AVALAUNCHER TARGETING

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ABSTRACT: This paper describes the development and verification of a basic targeting model for gas pressure launched explosive projectiles used for avalanche mitigation. The model uses the basic physics of flight including aerodynamic drag and the effects of gravity. The avalauncher round is unique, compared to artillery rounds, in that its drag coefficient changes during flight. This uniqueness is handled in a manner that relies on currently characterized avalauncher shot settings to establish the aerodynamic drag coefficients (C_d) empirically. The model has been used with good results to modify existing shot placement data, and also to develop new shot parameters. This model will reduce costs and significantly improve safety over trial and error techniques.

KEYWORDS: avalauncher, targeting, gas launched projectiles, avalanche mitigation

1.0 INTRODUCTION

The Snowbasin Resort Co. installed a Fire Ball avalauncher in 1977 supplementing a 75 mm recoilless rifle in use from the 1970s until 1998-99. Seven additional McCracken, breech-loading avalaunchers were purchased to control targets formally shot by the recoilless rifle. On a typical control morning 70 rounds are fired of the maximum 94 targets assigned to the seven guns. Recent changes in round availability and configuration, and the potential expansion into new terrain require a model to predict settings necessary to hit desired targets. The history of avalauncher use for avalanche control in ski resorts was described by Brennan (2006).

Targeting avalaunchers has mostly been conducted by trial and error, and judgment based on previous experience. With the increasing cost of avalauncher rounds ($50-$80 each), this method can become expensive. Also, using trial and error methods can create safety hazards due to the uncertain location of the explosive impact.

This paper presents an approach for developing a targeting model that utilizes readily available software (Microsoft Excel), and the basic physics of non-propulsive free flight, Hausmann (1957).

The avalauncher round has some unique characteristics compared to artillery rounds.

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The avalauncher round aerodynamic drag coefficient (C_d) changes during flight. In the early stage of flight (1 – 1.5 sec) the round has a base plate attached to the aft end that assists launching and also arming of the round. This base plate creates a significant increase in the aerodynamic drag of the round in flight. When the base plate comes off the round is armed and also the aerodynamic drag is reduced (See Figure 3.2.1). Also, avalauncher rounds fly at subsonic velocities and are launched by pressurized nitrogen gas. These differences create the need for a new approach for targeting avalauncher rounds. The targeting technology for artillery rounds is not directly applicable to avalauncher rounds. The cost of the avalauncher rounds and the safety concerns associated with uncertain explosive round impact points, justifies the development of a targeting model unique to avalaunchers.

2.0 TARGETING FUNDAMENTALS

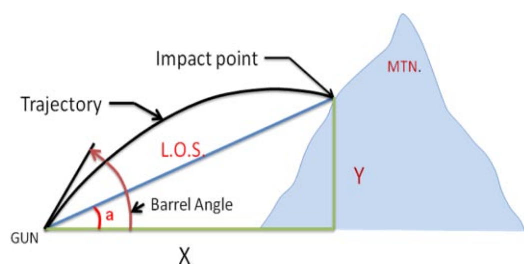


Figure 2.1 Targeting Fundamentals

A targeting model needs, as input data, the horizontal and vertical distances to the desired target point as illustrated by (X) and (Y) in Figure 2.1. Also, a barrel elevation angle ($theta_0$) must be selected that is greater than the angle (a) in Figure 2.1. These distances can be determined with a GPS unit. However, the person taking the measurement must stand at the desired target point and record the GPS coordinates. This is sometimes difficult, and is very time consuming. Also the GPS coordinates of the avalauncher must be recorded. Then the horizontal (X) and (Y) distances can be calculated from the two GPS points. A much better option is to stand at the avalauncher location and measure the line of sight distance (L.O.S.) and angle (a), as shown in Figure 2.1, using a range finder. The range finder method is also significantly more accurate than the GPS technique.

3.0 MODEL DEVELOPMENT

There are some technical challenges associated with developing a targeting model for avalaunchers. These challenges are summarized as follows:

1. Calculating the muzzle exit velocity for a pressurized gas launched projectile.
2. Developing a technique for handling the drag coefficient that changes during flight.
3. Creating a user friendly targeting model, and adapting it to field use.

3.1 Calculating muzzle velocity (V_0) from charge pressure (P_1):

Equations of force and motion: Baumeister (1967)

$$F = Ma \quad (1)$$
$$S = S_i + \tfrac{1}{2} at^2 \quad (2)$$
$$V = V_i + at \quad (3)$$

Pressure relationships

P_1 = Charge pressure

P_2 = Muzzle exit pressure

$P_{av} = (P_1 + P_2) / 2$, Average pressure

Average launch force (F_{av}):

$$F_{av} = P_{av} (A_b)$$

Where A_b = projectile base plate area

From equation No. 1

$$a = F_{av} / M$$

From equation No. 3

$$V_0 = at, \text{ since } V_i = 0 \quad (4)$$

Where (a) is the projectile acceleration in the barrel, and (t) is the time for the projectile to travel the length of the barrel(s).

From equation No. 2

$S_i = 0$, therefore

$t = (2s/a)^{1/2}$ where s = length that the round travels in the barrel

and $a = F_{av}/M$

substituting (t) and (a) into equation No. 4, it then becomes:

$$V_0 = F_{av}/M\,[(2Ms/F_{av})^{1/2}] \quad (5)$$

F_{av} is unknown and must be determined. In order to calculate F_{av} it is necessary to calculate P_2 and P_{av}. Since the pressure in the barrel decreases in a linear fashion, P_2 will be related to the charge volume (C_v) and the barrel volume (B_v) by the following equation.

$$P_2 = [(C_v - B_v)/C_v]\, P_1 \quad (6)$$

Therefore the average pressure (P_{av}) is as follows:

$$P_{av} = [P_1 + [(C_v - B_v)/C_v]P_1]/2 \quad (7)$$

Therefore:

$F_{av} = P_{av}A_b$ Where A_b is the projectile base plate area

Therefore:

$$F_{av} = [[P_1 + ((C_v - B_v)/C_v)P_1]/2]A_b \quad (8)$$

Substituting F_{av} into equation (5) and reducing the equation yields the following result:

$$V_0 = SQRT[P_1B_v(2C_v - B_v)/MC_v] \quad (9)$$

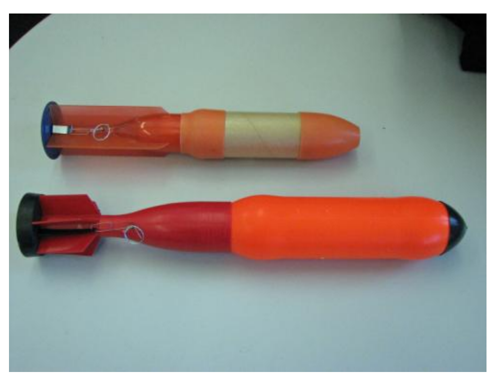


Figure 3.2.1 AVR-1 and Ace Rounds

3.2 Determining (C_d) for the AVR-1 Round

The aerodynamic drag coefficient (C_d) varies during the flight of the round. There is a base plate attached to the round for the first 1-1.5 seconds of the flight that has a relatively high drag coefficient (See Figure 3.2.1 top photo). After the base plate is ejected, the drag coefficient is reduced to a lower value. Drag coefficients are not available in the literature for either of these configurations. Snowbasin has approximately 84 shots already characterized and in use. Using the targeting model and the data for the characterized shot parameters it is possible to back calculate the drag coefficient. This was completed for a number of currently used shots. The empirically calculated drag coefficients vary as the line of sight (L.O.S.) distance. This relationship is shown in Figure 3.2.2.

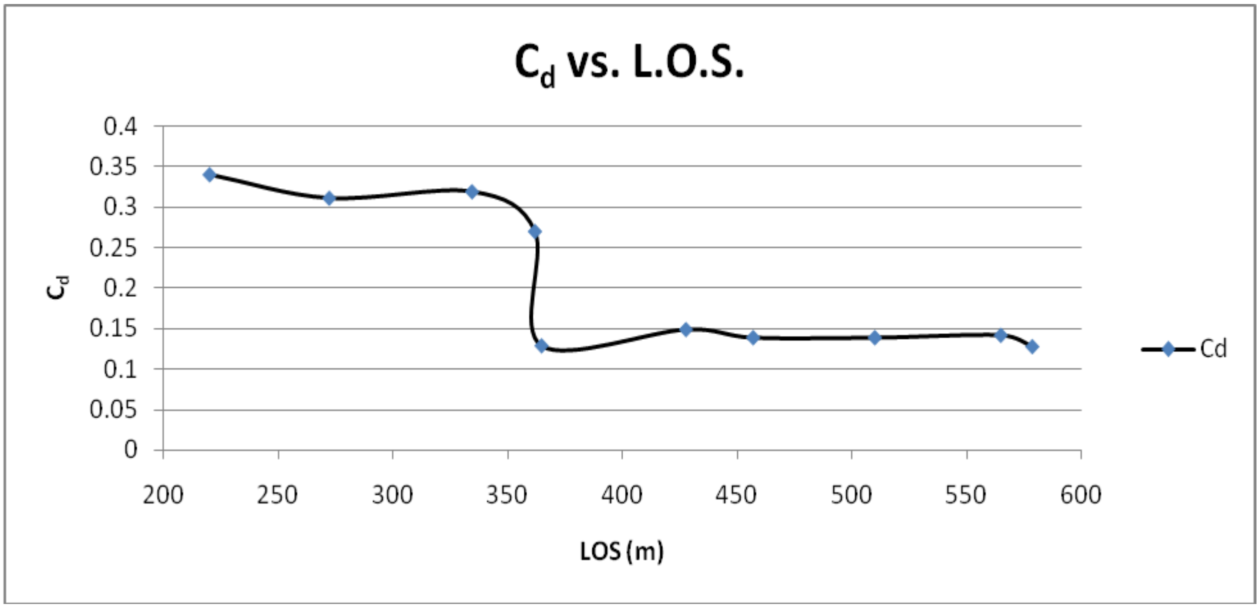


Figure 3.2.2 - C_d versus L.O.S.

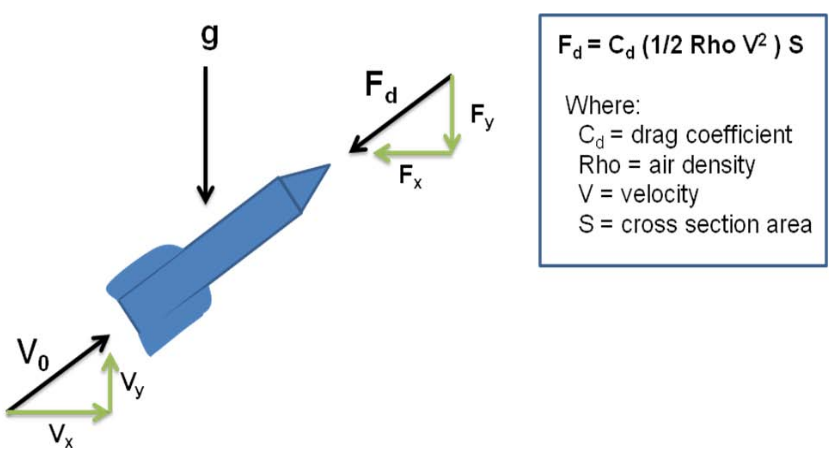


Figure 3.3.1 - Forces acting on a projectile in flight

3.3 Forces acting on a projectile in flight

Figure 3.3.1 illustrates the forces acting on a projectile when it exits the avalauncher barrel with an initial velocity of (V_0) and an exit angle of ($theta_0$). Once the projectile leaves the barrel the only forces acting on it are gravity (g) and aerodynamic drag (F_d) as illustrated in Figure 3.3.1. The force of gravity remains constant in magnitude and direction, however, the orientation of the projectile changes during flight. The drag force (F_d) is represented by the equation in Figure 3.3.1, and varies as the velocity squared (V^2), Bray (2007), and McCoy (1999). The drag force acts along the axis of the projectile and is in the opposite direction of the velocity.

3.4 Targeting model based on an incremental time step solution

A targeting model based on an incremental time step solution is a viable approach for providing an accurate solution for the subsonic avalauncher round. This approach is also easily handled with Microsoft Excel. Since the direction and magnitude of the accelerations, velocities and displacements are all varying with time, a solution that calculates the changes in these variables over very small time increments is a good approach to developing an accurate trajectory model.

The projectile exits the barrel with an initial velocity (V_0) and a barrel angle ($theta_0$). The forces acting on the projectile after it leaves the barrel are gravity (g) and aerodynamic drag (F_d). These are illustrated in Figure 3.3.1. Since the horizontal and vertical components of force act differently, they must each be calculated separately.

At time zero (t_0):

Velocity = V_0

$V_x = V_0 \cos(theta_0)$

$V_y = V_0 \sin(theta_0)$

$F_{d0} = C_d\,(1/2\ Rho\ V_0^2)\,S$, Figure 3.3.1

$F_{d0} = Ma_{d0}$ or, $a_{d0} = F_{d0}/M$, therefore,

$a_{dx0} = a_{d0}\cos(theta_0)$, horizontal acceleration due to drag

$a_{dy0} = a_{d0} \sin(theta_0)$, vertical acceleration due to drag

x = 0

y = 0

At time point one (t_1):

$V_{x1} = V_x - (a_{dx0})\ delta(t)$

$V_{y1} = V_y - (a_{dy0})\ delta(t) - g[delta(t)]$, where delta(t) is the time increment used

$V_1 = [V_{x1}^2 + V_{y1}^2]^{1/2}$

$theta_1 = \arctan(V_{y1}/V_{x1})$

$F_{d1} = C_d\,(1/2\ Rho\ V_1^2)\,S$, Where S is the cross sectional area of the round.

$a_{d1} = F_{d1}/M$

$a_{dx1} = a_{d1} \cos(theta_1)$

$a_{dy1} = a_{d1} \sin(theta_1)$

$x_1 = x_0 + V_x\,[delta(t)]$

$y_1 = y_0 + V_y\,[delta(t)]$

At each succeeding time point the same procedure is utilized. The results of these calculations yield an accurate representation of the projectile trajectory (see sample problem section 3.5). To determine the charge pressure (P_1), a value must be assumed and then varied until the model yields the desired x and y positions. This procedure is illustrated with a sample problem in section 3.5. This procedure for finding (P_1) is somewhat cumbersome, however, subsequent work will address improvements in this technique. Once the charge pressure P_1 is determined the shot parameters are complete. The results for a sample problem are shown in section 3.5

3.5 Sample Problem Solution

The sample problem is a real shot that is currently in service at Snowbasin. The input data is as follows.

Line of Sight Distance - 510 m

Line of Sight Angle - 0.192 rad

Barrel Angle - 0.419 rad

Drag Coefficient- 0.139 (Figure 3.2.2)

Horizontal Distance - 501 m

Vertical Distance - 97 m

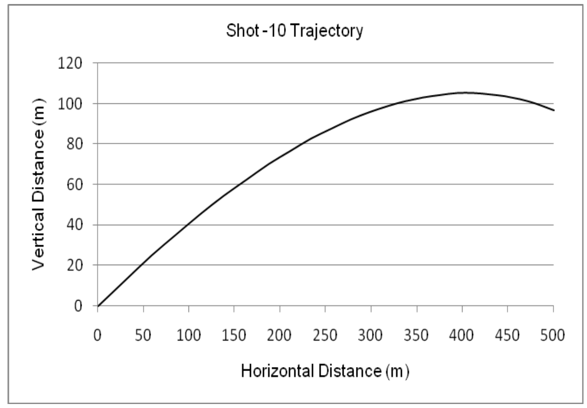
Time Increment - 0.06 sec

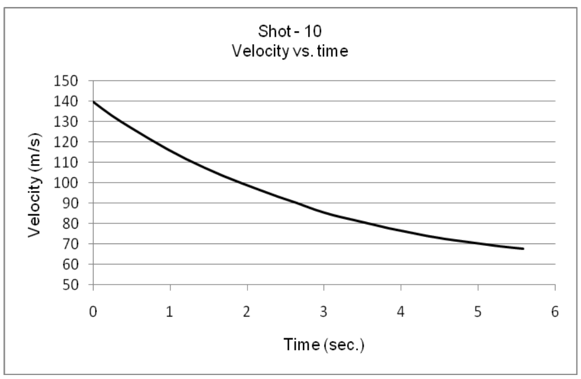
Sample problem results:

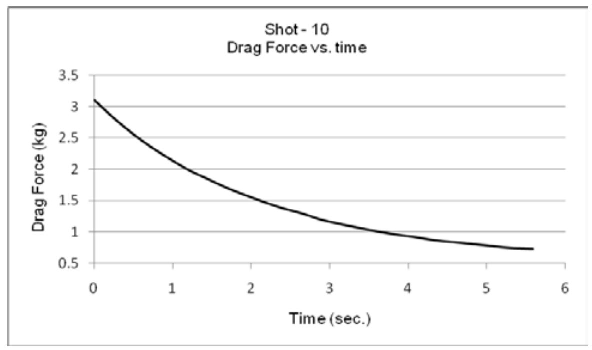
Charge Pressure - 9.842 kg/cm^2

Flight Time - 5.6 sec

The following three plots illustrate the results for the trajectory, velocity, and drag force.







4.0 RESULTS

Use of this new model for targeting avalaunchers has been somewhat limited to date, however, the results have been very encouraging. Six shots have been revised to yield a lower profile trajectory with higher velocity. This modification will provide greater accuracy on windy days and, in general yield greater consistency in hitting the target. Of the shots demonstrated, the results have been excellent. Also, a seventh shot which had never hit the target was revised with perfect results on the first try.

5.0 IMPLEMENTATION METHODS

Use of a computer model on a PC would not be feasible for use on the avalauncher tower, particularly on bad weather days. An approach that characterizes the pressure requirement for a given distance (L.O.S.) and elevation angle in tabular form would be relatively easy to use on the gun tower. A table could be generated with the targeting model that provides the necessary data to develop new targets, or improve existing shots. A table would need to be developed for each barrel angle setting planned for use. Figure 5.1 illustrates such tabular data for a barrel angle of 0.42 radians. Most avalaunchers use about four different barrel angle settings, which would then require four tables for each avalauncher.

	Line of Sight Distance (m)					
Elev. Angle (rad)	**250**	**300**	**350**	**400**	**450**	**500**
0.45	8.43	11.11	13.85	16.60	19.47	
0.40	6.05	7.87	9.91	11.95	14.06	16.24
0.35		6.33	7.87	9.49	11.25	12.94
0.30		5.27	6.61	8.01	9.49	11.03
0.25			5.76	7.03	8.37	9.70
0.20			5.20	6.33	7.52	8.72
0.15				5.76	6.82	8.01
0.10				5.34	6.33	7.45

Figure 5.1 Pressure (kg/cm^2) vs. LOS and Elevation angle (rad)

6.0 CONCLUSIONS

Use of a computer model to provide targeting parameters for avalaunchers is a viable approach to reduce the costs of developing targeting data and improving safety for avalauncher operation. This early development work has provided excellent results to date. Future work will continue to make improvements in the ease of use.

7.0 FUTURE WORK

Future work on this project will address streamlining the targeting model and developing a user friendly method for determining targeting parameters on the avalauncher tower. Also, work will continue on characterizing drag coefficients over a wide range of distances for several different avalaunchers. Also, work to characterize the drag coefficients for different rounds will be continued as needed. In addition, a planned expansion into new terrain will require an additional avalauncher. The targeting method outlined in this paper will be used to develop the targeting parameters for this new avalauncher.

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