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AN ACTIVE ROCKET LAUNCHER CONTROLLER DESIGN FOR AN ATTACK HELICOPTER

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ABSTRACT

In this paper rocket firing and helicopter's relationship is examined, and an active launcher controller is designed which changes launcher pitch angle with respect to the Earth and helicopter's attitude to satisfy the desired launch angle of the missile. The desired launch angle of the rocket is determined based on several factors including relative position of the target, the velocity of the helicopter, altitude, and temperature. In the case of a static launcher fixed to the aircraft body, helicopter pitch attitude has to be adjusted to launch the missile at the desired angle. This brings a constraint on helicopter motion, and it may be infeasible to adjust the helicopter attitude to meet launch angle requirements in a combat environment. An active launcher controller is designed in this work to launch the missile at the desired angle irrespective of the helicopter attitude. A regression model of the reference pitch angle is formed for an unguided rocket launching constraints that provide the desired launch angle. Then a launcher controller is designed to bring the launcher angle to the desired value with respect to the Earth.

INTRODUCTION

While firing conventional rockets, pilots have to use pitch delivery charts and graphs provided to aid in pre-flight preparations and during flight operations. First, pilot selects the appropriate chart for the type of fire, running or hover, and altitude and speed of the helicopter. Then the pilot examines the elevation and the range of the target and calculates correct pitch angle. The procedure for finding the right angle of launch brings an extra burden on the pilot, which can be critical during operations. Since the process depends on well-established rules and does not require human intelligence, it can safely be automated. Another difficulty in a traditional missile launch system where the launcher is fixed to the helicopter body is that it is the pilot's responsibility to adjust the helicopter attitude to bring the missile to the desired angle for launch. Aside from requiring pilot's attention, changing the helicopter position may change the airspeed, and this may be undesired in hostile territory [Ball, 2003; Joyce, 2008; Secretary of the Navy, 2003]. Especially when the flight condition changes, previously calculated launch angle for the initial flight condition may not be the optimal angle anymore. Consequently, the pilot either needs to recalculate the launch angle, spending precious time

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in a combat environment, or has to fire the missile with a suboptimal angle, reducing the chances of successful target engagement.

In this work, an active missile launcher is designed to automate the procedure described above. The proposed approach includes determination of the missile launch angle through a regression model, eliminating the need for the pilot to study pitch delivery charts. Also, an active launcher is proposed that can be tilted with respect to helicopter body [Koruba, Krzysztofik, & Dziopa, 2010]. The launcher will allow the desired launch angle to be satisfied without changing the helicopter pitch attitude. The proposed launcher reduces pilot workload and preparation time significantly and increases the possibility of launching the missile at an optimal angle without affecting helicopter flight condition. The proposed launcher is embedded to a UH-1H helicopter simulation which is developed in Simulation, Control and Avionics Lab of the Department of Aerospace Engineering, METU by [Yılmaz and Yavrucuk 2007]. A plenty amount of rockets are fired, and the proposed active launcher's performance is tested in this simulation by the first author, who is an attack helicopter pilot (900 flight hours) in Turkish Land Forces for 8 years.

PRELIMINARIES

Rocket Trajectory Model

The trajectory of a rocket with given physical properties and initial conditions is studied by including effects due to thrust, drag, change in mass, and gravity. The drag force of the rocket is estimated using Equation 1 and 2;

$$C_d = \frac{F_d}{\frac{1}{2}\rho V^2 A} \tag{1}$$

$$F_d = \frac{1}{2}\rho V^2 C_d A \tag{2}$$

The change in the thrust of rocket with time taken from the technical report of Dahike and Batiuk is digitized and re-modelled in Matlab as shown in Figure 1.

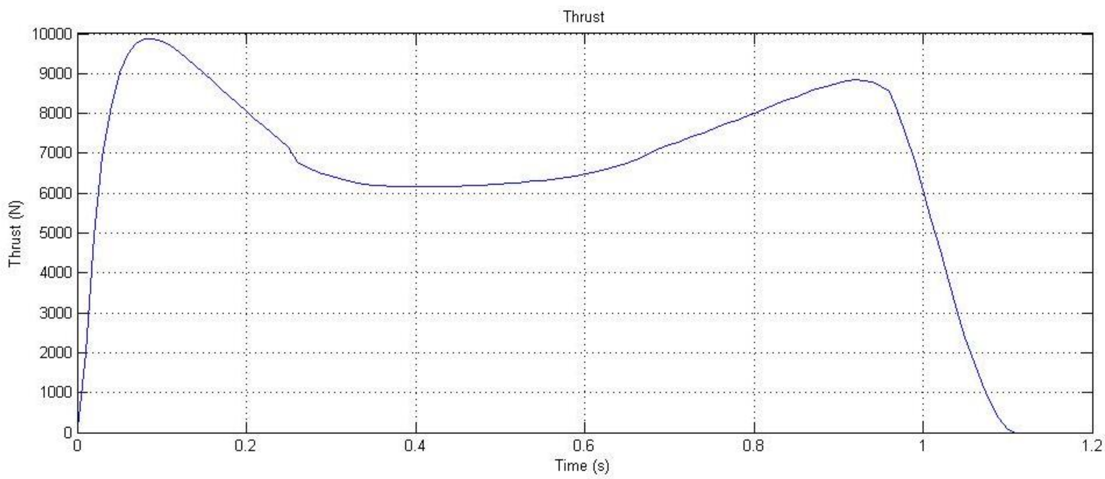

Figure 1: Thrust vs. Time [Dahlke & Batiuk, 1990]

The drag coefficient for Hydra-70 is also given in the technical report of Dahike and Batiuk for both power-on and coast with a change in Mach number. Figure 2, as in the reference, is digitized and re-created in MATLAB.

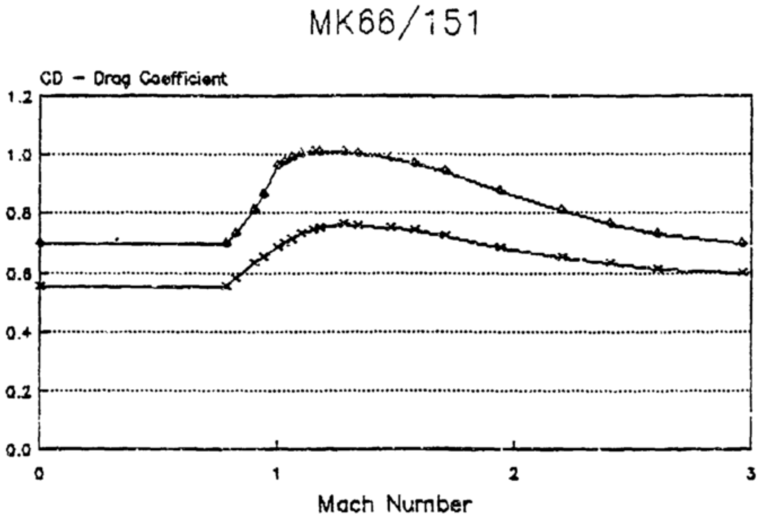

Figure 2: Drag Coefficients [Dahike & Batiuk, 1990]

The rocket trajectory is calculated with rational analysis and modeled in MATLAB. Kapulu has noted that main rotor inflow induces rocket launch. Thus, rocket range extends up to 388 meters for UH-60 Blackhawk and Hydra-70 with MK-40 motor [Kapulu, 2015].

In this study, the inflow of the main rotor is ignored. Trajectory simulation of Parsons is revised and reconstructed for the Hydra-70 introduced in this study [Parsons, n.d.]. Rocket projected area, initial horizontal and vertical speed is tuned by hand to adjust rocket ranges given in rocket delivery charts. Some of the results compared with rocket delivery charts to validate the model. It is seen that the results are almost same. Aerodynamic stability and additional effects such as thrust misalignment cause dispersion are not taken into consideration. Thus, the original trajectory on a flight reasonably will not be same as estimated in this study. The simulation results for the "ρ=0.885, h=15.24, θ=1, V=0" is shown in Figure 3.

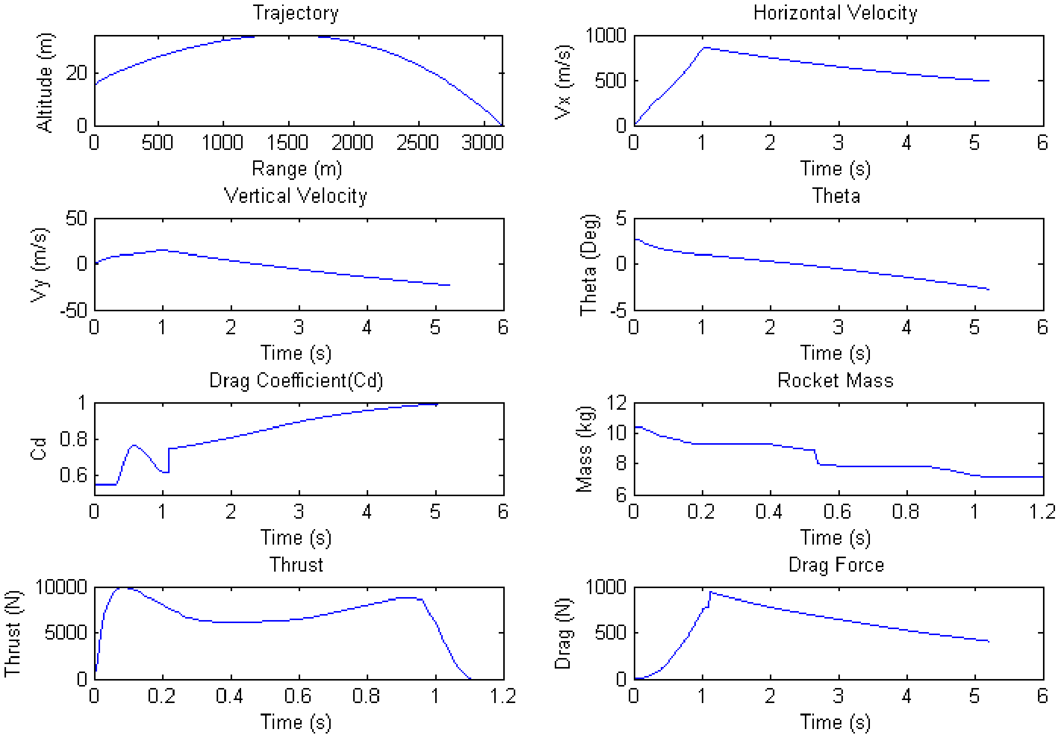

Figure 3: The Modified "Rocket Trajectory Simulation" Outputs

Polynomial Regression Model for Firing

The parameters for determining the launch angle are given below in the Table 1.

Table 1: Target Parameters

Parameter	Unit	Notation
Air Density	(kg/m^3)	ρ
Air Velocity (IAS)	Knot	V
Vertical Distance between target and helicopter	Meter	h
Horizontal Distance between target and helicopter	Meter	y
Required Pitch Angle	Degree	θ

The data set required to build the polynomial regression model is obtained and produced from the simulation runs. The parameter intervals of the simulation are given in Table 2.

Table 2: Parameter Intervals.

Parameter	Minimum	Maximum
Air Density (kg/m^3)	0.800	1.395
Air Velocity (IAS) (knots)	0	120
Vertical Distance between target and helicopter (meters)	15.24	609.6
Required Pitch Angle (degrees)	-8	18
Horizontal Distance between target and helicopter (meters)	211.13	9452.41

First, rocket trajectory is calculated to gain delivery of the rocket with a proposed launch angle. Then the new data set is obtained as five columns and 27,216 rows. The parameters of the data are described in Table 1, and a sample of data is given in Table 3.

Table 3: Sample Data

ρ	V	h	θ	y
1.225	0	15.24	1	211.497
1.225	60	243.84	3	5025.307
1.225	120	609.6	10	6749.468

The launcher has a +0 degrees pitch angle with respect to helicopter body. This required pitch angle is the command pitch angle that the aircraft should have with respect to earth.

Polynomial regression is one of the particular forms of linear regression and used to represent and fit nonlinear relations where the independent variable *x* and the dependent variable *y* is modeled as an *n*th degree polynomial in *x.*

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \cdots + \beta_n x^n \tag{3}$$

$$\theta = f(\vec{y}; \vec{\rho}; \vec{V}; \vec{h};) + \varepsilon \tag{4}$$

This regression method depends on the perception of the user, and the choice of degree of the polynomial defines the quality of the fit. First, linear models for each constraint are evaluated then the order of polynomials are increased. However, the change of the distance with the pitch angle is fitted by discrete Fourier transform. Obtained equations are just a curve-fit of sines and cosines, nothing more.

By curve fitting, orders of the polynomials are chosen. The most common method of curve fitting is “Least Squares” that finds the line of best fit for a data set. Furthermore, Non-Linear Least Squares is the form of the least squares that estimate the unknown parameters of the model by successive iterations. The basic form of the curve fit problem is given in Equation 5 [van de Geer, 2005; Pham, 2006].

$$y = f(\vec{x};\vec{\beta}) + \varepsilon \tag{5}$$

The relationship between pitch angle and other variables are examined one by one and as a result, four polynomials are estimated; then added up together. The estimated model is solved in SPSS 17 as a custom regression model to estimate the coefficients of the model. The estimated model is shown in Equation 6. The model details, contain coefficients in this section, are not presented in this paper.

$$\begin{aligned}
&\theta(y,h,V,\rho) = C1 + C2*\cos(y*w) + C3*\sin(y*w) + C4*\cos(2*y*w) \\
&+C5*\sin(2*y*w) + C6*\cos(3*y*w) + C7*\sin(3*y*w) \\
&+C8*\cos(4*y*w) + C9*\sin(4*y*w) + C10*\cos(5*y*w) \\
&+C11*\sin(5*y*w) + C12*\cos(6*y*w) + C13*\sin(6*y*w) \\
&+C14*\rho + C15*\rho^2 + C16*\rho*y + C17*\rho^3 + C18*\rho^2*y \\
&+C19*\rho*y^2 + C20*\rho^4 + C21*\rho^3*y + C22*\rho^2*y^2 \\
&+C23*\rho*y^3 + C24*\rho^5 + C25*\rho^4*y + C26*\rho^3*y^2 \\
&+C27*\rho^2*y^3 + C28*\rho*y^4 + C29*V + C30*V^2 \\
&+C31*V*y + C32*V^2*y + C33*V*y^2 + C34*V*y^3 \\
&+C35*V^2*y^2 + C36*V*y^3 + C37*V^2*y^3 + C38*V*y^4 \\
&+C39*h + C40*h^2 + C41*h*y + C42*h^3 + C43*h^2*y \\
&+C44*h*y^2 + C45*h^4 + C46*h^3*y + C47*h^2*y^2 + C48*h*y^3 \\
&+C49*h^5 + C50*h^4*y + C51*h^3*y^2 + C52*h^2*y^3 + C53*h*y^4 + C54*y \\
&+C55*y^2 + C56*y^3 + C57*y^4 + C58*y^5
\end{aligned} \tag{6}$$

The estimated model to calculate required launch angle has been run for complete data, and the results are compared. The mean absolute deviation of the regression model is e=0.1368, caused by residuals in the partial regression models. At closer horizontal distances, the error becomes high while there is relatively no error between 3000-5000 meters. Beyond these distances, the model's error becomes insignificantly higher. A sample data is given for validation and presented in Table 4 for V=60 knots, ρ=1.225 kg/m^3, and other varying parameters.

Table 4: Sample Estimated Pitch Data

ρ	***V***	***h***	θ	***y***	***Model Est.*** θ	***Error***
1.225	60	15.24	-8	242.3617	-6.86596	-1.13404
1.225	60	15.24	-4	498.182	-4.90175	0.901752
1.225	60	15.24	4	4163.806	3.91787	0.08213
1.225	60	15.24	12	5883.484	12.04226	-0.04226
1.225	60	15.24	16	6405.637	15.96188	0.038121
1.225	60	182.88	-8	1987.611	-8.22893	0.228927
1.225	60	182.88	-4	2960.649	-3.93081	-0.06919
1.225	60	182.88	4	4999.15	3.954383	0.045617
1.225	60	182.88	12	6246.9	12.06579	-0.06579
1.225	60	182.88	16	6679.957	15.96669	0.033308
1.225	60	548.64	-8	4082.113	-7.98977	-0.01023
1.225	60	548.64	-4	4778.315	-3.99598	-0.00402
1.225	60	548.64	4	5963.821	4.003275	-0.00327
1.225	60	548.64	12	6820.35	12.13745	-0.13745
1.225	60	548.64	16	7145.819	16.0172	-0.0172

Launcher and Rocket Physical Model

The physical characteristics for the M260 rocket launcher and the rocket are shown in Table 5.

Table 5: Physical Characteristics [Dahlke & Batiuk, 1990; Obermark & Key, 2004]

Component	#	**M260**	**Rocket**
Mass	*lbs*	35	22.95
Length	*ft*	5.5158	4.59375
Diameter	*ft*	0.8097	0.2296
xG	*ft*	0	0
yG	*ft*	0.40485	0.11155
zG	*ft*	2.86041	2.496
Ixx	*slug.ft^2*	0.123	0.00566
Iyy	*slug.ft^2*	2.63	1.3485
Izz	*slug.ft^2*	2.64	1.3485

The rockets can be launched in numbers with regard to pilot's choice. In this effort, rockets are fired one by one and estimations were done in that respect. The rocket and the launcher models are developed in CATIA environment as in shown Figure 4. The warhead and the rocket motor is assumed and modeled as a cylinder. Individual physical characteristics of each the rocket and the launcher are already presented in Table 4. In the view of this parameters, the mass, inertia, and center of gravity values are calculated together and separately for each situation where the rockets are fired in the order shown in Figure 5.

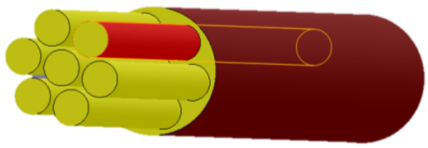

Figure 4: Front View of the CATIA Model,

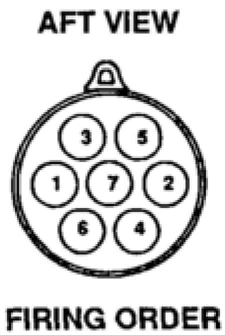

Figure 5: Rocket Firing Order [Office of the Chief of Naval Operations, 1997]

For each firing session, dynamics are changed as expected. For each case, the center of the gravity is estimated using CATIA with respect to a reference point at the front side zero line of the launcher. Then the parallel axis theorem [Boresi, Schmidt, & Mei, 2001] is used to calculate the inertias with respect to the helicopter center of gravity; results are shown in following Table 6.

Table 6: Center of Gravity, Mass and Inertia

Component #	***x_G [m]***	***y_G [m]***	***z_G [m]***	***I_{xx} [kg*m^2]***	***I_{yy} [kg*m^2]***	***I_{zz} [kg*m^2]***	***mass [kg]***
FULL	0.0000	0.1229	0.5008	92.1482	108.1109	28.7997	88.745
Rocket 1 fired	-0.0105	0.1229	0.5115	89.6614	101.4206	24.5884	78.3354
Rocket 2 fired	0.0000	0.1228	0.5256	86.4148	94.5298	20.9361	67.9254
Rocket 3 fired	-0.0068	0.1353	0.5447	80.1171	87.7247	16.6641	57.5155
Rocket 4 fired	0.0000	0.1230	0.5723	72.4764	79.1435	13.1719	47.1055
Rocket 5 fired	0.0107	0.1426	0.6154	60.4478	66.7308	8.6786	36.6956
Rocket 6 fired	0.0000	0.1234	0.6929	41.4730	46.6927	5.4076	26.2856
Rocket 7 fired	0.0000	0.1234	0.8718	0.16677	3.56580	3.5793	15.8757

Dynamic Modelling

The active launcher system contains a servo-motor mounted on the geometric center of the launcher that controls the launcher around the z-axis by applying torque. The angle change is measured in degrees as "θ." As can be seen from the Figure 6, at full rocket load, the center of the gravity is in front of the mount point by a distance λ. Alternative approaches for controlling the launcher may have also been developed.

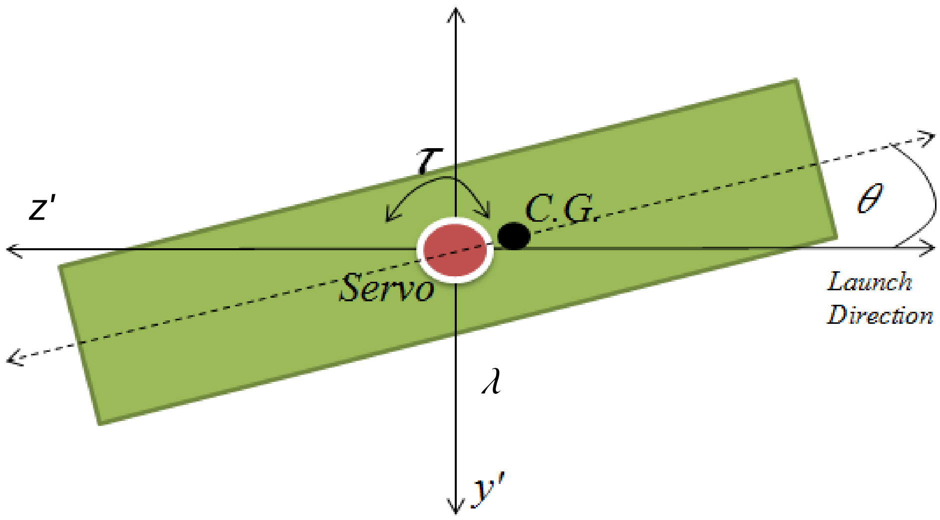

Figure 6: Servo Controlled Active Launcher

Equation of Motion

In this model, the second order linear effects are summed in one torque equation, and angular acceleration is calculated. Thus, the equation of motion becomes,

$$I'_{xx}\ddot{\theta} = -m'g'\lambda\theta + \tau - b\dot{\theta} \tag{7}$$

From the equation of motion equation, uncontrolled transfer functions are obtained for 7 firing conditions. The damping ratio of the servo-motor is assumed as *b*=300 N.s/m.

Controller Design

The block diagram of the proposed launcher controller is shown in the Figure 7. Ballistic Solution Calculator (BSC) takes attitude data from Air Data Computer and receives target data from so called cockpit control unit. With this data, the BSC recalculates reference control value by using the regression model achieved above. To make a stable pitch hold system for the launcher, the response has to be sufficiently fast and robust to helicopter attitude changes. As an initial design, PID controller structure is chosen, and the gains are calculated by pole placement method. For the design of the launcher controller, following requirements are determined;

Table 7: The Design Requirements

Rise time	1 s	Settling time	1.5 s	% Overshoot	1 %

With respect to the requirements, PID controller gains are calculated with N=40 derivative filter and results are given below;

Table 8: PID Gains

	Ts=1.5 sn		
	Kp	Ki	Kd
Full	3259.7	7286.6	469.1
Rocket 1 Fired	3211.8	7107.4	450.19
Rocket 2 Fired	3163.9	6928.2	431.28
Rocket 3 Fired	3025.2	6569.9	393.45
Rocket 4 Fired	2825.8	6092.1	343.02
Rocket 5 Fired	2504.3	5375.4	267.37
Rocket 6 Fired	1971.8	4240.6	147.59

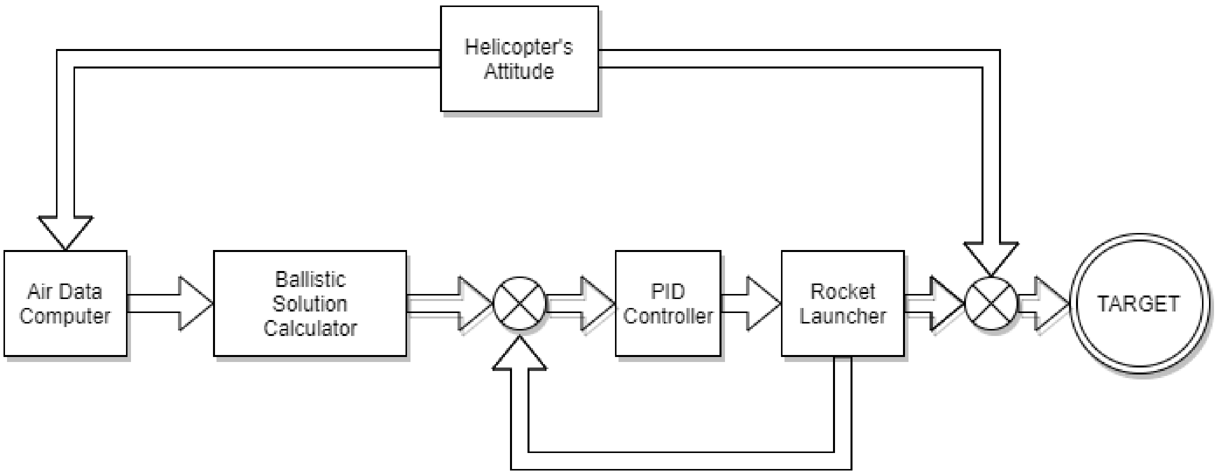

Figure 7: Proposed Active Missile Launcher System

RESULTS

A PID controller is designed in MATLAB with the requirements as mentioned. To test the performance of the controller, the designed and PID controlled active rocket launcher is embedded to the UH-1H Helicopter Simulation. 471 rockets are fired at zero degrees pitch-up fixed launcher, and 611 rockets are fired by the active launcher on the simulated flight by both single firing and ripple firing methods. With the collected data, proposed active launcher's performance is tested and compared with the required distances both down-range and cross-range. All results are obtained by flight on simulation, and no Monte-Carlo simulation is used in any steps. Scenarios are defined in real combat situations in the light of the first author's attack helicopter experiences and his colleagues' feedbacks in the combat zone. Target parameters are put into the simulation by knobs on the joysticks, real time on the flight.

A sequence of the simulation is given below in Figure 8. Helicopter's varying attitude is the disturbance of the controller. It is apparently seen that the controlled launcher follows the command irrespective of changing helicopter pitch angle. Little disturbances occurred due to the different pitch angles. Hence, the launcher is not affected by changing conditions of the aircraft as much at all. The step changes in the figure are the reactions of the launcher to the new target conditions. Sample simulation results of both fixed and active launcher are presented below in Table 9.

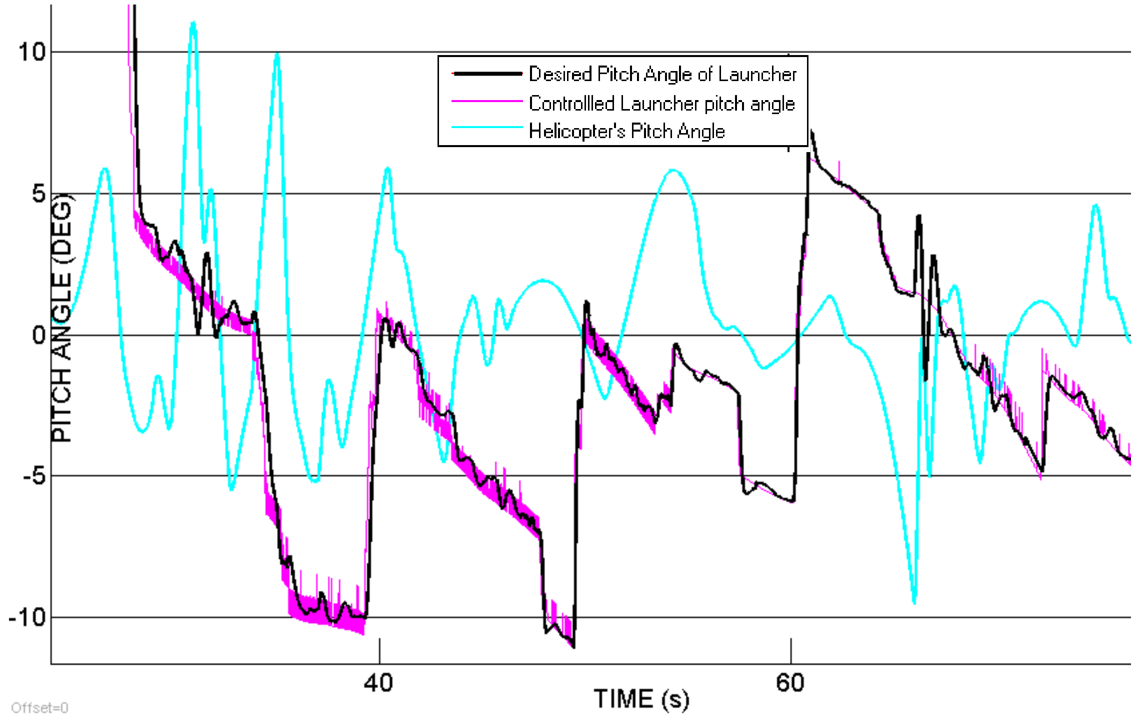

Figure 8: Pitch attitude hold performance of the launcher with helicopter pitching motion

Table 9: Simulation Outputs for the Fixed and the Active Launcher

	Helicopter				Target		Launcher			Error	
	Pitch *[deg]*	**Altitude** *[ft]*	**OAT** *[°C]*	**Velocity** *[kts]*	**Distance** *[m]*	**Height** *[ft]*	**Reference** *[deg]*	**Output** *[deg]*	**Hit Dist.** *[m]*	**Angle** *[deg]*	**Distance** *[m]*
Fixed	7.25	2169	10	57	6362	-451	6.29	7.25	5415	0.96	947
	4.57	4886	10	72	7037	520	3.94	4.57	6712	0.63	326
	0.3	4667	10	78	6284	1333	-0.04	0.3	6145	0.34	139
	-5.35	3339	10	58	4680	1751	-5.05	-5.35	4775	-0.3	-95
	-14.44	2622	10	101	1464	796	-12.05	-14.44	1920	-2.39	-457
	-2.03	1228	10	91	3328	592	-3.28	-2.03	2904	1.25	424
	-6.01	5467	10	90	3451	1101	-5.91	-6.01	3478	-0.1	-28
	1.75	2304	10	59	7594	1192	4.18	1.75	8333	-2.43	-739
Active	0.02	2165	-10	53	6205	546	9.21	9.28	6264	-0.07	-58
	-2.50	4432	-10	78	1457	1432	-12.92	-12.88	1439	-0.04	18
	-4.00	4553	-10	81	3362	1553	-2.37	-2.35	3364	-0.02	-2
	-1.08	1463	-10	41	6336	192	10.78	10.75	6342	0.03	-6
	0.23	1881	-10	41	4567	134	8.16	8.17	4525	-0.01	42
	-4.34	4984	-10	88	5059	698	5.84	5.76	4997	0.08	62
	-3.99	6187	-10	87	3842	393	4.93	4.95	3831	-0.02	11
	-0.07	1365	20	70	7026	94	11.48	11.47	7046	0.01	-20
	-4.49	3195	-10	75	2215	575	-0.12	-0.04	2266	-0.08	-51

For both launcher types, the hit positions of the rockets are standardized and scaled to zero-zero coordinates and given below in the Figure 9 and 10.

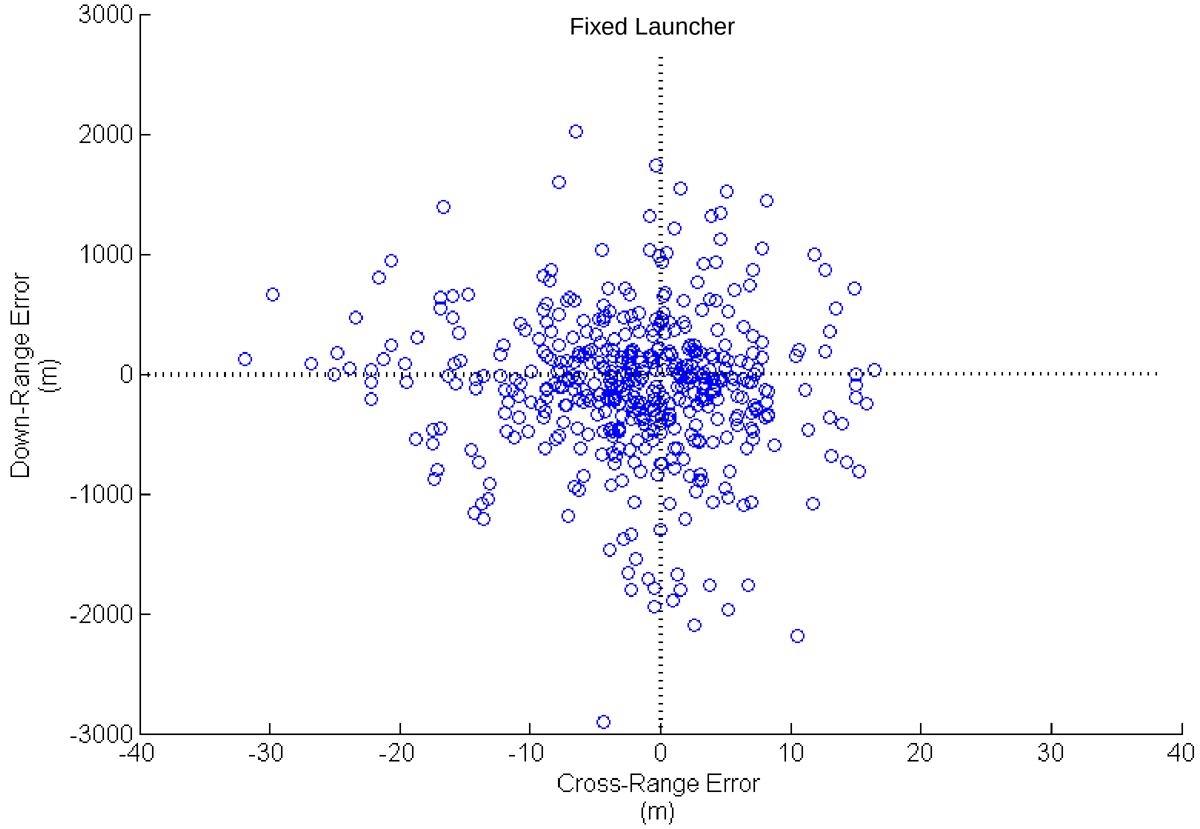

Figure 9: The Fixed Launcher Rocket Dispersion

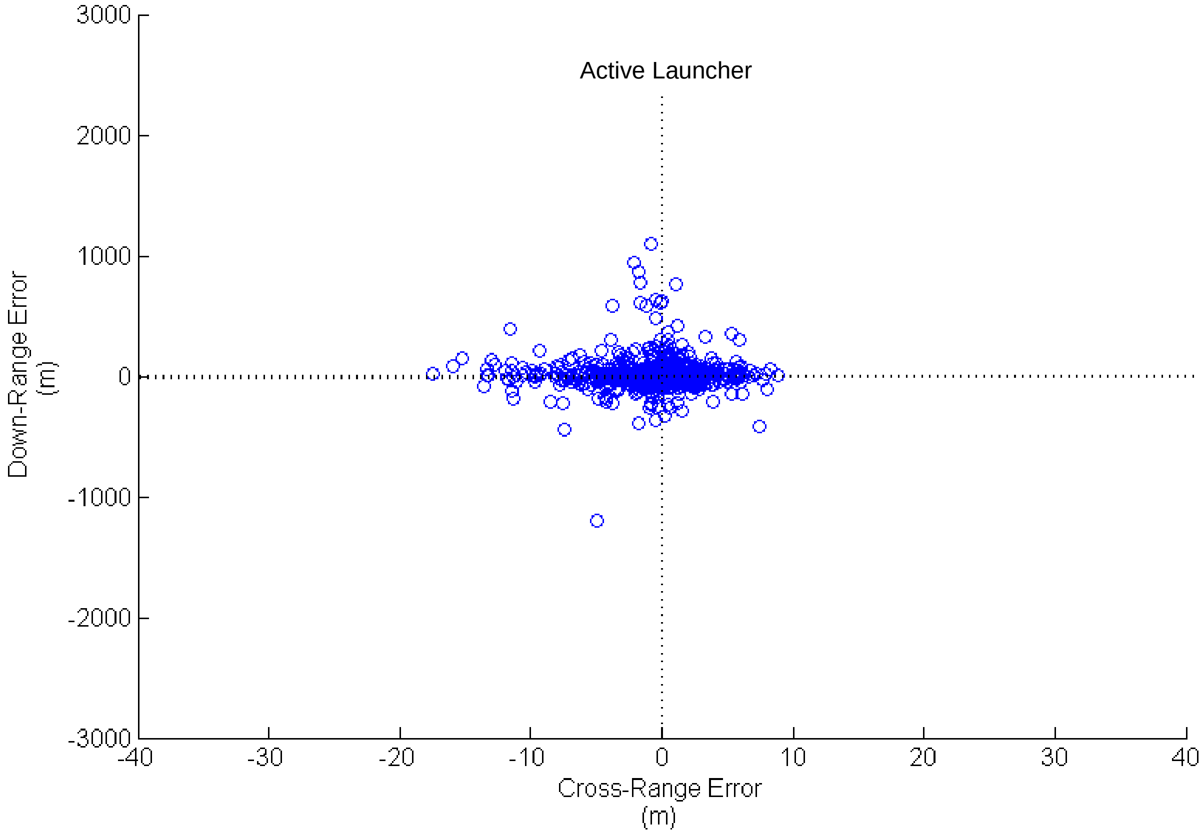

Figure 10: The Active Launcher Rocket Dispersion

As expected, by the active rocket launcher, the down-range performance is highly improved. Conversely, the down-range error is high by fixed launcher due to no controller applied in the yaw direction and occurred due to the pilot's command errors. Especially, for reference angles which need more cyclic inputs, errors grow relatively. Cross-range errors are nearly same with either active or fixed launcher as expected, since there is no control in the cross-range direction. The average absolute error of fixed launcher is 445.51 meters where the active launcher's is only 59.82 meters. It can be said the that active launcher enhanced the down-range dispersion ratio by 86.57%.

CONCLUSION & FUTURE WORKS

The pilots always prefer to use "fire and forget" missiles for their high survivability for the designator. The rockets are not an exact alternative for those precision guided missiles which has high kill ratios and armor penetration abilities. Besides, their simplicity of usage, easy manufacturing and no countermeasure capability of the enemy, make the rockets indispensable. We build on this study to identify the technology that can assist inaccuracy of unguided rockets. In this study, an active rocket launcher is designed to automate the procedure described. The proposed approach includes determination of the rocket launch angle through a regression model, eliminating the need for the pilot to study pitch delivery charts. Also, an active launcher is proposed that can be tilted with respect to helicopter body. The launcher will allow the desired launch angle to be satisfied without changing the helicopter pitch attitude. The proposed launcher reduces pilot workload and preparation time significantly and increases the possibility of launching the rocket at an optimal angle without affecting helicopter flight condition.

In the future plan, more advanced models with different controllers will be studied and implemented into the current research. The proposed system will be compared with an automatic flight controlled modern attack helicopter which can adjust the helicopter to the target in order to tilt the launcher. The ballistic solution algorithm will be improved with more parameters as implementing the wind, rotor downwash, humidity, etc. Also, the robustness and applicability of the system will be tested in a different attack helicopter simulator with different pilots.

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- And all personnel of "Attack Helicopter Batallion" for their glorious support and motivation.

Photos Of The Simulation Setup

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