An empirical method for the catapult performance assessment of the BPPT-developed UAVs

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Abstract. This paper provides an empiric method in estimating the UAV’s launched speed from the catapult. Besides its practicality, the method is applicable to validate the UAV performance in its development or configuration modification. Thus, using this method, a faster and accurate estimation of launch speed can be obtained from the catapult before launching the real UAV. Recently, the Indonesian Agency for The Assessment and Application of Technology (BPPT) has prototyped a launchable backpack UAV using the experience in the predecessors’ landing-gearied UAV. Such sequence was preferable, since any failure of the landing-gearied take off prevented severe damage compared to the gearless UAV. Thus, after the prototypes of the backpack version of UAV were ready for first flight, the flight test crew needed to ensure that the launcher produces an adequate launch speed.

The initial idea is building a dummy prototype equipped with flight telemetry module and measuring the speed directly. But "crashing" the dummy with embedded electronic module will be risky and causing severe damage to the electronics. Another method proposed was by using a stopwatch to measure the elapsed time between the start to the release point of launching. Although preferable since it excludes electronics on board, it will suffer low accuracy.

Thus, the solution carried out by performing generalization and transformation of the problem into the energy balance case. Using the conservation of energy, the equation of catapult releasing speed can be derived by launching the dummy UAV. Thus, the method only requires practical measurement device to obtain sophisticated result. Using this prior knowledge of the catapult performance, the BPPT successfully launched the backpack UAV by 4.86% of difference between the estimated and real launch speed.
1. Introduction

Unmanned Aerial System (UAS) which is widely known as Unmanned Aerial Vehicle (UAV), or PUNA in Indonesian, plays an important role in various aspects of human life. In the earliest time of the UAV, the vehicles were large in size, like Predator, while currently UAVs exist in smaller dimension, even in the form of rotorcraft, or drones. For example, the drones for photography purposes are quadrotor powered by DC motors to enable hovering flight.

The application of rotorcraft drones allows a dimensional reduction with more rotors installed. However, these vehicles’ power to fly was limited by their energy storage capacity which restricted the multicopter’s flight range and endurance. Such limitation encourages the development of the fixed wing configurations of UAV that is powered by combustion engines for longer flight endurance and range [1].

The development of tactical and strategic UAV has produced the knock-down version of airframes, whose parts can be uninstalled to be stored in smaller space and easier to be transported to the operation area. The most practical type of UAV is a backpack version which is portable enough to be put into a carrier bag and can be optimally operated by two people. The small dimension feature is applied by using a tailless UAV which is also known with the term “the flying wing aircraft”. The advantage of the tailless UAV is the drag reduction due to the narrower surface of the UAV resulted from the omission of the tail. This reduced drag will contribute to the increasing flight range and endurance of the UAV.

![Figure 1. The pre-launching of BPPT-04C “Sriti” from its catapult.](image)

Besides omitting the tail, UAV drag reduction can also achieved by removing the landing gear in the aircraft configuration. Thus, this gear-less aircraft will take off with the aid of its catapult and landed using the landing net mechanism, or just simply do the belly landing. For UAVs, such tailless and catapult-launched ideas are applied for the Unmanned Combat Aerial Vehicles (UCAVs) which are carrier-based [2] to small-sized drones for remote sensing from the transportation applications [1] to the animal monitoring at the national park [3]. The significances of the catapult launching stimulate many innovations such as designing the morphing geometry for UAV so they too can fit into the available catapult [4][5].

The catapult-equipped UAVs are applied for many areas of application, such as, for maritime patrol support in navy vessel missions [6], to be operated in areas without airfield or runways and the quick response missions like disaster mitigation. These conditions lead to the significant role of the launching performance, as one of the factors of success in the UAV mission. One of the launching parameters discussed in this paper is to determine the catapult launching speed. The Indonesian agency for the Assessment and Application of Technology (BPPT), also develops the catapult-launched UAV [6], using the experience in the development of the landing-geared UAV [7].

The UAV catapult provides a sufficient initial speed at a certain elevation angle to be proceeded as the take-off phase for the UAV. The related parameters which are also provided in the take-off launching are the climb angle and the upward vertical speed when the UAV leaves the catapult [8]. In this paper, the scope of the discussion is limited to the UAV launching speed. The upward component of the speed is excluded because if the launching speed is known, then the upward component of the speed can be obtained with the aid of the catapult elevation angle information.
There are several methods to calculate the catapult’s launching speed. But, the empirical method is the one that the flight test expert recommends, since this empirical method yields results with high level of confidence [9]. While the better new systems depend on the new technology, Ward [9] also emphasized that those new technologies in the aerospace world means basic research and much of the research must be empirical. Hence, to have the launch speed measured accurately and empirically, the catapult must be tested using a UAV dummy model. To present conclusive writings, this paper is organized as follows. After introducing the UAV in this section, the second section addresses the catapult and its launching performance as the theoretical bases for the third section which derives the empirical method in estimating the launching speed. The fourth section contains the discussion of the method and its results that is resumed in the final part, the fifth section’s concluding remarks.

2. Catapult and its launching performance

Although the catapult has become the vital equipment for launching the carrier-based aircrafts, the research about catapult is rarely published, and most of those published research is outdated [8]. It is understandable since those catapults are part of the fighter aircraft technologies. Several articles explained the interaction of the catapult and the aircraft launching for its aerodynamics [4], its steam jet [10], its ground effect [2], and even the analysis when an engine failure occurred [11], but only a few were focused on the catapult performance [8]. However, the fast development of the fixed-wing UAV—especially with the urge of to be able to take off without runway—stimulated the research for catapult technologies, in such rareness of its publication.

The carrier ship applied the steam-powered catapult [12] as the most widely used take-off device at present [8]. It notably shortens the take-off distance and ensures high frequency of taking off and landing on the carrier’s deck. It is also preferable since the device cannot generate strong magnetic field, so there is no electromagnetic interference occurred while taking off compared to Electromagnetic Aircraft Launch System catapult [8]. The catapult launched take-off depends on the high-power provided and the sufficient take-off speed to have the aircraft launched. Although these requirements are simple, but the launch process itself is not, i.e. the interacting forces are complex and the external forces involved are not constant. The process undergone in the catapult involves three working stages, first, the preloading stage, second, the launching stage, and third, the buffering stage [13]. The preloading period is the pumping of the high-pressure fluid into the cylinder, the launching stage occurs when the piston is accelerating to the highest achievable speed, and the buffering one occurs when the deceleration occurred before stopping at the end of the launcher.

The published analysis of catapult performance includes the discussion of bearing [14], internal cylinder [8], even the performance of electromagnetic catapult [15][16]. Thus, the rareness of the launching speed analysis stimulated this empirical method of estimation, described in the following section.

3. Empirical method in estimating the launching speed

The method to obtain the catapult’s launching speed is derived and then resumed in this section. Since the UAV is successfully launched if it superseded—at least—its stalling speed, thus the launching speed become the crucial parameter of the catapult’s performance. It is preferred that the UAV can be launched faster than the stalling speed, or at least the launcher was able to provide a certain speed which supports the following acceleration of the UAV maximum propulsion power to supersede its stalling speed. Alike with the empirical method to obtain the stalling speed [17][18], so does the catapult’s launching speed will be obtained empirically, by launching a crash test UAV dummy and measuring the horizontal distance traveled from catapult’s end-point to the dummy’s point of impact.

![Figure 2. The BPPT-04C “Sriti” experienced launching speed and then took off.](image-url)
3.1. Launching the crash test UAV dummy
To enhance the empirical aspect for the method, the launch speed estimation was conducted to a model of the UAV that has equal weight and accelerates in a real launching process from the analyzed catapult. Thus, the model was created by constructing a crash test UAV dummy with a suitable shape to be well fitted within the catapult launching mechanism and carry weighing ballast inside to match the mass with the real UAV.

The launch speed was estimated by conditioning that the UAV model experiences a projectile motion [19], thus by using energy balance concept, the launch speed can be associated with the distance travelled. Hence the crash test UAV dummy which is also constructed without wings was installed to eliminate any significant aerodynamic forces and moment which might interfere with the pure projectile motion to be experienced. Another important aspect is the ability of the crash test UAV dummy to endure multiple impacts for the measurement purposes, thus the dummy was built from proper material to absorb the effect of collision. However, since the main idea of this paper is to estimate the launching speed, the following explanation excludes the details of the dummy and focuses to the analysis of its trajectory instead.

Figure 3 illustrates the trajectory of the launched crash test UAV dummy from catapult. The dummy was launched with the velocity vector \( v_0 \), and elevated upward with the launch angle \( \theta_0 \). After leaving the catapult, the projectile motion of the dummy can be separately analyzed in the vertical and horizontal direction. When projected vertically, the projectile motion is accelerated downward, so the dummy slowed down in its upward movement, stopped for a moment at the peak, and then accelerated to the ground until the impact occurred. Orthogonally, while the dummy was in the air, the horizontal projection of the projectile motion drove the dummy further from the catapult until it hit the ground. Thus, it can be seen that the dummy traveled an amount of horizontal distance in a period of time until the vertical distance is equal with the ground level. After recognizing the phenomenon, an approach can be drawn to obtain a mathematical expression in the launching process that contains the launch speed to be estimated.

3.2. Calculate the catapult releasing speed
The horizontal range, \( R \), for the projectile motion case over a flat field is usually calculated with one of the memorable physics equation in the high school [19]:

\[
R = \frac{2v_0^2}{g} \sin \theta_0 \cos \theta_0 = \frac{v_0^2}{g} \sin 2\theta_0 \tag{1}
\]

Although the above expression is generally recognized, it will be invalid in obtaining the launch speed \( v_0 \), since it applies only when the projectile launch height is the same as the final altitude. The altitude difference shown in figure 3 between the end of catapult and the ground below it resulted a requirement for different method to obtain the launch speed. Thus, an approach to obtain the launch speed of a crash test UAV dummy from the catapult was developed in the following steps:
1. Modelling the launch process to obtain horizontal distance as a function of the initial speed.
2. Treating the initial speed as the unknown and inverting the equation to calculate the launch speed.

Consequently, these assumptions are required:
1. The aerodynamic drag (and all aerodynamic forces and moment) is neglected.
2. The wind around the launch site is neglected.

To perform the first part of the approach, the mathematical model which relates the horizontal range as a function of the dummy’s launch speed can be derived in the following steps [20]:
1. Calculating the required time in the vertical projected movement from the moment of the dummy is released from the end of the catapult until the dummy hit the ground.
2. Using the calculated time to obtain horizontal distance of the launched dummy.

The analysis of horizontal movement begins with the projected initial velocity \( v_{H0} \):

\[
v_{H0} = v_0 \cos \theta_0
\]

So the travelled horizontal distance, \( R \), is:

\[
R = v_{H0} \cdot t ; \quad R = v_0 \cos \theta_0 \cdot t
\]

Switching to the vertical movement, the analysis was started with calculating the distance travelled by an accelerated object, as follows:

\[
S = S_0 + V_0 t + \frac{1}{2} at^2
\]

Then applying the vertical projection of the dummy launching into previous equation.

\[
h = h_0 + v_c t + \frac{1}{2} gt^2
\]

The downward direction is defined as positive term. The ground is set as the datum altitude, as follows:

\[
h - h_0 = v_c t + \frac{1}{2} gt^2 ; \quad \Delta h = v_c t + \frac{1}{2} gt^2
\]

Since the vertically projected velocity is

\[
v_c = -v_0 \sin \theta_0
\]

the negative sign occurred since the dummy was initially launched upward. Thus, the following equation represents the vertically projected motion of the dummy.

\[
\Delta h = -v_0 \sin \theta_0 t + \frac{1}{2} gt^2
\]

To eliminate the time variable, \( t \), in equation (8), the time variable from equation (3),

\[
t = \frac{R}{v_0 \cos \theta_0}.
\]
was substituted into equation (8), as follows:

\[ \Delta h = -v_0 \sin \theta_0 \frac{R}{v_0 \cos \theta_0} + \frac{1}{2} g \left( \frac{R}{v_0 \cos \theta_0} \right)^2 \]  (10)

Finally, from equation (10), the launch speed \( v_0 \) can be obtained as a function of the horizontal distance \( R \), gravity acceleration \( g \), and the catapult’s top height \( \Delta h \), and elevation angle \( \theta_0 \), in the following compact form:

\[ v_0 = \frac{R}{\cos \theta_0} \sqrt{\frac{g}{2(\Delta h + R \sin \theta_0)}} \]  (11)

3.3. Energy balance in the launching process

The BPPT Backpack UAV catapult works as a launching device powered by elastic cord which provide the spring potential energy when it is stretched until the UAV carriage is “locked” at its lowest position with the aid of a metal pin in the pre-launch phase. Launching phase begins when the locking pin is pulled, and the elastic cord draws the carriage along its rail to accelerate the UAV before it is launched. In the acceleration phase, the spring speeds up the UAV and brings it upward. In the energy balance approach, the work done by the spring, \( W \), will be transferred into the kinetic energy, \( K \), and gravitational potential energy, \( U \). Thus, algebraically:

\[ W = K + U \]  (12)

Translated into detailed components, each of the terms can be defined as follows [19]:

\[ \frac{1}{2} k \Delta x^2 = \frac{1}{2} m v^2 + mgh \]  (13)

where \( k \) denotes the spring constants of the elastic cord, \( \Delta x \) is the cord’s stretched distance from the catapult’s lowest position and the top position of UAV carriage, while \( m \) stands for mass, \( g \) for gravitational acceleration constant and \( h \) is the height of the catapult’s lowest and the top position of UAV carriage. Since the catapult consists of the unchanged elastic chord (i.e. \( k_1 = k_2 = k_n \)) and also using same rail (i.e. \( \Delta x_1 = \Delta x_2 = \Delta x_n \)), the work done by the spring considered to be similar in amount regardless of any kind of UAV to be launched. Hence, 

\[ W_1 = W_2 = W_n \quad \text{since} \quad \frac{1}{2} k_1 \Delta x_1^2 = \frac{1}{2} k_2 \Delta x_2^2 = \frac{1}{2} k_n \Delta x_n^2 \]  (14)

with subscripts 1, 2, …, \( n \) denote the different UAVs or the different launching activities. Applying this condition (equation (14)) to the energy balance approach in equation (12) enhances the conservation of mechanical energy in the launching process, where

\[ K_1 + U_1 = K_2 + U_2 = K_n + U_n \]

\[ \frac{1}{2} m_1 v_1^2 + m_1 gh_1 = \frac{1}{2} m_2 v_2^2 + m_2 gh_2 = \frac{1}{2} m_n v_n^2 + m_n gh_n \]  (15)

The mechanical energy of a system \( (E_{mec}) \) can be defined as the sum of the potential energy, \( U \), and the kinetic energy, \( K \), of the system [19] and expressed as follows:

\[ E_{mec} = K + U \]  (16)

While the principle of conservation of mechanical energy applies, an increment of one form of energy will be exactly as much as the decrement of the other form. The mathematical expression between two
The launch speed estimation by using equation (11) was derived by assuming all provided information is correct, and the dummy is representing the real UAV. Thus, to show this empirical method’s adaptability to the unideal circumstances, this section discusses the possibilities of the incorrect dummy’s mass that deviates significantly from the real UAV prototype and the alternative solution when the calculation excluding the angular information.

4. Discussion

4.1. Issues of practicality in measuring launching speed

The method of obtaining the launch speed from the UAV catapult has been derived and it yields the equation (11). The launch speed \( v_0 \) can be estimated by measuring the horizontal distance from the impact point of the crash test UAV dummy to the catapult’s end \( R \), the information of catapult’s height \( h \), elevation angle \( \theta \), and the gravity acceleration constant \( g \). If this information is correct, then the estimated speed will be accurately estimated.

However, in the flight test field, not everything runs smoothly as ideally planned and there are cases required improvisations in the test item or the method. Such improvisation is never been desired for the crew, therefore, any possible worst case must be identified first to plan and design proper responding method or procedure, including emergency response. The frequent problem occurred when using a dummy to represent the studied object comes from the manufacturing irregularities, which might result the shape or geometrical deviation, or physical properties deviation such as different mass or different moment of inertia. These deviations were often unavoidable because of the constraint for budget or tight schedule or available resource to build the testing dummy, hence, the test crew and the data analyst must prepare the corrective scenario for such possible deviations.

The portable concept of the catapult results to the manual installation which allows slight angular difference on each of installation and uninstallation. On the other hand, the angular measurements in the field were never meant to obtain higher precision from the protractor or below 2º of error. For error occurrence, the empirical method’s \( v_0 \) can be safely neglected. If the trigonometric function is measured using the fraction of length, then for 1 cm of error to 5 meter of catapult length will contribute to 0.11º of error of elevation angle. This inaccuracy occurs when the calculation excluding the angular information.

4.2. The case of unequal mass

If the crash test UAV dummy has a different mass from the real UAV to be launched, or the other way around, the UAV will have to be modified so its current mass is different with its previous dummy’s mass, and then a corrective action can be designed. The corrective action must be carefully derived, so logically, any increment of mass should result decrement of corrected launch speed, and vice versa. By referring to the previously explained energy balance concept in the launching process, the equation (18) can be applied here since \( m_1 \neq m_2 \) and \( h_1 = h_2 = \Delta h \) so the \( v_{02} \) launch speed can be predicted from the previously tested \( v_{01} \) launch speed [21].

\[
\frac{v_{02}^2}{m_2} = \frac{2(m_1 - m_2)g \Delta h + m_1 v_{01}^2}{m_2}
\]

\[
v_{02} = \sqrt{\frac{2(m_1 - m_2)g \Delta h + m_1 v_{01}^2}{m_2}}
\]

Clearly from the above equation, the correction factor is the fraction of \( m_1 \) to \( m_2 \) or between the dummy mass compared to the actual UAV to be predicted. Thus, the lower the UAV mass, the higher
predictive launch speed will be, and vice versa, the higher the UAV mass the lower predictive launch speed will be, as estimated earlier.

4.3. The case of unavailability of launch angle information
The term “unavailability of information” for the launch angle can also refer to the inaccuracy of angular measurement or any doubt against the reliability of the provided information. Thus, the previous equation (11) requires modification so the trigonometrical terms can be represented using the length measurement result. Without the angular label, figure 3 turns into the following illustration:

![Figure 4. The catapult dimension excluding the elevation angle.](image)

From the illustration, the trigonometric terms can be defined as follows:

\[
\sin \theta_0 = \frac{\Delta h}{\ell}; \quad \cos \theta_0 = \frac{\ell_H}{\ell}; \quad \tan \theta_0 = \frac{\Delta h}{\ell_H}
\]

Hence the equivalent form of equation (11) becomes the following equation excluding the elevation angle [22]:

\[
v_0 = R \ell_H \sqrt{\frac{g}{2\Delta h \left( 1 + \frac{R}{\ell_H} \right)}}
\]

4.4. Implementation in the field test of the dummy “Sriti” launching
As derived from the explanations of the previous sub-sections, this estimation method is simple to be accomplished and it gains its validity from its mathematical base, i.e. the Newton’s law. Since Newton’s law’s validity is unquestionable, the result of this method should be accurate. Hence, the curiosity might be arisen whether this method is applicable or not, and the validity of the result might be also questioned. Such questions might arise since in many physical occasions, an accurate measurement often comes from complex tool and complex method. Thus, this subsection reports the field test of the dummy launching which yielded the estimated value of the launch speed. Furthermore, in the following subsection, the validity of the estimated launch speed is carried out using the flight data from the real “Sriti” UAV flight test.

The field test was performed using the dummy UAV with a similar weight to the future “Sriti” UAV to be launched. The catapult was tested to observe its functionality and performance. The catapult’s performance is determined from its launch speed, thus a dummy UAV was launched, and the following measurement in table 1 is reported [23].
Table 1. Quantities measured from field test for dummy “Sriti” launching.

| Type of Doc.            | Technical Note                          |
|-------------------------|-----------------------------------------|
| Doc. No.                | TN-068/FT/7.2/PUNA/XI/2010              |
| Date                    | November 09, 2010                       |
| Horizontal Launched Distance, $R$ | 660 cm                                  |
| Launcher Rail Length, $\ell$       | 388 cm                                  |
| Launcher Horizontal Rail Projected, $\ell_H$ | 378 cm                                  |
| Initial Height, $\Delta h$       | 78 cm                                   |
| Gravitation Acceleration, $g$     | 9.81 m/s                                 |

Thus, by substituting the numerical values from table 1 into equation (21), the estimated launch speed for dummy is 10.32 m/s. This estimated value will be validated with a real UAV flight test data in the following sub-section.

4.5. Validation with the real UAV “Sriti” flight test data log

The previous subsection has reported the estimated launch speed of the dummy UAV is 10.32 m/s. However, since an accurate measurement often comes from complex tools and complex methods, the validity of the estimated result might be questioned although it comes from an empirical-based method. Thus, this sub-section will address the issue of validity by comparing the estimated launch speed of the catapult with the real flight launch speed of the real “Sriti” UAV.

Figure 5. The speed and altitude of “Sriti” launching from flight data logger.

The flight data was taken from “Sriti” flight test held in Nusawiru Airport, on July 17th, 2011. The Flight Test was held to assess the flight characteristics of “Sriti”. Hence, the “Sriti” UAV was placed in its catapult, given full throttle for maximum power, and then launched and it flew with several maneuvers before doing belly landing. Thus, to validate the dummy launch speed estimation, the flight data of “Sriti” was started from 2 second before the launch-began until it launched and extended until “Sriti” gained altitude after the launching process. This extension was done to show that the take-off process successfully brought the “Sriti” UAV to flight, while the main concern is only at the “release point” of the plot.

In figure 5, the speed of the “Sriti” UAV is displayed with green dashed line and marked with orange triangle at the data points, while its altitude (height) is displayed with blue solid lines marked with circular blue dots in its data points. From the ground speed plot, the launching phase can be identified in the accelerated phase in the parabolic curve from 312$^{nd}$ second to 314$^{th}$ second, and then ended with the constant speed after “Sriti” UAV was fully released from the catapult. This launching identification was also validated from the altitude plot, which shows a steep ascent with constant gradient from 312$^{nd}$ second to 314$^{th}$ second and ends with a sharp change of gradient showing downward movement after “Sriti” UAV was fully released from its catapult. After the launching phase can be identified, the next step is obtaining the launch speed at the end of that launching phase. Thus, the speed at 314$^{th}$ second will be identified as the launch speed, i.e. 10.81 m/s.
Table 2. The comparison of estimated launch speed and flight data validation.

| Estimated Empirically<sup>a</sup> | Real Measure<sup>b</sup> | Differentiation percentage |
|----------------------------------|------------------------|--------------------------|
| 10.32 m/s                        | 10.81 m/s              | 4.86 %                   |

<sup>a</sup>From dummy’s field test measurement.
<sup>b</sup>From “Sriti”’s flight data log.

The real launch speed of “Sriti” UAV is 10.81 m/s from flight data log, compared to its estimated value, 10.32 m/s from the dummy launching of the field test, as seen in table 2. The real launch speed only differs 4.86% from the estimated value. The estimated speed gives lower value than the real speed, so that the method is reliable to perform estimation, since higher value can be expected in the real launching process. The low difference, which is below 5% proves the validity of the method of estimation with the real launch speed of the real UAV. Since the dummy is not equipped with propulsion, while the real UAV experienced maximum propulsion power before being launched, it is possible that the 4.86% higher value of the real UAV’s launch speed is caused by this pre-launch maximum propulsion effect.

5. Concluding Remarks

The BPPT-04C “Sriti” is a backpack version of Indonesian UAV with tailless or flying wing configuration that is launched from its catapult and then does belly landing after performing mission. The catapult plays significant role to provide sufficient launch speed to “Sriti” UAV so it can take off smoothly. In the development process, the flight test crew required early estimation of this catapult’s launch speed, before they installed “Sriti” UAV, so they could obtain adequate confidence to go for the prototype’s first flight.

Empirical method becomes a preferable method to estimate the launch speed of the catapult. By constructing a crash test UAV dummy, the flight test crew can simulate the launching process in a realistic fashion, using the real catapult on the field to obtain valid and reliable result. In this paper, the empirical method of estimation has been derived. Thus, the concluding remarks are as follows. First, this empirical method has successfully estimated the real UAV’s launch speed with 4.86% of difference. The estimated method yields lower value than the real UAV’s launch speed, thus it ensures that this method of estimation is reliable since the operator can guarantee that the real launch speed will not fall below the estimated value.

Second, the catapult’s launch speed $v_0$ can be empirically estimated by launching a crash test UAV dummy and measuring the horizontal distance ($R$) between the points of impact to the catapult’s end. The data processing will involve the following quantities: the gravity acceleration $g$, the catapult’s top height $\Delta h$, elevation angle $\theta_0$, as previously resumed in equation (11). Third, the launch speed $v_0$ estimation can be obtained even though the elevation angle is not measured, or the measurement is not reliable. Thus, the modified data processing requires substitutional length measurement: the length of the catapult rail $\ell$, and the horizontal projected length of the catapult rail $\ell_x$, as previously resumed in equation (21). Fourth, this empirical method for estimating launch speed can be corrected for UAV that is different in weight from the tested dummy’s weight. The main correction factor is the fraction between the dummy’s mass $m_1$ to the mass of actual UAV to be predicted $m_2$, combined with the provided dummy’s previously tested launch speed estimation $v_{01}$, as previously resumed in equation (19).

The empirical method for estimating launch speed in this paper has been derived and is suitable for the flight test field purposes. Its adaptability to the unideal circumstances in the flight test field has been shown. Thus, the method can be generalized to different catapults, since the latter three equations are independent to the spring constant. Hence, the air-pressure, steam, or even electromagnetic catapult can be subjected to be analyzed by this method.
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