

## RANGE LIMITED PROJECTILE

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This invention relates to a new and improved training projectile that has a predetermined range  
10 limited trajectory characteristic. More particularly, radially distributed flats induce the onset of gyroscopic instability at a predetermined range, thereby reducing the overall flight path of the projectile.

U.S. Patent Number 4,063,511 (Bullard) discloses a  
15 spinning shotgun projectile with grooves to streamline the projectile body thereby decreasing air resistance during flight.

U.S. Patent Number 4,520,972 (Diesinger et al.) discloses a spin-stabilized training projectile, which  
20 changes its axial stability by operation of a stabilizer mounted at the rear end of the projectile.

U.S. Patent Number 4,708,065 (Schilling et al.) discloses a training projectile with an annular recess around its circumference but does not use roll damping to  
25 truncate the normal trajectory of the projectile.

U.S. Patent Number 4,905,602 (Buckland) discloses a spin-damped training projectile, which has an array of spin-damping fins mounted on the nose of the projectile.

Ranges for testing the trajectory of large caliber ammunition require a great deal of area for obvious safety reasons. A typical range for a 25-mm projectile has a length of approximately 14-km because projectiles of 25-mm typically travel a distance of 12-km. These distances change depending on the size of the projectile.

10 The larger projectiles require a proportionally larger area. Many ordnance applications, i.e., target practice rounds, require projectiles to satisfy two conflicting objectives: 1) achieve a high performance flat trajectory to a specified range and 2) abruptly decelerate and

15 thereby not exceed a specified range limit. Conventional spin stabilized projectiles, due to their pointed cylindrical shape, are severely limited in the degree to which they can satisfy these two conflicting requirements.

20 The problem is that high initial velocities result in excessively long carry ranges; or alternatively, if the specified range limitation is met, the initial trajectory performance is inadequate.

The present invention solves this problem by

25 providing a training projectile with a roll damping augmentation section that causes the projectile to become

gyroscopically unstable after a traveling a predetermined distance. The gyroscopically unstable trajectory causes the projectile to begin high yaw and thereby reduces the distance the projectile will ultimately travel.

5        This invention relates to a projectile that achieves a flat trajectory to a specified predetermined distance and upon reaching that distance abruptly becomes gyroscopically unstable. Accordingly, one embodiment is drawn to a projectile having an ogival nose portion; a  
10    posterior portion; and a midportion.

         The midportion includes a longitudinally extending roll damping augmentation section disposed in a recess and extending outwardly no more than approximately the depth of the recess. The roll damping augmentation  
15    section has flats or flutes defining grooves which interact with oncoming air causing the projectile to become gyroscopically unstable at a predetermined range and continuously gyroscopically unstable thereafter.

         Figure 1 shows the range limiting characteristics of  
20    a projectile with augmented roll damping in accordance with the invention.

         Figure 2 shows the range limited projectile having a substantially conical nose portion and a roll damping augmentation section having flutes.

Figure 3 shows the range limited projectile having a substantially conical nose portion and a roll damping augmentation section having flats which define grooves.

Figure 4 shows the range limited projectile having  
5 canted flutes.

Figure 5 shows the range limited projectile having canted flats.

Figure 6 shows an axial cross-section of the projectile having a canted roll damping section.

10 Figure 7 shows a longitudinal cross-section of the projectile at 90°.

Figures 8A and 8B show variations in the number of flutes or flats respectively.

Figure 9 shows the range limited projectile having  
15 adjustable canted roll damping flutes.

Figure 10 shows a cross sectional view of the angle of orientation of the roll damping augmentation flutes or flats.

Figures 11A and 11B show an example of flute  
20 dimensions in a bi-conic configuration.

Figures 12A and 12B show an example of flute dimensions in a cone-cylinder configuration.

Figure 13 shows the range limited projectile having a solid roll damping augmentation section.

25 This invention relates to training rounds for which a range limitation mechanism has no substantial effect on

the trajectory within a specified range, but acts to curtail the range thereafter, preventing the training rounds from exceeding the boundaries of the training area.

- 5 Typically, a rotating projectile has stable flight when the gyroscopic stability factor, which enables a projectile to have an aerodynamic stabilized flight trajectory, is greater than 1.0 and the dynamic stability factor, which represents the ability of a projectile to  
10 maintain a stable trajectory, is between zero and 2.0.

A rotating projectile has a stable flight trajectory when  $S_g > 1$  where:

$$15 \quad S_g = \frac{I_x^2}{2I_y C_m \alpha \pi P d^3} \left( \frac{\omega d}{v} \right)^2$$

- V is the velocity of the undisturbed oncoming air flow;  $I_x$  is the axial moment in inertia of the  
20 projectile; P is the air density; d is the reference diameter of the projectile;  $I_y$  is the transverse moment of inertia of the projectile;  $\omega$  is the angular velocity about the longitudinal axis of the projectile and  $C_m \alpha$  is the aerodynamic pitching moment slope.

- 25 Standard International units may be used for consistency.

As d,  $I_x$  and  $I_y$  are fixed and P and  $C_m \alpha$  only vary slightly for low angle, high velocity trajectories, the

primary factor governing projectile gyroscopic stability  
is the ratio of angular velocity to forward velocity  
( $\omega/v$ ).

The present invention seeks to achieve a range  
5 limited projectile through augmented roll damping which  
causes the spin rate to decay faster than the forward  
velocity. In the course of a normal trajectory, the  
velocity decay is greater than the spin rate decay thus  
the projectile becomes more stable. If the spin damping  
10 of the projectile is increased sufficiently for the spin  
rate decay to exceed the velocity decay,  $S_g$  will decrease  
during flight and a projectile, which started off stable  
can have instability induced after travelling a critical  
distance. It is important that the roll damping  
15 mechanism does not increase the projectile drag, nor  
introduce extraneous pitching moment changes nor alter  
the Magnus moments in a manner that would adversely  
affect the capability of the training round to resemble  
as closely as possible a combat round that it is intended  
20 to simulate. The present training round design does not  
interfere with normal operation of full caliber  
projectiles on the use of subcaliber projectiles using  
sabots.

The instant invention enables a projectile to have a  
25 first segment of its trajectory gyroscopically stable and  
thus, correlate to a regular cartridge projectile. The

flight characteristics of the first segment of the trajectory can be observed and recorded. The data gathered from observing the first segment of the trajectory may be used to extrapolate the trajectory the projectile would have if the roll damping augmentation feature were not present.

The first section of the trajectory has a flight velocity imparted from a muzzle with a Mach number. The firing also imparts an angular velocity proportional to the barrel rifling twist angle. As the projectile proceeds along its flight trajectory, the flight velocity begins to decrease at a faster rate than the angular velocity. This decrease necessitates the inventive augmented roll damping section as shown in Figures 2 and 3 to include flutes 120 or flats defining grooves 220 in the body of the projectile to enhance the moment forces around the rotational axis of the projectile and hence decrease the stability of the flight trajectory. Otherwise, the projectile will have a stable flight trajectory and such a trajectory will increase the distance the projectile will travel.

A second segment of the trajectory is gyroscopically unstable due to an increase in the rotational pitching moment caused by the interface of air and the augmented roll damping section of the projectile. The gyroscopic instability causes the projectile to assume high yaw

angles. These high yaw angles provide high drag that decreases the distance the projectile will travel. One purpose of the recessed roll damping section 100 is to allow the design to be used in full caliber projectiles, fired from conventional gun barrels; or for the adaptation of existing sub-caliber projectile/sabot configurations without the need to modify the structurally critical subprojectile aft end/pusher base interface or the sabot manufacturing and/or molding process.

A rotating projectile used as a training round has a flight velocity ( $V$ ) which drops more rapidly than the angular velocity ( $\omega$ ). Thus, as the projectile slows down, the flight pattern becomes more stable. The present invention, by the use of an augmented roll damping section in the midportion of the projectile, causes the projectile to experience a moment about its rotational axis which causes  $(\omega/V)^2$  to decrease. This causes the projectile to become gyroscopically unstable and to begin a high yaw and/or tumbling trajectory.

As shown in Figures 2 and 3, the augmented roll damping section 100 can have either flutes 120 or flats defining grooves 220 to interact with the air flow surrounding the projectile. The design of the roll damping feature, specifically the number of recessed

flutes 120 or flats 220, angle of the flutes 120 or flats 220 with respect to the longitudinal axis and how deep the flutes 120 or flats 220 are recessed into the body of the projectile, determines at what point in the trajectory path the projectile will become gyroscopically unstable and begin a high yaw flight trajectory. This point is known as the "crossover point" because the projectile is crossing over from a gyroscopically stable trajectory to a gyroscopically unstable trajectory. The crossover point is a function of spin rate, which is the speed the projectile is rotating (angular velocity) and decay rate, which is how braking forces are affecting a projectile's trajectory. By adjusting how rapidly the decay rate increases it is possible to predetermine the crossover point and use that determination to design a projectile with a desired crossover point.

The flutes 120 and flats 220 can have planar or twisted and/or curved surfaces thereby causing the air to have a greater or lesser effect on the trajectory of the projectile. The cumulative effect of a plurality of longitudinally elongated flutes 120 or flats 220, deflecting air currents, causes the moment forces to overcome the tendency for the projectile to become more gyroscopically stable as it decelerates.

The flutes 120 or flats 220 are recessed in the midportion of the projectile 110 such that they do not

extend substantially past the ogival surface of the projectile. The depth of the flutes 120 or flats 220 is approximately equal to the depth of the recess in the midportion and should be at least twice as high as the  
5 boundary layer momentum height so they do not become submerged in the boundary layer. The boundary layer is an area that surrounds a moving projectile and exerts forces on the projectile.

Figure 2 and 3 show air flow along the surface of the projectile while in flight. The flutes 120 or flats 220 extend outwardly from the longitudinal axis 710 to overcome boundary layer effects and thus the flutes 120 or flats 220 will increase moment forces on the  
10 projectile 10.

Figure 2 shows the projectile 10 with a nose portion 20 which can be hollow and may be made of any resilient material such as aluminum or steel, a posterior portion 30 and a midportion 110. The midportion 110 has a recessed roll damping augmentation section 100 which  
15 includes flutes 120. Figure 3 shows the projectile 10 with a conical nose portion 20, a posterior portion 30 and the roll damping augmentation section 100 includes flats 220.

The flutes 120 and flats 220 may define air cavities 25 180, which are filled with on-coming air. The air cavities 180 may be of virtually any depth, however, a

depth of 2.5% to 7.5% of the projectile body diameter is preferred with 5.7% of the projectile body diameter being most preferred.

The flutes 120 are aligned along the longitudinal axis 710 of the projectile 10 as shown in Figure 7. The flutes 120 can be placed at varying degrees in relation to the axis and can vary in shape.

As shown in Figure 10, roll damping section 100 may be angled in relation to the longitudinal axis 710. The preferred angle of orientation,  $\gamma$  is  $90^\circ$  which maximizes the exposed surface area of the roll damping section 100 to oncoming air. As the angle of orientation of the flute or flat is decreased or increased from a  $90^\circ$  perpendicular angle, roll damping section 100 will have less surface area exposed to oncoming air flow because the roll damping section 100 will have more surface area closer to the body of the projectile. The angle of orientation  $\gamma$  also affects the shape of the air cavities 180. The midportion roll damping section 100 increases the spin decay rate and deliberately drives the projectile 10 into gyroscopic instability at a predetermined range.

The roll damping augmentation section 100 which includes the flutes 120 or flats 220 is placed in the midsection 110 of the projectile 10, which is near the center of gravity, thereby reducing undesired

perturbations in the flight trajectory. The roll damping augmentation section can be the entire length of the projectile. A preferred length is between 1 and 1.75 times the body diameter of the projectile. The most  
5 preferred length is 1.33 times the body diameter of the projectile.

The projectile 10 as shown in Figures 2 and 3 has an obturation band 160 to enable the muzzle to impart a spin on the projectile 10 as it is being discharged.

10 Through variations in the size, number and/or twist angles of the roll damping flutes 120 or flats 220, the projectile's aerodynamic roll damping torques can be tuned to control the time of onset for the high drag condition, thereby providing vast improvements in  
15 tailoring the respective fast and slow portions of the trajectory. The deeper the flutes 120 or flats 220 into the midportion 110, the sooner the projectile 10 will become gyroscopically unstable. The flutes 120 or flats 220 redirect the air flow around the surface of the  
20 projectile 10 because the flutes 120 and flats 220 cause the aerodynamic forces operating in opposite directions to produce a moment about the rotational axis, which decreases the gyroscopic stability and causes the projectile to being a high yaw and/or tumbling  
25 trajectory. As shown in Figures 8A and 8B, the roll damping section segments 100 can vary. Any number of

segments would work. However, a preferred number of segments are between 4 and 12 equally spaced around the circumference of the projectile.

As shown in Figures 4 and 5, the roll damping augmentation section 100 may be canted at an angle  $\beta$  counter to the flow of air to increase the roll damping effect. Increasing the canted angle  $\beta$  of the flutes 120 or flats 220 relative to the longitudinal axis 710, increases the angle at which the air interacts with the roll damping section 100. This facilitates crossover to a gyroscopically unstable projectile trajectory, which causes the projectile to have a reduced trajectory. Values for  $\beta$  can be between zero and thirty degrees from the longitudinal axis. However, angles between 3 and 5 degrees are preferred. Angles of canting exceeding 15 degrees cause instability early in the flight trajectory.

As shown in Figure 9, the roll damping augmentation flutes 120, may also be adjusted by the user so that the angle of canting may be varied in the field. The angle of canting  $\beta$  at which the recessed flutes 120 are attached to the posterior portion 30 may be altered by having a plurality of connection slots 140 in the posterior portion 30. Once the individual user selects a desired deflection angle of canting  $\beta$ , each of the flutes

120 can be affixed to a corresponding slot 140 of the posterior portion 30.

Figure 6 shows an axial cross-section of the midbody portion 110 when the roll damping section 100 is slightly canted. This depicts the relative depth of the roll damping section 100. The roll damping section is sufficiently recessed to overcome boundary layer momentum forces.

Figure 7 shows a longitudinal cross-section of the range limited projectile at 90°.

Figure 8 shows that the range limited projectile can have various numbers of roll damping means.

Figure 13 shows the roll damping section 100 may be solid. The flats 220 define grooves, which provide an interface with oncoming air thereby increasing the roll damping on the projectile 10. This embodiment does not include an air cavity..

#### Example 1

Figure 1 graphically illustrates comparative performance characteristics for a conventional spin stabilized projectile and a projectile with augmented roll damping. Reference line 12 shows the trajectory of a projectile without augmented roll damping. Reference line 14 shows the trajectory of the projectile of the instant invention with the augmented roll damping

feature. The projectile without the range limiting feature (reference line 12) travels up to 12-km, whereas the projectile with the range limiting feature travels less than 8-km, a range reduction of 33%. This difference in maximum travel range can be important when considering the physical limitations of existing training and test ranges. The distance traveled by a projectile is a function of the mass of the projectile. The larger the mass, the greater the distance of its trajectory. However, the inventive roll damping augmentation will proportionally reduce the distance any projectile travels. Thus, the instant roll damping features will apply to any size projectile.

15 Example 2

Figures 11A, 11B, 12A and 12B show examples of dimensions of flutes 120. The dimensions are expressed as a percentage of projectile body diameter and thus are applicable to any projectile. Figures 11A and 11B show a bi-conic projectile with flutes 120 having a depth from the surface of the projectile toward the longitudinal axis of 3.5% of the body diameter. Figures 12A and 12B show a cone-cylinder projectile where the flute depth is 5.7% of the body diameter for a cone-cylinder configuration. In both the bi-conic and cone-cylinder

configurations, the length of the roll damping section is 133% of the body diameter.

The cone-cylinder groove height of 5.7% of the body diameter provided four times the roll damping of a bi-  
5 conic groove height of 3.5% of the body diameter.

A preferred embodiment of the invention utilizes recessed flutes 120 having a flat vertical surface extending outward from the longitudinal axis. This configuration increases the effective surface area of the  
10 flutes 120. The flutes 120 have a length to height ratio of 15:1. A tungsten cylinder as the midportion 110 allows tailoring of gyroscopic stability to ensure cross-over and range truncation regardless of the ambient air temperature. The crossover rate will be unaffected in  
15 muzzle temperatures ranging from +150°C to -60°C when a tungsten cylinder is utilized. The flutes 120 or flats 220 may be molded into the tungsten cylinder or may be carved into the tungsten cylinder.

While preferred embodiments of the present invention  
20 have been illustrated in detail, it should be apparent that modifications and adaptations to those embodiments may occur to one skilled in the art without departing from the scope of the present invention as set forth in the following claims.

WHAT IS CLAIMED IS:

1. A projectile (10) characterized by:
  - an ogival nose portion (20);
  - 5 a posterior portion (30); and
  - a midportion (110) disposed between said nose portion and said posterior portion, said projectile defining an elongated, aerodynamically-shaped body having an axis of rotation (710);
  - 10 said midportion comprising a longitudinally extending roll damping augmentation section (100) disposed in a surface recess thereof, said roll damping augmentation section extending outwardly no more than about the depth of said recess, for
  - 15 causing said projectile to become gyroscopically unstable at a predetermined range and continuously gyroscopically unstable thereafter.
2. The projectile (10) as described in claim 1
- 20 characterized in that said nose portion (20) is substantially conical in shape throughout the axial dimension thereof.





3. The projectile (10) as described in claim 1  
characterized in that said roll damping augmentation  
section comprises a plurality of elongated  
juxtaposed flutes (120) in said body and extending  
5 longitudinally between said nose portion (20) and  
said posterior portion (30) wherein the flutes  
extend outwardly no more than about the depth of  
said recess in said midportion (110).
- 10 4. The projectile (10) as described in claim 3  
characterized in that the number of flutes (120) is  
between 4 and 12.
5. The projectile (10) of claim 3 characterized in that  
15 the projectile has a series of slots (140) of  
sufficient size for receiving a terminal portion of  
an associated flute (120).
6. The projectile (10) as described in claim 3  
20 characterized in that the flutes (120) extend  
radially outward perpendicular to the axis of  
rotation (710).
7. The projectile (10) of claim 1 characterized in that  
25 the roll damping section (100) is canted relative to

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the longitudinal axis (710) in the direction of  
oncoming air.

8. The projectile (10) as described in claim 7  
characterized in that the roll damping section (100) is  
5 canted at an angle between about 3° and 5° from the  
longitudinal axis (710) in the direction of oncoming air.

9. The projectile (10) as described in claim 1  
characterized in that said roll damping augmentation  
10 section (100) comprises a plurality of juxtaposed  
flats (220) defining grooves (180) formed in the  
body and extending longitudinally between the nose  
portion (20) and the posterior portion (30), said  
flats extending outwardly approximately no higher  
15 than the depth of the recess in the midportion  
(110).

10. The projectile (10) as described in claim 9  
characterized in that the number of flats (220) is  
20 between 4 and 12.

11. The projectile (10) as described in claim 10  
characterized in that the flats (220) are spaced  
equi-distant around the circumference of the  
25 projectile.





12. The projectile (10) as described in claim 1  
characterized in that the length of the roll damping  
augmentation section (100) is up to 2.0 times the  
body diameter of the projectile, and defines a  
5 plurality of air cavities (180) each having a depth  
of between 3% and 7% of the body diameter of the  
projectile.
13. The projectile (10) as described in claim 1  
10 characterized in that said roll damping augmentation  
section (100) contains the center of gravity of said  
projectile.
14. The projectile (10) as described in claim 1  
15 characterized in that an obturation band (160) is  
disposed between said roll damping augmentation  
section (100) and said posterior portion (30).

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15. A projectile (10) characterized by:  
a body having an axis of rotation (710) and  
including:

an ogival nose section (20);

5 a posterior section (30); and

a roll damping section (100) disposed  
therebetween;

said body having aerodynamically shaped outer  
surface and rotating about the axis of rotation  
10 during an initial and gyroscopically stable portion  
of a trajectory of said body;

said roll damping section comprising:

a plurality of circumferentially disposed  
aerodynamic surfaces (120, 220) individually  
15 configured to create sufficient aerodynamic  
perturbations on said body following said initial  
portion of said trajectory, thereby decreasing the  
gyroscopic stability of said projectile during a  
subsequent portion of said trajectory;

20 said surfaces (120, 220) defining a plurality  
of air cavities (180);

said surfaces (120, 220) having a length of up  
to two times the body diameter of the projectile and  
a depth from the surface of between about 3.5 and  
25 6.0 percent of the body diameter.



## AMENDED CLAIMS

[received by the International Bureau on 22 March 1999 (22.03.99);  
original claims 1-14 amended; original claim 15 cancelled (4 pages)]

1. A spin-stabilized projectile (10) characterized by:
- an ogival nose portion (20);
- a posterior portion (30); and
- a midportion (110) disposed between said nose
- 5 portion and said posterior portion, said projectile
- defining an elongated, aerodynamically-shaped body having
- an axis of rotation (710);
- said midportion comprising a longitudinally
- extending roll damping augmentation section (100)
- 10 disposed in a circumferential surface recess thereof,
- said roll damping augmentation section (100) comprising a
- plurality of members which extend outwardly no more than
- about the depth of said recess and at least twice as high
- as the projectile boundary layer momentum height, for
- 15 causing said projectile (10) to become gyroscopically
- unstable at a predetermined range and continuously
- gyroscopically unstable thereafter.
2. The spin-stabilized projectile (10) as described in claim
- 1 characterized in that said nose portion (20) is
- substantially conical in shape throughout the axial dimension
- thereof.





3. The spin-stabilized projectile (10) as described in claim 1 characterized in that said roll damping augmentation section members comprise a plurality of elongated juxtaposed flutes (120) in said body and extending longitudinally between said nose portion (20) and said posterior portion (30) wherein the flutes extend outwardly no more than about the depth of said recess in said midportion (110).

4. The spin-stabilized projectile (10) as described in claim 3 characterized in that the number of flutes (120) is between 4 and 12.

5. The spin-stabilized projectile (10) of claim 3 characterized in that the projectile has a series of slots (140) of sufficient size for receiving a terminal portion of an associated flute (120).

6. The spin-stabilized projectile (10) as described in claim 3 characterized in that the flutes (120) extend radially outward perpendicular to the axis of rotation (710).

7. The spin-stabilized projectile (10) of claim 1 characterized in that the roll damping section members are canted relative to the longitudinal axis (710) in the direction of oncoming air.



8. The spin-stabilized projectile (10) as described in claim 7 characterized in that the roll damping section members are canted at an angle between about  $3^{\circ}$  and  $5^{\circ}$  from the longitudinal axis (710) in the direction of oncoming air.

9. The spin-stabilized projectile (10) as described in claim 1 characterized in that said roll damping augmentation section members comprise a plurality of juxtaposed flats (220) defining grooves (180) formed in the body and extending  
5 longitudinally between the nose portion (20) and the posterior portion (30), said flats extending outwardly approximately no higher than the depth of the recess in the midportion (110).

10. The spin-stabilized projectile (10) as described in claim 9 characterized in that the number of flats (220) is between 4 and 12.

11. The spin-stabilized projectile (10) as described in claim 10 characterized in that the flats (220) are spaced equidistant around the circumference of the projectile.



12. The spin-stabilized projectile (10) as described in claim 1 characterized in that the length of the roll damping augmentation section (100) is up to 2.0 times the body diameter of the projectile, and defines a plurality of air  
5 cavities (180) each having a depth of between 3% and 7% of the body diameter of the projectile.

13. The spin-stabilized projectile (10) as described in claim 1 characterized in that said roll damping augmentation section (100) is disposed at the center of gravity of said projectile.

14. The spin-stabilized projectile (10) as described in claim 1 characterized in that an obturation band (160) is disposed between said roll damping augmentation section (100) and said posterior portion (30).