Practical Test: 8 Hours of Flying through the Night

with

Electronic Burner Control

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Night rides in a hot air balloon are a special experience! Anyone who has experienced the charm of this play of colors in the evening at sunset and the morning in the change from deep blue tones to rich red at the slow dawn emanating from the northeast cannot resist. Flying through the night, however, is also a challenge. Of course, the question of the sense and the results of such undertakings arises as a matter of priority. This contribution is intended to provide answers.

Final preparations at the launch site near Treuenbrietzen in Brandenburg, Germany on 27 July 2022. Photo: Christoph Tatray

We have already described our experiences with night flights in hot air balloons from sunset to sunrise several times (compare "From contours to structures" in BSM ... together with Bernd Pulzer and the report on the 8th Thuringian Forest Long Distance Flight "Kasparov vs Deep Blue" BSM 1/15). The trip, which is highlighted in the following, was actually supposed to take place a year earlier. For this, all preparations were made on the evening of 21 June 2021, the weather forecasts were excellent and the rigging of the balloon was completed well before sunset. We planned a solo flight with further perfected control software in the PC version with the proven external control unit (see https://hlballon.com). However: That evening, shortly before take-off, no connection could be established between the computer and the solenoid valves!

The anger about the missed opportunity was naturally deep. In the end, the cause of the unexpected malfunction of the control system turned out to be a faulty Windows update. This negative experience showed unmistakably that although the balloon control system worked perfectly after the long development period, the technology and the computer remained vulnerable. We had thought several times about switching to processor technology, such as the ESP32 basis. But the decision to venture a new development was lacking. With the deep disappointment of the aborted start to the longed-for night flight in our stomachs and the new acquaintance with Vincent Amon and Michael Haberler from Austria in our minds, who had created a compact balloon vario based on ESP32 technology with an integrated display and a temperature and baro module designed by Vincent, we immediately began to intensively port to the new technology and necessarily to programme again.

This time, of course, the balloon was set up after an extensive test of the technique, which I was able to concentrate on thanks to the proficient launch team. Photo: Christoph Tatray

A brief review: The dream of being able to use an autopilot in a hot air balloon is an old one. There are countless projects on this subject, but systems that work in practice are rather rare. The hot-air balloon, with its mode of operation based on the principle of buoyancy, is physically simple to model, but material properties of the balloon envelope, meteorological conditions and, last but not least, solar radiation make the system highly non-linear and thus difficult to determine and predict by calculation. This means that electronic control systems quickly reach their limits.

If one hands over the control of the burner impulses to a computer, it soon becomes apparent that a hot-air balloon is truly a very stubborn vehicle. In balanced flight, what the computer calculates works, but at some point the balloon begins to fall and no computer or control system can catch it again without an "overshoot" and resulting instabilities. This behavior also leads to excessive throttle consumption when flying inattentively by hand. This is where our control system should come in, relieve the pilot and significantly reduce gas consumption during controlled heating.

Generalizations in the physical understanding of the flying conditions of a hot-air balloon are prerequisites for realizing control tasks in terms of programming. But the real challenge seems to be to teach the computer the art of the experienced balloon pilot in anticipatory, situation-dependent heating. The ingenious ideas for solving such tasks were developed long before the computer age by Prof. Rudolf E. Kalman in the 1960s. The algorithm he developed convinced like hardly any other mathematical theory in the realization of the moon landings in NASA's Apollo programme. To this day, it is one of the most powerful tools for technicians and programmers in space travel, aerodynamics and for solving complex control tasks.

With the help of the Kalman filter process, which could now be implemented on the ESP32 processor technology, only the absolutely necessary energy is supplied to the hot air balloon as "precisely as possible for the next heating impulse applied at the optimal time" from the observed dynamics of the balloon via the burner operated with solenoid valves. We calculate the accelerations or, in the physical sense, the resulting forces on the balloon via Kalman from the barometric pressure values and estimate their expected change over time. In the next heating step, the "change in force at the balloon" that actually occurred is then compared with the prediction and corrected in the following step with the measured error. The advantage of using the new ESP32 technology for the procedure that has been working in our balloon for years instead of a computer is that the processor has only this control task quasi "burnt in" to the system, can be switched on and off at will, is hardly the size of a cigarette packet and requires only minimal energy to operate. In other words, it was possible to precisely overcome the decisive disadvantages that had previously prevented the widespread use of our control system. What remained was to plan a new night drive and to test its practicality also with regard to system stability and the optimization of gas consumption.

As described in previous articles here in the German “Ballonsport Magazin”, objective data on gas consumption in hot air balloons is difficult to quantify due to the significant influence of solar radiation and constantly changing loading and weather conditions. At night, not only are "all cats grey" but the "disturbing" influence of the sun is absent. Therefore, on long journeys through the darkness, the calculation or estimation of propane consumption is more feasible. We know very well how much lighter we become in the course of the longer journey. This allows us to build up a system of equations with different "loadings", which sufficient accuracy to represent the conditions in the atmosphere such as pressure, temperature and humidity from meteorological modelling or soundings with the unknown parameters of the energetics of our balloon. This already outlines the experiment and the possibility of determining the multitude of influencing variables in retrospect by calculation.

So: A drive through the night should provide us with detailed consumption values for later evaluation and calculation of the gas consumption, the solar contribution as well as the share of infrared radiation from the earth and the atmosphere in the balloon's energy balance.

The time around the summer solstice is ideal for our destinations. Unfortunately, it was not possible to use the shortest nights due to the weather. The last decade in July already requires autonomy times of 8 hours to get safely through the night. A challenge for the mission calculation with regard to propane consumption and optimization of the loading. This time we also wanted to pay tribute to our advanced age by not going solo. Jens Berger, an experienced gas balloon pilot with night-time experience, agreed to come along. The table opposite shows the optimal consumption values simulated in advance and calculated afterwards, compared with the measured real consumption for our flight on 27 July 2022. Fabienne Muriset contributed the underlying meteorological data. Her wealth of "Gordon Bennett" experience, the precise analytical evaluation of the model data, but especially the structured pre-launch briefing were essential elements in ensuring that our undertaking could be prepared in the best possible way and that as many elements of uncertainty as possible could be excluded. We would like to take this opportunity to thank Fabienne once again.

Emotions pure

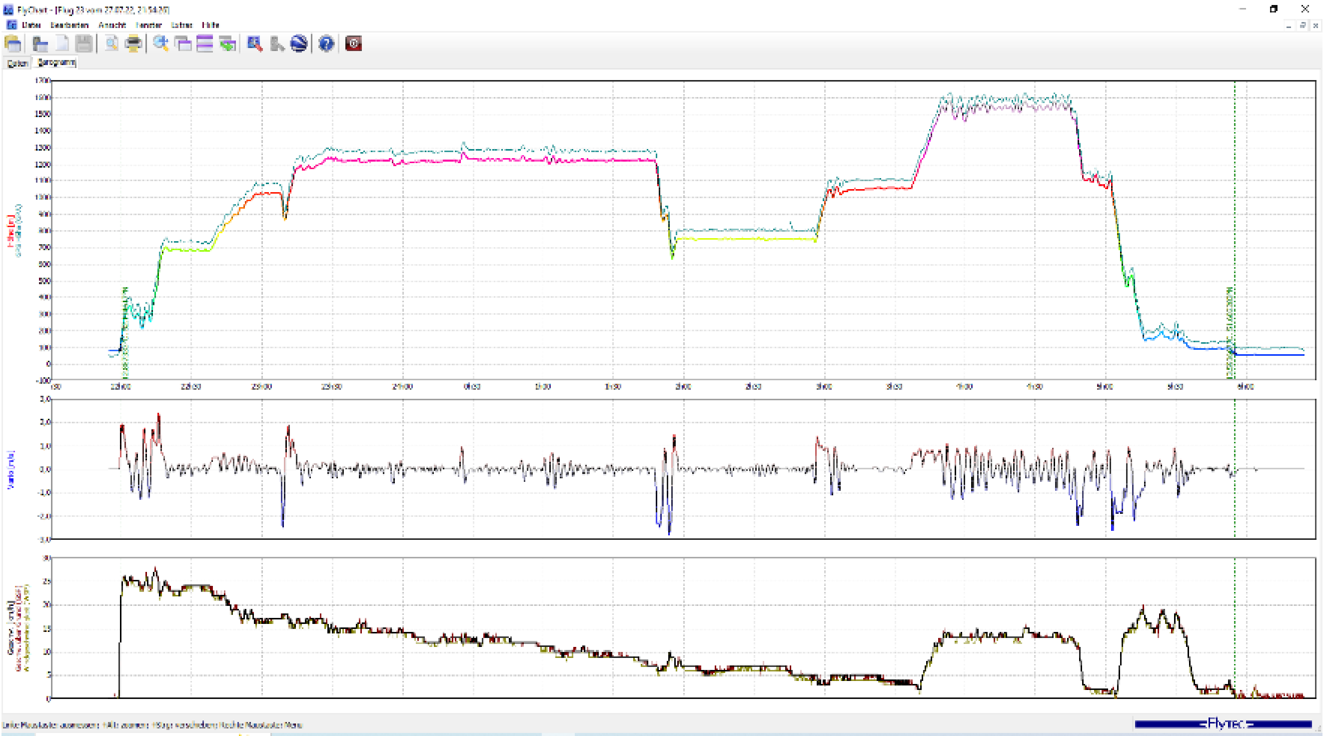
The forecasted route with the start near Treuenbrietzen was stable over the days and with the support of Christoph Tatray & Sebastian Hanisch, we had an experienced starter team at our side. Both have accompanied our developments over the years and helped optimize the equipment for endurance rides.

21:55. All systems are running. We are ready for take-off and in the air 5 minutes later. Photo: Christoph Tatray

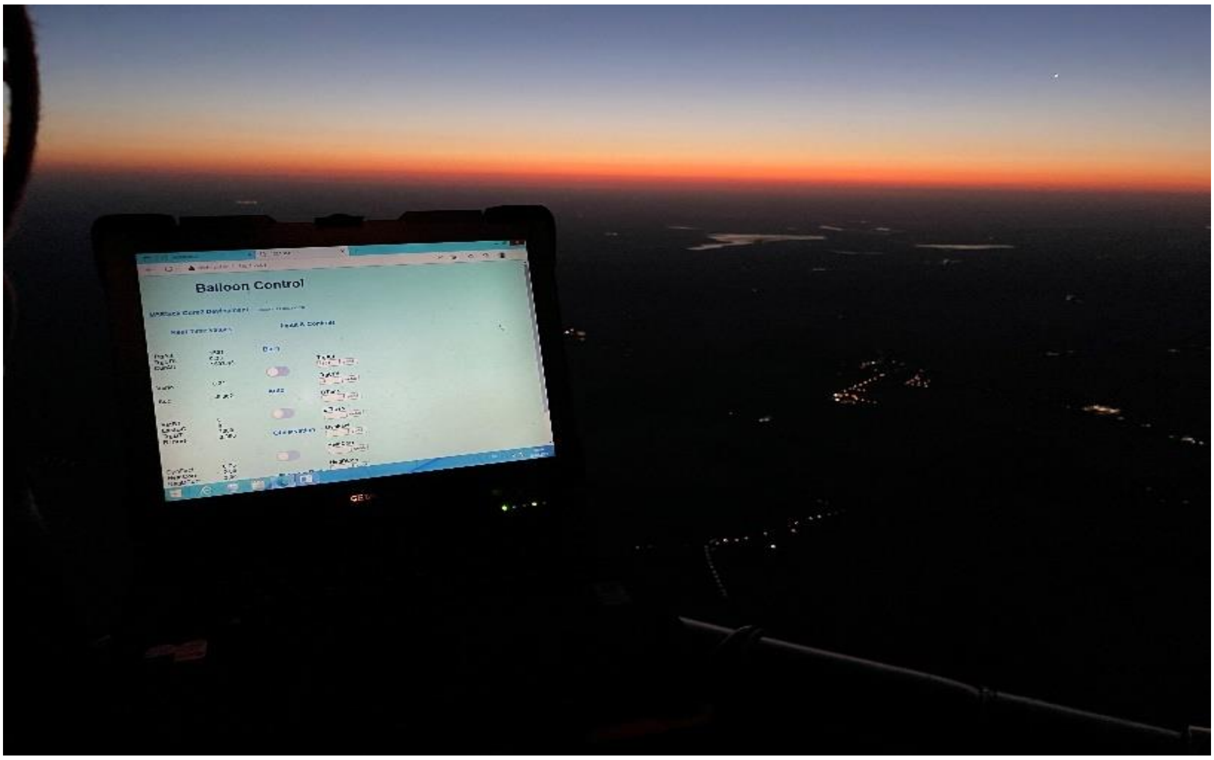
Balloon-wise, Christoph, Sebastian, Jens and Angelika had the Schroeder HB-QND - a 4250 m³ with the FB6 solenoid burner - ready to go in no time. We took off right on time at 10pm (local) in the last twilight with exactly the envelope temperature previously discussed in the team.

So payload and ambient conditions as calculated. At safety altitude we switched to our compact control box: An M5Stick Core2, integrated 4-fold relay card (2 each coupled for redundancy reasons) and, to increase accuracy, 3 slave processors connected via WLAN - also coming from the M5 controller series. The technical details of the processor-specific implementation and the merged solution elements will be reported on separately here together with Vincent and Michael as the core of the inspiring and profound development team.

From then on, the autonomous system served as a flying aid and the ascent of our heavy balloon was now already "processor-controlled" at a steady average speed of 0.5 m/s. From this point on, the FB6 burner's drive valves were only touched to change bottles, the subsequent test burn by hand and the descent to landing. The envelope temperature was in the expected range of 84°C shortly after take-off in the climb. It darkened quickly. Already, hardly any structures could be made out on the earth's surface. The contours of the night and the illuminated settlements offered an impressive contrast. Jens did the first positioning, keeping an eye on the numerous wind farms and Hilmar on the various displays of the navi, vario and control system. The electronic control of the burner valves worked like Swiss clockwork. Our balloon gained altitude steadily. The obligatory contact with air traffic control was stable and especially helpful that night. Many thanks to the German Air Traffic Control and the controllers on night duty, especially for the friendly support with current weather and wind data and the coordination or navigation near the large forest fire area near Falkenberg in Brandenburg.As can be seen from the attached altitude profile, the altitude control was carried out over hours with the accuracy of +/- 8 m.



Complete documentation of the 8-hour course in the Flytec 6040: Note the stable altitude accuracy of 6-8 m standard deviation over hours, which can never be achieved by hand! The intermittent variations resulted from the bottle change and the subsequent manual burner tests. This allows the burning time of the individual cylinders to be easily assigned and verified.



Our web interface of the new "Balloon Control" based on M5Stack Core2. All relevant control parameters are displayed and can be changed interactively via WLAN and web in the basket in addition to the display on the controller. Here is the status at 2:19 UTC. Displayed at the top is the "Target altitude" 1501 m, below it "Current altitude: 1502.46 m, "Current climb rate" Vario: 0.31 m/s, "Current acceleration" ACC: -0.002 m/s². The latter corresponds to a downward resulting force on the balloon of about 12 N at this moment. Photo: Hilmar Lorenz

After about 45 minutes of flying, the level indicator of the first 40 kg bottle started to move. This time interval was already good. Finally, the first bottle supplied us with gas for 71 minutes. We had expected 66 minutes. That was even 5 minutes more than estimated. Our faces brightened up, because the calculated gas supply should be adequate with enough reserve for the trip through the night. The picture repeated itself with bottle two. Here already a positive deviation of 7 minutes to the estimated burning time of 70 minutes. All consumption data and the values calculated before the trip with the help of Fabienne's vertical profile are listed in Table 1.

For comparison, the "user interface" of the old system. On the left of the display, the control parameters that used to be necessary. On the right, the extremely useful overviews of "direction over altitude" and "groundspeed over altitude". These displays have proven themselves over the years. That is why the notebook is still in the basket as a display and control device. In addition, comparative data for later "offline" verification of the calculated control impulses were obtained during this subsequent flight. Here is the status during our trip: 0:34 UTC. Photo: Hilmar Lorenz

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Rationales of the Night

The visibility was good enough and the sky was clear. Unfortunately, I had no view of stars this night. Jens reported shooting stars, but my enthusiasm this time was for the precision of the control.

Romantic in the instrumented balloon basket. In the east, delicate beginnings of dawn are already perceptible with the transition from deep blues to soft pinks. In still stark contrast, the deep red of the ubiquitous flashing wind farms. Photo: Jens Berger

With all the impressions and emotions of this night flight: What answers does the balloon give us to our most important question, the gas consumption? Already in the final phase of planning for the flight, it had become clear that the expected meteorological conditions would be challenging in terms of gas consumption due to the duration of the dark night. The forecasted vertical profiles showed the expected high temperature values and also relatively high humidity for the end of July. What was apparent in each case was high humidity even in upper air layers. This could lead to uncertainties in the gas consumption calculations. This is precisely why the leveling out of the first cylinder was awaited with such high anticipation. Early on, during the journey, it became clear not only that the values calculated with a great deal of effort did not show any fundamental errors, but that the smooth control obviously meant that impressively low consumption values could still be expected.

Our gas consumption started at the beginning of the night with a value of 33.8 kg/h. The last bottle before landing that was still operated in absolute darkness resulted in just under 27 kg/h with the now light balloon. Sensational for a journey through the night without any solar contribution! How are these values to be assessed? We were able to measure comparative values between 43 kg/h and 31 kg/h with Bernd Pulzer 11 years ago during the flight documented here in Ballonsportmagazin under similar atmospheric conditions, altitudes and balloon loads. Thus, the direct comparison leads us to more than 20% lower gas consumption. All this with an envelope that is now 15 years old and frequently used at high altitudes with high UV content!

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By means of computer technology and electronics on board, flying and navigating is considerably simplified, especially under night-time conditions. Before dawn, the old notebook had run out of power. From then on, the control was done via the web interface of the control system, even during manual descent and landing. On the right, another M5Stack Core2 can be seen as our "monitoring system" on board. This was used to record humidity, outside and hull temperature over the entire trip, which were used in the analytical evaluations shown above.

Note: The sensor reaching over the basket wall and temporarily fixed with grey tape is a ToF IR laser "distance radar" with a range of 180 m, which will be used together with the control system in the future and will have safety-relevant functions near the ground. Photo: Hilmar Lorenz

The differences during the climbing phase were particularly impressive. This time it ran absolutely evenly and smoothly. We needed 9.3 kg/h or 27% more gas in 2011 than now in Brandenburg! Since the increase in hull temperature from balanced flying increases quadratically with the momentary rate of climb and thus the energy radiation grows to the fourth power to the surface temperature of the hull, there are extremes here when comparing manual to guided flying when climbing. In addition, every "sag" and the necessary "interception" drastically increases the energy input during manual flying.

Table 1 also shows estimated values with hypothetical solar radiation of 600 Wh/m² in the right-hand column. From this, the next interesting parameter can be derived: The sun contributes 30% to 35% of the energy in our sport! Question: What means of transport with moving masses of several tonnes can make such percentage contributions? Yes, in absolute terms we are probably to be considered energy-intensive in ballooning, but the future development potential in our sport with automatic control and "solar" balloon becomes more than clear!

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Flaschenmanagement			Berechnungstabelle (alle Zeiten MESZ)									
Position	Gewicht [kg]	Anschluss-zeit	Brenner	Abschluss-zeit	Brennzeit	Verbrauch [kg/h]	Brennzeit [h]	Brennzeit [min]	Verbrauch Vorhersage [kg/h]	Brennzeit Vorhersage [min]	Brennzeit Differenz [min]	simul. Verbrauch 600 Wh/m² [kg/h]
1	30	4:45					0.00					
2	40	22:00		23:11	1:11	33.80	1.18	71	32.30	74	-3	23.50
3	40	23:11		0:25	1:14	32.43	1.23	74	31.00	77	-3	21.40
4	30	4:45					0.00					
5	40	3:16		4:45	1:29	26.97	1.48	89	27.10	89	0	19.40
6	Aufrüstflasche				0:00		0.00					
7	40	0:25		1:48	1:23	28.92	1.38	83	29.60	81	2	18.10
8	40	1:48		3:16	1:28	27.27	1.47	88	28.20	85	3	19.40
Landzeit:		5:55										
Fahrzeit		7:55										

Table 1: Simulation and consumption data.

Conclusion:

In the present development phase, the electronic burner control is far more than a flying aid for the pilot. The proven stability as well as accuracies of +/- 8 m over hours in absolute altitude control and, based on this, more than 20% fuel savings are hardly achievable manually. What Prof. Kalman was able to prove mathematically correct to his students: A usable signal can certainly be filtered from barometric data, as long as one knows the static properties of the measuring sensor and can physically describe the laws of motion of the system. With this, many tonnes of inertial balloons can be reliably controlled in advance. Our night flight from sunset to sunrise also proved convincingly that modern technologies and algorithms, which were used for the moon landing and in space travel, also show us in ballooning, the oldest branch of aviation, ways of development in the future and towards better energy efficiency.

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