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METHODS FOR DETERMINING THE TAKE-OFF SPEED OF LAUNCHERS FOR UNMANNED AERIAL VEHICLES

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Abstract

Unmanned aerial vehicles (UAV) are currently a very rapidly developing type of aviation. The problem of support during the take-off with the use of, i.e. take-off launchers arose along with their development, especially for UAVs with weights and dimensions preventing manual take-off. One of the major issues associated with UAV take-off launchers is for its UAV accelerating element to obtain its initial speed. The article presents three methods of determining launcher take-off speeds for unmanned aerial vehicles, i.e. the concentrated very oblique projection method, the high-speed camera methods, and the acceleration recorder method. The take-off launcher carriage speed in the oblique projection method is determined from a formula. This method involves "ejections" of concentrated masses from the UAV mass range and measuring the component values resulting from the used formula, which contains the range of the oblique projection, the elevation of the projection and its angle. The method using the high-speed camera involves recording the course of ejections of the concentrated mass from the launcher. The average take-off speed is determined on the basis of a take-off run length (section of the launcher race, where the unit accelerates) and defining the start and end frame of the carriage movement. The third method for the determination of the take-off speed utilizes an acceleration recorder. The method with the recorder involves registering a change in the accelerations when the take-off carriage is being accelerated by a system fixed on the carriage or the accelerated object. The article presents the methodology of dynamic tests of object acceleration on a launcher, necessary for the determination of speed with the mentioned methods. Selected results from actual tests with the use of the 01/WS/2015 launcher, which is an element of the ZOCP JET2 set, were presented. The test results are presented in a tabular form. The methods for the determination of the take-off speed were compared on the basis of performed tests. Based on the obtained results, the factors impacting the accuracy of each of the methods were identified.

Keywords: *aviation, unmanned aerial vehicle, take-off launcher, take-off speed, acceleration recorder*

1. Introduction

The unmanned aerial vehicles (UAV) we encounter include vehicles of various types with the aircraft group being the largest [1]. Many of these aircraft, due to their weight and dimensions preventing manual take-off, as well as high load of the carrying surface and thrust, require take-off support, which is provided by, e.g. a take-off launcher [2, 6]. A very high range of unmanned aircraft take-off weights results in the use of various take-off launchers; starting from relatively simple, rubber ones and ending with rather complex hydro pneumatic launchers. There is no universal type of a launcher suitable for the entire UAV family. Each launcher is designed for specific tasks and a defined UAV type.

In the case of each newly constructed take-off launcher, regardless of the used propulsion, it is necessary to determine the obtained take-off speeds within a strictly specified weight range. As a result, each launcher is subject to experimental tests, in order to determine the take-off speed and the speed envelope for a given launcher. An example of a speed envelope for linear drive launchers constructed at AFIT is shown in Fig. 1 [3]. In order to determine the range of the speed and take-off weight for a launcher, a series of "ejections" of concentrated mass from the UAV weight range for which the launcher is dedicated need to be performed. There are different methods for the determination of the take-off speed based on the performed ejections. Three methods for the determination of the UAV launcher take-off speed are implemented at the Air Force Institute of Technology.

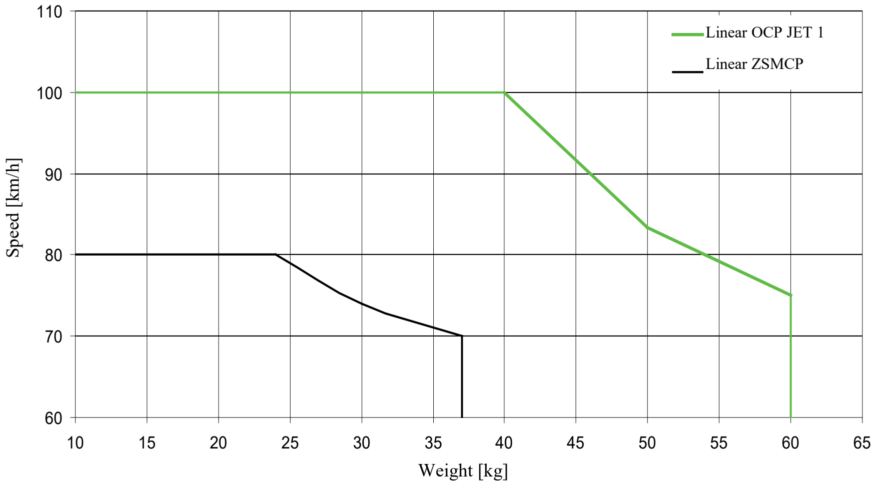

Fig. 1. Speed envelope for the linear launcher ZSMCP (black), OCP JET 1 (green) [3]

The basic method for the determination of the take-off launcher carriage speed is the concentrated very oblique projection method [4, 5]. The take-off launcher carriage speed is determined in the oblique projection method from a formula, which includes the range of the oblique projection, elevation of the oblique projection and the angle of the oblique projection. Component values for the formula are derived from their actual measurements. Another method for the determination of the take-off launcher carriage speed is a method utilizing a high-speed camera. This method involves recording the travel of the carriage with the concentrated mass along the launcher race during acceleration. The take-off launcher carriage speed is determined on the basis of inputting the length of the run path to the software and determining the carriage movement start and end frames. The third of the take-off launcher carriage speed determination methods utilizes an acceleration recorder. The recorder is permanently installed on the launcher carriage and the data are read via a USB port. The measurement in this method involves recording the launcher carriage movement time and the accelerations, which the take-off launcher carriage undergoes.

2. UAV design requiring take-off support

Many of the UAVs require support during take-off [1, 2]. Giving the UAV its take-off speed is possible due to the use of a take-off launcher. Take-off launchers increase UAV operational capabilities, due to the possibility of its take-off in any terrain conditions with no runway. Below you can find the jet-propelled UAV family, as manoeuvring air targets, designed and constructed at AFIT and operated by the Polish Armed Forces, with take-off supported by a take-off launcher.

The jet air target "JET-2B" (Fig. 2) is used as a manoeuvring imitator for training and rocket firings by air defence forces with the use of OSA and KUB sets. Automatically controlled, Basic data „JET-2B":

– propulsion system:	2 jet engines with a 147 N thrust each,
– maximum take-off weight:	80 kg,
– airspeed:	50-150 m/s,
– span:	2.8 m,
– length:	3.5 m,
– operating radius:	40 km
– practical ceiling:	200-4000 m,
– flight time:	60 min,
– start:	take-off launcher.

Fig. 2. Jet air target "JET 2B"

For each of the aforementioned jet air targets (JAT), it is necessary to determine the minimum take-off parameters, which enable safe take-off and operation of a JAT. The most important of the launcher take-off parameters is the minimum take-off start ensuring safe take-off of a JAT. Therefore, prior to handing over a take-off launcher for operation with a specified JAT, it is necessary accurately to determine the take-off speeds obtained on that launcher. The tests of take-off launchers, in this scope, are based on ejecting a concentrated mass corresponding to a given UAV in terms of weight, and determining the maximum ejection speed next.

3. Determination of the maximum take-off launcher carriage speed with the use of an oblique projection method

A diagram of a test rig in the oblique projection method is presented in Fig. 3 and 4. The oblique projection method involves ejecting a defined concentrated weight and measuring: the mass, the launcher race set angle (projection angle) α (Fig. 3), the set elevation of the point at which the concentrated mass is released from the take-off carriage (vertical distance) y (Fig. 3), the vertical elevation of the reference line of the leveller in a plane perpendicular to the launcher, passing the point at which the concentrated mass is released from the carriage (y_1, Fig. 4), the vertical elevation of the reference line of the leveller where the concentrated mass touches the ground (y_2 in Fig. 4), the horizontal distance between the leveller's position and the point at which the concentrated mass is released from the take-off carriage x_1 (Fig. 3), the horizontal distance between the leveller and the concentrated mass's point of impact x_2 (Fig. 3). The take-off launcher carriage maximum speed is determined from a formula (1), substituting the aforementioned components, derived from actual measurements. Horizontal distance of the oblique projection x (Fig 3) is a sum of the horizontal distance between the leveller and the point, at which the concentrated mass separates from the take-off launcher carriage x_1 (Fig. 3) and the horizontal distance between the leveller and the concentrated mass ground impact point x_2 (Fig. 3) [4].

The take-off launcher carriage maximum speed is determined from the relation [1, 2]:

$$V = \sqrt{\frac{g\,x^2}{2\cos^2\alpha\,(x\,\mathrm{tg}\alpha + y_p)}}\ [\mathrm{m/s}]. \tag{1}$$

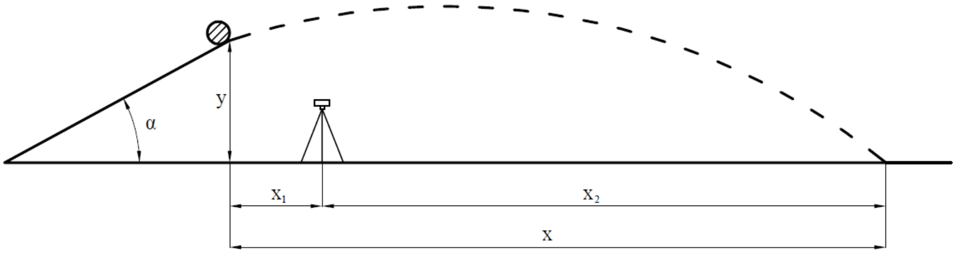

Fig. 3. Concentrated mass flight path [4]

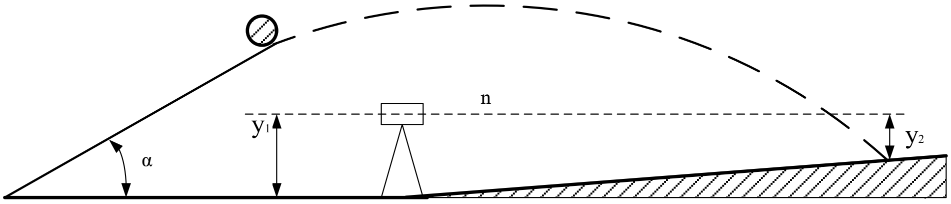

Fig. 4. Levelling of the concentrated mass contact point with the ground; n – leveller reference line

4. Determination of the maximum take-off launcher carriage speed with the use of a high-speed camera

This method involves using a high-speed camera to record the movement path of a carriage with concentrated mass along the launcher race during its acceleration. The launcher carriage time and path are measured in this method. Distance markers are applied on the take-off race of the launcher, which enable accurate identification of the carriage's path. The film recorded by the camera, showing the movement of the carriage along the race, is then processed by software. The take-off launcher carriage speed is determined on the basis of inputting the length of the run path (reading taken from the applied markers) to the software and determining the carriage movement start and end frames.

The maximum speed of a take-off launcher carriage is determined on the basis of parameters read from the camera record (path and time), according to the relation:

$$V_0 = \frac{\mathrm{d}x}{\mathrm{d}t}, \tag{2}$$

where:
$\mathrm{d}x$ – path increment,
$\mathrm{d}t$ – time increment.

5. Determination of the take-off launcher carriage maximum speed with the use of an acceleration recorder

The measurement in this method involves recording the launcher carriage movement time and the accelerations it undergoes. The recorder, with its block diagram presented in Fig. 5, is fixed permanently to the launcher carriage. The recorder data are read via a USB port. Recording starts after acceleration exceed 0.5 g. Recording stops after the acceleration sense changes to opposite. After the concentrated mass is ejected, use a USB port to read the recorded data and on their basis, determine the maximum speed of a take-off launcher carriage. Acceleration recorder parameters:

- accelerometer range: ±16 g,
- recording frequency: 1 kHz,
- start and end of recording based on read accelerations,
- system powered with a built-in NiMH (x4) battery,
- FLASH memory recording,
- data read via a USB port.

An exemplary record from the acceleration recorder is shown in Fig. 6.

6. Results of the performed tests

Dynamic tests with the use of the aforementioned methods were performed on AFIT premises. A WS launcher no. 01/WS/2015 constructed at the Air Force Institute of Technology (AFIT) in 2015, was used for the ejections. Fig. 7 shows a WS launcher no. 01/WS/2015 on a test rig, together with measuring instruments.

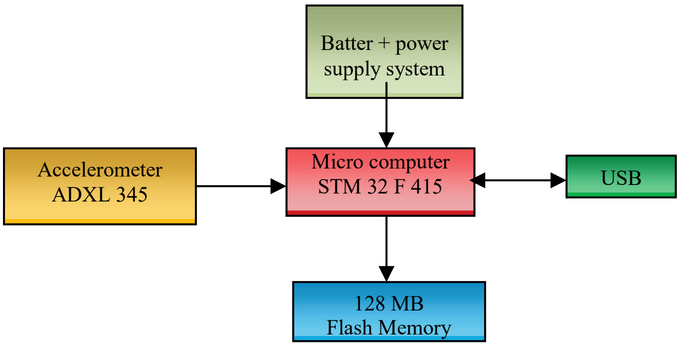

Fig. 5. Block diagram of the acceleration recorder

Fig. 6. An exemplary record of accelerations from the recorder

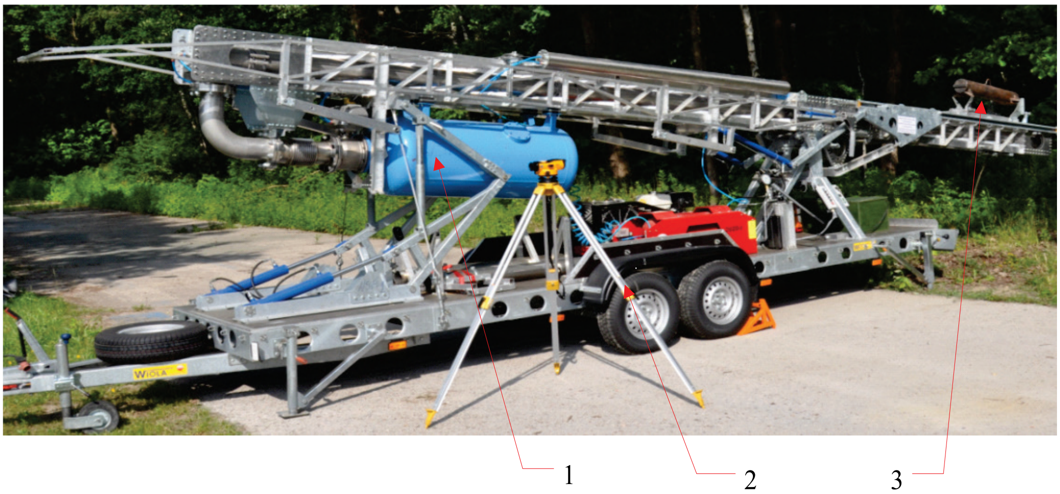

Fig. 7. Launcher WS no. 01/WS/2015 on a test rig in the draft versions: 1 – launcher, 2 – leveller, 3 – UAV equivalent concentrated mass

The tests involved the determination of the take-off carriage speed at the time of concentrated mass release for different loading pressures of the main tank. The following was measured directly: weight of concentrated mass, actual lift angle of the launcher race, concentrated mass release elevation, distance (range).

In the course of the concentrated mass ejections using the take-off launcher, a high-speed camera recorded the movement of the take-off carriage. A PHANTOM V4.0 camera with the below parameters was used for the measurements:

- frequency 1 kHz,
- resolution 512×512 pixels.

Simultaneously, the take-off carriage had a fixed measuring system recording the acceleration.

The tests were performed in the following order:

- weighing of the concentrated mass,
- measuring of the elevation at the point, at which the concentrated mass separates from the take-off launcher,
- measurement of the actual shot angle of the take-off launcher,
- 3 test shots prior to the actual test of the take-off launcher,
- the execution of three "ejections" of concentrated mass of 85.3 kg using a take-off launcher with a supply pressure of 9 bar,
- recording the movement of the launcher carriage with concentrated mass along the take-off race with a PHANTOM V4.0 camera,
- the measurement, in each case, of the vertical distance between the take-off point and the point of mass hitting the ground, which determines the actual range of the oblique projection,
- the execution of three "ejections" of concentrated mass of 85.3 kg using a take-off launcher with a supply pressure of 10 bar,
- recording the movement of the launcher carriage with concentrated mass along the take-off race with a PHANTOM V4.0 camera,
- the measurement, in each case, of the vertical distance between the take-off point and the point of mass hitting the ground,
- calculating the speed of a take-off launcher carriage.

Results of the measurement with the oblique projection method for main tank loading pressures of 0.9 and 1.0 MPa and calculated maximum and average carriage speeds are shown in Tab. 1. Results of the measuring the maximum speed with the PHANTOM V4.0 high-speed camera method for main tank loading pressures of 0.9 and 1.0 MPa, the calculated maximum and average carriage speeds are shown in Tab. 2. Results of the measurement with the acceleration recorder method for main tank loading pressures of 0.9 and 1.0 MPa and determined maximum and average carriage speeds are shown in Tab. 3.

Tab. 1. Results of the measurement with the oblique projection method

No.	Shot angle, α, $u(\alpha)$	Weight, m, $u(m)$	Horizontal distance, x, $u(x)$	Vertical distance, y, $u(y)$	Maximum carriage speed, V_0	Average speed, V
	[°]	[kg]	[m]	[m]	[m/s]	[m/s]
1	6.5	85.35	38.96	2.25	33.58	33.52
2	6.5	85.35	38.34	2.25	33.22	
3	6.5	85.35	39.29	2.25	33.77	
4	6.5	85.35	41.80	2.25	35.18	35.01
5	6.5	85.35	41.20	2.25	34.85	
6	6.5	85.35	41.50	2.25	35.02	

Tab. 2. Results of the measurement with the high-speed camera method

No.	Shot angle	Weight	Maximum carriage speed	Average speed
	[°]	[kg]	[m/s]	[m/s]
1	6.5	85.35	32.52	31.98
2	6.5	85.35	32.12	
3	6.5	85.35	31.32	
4	6.5	85.35	33.12	34.13
5	6.5	85.35	34.78	
6	6.5	85.35	34.50	

Tab. 3. Results of the measurement with the acceleration recorder method

No.	Shot angle	Weight	Maximum carriage speed	Average speed
	[°]	[kg]	[m/s]	[m/s]
1	6.5	85.35	34.64	34.63
2	6.5	85.35	34.94	
3	6.5	85.35	34.33	
4	6.5	85.35	36.76	36.89
5	6.5	85.35	37.49	
6	6.5	85.35	36.42	

7. Comparison of measurement methods

The results for the maximum speed for three methods, with the main tank charge pressure of 0.9 and 1.0 MPa are listed in Tab. 4, while the summary of average speeds from these measurements are presented in Fig. 8. Maximum speeds obtained with three methods (Tab. 4) for equal weights and launcher take-off parameters (take-off pressure) coincide.

Tab. 4. The results for the maximum speed for three methods

No.	Take-off launcher carriage speed determined			Take-off launcher carriage average speed determined		
	from the range method	from the high-speed camera recording	from the acceleration recorded	from the range method	from the high-speed camera recording	from the acceleration recorder
	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
1	33.58	32.52	34.64	33.52	31.98	34.63
2	33.22	32.12	34.94			
3	33.77	31.32	34.33			
4	35.18	33.12	36.76	35.01	34.13	36.89
5	34.85	34.78	37.49			
6	35.02	34.5	36.42			

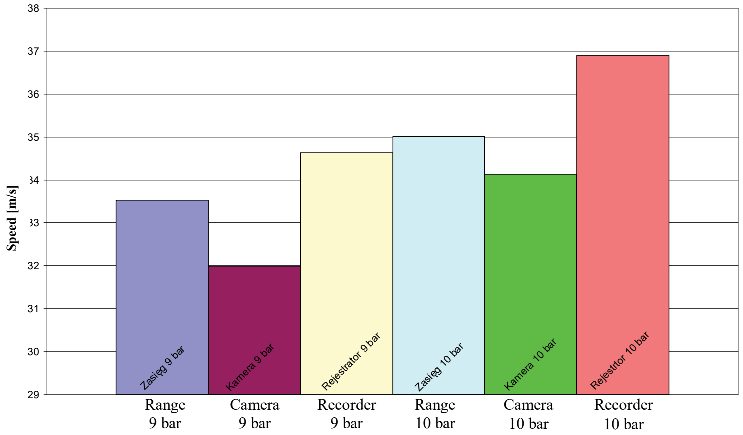

Fig. 8. A summary of average speeds for three methods, for the main tank pressure values of 9 and 10 bar

The factors impacting the measurement accuracy in the range method are:

- accuracy of measuring equipment,
- positioning of the measuring station,
- human factor.

The factor impacting the measurement accuracy in the method utilizing the PHANTOM V4.0 high-speed camera is the accuracy of determining the measurement start and end frames. The factors impacting the measurement accuracy in the method utilizing the acceleration recorder are sampling frequency and the data processing filter.

8. Conclusions

The UAV take-off launcher average speed determination methods presented in this article, in combination with the presented examples of the study results show differences between the methods, as well as a certain dispersion of obtained results. The launcher take-off speed at the moment of the loading weight release for the same take-off parameters of the launcher, obtained with the range method, is comparable to the high-speed camera recording method and just slightly differs from the results obtained from the acceleration recorder.

The performed tests show that despite slightly different results, the method using the acceleration recorder seems to be the most accurate one due to the actual acceleration measurement of the accelerated object. The two other methods involve measuring indirect parameters.

Summing up, the application of any of these methods, i.e., oblique projection of concentrated mass, with the use of a high-speed camera, an acceleration recorder, allows determining the maximum take-off speed for a defined UAV take-off weight. Determining the take-off speed for a given weight allows to match optimum launcher take-off parameters and to define the speed envelope for the launcher, which is so important during its operation. In light of obtaining comparable results, the choice between these methods is governed mainly by economic considerations.

References

[1] Gruszczyński, J., *Unmanned aircraft in western European countries and the USA*, New Military Technique 10, pp. 24-26/43 − 8, 2002.

[2] Jastrzębski, G., *Impact of opening time of the take-off pneumatic launcher main valve on take-off pressure losses,* Journal of KONES Powertrain and Transport, Vol. 23, No. 4, pp. 175-182, 2016.

[3] Jastrzębski, G., Jóźko, M., Szczepaniak, P., Ułanowicz, L., *Przegląd i kryteria doboru wyrzutni BSP (UAV)*, ML-XVII Mechanics in Aviation, pp. 145-154, Warsaw 2016.

[4] Jastrzębski, G., *Determination of the functional properties of a WPA-1 pneumatic launcher with a take-off pneumatic system*, ML-XV Mechanics in Aviation, Warsaw 2012.

[5] Jastrzębski, G., *Research procedure PB-01/LBBSP. Determination of an unmanned aerial vehicle take-off launcher carriage speed*, Air Force Institute of Technology, Warsaw 2014.

[6] Perkowski, W., *Pneumatic launcher for unmanned aerial vehicles*, N27 − Riga, Transport and Engineering. Transport. Aviation Transport, RTU, pp. 181-187, Riga 2008.

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