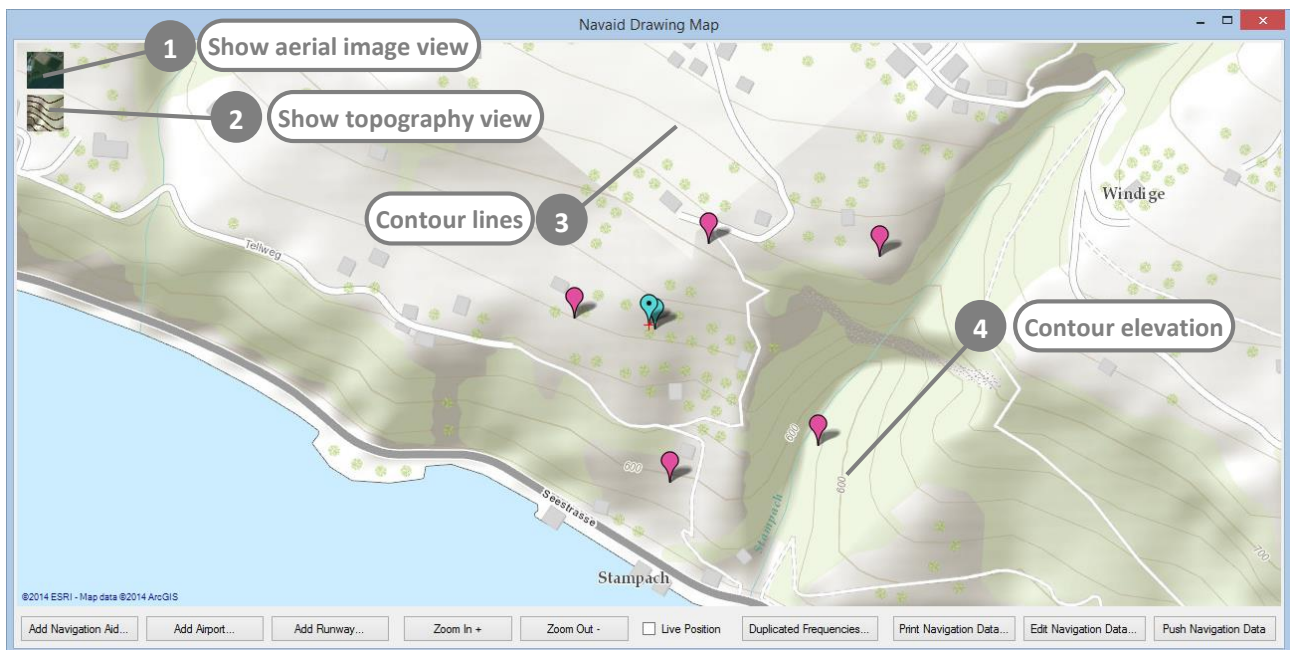


Element	Purpose
1 Show aerial image view	This button shows the aerial image view (default).
2 Show topography view	This button activates the topography view (see below for a screenshot). The topography view shows the contour lines which allow the user to determine the elevation of navigation aids.
3 Map center marker	The map center marker needs to be placed correctly (by moving the map) before one of the add-... buttons is clicked.
4 Navigation aid symbols	Added navigation elements (navigation aids, airports or runways) are shown on the map with one of these symbols: <div style="display: flex; align-items: center; margin-top: 5px;">  <div style="margin-left: 10px;">Navigation aid symbol</div> </div> <div style="display: flex; align-items: center; margin-top: 5px;">  <div style="margin-left: 10px;">Airport symbol</div> </div> <div style="display: flex; align-items: center; margin-top: 5px;">  <div style="margin-left: 10px;">Runway symbol</div> </div> <p>By clicking on any of these symbols, the property view opens on the right side of the screen (see chapter 7.2.9).</p>

5	Add navigation aid	This button adds a navigation aid at the coordinates where map center marker is positioned.
6	Add airport	This button adds an airport at the coordinates where map center marker is positioned.
7	Add runway	This button adds a runway at the coordinates where map center marker is positioned.
8	Zoom in button	This button scales up the shown area on the screen.
9	Zoom out button	This button scales down the shown area on the screen.
10	Live position	By clicking on this checkbox, the map center starts following any reported location from a connected sensor device. It does not show position of the simulation, if running.
11	Duplicated frequencies	<p>This buttons opens a small popup window which shows any duplicated frequencies. This information enables detection and correction of frequencies, which have been assigned two or more times:</p> 
12	Print navigation datasheet...	This button allows printing a cheat sheet which lists all navigation aids, airport and runways.
13	Edit data in text editor...	This button opens the text files of the navigation database in text editors.
14	Push navigation data	Forces updated navigation data to be sent to the attached groundstations again (the same functionality as on the main screen).

## 7.2.8 Navigation aid drawing map – topography view

Alternatively, to the aerial image view, the topography view can be activated:

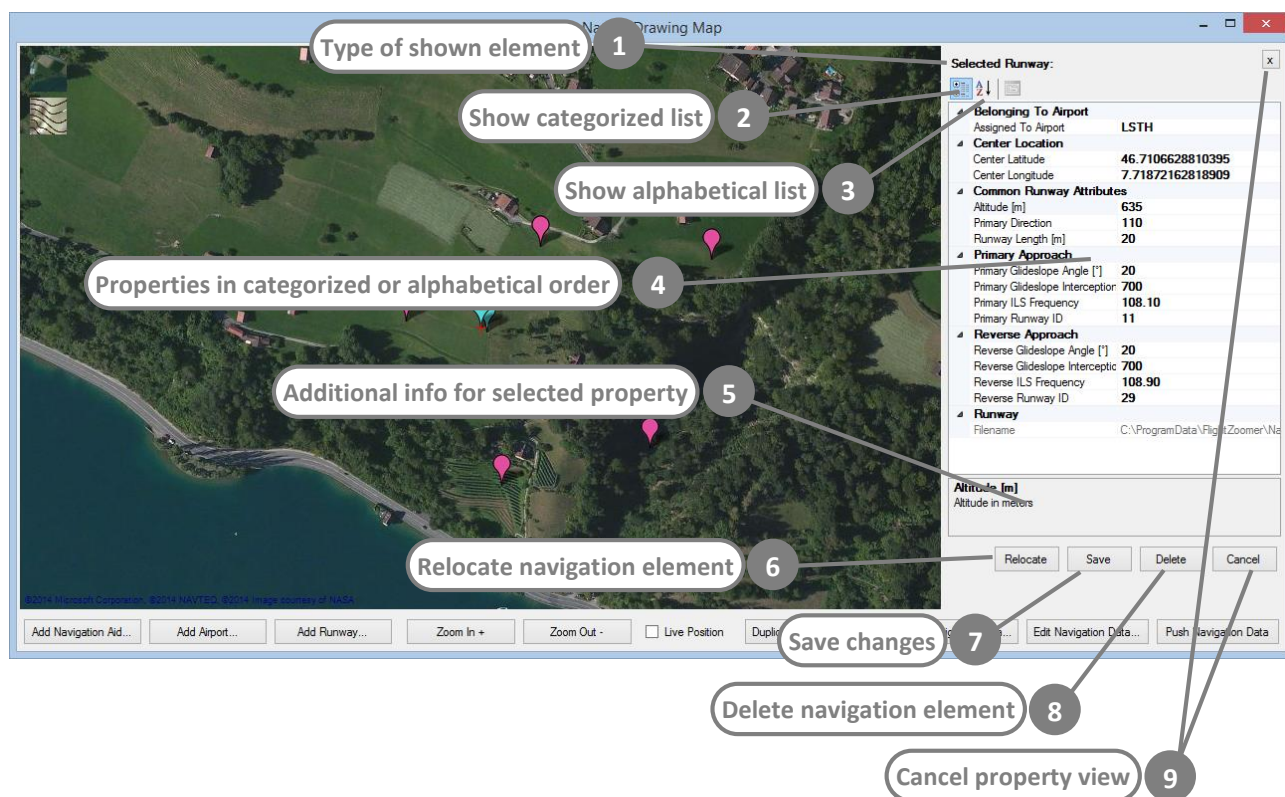


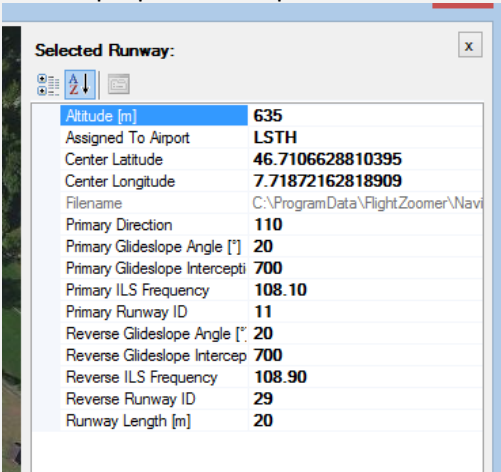
Element	Purpose
1 Show aerial image view	This button shows the aerial image view (default).
2 Show topography view	This button activates the topography view (see below for a screenshot). The topography view shows the contour lines which enable determination of the elevation of navigation aids.
3 Contour lines	This view shows lines of equal elevation.
4 Contour elevation	The elevations of the major contours are printed on the map as well (in meter).



## 7.2.9 Navigation aid drawing map – property view

By clicking on an existing navigation element or by add a new navigation element, the properties are shown and the center mark is placed on the selected navigation element:



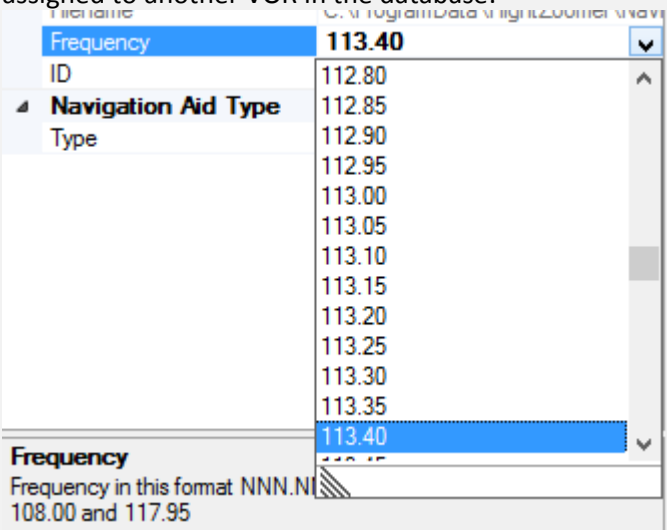
Element	Purpose
1 Type of shown element	This text label shows the type of the selected navigation element.
2 Show categorized list	List the properties in categorized order.
3 Show alphabetical list	List the properties in alphabetical order as follows:
	
4 Properties in categorized or alphabetical order	<p>The property list itself. Any property of the selected navigation element is shown.</p> <p>The properties can be defined or changed by clicking on the property and entering the correct value.</p>



		For some properties the possible list of values is presented in a drop down box. Some properties are read-only.
5	Additional info for selected property	If a particular property is selected, additional information is shown on this panel at the bottom of the property list.
6	Relocate navigation element	This button enables storing a different location for a navigation element. Proceed as follows: Move the map until the center mark is at the new location for the selected navigation element. Click on the Relocate button. Click on the Save button to store the changes.
7	Save changes	With this button changed properties can be saved.
8	Delete navigation element	This buttons deletes the selected navigation element from the navigation database. Before the deletion is executed a confirmation popup window appears.
9	Cancel property view	This button closes the property view without storing any changes.

## Special properties

The following list of properties offers not just a plain textbox but a list of the possible values presented in a drop down box:

Property	Purpose
1 Frequency (navigation element: navigation aid and airport)	<p>The dropdown list presents all available frequencies in the air navigation VHF band 108.00 to 117.95, which have not been assigned to another VOR in the database:</p> 
2 Primary ILS Frequency and Reverse ILS Frequency (navigation element: runway)	<p>The dropdown list presents all available frequencies in the ILS band 108.00 to 111.95, which have not been assigned to another ILS in the database:</p>

Primary Glideslope Intercept	700
Primary ILS Frequency	108.10
Primary Runway ID	108.10
<b>Reverse Approach</b>	108.15
Reverse Glideslope Angle [°]	108.30
Reverse Glideslope Intercept	108.35
Reverse ILS Frequency	108.50
Reverse Runway ID	108.55
<b>Runway</b>	108.70
Filename	108.75
	108.90
	108.95
<b>Primary ILS Frequency</b>	109.10
Frequency in this format NNN.NN	109.15
108.00 and 111.95	109.30
	109.35

- 3 Assigned to airport  
(navigation element: runway)

The dropdown list enables selecting one of the available airports to assign the runway to:

<b>Belonging To Airport</b>	
Assigned To Airport	LSTH
<b>Center Location</b>	LSSC
Center Latitude	LSWH
Center Longitude	LSNF
<b>Common Runway Attributes</b>	LSHG
Altitude [m]	LSBZ
Primary Direction	LSTH
Runway Length [m]	20

## 7.3 FlightZoomer Groundstation-app

The FlightZoomer Groundstation-app is the second app that belongs to FlightZoomer. It runs on a smartphone, which serves as cockpit to the pilot of an RC aircraft. The app displays the sensor data which is received and forwarded from the onboard sensor device.

The additional features are:

- Cockpit instruments with primary- and navigation-display.
- Design and features modeled after the Boeing 787 Dreamliner.
- Synthetic voice output for pilot guidance (“Barking Bob”-feature).
- Radio navigation (based on virtual radio beacons).
- Instrument Landing System.
- Flight Management System for flight planning.

### 7.3.1 Welcome screen

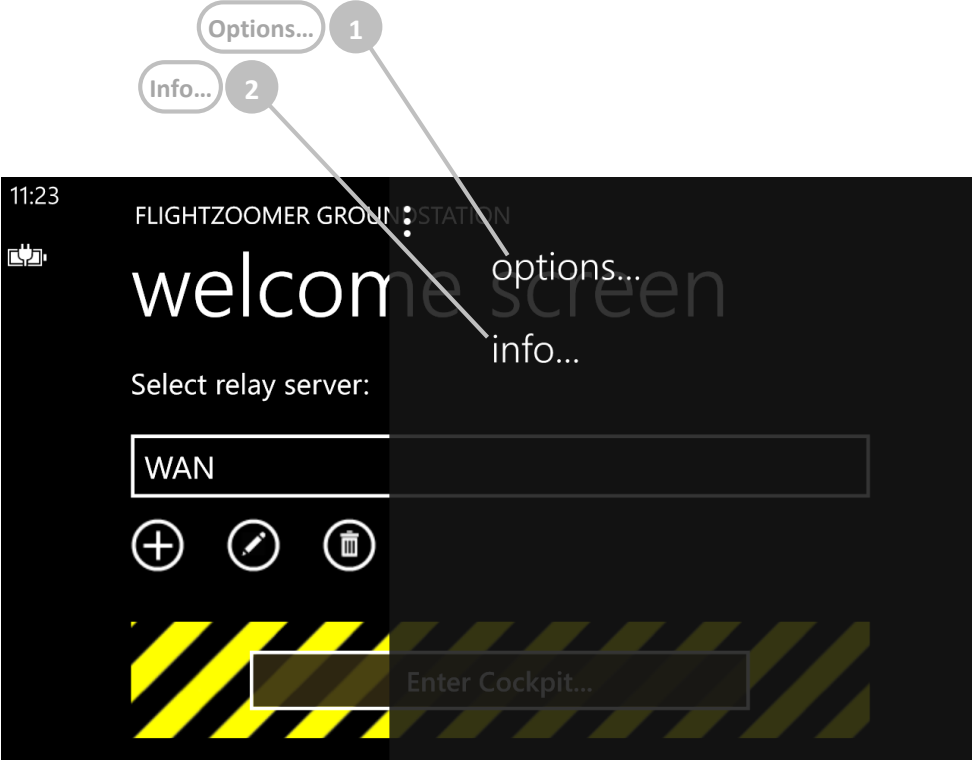


This screen is shown in order to add or modify a relay server.

Element	Purpose
1 Relay server selection box	This selection box shows the currently selected relay server. The box is empty as long as no relay server has been defined.
2 Collapsed options menus	Pressing on the collapsed menu symbol will show the full menu (see chapter 7.3.2).

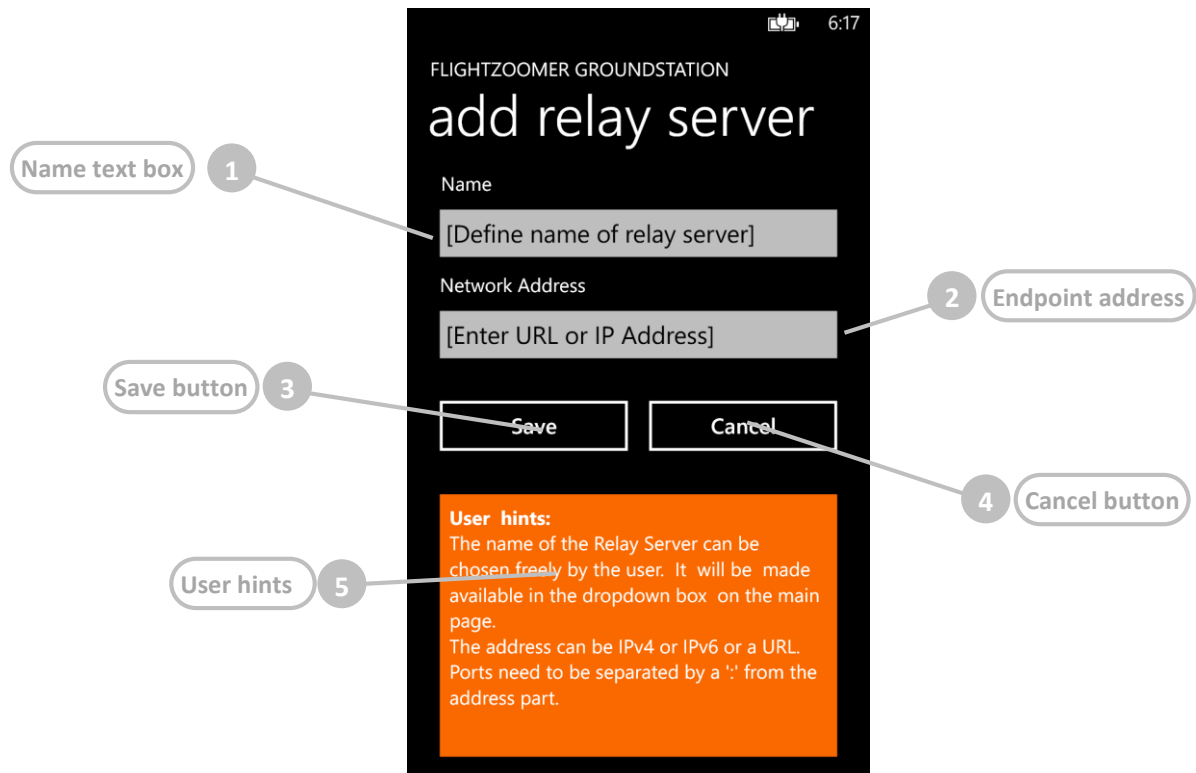
3	Add relay server	The app enables configuration and storage of an unlimited number of relay servers. This button opens a menu to define and add a new relay server. A relay server definition is a combination of a plain text name, an URL (or an IP address) and a port number. Pressing on the button opens the screen as described in chapter 7.3.3.
4	Modify relay server	This button opens a menu to modify the relay server displayed in the selection box. Pressing on the button opens the screen as described in chapter 7.3.3.
5	Delete relay server	This button deletes the relay server displayed in the selection box from the list of stored relay servers.

7.3.2 Welcome screen with options menu expanded



Element	Purpose
1 Options...	This menu command opens the options screen. Pressing on the buttons opens the screen described in chapter 7.3.4.
2 Info...	This menu command opens the info screen, which shows the version, the build date and links for support purposes.

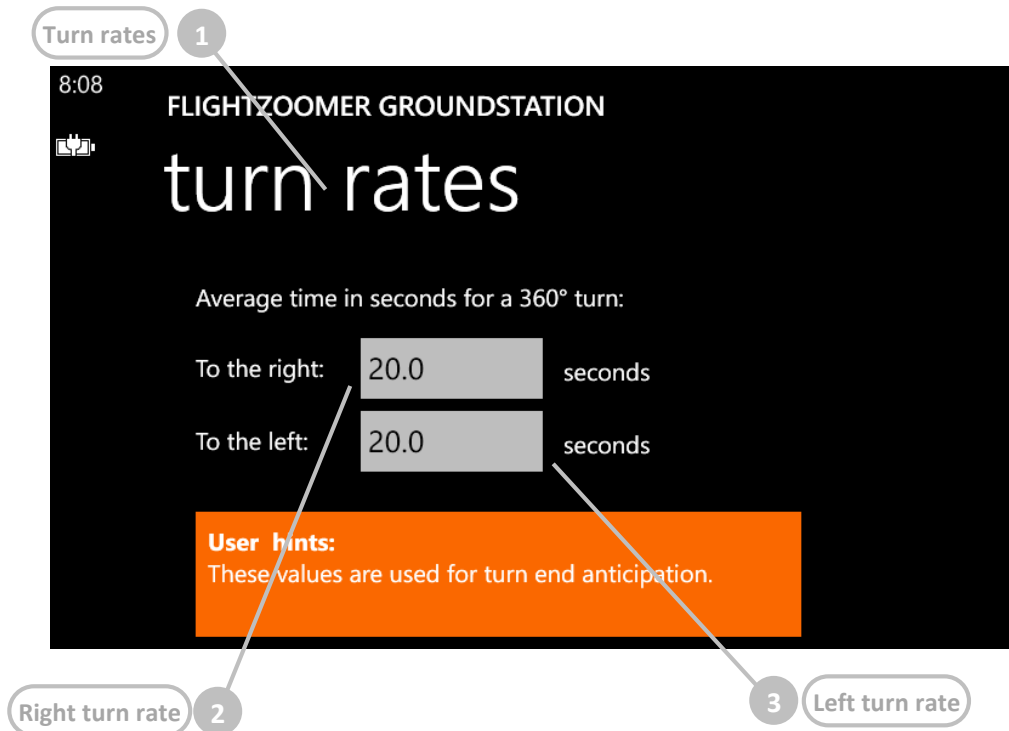
### 7.3.3 Add/modify relay server screen



Element	Purpose
1 Name text box	This text box enables definition of the name of the relay server. The name of the relay server can freely be chosen by the user. It will be available in the selection box on the welcome screen.
2 Endpoint address	This text box enables definition of the IP address (IPV4 or IPV6) or a URL for the relay server. In addition, the destination port can be specified (if it is missing 57778 is taken as default). If specified, the port must be separated by a colon-character (:) from the IP address/URL. The FlightZoomer Sensorics App will connect to this endpoint when building up UDP connectivity with the relay server.
3 Save button	Store the definition/changes.
4 Cancel button	Leave this screen without saving the definition or modification.
5 User hints	Usage and instruction summary

### 7.3.4 Options screen

The options screen can be opened from the *options...*-menu command on the welcome screen. It allows manually setting the standard (average) turn rates. These values can also be determined automatically by the flight test feature (see chapter 7.3.11).



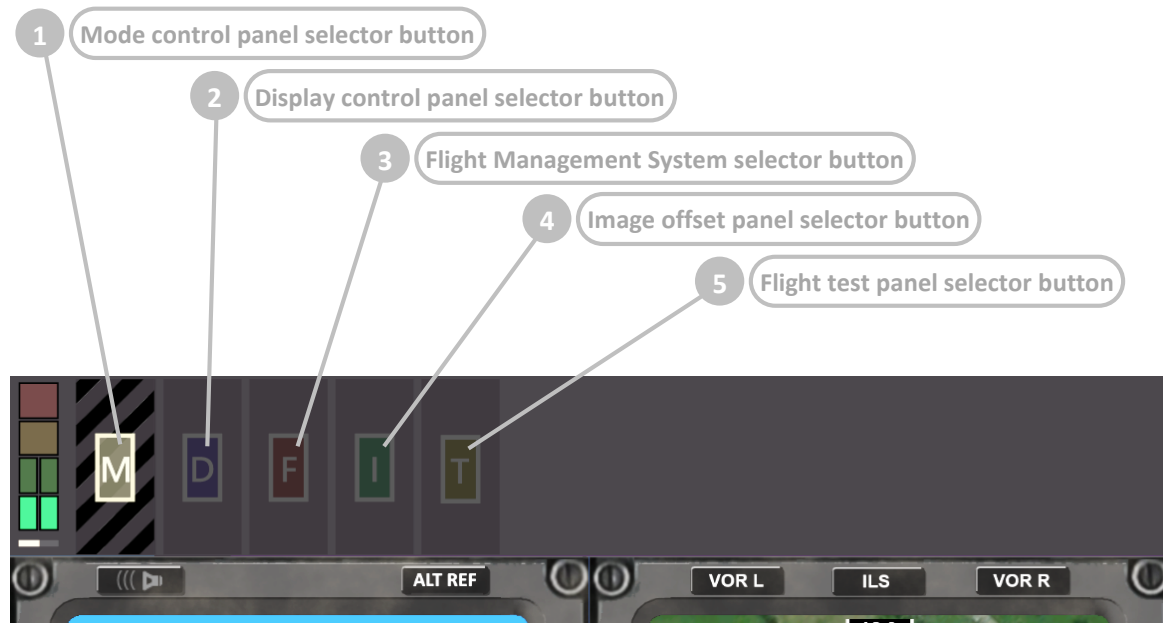
Element	Purpose
1 Turn rates	Currently there is only the <i>turn rates</i> -options screen.
2 Right turn rate	The standard right run rate is the duration in seconds of a 360° right turn. There is a separate setting for the left turn rate (see below).
3 Left turn rate	The standard right run rate is the duration in seconds of a 360° left turn. There is a separate setting for the right turn rate (see above).

### 7.3.5 Main screen – overview



### 7.3.6 Selectable panel bar – overview

The selectable panel bar gives quick access on the various features of the app. By pressing on the capital letters the associated panels can be opened and collapsed again.



Element	Purpose
1 Mode control panel selector	Pressing on the <i>M</i> -button opens the mode control panel.
2 Display control panel selector	Pressing on the <i>D</i> -button opens the display control panel.
3 Flight Management System selector	Pressing on the <i>F</i> -button opens the Flight Management System.
4 Image offset panel selector	Pressing on the <i>I</i> -button opens the image offset panel.
5 Flight test panel selector	Pressing on the <i>T</i> -button opens the flight test panel.

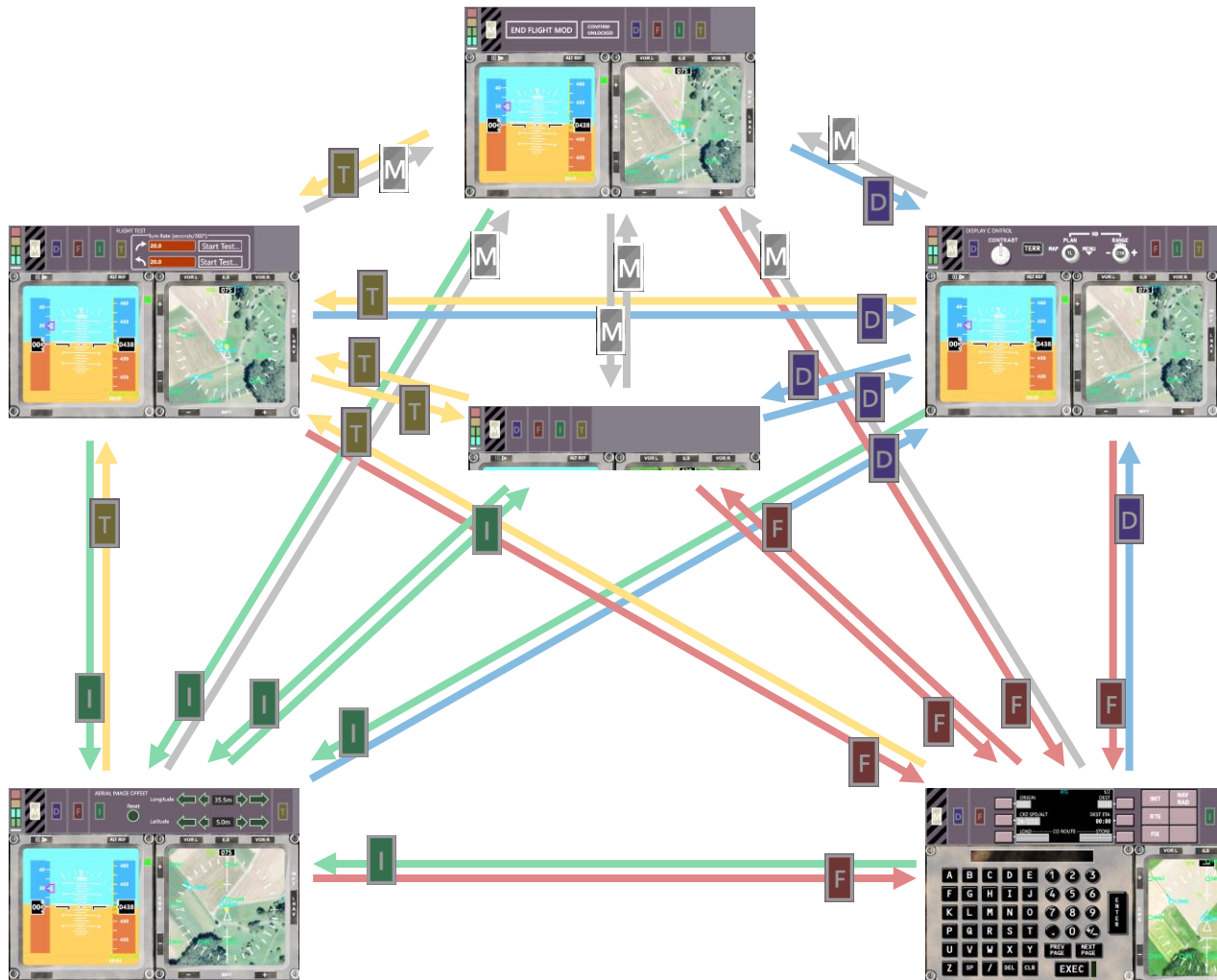
Using the selector buttons on the selectable panel bar any panel can be opened at any time regardless which panel currently is selected. At any time only one selectable panel can be open. The screenshot above shows the selectable panel bar with all panels collapsed so only the selector buttons themselves are visible.

Pressing on a selector button once opens the associated panel. Pressing on the same selector button a second time collapses the associated panel again and returns to the presentation as shown in the screenshot. Pressing on another selector button opens the associated panel and collapses the panel which was shown before.

Opening an associated panel typically means that the selected panel is shown in the selectable panel bar beside the selector button. If *F* is pressed (for FMS) also the lower area of the screen is changed in order to slide in the Flight Management System.



The following diagram shows how any panel can be reached from any other panel:







### 7.3.7 Selectable panel bar – mode control panel

The mode control panel allows switching on and off the Flight Lock mode from the groundstation (as an alternative from using the Flight Lock mode switch on the Sensorics-app). This is useful if there is no easy access to the sensor device while it is mounted on the aircraft.

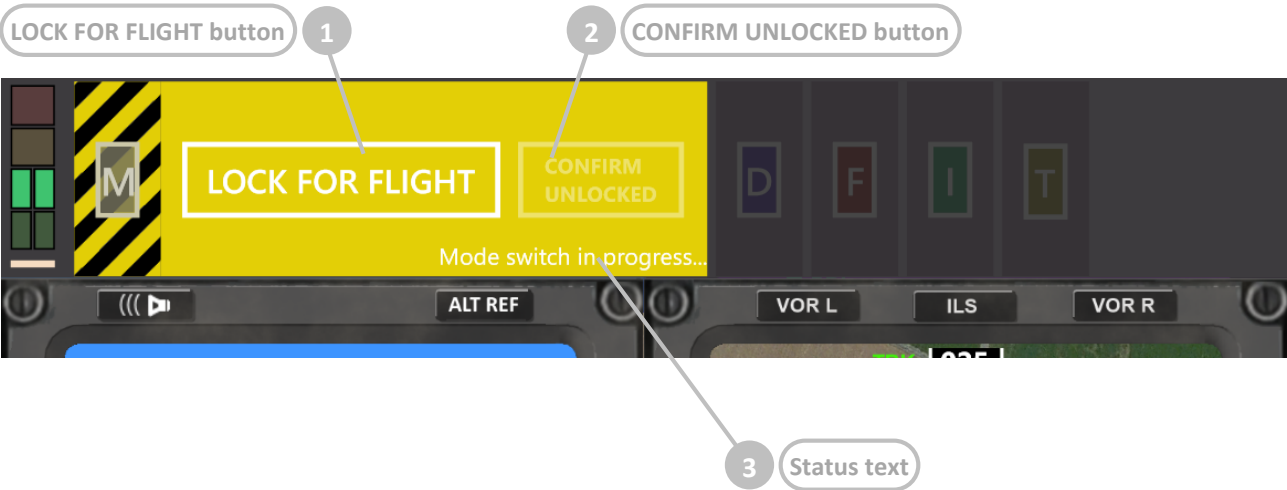
The Flight Lock mode is also coupled with the armed mode of the Ardupilot firmware via MAVLink so alternatively it can be activated also using the RC transmitter.

The FlightZoomer functionality which goes along with Flight Lock mode is locking the screen of the sensor device for user input and starting to record flight data (on the relay server).

As airworthiness is not given unless the Flight Lock mode is switched on, the mode control panel is colored with eye-catching signal colors (yellow and black) prior Flight Lock activation. This also applies to the selector button if the mode control panel is collapsed:

Mode control panel	Flight Lock not active	Flight Lock active
Collapsed		
Open		

The mode control panel in unlocked condition looks like this:



Element	Purpose
1 LOCK FOR FLIGHT button	This button can be used to toggle the Flight Lock mode. The command is propagated to the Sensorics-app and puts the entire system into flight readiness. Once the Flight Lock mode is activated, the background of the panel becomes grey and the caption of the button changes to END FLIGHT MOD.
2 CONFIRM UNLOCKED button	This button overrides the Unlocked Flight Protection feature (see below). This can be useful if aircraft movements are simulated by the relay server.
3 Status text	This text label is only shown while a mode switch has been requested and for the time until the mode has changed.

### Unlocked Flight Protection

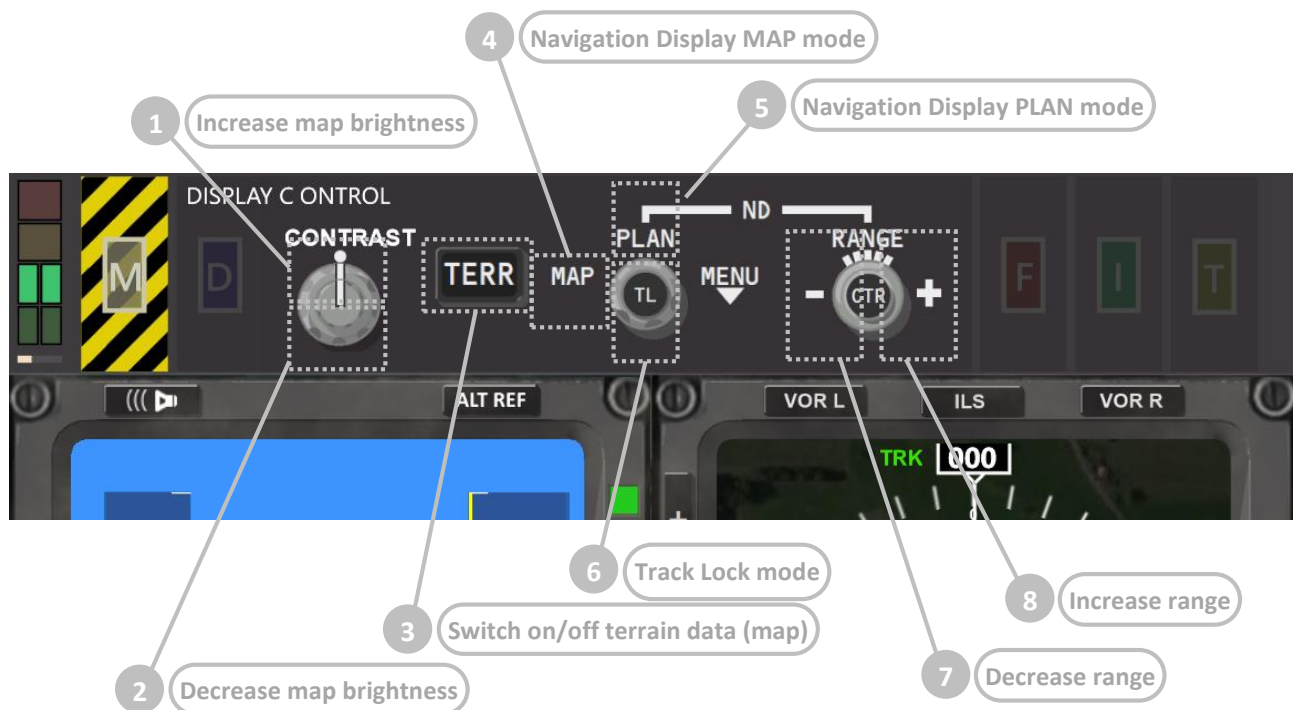
This panel can not only be opened manually by pressing on the *M*-panel selector button, but there is also the Unlocked Flight Protection-feature which prevents flying with the Flight Lock mode not activated. This protection automatically switches to the yellow mode control panel if the Flight Lock mode is not active and the sensor device starts reporting movements.




### 7.3.8 Selectable panel bar – display control panel

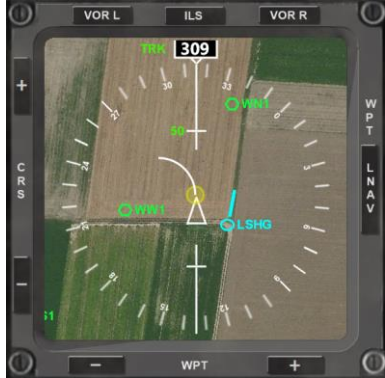

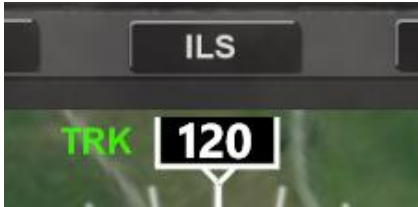

The display control panel is modelled after the EFIS ND Control Panel, which is located on the glareshield of the real Boeing 787:



On this panel the appearance of the Navigation Display can be controlled.



Element	Purpose
1	<p data-bbox="229 210 392 277">Increase map brightness</p> <p data-bbox="528 210 1434 322">By pressing repeatedly on the upper half of the CONTRAST control, the brightness of the terrain on the Navigation Display increases. At maximum brightness the Navigation Display appears like this:</p> 
2	<p data-bbox="229 736 392 804">Decrease map brightness</p> <p data-bbox="528 736 1434 848">By pressing repeatedly on the lower half of the CONTRAST control, the brightness of the terrain on the Navigation Display decreases. At minimum brightness the Navigation Display appears like this:</p> 
3	<p data-bbox="229 1263 507 1330">Switch on/off terrain data (map)</p> <p data-bbox="528 1263 1434 1330">By pressing on this button the terrain can be switched on/off. Without terrain the Navigation Display appears like this:</p> 

4	Navigation Display MAP mode	<p>By pressing on the MAP label the Navigation Display MAP mode is activated. In this mode the compass rose is shown, the aircraft symbol is a triangle which always points upwards while the whole map rotates to indicate the current direction (heading or track in Track Lock mode):</p> 
5	Navigation Display PLAN mode	<p>By pressing on the PLAN label the Navigation Display PLAN mode is activated. In this mode the compass rose is hidden, range circles are shown instead, the aircraft symbol is shaped like an aircraft which rotates according to the current direction (heading or track in Track Lock mode) while the whole map always stays fixed with north pointing upwards:</p> 
6	Track Lock mode	<p>By pressing on the <i>TL</i>-knob the Track Lock mode can be switched on and off. The Track Lock mode determines whether the heading (compass) or the track (from GPS) is taken as source for the current direction. The green label beside the current direction indicates whether the Track Lock mode is active:</p> <div style="display: flex; justify-content: space-around;"> <div> <p>Track Lock mode (label = TRK):</p>  </div> <div> <p>Heading mode (label = HDG):</p>  </div> </div> <p>Further information about the Track Lock mode can be found in chapter 8.1.5.</p>
7	Decrease range	By pressing on the left half of the RANGE control, the range (zoom) of the Navigation Display decreases.
8	Increase range	By pressing on the right half of the RANGE control, the range (zoom) of the Navigation Display increases.



### 7.3.9 Selectable panel bar – Flight Management System (FMS) control panel

The Flight Management System (FMS) control panel is modelled after the FMS, which is located on the forward aisle stand in the real Boeing 787:



While on the Flightzoomer Groundstation-app the controls are arranged somewhat differently, the main features of the generic user interface are there:

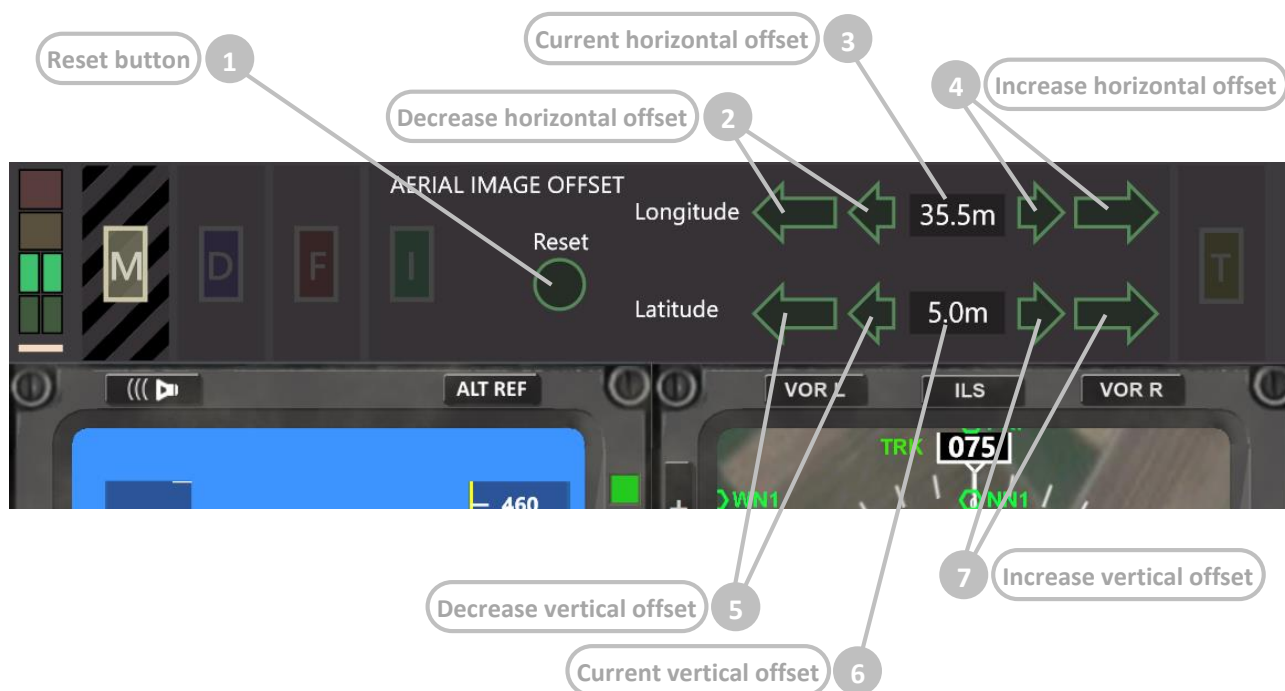


The FMS is described in detail in the chapters 7.3.21 to 7.3.28.

### 7.3.10 Selectable panel bar – aerial image offset panel

In some case the satellite images lack accuracy. If this is the case typically there is a constant offset between the real and the displayed location. The *aerial image offset panel* enables a constant offset to the terrain images to correct any given offset. As long as the aircraft stays in the same area, a constant offset is sufficient to correct any position error. This means that a particular offset setting can be kept as long as flying happens in the same area.

This panel controls the offset in meters of the shown location on the map. The offset only affects the positioning of the terrain. The navigation data symbols are not shifted relative to the aircraft position.



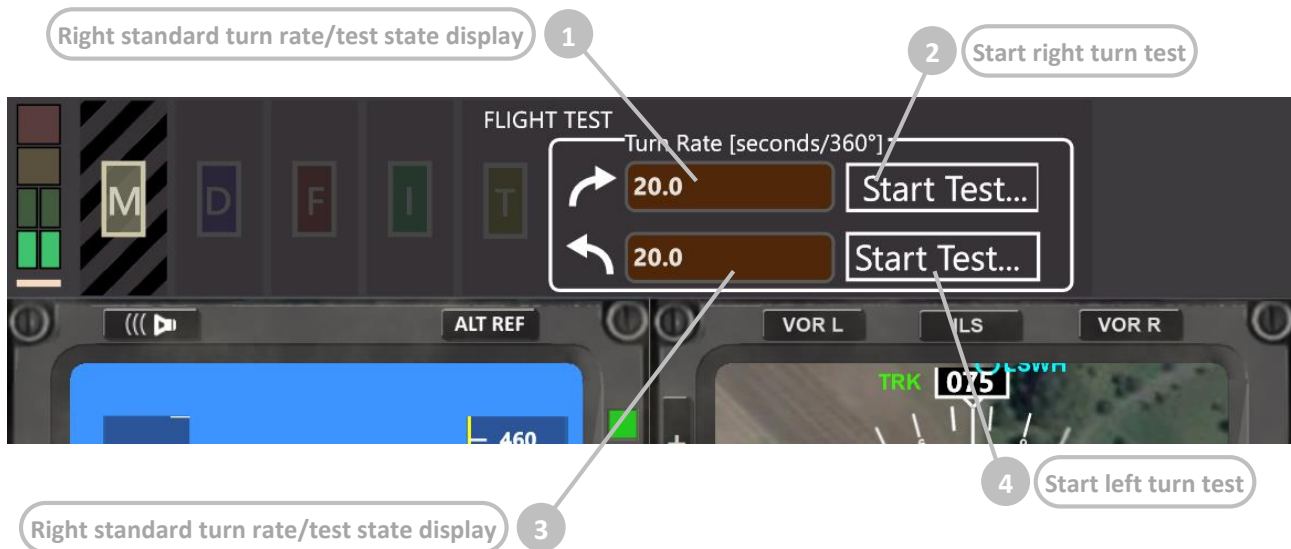
Element	Purpose
1 Reset button	Reset the offset to 0.0m/0.0m
2 Decrease horizontal offset	Decrease the horizontal offset by 5m (larger arrow) or 0.5m (smaller arrow).
3 Current horizontal offset	This readout shows the current horizontal offset in Meter.
4 Increase horizontal offset	Increase the horizontal offset by 5m (larger arrow) or 0.5m (smaller arrow).
5 Decrease vertical offset	Decrease the vertical offset by 5m (larger arrow) or 0.5m (smaller arrow).
6 Current vertical offset	This readout shows the current vertical offset in Meter.
7 Increase vertical offset	Increase the vertical offset by 5m (larger arrow) or 0.5m (smaller arrow).

### 7.3.11 Selectable panel bar – flight test panel

As explained earlier (chapters 1, 6.4.3 and 6.5.2) the standard turn rates in both directions can either be set manually in the *Options...*-menu (see chapter 7.3.4) or be determined automatically by the flight test feature.

The flight test panel supports the execution of the flight test.

The test consists of flying a steady turn and measuring the time it takes until the initial course is reached again. Thus the turn rate is defined as the time to complete a full 360° turn. The test has to be flown in both directions separately so (slightly) different result should be expected.



Element	Purpose
1 Right standard turn rate/test state	This is a read-only textbox initially but after a successfully completed test contains the currently defined right standard turn rate. During a running right turn test the display changes to "Msrg..:" concatenated by the already passed turn angle in degrees. If the test fails, the text changes to "Failed...". If the test did not complete because the turn has been interrupted the text changes to "Discontinued...".
2 Start right turn test	This button initiates a right turn test. The test procedure looks like this: <ol style="list-style-type: none"><li>1. Initiate a steady right turn, preferably with a reproducible and consistent yaw command (see also chapter 6.5.2).</li><li>2. Press this button to start the test.</li><li>3. Monitor the progress of the test on the display.</li><li>4. Once the 360° turn is over the test automatically ends and the result is shown in the test state display.</li></ol>
3 Left standard turn rate/test state	This is a read-only textbox initially but after a successfully completed test contains the currently defined left standard turn rate. During a running left turn test the display changes to "Msrg..:" concatenated by the already passed turn angle in degrees. If the test fails, the text changes to "Failed...". If the test did not complete because the turn has been interrupted the text changes to "Discontinued...".

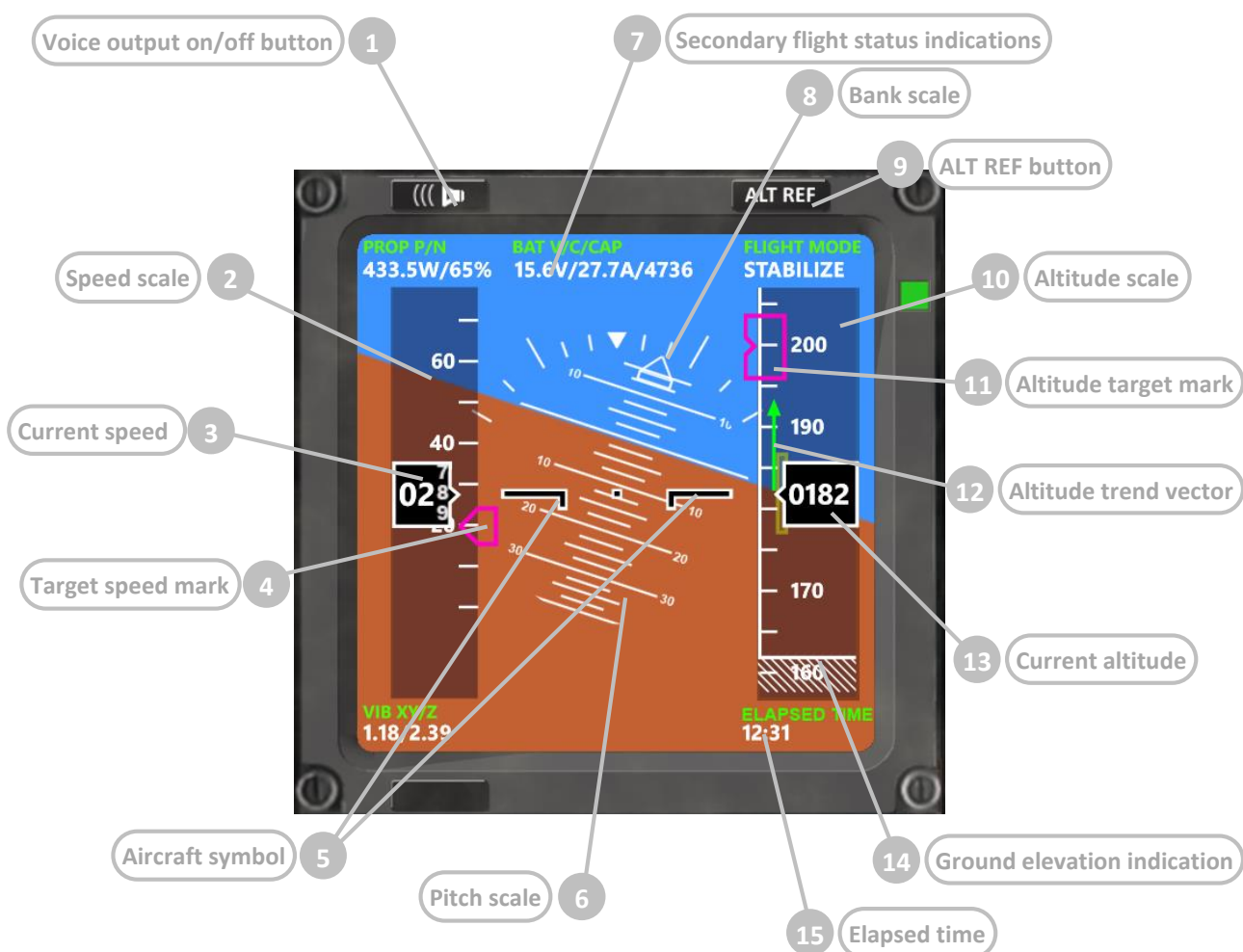


#### 4 Start left turn test

This button initiates a left turn test. The test procedure looks like this:

1. Initiate a steady left turn, preferably with a reproducible and consistent yaw command (see also chapter 6.5.2).
2. Press this button to start the test.
3. Monitor the progress of the test on the display.
4. Once the 360° turn is over the test automatically ends and the result is shown in the test state display.

### 7.3.12 Instruments – Primary Flight Display (PFD) – overview



Element	Purpose
1 Voice output on/off button	This buttons allows switching on and off the synthetic voice output (Barking Bob feature). For more details, see chapter 7.3.29.
2 Speed scale	The speed scale moves vertically in order to keep the current speed at the center.
3 Current speed	The current speed indication shows the momentary groundspeed in the unit chosen on the INIT page of the FMS (see chapter 7.3.23).
4 Target speed mark	The target speed mark indicates the target speed which was defined for the current flight plan (see chapter 7.3.24).

5	Aircraft symbol	The aircraft symbol consists of two wings and indicates the position of the aircraft in relation to the artificial horizon.
6	Pitch scale	The pitch scale indicates the pitch angle of the aircraft. On the screenshot above the aircraft is tilted downward by 7°.
7	Secondary flight status indications	<p>At the top and the bottom (left) of the display a number of secondary flight parameters and status information are displayed. The following data is shown:</p> <p><b>PROP P/N</b> Propulsion power [W] / propulsion power [%]</p> <p><b>BAT V/C/CAP</b> Battery voltage [V] / current [A] / remaining capacity [mAh] The remaining battery is calculated from charged battery capacity as entered on the PERF page in the FMS.</p> <p><b>FLIGHT MODE</b> The current flight mode from the (Ardupilot based) flight controller as received via MAVLink</p> <p><b>VIB XY/Z (at the bottom left)</b> Vibration in the X or Y axis (horizontal, the larger value of the two is shown) / Vibration in the Z axis (vertical)</p>
8	Bank scale	The pitch scale indicates the pitch angle of the aircraft. On the screenshot above the aircraft is banked left by 8°.
9	ALT REF button	The ALT REF button allows setting the current altitude as reference ground elevation. Prior to taking off this button can be used to enforce that the ground elevation indication matches the actually received altitude.
10	Altitude scale	The altitude scale moves vertically in order to keep the current altitude at the center.
11	Altitude target mark	The target altitude mark indicates the target altitude which was defined for the current flight plan (see chapter 7.3.24).
12	Altitude trend vector	The altitude trend vector points to the altitude which will be reached in three seconds if the aircraft continues to climb or descend at the current vertical speed.
13	Current altitude	The current altitude indication shows the momentary altitude in the unit chosen on the INIT page of the FMS (see chapter 7.3.23).
14	Ground elevation indication	<p>The crosshatched area represents the ground which moves along the altitude scale in order to indicate the aircraft altitude above ground. For altitudes above ground between 0 m to 15 m the indication appears in amber, above 15 m in white. Above 25 m the ground elevation indication is not visible.</p> <p>The reference ground elevation can be set either manually (see ALT REF button above) or is set automatically according to these rules:</p> <ul style="list-style-type: none"> <li>- If a flight plan is activated using the EXECUTE button the mean elevation of all the runways of the origin airports are taken as reference ground elevation.</li> <li>- If the flight mode changes to LOCKED and the ground elevation has not been set earlier, the current altitude is recorded as reference ground elevation.</li> </ul> <p>The reference ground elevation is always valid for a static spot. It is not updated according to the actual position of the aircraft.</p>
15	Elapsed time	The elapsed time shows the past time after the activation of the Flight Lock mode. This time can be interpreted as the duration of the flight because

activating the Flight Lock mode is intended to happen immediately prior to taking off.

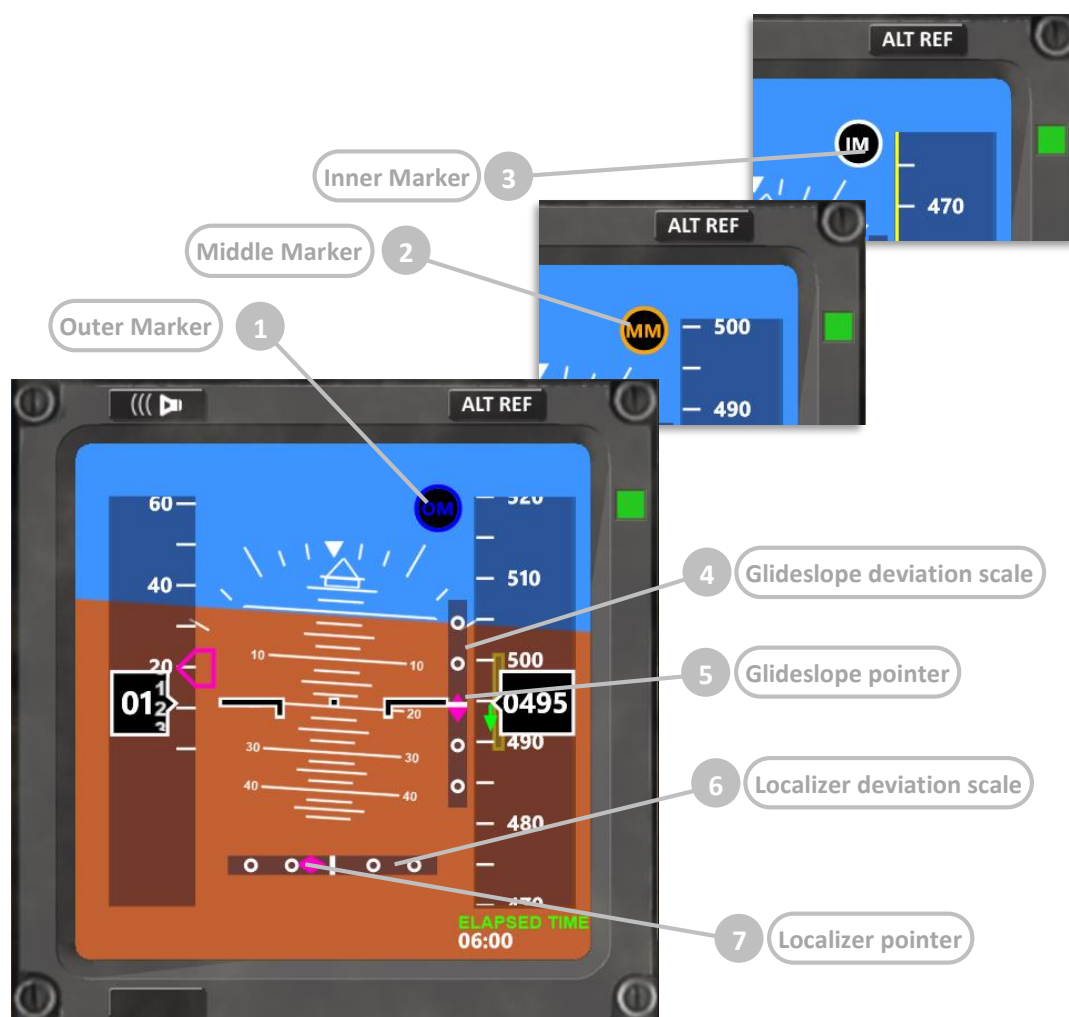
### 7.3.13 Instruments – Primary Flight Display (PFD) – ILS mode

The ILS (Instrument Landing System) allows approaching a runway on the extended runway center line (see chapter 5.6.3). In real world aviation an ILS consists of a localizer which provides directional feedback (how is the aircraft positioned horizontally vs the runway center line) and the glideslope which provides altitude feedback (how much does the aircraft deviate vertically from the glideslope).

FlightZoomer simulates this system using the following components:

- The navigation database which contains user defined runways and ILS approaches (see chapter 5.6.3)
- The NAV RAD page on the FMS which allows the selection of an ILS approach by tuning to the desired frequency (see chapter 7.3.28)
- The deviation and status indications which are shown on the Primary Flight Display during the actual approach, described in this chapter.

The following screenshots show the ILS specific indications on the Primary Flight Display. The ILS specific indications are only visible, if the navigation receiver has been tuned to the primary or reverse ILS frequency of a runway (see chapter 7.3.28) and the ILS mode has been activated on the Navigation Display (see chapter 7.3.15).



Element	Purpose
1 Outer Marker	While overflying the Outer Marker the “OM”-symbol is flashing. Additionally, a 400 Hz tone is beeping. Further details see below.
2 Middle Marker	While overflying the Middle Marker the “OM”-symbol is flashing. Additionally, a 1300 Hz tone is beeping. Further details see below.
3 Inner Marker	While overflying the Inner Marker the “OM”-symbol is flashing. Additionally, a 3 kHz tone is beeping. Further details see below.
4 Glideslope deviation scale	The glideslope deviation scale indicates how much above or below of the glideslope the aircraft currently is.
5 Glideslope pointer	The glideslope pointer moves up and down on the glideslope deviation scale. If the pointer is above the center, the aircraft flies lower than the glideslope. If the glideslope is captured from below the pointer initially sticks to the top of the scale and then moves steadily to the center the closer to the glideslope the aircraft gets.
6 Localizer deviation scale	The localizer deviation scale indicates how much to the left or to the right of the extended runway center line the aircraft currently is.
7 Localizer pointer	The localizer pointer moves left and right on the localizer deviation scale. If the pointer is on the left side, the aircraft is flying too much to the right. If the localizer is captured from the right side the pointer initially sticks at the

left end of the scale and then moves steadily to the center the closer to the runway center line the aircraft flies.

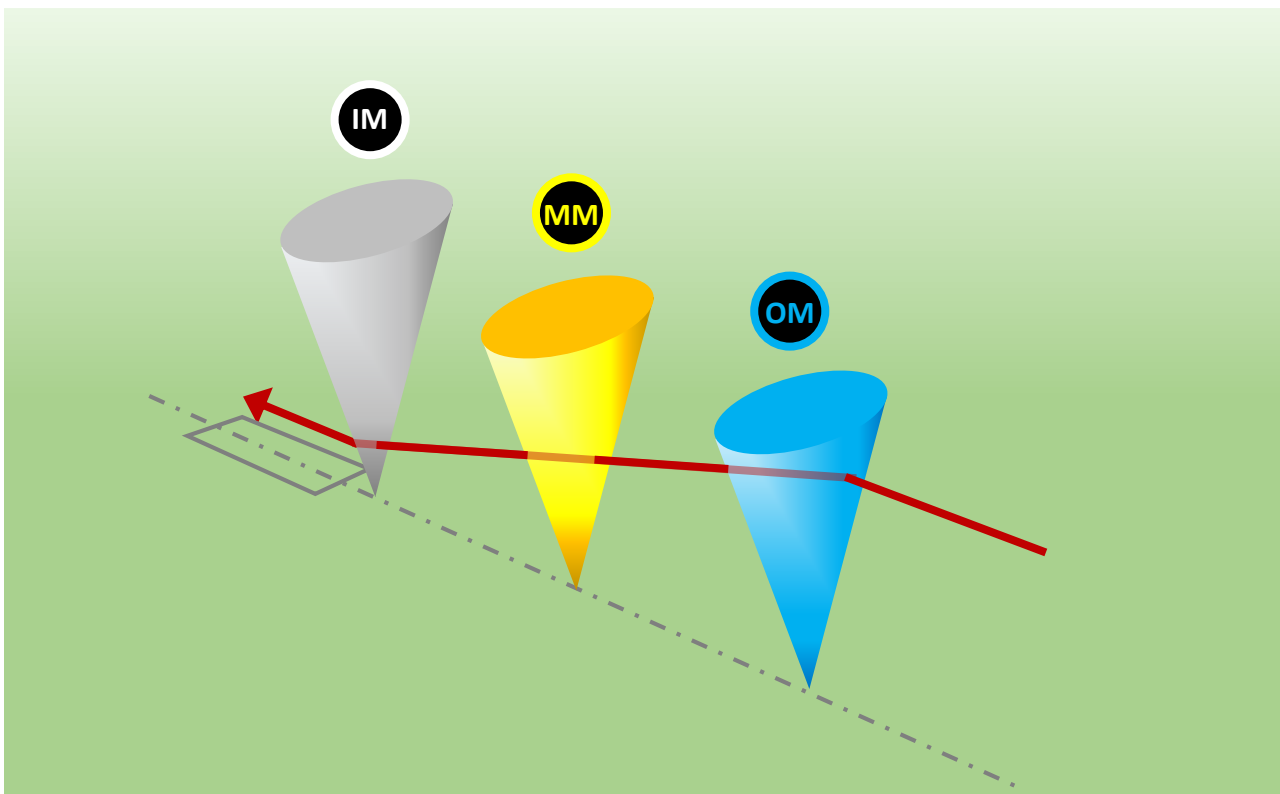
### Marker beacons

In real world aviation the marker beacons are providing aural and visual feedback about the progress of an approach. There are three marker beacons, the outer being placed between 6.5 and 11 km from the runway threshold, the middle being placed at a distance of 3500 ft from the runway threshold and the inner being placed very close to the runway (at Cat II minima).

FlightZoomer marker beacons are placed at the following distances:

- Outer marker beacon: where the capturing altitude intersects the glideslope (see chapter 5.6.3).
- Middle marker beacon: at half of the approach.
- Inner marker beacon: at about 20 ft before the threshold.

The marker beacons represent a vertical cone and while flying through that cone, the respective tone is beeping and the respective symbol on the navigation display flashes:



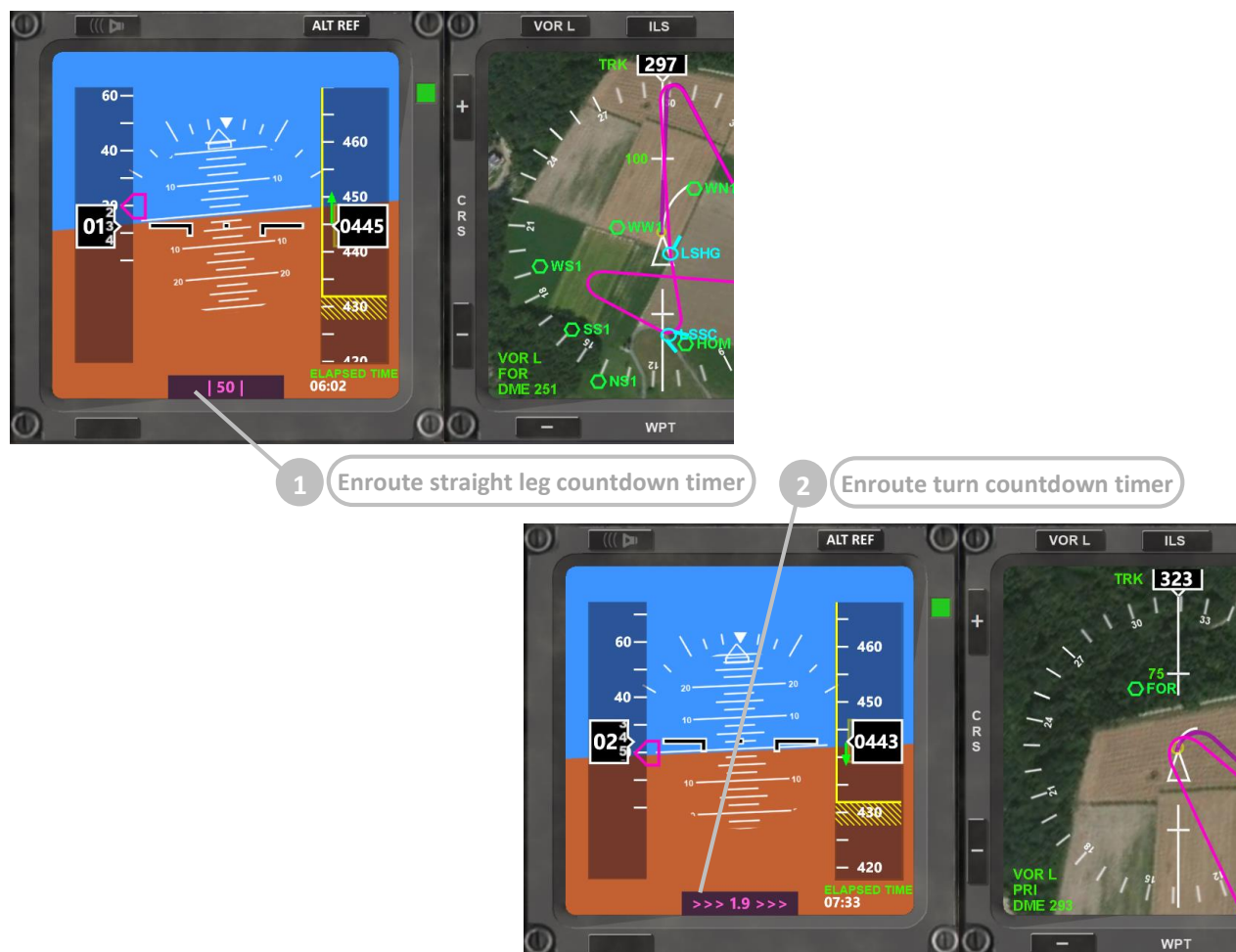
### 7.3.14 Instruments – Primary Flight Display (PFD) – Flight Director mode

In the cockpit of real aircraft, the flight director consists of vertical and a horizontal bars which are displayed on the Primary Flight Display. These bars indicate to the pilot the exact pitch and roll steering commands which are needed e.g. to let the aircraft follow the programmed flightplan. A semi-automatic autopilot so to speak: the system tells the pilot how to manipulate the control stick.

The real 787 flight director bars look like on the following extract from the Boeing Crew Operation Manual. In this example the pilot currently needs to apply some roll-right and pitch-up corrections:



The following image shows the two modes of the FlightZoomer flight director:

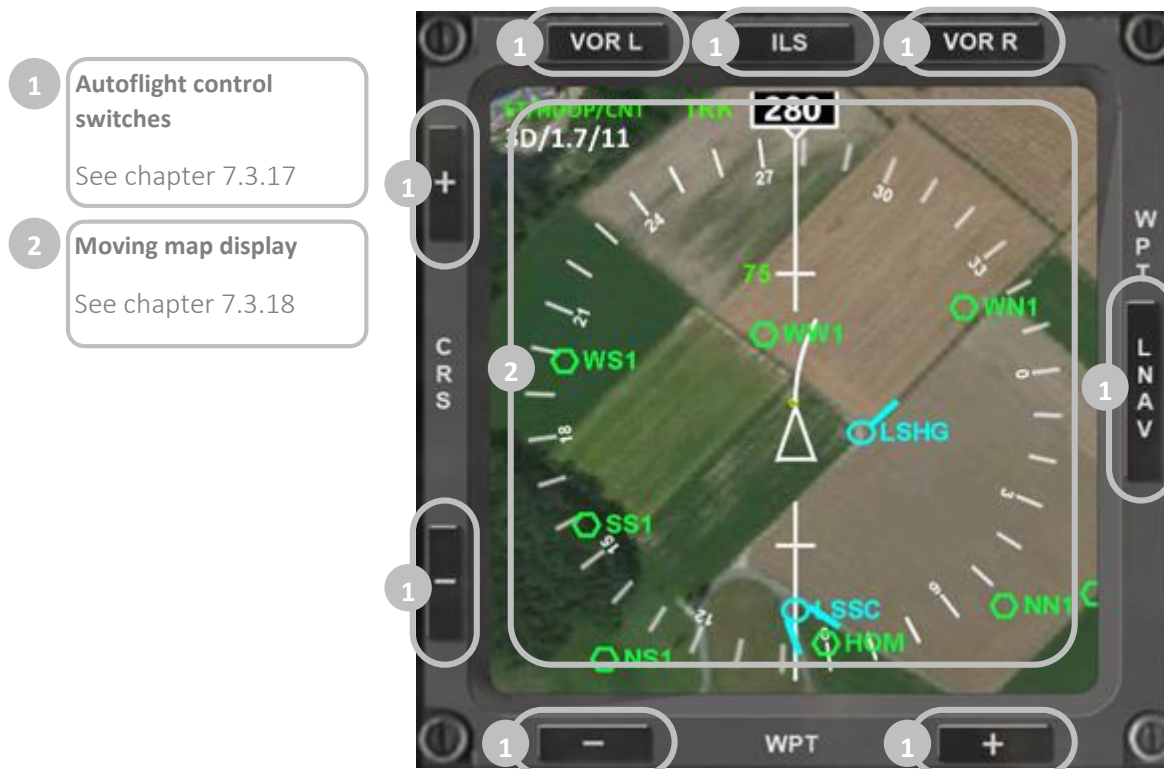


Element	Purpose
1 Enroute straight leg countdown timer	<p>This timer counts down the seconds of the current straight leg while approaching the next turn.</p> <p>Important: the system does not guide the pilot to apply the small corrections needed to follow the deviations which always occur following the straight line. The system only shows the remaining seconds until the next turn needs to be initiated (considering the exact current flight path). For the small corrections the pilot should refer to the Navigation Display.</p> <p>The displayed text pattern is:   [RS]   [RS] = remaining time of the current straight leg in seconds. No places after the decimal point.</p>
2 Enroute turn countdown timer	<p>The turn countdown timer indicates how long the current turn needs to be continued until the correct course for the next leg is established. The calculation of the remaining turn time is based on the standard turn rate. For further information about the standard turn rate refer to chapter 7.3.4 and 7.3.11.</p> <p>The displayed text pattern is either: &gt;&gt;&gt; [RT] &gt;&gt;&gt; or &lt;&lt;&lt; [LT] &lt;&lt;&lt; [RT] = remaining right turn time in seconds. One digit after the decimal point. [LT] = remaining left turn time in seconds. One digit after the decimal point.</p>

### 7.3.15 Instruments – Navigation Display (ND) – overview

The Navigation Display offers situational awareness to the pilot. Additionally, there are several switches which provide control over the autoflight modes and settings.

The following screenshots shows the layout of the Navigation Display:



### 7.3.16 Instruments – Navigation Display (ND) – basic settings

The appearance of the Navigation Display can be controlled by the autoflight control switches (see the next chapter). Additionally, the following basic settings can be controlled by the display control panel:

- Map brightness (see chapter 7.3.8)
- Terrain on/off (see chapter 7.3.8)
- Track Lock (see chapter 7.3.8)
- MAP mode (see chapter 7.3.18)
- PLAN mode (see chapter 7.3.18)



### 7.3.17 Instruments – Navigation Display (ND) – autoflight control switches



Element	Purpose
1 VOR L mode button	Activates radio navigation for the left VOR receiver. The frequency to which the VOR L receiver is tuned on the NAV RAD page selects the actual target radio station (for which a radial shall be captured/followed). By activating VOR L the deviation indicator and DME indications start being displayed on the Navigation Display. Pressing this buttons switches off any other active navigation mode.
2 ILS mode button	Activates the ILS approach which by selecting the ILS receiver. The frequency to which the ILS-GLS is tuned on the NAV RAD page determines the runway which is approached. By activating ILS the deviation indicator and DME indications start being displayed on the Navigation Display. Additionally, the Primary Display changes into ILS mode. Pressing this buttons switches off any other active navigation mode.
3 VOR R mode button	Activates radio navigation for the right VOR receiver. The frequency to which the VOR R receiver is tuned on the NAV RAD page selects the actual target radio station (for which a radial shall be captured/followed). By activating VOR L the deviation indicator and DME indications start being displayed on the Navigation Display. Pressing this buttons switches off any other active navigation mode.
4 Increment Course	Pressing this button increments the course of the expected radial on which a radio beacon can be approached.

5	Decrement Course	Pressing this button decrements the course of the expected radial on which a radio beacon can be approached
6	LNAV mode button	The precondition for using LNAV is an activated flightplan. Pressing the LNAV button activates the mode, where the active flightplan is followed. Pressing this buttons switches off any other active navigation mode.
7	Activate the previous waypoint	Pressing this button while following the flightplan causes the active waypoint to be set to the previous waypoint.
8	Activate the next waypoint	Pressing this button while following the flightplan causes the active waypoint to jump to the next waypoint.

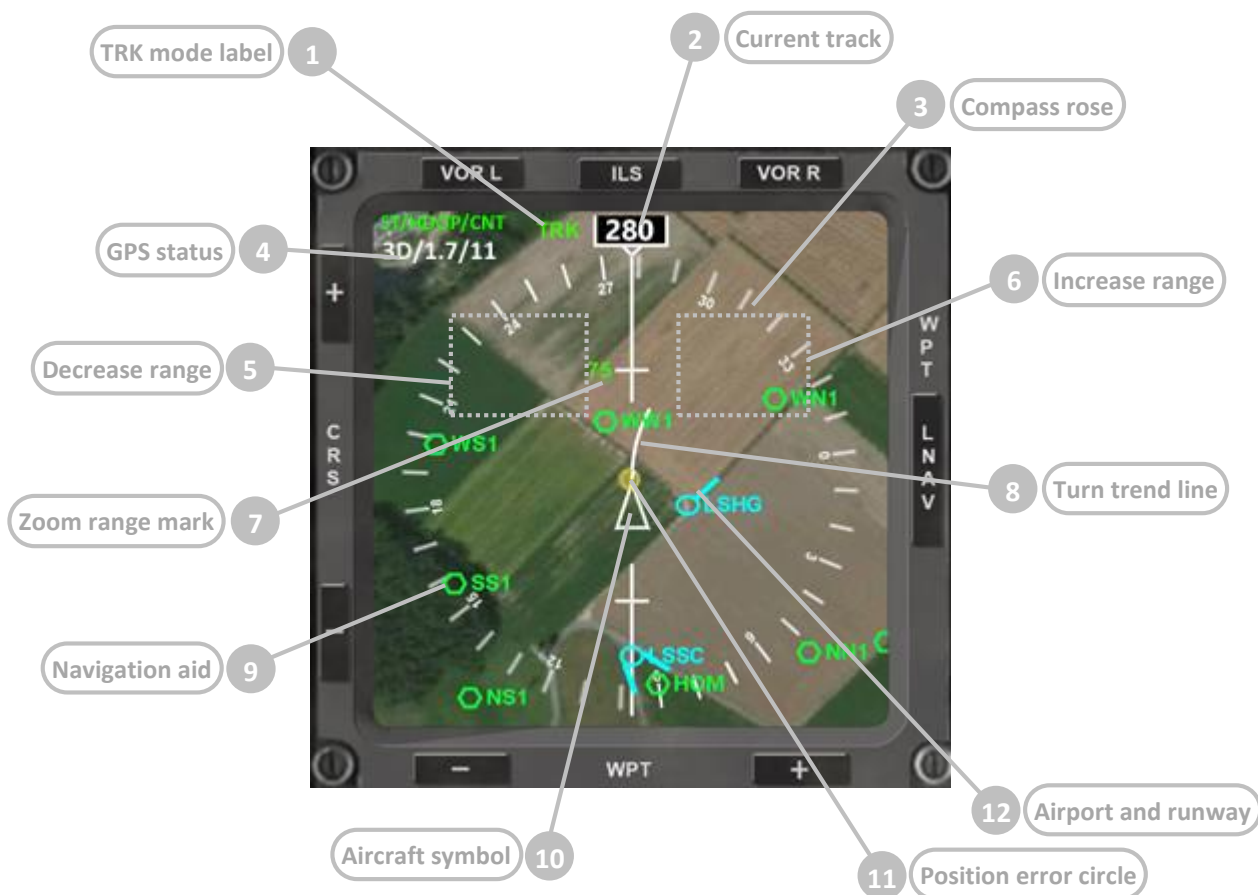
### 7.3.18 Instruments – Navigation Display (ND) – moving map display

The Navigation Display has four basic combinations regarding the presentation of the directional information. The following matrix shows vertically the two sources for directional information (track over ground and magnetic aircraft heading) and horizontally the two basic modes (MAP and PLAN):




	MAP mode	PLAN mode
Track over ground	In MAP mode the aircraft symbols always point exactly upwards. The map is rotated to show the flying direction over ground (derived from GPS).	In PLAN mode the map stays fixed and North is always pointing upwards. The aircraft symbol is rotated to show the flying direction over ground.
Aircraft magnetic heading	Instead of showing the track over ground the map is rotated to show the aircraft heading.	Instead of showing the track over ground the aircraft symbol is rotated to show the heading.

### [Option - MAP mode, Track over ground directional source]

In MAP mode the current track over ground is shown exactly upwards and the map does rotate accordingly. The heading information is not provided.



Element	Purpose
1 TRK mode label	This label indicates the source for the directional information either by showing TRK or HDG. TRK means that the track over ground is shown.
2 Current track	The current track over ground as a 3 digit number with the range 0...360.
3 Compass rose	The compass rose rotates around the aircraft location.
4 GPS status	At the top left the current GPS status information is displayed (this only applies to the GPS information coming from MAVLink). The following information is there: <b>ST/HDOP/CNT</b> GPS Status / reported HDOP / satellite count
5 Decrease range	Pressing this overlay button zooms into the map.
6 Increase range	Pressing this overlay button zooms out of the map.
7 Zoom range mark	The zoom range mark gives an indication about the current scale of the map. The figure is the distance between center of the map and the white small horizontal mark beside the figure. The distance from the center to the compass rose is the double of this distance. The units are always metric. The following range values can be selected:

		- 6.5m; 15m; 30m; 50m; 75m; 100m; 150m; 200m; 300m; 400m; 500m; 700m; 1000m; 2000m; 3000m; 5000m; 50km; 500km; 3000km
8	Turn trend line	This line indicates the flown radius if the current turn rate is maintained.
9	Navigation aid	On the map all the navigation aids are displayed. Beside printing the ID of the navigation aid the following symbols are used: <ul style="list-style-type: none"> <li>- VOR, GPS FIX </li> </ul>
10	Aircraft symbol	The aircraft symbol is a white triangle.
11	Position error circle	A yellow circle shows the estimated position error (HDOP if the flight controller is the source).
12	Airport and runway	On the map also all the airports are displayed. Beside printing the CODE of the airport the following symbols are used: <ul style="list-style-type: none"> <li>- Airport </li> <li>- Runway (showing length and direction) </li> </ul>

### [Option - MAP mode, Heading directional source]

In this mode the current magnetic heading of the aircraft is shown exactly upwards and the map does rotate accordingly. The track information is provided by the track indicator.

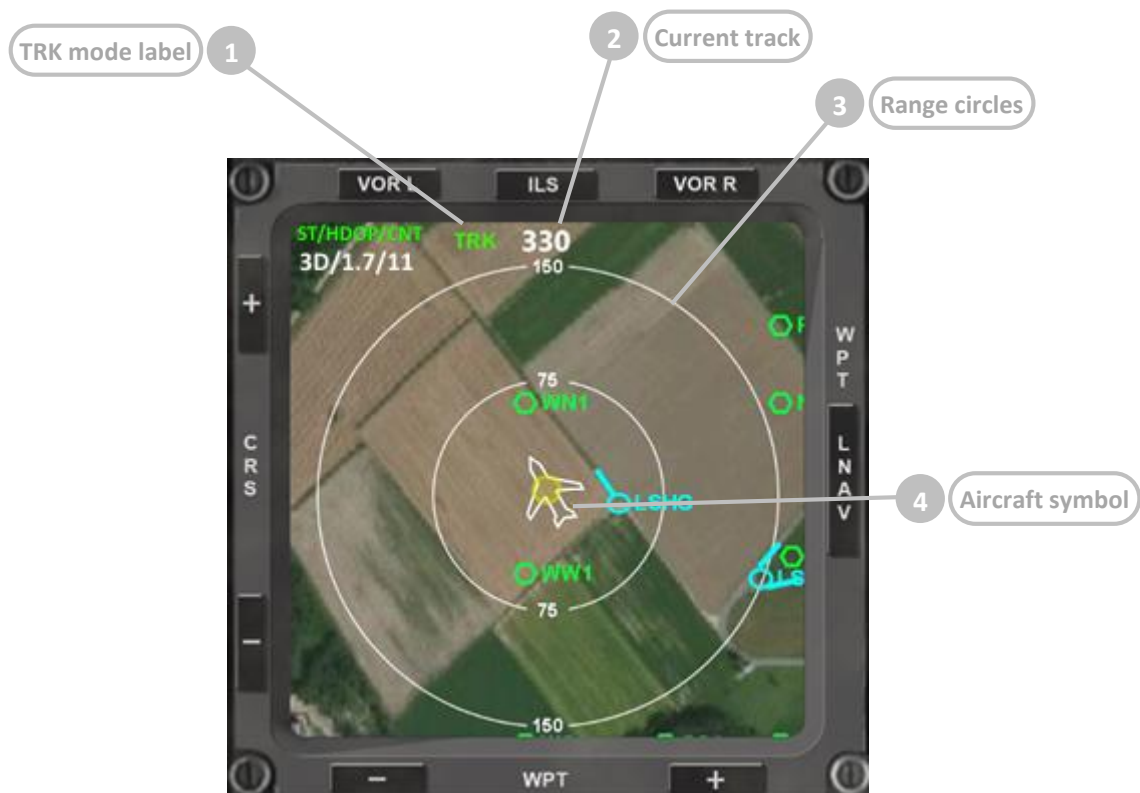


Element	Purpose
1 HDG mode label	This label indicates the source for the directional information either by showing TRK or HDG. HDG means that the heading is shown (where is the aircraft's nose pointing to). Due to side wind components the actual track above ground can differ from the heading.
2 Current heading	The current heading as a 3 digit number with the range 0...360.
3 Track indicator	The track indicator shows the track over ground as additional information.

### [Option - PLAN mode, Track over ground directional source]

In PLAN mode the aircraft symbol does rotate according to the current track over ground and the map stays fixed with north pointing upwards. The heading information is not provided.

The following description only highlights the differences to the MAP mode. The range control buttons and the symbols stay the same.



Element	Purpose
1 TRK mode label	This label indicates the source for the directional information either by showing TRK or HDG. TRK means that the track over ground is shown.
2 Current track	The current track over ground as a 3 digit number with the range 0...360.
3 Range circles	The range circles are centered at the aircraft position and show zoom range and the double zoom range.
4 Aircraft symbol	In PLAN mode the aircraft symbol looks like the silhouette of an aircraft.

### [Option - PLAN mode, Heading directional source]

In this mode instead of the map the aircraft symbol does rotate according to the current heading. The map is fixed with north pointing upwards. The track information is provided by the track indicator.



Element	Purpose
1 HDG mode label	This label indicates the source for the directional information either by showing TRK or HDG. HDG means that the heading is shown (where is the aircraft's nose pointing to). Due to side wind components the actual track above ground can differ from the heading.
2 Current heading	The current heading as a 3 digit number with the range 0...360.
3 Track indicator	The track indicator shows the track over ground as additional information.



### 7.3.19 Instruments – Navigation Display (ND) – flight plan

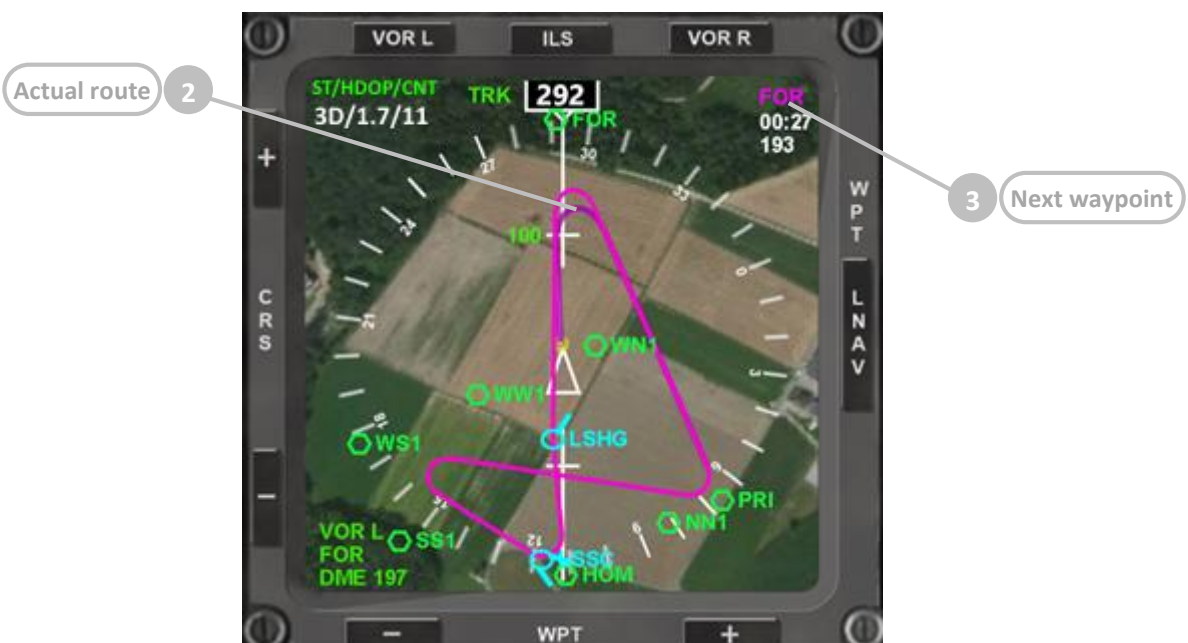
#### [After EXEC, prior LNAV mode activation]

Immediately after pressing *EXEC* in the FMS, the planned route is displayed on the Navigation Display:



#### [After EXEC, after LNAV mode activation]

After pressing on the LNAV toggle mode button on the right side of the display the actual route is shown with a darker magenta.



	Element	Purpose
1	Planned route	The planned route is shown with a magenta line. The turn radius is derived from the planned cruise speed (as entered on the RTE page of the FMS) and the standard turn rate as either entered on the <i>Options</i> screen (see chapter 7.3.4) or determined by flight testing (see chapter 7.3.11).
2	Actual route	As the flown route often does not precisely follow the planned route (especially if flown manually), the actual route which approximates the planned route best is shown in darker magenta in addition. Deviations from the planned route can be corrected by following the darker magenta line.
3	Next waypoint information	The most important information regarding the next waypoint is displayed at the top right corner of the Navigation Display: <ul style="list-style-type: none"> <li>- The ID of the navigation aid in magenta letters</li> <li>- The remaining time in white letters</li> <li>- The remaining distance in white letters (in display unit)</li> </ul>

### 7.3.20 Instruments – Navigation Display (ND) – radio navigation

Radio navigation allows flying to or from radio beacons. The radio navigation features offered in FlightZoomer allow en-route navigation using VORs as waypoints or ILS approaches.

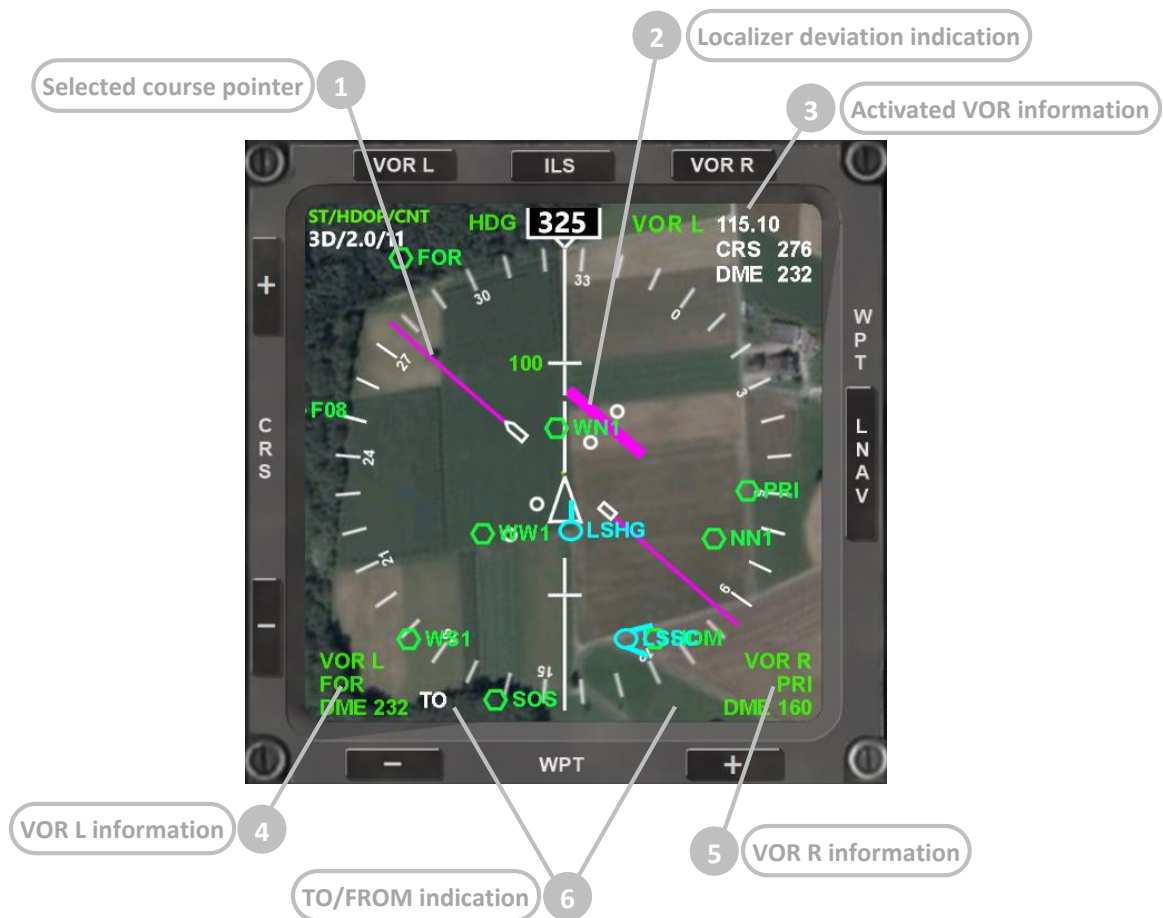
Activating radio navigation requires a two-step procedure:

- Tuning the VOR L, VOR R or ILS receiver to particular VOR or ILS frequency and setting the desired course (on the NAV RAD page of the FMS).
- Activating one of the radio navigation buttons at the top of the Navigation display (VOR L, ILS or VOR R).

Because the activation happens in the second step using dedicated buttons for each of VOR L, ILS or VOR R, the respective receivers can be tuned at the same time to a suitable radio beacon.






[Option – VOR L (or R) activated, MAP mode]



[Option – ILS activated, PLAN mode]



Element	Purpose
1	<p>Selected course pointer</p> <p>The selected course pointer shows the direction of the target radial towards the localizer. It allows flying to (or from) the radio beacon on any particular radial and not only on the direct course between the aircraft's position and the station. This means that if the direct course does not match the selected course the aircraft first needs to capture the radial. Very typically this is required flying an ILS approach to capture the extended runway centerline.</p> <p>The selected course must be defined on the NAV RAD page on the FMS. For ILS approaches the selected course must match the runway direction.</p> <p>At any time the selected course can be fine-tuned using the CRS + and CRS – buttons on the Navigation Display frame. In this manner, the direct course to a VOR can be identified.</p>
2	<p>Localizer deviation indication</p> <p>The localizer deviation indicator is a magenta bar which moves sideways in parallel to the selected course pointer. The lateral deflection indicates the closeness to the selected radial towards the localizer.</p> <p>While the localizer is being captured the deviation indication moves into the middle until the course pointer and the deviation indicator are in-line.</p>
3	<p>Activated VOR information</p> <p>If one of the VOR receivers is activated for navigation the detail information is presented in the top right corner of the display. This consists of the following parameters:</p> <div data-bbox="564 1003 1299 1238">  </div>
4	<p>VOR L information</p> <p>Whenever the VOR L receiver is tuned to a valid frequency of a VOR, the most relevant information is shown in the bottom left corner of the Navigation display. The following parameters are shown:</p> <div data-bbox="600 1440 1185 1585">  </div> <p>This information is also present if none, the other VOR, or the ILS receiver is activated for navigation.</p>
5	<p>VOR R information</p> <p>As for the VOR L the information of the tuned VOR R receiver is shown in the right bottom corner of the display.</p>
6	<p>TO/FROM indication</p> <p>This text label either shows TO or FROM depending on whether the selected course is leading away or to the radio beacon (from the perspective of the current position). The label appears on the left side if the active VOR is VOR L and on the right if the active VOR is VOR R.</p>
7	<p>Activated ILS information</p> <p>While approaching a runway using activated ILS the following detail information is presented in the top right corner of the display:</p>



ILS label

Frequency

Selected course

Distance in display unit

**8**    Approached runway    Symbol for the runway for which the aircraft is on final approach.

### 7.3.21 Flight Management System – overview



Element	Purpose	
1	CDU Display	The CDU Display shows the state of
2	Scratchpad	The scratchpad is used for any operation
3	Keypad	

### 7.3.22 Flight Management System – CDU (Control Display Unit)

In this chapter the main components and mechanisms of the Control Display Unit are described. More than 90% of the descriptions are copied one-for-one from the Boeing 787 FCOM!

#### [CDU overview]



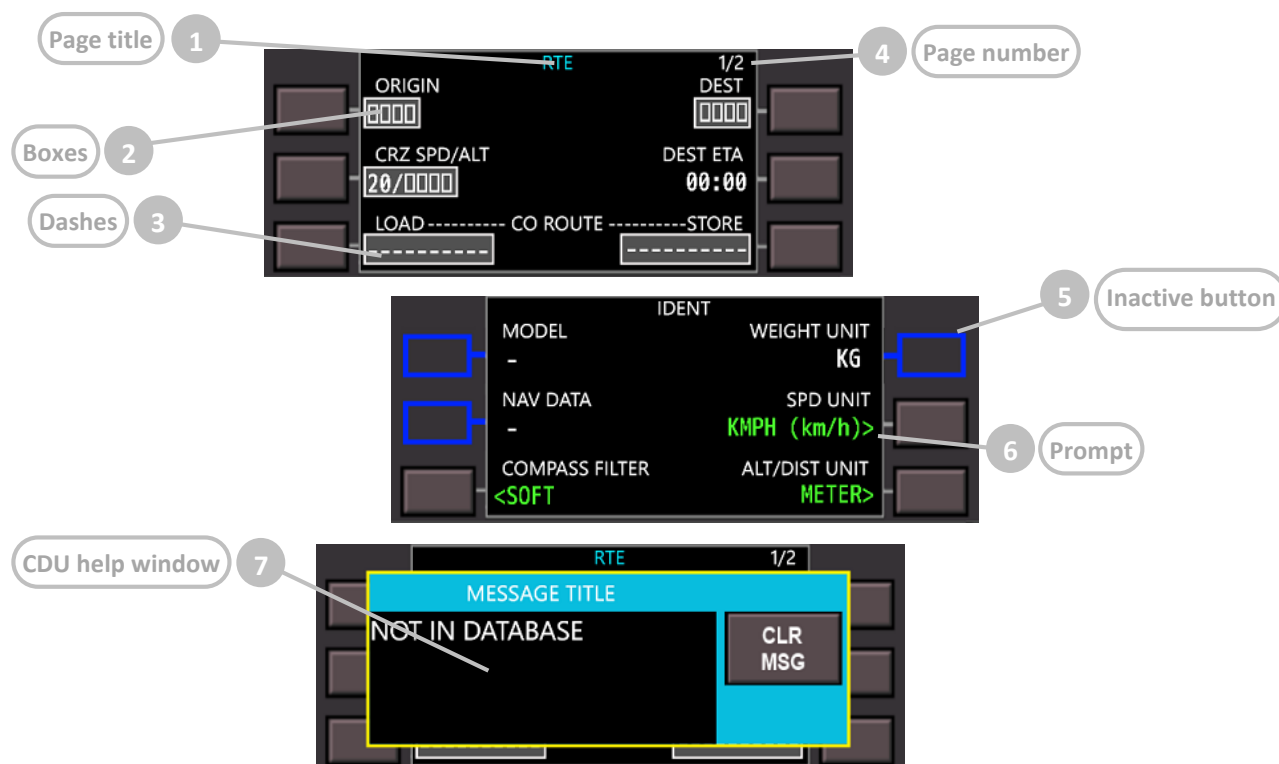
Element	Purpose
1 CDU display	Displays FMS data pages.
2 Line select keys	Push – <ul style="list-style-type: none"> <li>- moves data from scratchpad to selected line</li> <li>- moves data from selected line to scratchpad</li> <li>- selects page, procedure, or performance mode as applicable</li> <li>- deletes data from selected line when "DELETE" displays in scratchpad</li> </ul> Conventions – <ul style="list-style-type: none"> <li>- scratchpad must be blank for line select transfer</li> <li>- data cannot be transferred to a blank line</li> <li>- a blank scratchpad cannot be transferred to a line</li> <li>- not all data can be modified</li> <li>- message displays if inappropriate entries are attempted</li> <li>- The keys are designated like this:</li> </ul> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 2px 5px;">1L</div> <div style="border: 1px solid black; padding: 2px 5px;">1R</div> </div> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 2px 5px;">2L</div> <div style="border: 1px solid black; padding: 2px 5px;">2R</div> </div> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 2px 5px;">3L</div> <div style="border: 1px solid black; padding: 2px 5px;">3R</div> </div>
3 Scratchpad	Displays operator-entered data or operator line-selected data. <ul style="list-style-type: none"> <li>- data may be transferred to and from the scratchpad by pushing a line select key.</li> <li>- data may also be transferred to the scratchpad while using the PICK WPT function on the FIX page</li> </ul>

The following operations can always be accomplished the same way using the scratchpad:

Operation	Steps
Enter parameter	<ol style="list-style-type: none"> <li>1. Write the new value into the scratchpad</li> <li>2. Press the line select key beside the parameter on the CDU</li> </ol>
Copy parameter	<ol style="list-style-type: none"> <li>1. Ensure that the scratchpad is empty (if not press and hold the CLR key).</li> <li>2. Press the line select key that contains the value which will be copied.</li> <li>3. Press the line select key beside the parameter where the value will be copied into.</li> </ol>
Delete/reset parameter	<ol style="list-style-type: none"> <li>1. Press the DEL key -&gt; "DELETE" is written to the scratchpad</li> <li>2. Press the line select key beside the parameter which will be deleted/reset.</li> </ol>
Select waypoint	<ol style="list-style-type: none"> <li>1. Ensure that the scratchpad is empty (if not press and hold the CLR key).</li> <li>2. Press the line select key beside an undefined waypoint -&gt; a list appears which allows browsing all available waypoints for selection based on the ID.</li> </ol>

### [CDU page components]

The following screenshots are examples that show the various generic components on the CDU display.

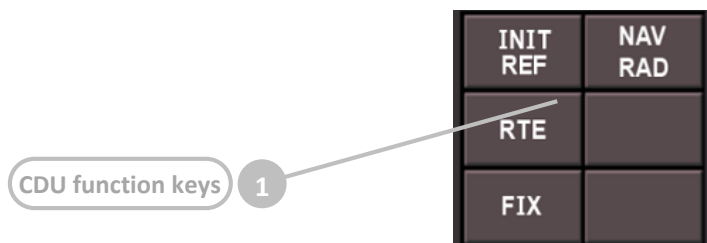


Element	Purpose
1 Page title	Subject or name of data displayed on page.
2 Boxes	Data input is mandatory.
3 Dashes	Data input is optional.
4 Page number	Left number is page number. Right number is total number of related pages. Page number is blank when only one page exists.
5 Inactive button	No supported positions on the display have a blue button outline.
6 Prompt	Display pages, select modes, and control displays. Caret "<" or ">" is before or after prompt.
7 CDU help window	Displays error/help messages to the crew.

Color is used as follows:

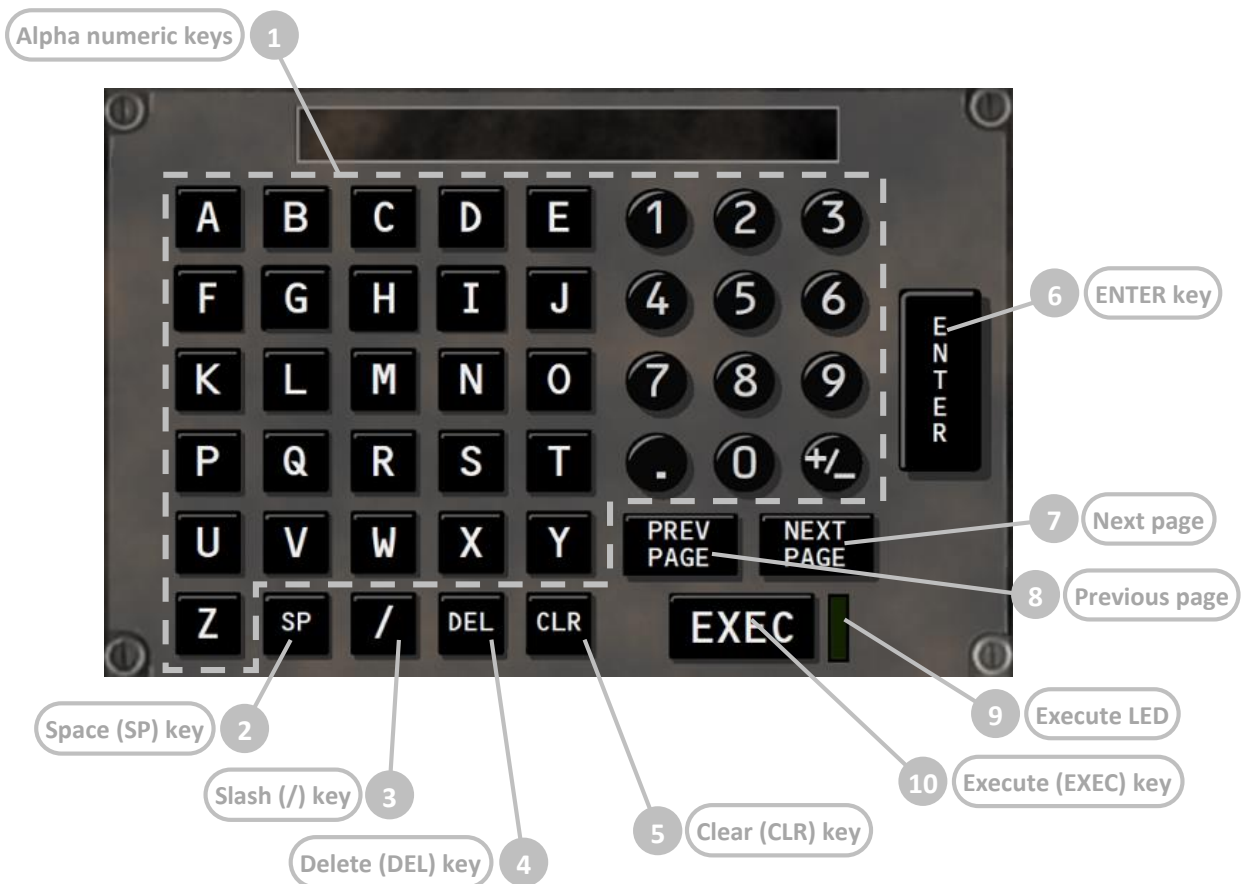
- black –
  - background color of page
- cyan –
  - inactive RTE page title
  - inactive button outline
- green –
  - navigation radio data
  - active state of two–position and three–position selectors
- magenta – data used by FMC for lateral and vertical flight commands
  - active waypoint
  - active airspeed
  - active altitude
  - cursor
  - highlight box
- shaded gray –
  - input field
- shaded white –
  - modifications
  - MOD precedes page titles of modified pages
- white – most data

#### [Function keys]



	Element	Purpose
1	CDU function keys	Press – <ul style="list-style-type: none"> <li>- INIT REF – displays page for data initialization or for reference data.</li> <li>- RTE – displays page to input or change origin, destination and route.</li> <li>- FIX – displays page to browse through the navigation aid and airport database.</li> <li>- NAV RAD – displays page to view or control navigation radio tuning.</li> </ul>

## [Multifunctional keypad]



Element	Purpose
1 Alpha numeric keys	Press – <ul style="list-style-type: none"> <li>- puts selected character in scratchpad</li> <li>- Plus Minus (+/-) key – first push enters “-” in scratchpad. Subsequent pushes alternate between “+” and “-”</li> </ul>
2 Space (SP) key	Press – enters space in scratchpad
3 Slash (/) key	Press – enters “/” in scratchpad
4 Delete (DEL) key	Press – enters “DELETE” in scratchpad. “DELETE” can then be applied to any data input line to delete the current content.
5 Clear (CLR) key	Press – clears last character of data in the scratchpad. Press and hold – clears all scratchpad data.
6 ENTER key	Not used
7 Next page	Press – displays next page of multiple page displays
8 Previous page	Press – displays previous page of multiple page displays
9 Execute LED	Illuminated (green) – active data is modified but not executed.
10 Execute (EXEC) key	Press (while EXEC light is illuminated green) – <ul style="list-style-type: none"> <li>- activates data modification(s)</li> <li>- extinguishes execute light</li> </ul>



### 7.3.23 Flight Management System – INIT/REF page (initialization)

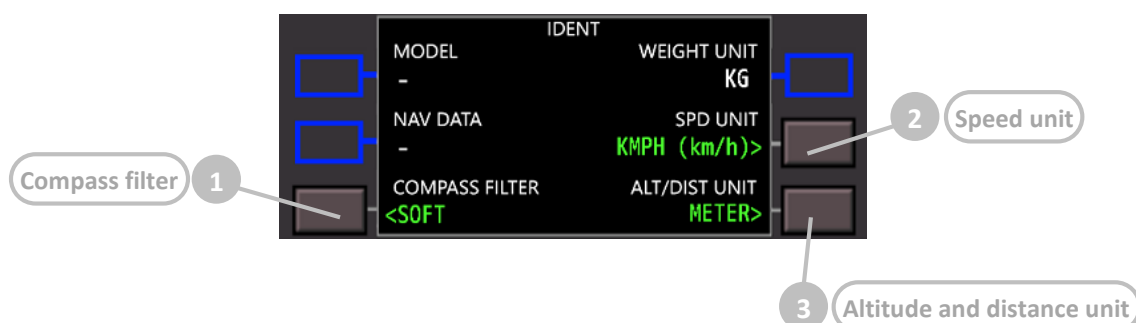
The initialization/reference index page allows manual selection of FMC pages. It gives access to pages used during preflight and is not usually used in flight.



Element	Purpose
1 Open IDENT page	The IDENT allows the identification of static system parameters. Additionally, some system configurations can be performed.
2 Open PERF page	The PERF page allows entering actual parameters which are relevant for performance calculations.
3 Open FIX page	The FIX page enables browsing of the navigation database.
4 Open RTE page	The RTE (route) page enables definition and maintenance of flight plans.
5 Open NAV RAD page	The NAV RAD (radio navigation) page tunes the radio receivers.

### 7.3.24 Flight Management System – IDENT page (identification and preflight checks/settings)

The IDENT page is used to verify basic aircraft data and define operational FlightZoomer settings. A number of parameters are constants or are not yet populated. In addition, the page allows selection of various system settings. This includes display units for speed and distances. While the whole transmission and processing of data is strictly based on SI units, display units can be used to change the units which are used on the presentation layer of the groundstation.



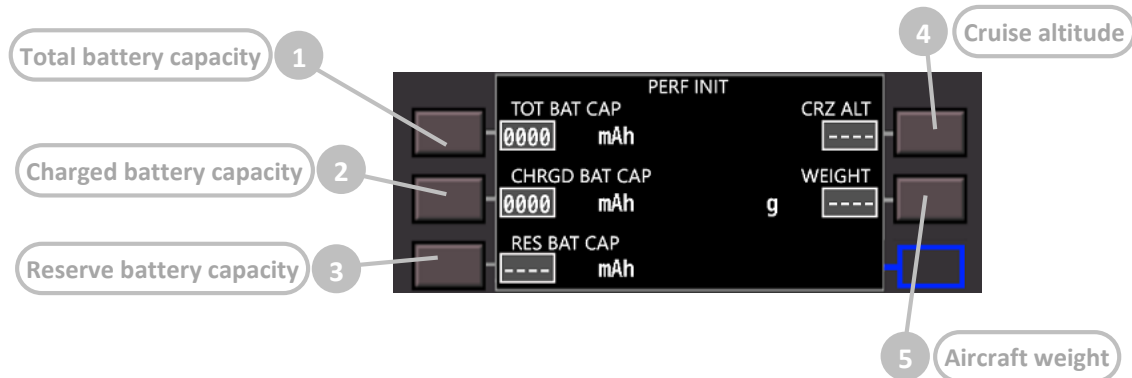
Element	Purpose
1 Compass filter	There are four compass filter settings which can be applied to the received raw compass data: <b>NONE, SOFT, MEDIUM, STRONG</b>
2 Speed unit	The following speed units are available: <b>KMPH, KTS, MPH</b>



- |   |                            |   |
|---|----------------------------|---|
| 3 | Altitude and distance unit | For distances, altitudes and also vertical speed (per second) the following units are available: <b>METER, FT</b> |
|---|----------------------------|---|

### 7.3.25 Flight Management System – PERF page (routes & flightplans)

The PERF INIT page is used for initialization of data required for VNAV operations and performance predictions.

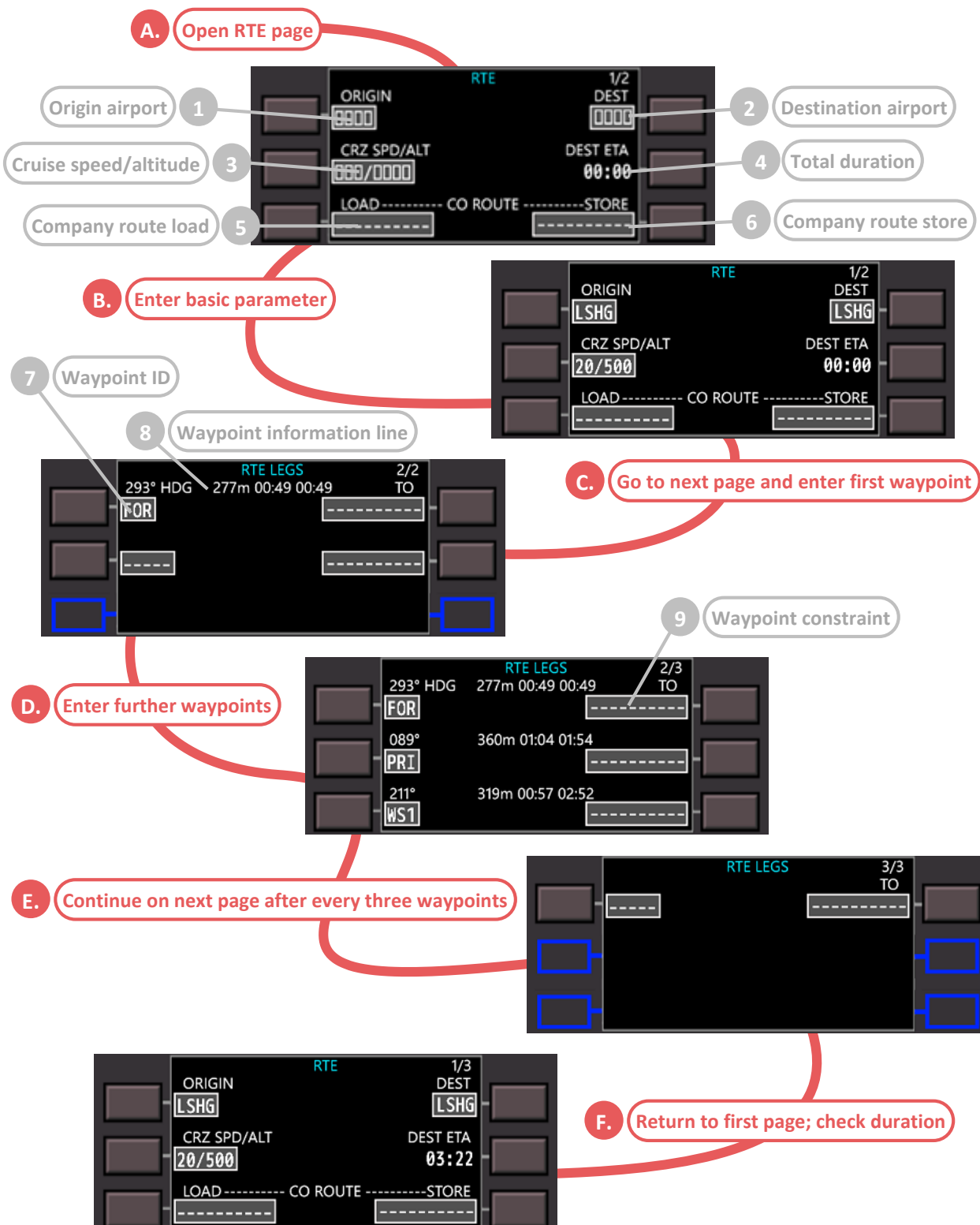


Element	Purpose
1 Total battery capacity	The total battery capacity is stored in the app settings and stays always the same as long as the same battery type/capacity is used.
2 Charged battery capacity	The charged battery capacity is the currently available battery capacity. While the battery is discharging this value decreases. At app start the value is taken from the total battery capacity but it can also be manually set at any time to reflect a partially charged battery.
3 Reserve battery capacity	The reserve battery capacity can be defined to calculate the overall useable capacity. Currently the system does not use this value.
4 Cruise altitude	The cruise altitude is the altitude during the cruise phase of the flight. This value is used to set the altitude target mark on the Navigation Display. This parameter can also be set on the RTE page. On the PERF page it is optional.
5 Aircraft weight	The aircraft weight is used for various performance calculations, however currently the system does not use this value.

### 7.3.26 Flight Management System – RTE page (routes & flightplans)

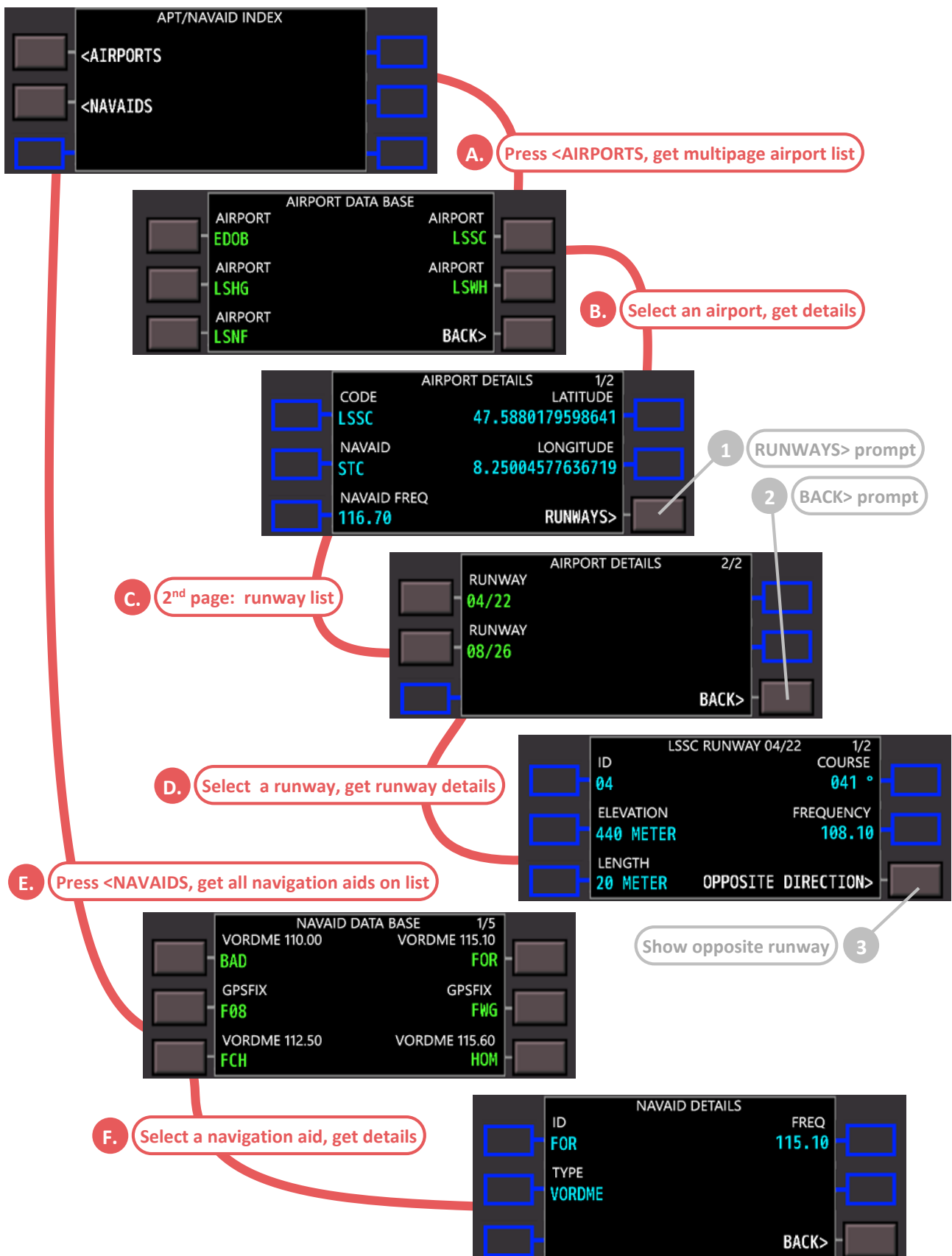
The FMS RTE page consists of several sub-pages that are used for entering flightplans during flight preparation. Flightplans can also be stored and loaded into the navigation database. The activity of creating a flightplan includes the selection of an origin and destination airport, the cruise altitude, cruise speed and any number of waypoints.

The following diagram shows the various components of the RTE page and the steps of the activity (in red):



Element		Purpose
1	Origin airport	Origin airport of the flight. Enter an existing airport CODE as defined in the navigation database. This parameter is mandatory.
2	Destination airport	Destination airport of the flight. Enter an existing airport CODE as defined in the navigation database. This parameter is mandatory.
3	Cruise speed/altitude	Enter the planned cruise speed and cruise altitude in display unit. The two values must be separated by a dash-character ("/"). Entering a number without "/" means that only the cruise speed is changed. Entering "/" followed by a number allows changing the altitude alone while the speed is kept unchanged. This parameter is mandatory.
4	Total duration	Total duration of the flight, updated after every change. Check after the last waypoint has been entered, to see the total expected flight duration.
5	Company route load	This feature can be used to load existing company routes (see the next point how company routes can be created). Enter the name of a route in the scratchpad and press the 3L key.
6	Company route store	Any flightplan which has been created can be stored using this feature. Enter a route name in the scratchpad and press the 3R key. A status information text will display the progress and once the flightplan is stored completely.
7	Waypoint ID	On the following subpages of the RTE page, waypoints can be added. Enter either the ID or the VOR frequency of an existing waypoint in the scratchpad and press 1L, 2L or 3L. Waypoints can either be added at the last position or replace earlier defined waypoints. If the scratchpad contains "DELETE" (DEL key) the waypoint at the selected position is removed. If the scratchpad is empty, a special page opens which lists all available waypoints. After three waypoints a new subpage is added which can be opened using the NEXT PAGE key. Waypoints which require 180° turns are not supported while flying.
8	Waypoint information line	After a waypoint has been set, the waypoint information line gets updated. The following information is shown from the left to the right: <ul style="list-style-type: none"> <li>- Heading of the inbound leg (from the origin or the previous waypoint to this waypoint).</li> <li>- Distance in display unit of the inbound leg.</li> <li>- Duration of the inbound leg.</li> <li>- Total duration of all legs up to this waypoint.</li> </ul>
9	Waypoint constraint	Not currently supported.

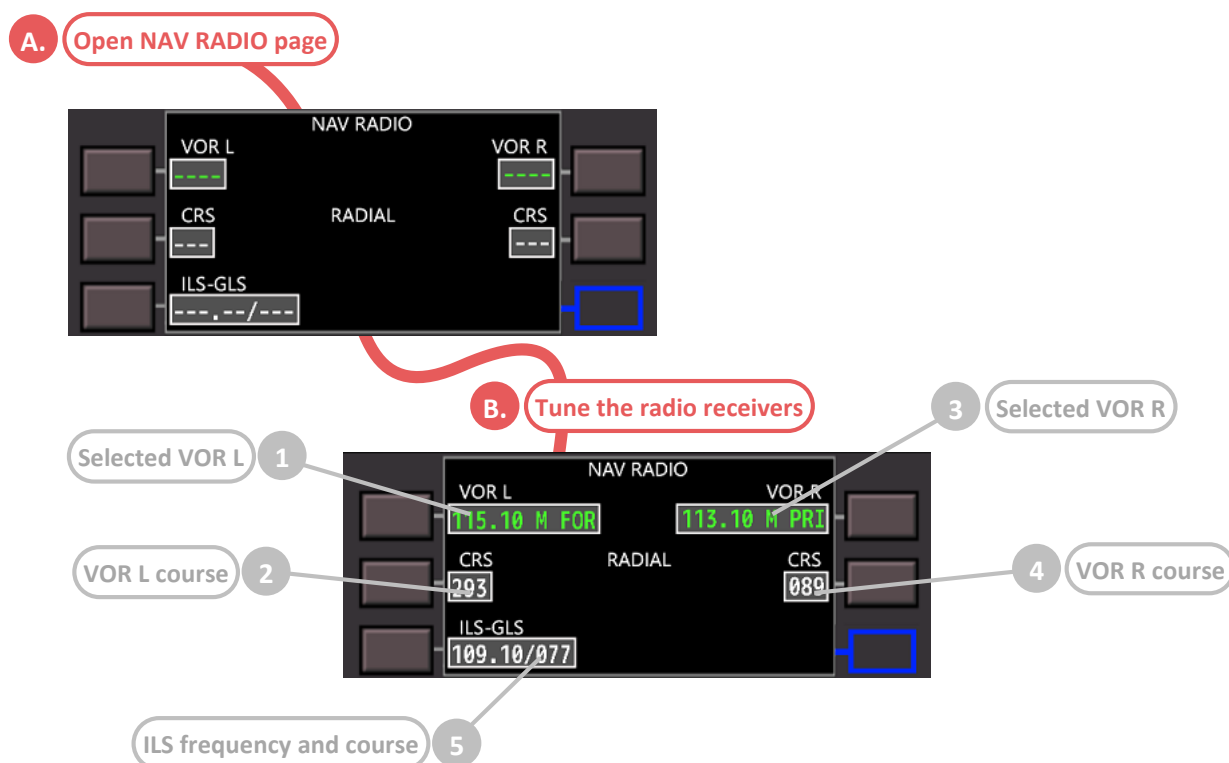
### 7.3.27 Flight Management System – FIX page (browse navigation database)



Element	Purpose
1 RUNWAYS> prompt	Press to show the runways of an airport on the AIRPORT DETAILS page.
2 BACK> prompt	Use to return to upper levels while browsing.
3 Show opposite runway	Press to open the details of the reverse runway.

### 7.3.28 Flight Management System – NAV RAD (radio navigation)

VOR navigation radios are normally autotuned by the FMS. The NAV RADIO page displays the VOR and ILS-GLS status and allows manual control of these radios. Entering data on this page tunes the selected navigation radio. VOR courses can also be entered.



Element	Purpose
1 Selected VOR L	<p>The shown data is the frequency of the selected VOR L, the tuning status and the ID.</p> <p>Enter either the frequency or the ID in the scratchpad to tune the left receiver.</p> <p>The tuning status can be one of the following:</p> <ul style="list-style-type: none"> <li>- M: the receiver has been tuned manually</li> <li>- A: the receiver has been tuned by the LNAV feature following the flight plan</li> </ul>
2 VOR L course	The target radial to be followed towards (or from) the VOR L.

3	Selected VOR R	<p>The displayed data is the frequency of the selected VOR R, the tuning status and the ID.</p> <p>Enter either the frequency or the ID in the scratchpad to tune the right receiver.</p> <p>The tuning status can be one of the following:</p> <ul style="list-style-type: none"> <li>- M: the receiver has been tuned manually</li> <li>- A: the receiver has been tuned by the LNAV feature following the flight plan</li> </ul>
4	VOR R course	The target radial to be followed towards (or from) the VOR R.
5	ILS frequency and course	<p>The shown data is the frequency of the selected ILS and the course.</p> <p>Enter the frequency the desired ILS approach in the scratchpad to tune the ILS receiver. The course is then selected automatically.</p>

### 7.3.29 Synthetic voice generation for pilot guidance

To be completed.

## 8 Appendix

### 8.1 System accuracy

As with any technical system, there is a gap between the ideal, perfect accuracy and what can be achieved with the actual implementation. FlightZoomer is not different in that regard. There are several areas, which need to be looked at separately in the following chapters.

In general, the system accuracy largely depends on whether the flight controller feeds sensor data (via MAVLink) or whether the phone's sensor stack is being used (see chapter 5.5).

The information in this chapter mostly is applicable only for phone sourced data.

In each of the following chapters the two possible data sources are marked with the following two symbols:






Data coming from the phone's sensors






Data coming from via the MAVLink connection  
(the source is the flight controller)


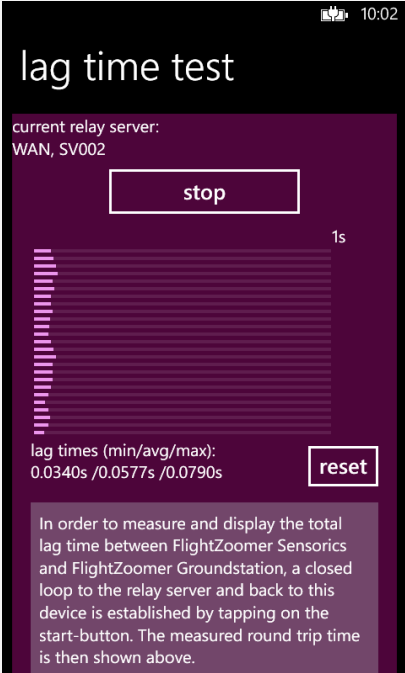
### 8.1.1 Time accuracy (lag time)

Description	Affected sensors
<p>Due to the system architecture of FlightZoomer the transmission and display of sensor data is not possible in absolute real-time. Obviously mobile network coverage can be impaired temporarily or even be marginal for an extended period of time, depending on a number of factors, including antenna coverage.</p> <p>As a result, there is a lag time from transmission by the Sensorics app until the newest data appears on the groundstation.</p>	

Lag time in numbers			Affected sensors
	Value	Unit	
Typical lag time	40...120	ms	
Sporadic max. lag time	Several seconds	-	


Contributing factors to the lag time		Affected sensors
The currently available network speed	While a stable 3G connection does easily support the figures above (min 40ms, max 120ms, average 80ms) a 2.5G connection will degrade the average lag time by several 100ms.	
Phase while the network type switches	During the phases while the device is switching between different network types (2.5G, 3G or 4G), the lag time temporarily can worsen. In order to avoid connectivity drops while the device switches between network modes, we recommend to configure the sensor device to stick to a lower connection speed (than the highest). FlightZoomer does not need 4G, so restricting the network on the sensor device to 3G is sufficient.	
Distance between sensor device and groundstation	A very small impact also comes from the actual distance between the sensor device and the groundstation (via the relay server). Switching from a closely located relay server (e.g. home based) to a cloud based server can add some dozens of milliseconds to the total lag time. At any rate, users must have a working knowledge of where potential chokepoints are on the connection paths between the three elements of FlightZoomer.	









FlightZoomer design provisions to minimize the effect of lag time	
Communication channel	The design of the communication channels from the sensor device to the groundstation is focused especially on recovering from any kind of failure modes. So whenever the connection is lost, connectivity will be reestablished as soon as the network will allow it.
Lag time indication on the ground-station display	<p>FlightZoomer continuously measures and displays the current time lag on the groundstation. At any time and on all screens on the top left of the display the time lag bar is indicated:</p>  <div data-bbox="738 526 1428 734"> <p><b>Time lag bar</b></p> <p>This bar grows to the right as long as no updated sensor data is received. With each set of new received sensor data (location, altitude, speed, track), the bar is reset. The white bar will reach 100% width after three consecutive seconds without receiving updated sensor data.</p> </div>
Lag time test feature	<p>The FlightZoomer Sensorics app has a built-in feature to measure and display exactly how long it takes for each single transmitted packet over the entire communication channel from the sensor device to the groundstation device.</p> <p>The lag-time-test is accomplished solely by the Sensorics-app and the relay server and does not need the Groundstation-app. Once the test is started, a second connection from the sensor device to the relay server is established which is used to simulate the complete end-to-end connection.</p> <p>While the test cannot be performed during the flight (because the Sensorics app needs to be manipulated), the test feature is still very helpful in understanding the system time response and the factors that impact it positively and negatively. The lag-time-test would be a useful Pre-Flight check during ground station setup.</p> <p>The following screenshot shows the lag time test screen. For more details, refer to chapter 7.1.9:</p> 

Pilot guidelines to mitigate the lag time	
•	The time lag bar needs to be considered while flying.
•	In case of excessive lag time the displayed information quickly becomes outdated and should not be trusted anymore.
•	With a multicopter: speed shall be reduced and the LOITER mode should be activated.
•	If connectivity does not recover before any situational awareness is lost, the flight must continue with visual guidance or the FlightZoomer independent fallback mechanism will be triggered (e.g. the RETURN-TO-LAUNCH feature of the flight controller).
•	Special caution is warranted whenever the current flight trajectory would intersect terrain or obstructions such as towers or buildings (e.g. during descends or when flying towards higher terrain).

### 8.1.2 Position accuracy

Description	Affected sensors
Position determination is crucial for the system. It is not only the primary source for navigation but also speed and course are derived from it. Position accuracy is one of the areas where the flight controller offers greatly improved accuracy over data coming from the phone's sensors. So the following description more or less applies only for phone sourced position data (see chapter 7.1.7 for details about how the data source priority can be configured).	

Position error in numbers			Affected sensors
	Value	Unit	
Typical position error phone	5..15	m	
Typical position error flight controller	0.5..2	m	

Contributing factors to the position error		Affected sensors
GPS inaccuracy	The GPS accuracy depends on momentary conditions such as the number of satellites in view of the device. Newer smartphones often also support GLONASS which improves the position accuracy somewhat.	
Capabilities of the chosen device	More than one would expect, the actual device has an impact on the position accuracy. During flight testing several devices have been used and the accuracy differences between them are notable.	
Time lag of position feed	Any movement of the aircraft since the last received sensor data obviously contributes to the location error.	 
Constant error of the aerial images placement	Sometimes the aerial images have a constant error between real and displayed location. This can be corrected using the <i>aerial image offset correction</i> -feature (see chapter 7.3.10 Selectable panel bar – aerial image offset panel).	 

## FlightZoomer design provisions to minimize the effect of the position error

### Position error indication on the ground-station display

The navigation display on the groundstation shows at any time a yellow circle around the center mark, which indicates the current position error:



#### Position error circle

This circle indicates at any time the largest possible error between the displayed and the actual position. The actual position therefore lays somewhere within the boundaries of the yellow error circle. On this screenshot a moderately degraded location accuracy is shown.

The circle size scales up and down with the display range (zoom).

#### Maximum error


On this screenshot the largest displayed error is shown. In case of larger errors the error circle will still stay within the compass rose.




## Pilot guidelines to mitigate the position error

- First and foremost, make use of sensor data coming from the flight controller via MAVLink as the primary position information feed. Mavlink data reduces the impact of the following items.
- The position error circle needs to be considered while flying.
- The yellow position error circle should stay away from obstacles.
- In case of a sudden loss of position accuracy the flight should be slowed down and continued using fallback navigation mechanisms (visual guidance, RETURN-TO-LAUNCH feature of the flight controller).
- Considerable time should be spent flying simple flight profiles and circuits to become familiar with the system response.
- Ensure that at any time fallback capabilities are available.
- Better results and more safety can be achieved with spacious and extensive flight profiles.
- FlightZoomer ideally is used to cruise along routes with ample straight legs and not too many (and too tight) turns.
- FlightZoomer does not support 3D flying.


### 8.1.3 Altitude accuracy

Description	Affected sensors
The altitude is derived from the same source as the position (GPS). Therefore, the description in the previous chapter is fully applicable for the altitude as well.	

Position error in numbers			Affected sensors
	Value	Unit	
Typical altitude error phone	5..20	m	
Typical altitude error flight controller	1..3	m	

**Altitude error indication on the ground-station display**

The current altitude error is shown on the primary display as follows:




**Altitude error bar:**


The vertical yellow bar indicates at any time the largest possible error between the displayed and the actual altitude.

The actual altitude therefore with a high probability lays somewhere within the boundaries of the error bar.

Pilot guidelines to mitigate the altitude error
<ul style="list-style-type: none"><li>As the terrain tends to be more important in the vertical than horizontally (except very close to mountains), the UAV altitude ("z vector") tends to be more safety relevant than the position (x, y vector).</li><li>To create good altitude awareness therefore additional feedback should be considered (visual tracking, fly with activated ALTITUDE-hold mode, stick to one altitude while cruising, close examination of terrain maps whilst planning the UAV mission...).</li><li>Double check the reliability/accuracy of altitude readouts while descending. Even rather short altitude feed interruptions can develop to dangerous situations. The UAV could be quickly lower than indicated.</li></ul>


## 8.1.4 Turn indication accuracy





Description	Affected sensors
One of the areas which is affected the most from lag time and the position error is the situational awareness during turns (both about the turn rate and the turn progress). Though using directional data from the flight controller gives much better results, getting turns right is so crucial, that the feature described below is useful in all cases.	

FlightZoomer design provisions to optimize the turn accuracy	
<b>Flightplan turn countdown timer</b>	<p>When following flightplan routes, the Flight Director provides a countdown timer both as synthetic voice (“Barking Bob”-feature) and visually on the primary display indicating the beginning of the turn. Once the turn has started there is another timer counting down the remaining turn time (assuming a constant turn rate, see below). The following screenshot shows the Flight Director indicating the current right turn to be continued for exactly another 7.5 seconds:</p>  <p>Once the countdown timers reach zero, the stick will be released and the aircraft is expected to fly the new course. Additionally, the synthetic voice counts down the seconds audibly.</p> <p>This feature requires the standard turn rate to be set for the given UAV aircraft. The standard turn rate can either be set manually in the <i>options...</i>-menu of the Groundstation-app (see chapter 7.3.4) or also be determined automatically by the turn test feature (see chapter 7.3.11).</p>

Pilot guidelines to improve the turn accuracy
<ul style="list-style-type: none"><li>• During free flight apply only rather small turn rates (this behavior is not unrealistic when thinking about real aircraft).</li><li>• Also don't fly extended long turns. In general, apply rather small course corrections (also this is a realistic behavior looking at real aircraft).</li><li>• Consider a RC transmitter configuration as described in chapter 6.5.2. This allows applying constant turn rates which helps getting a feeling about the turn progress even in case of a small time lag on the displays.</li><li>• Use the aforementioned feature above to reduce turn control input durations.</li></ul>


### 8.1.5 Compass accuracy



Description	Affected sensors
<p>Compass accuracy is one of the areas that benefits greatly from the much higher accuracy the onboard flight controller usually offers. Therefore, the following description more or less only applies for compass data coming from the phone's internal magnetometer (see chapter 5.5 for details about how the data source priority can be configured).</p> <p>The direction of the compass rose on the primary display always displays either the magnetic direction from the compass sensor (= heading) or - alternatively - the calculated track from the GPS (called Track-Lock mode). The accuracy of the later is covered in chapter 8.1.2.</p> <p>The requirements for a good flight experience with the compass is a small lag time and a smooth step response. While the compass of the smartphone usually responds quicker to directional changes than the GPS Track Lock, in testing, the output of the phone's magnetometer sensor almost always proved to be quite erratic. Therefore, avoiding the heading mode completely and choosing the Track Lock mode would be the recommended option if flying without MAVLink data.</p> <p>The GPS Track Lock mode has the disadvantage that it does not show the direction if there is no forward speed. Also crab angles can't be derived from the GPS track only. On the other hand, the track above ground is more relevant for navigation.</p>	

Contributing factors to compass error		Affected sensors
The actual device	Current generation (and newer) devices like the Lumia 925 have performed better regarding magnetometer accuracy. While still far outclassed by heading data coming from the flight controller it was marginally useable while the older OMNIA 7 had to be flown in GPS Track Lock mode all the time.	
The compass calibration	After each power-on the compass of the smartphone needs to be calibrated. See 7.1.5.	
How the phone is mounted on the aircraft	Proximity of the magnetometer sensor to other electrical (especially high power) devices.	
The compass smoothing setting	There are four compass-smoothing settings available on the groundstation (none, soft, medium or strong).	

Pilot guidelines to mitigate compass error
<ul style="list-style-type: none"><li>Enough time should be spent testing various options (with GPS track, witch compass, compass smoothing options) to ascertain which combination is the best match for the actual hardware setup and your personal preferences.</li><li>If a reliable compass feedback can't be achieved, revert to the GPS Track Lock mode (which offers nearly the same flying experience).</li></ul>

### 8.1.6 Attitude accuracy

Description	Affected sensors
<p>Like the compass, the attitude benefits greatly from improved accuracy when coming from the flight controller. Because horizontal accelerations do wrongly impact gravity determination, bank and pitch should only be trusted when the source is the MAVLink.</p> <p>Nevertheless, the attitude arguably is of lesser importance when flying with stabilized aircraft like a multicopter, so for all practical purposes the attitude is usually accurate enough.</p>	

Contributing factors to the attitude error		Affected sensors
Geometry capturing	Conducting the geometry capturing sequence precisely (see chapter 7.1.8).	
Transmission lag time	The current time lag of the data feed.	

## 8.2 Glossary

Abbreviation/term	Description	Real aviation term
FMS	Flight Management System	X
ILS	Instrument Landing System	X
IM	Inner Marker	X
LNAV	Lateral Navigation Auto flight mode where the loaded flight plan is being followed.	X
MM	Middle Marker	X
ND	Navigation Display	X
OM	Outer Marker	X
PFD	Primary Flight Display	X
VOR	VHF omnidirectional range	X