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**K. V. Kryvenko**, stud.,
**N. F. Tupitsin**, Ph. D.

# TESTING OF AUTOMATIC FLIGHT DATA RECORDING SYSTEM "ELOGGER V4" ON GLIDER

National aviation university, e-mail: kyrill.kryvenko@mail.ru

*Ground and flight testing was performed for a miniature flight data recording system "eLogger V4". Program for data processing and graphing was developed in MATLAB environment. The proposed system may be suitable as a basic measuring and data recording device for unmanned aerial vehicle flight testing.*

**Keywords:** flight data recording system, flight recorder, unmanned aerial vehicle, flight testing, indicated airspeed, airdata system, radio controlled.

**Introduction and task statement.** As known [1], flight data recording system (FDRS) is installed for registration of flight, work of engine, control system and so on. With development of aviation the FDRS are consistently modified.

Installed on large aircrafts the FDRS have a significant weight and may register more than hundred parameters for a long time. For example, Russian FDRS [2] may register more 250 parameters during 24 hours and its weight is 21,6 kg.

For small aircrafts and unmanned aerial vehicles (UAVs) require more compact FDRS with less quantity of recorded parameters, working time and weight. By modernizing FDRS [2] a system with less weight and sizes is obtained, and all of its modules placed in the same enclosure [3].

Among modern compact flight recorder (FR) for UAV to analyze and research their work is chosen flight recorder [4]. Purpose of the work is testing of FDRS [4] on ground and on radio controlled (RC) glider, estimation of its qualities of data acquisition and processing.

Modular design of FDRS can be expressed with the scheme, which is shown in fig 1.

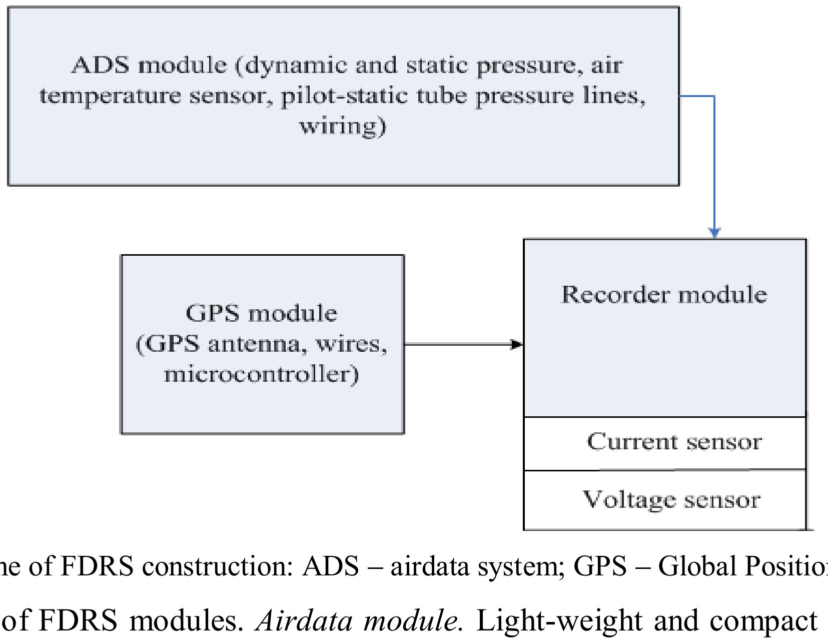


Fig. 1. Scheme of FDRS construction: ADS – airdata system; GPS – Global Positioning System

Description of FDRS modules. *Airdata module.* Light-weight and compact arrangement of 2 electronic pressure sensors on small circuit board, connected by pressure lines to pilot-static tube and joined via $I^2C$ interface ($I^2C$ Bus) to the recorder module, performs measurement of indicated airspeed and barometric altitude. As the pressure sensors selected miniature MPXV7002 and MPX4100 [5; 6], weighting only grams, with embedded temperature compensation, which pre-calibrated on factory.

Absolute pressure sensor has maximum fractional error of 1,8 % in the temperature range from 0° to 85°C and range of measurement 60–105 kPa. Differential pressure sensor offers maximum fractional error of 2,5 % in the temperature range from +10°C to +60°C.

***GPS module.*** The GPS module supplies the FDRS 7 measured values. The basic four of them are longitude, latitude, GPS altitude and Coordinated Universal Time (UTC) time. Other parameters, ground speed, vertical speed and accelerations are derived by basis three coordinates in space and time. It should be stressed that in case of having good satellites coverage, measurements of altitude by GPS are performed more accurately than by help of barometric instrument almost 10 times. Using GPS, it is easy to measure ground speed, without Doppler navigator or other specific instrument. Disadvantages considered module are sensitivity to electromagnetic emissions, strong dependence on satellites coverage and from location this module on the glider.

The major advantages are high positioning accuracy and update rate of 10 Hz, high sensitivity and support of differential GPS and assisted GPS. It should be mentioned, that most of mobile GPS modules, including even UAV autopilots' modules, make use 1 Hz or 4 Hz GPS module, while the proposed module has 10 Hz frequency. Update rate of 10 Hz allows tracking UAV, which is moved with velocity up to ~30 m/s without inertial navigation system support.

Table 1 contains main technical characteristics of GPS receiver, installed in GPS module.

*Table 1*

**Technical characteristics of GPS receiver, installed in GPS module**

| | |
|---|---|
| GPS microcontroller | MTK MT3329 |
| Frequency | L1, 1575.42 MHz |
| Sensitivity | – Acquisition – 148 dBm, cold start<br>– Reaquisition – 160 dBm<br>– Tracking – 165 dBm |
| Number of channels | 66 channels |
| Time to first fix | – Hot start – 1 sec. typ.<br>– Warm start – 33 sec. typ.<br>– Cold start – 35 sec. typ. |
| Position accuracy | 3,0 m RMS (root mean square error) |
| Velocity accuracy | 0,1 m/s |
| Acceleration accuracy | 0,1 m/s$^2$ |
| Timing accuracy | 100 ns RMS |
| Max. measured altitude | 18000 m |
| Max. measured velocity | 515 m/s |
| Max. measured acceleration | 4 g |
| Update rate | 1 Hz to 10 Hz |
| Power supply | $V_S$ = 3 V…3,6 V; $V_{BACKUP}$ = 2,0 V…4,3 V |
| Current consumption | Max 30 mA |
| Working temperature | -40°C to +85°C |
| Dimensions | 16 × 16 × 6 mm |
| Weight | 6 grams |

***Recorder module.*** Recorder module (RM) is the central block in the FDRS, receiving data from GPS module, air data module and other sensors through USB, $I^2C$ and analog interfaces. Recorder module itself contains scheme for voltage measurement and Hall-effect sensor ACS752SCA-100 for current measurement [7]. It is useful for measurement of electric power systems and airborne networks (Table 2).

Important characteristics of RM are: capture rate and memory volume. Capture rate defines the frequency, at which the data are recorded. Information from sensors is taken at a time, and result is a set of discrete data in time. Capture rate can be assigned in software and when setting of RM. Possible values are: 1sample/5min; 1sample/min; 1, 2, 4, 8, 10, 20, 40 or 50 samples per second. Capture rate of 10 samples per second was used in testing on glider, because GPS update rate is 10 Hz.

**Flight tests results.** Flight tests were conducted on the field with coordinates: longitude 30,243212˚ east, latitude 50,286054˚ north. True altitude of flying field + 170 m above the Mean sea level (MSL).

At testing were the following weather conditions:

– Atmopheric pressure 765 mm Hg;
– Wind: north-western, 5m/s, gusty;
– Air temperature +15˚C;
– Air humidity 66 %.

*Table 2*

**Characteristics of recorded parameters**

| **Recorded parameter** | **Units of measurement** | **Range of measurement** |
|---|---|---|
| Current* | A | -100…100 |
| Voltage | V | 5…80 |
| Pressure altitude | M | -300…3000 |
| Indicated air speed | km/h | 3…563 |
| GPS altitude | M | 0…18000 |
| GPS speed | m/s | 0…515m/s |
| GPS longitude | deg. | - |
| GPS latitude | deg. | - |
| GPS UTC time | Ns | - |
| GPS course | deg. True North | 0…360 |
| GPS distance to operator | m | - |
| Temperature 1 | ˚C | -20…+120 |
| Temperature 2 | ˚C | -20…+120 |
| Temperature 3 | ˚C | -40…+216 |
| Date | DD:MM:YYYY format | - |
| PWM servo signal* | ms | 1…2 |
| Engine rotation speed* | rpm (Revolutions per minute) | 50-36000 |

Note: * marked variables were not recorded in experiments of this research.

Five flights with recoding flight data were performed. Totally 31 photos and 17 videos were filmed. Glider was launched via bungee start. After each flight, RM was turned off, and data was downloaded to laptop through USB cable. Totally 5 *.fdr files and 10 *.kml files were recorded during flight tests.

***Flight data processing and analysis***. The basic input information for data processing and analysis are *.fdr files, recordered by FDRS. These files were downloaded to PC via USB bus. The most qualitive data of coordinates recording was archieved in the second flight, which was the subject for the next analysis. Recorded data was processed with the help of program written in MathWorks MATLAB 7.11.

**1.** ***Calculation of flight duration.*** Analysis of second flight results that lasted for 98,4 seconds, was performed. Video of flight shows approximately the same result. The flight started at moment 11,6 seconds after switching on the recorder. The glider landed at the end of 110$^{th}$ seconds. On the basis of this information time interval was cut, and consisted of only from 11,6 to 110 seconds.

**2**. ***Two-dimensional trajectory, path length and ground speed calculation.***

Parameters of trajectory was succesfully logged by GPS module. Trajectory is relatively smooth and well accorded with the trajectory on the video. Trajectories were constructed on figures in two ways:

a) By using MATLAB program the trajectory was plotted in longitude and latitude axis. Projection of glider's flight trajectory on horizontal plane is shown in fig. 2;

b) By exporting data from *.fdr file to Google Earth *.kml file, and visualizing it with the help of program GoogleEarth plotted the trajectory of glider. Measurements in program GoogleEarth allowed to define the length of projected trajectory – 591 m. Projection of glider's flight trajectory on horizontal plane – plotted by help Google Earth is shown in fig. 3.

Parameters of trajectory in MATLAB were found by using navigation functions 'leg' and arrays 'lat'(latitude) and 'lon' (longitude), which containing coordinates of trajectory in degrees. As a result, the length of trajectory 591,15 m was obtained. Average ground speed was calculated in two ways: 1) by averaging of the ground speed, which measured by GPS (6,0076 m/s), 2) by dividing the trajectory length on the time of flight (5,6188 m/s).

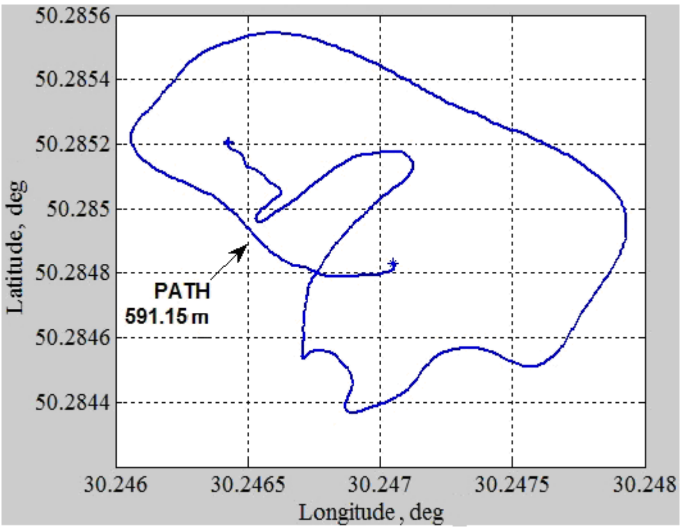


Fig. 2. Projection of glider's flight trajectory on trajectory horizontal plane: --- track; * take-off point; + landing point

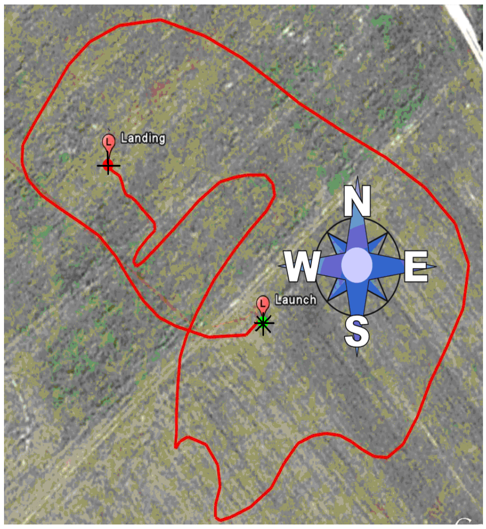


Fig. 3. Projection of glider's flight on the Earth's surface: * take-off point; + landing point

**3.** ***Three-dimensional trajectory.*** During flight tests altitude was measured by two instruments: GPS module and pressure altimeter. The true altitude (altitude above MSL) was measured by help of GPS and the pressure altitude was defined relatively point of take-off.

Three-dimensional trajectories of glider motion in space was plotted in MATLAB program using both GPS true altitude and pressure altitude plus the height of the airfield above MSL (fig. 4). The points take-off and landing are marked in the fig. 4.

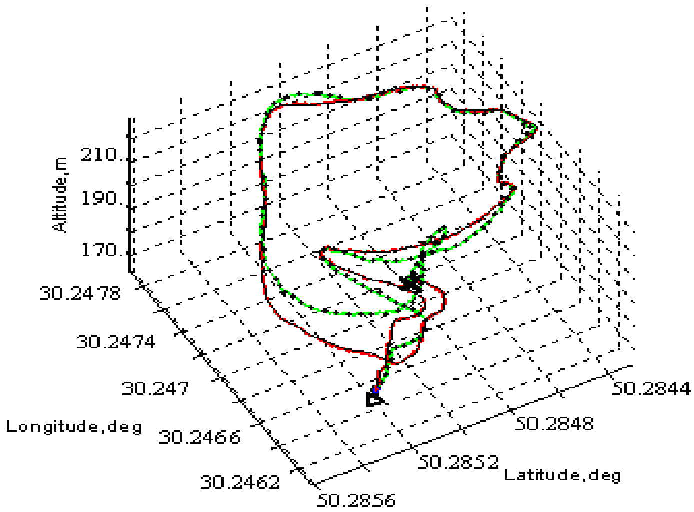


Fig. 4. Three-dimensional trajectories of glider motion in space: Δ – landing point; × – take-off point; •• – pressure altitude:

– GPS altitude

**4.** ***Determination of flight altitudes measured by GPS and pressure altimeter.*** Using GPS and pressure altitude data, maximal values of flight altitudes were calculated (57 and 58 m, respectively). Dependences of flight altitudes glider's in time are presented in fig. 5. Dependences of air temperature and flight altitude measured by ADS module are shown in fig. 6. Maximal pressure altitude was less that 100 m, but a little drop in temperature was observed.

**5.** ***'Distance to operator'.*** 'Distance to operator' graph is obtained on the basis of navigation calculations of distances between points with current coordinates of flight and the point of take-off (fig. 7). Actually this is the length of radius-vector from the point of take-off to the glider. The glider landed 41,4 meters away from the point of take-off. You can see rapidly increasing distance in the beginning, this correlates with fast bungee launch.

**6.** ***Indicated airspeed and ground speed.*** Dependences of indicated airspeed (IAS) and ground speed in time are shown in fig. 8. Maximal values of IAS and corresponding time moments are marked on axes.

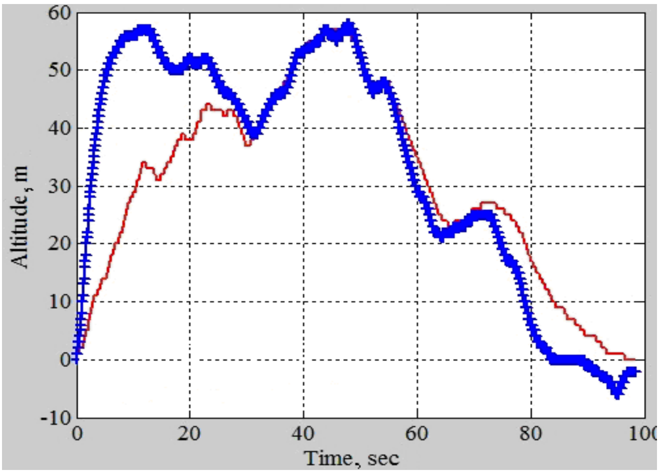


Fig. 5. Dependence of flight altitude glider's in time: ++ – pressure altitude; —– GPS altitude.

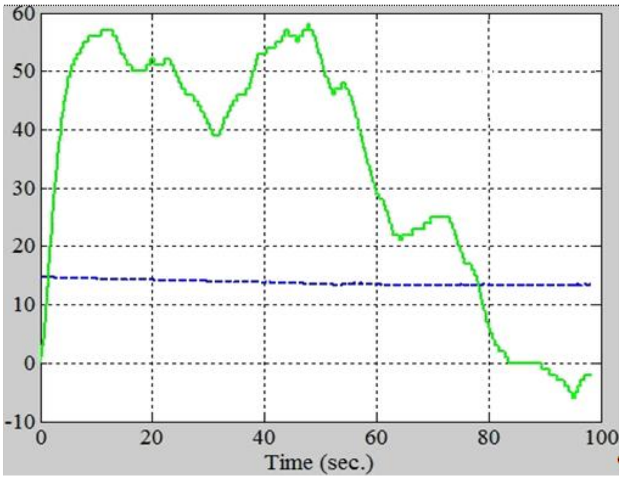


Fig. 6. Dependences of air temperature and flight altitude measured by ADS module: ··· – temperature, °C; —– altitude, m

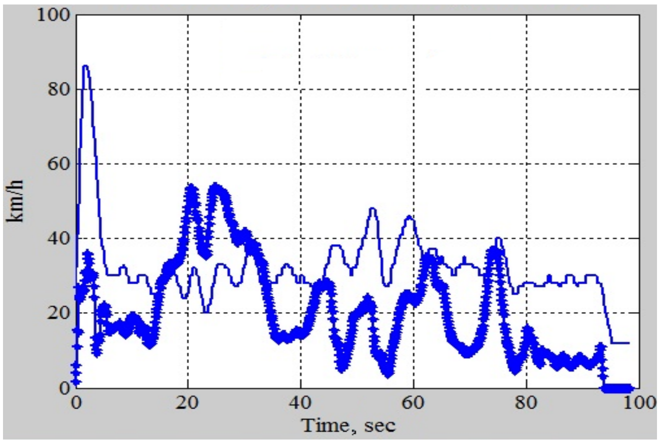


Fig. 7. Dependences of IAS and ground speed of glider in time: —– indicated airspeed; ++ – ground speed

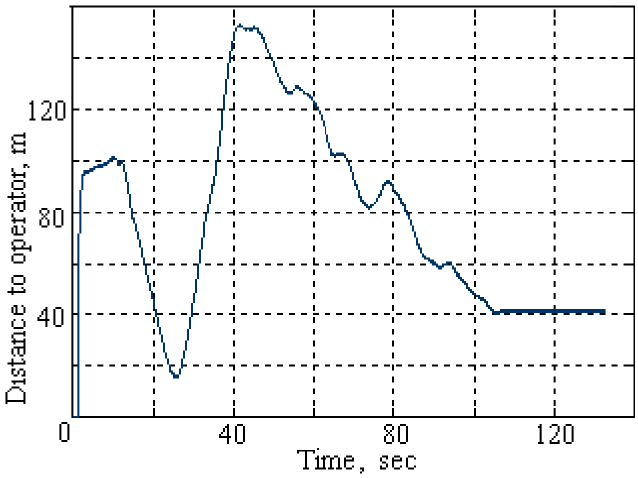


Fig. 8. Dependence of distance between operator and glider in time

**Conclusions.** Automatic flight data recording system is investigated in this work. The structure and functioning of FDRS were investigated in details. Main properties and characteristics were defined. Automatic FDRS was installed in RC glider. Ground tests were carried out. The GPS cross-track error was estimated. Adequateness of measurements was proved during ground tests. A series of 5 flight tests was carried out, flights were recorded on video. There were recorded 33 parameters in flight, only portion of them were used further. Experimental data was downloaded to PC, processed by Data Recorder v8,98 program, exported to .kml Google Earth files and saved as .fdr files. Google Earth files was edited, take-off and landing points were marked. Results of ground and flight tests were processed by different software. A special program was developed in MATLAB environment for flight data processing and graphing.

Duration of flight was determined. Trajectory of flight was plotted on a plane and in three-dimensional space. Length of trajectory was calculated by Google Earth and by MATLAB program using data from GPS. The obtained values were compared and are equal. Average ground speed was calculated by two different methods, results vary by approximately 0,4 m/s. Dependences of pressure altitude, GPS altitude, IAS and ground speed in time were plotted. Maximal pressure and GPS altitudes were determined. There was found a correlation between air temperature and pressure altitude.

A variance between values of altitudes measured by ADS module and GPS (see fig. 2, 4, 5) is explained by inertia of pressure sensor. The negative values of altitudes are explained difference altitudes between point of landing in comparison with point of take-off.

The automatic FDRS can be expanded by additional sensors, MATLAB program can be upgraded for calculation of other derived information, such as true airspeed, Mach's number, rate of climb etc.

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К. В. Кривенко, М. Ф. Тупіцин

**Тестування системи автоматичного запису польотих даних «eLogger V4» на планері**

Проведено наземні та льотні випробування для мініатюрних бортових самописців польотних даних системи «eLogger V4». Розроблено програму для оброблення даних і побудови графіків у середовищі MatLab. Запропонована система може бути придатна для вимірів і запису даних під час льотних випробувань безпілотних літальних апаратів.

К. В. Кривенко, Н. Ф. Тупицин

**Тестирование системы автоматической записи полетных данных «eLogger V4» на планере**

Проводены наземные и летные испытания для миниатюрных бортовых самописцев полетных данных системы «eLogger V4». Разработана программа для обработки данных и построения графиков в среде MatLab. Предлагаемая система может быть пригодна для измерений и записи данных во время летных испытаний беспилотных летательных аппаратов.