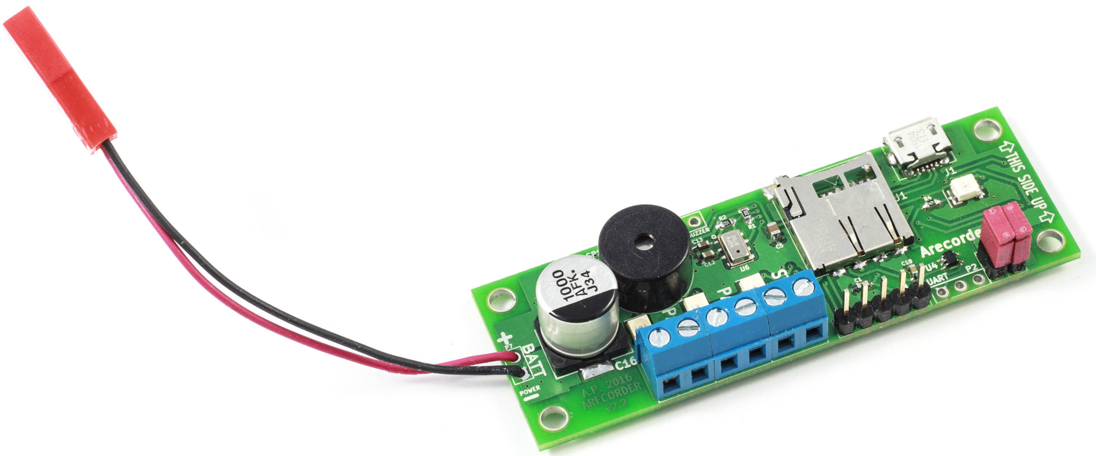
Arecorder

v. 2.2



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Acknowledgements

Special thanks to Andrzej and Robert Magiera,
without their help i wouldn't be able to create Arecorder.

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1. Introduction

- pressure measuring in range 0 - 110 kPa (in range 50 - 110 kPa with 100 Pa accuracy),
- acceleration measurement - three axis ± 24 g, one axis (along rocket axis) ± 80 g,
- temperature measurement inside rocket in range -50 to +130 [°C] (-58 to 266 [°F]),
- data recording into microSD card,
- frequency of data sampling 100 $\frac{Sa}{s}$,
- Kalman filter implemented to reduce noise in pressure data,
- detection and signalling of connected fuses,
- firing up to three fuses - two parachutes and one for second stage engine ignition,
- firing main parachute when altitude parachute failure is detected,
- detecting and recording inclination of rocket at launchpad,
- measuring of Arecorder's power supply,
- programmable delay between burnout of first stage engine and firing second stage engine,
- selection of one of four sets of Arecorder configuration parameters,
- Arecorder's configuration parameters and owners first name, last name, phone number and also setting rocket descending velocity at which emergency parachute deployment will happen or disabling it, programming by software installed on a PC computer,
- writing summary of several most important flight parameters into separate file.

Arecorder is a device designed to record data during flight of rocket and trigger fuses in specified moments. Device is suited for medium and big model rockets, also two-stage and/or supersonic. Employed algorithms allow to detect abnormal situations (e.g. rocket flying at low inclination) and react to them properly reducing risk rocket destruction.

It is not necessary for user to read whole manual. However it is recommended to read chapters 1, 2, 4.2, 4.3 and 7.

ATTENTION - If operation of Arecorder at any moment is different from designed, please send all avaible information about flight (especially Arecorder measurements and videos from rocket's onboard camera) to designer's mail arekpalinski@gmail.com in order to verify Arecorder operation and correction of possible errors. Designer have rights to update manual without prior notice.

2. Connectors

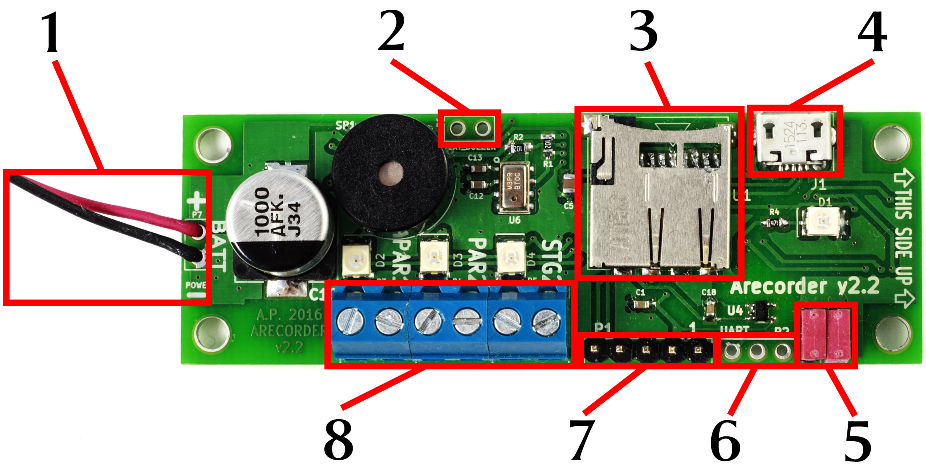

Figure 2.1: Arecorder's connectors.

1. power supply 2.1
2. additional buzzer 2.2
3. micro SD card connector 2.3
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2.1. Power source

Arecorder accepts any power source which can supply voltage in range 4 - 10 V and has low impedance (i.e. can source high current). If Arecorder is being used only as a data recorder (it does not have to fire fuses and no fuses are connected) it can be powered with any power supply with voltage in range 3,8 - 10 V.

Recommended power supply is one or two LiPo cells (if one cell is being used it should be fully loaded).

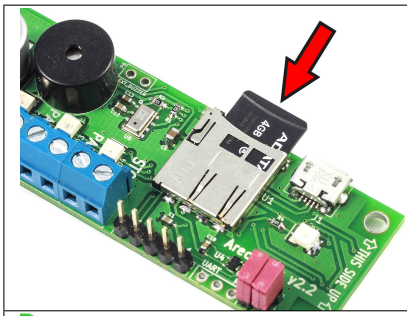
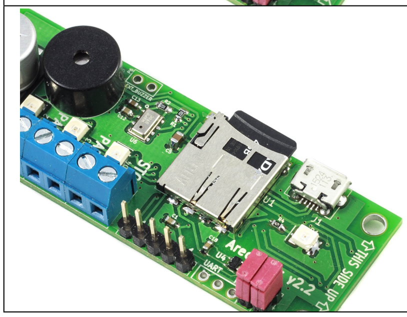
See also 5.1 and 5.2.

2.2. Additional buzzer connector

To additional buzzer connector can be connected any direct current powered buzzer. Additional buzzer's maximum voltage input must be greater than Arecorder's power supply. Additional buzzer should be used only when volume of built-in buzzer is insufficient.

2.3. Micro SD card connector

Table 2.1: Inserting and ejecting of micro SD card

	User should put card inside the hole, lightly press i release. Card will retract a little and block from coming out.
	To remove card user should again lightly press it and release. Card will retract a little further away and will be easly removable.

User should put micro SD card inside micro SD connector. All measured data will be recorded onto this card. Arecorder is able to write files with numbers from 1 to 99 in one card (at each power on Arecorder is creating two files with the same numbers - one with all data and one with flight summary), though it is recommended to format card before each flight.

Micro SDHC card version of smaller capacity (smaller than 32 GB) is strongly recommended.
It is recommended to format SD card before each flight although it is not necessary.

2.4. User programming connector

User can connect a PC with installed AreConfig application to Arecorder's user programming connector. It will enable programming user preferences such as owners name, phone number and Arecorder's parameter sets. With AreConfig user also can test firing fuses.

In order to connect Arecorder with AreConfig software, user must:

1. Connect Arecorder to the PC through USB cable
2. Run AreConfig program
3. Choose port to which Arecorder is connected. Usually the correct port should be already chosen right after AreConfig is started, but if this is not the case or if AreConfig was started before connecting Arecorder, user should click button *Scan* and try to connect to the right port. Usually there should be just one port found. If on the list is more than one port, the user can click *Start button*, clicking *Control Panel*, clicking *System and Security*, and then, under System, clicking *Device Manager*. From the list choose *Ports (COM and LPT)* - port, at which Arecorder is connected to, will have name beginning with *USB Serial Port*,
4. Click button *Connect* in AreConfig,
5. Arecorder will be automatically discovered and connected with AreConfig.

2.5. Connector for choosing parameter sets

This connnector enables user to choose one of four parameter sets by appropriately setting jumpers. Affected parameters are:

— main parachute deployment altitude,
— launchpad height,
— delay between burnout of first stage engine and ignition of second stage engine,
— rocket descending velocity at which emergency main parachute deployment will happen (velocity "0" means disabling the emergency parachute deployment).

Arecorder is reading data from jumpers only once, at power up. Removing or inserting jumpers later has no effect on Arecorder's operation.

Table 2.2: Choosing parameter sets by appriopiately setting jumpers

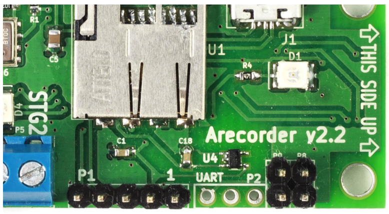
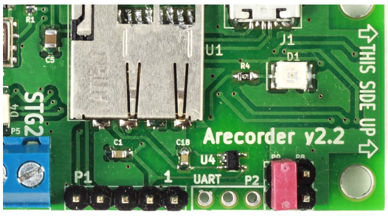
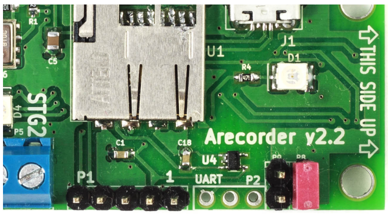
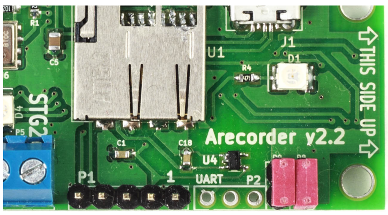
	parameter set number
	1
	2
	3
	4

Table 2.3: Default program sets

parameter set number	main parachute [m]	launchpad height [m]	second stage ignition delay [s]	emergency parachute deployment at speed [m/s]
1	200	1	0	50
2	150	1	0	50
3	100	1	0	50
4	50	1	0	50

2.6. Microcontroller programming pins

Connector used to program Arecorder's firmware. User should not use this connector.

2.7. Fuse firing

Fuses should be connected to the appropriate fuse out (PAR1, PAR2, and STG2 which fire appropriately drogue parachute fuse, main parachute fuse and second stage engine fuse).

Each fuse out is connected to positive power supply and drain of appropriate transistor. In case fuse is about to be fired, appropriate transistor is turned on which connects fuse to ground through transistor and causes conducting high current (current is dependant on power supply).

Each of fuse has additional transistor connected which, when enabled, conducts small current through fuse and LED. This current is dependant on power supply and is in range 2 - 8 mA. It is too small to fire a fuse but large enough to emit light by LED and indicate that the fuse is present.

3. Measured data formatting

Data are saved on SD card in *.CSV format i.e. columns are separated by comma and rows are separated by new line. Data written in this manner can be opened in any spreadsheet.

3.1. Formatting of file containing measured data

File containing data consists of three parts - header, measured data and summary of flight.

3.1.1. Header

In the header are written configuration data, Arecorders calibration data, owners name, surname and phone number and information about hardware and firmware version of Arecorder.

```
Hardware version,2.2
Software version,Apr 21 2016 21:28:27
Serial number,61
Owner name,Arkadiusz Palinski
Owner phone,+48 697-541-538
Configuration selected,4
X_1_g (24g),85
Hx_1_g (80g),24
X_0_g (24g),-4
Hx_0_g (80g),-47
Y_0_g (24g),-1
Z_0_g (24g),1
Hacc present,1
SecondEngineDelayTrigger [s],0
MainParachuteTriggerHeight [m],200
LaunchpadHeight [m],1
Drogue parachute failure detection [m/s],50
TemperatureOffset1 [deg],1
Pressure coefficient #1,44330.77
Pressure coefficient #2,0.1902632
Pressure at sea level [Pa],101325
Samples per second,100

```

```
24 seconds,1/100 of second,X_acc,Y_acc,Z_acc,HX_acc...
```

1. line informing about hardware version of Arecorder,
2. line informing about software version of Arecorder (code compilation time and date),
3. serial number,
4. owners name,
5. owners phone number,
6. chosen parameter set number detected at the power up of Arecorder,
7. number of divs per 1 g in ±24 g accelerometer,
8. number of divs per 1 g in ±80 g accelerometer,
9. calibration data - number of divs in X axis in ±24 g accelerometer, when measuring accelerationg is 0 g,
10. calibration data - number of divs in X axis in ±80 g accelerometer, when measuring accelerationg is 0 g,
11. calibration data - number of divs in Y axis in ±24 g accelerometer, when measuring accelerationg is 0 g,
12. calibration data - number of divs in Z axis in ±24 g accelerometer, when measuring accelerationg is 0 g,
13. information about detection accelerometer ±80 g,
14. delay between first engine burnout and ignition of second stage engine (in seconds),
15. main parachute trigger altitude (in meters),
16. launchpad height (in meters),
17. velocity about rocket descending speed above which main parachute will be deployed emergency, zero means algorhitm is disabled,
18. calibration data - number of Celsius degrees subtracted from temperature sensor measurements (temperature data are written after subtraction),
19. first coefficient used to calculate altitude from pressure,
20. second coefficient used to calculate altitude from pressure,
21. pressure at mean sea level (in Pa), constant value,
22. number of measurements per second,
24. column descriptions.

3.1.2. Measured data

Data consists of rows filled with data. Columns in each row are separated with commas, dot is used as decimal separator. Row ends with “end of line” char.

An example of row with data:

```
48.81,145,34,-28,-10,102186,102182,14.9,2.4,0,0.3,1,0.0,0
```

where:

48.81	— time in seconds and 1/100th of second,
145,34,-28,-10	— raw measured acceleration data in axis X, Y, Z of ±24 g accelerometer and axis X of ±80 g accelerometer, respectively (see also section 3.1.4),
102186,102182	— raw pressure measured by pressure sensor and pressure after Kalman filtering, units are [Pa],
14.9	— temperature measured by on board temperature sensor, units are [°C]
2.4	— rocket velocity, calculated by Arecorder, units are [$\frac{m}{s}$]
0	— altitude calculated from pressure data, units are [m],
0.3	— altitude calculated from accelerometer data, units are [m],
1	— current Arecorder state number (see also 4.1),
0.0	— velocity calculated from pressure data,
0	— auxiliary variable calculated only in state number 7 (see also 4.9,

3.1.3. Summary of flight

It is a copy of data from summary data file, see description of summary data file in section 3.2.

3.1.4. Data conversion

In order for raw data from accelerometers be useful they need to be covnerted to desired unit.

Current values of X_1_g, Hx_1_g, X_0_g, Y_0_g, Z_0_g and Hx_0_g are always written in the header of file containing measured data.

$$a\ [g] = \frac{a_{meas} - a_{offset}}{a_{gain}}, \tag{3.1}$$

where:
$a\ [g]$ - calculated acceleration in [g],
a_{meas} - raw data from accelerometer,
a_{offset} - offset of chosen accelerometer and axis respectively X_0_g, Y_0_g, Z_0_g for accelerometer ±24 g or Hx_0_g for accelerometer ±80 g,
a_{gain} - gain, respectively X_1_g for accelerometer ±24 g or Hx_1_g for

accelerometer ±80 g.

$$a\,[\frac{m}{s^2}] = g \cdot a\,[g], \tag{3.2}$$

where:
$a\,[\frac{m}{s^2}]$ - calculated acceleration in $[\frac{m}{s^2}]$,
$a\,[g]$ - calculated acceleration in [g],
g - gravitational acceleration (9,81 $\frac{m}{s^2}$).

3.2. Formatting of file containing summary of flight

Flight summary is a list of several most important flight parameters. Flight summary data is written after Arecorder detects rocket landing.

```
Rocket angle at launch,80.7,[deg]
Velocity at the moment of leaving launchpad,10.6,[m/s]
Pressure at ground level,100552,[Pa]
Pressure at apogee,95664,[Pa]
Maximum velocity at rocket axis,91.2,[m/s]
Maximum altitude (acc),426,[m]
Maximum altitude (pressure),417,[m]
Velocity at first engine burnout,91.2,[m/s]
Altitude  at first engine burnout,154,[m]
Pressure at first engine burnout,98368,[Pa]
Rocket angle at first engine burnout,76.3,[deg]
Velocity at second engine burnout,0,[m/s]
Altitude  at second engine burnout,0,[m]
Pressure at second engine burnout,0,[Pa]
Rocket angle at second engine burnout,0,[deg]
Rocket launch,94.18,[s]
Burnout of first stage engine,95.52,[s]
Ignitting second stage engine fuse,95.63,[s]
Firing second stage engine,95.63,[s]
Burnout of second stage engine,95.63,[s]
Apogee detection,103.72,[s]
Minimum velocity around apogee,103.99,[m/s]
Firing drogue parachute,104.70,[s]
Firing main parachute,125.76,[s]
Rocket landing,161.00,[s]
First engine burning time,1.34,[s]
Second engine burning time,0,[s]
Time to apogee,9.54,[s]
Total flight time,66.82,[s]
```

1. angle between rocket and ground plane at the launchpad before launch, units in [°],
2. velocity at the moment of leaving launchpad, units in [$\frac{m}{s}$],
3. measured pressure at the ground level before launch, units in [Pa], data after Kalman filtering,
4. measured pressure at apogee, units in [Pa], data after Kalman filtering,
5. maximum velocity in rocket axis during the flight, calculated from acceleration data, units in [$\frac{m}{s}$],
6. maximum altitude, units in [m], calculated from acceleration data,
7. maximum altitude, units in [m], calculated from pressure data,
8. velocity at the moment of detecting first stage burnout, units in [$\frac{m}{s}$],
9. altitude at the moment of detecting first stage burnout, units in [m],
10. pressure at the moment of detecting first stage burnout, units in [Pa],
11. angle of the rocket at the moment of detecting first stage burnout, units in [°],
12. velocity at the moment of detecting second stage burnout, units in [$\frac{m}{s}$],
13. altitude at the moment of detecting second stage burnout, units in [m],
14. pressure at the moment of detecting second stage burnout, units in [Pa],
15. angle of the rocket at the moment of detecting second stage burnout, units in [°],
16. time when rocket launch has been detected, units in [s],
17. time when burnout of first stage engine was detected, units in [s],
18. time when Arecorder fired fuse igniting second stage engine, units in [s],
19. time when igniting second stage engine was detected - firing fuse is not equivalent to igniting second stage engine, so these two events are separated, units in [s],
20. time when burnout of second stage engine was detected, units in [s],
21. time when apogee was detected, units in [s],
22. time between burnout of engines and firing parachutes, when rocket has minimum velocity, units in [s],
23. time when drogue parachute fuse was fired, units in [s],
24. time when main parachute fuse was fired, units in [s],
25. time when rocket landing was detected (detection is few seconds after actual landing), units in [s],
26. first engine burning time (difference between ignition and burnout of engine), units in [s],
27. second engine burning time (difference between ignition and burnout of engine), units in [s],
28. time from launch to detecting apogee, units in [s],
29. total flight time (difference between detected launch and landing times, be-

couse of delay in detecting landing it may be a few seconds too long), units in [s],

For data from positions 16 to 21 and 23 to 25 time is being calculated as an offset from Arecorder power up.

4. Description of operation

After power up Arecorder is in one of predefined states. Each of them represents different part of rocket flight and different decidions made by Arecorder.

Table 4.1: Arecorder states

state number	description
0	awaiting for initialization complete
1	awaiting for rocket launch
2	first stage engine active
3	first stage engine burnout, awaiting for end of second stage engine ignition delay
4	awaiting for second stage engine ignition and awaiting for detecting apogee
5	second stage engine active
6	second stage engine burnout, awaiting for detecting apogee
7	first parachute fired, awaiting for condition to trigger main parachute
8	awaiting for landing
9	rocket has landed
10	disable data recording
11	buzzer beeping

4.1. Calculations made by Arecorder

Raw data measured by Arecorder are acceleration in three axis ($\pm$24 g in three axis and $\pm$80 g in rocket axis), pressure measurements and temperature measurements (temperature measurements are not used in any calculations). These data are written in raw format (directly measured by sensors, with no calculations), only temperature data is converted from measured voltage to temperature data in [$^\circ$C] with correction offset applied.

Before launch, Arecorder measures rocket angle. Rocket angle is angle between ground plane and axis parallel to the rocket axis. This angle is used for calculating rocket height and velocity during the fligh; it is then important to care-

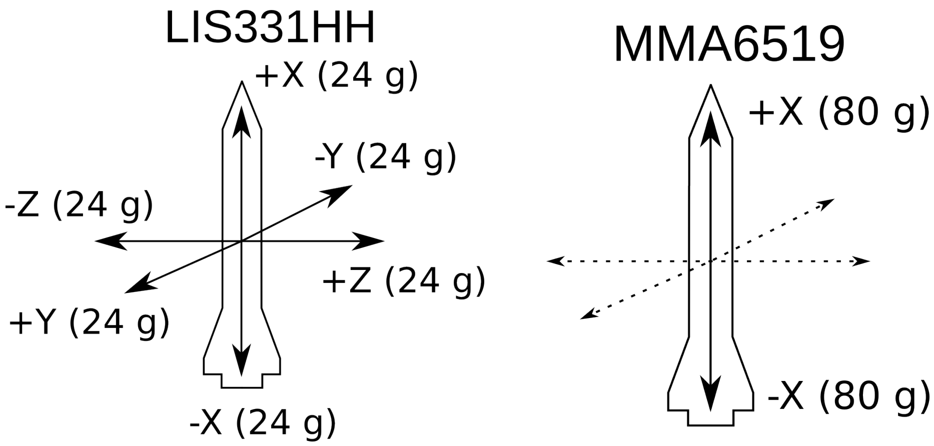


Figure 4.1: Axis of a rocket with marked accelerations measured by particular accelerometers.

fully mount Arecorder to the rocket, so that Arecorder's axis and rocket axis are as parallel as possible. See also drawing A.1.

Rocket angle is updated in real time, so if after Arecorder's power up and before launch rocket angle will change, it will be updated. After launch detection calculation of rocket angle is paused until rocket leaves launchpad. After that rocket angle is calculated on the basis of accelerations acting upon rocket (engine thrust and gravity) and previous rocket angle. See equation B.12.

On the basis of acceleration at the rocket axis and rocket angle Arecorder calculates rocket velocity, rocket ascend speed, altitude and updated rocket angle. Rocket velocity is calculeted based on data from accelerometer ± 24 g, but in case the measured acceleration is higher than 20 g, Arecorder will use data from accelerometer ± 80 g.

Pressure is first being filtered using Kalman filter to reduce noise. Filtered pressure is then used to calculate height above mean sea level (MSL) of launchpad which will be used as a zero point for calculating relative altitude (from absolute altitude above mean sea level calculated from pressure).

4.2. State 0 - awaiting for initialization complete

After power up, Arecorder detects number of selected parameter set and beebs its number. Then it measures voltage on battery - if this voltage is zero, it means Arecorder is powered through USB and switches into "Configuration" mode. Otherwise Arecorder switches to "Flight" mode. After initial switch to either mode, Arecorder will not change it until power down, this enables later to connect battery in order to test fuses. This makes impossible to change mode to "Configuration" during the fligh.

Before switching to one of operation modes, Arecorder initializes sensors, reads programmed parameters, writes pressure data (used to calculate reference altitude for relative altitude measuring) and begins testing presence of fuses (if fuse presence is tested, red LEDs are litted next to detected fuses).

4.2.1. Configuration mode

In order for Arecorder to switch to configuration mode, user needs to attach Arecorder through USB cable to a PC with Areconfig application running and properly configured. See Areconfig manual or section 2.4 for further details.

In configuration mode user can edit few Arecorder parameters:

— altitude at which main parachute will be deployed,

— launchpad height,

— delay between first stage engine burnout and second stage engine ignition,

— owner's first and last name and phone number.

Beside the last position, all settings are programmed separately for each four parameter sets chosen by jumpers.

Arecorder always stays in AWAITING_FOR_ARECORDER_READY state when it is in configuration mode.

Detailed descpription of configuration of Arecorder by Areconfig application is in Areconfig manual - `http://www.palinski.org/Areconfig`.

4.2.2. Flight mode

If Arecorder does not detect adapter attached to computer with Areconfig application running and configured, flight mode is switched on. In this mode Arecorder initializes micro SD card and creates two files to which data will be written - one file named "MEASxx.CSV" and one named "SUMMxx.CSV", where xx is two-digit number set to consecutive files in a card; MEAS and corresponding SUMM numbers are always equal. After each card initialization Arecorder reads if there are any files written before and creates files with incremented number compared to previously written; in this way Arecorder can write up to 99 each MEAS and SUMM files in one card. However it is recommended to format card before each flight.

After files are created, there are three buzzer beeps - each of these beeps reprezents presence or lack of corresponding fuse. Short beep means that fuse is detected while long beep means that fuse was not detected by Arecorder. First beep represents fuse deploying drogue parachute, second beep represents fuse deploying main parachute and third beep represents fuse ignitting second stage engine.

Next Arecorder writes to MEAS file configuration data and there is one long beep indicating that initialization state is over and Arecorder starts reading sensors and detecting rocket launch; since that moment green LED starts flashing. After ten second fuse testing is turned off (red LEDs stop flashing). Arecorder changes state to state 1.

> CAUTION - after Arecorder power ups and signals beginning of detecting rocket launch it is recommended to wait about two minutes for pressure sensor to stabilize.
> In case of earlier launch error of altitude measurements can be as large as few meters.
> In order to compensate this error user should use average of two pressure measurements - one immediately before launch and second shortly after landing - as a pressure for calculating reference altitude for relative altitude measuring.

Arecorder by means of beeping informs about chosen parameter set, detected fuses and beginning of detecting rocket launch. Number of initial beebs means which programming set was chosen. Then, after short pause, three beebs inform about detected fuses - short beeb means fuse was detected and long beeb means it wasn't detected. First beeb is drogue parachute fuse, second - main parachute fuse and the third one is second stage engine fuse. At the end, after another pause, there is long beeb meaning Arecorder started taking measurements.

For example the following sequence of beeps (short line is short beep, long line is long beep and long space between lines is noticably longer pause between each beep sequence):

- -   - - ——   ——

means that second parameter set is active, both parachute fuses are detected but second state engine fuse was not detected and Arecorder started detecting rocket launch and rocket can be launched.

4.3. State 1 - awaiting for rocket launch

In this state Arecorder is initialized and is reading data from sensors in order to detect rocket launch.

Rocket launch is detected when rocket reaches altitude higher than height of launchpad (height of launchpad is programmed earlier by user as a one of parameters). Based on acceleration data Arecorder calculates current rocket velocity and altitude. Additionally, if measured acceleration in rocket axis is greater than 1,2 g (i.e. rocket is accelerating more than 0,2 g), buzzer will start to beep indicating possible launch (until launch is confirmed by rocket reaching altitude higher than height of launchpad).

> Arecorder can be turned on, when rocket is in horizontal position, it will be detected correctly.

> If the rocket is being moved while on the launchpad, it may happen, that temporalily acceleration will exceed 1,2 g. Arecorder will then turn on buzzer signaling potential launch detection, but it will be turn off fraction of second later, when temporary acceleration will decrease. It is completely normal behaviour and launch will not be detected until rocket reaches altitude higher than height of launchpad.

In this state if possible launch is not being detected, pressure at launchpad and rocket angle are updated.

If launch is detected Arecorder will start to write measured and calculated data in micro SD card starting from several samples before launch. Also rocket launch timestamp will be recorded (for later data written to SUMM file).

After detection of rocket launch, Arecorder changes state to state 2.

4.4. State 2 - first stage engine active

In state 2 rocket is flying and first stage engine is active, i.e. thrust of first stage engine is greater that aerodynamic drag force (meaning that acceleration in rocket axis is greater than zero and rocket velocity is increasing). If rocket acceleration becomes lower than zero, a first stage engine burnout will be detected. Acceleration is filtered, so one acceleration measurement will not trigger false detection of burnout.

After burnout detection, first stage engine burnout timestamp is recorded and Arecorder changes state to state 3.

4.5. State 3 - first stage engine burnout, awaiting for end of second stage engine ignition delay

In state 3 Arecorder is awaiting for delay between burnout of first engine and second engine ignition delay (this delay is programmed earlier by user as a one of parameters), after which second stage engine fuse is fired.

In this state there is also a timestamp recorded - timestamp for firing second stage engine fuse.

After that Arecorder changes state to state 4.

4.6. State 4 - awaiting for firing second stage engine and awaiting for detecting apogee

State 4 is both awaiting for confirmation of firing second stage engine and awaiting for reaching maximum altitude.

If second stage engine thrust is greater than aerodynamic drag force, then second stage engine is active. While second stage engine is active, Arecorder is blocking deployment of first parachute. If second stage engine is active for minimum 0,5 s, then Arecorder changes state to state 5.

If there is no second stage engine or it failed to ignite, Arecorder detects if there are conditions to deploy first parachute. These conditions are described in state 6 - section 4.8 becouse they are identical. In case first parachute is deployed Arecorder changes state to state 7.

In this state Arecorder writes timestamp of second stage engine fire or, in case of no second stage engine (or failure to ignite it), Arecorder writes timestamp of maximum altitude and timestamp of minimum rocket velocity.

4.7. State 5 - second stage engine active

State 5 means that Arecorder detected firing of second stage engine and awaits for burnout. In this state it is impossible to deploy parachute.

Similarly as in state 2, if second stage engine generates thrust greater than aerodynamic drag force, it is active and Arecorder stays in state 5. Otherwise Arecorder changes state to state 6.

In this state Arecorder writes timestamp of burnout of second stage engine.

4.8. State 6 - second stage engine burnout, awaiting for detecting apogee

In state 6 Arecorder detects if apogee has been reached. Arecorder detects if pressure begins to rise (meaning lowering altitude). If pressure after Kalman filtering is higher than lowest recorded pressure for every sample taken within last second of measurements, Arecorder decides if drogue parachute should be deployed on the basis of altitude calculated from pressure. If altitude is lower than 200 m, Arecorder deploys drogue parachute immediately. If altitude is higher than 200 m Arecorder waits with deployment of drogue parachute until calculated rocket velocity reaches minimum.

In case of rocket angle at the launch is small, after reaching apogee, rocket axis velocity may be large. Drogue parachute's ropes can break if deployed when rocket velocity is too large. After reaching apogee rocket aerodynamic drag force may be so large, that rocket velocity is lowering despite rocket descending (immediately after reaching maximum altitude rocket axis is almost perpendicular to earth's plane, it's just slightly turned toward ground, so gravity force in rocket's axis is lower than aerodynamic drag force). Delay in drogue parachute deployment until rocket velocity reaches minimum will reduce risk of breaking parachute's ropes.

In this state Arecorder writes timestamp of reaching maximum altitude, timestamp of reaching minimum velocity. Also minimum measured pressure is recorded, which will be used to calculate maximum altitude.

After drogue parachute deployment, Arecorder changes state to state 7.

4.9. State 7 - drogue parachute fired, awaiting for condition to trigger main parachute

In state 7 Arecorder is detecting how rocket acts after deployment of drogue parachute. If rocket is descending with parachute deployed, main parachute will be deployed when rocket descends below programmed main parachute trigger altitude (the default is 200 m).

Arecorder will deploy main parachute at programmed altitude in respect to launchpad. If rocket is descending on place, which is higher above mean sea level than launchpad, the actual main parachute trigger altitude relative to ground will be lower than desired. Similarly, if rocket descends on place, which is lower above mean sea level than launchpad, the actual main parachute trigger altitude relative to ground will be higher than desired.

> CAUTION - User should take into consideration topography of area near launch site, when programming main parachute trigger altitude.

After deployment of drogue parachute Arecorder turns on an algorithm designed to detect if drogue parachute was deployed properly. If Arecorder detects, that rocket descent faster than programmed velocity rate is rising, the main parachute is deployed immediately. After five seconds from deployment of drogue parachute, algorithm is disabled for safety reasons. If drogue parachute was not deployed properly, algorithm will detect it within these five seconds. If drogue parachute was deployed properly, disabling algorithm after five seconds prevents false positive detection of drogue parachute failure, when rocket is descending safely.

In this state Arecorder writes timestamp of main parachute deployment.

After main parachute deployment Arecorder changes state to state 8.

4.10. State 8 - awaiting for landing

In this state Arecorder is detecting rocket landing based of pressure data. Becouse algorithm is using pressure data after Kalman filter, landing can be detected even few seconds after actual landing.

In this state Arecorder writes timestamp of detected rocket landing.

After rocket landing Arecorder changes state to state 9.

4.11. State 9 - rocket has landed

After rocket landing detection, for safety reasons, Arecorder writes ten more seconds of data and then changes state to state 10. In state 9 buzzer beeping is turned on.

4.12. State 10 - disable data recording

In state 10 Arecorder stops writing data to micro SD card and writes summary of flight to both SUMM and MEAS files. When all data is written, Arecorder changes state to state 11.

4.13. State 11 - buzzer beeping

In this state buzzer beeps every second. Arecorder stays in this state until power off.

5. Technical characteristics

5.1. Absolute maximum ratings

CAUTION Stresses above those listed as *Absolute maximum ratings* may cause permanent damage to the Arecorder. These are stress ratings only and functional operaton of the Arecorder under these conditions or greater than described as *Electrical characteristics* is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

Table 5.1: Absolute maximum ratings

Parameter	Min	Max	Unit	Comments
Supply voltage	-0,7	10,5	V	
Acceleration	-	1000	g	1), 2)
Pressure	0	110	kPa	
Operating temperature range	-50	85	[°C]	
Storage temperature range	-50	125	[°C]	

1) not tested,

2) any axis.

5.2. Electrical characteristics

Table 5.2: Electrical characteristics

Parameter	Min	Typ	Max	Unit	Comments
Supply voltage	4	4,2	10,5	V	1)
	3,8	4,2	10,5	V	2)
Operating current consuption	28,8	-	31,7	mA	3) 4)
	30	-	36	mA	3) 5)
	-	35	-	mA	6)
Acceleration measurement range	0	-	24	g	7)
	0	-	80	g	8)
Acceleration sensitivity	-	0,042	-	g	7)
	-	0,012	-	g	8)
Pressure measurement range	0	-	110	kPa	
Pressure sensitivity	-	1,5	-	Pa	
Temperature measurement range	-55	-	130	[°C]	9)
Temperature sensitivity	-	0,25	-	[°C]	

1) if Arecorder fires fuses,

2) if Arecorder does not fire fuses,

3) except when fuse is fired,

4) current consuption when data are not written to micro SD card,

5) current consuption when data are written to micro SD card,

6) average current consuption in state 11 - buzzer beeping,

7) LIS331HH accelerometer, three axis,

8) MMA6519 accelerometer, one axis,

9) temperature sensor measurement range exceeds operating temperature of the Arecorder,

5.3. Physical and mechanical parameters

Table 5.3: Physical and mechanical parameters

Parameter		Unit	Comments
Width	25	mm	1)
Length	74	mm	
Height	14	mm	2)
Mass	16,4	g	

1) if fuses are to be connected additional space at the Arecorder's side is required,
2) maximum height of component at the top side is 10,5 mm, at the bottom side is 2 mm, board with is 1,5 mm,

6. Dimentions

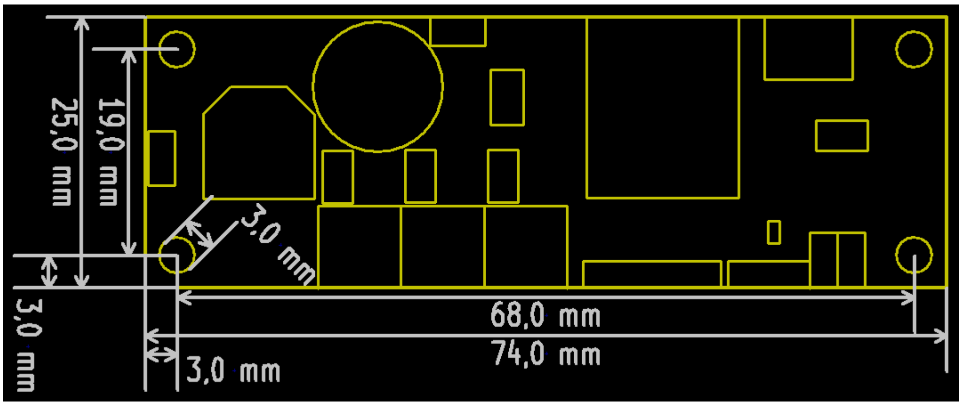


Figure 6.1: Dimensions associated with Arecorder's PCB board along with outlines of important components on top side.

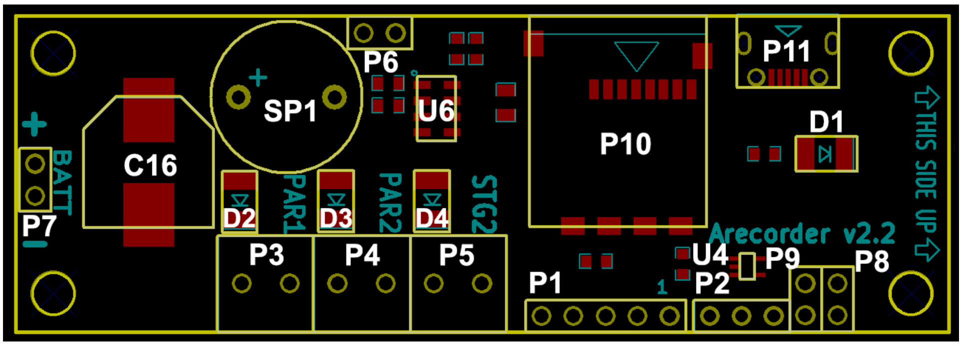


Figure 6.2: Location of important components on top side of Arecorder's PCB board.

C16 - capacitor,

D1 - orange LED,

D2, D3, D4 - red LEDs,

P1 - firmware programming connector,

P2 - additional communication connector,

P3, P4, P5 - fuses connectors,

P6 - additional buzzer,

P7 - power supply,

P8, P9 - connector for choosing parameter sets,

P10 - micro SD card connector,

P11 - communication connector,

SP1 - buzzer,

U4 - temperature sensor,

U6 - pressure sensor.

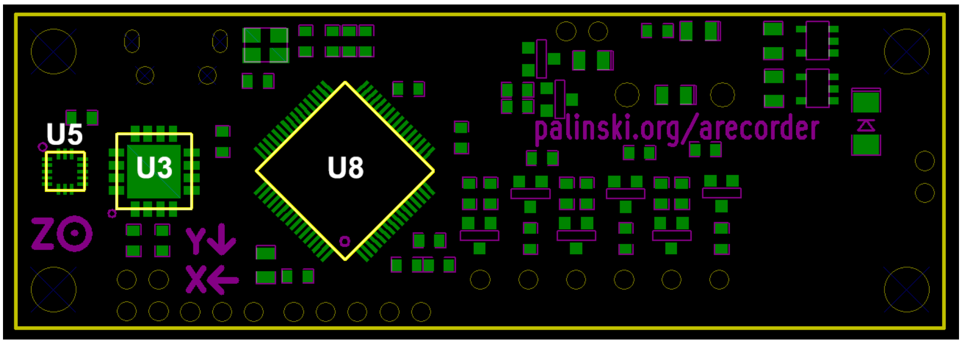


Figure 6.3: Location of important components on bottom side of Arecorder's PCB board.

U3 - accelerometer ±80 g,

U5 - accelerometer ±24 g,

U8 - microcontroller.

7. F.A.Q.

Does chamber containing Arecorder need to be isolated from parachute section?

No, it is not necessary. Maximum altitude is detected before fuse triggering and pressure change resulting from drogue parachute fuse firing will not change this value. However it is recommended to isolate Arecorder's chamber from parachute section, becouse it may influence parachute failure detection algorithm. At low altitudes it can also cause main parachute to deploy prematurely.

If during the flight there was accident and the Arecorder was destroyed, would there be any data recorded?

Yes, assuming micro SD card would be intact. Arecorder writes data to micro SD card every 200 ms. If Arecorder was destroyed, all data except last 200 — 800 ms would be recorded.

Does Arecorder need special preparations before flight?

No, user can just put Arecorder inside rocket in such a way, that Arecorder's axis will be parallel to rocket axis, headed proper way to the nosecone and the mounting to rocket will be stiff. However it is recommended to copy flight data from micro SD card and format card after each flight. Before each flight it is recommended to make sure that battery powering Arecorder is fully charged.

What should i do if i don't want to connect any fuses to Arecorder? Do i have to connect something instead?

No, just don't connect any fuses. If fuses will not be connected to Arecorder, it will be signalled after power up. No matter if fuses were detected or not, Arecorder still will try to fire them (this is to prevent not firing fuses becouse detection was false negative). If there will be no fuses electric pulse will not be triggered. Arecorder does not detect if fuse was fired in reality (and if fuse was connected during firing it), there is only recorded time, when Arecorder released electric pulse which fires fuse.

A. Glossary of terms used in this instruction

Apogee

Point in flight path when rocket is at highest altitude.

Rocket axis

Line going from tip of the nose cone to the middle of the base of the rocket. In this axis engine is generating thrust. In the this manual the term "rocket acceleration" always means "acceleration in rocket axis".

Rocket angle

Smallest angle between rocket axis and plane perpendicular to local vertical direction.

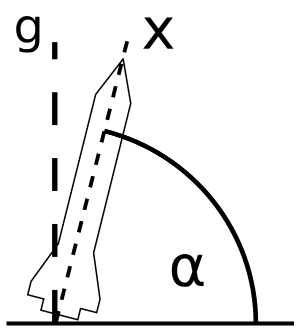


Figure A.1: Visualization of rocket angle in respect to the ground. x is rocket axis, g is local vertical direction.

Relative altitude

This is the altitude above ground. This is the altitude user is interested in. In the further part of manual the term "altitude" always means "relative altitude".

Absolute altitude

This is the altitude above mean sea level (MSL).

Reference pressure

This is the pressure measured at the launchpad. It is used to calculate absolute altitude of launchpad and then subtracted from absolute pressure calculated in Arecorder in order to get relative altitude.

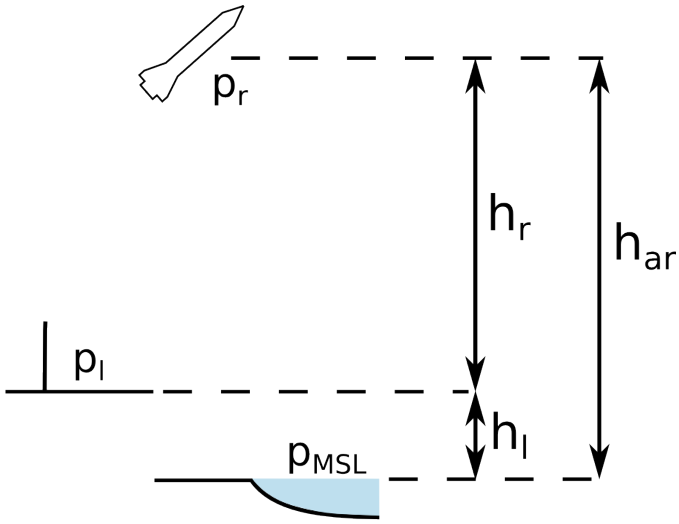


Figure A.2: Visualization of pressure measurements and height calculations. p_{MSL} is pressure at mean sea level (101.325 kPa), p_l is pressure at measured at launchpad (reference pressure), from which h_l, absolute altitude of launchpad is calculated. p_r is pressure measured by Arecorder during the flight; from this pressure absolute altitude of rocket (h_{ar}) is calculated.

B. Forces acting upon rocket

B.1. Forces acting upon rocket at launchpad

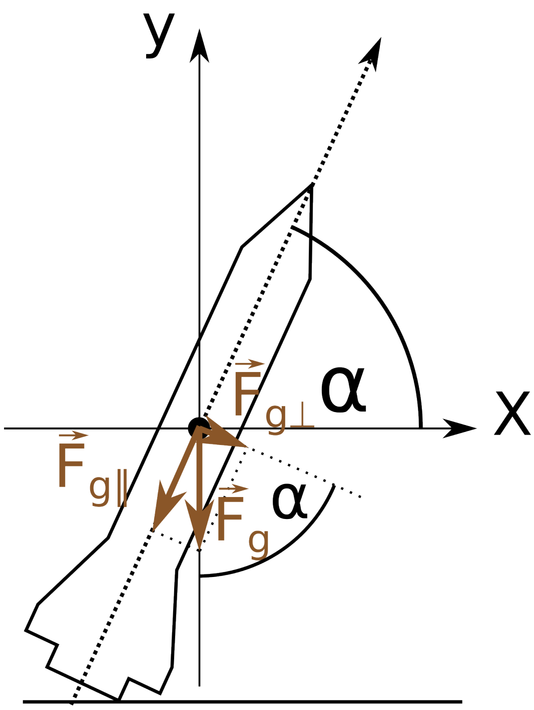


Figure B.1: Forces acting upon rocket at launchpad.

where:
$\overrightarrow{F}_g$ - gravity force,
$\overrightarrow{F}_{g\|}$ - gravity force component parallel to the rocket axis,
$\overrightarrow{F}_{g\perp}$ - gravity force component perpendicular to the rocket axis,
α - rocket angle.

When rocket is standing at the launchpad, only gravity force is acting upon it. Becouse accelerations measured by accelerometers are proportional to perpendicular and parallel components of gravity force (see equations B.1, B.2 and B.3), Arecorder is able to calculate rocket angle by using equation B.4 or B.5.

$$\overrightarrow{a}_{g\|} = \frac{\overrightarrow{F}_{g\|}}{m} \tag{B.1}$$

$$\vec{a}_{g\perp} = \frac{\vec{F}_{g\perp}}{m} \tag{B.2}$$

$$\vec{a}_{g} = \frac{\vec{F}_{g}}{m} \tag{B.3}$$

where:
$\vec{a}_g$ - gravitanional acceleration, $\vec{a}_{g\perp}$ - gravitanional acceleration component perpendicular to the rocket axis, $\vec{a}_{g\|}$ - gravitanional acceleration component parallel to the rocket axis, $\vec{F}_g$ - gravitanional force, $\vec{a}_{g\|}$ - gravitanional force component parallel to the rocket axis, $\vec{a}_{g\perp}$ - gravitanional force component perpendicular to the rocket axis, m - rocket mass.

$$\cos(\alpha) = \frac{\|\vec{a}_{g\perp}\|}{\|\vec{a}_{g}\|} \tag{B.4}$$

$$\sin(\alpha) = \frac{\|\vec{a}_{g\|}\|}{\|\vec{a}_{g}\|} \tag{B.5}$$

B.2. Forces acting upon rocket during the flight

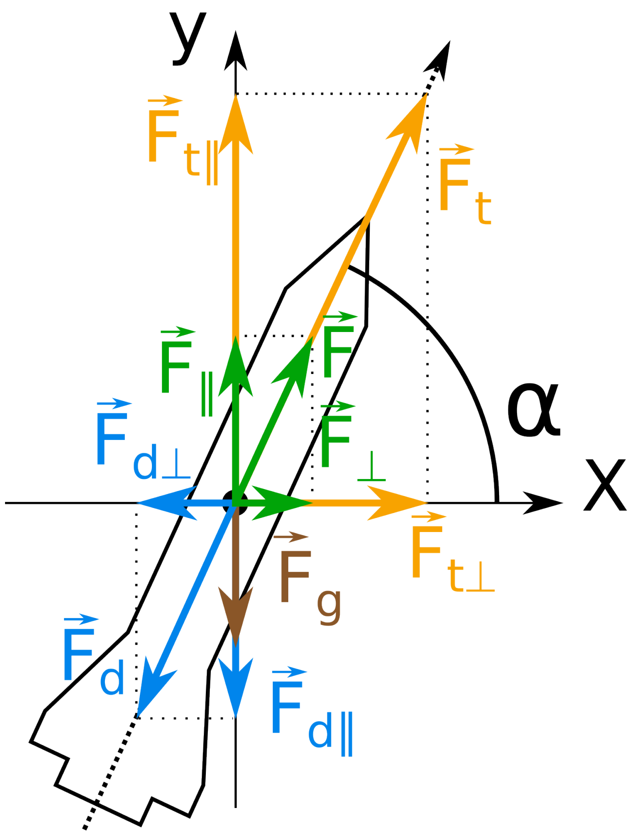


Figure B.2: Forces acting upon rocket during the flight

where:
$\vec{F}_t$ - thrust,

$\overrightarrow{F}_d$ - aerodynamic drag force,
$\overrightarrow{F}_g$ - gravitaional force,
$\overrightarrow{F} = \overrightarrow{F}_d + \overrightarrow{F}_t$ - net force of thrust and aerodynamic drag force,
$\overrightarrow{F}_{t\|}$, $\overrightarrow{F}_{d\|}$, $\overrightarrow{F}_{\|}$ - vertical components of forces,
$\overrightarrow{F}_{t\perp}$, $\overrightarrow{F}_{d\perp}$, $\overrightarrow{F}_{\perp}$ - horizontal components of forces.
α - rocket angle during flight.

There are three main forces acting upon rocket during flight - thrust $\overrightarrow{F}_t$, aerodynamic drag force $\overrightarrow{F}_d$ and gravitational force $\overrightarrow{F}_g$, which is shown in the drawing B.2. Thrust and aerodynamic drag force have the same direction, but opposite sense; they always act along the rocket axis. Gravitaional force is always parallel to local vertical direction and the sense is directed toward earth.

Acceleration measured by acceleration during the flight is proportional to net force of thrust and aerodynamic drag force.

$$a = \frac{\|\overrightarrow{F}\|}{m} \tag{B.6}$$

Accelerometers are not able to measure gravitational acceleretion, becouse in reality integrated accelerometers measure only the difference between acceleration acting upon accelerometer's case and inner circuit - gravity acts upon whole accelerometer so there is no difference (at the launchpad accelerometers measure in reality force from the floor to the Arecorder counteracting gravitanional force). Gravitational acceleration is approximated by assumption, that at Arecorders maximum working altitude the gravitational acceleration is approximately equal to gravitational acceleration at launchpad and is equal to 9,81 $\frac{m}{s^2}$.

At the flight Arecorder calculates horizontal and vertical acceleration from acceleration along rocket axis with the correction of gravitational acceleration in the case of vertical acceleration.

$$a_{\|} = a \sin \alpha - g \tag{B.7}$$

where:
$a_{\|}$ - vertical acceleration,
a - acceleration along rocket axis,
α - rocket angle during flight,
g - gravitational acceleration (9,81 $\frac{m}{s^2}$).

$$a_{\perp} = a \cos \alpha \tag{B.8}$$

where:
$a_{\|}$ - horizontal acceleration,

a - acceleration along rocket axis,
α - rocket angle during flight.

Arecorder calculates vertical (e.g. speed of altitude change) and horizontal velocity (speed of rocket changing distance from launchpad) according to equations B.9 and B.10 respectively. Vertical and horizontal velocities are updated at each measurement cycle by calculated change - vertical and horizontal velocities are the sum of all calculated velocity changes since rocket launch.

$$\triangle V_{\parallel} = a_{\parallel} \triangle t \tag{B.9}$$

where:
$\triangle V_{\parallel}$ - change in vertical velocity in current measurement cycle,
$a_{\parallel}$ - vertical acceleration,
$\triangle t$ - measurement cycle period (10 ms).

$$\triangle V_{\perp} = a_{\perp} \triangle t \tag{B.10}$$

where:
$\triangle V_{\perp}$ - change in horizontal velocity in current measurement cycle,
$a_{\perp}$ - horizontal acceleration,
$\triangle t$ - measurement cycle period (10 ms).

Velocity at rocket axis is calculated from vertical and horizontal velocities according to the equation B.11.

$$V = \sqrt{V_{\parallel}^2 + V_{\perp}^2} \tag{B.11}$$

where:
V - velocity along rocket axis,
$V_{\parallel}$ - vertical velocity,
$V_{\perp}$ - horizontal velocity.

Rocket angle is calculated based on updated velocities according to the equation B.12.

$$\alpha = \arccos(\frac{V_{\perp}}{V}) \tag{B.12}$$

where:
α - rocket angle during the flight,
$V_{\perp}$ - horizontal velocity,
V - velocity along rocket axis.

C. History of changes

2013.12.27

— Initial release of english version of manual.

2014.03.16

— Added section 3.1.4 about converting raw acceleration data into data in units [g] and [$\frac{m}{s^2}$].

2015.05.03

— Instruction updated for Arecorder version 2.1.

2015.05.04

— Added table of default Arecorder program sets.

2016.06.05

— Changed information about Arecorder programming - now it is done through USB.
— Updated data header in 3.
— Added information about programming rocket descend velocity at which main parachute will be deployed emergently and information about disabling it.
— Added velocity descend parameter at which main parachute will be deployed emergently do the default program sets table 2.3.
— Arecorder is now able to resume saving data to SD card after temporary physical SD card connection loss.
— Updated power consumption in table 5.2.
— Changed Arecorder dimensions in version 2.2.