March 19, 1963 E. A. KAMP ETAL 3,081,703

SPIN-CONE STABILIZED PROJECTILE

Filed July 29, 1958 3 Sheets-Sheet 1

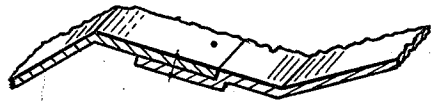


Fig. 5

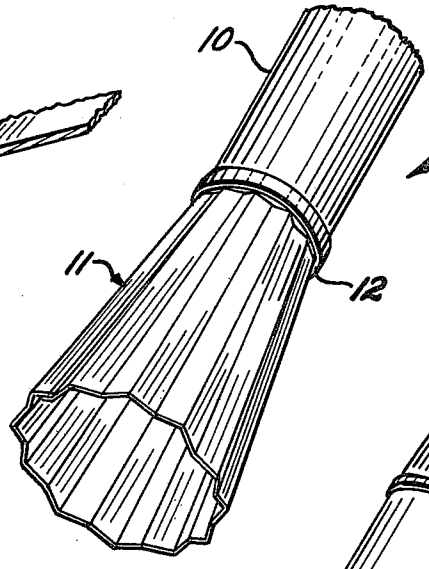


Fig. 2

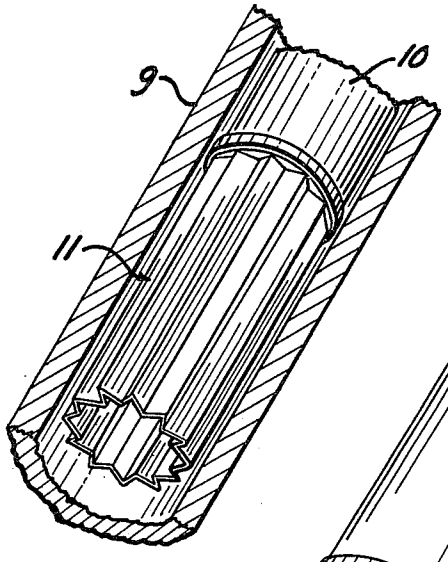


Fig. 1

Fig. 4

Fig. 3

INVENTORS
EWALD A. KAMP
THOMAS G. MORRISON
& ANDREW H. SOLARSKI
BY
Wade Lowry and
Carl A. Churchill
ATTORNEYS

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SPIN-CONE STABILIZED PROJECTILE

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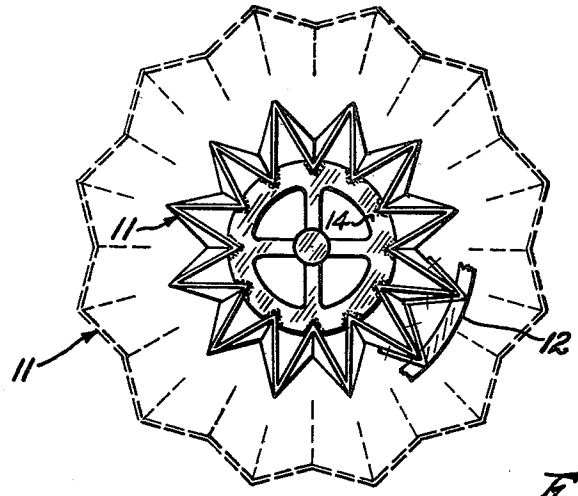


Fig. 6

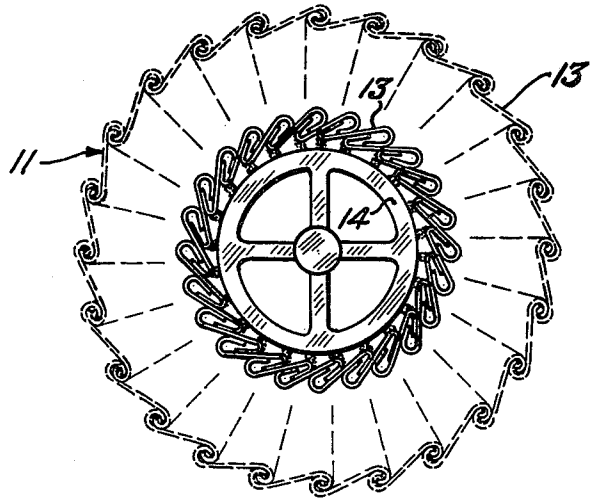


Fig. 7

INVENTORS
EWALD A. KAMP
THOMAS G. MORRISON
& ANDREW H. SOLARSKI
BY
Wade Langley Jr.
Carl A. Christiansen
ATTORNEYS

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SPIN-CONE STABILIZED PROJECTILE

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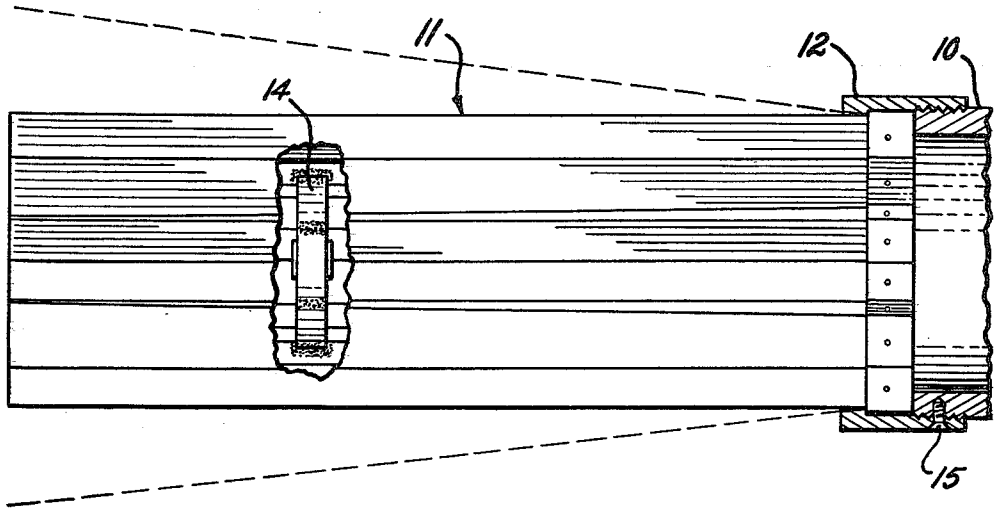


Fig. 8

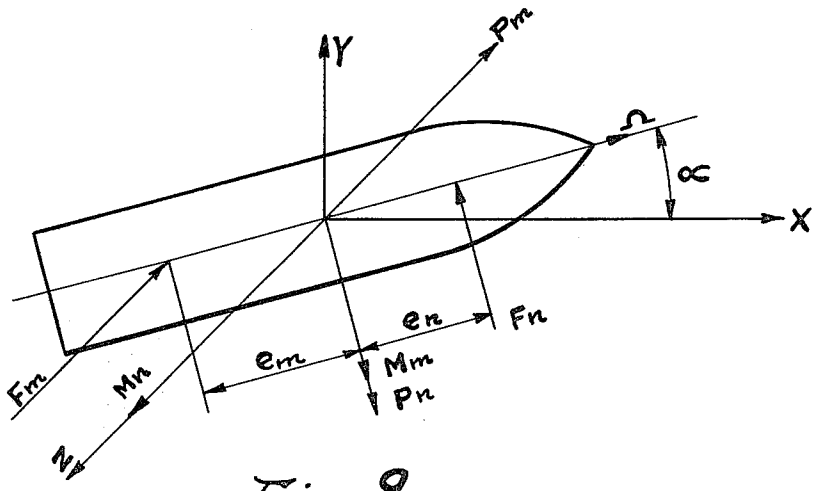


Fig. 9

INVENTORS
EWALD A. KAMP
THOMAS G. MORRISON
& ANDREW H. SOLARSKI
BY
Wade Cook
Arthur Christopherson
ATTORNEYS

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SPIN-CONE STABILIZED PROJECTILE

Ewald A. Kamp, Chicago, and Thomas G. Morrison and Andrew H. Solarski, Highland Park, Ill., assignors to the United States of America as represented by the Secretary of the Air Force

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1 Claim. (Cl. 102—50)

This invention relates to improvements in projectile stabilization and more particularly to expandable conical stabilizing structures.

Projectile stabilization has been attempted by fin stabilizing structures and by high speed rotors which rotate the entire projectile or the tail assembly thereof. The rotation of finned missiles introduces disturbing effects and the rotors add weight to the projectiles and also present manufacturing and mounting problems.

An object of this invention is to provide a stabilizing structure of relatively simple design which will be easy to manufacture and install and which will provide projectile stabilization at a practical spin rate.

A further object is to provide a thin conical frustum as a stabilizing element which will be built to collapse while in the launching tube and to open upon emergence.

The nature of the invention as well as other objects and advantages thereof will clearly appear from a description of a preferred embodiment as shown in the accompanying drawings on which:

FIG. 1 is a view, partly in section, illustrating a projectile inside a launching tube and having an expandable conical lift element in collapsed position.

FIG. 2 is a view of a projectile showing an expandable lift element in expanded position.

FIG. 3 is a view of an alternate construction with the lift element in collapsed position.

FIG. 4 is a view similar to FIG. 3 but with the lift element in expanded position.

FIG. 5 is a fragmentary view, partly in section, of the corrugated lift element showing the seam in one possible construction. The element could also be constructed of seamless tubing.

FIG. 6 is an end view of a corrugated lift element showing both the collapsed and expanded positions.

FIG. 7 is an end view of a plaited conical lift element showing both the collapsed and expanded positions.

FIG. 8 is a view in side elevation showing the attachment of the lift element to the body of the projectile.

FIG. 9 is a free body diagram of the instantaneous moment system applied to a spinning projectile.

Referring to the drawings wherein like characters refer to similar parts, there is shown in FIG. 1 a rocket projectile **10** embodying this invention inside launching tube **9**. A lift element **11** is of corrugated construction consisting of a plurality of circumferentially equispaced corrugations, the periphery of which is substantially cylindrical. The forward end of said lift element is fixed to an annular ring **12** which is attached to the aft end of the body of the projectile **10** by conventional means. Said ring may be locked in position by suitable locking screw **15** as shown in FIG. 8. Upon firing of the projectile **10**, the hot gases that emerge from the aft end impinge upon a series of curved flanges (not shown) attached inside the body at the extreme aft end causing the projectile to spin about its longitudinal axis and create a centrifugal force which opens said lift element **11** to its true conical shape just after launching, as shown in FIG. 2.

An alternate construction of the lift element is shown in FIGS 3 and 4 wherein the cone **11** is comprised of a plurality of interleaved vanes **13** of thin spring steel or other suitable material. Adjacent vanes **13** interlock at the edges to prevent centrifugal separation thereof. The free position of the vanes **13** is open, forming a complete cone. The vanes **13** can be held in collapsed position by a combustible spider **14**, as shown in FIG. 7.

A projectile too long to be spin stabilized at a practical spin rate can be made stable by adding to the base a conical lifting surface of perhaps 2 or 3 calibers length. The additional magnus and normal forces induced by the cone will stabilize the projectile at a relatively low spin rate.

Two distinct systems of forces are applied to a spinning projectile by the air stream through which it is moving:

(1) The pressure forces. These are further subclassified as lift and drag, depending on the direction of their action line with respect to the trajectory.
(2) The magnus forces caused by the component of airstream velocity normal to the axis of spin.

Due to the spin, the projectile **10** behaves as a gyroscope and the pressure forces and magnus forces induce gyroscopic couples which in turn cause the projectile to precess and nutate.

The precession and nutation continuously change the instantaneous airstream velocity relative to the projectile. These changes induce second order variations in the lift, drag, and magnus forces. The accurate theories of spinning projectiles account for the effects of these second order changes and result in considerable complexity. In the analysis that follows, the second order variations are neglected.

For convenience in computation the normal forces distributed over the entire surface of the projectile are assumed concentrated at the center of lift. This point usually lies within the ogive near its base. The exact position of the point is determined by experiment.

The magnitude of the normal force is given by

$$F_n = 1/2 P C_n S V^2 \alpha \qquad (1)$$

where C_n is the normal force coefficient (determined experimentally), V is the airstream velocity, α is the angle of yaw (angle of attack), P is the precession force, and S is surface area.

The magnus force applied to a differential length of cylinder moving through the air at a velocity V and with an angle of yaw is given by the formula

$$dF_m = 2PV\Omega \sin\alpha S dL \qquad (2)$$

where dL is the differential length and Ω is the rate of spin. This formula is strictly true for subsonic flow only, but since the normal wind component is subsonic, it is used in this approximate analysis.

A first approximation of the magnus force can be obtained by integrating Equation 2 over the length of the projectile, assuming that the expression for two dimensional flow over an infiite cylinder holds for differential elements in three dimensional flow.

An alternate notation often used is $F_n = K_n P V^2 d^2 \alpha$ Then,

$$F_m = 2PV\Omega \sin\alpha \int_0^L S dL$$

$$F_m = 2PV\Omega \sin\alpha Z \qquad (3)$$

where Z is the volume of the projectile.

In a similar way, to a first approximation, the center of magnus force can be shown to be at the volume centroid of the projectile.

Thus, the magnus force and the normal force are proportional to the sine of the angle of yaw and are applied at points whose positions are independent of the angle of yaw. For the small angles of yaw encountered α is usually substituted for sin α in the formulas.

Referring now to FIG. 9 which is a free body diagram of the instantaneous moment system applied to a spinning projectile.

The moment M_n due to normal force is directed along the positive Z axis; the moment M_m due to magnus force lies in the XZ plane. Since at any instant precession P, spin Ω, and moment M form a right hand set of orthogonal vectors, the instaneous precession vector due to normal force, P_n, is coincident with the moment vector M_m. This precession vector has a component on the positive X axis. Similarly, the instantaneous precession vector due to magnus moment lies on the negative Z axis. It should be observed that the precession due to magnus moment tends to decrease the angle of yaw α. The necessary and sufficient condition that this be true is that the center of magnus force lie behind the center of gravity.

Reference to the standard gyroscopic theory shows that if a projectile is launched at an initial angle of yaw α_0 where α_0 is defined as an angle of yaw where the angular velocity α_0 is zero, then regardless of the spin given the projectile, the lift and drag forces cannot cause gyroscopic action to decrease the angle of yaw smaller than α_0. Thus, it must be concluded that even for standard projectiles it is the magnus moment that causes projectiles to trail.

Addition of a tail cone lift surface to a projectile has these significant effects:

(1) The total normal force F_n is increased.
(2) The eccentricity e_n is greatly decreased; the moment $F_n e_n$ is decreased.
(3) The magnus force F_m is increased.

through the center of gravity, and K_m the ballistic moment coefficient is given by

$$K_m=\frac{dC_n}{d\alpha}\Big|_0 \frac{\pi}{8}\frac{e_n}{d}$$

Then resonant spin at the muzzle, Ω_R, can be computed from

$$\Omega_R=2\pi\frac{V_0}{l}$$

radians per second. Now, if a statically stable round is spun at about 5 times resonant spin, dispersions due to asymmetries are considerably reduced.

It is found that for a long rocket five times resonant spin is low enough so that the magnus moment developed is less than half the lift moment and that, therefore, the rocket can be considered to be simply a statically stable missile of superior dispersion characteristics.

It is instructive to compare the relative orders of magnitude of the normal force moments and magnus moments for projectiles with and without a tail cone lift surface. For this purpose a 60 mm. rocket 15 calibers total length having a tail cone 3 calibers long of included angle 13.4° is assumed. The assumed muzzle velocity is 1835 feet per second with corresponding spin velocity of 1300 radians per second. Lift and magnus forces are also computed at five times resonant spin.

The following table summarizes the values computed for the two rounds, where round 1 is a rocket projectile 12 calibers long and round 2 is a rocket projectile similar to round 1 with the tail cone 3 calibers long attached.

Round	Wt. W_0	Spin rad., sec.	C_n	$F_n\alpha$, lbs.	e_n, ft.	$M_n\alpha$, lb. ft.	Vo. Z, cu. ft.	$F_m\alpha$, lbs.	e_m, ft.	$M_m\alpha$, lb. ft.
1	7.95	1,300	3.3	216	+.80	+173	.066	398	−.22	−88
2	8.85	1,300	6.9	452	−.23	−104	.108	650	−.65	−422
2	8.85	*172	6.9	452	−.23	−104	.108	86	−.65	−56

*5 times resonant spin.

(4) The eccentricity e_m is increased and, consequently, magnus moment $F_m e_m$ is considerably increased.

Thus, from this greatly simplified analysis it can be concluded that the addition of a tail cone lift surface will increase the tendency of the projectile to trail and decrease the overturning moment. The effects of interaction of the various forces could be obtained from a complete analysis.

In general, the addition of a tail cone will result in either a statically stable or unstable round depending on the length and central angle of the cone. In either case the result will be beneficial to performance. The statically unstable round can be given a relatively large gyroscopic stability factor at low spin; the statically stable round can be spun at a rate many times higher than that permissible for a finned missile without introducing the disturbing effects consequent to spinning a finned round. Thus, the increases in dispersion caused by geometric asymmetries usually suffered by a statically stable round can be expected to be considerably reduced.

The relatively large value of magnus moment obtained for a tail cone round is a controllable factor—it may be varied by changing both cone length and spin rate. Thus, if undesirable additional effects (excessive nutation) were to become evident in a more complete study, it might still be possible to achieve the desired results by proper design.

Considering the round to be a statically stable missile the yaw wave length can be computed from the formula

$$l=2\pi\sqrt{\frac{B}{K_m e d^3}}$$

where $B=Mk^2$, M being the mass of the rocket and k being the radius of gyration about a transverse axis

A projectile provided with a thin conical frustum or small central angle and one to three calibers length fixed to the base provides gyroscopic stability at a relatively low spin velocity as compared with the spin necessary for stability of a projectile without a cone. Stabilization of the projectile is obtained not by the corrugations or plaits but only by the conical configuration.

This method of stabilization combines the desirable performance characteristics of the fin-stabilized rocket (high thrust and low aerodynamic drag) with the low dispersion characteristics of the spin-stabilized rocket. In flight the cone induces additional aerodynamic lift forces driving the center of lift rearward and close to the center of gravity of the projectile, and also induces considerable magnus force. The moment of the magnus force causes the projectile to trail.

For best operation, the lift, spin and magnus forces must be properly balanced. Balance can be accomplished by varying the spin rate, the length, and the central angle of the cone.

The foregoing embodiment describes a collapsible lift element 11 of corrugated or plaited construction fixed to the body of the projectile. It will be apparent to those skilled in the art that many modifications are possible within the spirit and scope of the invention. Under certain conditions it may be desirable to make the lift element rotatable, which can be accomplished by providing a flanged retainer ring and an annulus with a raceway for antifriction bearings. The longitudinal corrugations or plaits could be disposed at an angle to the longitudinal axis of the lift element and the expanding discharge gases would provided rotational force in addition to the magnus force.

What is claimed is:

In a reaction propulsion device having a tubular body adapted to contain a combustible propelling charge, a stabilizing member comprising an expandable lift element, an annular ring fixed to the aft end of said body and to the forward end of said element, said lift element comprised of a plurality of interleaved trapezoidal vanes interlocked at the edges, and a combustible spider for holding said lift element in collapsed position substantially cylindrical in shape, said lift element being expandable upon firing of the propulsion device to form a frusto-conical discharge nozzle having its smaller diameter coincident with the diameter of the body of said propulsion device and its axis in alignment with the axis of said body.

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