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Analysis of a UAV Bungee Cord Launching Device

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This paper analyzes Unmanned Aerial Vehicle (UAV) launching devices (LDs), with an emphasis on Bungee Cord LDs as a representative of widely spread launching devices of a simpler structure. Four analyses are given in this paper: LD systems analysis against critical design requirements and the customer requirements, Analysis of the motion of the UAV-Cradle subsystem on the rail, Analysis of the cord selection and energetic capability of the cord according to design requirements, Analysis of the influence of aerodynamic lift and drag forces on the mathematical and mechanical/physical models – with the results compared. The paper recommends some types of Bungee Cord LDs in the early phase of design.

Key words: **UAV, launching, launching device, catapult, design, mathematical model.**

Nomenclature

$\dot{x}, v$	– UAV-Cradle velocity
v_F	– final velocity of UAV -Cradle at the end of the rail
t_F	– final time-duration of launching
$\ddot{x}, a$	– acceleration
α	– launching rail elevation angle
R_z,R_z	– force of lift, force of drag
q	– stiffness of the fictive elastic cord
b	– cord length (non-elongated)
Δx	– cord elongation
L	– effective rail-launching length
m_{UAV}	– mass of Unmanned Aircraft Vehicle
m_{CRD}	– mass of the cradle
μ	– static friction coefficient
N	– inclined plane perpendicular reaction
T	– UAV propulsive force
F_e	– force of the fictive elastic cord
q_r	– real elastic cord stiffness
F_μ	– frictional sliding force
$t_0, \dot{x}_0, x_0$	– initial values of differential equation
E_k	– UAV-Cradle kinetic energy
A_g	– -gravitational force work
A_μ	– frictional sliding force work
A_c	– fictive elastic cord force work
A_{CR}	– real elastic cord force work
A_T	– propulsive force work
Fer	– force of the real elastic cord
S	– aerodynamic surface of the wing

Introduction

SEVERAL systems of launching devices (LDs) for Unmanned Aerial Vehicles (UAVs) have been developed so far, [2]. During their use, the advantages and disadvantages of each type of individual LDs were perceived. This led to the conclusion that an LD must be lightweight, must be able to be operated with minimal personnel, and must have a small storage volume. These factors need to be considered and incorporated into the conceptual design of LDs. Also, the UAV launching device must have the possibility to be set up and to launch a UAV within fifteen minutes. The important factor is the purchase price and the cost of LD maintenance, which perhaps is crucial to the military budget.

Existing LDs could be grouped into five categories: Pneumatic, Hydraulic, Bungee cord, Kinetic Energy and Rocket Assisted Take-off (RATO), [2].

LD systems analysis against critical design requirements and the customer requirements (Benchmarking)

Benchmarking is a process where existing systems are analyzed against critical design requirements and measures. It allows the design method to define the level of real performance required to produce the required level of perceived performance, assisting in a crucial design analysis, (Heslehurst, 2010). For this paper, the benchmark process was compared to a ranked list of customer requirements.

Quality Function Deployment (QFD): This process steps through the design process to fully understand the design requirements, without trying to solve the design initially. It is an eight step process which generates measurable engineering specifications and relates these to customer requirements and engineering specifications, (Heslehurst. 2010). This will enhance a good design solution, simplify the problem and provide documentation of the whole process.

The need for the UAV to be safe, reliable and easy to operate, together with the capability of disassembly design, ranked highest in this procedure. A final list of essential requirements is shown below in Table 1.

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Table 1. Final list of essential requirements

Final Launch Velocity	Launching Angle Range
Maximum Take-off Mass	Launching Remote Control
Operational Temperature Range	Set Up Time < 15 minutes
LD Mass	LD Disassembling for storage
Maximum Length of the Launch Envelope	Number of the Set Up Personnel
Acceleration at Launch ≤ 10G	LD Safety, Reliability and easiness to operate

A representative LD Benchmark analysis was presented by J. Francis, at his Final Thesis Report, 2010, [4]. The selection of the LD involved an investigation and evaluation into each design, which confirmed the suitability to the governing customer requirements and engineering targets for the LD. This used the QFD process and ranked each design against the essential and desirable customer requirements. An example of the weighted scoring system is shown below (Fig.1), with the comparison of the LD against the customer requirements, [4].

The histogram represents the leading Bungee Cord LD (326.8 points of total 394) in front of the Pneumatic Actuator LD (320 points) and RATO (279) as third. Through this numerical analysis, and the comparison with the customer requirements and engineering targets, the bungee cord system was selected as the conceptual design for the LD. The results showed the potential of a pneumatic actuator conceptual design, as it scored similar results to the bungee cord design when compared to the customer requirements. Pneumatic designs have a large number of sub-components, usually employed to magnify the speed of the actuator. As a result, this design takes longer to set up and was chosen as unsuitable in the thesis scope.

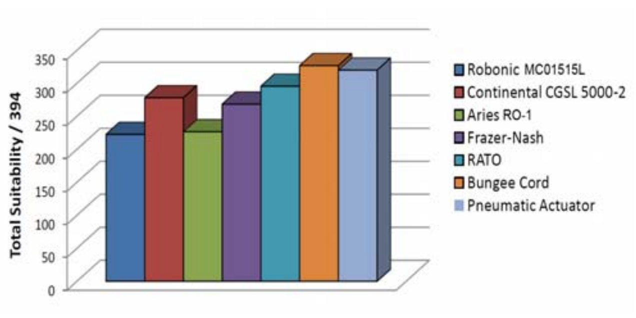

Figure 1. Comparing benchmark and conceptual design LDs to customer requirements, [4]

Today, the Bungee cord technology was improved significantly as for its power and elasticity in comparison with the 90's. The result of take-off mass and launching speed is increasing. Universal Target Systems Ltd. developed the Aerial Target System MSAT-500 NG whose bungee catapult can launch 105 kg UAV with a launching speed of 24m/s.

Functional Schema of the Bungee Catapult

The bungee cord catapult (Fig.2) is considered as a material system made of a stationary catapult body-launching rail (1), and a dynamic system which consists of a cradle (2), an elastic cord set (3), a rear roller (4), a front roller (5) and a UAV (6). The catapult body design enables an adjustable setup launching rail elevation angle (α=5°÷15°) in order to compensate for the local ground declination.

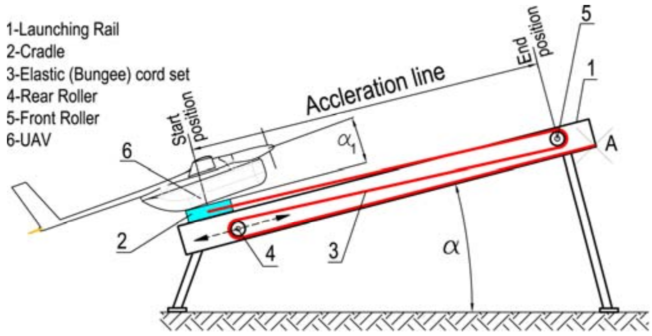

Figure 2. Bungee catapult functional schema

Dynamic System Description

The cradle has the possibility of moving along the inclined plane (launching rail) from its start to the end position. The elastic cord set is connected to the cradle by one of its ends and then enwrapped over a system of rollers and by the other end it is firmly attached to the rail body, (point A). The elastic cords are tensioned by the cradle moving to the start position where it is locked. After releasing, the force of the elastic cords accelerates the cradle with a jerk along the launching rail to the end position. From its rest, the start position, the cradle reaches a maximum speed at the end position where the damper stops it. After the cradle stops, the forward momentum causes the UAV to continue forward and takes over the flight with its propulsion assistance.

The front roller is allowed its own rotation, but it has fixed position on the launching rail. Except of its own rotation, the rear roller is given adjustable displacement by means of the wheelchair to move longitudinally within the rail body. Moving the wheelchair back and forth to vary previous tension cords gives a possibility to accommodate a wider range of UAV take-off mass.

Producers of bungee cords in accordance with aeronautical standards recommend operation from 20% to 80% of the elongation range where they can guarantee approximately linear bungee cords characteristic as this delivers improved predictable results. Also, they do not allow the elongation over 100% of the „un-stretched" bungee cord length.

The return of the cradle or the movement of the lower wheelchair with the rear roller is performed by means of a steel rope wounded by an electric winch on the back side of the catapult. This system operates using a pull or a remote lanyard which releases the UAV cradle along the launch rail.

Design Task Setup of the Bungee Catapult

The bungee catapult main task is to hand over to UAV previously accumulated energy in elastic cords so that the UAV at the time of leaving the catapult has a speed of at least 15% greater than the stall speed for a given configuration of the UAV. To have a successful takeoff, the UAV should have sufficient lift force after the instant of leaving the catapult when its own driving propeller achieves stable flight take over.

According to the selected functional schema (Fig.2, for an effective launching rail length, it is required to define necessary elastic cord stiffness, so that required takeoff speed of the UAV is feasible and that the acceleration is less than 10g. The additional requirement has to be fulfilled with the functioning of elastic cords within the range of 20% to 80% of its elongation. This includes the „un-stretched" cord length pairing to the launching rail total length and the rollers axle distance (design characteristics) to make a minimal number of rollers in the catapult (two), and to achieve the pre-tensioning of cords for the 20% elongation.

With bungee catapult dynamic system design, aspiration is expressed for the minimal number of moving parts, i. e. the mass of the selected elements ought to be as little as possible. Also, the launch ramp and the moving parts (cradle, rollers) must have sufficient rigidity so that the energy of elastic cords would not be wasted needlessly on the deformation work.

Mathematical Model

The result of the consideration of the following Assumptions is Fig.3. which represents a simplification of the working forces in a bungee catapult dynamic system.

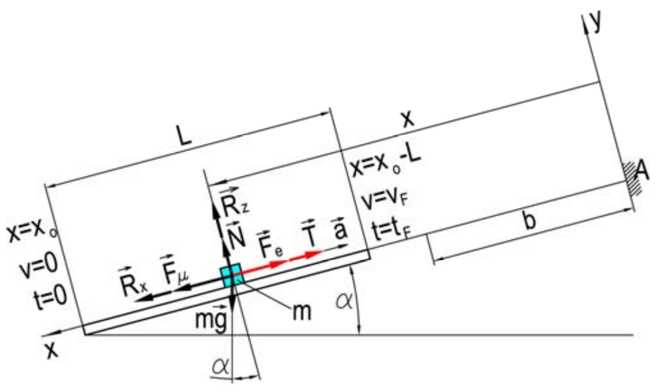

Figure 3. Free body diagram for the launch of a mass along a projected angle α

Assumption 1.
The catapult is a dynamic system considered as the kinetics of a particle.

- Since the UAV and the cradle travel linearly on the inclined plane, this Assumption can be adopted in addition to the adoption of the next two Assumptions.

Assumption 2.
The mass of the elastic cords is neglected.

Assumption 3.
The mass of the rollers is neglected.

- These neglected masses actually exist in the catapult dynamic system (elastic cord mass is more influential), but their influences have to be compensated by the energy reserve in the elastic cords.

Assumption 4.
Direction of the force of the elastic cords that tows the cradle with the UAV is coplanar to the inclined plane.

- The cradle towing force always acts at an angle to the inclined plane due to structural constraints. This angle is smallest when the cradle is at the start position and growing when the cradle moves to its end position. For this reason, the front roller should be set up as close as possible to the inclined plane on which the cradle moves.

Assumption 5.
The friction force of the elastic cords over the rollers is neglected.

- Since the rollers are given its own rotation, this significantly decreases the friction force of the elastic cords over the rollers.

Assumption 6.
Stiffness of the elastic cords is constant.

Assumption 7.
The work of the friction force when the UAV slips off the cradle at the end position is neglected.

- The work of the friction force when the UAV slips off the cradle is comparatively small due to short run distance.
- All neglected forces of friction have to be compensated by the energy reserve in the elastic cords.

Assumption 8.
Summable elastic cords force Fe is linear to elongation.

- The Assumption is valid if the elongation is in the range of 20% to 80%.

Assumption 9.
It is considered that the forces T and Rx are coplanar to the inclined plane. Also, the force Rz is collinear to N, i. e. they act perpendicularly to the inclined plane.

- In order to achieve sufficient lift force, the UAV is set up onto the cradle at the angle α_1 to the inclined plane. Since the angle α_1 is relatively small ($\cos\alpha_1 \sim 1$) this Assumption can be adopted as correct.

The differential equation of motion of free particles in a vector form is:

$$m\vec{a} = \sum_{i=1}^{n} \vec{F}_i^a + \sum_{i=1}^{n} \vec{F}_i^r \tag{1}$$

Applying (1) on the catapult mathematical model, one can obtain:

$$m\vec{a} = \vec{F}_e + m\vec{g} + \vec{F}_\mu + \vec{R}x + \vec{R}z + \vec{T} + \vec{N} \tag{2}$$

The force of the fictive elastic cords is:

$$F_e = q(x-b) \tag{3}$$

The UAV and cradle mass is:

$$m = m_{UAV} + m_{CRD} \tag{4}$$

The UAV drag force is:

$$R_x = C_x \frac{\rho v^2}{2} S \tag{5}$$

The UAV lift force is:

$$R_z = C_z \frac{\rho v^2}{2} S \tag{6}$$

The UAV propeller pulling force, [8] is:

$$T = T_o\left(1 - \frac{\dot{x}}{v_s}\right) \cong T(\dot{x}) \tag{7}$$

The frictional sliding force is:

$$F_\mu = \mu N \tag{8}$$

Assumption 10.
The UAV drag force Rx is neglected.

Assumption 11.
The UAV lift force Rz is neglected.

- These two Assumptions are taken into consideration in order to simplify equation (2). The UAV lift force R_z decreases the frictional sliding force F_μ indirectly for the approximate R_x amount.

Assumption 12.
It is considered that the UAV propeller pulling force T is constant.

- This Assumption is taken into consideration in order to simplify equation (2). The value of T decreases with speed increase. It is assumed that the average constant value T performs the same work as the real T.

Applying Assumptions 10 and 11, equation (2) assumes the form:

$$m\vec{a} = \vec{F}_e + m\vec{g} + \vec{F}_\mu + \vec{T} + \vec{N} \tag{9}$$

Since the particle motion is planar and linear by the projection (9) on the x-axis and on the y-axis, is obtained:

$$m\ddot{x} = F_\mu + mg \cdot \sin\alpha - F_e - T \tag{10}$$

$$N = mg\sin\alpha \tag{11}$$

then:

$$\ddot{x} + \frac{q}{m}x = g(\mu\cos\alpha + \sin\alpha) + \frac{q}{m}b - \frac{T}{m} \tag{12}$$

The solution of non-homogeneous equation (12) is:

$$x(t) = C_1\cos\sqrt{\frac{q}{m}}t + C_2\sin\sqrt{\frac{q}{m}}t + \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) + b - \frac{T}{q} \tag{13}$$

For the initial values: t=0, x=x_0, $\dot{x}_0$=0, equation (13) assumes the form:

$$x(t) = \left[x_0 + \frac{T}{q} - \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) - b\right]\cos\sqrt{\frac{q}{m}}t + \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) + b - \frac{T}{q} \tag{14}$$

Equation (14) represents the motion law on the catapult. By finding the first derivate of (14), the speed expression on the catapult is:

$$\dot{x}(t) = -\left[x_0 + \frac{T}{q} - \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) - b\right]\sqrt{\frac{q}{m}}\sin\sqrt{\frac{q}{m}}t \tag{15}$$

Applying the final values t=t_F, $x(t_F)$=x_0-L in equation (14), the expression of the final moment t_F when the cradle reaches the end position is obtained:

$$t_F = \sqrt{\frac{m}{q}}\arccos\frac{x(t_F) - \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) - b + \frac{T}{q}}{x_0 + \frac{T}{q} - \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) - b} \tag{16}$$

By finding the derivative of (15), the acceleration expression on the catapult is:

$$\ddot{x}(t) = -\left[x_0 + \frac{T}{q} - \frac{mg}{q}(\mu\cos\alpha + \sin\alpha) - b\right]\frac{q}{m}\cos\sqrt{\frac{q}{m}}t \tag{17}$$

Numerical Example

According to the selected Functional schema (Fig.2) and Mathematical model (Fig.3), the Design Characteristics (q, L, b,) are varied into (15), (16) and (17) in order to fulfill all the requirements of the Design Task Setup of Bungee Catapult.

For the varied values (q, L, b,) and adopted Design Characteristics:

$$m = m_{UAV} + m_{CRD} = 65 + 5 = 70 \text{ kg}$$

L=5m,

b=8m,

(b must be chosen to satisfy the pre-tensioning of cord and the operational range of the cord),

$$\mu = 0.1,$$

α=15° (0.175rad),

T=250N,

and initial (Fig.3) values:

t=0, x=x_0=14.5m, $\dot{x}_0$=0m/s,

(x_0 - length of the cord at the start position: depends on the b - length of the un-stretched cord, the rollers axle distance and the L - effective rail-launching length), final (Fig.3) values:

t=t_F, x=x_0-L=9.5 m, $\dot{x}$ = v_F,

the cradle speed is obtained at the instant of UAV leaving the catapult: t_F=0.9 s, v_F=21.5 m/s, for the aggregate stiffness of fictive elastic cords: q=800 N/m.

The graph (Fig.4, derived from the Mathcad 7 Professional software) represents the change in speed and acceleration on the bungee catapult.

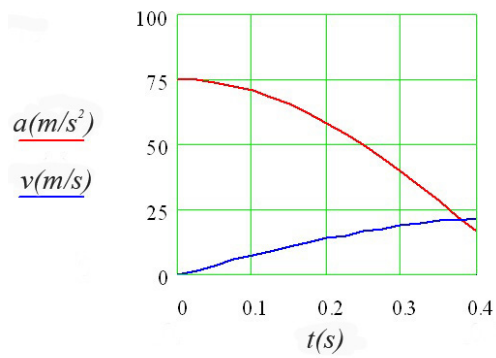

Figure 4. Fictive Bungee Cords Speed-Acceleration Diagram

Verification of the Results

The verification of the results (v_F=21.5m/s, q=800N/m) can be done by means of the work kinetic energy theorem.

$$E_{K_F} - E_{K_0} = \sum_i A_i \tag{7}$$

The elastic cords and the UAV propulsion enter effective work into the bungee catapult. The elastic cords effective work A_C is:

$$A_C = q\left(\frac{\Delta x^2{}_0}{2} - \frac{\Delta x^2}{2}\right) = 16000 \text{ J} \qquad (18)$$

The UAV propulsion effective work A_T is:

$$A_T = T \cdot L = 1250 \text{ J} \qquad (19)$$

The elastic cords and the UAV propulsion effective work is converted to the UAV and the cradle kinetic energy E_K, and wasted to the gravitational force work of the UAV and the cradle A_g, and to the frictional sliding force work A_μ.

$$E_K = m\frac{v_F^2}{2} = 16178 \text{ J} \qquad (20)$$

$$A_g = mg(y - y_0) = mgL\sin\alpha = 888 \text{ J} \qquad (21)$$

$$A_\mu = F_\mu \cdot L = \mu mgL\cos\alpha = 331 \text{ J} \qquad (22)$$

The result is:

$$A_C + A_T \sim E_K + A_g + A_\mu$$

$$(17250 \text{ J} \sim 17397 \text{ J}) \qquad (23)$$

with the error less than 1% so the calculation could be accepted as correct.

Real Elastic Cords

The real elastic cord is chosen according to the previously calculated effective work A_C=16000J. The real elastic cord is adopted from the Force/Elongation Diagram (Fig.5), [9] in order to satisfy the following condition

$$A_{CR} \geq 16000 \text{ J}. \qquad (24)$$

Assumption 13.
The hysteresis of the bungee cords with diameters ≤ 18mm is neglected.

- The bungee cord producers represent hysteresis on the Force/Elongation diagram of bungees with diameters ≥ 20mm, where it must be taken into consideration.

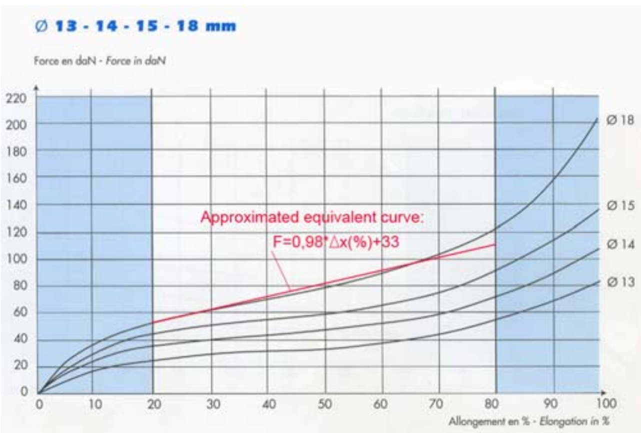

Figure 5. Force/Elongation diagram of real bungee cords, [9]

By the approximation of the real bungee cord curve (Fig.5) of the adopted cord Ø18, with the equivalent straight line in the range 20% to 80%, one cord force expression in the function of relative elongation (%) is obtained:

$$F_{er}^1 = 0.98 \cdot \Delta x(\%) + 33 \qquad (25)$$

namely, after the transformation of relative elongation to absolute elongation, expression (25) assumes the form:

$$F_{er}^1 = 122.4x + 330 = q_r^1 x + n_r^1 \ [\text{N}] \qquad (26)$$

The use of four of adopted real bungee cords Ø18 is enough to meet demands of the catapult as the condition (24) was satisfied. The summable four real bungee cords force is:

$$F_{er} = 4 \cdot F_{er}^1 = 489.6x + 1320 = q_r x + n_r \ [\text{N}] \qquad (27)$$

One real bungee cord effective work is:

$$A^1{}_{CR} = \int_{1.5}^{6} F_{er}^1 dx = 4098 \text{ J} \qquad (28)$$

The summable four cords effective work is:

$$A_{CR} = 4 \cdot A_{CR}^1 = 16392 \text{ J} \qquad (29)$$

Taking into consideration the recommendations of bungee cord producers and the Force/Elongation diagrams of real bungee cords, it can be noticed that the Fictive force of elastic cords is different from the Real bungee cord force to some extent. Also, it can be noticed that these forces produce approximately the same work (16000J and 16392J), but if (27) is applied to (3), we obtain the following form of the real bungee cords force:

$$F_{er} = q_r(x - b) + n_r \qquad (30)$$

Thereafter, equations (14), (15), (16) and (17) obtained the following forms, respectively:

$$x(t) = \left[x_0 + \frac{T + n_r}{q_r} - \frac{mg}{q_r}(\mu\cos\alpha + \sin\alpha) - b\right]\cos\sqrt{\frac{q_r}{m}}t + \frac{mg}{q_r}(\mu\cos\alpha + \sin\alpha) + b - \frac{T + n_r}{q_r} \qquad (31)$$

$$\dot{x}(t) = -\left[x_0 + \frac{T + n_r}{q_r} - \frac{mg}{q_r}(\mu\cos\alpha + \sin\alpha) - b\right]\sqrt{\frac{q_r}{m}}\sin\sqrt{\frac{q_r}{m}}t \qquad (32)$$

$$t_F = \sqrt{\frac{m}{q_r}}\arccos\frac{x(t_F) - \frac{mg}{q_r}(\mu\cos\alpha + \sin\alpha) - b + \frac{T + n_r}{q_r}}{x_0 + \frac{T + n_r}{q_r} - \frac{mg}{q_r}(\mu\cos\alpha + \sin\alpha) - b} \qquad (33)$$

$$\ddot{x}(t) = -\left[x_0 + \frac{T + n_r}{q_r} - \frac{mg}{q_r}(\mu\cos\alpha + \sin\alpha) - b\right]\frac{q_r}{m}\cos\sqrt{\frac{q_r}{m}}t \qquad (34)$$

Using the values and the conditions from the Numerical Example and the real bungee cords characteristics q_r=489.6 N/m and n_r=1320N, the values t_F=0.41 s, v_F=21.86 m/s are obtained, as well as the change in the speed and acceleration graph (Fig.6) of real bungees of the catapult.

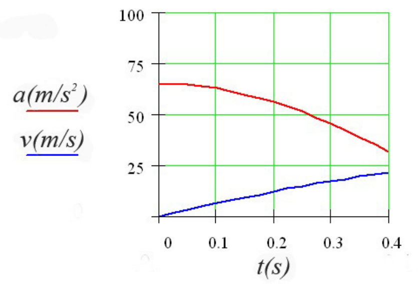

Figure 6. Real Bungee Cords Speed-Acceleration Diagram

Verification of the Final Results

In order to confirm the obtained results from the aspect of aerodynamics, in this chapter Assumptions 10 and 11 that excluded force of lift and drag from the calculations are ignored; thus equations (1) and (2) are now changed:

$$m\vec{a} = \vec{F}_{er} + m\vec{g} + \vec{F}_{\mu} + \vec{T} + \vec{N} + \vec{R}x + \vec{R}z \quad (35)$$

$$m\ddot{x} = F_{er} - mg\sin\alpha - F_{\mu} + T - Rx \quad (36)$$

$$m\ddot{y} = N - mg\cos\alpha + Rz = 0 \quad (37)$$

Equations (36) and (37) represent a system of nonlinear DE that describes a motion in the **x-**direction (along the rail-in direction of motion) and the **y-**direction (perpendicular to the rail, opposite to **g**).

Differential equations are solved numerically by using Wolfram Mathematica Software.

The results of the calculations are represented on the graph, where it can be noticed that for the time $t_F \approx 0.41$ s, the launching velocity is $\upsilon_F \approx 21.7 m/s$.

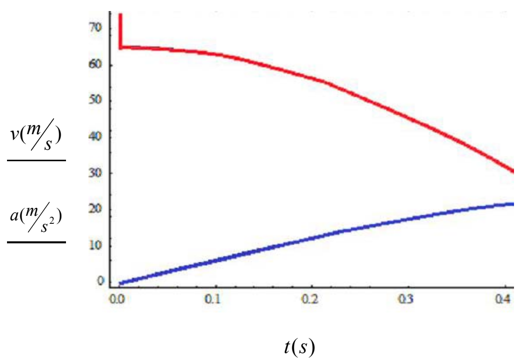

Figure 7. Velocity and acceleration results

From the results of the calculations, one can see that it is justified to introduce Assumption 10 and Assumption 11 because the differences in the results between the model with aerodynamic forces and the one without aerodynamic forces are minimal and can be neglected. Also, it must be said that neglecting aerodynamics forces is justified if launching velocities are not approaching 30 m/s.

Conclusion

The UAV launch speed and the UAV-cradle cumulative mass define the concept of catapult choice. The bungee cord technology is considerably improved so that today catapults are able to launch weight of more than 100kg. The result of benchmark analyses shows that bungee catapults have an advantage over pneumatic catapults.

The calculation of the fictive elastic cord (which is most commonly encountered in the literature) cannot be accepted as credible because its acceleration graph is significantly different from the acceleration achieved by the real elastic cord (to compare Fig.4 and Fig.6).

The initial jerk of the fictive cord is 7.5g after the cradle hitting the dumper with the acceleration of 1.6g. In the case of the real bungee cord, these values are 6.5g and 3.2g, respectively. Effective work achieved by the fictive cord can still be accepted as realistic as it reaches a final speed of 21.5 m/s. According to this work, the real bungee cord is selected-the condition (24). The defined mathematical model is valid for the hypotheses adopted. For all hypotheses that directly or indirectly diminish the stiffness of the cord (cord pulling force), compensation will be made through a power reserve-additional stiffness. The results of these adjustments are reflected in the final velocity, v_F = 21.86 m/s, which is significantly higher than the required margin of safety of 15%. In addition, the cord tension can be corrected by moving the rear roller within the catapult, by which the maximum tensile force can be varied for ±15%. At the same elongation, the cord should remain in the range of 20% to 80%. This is especially useful if the UAV mass varies due to changeable payloads. The calculation of the real bungee cords enables proper selection and the number of real bungee cords, while the positioning of the rear roller makes additional adjustments of the tensile force in experimental trials.

The electric winch and the dumper are the accessories to be fitted to the catapult. It is also useful to install a clinometer and a speedometer into the catapult.

The calculation using a real bungee cord could be accepted as relevant for UAV bungee LD design.

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Analiza lansirnog uređaja sa bandži užadima za bespilotne letelice

U ovom radu se analiziraju lansirni uređaji (LU) bespilotnih letelica sa akcentom na bandži katapult kao predstavnika široko rasprostranjenih LU prostije strukture. U radu su date četiri analize: Analiza sistema LU prema najznačajnijim projektnim zahtevima i zahtevima kupaca, Analiza kretanja podsistema BL-kolevka na lansirnoj rampi, Analiza izbora i energetskog kapaciteta užadi prema projektnim zahtevima i Analiza uticaja sila aerodinamičkog uzgona i otpora na matematički, odnosno mehanički/fizički model-poređenje rezultata. Rad daje preporuku za izbor rešenja bandži katapulta u ranoj fazi projektovanja.

Ključne reči: **bespilotna letelica, lansiranje, lansirni uređaj, katapult, projektovanje, matematički model.**

Анализ пускового устройства с банджи верёвкой для беспилотных летательных аппаратов (БПЛА)

В данной статье анализируются пусковые устройства (ПУ) беспилотных летательных аппаратов с акцентом на банджи-катапульте, как представителе широкораспространённых ПУ попроще структуры. Эта статья представляет четыре анализа: анализ системы ПУ на удовлетворение основных требований проекта и требований заказчика; анализ движения субсистемы БПЛА-колыбели на стартовой площадке; анализ отбора и анализ энергетических мощностей кабелей в соответствии с требованиями проекта и анализ действия аэродинамических сил подъёмной силы и сопротивления на математическую и механическо/физическую модель сравнения результатов. Здесь предложены рекомендации по выбору решений банджи- катапульта на ранних стадиях проектирования.

Ключевые слова: **беспилотный летательный аппарат, запуск, пусковое устройство, катапульты, дизайн, математическая модель.**

Analyse du dispositif de lancement bungee aux cordes pour les aéronefs de lancement

Dans ce papier on analyse le dispositif de lancement (DL) pour les aéronefs sans pilote notamment la catapulte bungee qui représente un DL de structure simple et très rependu . On a donné quatre analyses: analyse du système du DL selon les plus importantes exigences de la conception et selon les exigences des acheteurs, analyse du mouvement du sous système berceuse – BL sur la rampe de lancement, analyse du choix et de la capacité énergétique des cordes selon les exigences de la conception et analyse de l'influence des forces de la poussée aérodynamique et la résistance au modèle mathématique, mécanique et physique – comparaison des résultats. Ce travail donne également la référence pour le choix des solutions de la catapulte bungee dans la première phase de la conception.

Mots clés: **aéronef sans pilote, lancement, dispositif de lancement, catapulte, conception, modèle mathématique**