Development of a Russian pendant seeder-spreader for a multicopter in the conditions of import substitution

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Abstract. The purpose of the study was the laboratory testing of the pendant seeder-spreader "G-1" (production of China) as part of the universal unmanned aircraft system "OSA HEXA" based on UAV "OSA" (the developer and producer was Bozon LLC, Moscow). The tests were carried out on December 18-19, 2018 in a closed hangar with a total area of 9500 m² and a height of 15 m, in accordance with the "Program and Test Methodology for Spreading Device Based on the UAV "OSA"", developed by the AgroEcology laboratory in collaboration with Bozon LLC. In the testing process numerous design weaknesses of the seeder-spreader were identified, based on which it was concluded that the pendant agricultural equipment was unsuitable for fieldwork in the conditions of Russia. The R&D department of Boson LLC was recommended to carry out a deep modernization of the seeder-spreader in order to eliminate the identified design weaknesses. The results obtained are recorded in the following documents: "Act No.1 of testing the spreading device based on UAV "OSA"" and "Protocol No. 1 of laboratory testing of pendant equipment of UAS "OSA"". Bozon LLC took into account the identified design weaknesses and recommendations and developed and mastered in 2019 the production of the seeder-spreader "S-1", which could be installed on the hexacopter "OSA HEXA", designed for automatic sowing of small seeds or spreading solids on arable fields, forest land and fishery basins.

1. Introduction
In 2018, the Ministry of Agriculture of the Russian Federation adopted the departmental project "Digital Agriculture", designed for 2019-2021. Samara State Agrarian University also acted as a co-developer of the project [1, 2].

The introduction of unmanned aerial vehicles (UAVs) in agriculture and crop production is one of the main elements of the digitalization of the agro-industrial complex. Together with the complex of pendant interchangeable agricultural machines (sprayer, fumigator, seeder, and device for Trichogramma distribution) for the precision application of plant protection products, fertilizers, seeds and feed and various cameras, UAVs are a universal unmanned aircraft system (UAS).

The application of UAS in agriculture and crop production allows us not only to reduce the costs of non-renewable energy and labor costs, to respond quickly to the operational situation in large areas of forest, fish and farmland, but also to switch to Digital Organic Farming through the precision
application of plant protection products and fertilizers, which is a high-end peak of agricultural systems in general [3–7].

On December 01, 2018, an agreement on scientific and technical cooperation was signed between FSBEI HE Samara State Agrarian University and Bozon LLC (Moscow, Russia) to carry out scientific and research work on the topic "Development of technology for using unmanned aerial systems for performing individual agricultural operations during the cultivation of field and vegetable crops" (the duration of the work was from 01.12.2018 to 12.25.2020).

We are also doing the work on the topic "Ultra-early sowing of small-seeded cold-resistant crops using a pendant seeder for UAS" within the framework of the agreement.

The aim of the research was a laboratory testing of a pendant seeder-spreader as part of the universal unmanned aircraft system "OSA HEXA" based on UAV "OSA" (developed and manufactured by Bozon LLC, Moscow).

The tasks of the research were: 1) determination and assessment of performance indicators of the functioning of spreading device; 2) selection of the best modes of application of the test object; 3) selection of significant factors affecting the quality indicators of the functioning of the test object; 4) determination of the achieved characteristics of seeding time; 5) determination of the achieved characteristics by the optimal seeding rate; 6) determination of the achieved characteristics by the optimal seeding height; 7) assessment of the correctness of the choice of the angle of inclination of the seeder-spreader.

Research materials were a Chinese-made (available for purchasing on aliexpress.com) pendant seeder-spreader (fig. 1) and seeds of the following crops: mustard, coriander, yellow melilot, spring wheat, chick-pea, lentil, pea. Research methods were developed by the AgroEcology laboratory at the Department of Land Management, Soil Science and Agrochemistry in cooperation with BOZON LLC and were described in the "Program and Test Methodology for Testing the Spreading Device Based on the UAV "OSA"") (available at the department).

Figure 1. Pendant seeder-spreader (production of China) as part of the universal unmanned aircraft system "OSA HEXA" based on UAV "OSA"

The composition of the checks, the scope and the sequence of the tests are shown in table 1.
Table 1. The composition of the checks, the scope and the sequence of the tests

| Type of the check               | UOM             | Testing methods                                                                                                                                                                                                 |
|---------------------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Appearance check                | –               | Check up visually the absence of physical damage to electronic components, clamping corners, propeller group, GPS / GLONASS module antenna. The test object is considered to have passed the test if there is no damage to the electronic components, clamping corners, propeller group, GPS / GLONASS module antenna, or by decision of the work manager, if they do not control the performance of the test object, which should be recorded in the reporting documents. |
| Determining the seed weight in the seed tank | Kg              | Fill in the tank of the test object with the seeds of one of the proposed crops. Carry out the weighing of the test object on the balance. Record the measured value. Fill in the tank of the test object with the seeds of one of the proposed crops. Use the controller of the test object, turn on the spreading device, and select the rotation speed. Record the time of sowing seeds of the current crop from the tank at this speed of rotation. If it is necessary, change the rotation speed of the spreading device and repeat the previous operations. Arm the test object for flight. The flight mission should include the non-stop movement of the test object. Turn on the power of the propeller group. After the test object gets off, start the telemetric information monitoring program. Record the time when the threshold value on the power batteries of the test object grows to 3.5 V. |
| Determining the sowing time     | Min             | Arm the test object for flight. The flight mission should include the movement of the test object on 1 hectare. Turn on the power of the propeller group. Turn on the spreading device and set its rotation speed. Take a flight over an area of 1 ha. Record the sowing time of 1 ha. If it is necessary, repeat the previous operations by changing the spreading device rotation speed or the flight speed. |
| Determining the flying time     | min             | Arm the test object for flight. The flight mission should include the discrete lift of the test object. Turn on the power of the propeller group. Take off the test object to a height of 2 m. Turn on the spreading device and select its rotation speed. Stop the spreader. Record the spreading area at a given height and speed. Compare the results with previous tests. |
| Determination of the sowing time of 1 hectare area | min             | Arm the test object for flight. The flight mission should include the discrete lift of the test object. Turn on the power of the propeller group. Take off the test object to a height of 2 m. Turn on the spreading device and select its rotation speed. Stop the spreader. Record the spreading area at a given height and speed. If it is necessary, change the height or speed of the spreading device. Repeat previous operations. Land the test object. |
| Determination of the seeding height | m              | Based on the data obtained when determining the seeding height, determine the optimal seeding rate of the seeds of the crop. Make design changes (if it is possible) by changing the angle of the spreading device. Arm the test object for flight. The flight mission should include a discrete lift of the test object. Turn on the power of the propeller group. Take off the test object to a height of 2 m. Turn on the spreading device and select its rotation speed. Stop the spreader. Record the spreading area at a given height and speed. Compare the results with previous tests. |
| Determination of the optimal seeding rate | g/min          |                                                                                                                                                                                                              |
| Determination of the spreader elevation angle | grade           |                                                                                                                                                                                                              |

2. Results
The tests were carried out in December 2018 in a closed hangar with a total area of 9500 m² and a height of 15 m. The following climatic conditions were observed: ambient temperature was +20±10 °C; relative humidity of air was from 30 to 80 %; atmospheric pressure was from 630 to 800 mm of...
mercury. Measures to protect the UAS from direct ingress of moisture and static electricity were taken during the tests.

Tests were allowed the personnel who have the qualification of an engineer and who studied the "Program and Test Methodology for Testing the Spreading Device Based on the UAV "OSA"" and the operational documentation for the equipment that used during the tests.

Tables 2, 3 and 4 (from "Protocol No. 1..." ) are shown as an example of the studies performed, which demonstrate the results of sowing seeds.

**Table 2.** Test results for mustard seeds; time and sowing features of the seeder-spreader "G-1" in a stationary position with a single loading of the tank

| Indicator | Operation speed of dropping device/ Seeding hole diameter |
|-----------|---------------------------------------------------------|
|           | Max / min | Max / min | Max / 50 % | Max / 25 % | Max / 12 % | 70 % of max | 70% of max |
|           | of max    | of max    | of max    | of max    | speed / 25 % | speed // 10 % | speed      |
| diameter  | diameter  | diameter  | diameter  | speed     | of max      | of max      |            |
| Seed time | 2 min 15 s| 27 min    | 2 min 4   | 3 min 8 s | 7 min 13 s  | 3 min 18 s  | 8 min 12 s |
| Sowing features | Seeding is more to the left. The rest - 150 g | Seeding is more to the left. The rest - 150 g | Seeding is more to the left. The rest - 150 g | Seeding is equal. The rest - 150 g | Seeding is equal. The rest - 150 g | Seeding is equal: 2x3 m. | The rest - 100 g |
| Indicators for mustard | **Mass of 1000 seeds - 5-6 g** | **Weight of the seeds in the tank of the seeder - 6.60 kg** | **Recommended seeding rate - 10 kg / ha** | **Optimal mode** |
The test results exposed two main disadvantages of the seeder-spreader "G-1": the non-functional tank form, including the insufficient tank volume (which does not allow to sow 1 hectare with one filling), and the unreliable dropping device (Figure 2).

Table 3 demonstrates the results of determining the weight of seeds of different crops in the seeder tank, as well as the basic calculated data on the optimal agrotechnical indicators of sowing, such as the area under one tank refilling, seeding time of one hectare and others.

Tests revealed that the tank volume with an increase of about 30-40 % would be sufficient for small-seeded crop seeding on an area of one hectare for one tank refilling, which almost coincides in time with one charge of the copter's battery. Small-seeded crops, for example, also include alfalfa, phacelia, clover, deervetch, galega herb, oilseed radish, rapeseed, smooth brome, fescue grass and others.

It is impossible to seed wheat, lentil, pea, and, accordingly, other cereal and leguminous crops with the help of current UAV at this stage of technical development.

Table 3. Test card (Appendix "B" to the "Program and Test Methods for Spreading Device Testing")

| Indicators                                           | Mustard | Coriander | Yellow melilot | Spring durum wheat | Lentil | Pea |
|------------------------------------------------------|---------|-----------|----------------|--------------------|--------|-----|
| The weight of the seeds in the seed tank, kg         | 6.60    | 2.70      | 7.40           | 7.70               | 8.30   | 7.30|
| Seeding time of 1 ha, min                            |         |           |                | 10 - 12            |        |     |
| Flight time per 1 battery, min                       |         |           |                | 10 - 12            |        |     |
| Seeding area for 1 tank refilling, ha                |         |           |                | 1                  |        |     |
| Optimal seeding speed, m/s                           |         |           |                | 3 - 6              |        |     |
| Flight height, m                                      |         |           |                | 4 - 5              |        |     |
| Seeding rate, recommended, kg / ha                   | 10      | 10        | 12             | 150 - 220          | 100 - 200 - 220 |     |
| Table 4. Test results for mustard seeds: experimental data of sowing with the seeder-spreader "G-1" in the flight position |

| Type of the check         | UOM | Rated value | Marginal deviations |
|---------------------------|-----|-------------|---------------------|
| Appearance check          | –   | corresp.    | –                   |
| Determining the seed weight in the seed tank          | kg  | 6.6         | 6.5 – 6.7           |
| Determining the sowing time                               | min | 8 min 43 s  | 8 min 24 s – 9 min 12 s  |
| Determining the flying time                               | min | 9 min 3 s   | 8 min 37 s – 9 min 25 s |
| Determination of the sowing time of 1 hectare area      | min | 8 min 43 s  | 8 min 24 s – 9 min 12 s |
| Determination of the optimal seeding rate               | g / min | 746           | 774 - 707          |
| Determination of the seeding height                      | m   | 4           | 3 - 5               |
| Determination of the spreader elevation angle           | grade | 10 - 15 | 10 - 25 |
Experimental data of sowing with the seeder-spreader "G-1" in a flight position show that, when eliminating design weaknesses, the use of a pendant seeder for UAS can be quite effective in special cases. These cases are, for example, sowing forage herbs in places inaccessible for large agricultural machinery (steep slope, high soil moisture on the field, etc.), sowing small fields with a complex contour with small seeded cold-resistant crops such as mustard, safflower and others in the early spring immediately after snow melting (Figure 3).

Figure 3. Testing of mustard seeds with a seeder-spreader "G-1" in a stationary position in a flight position

In the testing process, numerous design weaknesses of the Chinese-made seeder-spreader were identified (they were set out in "Protocol No. 1 of laboratory testing of the pendant equipment UAS "OSA"", which can be found at the Department of Land Management, Soil Science and Agricultural Chemistry):

1. In the window of the passage of seeds of the spreading device, within the spreading rate of 1 kg/min, some seeds were stuck, for example, lentil seeds, due to the geometry or surface of the seeds.
2. The shutter of window opening regulation was opened manually using a differential switch from the controller, which made it difficult to select the optimal window-opening diameter.
3. The seeds were stuck between the shutter and the seeder body that possibly also made it difficult to open the shutter at the specified parameters.
4. Due to the presence of one spreader screw, the seeds were distributed irregularly with the derivation to the left of approximately 60-70% of the seeds.
5. It was necessary to select the inclination angle of the sowing in order to avoid the problem specified in point 4.
6. The tank capacity of 10 l did not allow pouring the optimal amount of seeds, based on the flight time of one recharge, so we needed a volume of at least 12 l (optimally 15 l).
7. The loading hole of the tank had an insufficient diameter. We need a special device (a cone) to reduce the time of loading seeds into the tank.
8. The tank shape did not allow filling it to the brim without an additional ramming tool and tilting the UAV to an angle of 45°.
9. The peculiarity of the tank shape did not allow sowing the entire volume of seeds. 100, 150 or 200 g of seeds, depending on the crop, remained in the tank after sowing, which was a significant amount for small-seeded crops.
10. The matt color of tank did not allow carrying out the in-process monitoring of its filling with seeds.

We drew the following conclusions from the test results (they were set out in "Protocol No. 1 of laboratory testing of the pendant equipment UAS "OSA""

1. The Chinese-made pendant seeder-spreader as part of the UAS "OSA HEXA" was not suitable for sowing work and needed to be thoroughly modernized in order to eliminate identified design weaknesses. During sowing, work should be carried out promptly and without additional technological operations.

2. It was recommended to consider changing the shape and color of the seeder tank to eliminate the problems associated with it.

3. R&D department of Boson LLC was recommended to carry out a deep modernization of the seeder-spreader in order to eliminate the identified design weaknesses.

In 2019, the R&D department completed design work on the creation of a pendant seeder-spreader, taking into account the weaknesses identified during testing, and mastered the production of a new own "S-1" model (fig. 4).

"S-1" seeder is a removable interchangeable pendant equipment (agricultural machine) for the "OSA HEXA" universal platform.

The seeder can be quickly removed in the field and replaced with another payload: a sprayer, a fog generator (fumigator), a device for Trichogramma distribution (insect spreader), a video camera and others. In this case, one OSA HEXA universal platform is enough.

It has the following characteristics: 9 l tank capacity (there are plans to increase it to 12 l), electric drive, 4-6 m spreading width (strip), depending on the flight height and the angle of the seeder, controlled spreading speed.

Figure 4. Pendant seeder-spreader "S-1" developed and manufactured by Bozon LLC (Moscow)

The hexacopter "OSA HEXA S-1", which is a pendant seeder-spreader "S-1" as part of the universal unmanned aerial system "OSA HEXA" based on UAV "OSA", was designed for automated sowing of seeds or spreading solids (granular fertilizers and feed, insects) on arable fields, forest land and fishery basins (figs. 5 and 6).
It can be used for ultra-early sowing of small-seeded cold-resistant crops, including forage grasses (sowing in moist soil immediately after snow melting, including sowing without damaging seedlings), as well as for early spring feeding of winter crops with nitrogen granular mineral fertilizers.

It has the specification: maximum take-off weight is 26 kg; payload weight is 7 kg (maximum up to 10 kg); preflight preparation time is 20 min; flight duration at full load is up to 12 min; flight duration without load is up to 18 min; working flight speed is 3-6 m/s; maximum allowable wind speed is 8 m/s; recommended flight altitude above the vegetation is 3-4 m; minimum safe flight height above vegetation is 1.5 m; supporting platform is folding; frame material is carbon; motors are electric, brushless, 6 pcs.; screws are 22*6.6, 6 pcs.; overall dimensions are 175*175*70 cm; dimensions in transport condition are 80*74*70 cm; telemetry range is up to 1 km; take-off / landing is in automatic / manual mode on a solid flat area of 10 m²; operating temperature range is from 0 to +40 °C; duty cycle is 1 ha / 10 min; seed consumption is 0.10 - 9 l/ha, depending on the crop and seeding rate.

**Figure 5.** Hexacopter "OSA HEXA S-1", which is a pendant seeder-spreader "S-1" as part of the universal unmanned aerial system "OSA HEXA" based on UAV "OSA" developed and manufactured by Bozon LLC (Moscow)

**Figure 6.** Current prototype of the hexacopter "OSA HEXA S-1"
The basic configuration contains the minimum sufficient set of equipment and components necessary for working flights in the field conditions (table 5).

Table 5. The basic configuration of the hexacopter "OSA HEXA S-1", recommended for carrying out production work in the field conditions

| Equipment                                                                 | Quantity |
|---------------------------------------------------------------------------|----------|
| Universal platform "OSA HEXA"                                            | 1 pcs.   |
| Payload (removable, replaceable): seeder-spreader S-1                      | 1 pcs.   |
| Battery "16000 mAh 6S LiPo" (recharge cycle is up to 500 cycles; charging time is 50-60 min) | 6 pcs.   |
| Twin-channel battery charger                                             | 3 pcs.   |
| Manual controller                                                         | 1 pcs.   |
| Transporting case                                                         | 1 pcs.   |
| Spare tools and accessories kit                                           | 1 pcs.   |
| Software support "Agrodrone" (OS Windows or Android optionally)           | 1 pcs.   |
| Operating manual                                                          | 1 pcs.   |
| Product certificate                                                       | 1 pcs.   |
| Petrol generator                                                          | 1 pcs.   |
| Notebook with processor no lower than Intel Core i5                       | 1 pcs.   |
| Anemometer                                                                | 1 pcs.   |
| Navigation receiver / GPS tracker                                        | 1 pcs.   |

3. Conclusion
Thus, the laboratory tests conducted by the AgroEcology laboratory together with Bozon LLC revealed significant design weaknesses in the Chinese-made pendant seeder-spreader for the OSA HEXA universal unmanned aerial system (platform).

On the basis of deep modernization, a Russian advanced model of the S-1 seeder-spreader was developed, and the production of the hexacopter "OSA HEXA S-1" was developed, both designed for sowing small-seeded crops and for introducing solid substances, for example, granular fertilizers and feed, as well as insects, in the field crop bioprotection system.

The next stage of the research is the production testing of the unmanned aircraft system "OSA HEXA S-1" in 2020 and its further modernization and adaptation to various production tasks based on the test results.

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