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First Named Inventor/Applicant Name:	Ronald M. Barrett
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1		UKAN_P0022US_P1.pdf	3230474 d26a2e59d2801b5ecff8b1d8cd2f019b09276aef	yes	83

Multipart Description/PDF files in .zip description

Document Description	Start	End
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Drawings-only black and white line drawings	55	76
Application Data Sheet	77	83

Warnings:

Information:

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2	Fee Worksheet (SB06)	fee-info.pdf	29785 9ba5169b135ab283377f145baf0d4df87708462a	no	2

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Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM
First Named Inventor/Applicant Name:	Ronald M. Barrett
Filer:	Nathan John Rees/Donna Dobson
Attorney Docket Number:	UKAN.P0022USP1/1001071694

Filed as Small Entity

Filing Fees for Provisional

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
PROVISIONAL APPLICATION FILING FEE	2005	1	140	140
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
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Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

PROVISIONAL APPLICATION FOR PATENT COVER SHEET – Page 1 of 2

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. ______________________

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Ronald M.	Barrett	Lawrence, Kansas
Lauren Nicole	Schumacher	Rolla, Missouri

Additional inventors are being named on the ____________ separately numbered sheets attached hereto.

TITLE OF THE INVENTION (500 characters max):

MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

[X] The address corresponding to Customer Number: 29053

OR

[ ] Firm or Individual Name

Address

City	State	Zip
Country	Telephone	Email

ENCLOSED APPLICATION PARTS (*check all that apply*)

[X] Application Data Sheet. See 37 CFR 1.76.

[ ] CD(s), Number of CDs ____________

[ ] Drawing(s) *Number of Sheets* ____________

[ ] Other (specify) ____________

[X] Specification (e.g., description of the invention) *Number of Pages* ____________

Fees Due: Filing Fee of $280 ($140 for small entity) ($70 for micro entity). If the specification and drawings exceed 100 sheets of paper, an application size fee is also due, which is $400 ($200 for small entity) ($100 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

METHOD OF PAYMENT OF THE FILING FEE AND APPLICATION SIZE FEE FOR THIS PROVISIONAL APPLICATION FOR PATENT

[X] Applicant asserts small entity status. See 37 CFR 1.27.

[ ] Applicant certifies micro entity status. See 37 CFR 1.29.
Applicant must attach form PTO/SB/15A or B or equivalent.

[ ] A check or money order made payable to the *Director of the United States Patent and Trademark Office* is enclosed to cover the filing fee and application size fee (if applicable).

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Provisional Patent Application Transmittal

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Dated: April 26, 2019

Signature: Donna Dobson (Donna Dobson)

PROVISIONAL APPLICATION FOR PATENT COVER SHEET – Page 2 of 2

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[X] No.

[ ] Yes, the invention was made by an agency of the U.S. Government. The U.S. Government agency name is: ____________

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SIGNATURE /Allan Braxdale/ DATE April 26, 2019

TYPED OR PRINTED NAME Allan Braxdale REGISTRATION NO. 64,276
(if appropriate)

TELEPHONE (214) 855-7496 DOCKET NUMBER UKAN.P0022US.P1/1001071694

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR U.S. LETTERS PATENT

Title:

MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM

Inventors:

Ronald Martin Barrett

Lauren Nicole Schumacher

MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM

TECHNICAL FIELD

[0001] Aspects of the present disclosure generally relate to sabots.

BACKGROUND

[0002] A sabot is a structural device used in or with firearm ammunition or cannon ammunition to keep a projectile (aka flight projectile), such as a bullet or arrow-type projectile, in a center of a barrel when fired, when the projectile (e.g., a sub-caliber projectile) has a significantly smaller diameter than a bore diameter (i.e., caliber) of the barrel. A sabot enables a smaller diameter projectile to be launched at greater muzzle velocity than if the projectile alone were fired from a barrel of equal caliber (full-bore).

[0003] A function of a sabot is to provide a larger bulkhead structure that fills the entire bore area between the sub-caliber projectile and the barrel. The bulkhead structure provides a larger surface area for propellant gasses to act upon as compared to only a base of the sub-caliber flight projectile. Efficient aerodynamic design of a projectile usually does not coincide with efficient interior ballistic (barrel ballistics or ballistics inside the barrel) design to achieve high muzzle velocity. This is especially true for arrow-type projectiles, which are long and thin for low drag efficiency, but too thin to shoot from a gun barrel of equal diameter to achieve high muzzle velocity. The physics of interior ballistics demonstrates why the use of a sabot is advantageous to achieve higher muzzle velocity with an arrow-type projectile. Propellant gasses generate high pressure, and the larger the base area that pressure acts upon the greater the net force on that surface. Force, pressure times area, provides an acceleration to the mass of the projectile. Therefore, for a given pressure and barrel diameter, a lighter projectile can be driven from a barrel to a higher muzzle velocity than a heavier projectile, assuming surface area and shape are constant. However, a lighter projectile may not fit in the barrel, because it is too thin. To make up this difference in diameter, a properly designed sabot provides increase or full bore like surface area for propellant gasses to act and less parasitic mass than if the flight projectile were made full-bore.

[0004] Nevertheless, the weight of the sabot represents parasitic mass that must also be accelerated to muzzle velocity, as least while in the barrel. The sabot does not contribute to the terminal ballistics of the flight projectile. Accordingly, great emphasis is placed on selecting strong yet lightweight structural materials for the sabot, and configuring the sabot geometry to efficiently employ these parasitic materials at minimum weight penalty.

[0005] Sabots have been used since ancient times. For example, works showing the use of a saboted projectile being expelled from a cannon were published in 1326 by Walter De Milemete in *Nobilitatibus Sapientii et Prudentiis Regum* and *De Secretis Secretorum Aristotelis.* These documents claim to pass down techniques of warfare and weapons used as far back as Aristotle's time, and depict arrow-shaped projectiles being shot from cannon with what appears to be sabots encasing a portion of the arrow-shaped projectiles.

[0006] While sabots have evolved from the classical and medieval approaches referenced above to the hypersonic designs of today, several principles have held steady through time: i.) a sabot is placed around a projectile and is composed of one or more pieces of comparatively low-density material; ii.) the projectile is made from comparatively higher-density material and lies within the sabot; iii.) during the launching event in the barrel, the sabot transfers kinetic energy from propellant gasses to the projectile and the sabot helps guide the projectile down the barrel; iv.) the projectile is inherently stable or spin stabilized following barrel exit and sabot separation; v.) the sabot and its pieces are unstable and tumble upon barrel exit and sabot separation.

[0007] Outside of the above general common characteristics, the configurations of sabots and projectiles vary widely, encompassing varied geometry and muzzle velocities ranging from low subsonic through hypersonic. To illustrate, many different types of sabots are known, such as cup sabots, expanding cup sabots, base sabots, spindle sabots, and ring sabots.

[0008] For a long time, round cannon balls were used as projectiles in warfare on land and sea. U.S. Pat. Nos. 12,629 and 15,075 show configurations wherein wooden blocks are placed behind the cannon balls and are used to push the balls down the barrel. These sabot configurations had several advantages in that their tighter fits meant that fewer gun gasses would escape around the ball as it would travel down the barrel. Another profound advantage was that the ball would no longer be spun in an axis perpendicular to the barrel longitudinal axis as the round would ballot down the barrel. This lack of spin means that the Magnus effects and forces would be reduced as the cannon ball would travel downrange, thereby improving accuracy.

[0009] U.S. Pat. No. 27,245 shows a wooden sabot wrapping around a projectile that generates spin in a direction parallel to the barrel longitudinal axis after sabot release. Once again, the pieces of the sabot are not designed with inherent stability; as there is no prescription for c.g. positioning with respect to a.c. location of the individual sabot pieces, they will tumble upon release.

[0010] U.S. Pat. Nos. 39,180, 39,369 and 40,198 teach a different approach to sabot-projectile integration as the sabot takes the form of a pusher plate mounted at the back of the round. As previous sabot designs demonstrate, the pusher plate and all other components of the sabot are not aeromechanically stable as they prescribe no positioning of c.g. with respect to a.c. and their geometries indicate that they will tumble upon barrel exit and projectile release.

[0011] U.S. Pat. No. 44,670 teaches a different variation of a similar configuration. A single piece sabot envelopes the projectile, but upon projectile release, the sabot remains intact. Because the projectile does not protrude past the base of the sabot, the entire configuration is limited to low fineness ratio projectiles. Although the very concept of aeromechanical stability had not been described or analyzed scientifically in 1864, it is easy for one who is skilled in the art of weapon system design to recognize that the combined sabot-projectile system is directionally and longitudinally stable. However, the gross instability of the sabot upon separation from the projectile is just as obvious. This instability will induce flight path divergence and tumbling of the sabot upon projectile release.

[0012] By 1877, the concepts of projectile aeromechanical stability were becoming more refined as seen in U.S. Pat. No. 195,040. However, the sabot pieces which are taught are clearly aeromechanically unstable and suffer from the same divergence and tumbling motions described above.

[0013] Between the late 1800's and the 1960's, the concept of aeromechanical stability by positioning c.g. with respect to a.c. was well understood as a guiding principle for inherently stable flight. With that said, sabot designs still did not possess inherent aeromechanical stability, the principal reason being they had to tumble to bleed off airspeed quickly for safe combat operation. As described in Siegelman and Wang and Carulcci and Jacobsen, sabots come apart rapidly to bleed off airspeed by design. This property allows cannon to be positioned behind friendly troops; firing over friendly forces in support of their operations while not exposing them from behind with dangerous high velocity sabot pieces.

[0014] U.S. Pat. No. 3,148,472 shows just such a family of sabot designs using splitting wedges mounted in the barrel so as to initiate sabot disintegration upon barrel exit. Just as all of the earlier sabot designs teach, the sabot segments and whole sabot described in 3,148,472 make no mention of aeromechanical stability. Rather, the patent speaks of "sabot disintegration" and cutting upon emergence from the barrel. This would generate aeromechanically unstable pieces with high tip-off angles that tumble upon barrel exit.

[0015] U.S. Pat. No. 3,164,092 teaches a pre-split design which peels open like a fleur-de-lis to expose a central projectile during lateral separation of the individual sabot arms. Once again, the sabot design is inherently aeromechanically unstable upon projectile release and will repeatedly swap ends and/or tumble upon projectile release.

[0016] U.S. Pat. No. 3,834,314 teaches a gripping puller sabot with full-length finned projectiles. As with many other designs, upon barrel exit the sabot separates into aeromechanically unstable pieces that are flung laterally away from the projectile, diverging and tumbling as they fly through the air.

[0017] A system of telescoping tubes with a high-density projectile is taught in U.S. Pat. No. 3,842,741. The overall design also shows a number of aeromechanically unstable petals and protective pieces flying off in all directions (e.g., left, right, up and down, etc.) as the projectile exits the barrel. Additionally, the tubes telescope and fly downrange as the projectile exits the barrel.

[0018] U.S. Pat. No. 4,187,783 teach a modern sabot similar to modern US Army tank ammunition. This sabot design is of a double bourrelet, “gripper” configuration as its multiple segments interface with the projectile via a number of ridges spread down the length of the projectile. The front of the sabot is concave and designed to peel cleanly and quickly from the projectile. The sabot splits into multiple components which are flung laterally, then diverge in flight path and tumble as the components are aeromechanically unstable.

[0019] The sabot described in U.S. Pat. No. 4,284,008 possesses the same overall aeromechanical characteristics as '783, but one incarnation shown in '008 is not a double bourrelet configuration; instead, it takes the form of a single bore rider with a "cylindrical bore-riding guidance member." The chief difference between the two patents is the configuration of the gripping ramps holding the sabot pieces to the projectile during the firing event. As taught in '783, the sabot pieces are flung laterally away from the projectile only to diverge and tumble through the air following projectile release.

[0020] Another unstable sabot configuration is taught in U.S. Pat. No. 4,800,816. This configuration is incrementally different than the previous designs as the sabot maintains most of its structural integrity as a single piece upon barrel exit. While several nose cap pieces are ejected randomly upon barrel exit, the bulk of the sabot mass continues a short distance forward from the launching aircraft. While FIG. 1 of '816 shows an idealized flight path of the sabot, the actual flight path of an unstable sabot of this configuration will be quite different given basic aeromechanics and the fundamental physics associated with reactive expulsion of the sabot. The sabot taught in '816 possesses a c.g. which is necessarily behind the a.c. of the sabot in both subsonic and supersonic flight, longitudinally and directionally. This aft ward positioning of the c.g. with respect to the a.c. guarantees that the sabot will be aeromechanically unstable once separated from the projectile. Because the sabot is inherently longitudinally and directionally unstable, it will rotate through at least a 180 deg. turn around the body y or z axes upon projectile expulsion to orient the comparatively heavier aft end into the relative wind, and in many cases the configuration will tumble. As it turns, the flight path will deviate substantially up, down, left or right, frequently presenting large cross-sections perpendicular to the flight path direction. This flight path deviation combined with the sabot's low weight and high drag run the very real risk of ingestion into the launching aircraft engine inlets.

[0021] Unlike the modern sabot-projectile configurations taught in '783 and '008, the projectile taught in '816 cannot extend past the base of the sabot. This is because the design calls explicitly for an expulsion charge to be placed at its base of the projectile, within the sabot. While guaranteeing clean separation of the sabot from the projectile, the high mass of the projectile relative to the sabot guarantees that the reward velocity increment of the sabot will be comparatively high. This leads to a dangerous situation in which the sabot itself is shot towards the launching aircraft. Because the tip-off of the sabot upon ignition of the expulsion charge could be nontrivial and the geometry exhibits inherent aeromechanical instability, the danger to the launching aircraft is ever present.

[0022] Another artifact of the use of an expulsion charge configuration in '816 is seen in the compromised fineness ratio of the penetrator itself. Because '816 teaches that the projectile cannot protrude past the end of the sabot, the fineness ratio of the '816 projectile is forced to be dramatically lower than the fineness ratios of the projectiles taught in '783 and '008 which can lie deep in the cartridge. This reduction in fineness ratio increases the drag and aeromechanical instability of the '816 projectile with respect to the projectiles taught in '783 and '008.

[0023] A hollow windscreen gripper sabot configuration is taught in U.S. Pat. No. 4,833,995. This configuration sabot is composed of pieces that are even more unstable than those taught in '783 and '816 because of the extremely low weight of the windscreen section; this induces a large aftward shift of c.g. The debris field following projectile separation from the sabot includes a plastic sealing disk which is similarly unstable and will fly in many different directions and also includes a thrust ring which is the primary structural connection between the sabot and the projectile.

[0024] A hybrid of the gripper bourrelet configuration taught in '783 and '008 is also taught in U.S. Pat. No. 5,359,938. The major difference between the aforementioned is that the forward bore rider is composed of not a single disk, but four orthogonal bore-riding arms called “stabilizing posts.” As with the sabots taught earlier, once the segments separate from the projectile, their aeromechanically unstable configurations induce tumbling and flight path divergence of both the individual and collective sabot pieces.

[0025] Another sabot configuration which employs aeromechanically unstable pieces is taught in U.S. Pat. No. 5,388,523. As is the case with sabots taught in '741, '783, '995 and '938, individual aeromechanically unstable sabot pieces separate laterally to release the projectile, then the components diverge and tumble.

[0026] Sabots are even used in missile systems as shown in U.S. Pat. No. 6,234,082. As with hard-launched munitions like cannon shells, the sabot shown in '082 shows aeromechanically unstable pieces laterally separating from a projectile. Because of their aeromechanical instability, the pieces of the sabot will necessarily diverge then tumble.

[0027] As shown in '092, U.S. Pat. No. 6,814,006 describes a sabot that opens like petals of a flower or fleur-de-lis to release its projectile. The inherently unstable post-release configuration along with the associated base cap or "driving speculum" are both aeromechanically unstable and will tumble following projectile release.

[0028] U.S. Pat. App. Pub. No. 2013/0312631 A1 teaches that the arms do not substantially bend or open like the petals on a flower to allow for projectile release although arranged in a similar multi-arm holder configuration of sabot as taught in '006. Rather, the projectile and sabot are designed to slide away from each other along the projectile body x-axis. This translation is intended to minimize tip-off disturbances following barrel exit. This is essentially the same scheme of projectile-sabot separation taught in '816, but without the explosive ejection charge. As with the sabot taught in '816, the sabot taught in '631 is aeromechanically unstable and will swap ends and tumble, leading to the same types of flight path deviations experienced by the sabot laid out in '816.

[0029] U.S. Pat. App. Pub. No. 2011/0214582 A1 describes a high velocity projectile held within several aeromechanically unstable sabot segments. As taught earlier in '783, these segments separate laterally upon barrel exit, diverge in flight path away from the projectile, and tumble due to their unstable nature.

[0030] Accordingly, conventional sabots and pieces thereof are aeromechanically unstable and tend to swap ends, diverge and/or tumble upon projectile separation from the sabot. Because of the unstable trajectory of sabots and pieces thereof, conventional sabots cannot be incorporated into vehicles, such as aircraft, because the sabots and pieces thereof pose a risk to the vehicles. For example, sabots and pieces thereof may strike an body of the aircraft causing damage or may be ingested into a propulsion system of the aircraft and cause engine failure.

SUMMARY

[0031] The presently disclosed sabot systems include sabots and sabot pieces which are aeromechanically stable and that achieve stable flight upon separation of the sabot system from a projectile that the sabot system is designed to launch. Aeromechanically stable as used herein includes an object (flight vehicle) which returns to a steady flight state condition following perturbation with neither static nor dynamic flight path divergence. Such an object may be actively controlled to produce such stability or an object may possess such stability inherently. Aeromechanical stability may also be referred to as positive stability, such as positive static stability, positive dynamic stability, or both.

[0032] Inherent aeromechanical stability as used herein includes the inherent property (e.g., by design) of an object (flight vehicle) to return to a steady flight state condition following perturbation with neither static nor dynamic flight path divergence. Directional stability describes the characteristic of an object to inherently point into a prevailing wind when disturbed in yaw. Longitudinal stability describes the characteristic of an object to inherently point into a prevailing wind when disturbed in pitch. Both static and dynamic stability are important and depend on a number of factors including principally a relative positioning between a center of gravity (c.g.) of the object and an aerodynamic center (a.c.) of the object. When the center of gravity (c.g.) of the object is farther forward than the aerodynamic center (a.c.) of the object, the object experiences aeromechanical stability, i.e., inherent aeromechanical stability because it is caused by the design or physical configuration of the object.

[0033] By examining a longitudinal equilibrium equation for a rigid body traveling through the air with neither significant angular momentum nor under power in steady-state flight, a basic set of equilibrium equations can be seen using standard aeromechanics nomenclature established by authors like Etkin and Roskam. An example of such equilibrium equations is provided below by set of Equations 1:

[0034] $m(\dot{U} - VR + WQ) = mg\sin\theta + F_{Ax}$

[0035] $m(\dot{U} - VR + WQ) = mg\sin\theta + F_{Ax}$

[0036] $m(\dot{W} - UQ + VP) = mg\cos\phi\cos\theta + F_{Az}$

[0037] $I_{xx}\dot{P} - I_{xz}\dot{R} - I_{xz}PQ + (I_{zz-}I_{yy})RQ = L_A$

[0038] $I_{yy}\dot{Q} - I_{xz}\dot{R} + I_{xz}(P^2 - R^2) + (I_{xx-}I_{zz})PR = M_A$

[0039] $I_{zz}\dot{R} - I_{xz}\dot{P} + I_{xz}QR + (I_{yy-}I_{xx})PQ = N_A$.

[0040] By assuming the flight state conditions above, the longitudinal stability derivative can be determined by the following equation, Equation 2:

[0041] $C_{mcg\alpha} = {dC_{mcg}}/{d\alpha} = C_{L\alpha}(\bar{X}_{cg} - \bar{X}_{aclong})$.

[0042] This basic stability term is used to assess the amount of (stabilizing) nose-down pitching moment induced by a given increment in lift or increase in angle of attack, α. Accordingly, Equation 3 below illustrates longitudinal static stability for inherent rigid body aircraft.

[0043] $C_{mcg\alpha} < 0$.

[0044] In lay-terms, this basic equation means that for every increment in lift that is generated, the aircraft will inherently experience an increment in nose-down pitching moment. It should be easy to see that this condition describes basic static longitudinal stability itself as the aircraft pitches nose down, the lift increment is therefore reduced, eventually settling at a trim point. There is, of course, a directional stability analog describing the yawing moment coefficient about the center of gravity, see Equation 4 below:

[0045] $C_{ncg\beta} = {}^{dC_{ncg}}\!/_{d\beta} = C_{Y\beta}(\bar{X}_{acdir} - \bar{X}_{cg})$.

[0046] Given traditional aeromechanics sign conventions (like those described by Roskam or Etkins), static directional stability is indicated by Equation 5:

[0047] $C_{ncg\beta} > 0$.

[0048] When this condition is met, the aircraft inherently yaws into the wind as it comes from a given quadrant. Accordingly, this type of stability is normally referred to as "weathercock" or "weathervane" stability.

[0049] In both cases, it is obvious that the distance between the aerodynamic centers and the centers of gravity are as critical as is the sign of their relative positions for stability. By examining the equations above, it is easy to see that the center of gravity must be ahead of the aerodynamic centers both longitudinally and directionally for static stability. Accordingly, the longitudinal and directional static margins are indicated by set of Equations 6 :

[0050] $S.M._{long} = -{}^{dC_{mcg}}\!/_{dC_L} = (\bar{X}_{aclong} - \bar{X}_{cg})$

[0051] $S.M._{dir} = {}^{dC_{ncg}}\!/_{dC_y} = (\bar{X}_{acdir} - \bar{X}_{cg})$.

[0052] If one examines the dynamic case, using Routh's stability criterion, the longitudinal condition of set of Equations 6 above changes slightly considering cases of aircraft flying into compressible flight regimes, particularly the ones which may induce troubles with Mach tuck, to Equation 7:

[0053] $S.M._{long} = \bar{X}_{aclong} - \bar{X}_{cg} > \left|\frac{C_{mcgu}}{C_{Lu}+2C_{L1}}\right|$.

[0054] Of course, the expressions for short period aeromechanical modes are important for many ballistic projectiles as sabot separations often induce high tip-off angular accelerations. If one examines the maneuver point which is associated with a condition for divergence of the short period mode, one can see, again, that it can be cast in terms of static margin, Equation 8:

[0055] $S.M._{long} = \bar{X}_{aclong} - \bar{X}_{cg} > \left|\frac{C_{mq}\rho S\bar{D}g}{4W}\right|$.

[0056] As such, the static margin is demonstrated to be critically important for both static and dynamic stability of a given projectile and for an aeromechanically stable sabot. Again, in lay terms, what the equations describe is a projectile that flies through the air like a dart -- with a heavy part at the front and light tail feathers aft. To do this, the heavy part shifts the center of gravity forward while the tail feathers shift the aerodynamic center aft. When this relative position is not maintained, the projectile will fly through the air more like an unspun football -- wobbling and tumbling as it goes through the air.

[0057] Given the aforementioned critical nature of maintenance of a positive static margin longitudinally and directionally, a designer who wishes to design a stable sabot system can call upon this knowledge to lay out a workable aeromechanically stable sabot. Accordingly, this presently disclosed sabot employs the principles of static and dynamic longitudinal and directional stability in that the sabot will, necessarily, possess a heavy forebody and a lighter afterbody such that the center of gravity is displaced much farther forward on the sabot than the aerodynamic center following release of the projectile from the sabot.

[0058] While the previous equations and concepts hold for symmetric, trimmed, unpowered flight of aircraft that are not spinning, another equilibrium equation can describe steady-state longitudinal trim, Equation 9:

[0059] $C_{mcg} = (C_{Lowb} + C_{L\alpha wb}\alpha)(\bar{X}_{cg} - \bar{X}_{aclongwb}) + C_{mocgwb} - C_{L\alpha c}\frac{S_c}{S_{ref}}(\bar{X}_{acc} - \bar{X}_{cg})\left\{\alpha - \left(\varepsilon_o + \frac{d\varepsilon_c}{d\alpha}\alpha\right)\right\}$.

[0060] From Equation 9 (which omits but not tail/fin coefficients) it is easy to see that for a symmetrical dart-shaped projectile, the pitching moment coefficient about the center of gravity, C_{mcg} will be close to zero as the angle of attack goes to zero. It is this state that most flechette and dart like projectiles fly in following sabot release.

[0061] Equation 9 describes a completely different flight state for a traditional sabot which is normally designed to tumble through the air. Given that property and the static margin for the entire traditional sabot and individual sabot pieces, very small angular pitch and yaw perturbations tend to grow large. That perturbation often comes from the very irregular shape of the sabot which generates large values of the steady state pitching moment coefficient about the center of gravity due to the wing-body combination C_{mocgwb}. This perturbation in turn typically initiates pitch and/or yaw divergence, which then grows into a full-blown tumble. It is this very dynamic that is universally found among all prior art sabots and is very different than the presently disclosed sabot system.

[0062] The presently disclosed sabot maintains values of steady state pitching moment coefficient about the center of gravity C_{mocg} and the steady state yawing moment coefficient about the center of gravity C_{nocg} which are low enough so as not to induce a tumble, but high enough to generate a finite α or β trim angles. These trim angles in turn will generate lift and/or sideforces that are great enough so as to allow the sabot to clear the launching aircraft and all friendly aircraft in the associated formation without undue risk of engine ingestion or airframe strike. Further aiding stable flight of the presently disclosed sabot is the fact that the sabot and its pieces are aeromechanically stable, which means that the center of gravity is ahead of the aerodynamic center. In aeromechanics parlance, the longitudinal and directional static margins as described in equations 6 - 8 are positive.

[0063] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] For a more complete understanding of the disclosed methods and apparatuses, reference should be made to the embodiments illustrated in greater detail in the accompanying drawings, wherein:

[0065] FIGS. 1A-1G illustrate a conventional sabot and behavior of the conventional sabot after firing from an aircraft;

[0066] FIG. 2A-2F illustrate an aeromechanically unstable prior-art sabot and behavior of the sabot firing from an aircraft;

[0067] FIGS. 3A-3C illustrate enlarged perspective views of the aeromechanically unstable prior-art sabot and projectile of FIGS. 2A-2F;

[0068] FIGS. 4A-4H illustrate perspective views of a variety of projectile configurations which are compatible with sabots of the present disclosure;

[0069] FIGS. 5A-5F illustrate an example sabot of the present disclosure including a matched right-circular cross-section projectile and a trajectory of the sabot after firing from an aircraft;

[0070] FIGS. 6A-6F illustrate an example sabot of the present disclosure including a monolithic bluff-body and the sabot releasing a square cross-section projectile;

[0071] FIGS. 7A-7F illustrate an example sabot of the present disclosure including a segmented bluff-body variant and the sabot releasing a round-cross-section projectile;

[0072] FIGS. 8A-8E illustrate an example sabot of the present disclosure including a monolithic low drag body and an expanding drag skirt;

[0073] FIGS. 9A-9E illustrate an example sabot of the present disclosure including a monolithic low-drag body and the sabot releasing a regular polygon cross-section projectile with fins;

[0074] FIGS. 10A-10F illustrate an example sabot of the present disclosure including a monolithic low-drag body and the sabot releasing a regular polygon cross-section projectile with fins;

[0075] FIGS. 11A-11E illustrate an example sabot of the present disclosure including a segmented low-drag body and the sabot releasing a regular polygon cross-section projectile;

[0076] FIGS. 12A-12E illustrate an example sabot of the present disclosure including a monolithic low-drag body and a rocket motor and the sabot releasing a round cross-section projectile with fins;

[0077] FIGS. 13A-13E illustrate an example sabot of the present disclosure including a monolithic body and articulated fins and the sabot releasing a regular polygon cross-section projectile with fins;

[0078] FIGS. 14A-14H illustrate an example guided sabot of the present disclosure including attitude sensors and active steering and illustrate post-launch trajectories of the sabot;

[0079] FIGS. 15A-15E illustrate an example sabot of the present disclosure including an articulated fins in a fin-forward configuration and illustrate the sabot exhibiting shuttlecock stability after firing;

[0080] FIGS. 16A-16H illustrate an example sabot assembly of the present disclosure including a segmented bluff-body where segments of the sabot assembly exhibit shuttlecock stability after projectile separation;

[0081] FIGS. 17A-17C illustrate an example sabot assembly of the present disclosure including a segmented bluff-body with a plurality of small segments;

[0082] FIGS. 18A-18C illustrate an example sabot assembly of the present disclosure including a segmented bluff-body with a plurality of small segments with more clearly tailored chamfers for maintenance of free-flight trim angles of attack and sideslip;

[0083] FIG. 19 is a block diagram that illustrates a sabot system in accordance with aspects of the present disclosure;

[0084] FIG. 20 is a block diagram that illustrates a controller of a sabot system in accordance with aspects of the present disclosure;

[0085] FIG. 21 is a block diagram that illustrates an aircraft including a sabot system in accordance with aspects of the present disclosure;

[0086] FIG. 22 is a block diagram that illustrates a cannon including a sabot system in accordance with aspects of the present disclosure;

[0087] FIG. 23 is a flowchart in accordance with aspects of the present disclosure;

[0088] FIG. 24 is a flowchart in accordance with aspects of the present disclosure; and

[0089] FIG. 25 is a flowchart in accordance with aspects of the present disclosure.

[0090] It should be understood that the drawings are not necessarily to scale and that the disclosed embodiments are sometimes illustrated diagrammatically and in partial views. In certain instances, details which are not necessary for an understanding of the disclosed methods and apparatuses or which render other details difficult to perceive may have been omitted. It should be understood, of course, that this disclosure is not limited to the particular embodiments illustrated herein.

DETAILED DESCRIPTION

[0091] The presently disclosed sabot represents a major deviation in the overall design philosophy of sabots. Since at least 1326, sabots have been necessarily designed to be aeromechanically unstable items which are discarded as quickly as possible after firing. The property of inherent aeromechanical instability is important to the design of conventional sabots as it enables rapid sabot separation from the projectile with minimal tip-off, nutation and precession excitation, thereby minimizing the circular-error-probable (CEP) downrange.

[0092] Referring to FIGS. 1A-1G, a conventional sabot configuration for a munition (e.g., ammunition) and behavior thereof is depicted. FIGS. 1A-1G illustrate behavior for a modern, fielded sabot configuration used by armed forces around the world. At the core of the design is a projectile 10 which is housed within a plurality of sabot segments 20. As is conventional in stability and control analysis methods employed in the United States, a right-hand axis system is typically called out as denoted by the X, Y, and Z-body axes shown clearly in FIG. 1A. FIG. 1B illustrates the projectile 10 and the sabot 20 (e.g., sabot system or sabot assembly) of the munition, often referred to as the two main components thereof. As illustrated in FIG. 1B, the sabot 20 includes 4 pieces or segments.

[0093] After an explosive is detonated (e.g., such an explosive in a cartridge in the projectile 10 or a barrel 30), the projectile 10 and sabot 20 travel down the barrel 20 as seen in FIGS. 1C and 1D. After the projectile 10 and sabot 20 leave the barrel 30 as shown in 1E, the segments of the sabot 20 peel off the projectile 10, releasing the projectile 10. This allows the projectile 10 to fly downrange in a low drag configuration, thereby increasing the impact velocity and kinetic energy of the projectile 10 while reducing the time of flight and flattening the trajectory the projectile 10.

[0094] Following projectile 10 release, the individual sabot segments fly as aeromechanically unstable objects. This is caused by a center of gravity 21 being positioned well behind the aerodynamic center 22. The tailored shape of the conventional sabot 20 also generates a large static pitching moment and/or yawing moment 23. The combination of aeromechanical instability and large moments induce the pieces of the sabot 20 to tumble rapidly and repeatedly around multiple axes. This tumble in turn intermittently presents a maximum cross-sectional area of the pieces of the sabot 20 to the flow of air. Given that drag increases with cross-sectional area, especially in supersonic flight, the airspeed of the pieces of the sabot 20 is rapidly reduced. While this behavior is good and specially designed into rounds for ground-based gunnery applications, an extremely dangerous dynamic occurs if these events unfold during aerial gunnery exercises. Indeed, FIG. 1G shows the inevitable ingestion of the pieces of the sabot 20 into launching aircraft 40 engine inlets or impact with an airframe of the launching aircraft 40. This dynamic illustrates why no currently fielded fixed-wing fighter or attack aircraft fires conventionally saboted rounds as shown in FIGS. 1A-1G.

[0095] Incrementally different than a conventional sabot, the art taught in '816 is a monolithic sabot (rather than a segmented sabot) and therefore will be composed of one principal piece rather than multiple pieces. This art, depicted in FIGS. 2A-2F shows a projectile 110 (e.g., short penetrator projectile) which is contained within a sabot jacket 120 and expelled from the sabot jacket 120 after leaving a barrel 130 by an expulsion charge 140. FIG. 2A shows the arrangement of the major components. FIG. 2B shows the combined projectile 110 and sabot jacket 120 as expelled from the barrel 130 (e.g., gun barrel or cannon barrel).

[0096] FIG. 2C shows the downrange flight of the combination prior to ignition of the expulsion charge 140. FIG. 2D shows the expulsion of the projectile 110 from the sabot jacket 120. The sabot pictured in FIGS. 2A-2E possesses an aerodynamic center 22 which is in front of the center of gravity 21 both subsonically and supersonically. This adverse configuration indicates that the sabot is aeromechanically unstable. Because the sabot is unstable, it will swap ends upon barrel exit as depicted in FIG. 2E. As was the case of the pieces of the sabot 20 in FIGS. 1A-1G, the sabot in FIGS. 2A-2F has no configuration artifact to make $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$. Similarly, C_{mq} and C_{nr} are too low to resist a longitudinal or directional tumble. As a result, the sabot jacket 120 will tumble around the body y and/or z axes, intermittently presenting the maximum cross-sectional area to incoming air. This maximum cross-sectional area in turn causes extremely large spikes in total drag, leading to the same kind of adverse dynamics seen in FIGS. 1A-1G. If multiple rounds (110, 120) are fired as depicted in FIG. 2F, then the associated sabot jackets 120 will tumble and fly downstream with a high probability of engine ingestion and airframe impact. Although

'816 bears a priority date more than 30 years ago, no fielded fixed-wing fighter or attack aircraft in the world is equipped with rounds like this, most likely because of the aforementioned aeromechanics and associated flight risks.

[0097] The most common penetrator round configuration is shown in FIGS. 3A-3C. Cannon shells, such as the PGU-14, fired by aircraft, such as the Fairchild A-10 Warthog, represent some of the most common types of penetrator rounds flown and fielded by the US armed forces. These rounds are configured as shown in FIGS. 3A-3C with an outer jacket, sabot jacket 220, made out of more lightweight materials like aluminum or polymers and an inner penetrator, projectile 210, made out of high-density materials like depleted uranium (DU) or tungsten. The exceptionally high specific gravity of DU (19.1g/cc) increases its penetration depth. Conversely, the low density of aluminum (2.72 g/cc) makes it well suited to being used in a sabot.

[0098] Unfortunately, the adverse aeromechanics of conventional sabots depicted in FIGS. 1A-1G and 2A-2F preclude their use in aerial gunnery. Accordingly, rounds like the PGU-14 keep the projectile 210 (penetrator projectile) and the sabot jacket 220 over the entire flight until impact. Only after impact does the projectile 210 separate from the sabot jacket 220 as the projectile 210 makes its way into the target. While this configuration has worked well for the PGU-14 and many other similarly configured rounds for aerial gunnery, the price paid is extremely high. The axial force coefficient, C_A, or drag coefficient, C_D, are direct functions of the base area of the entire round, i.e., projectile 210 and sabot jacket 220. Accordingly, if the projectile 210 shown in FIGS. 3A-3C were to fly on its own, given that its diameter (in the case of the PGU-14) is roughly 1/3 that of the main round caliber, it would have only 1/9th the drag of the entire PGU-14. Accordingly, it would fly much farther and faster with a lower time to reach the target and with a flatter trajectory than a conventionally configured round. Unfortunately, none of the aforementioned conventional sabot technologies are compatible with fixed-wing aerial gunnery, given flight safety concerns.

[0099] The presently disclosed sabots or sabot systems overcome the aforementioned aeromechanical challenges. Referring to FIGS. 4A-4H, different examples of projectiles which are compatible with the presently disclosed sabot systems are depicted. FIG. 4A depicts a circular cross-section penetrator 300A with a nose and main body 310A, stepped grapple—which allows the presently disclosed sabots to transfer launch forces to the projectile 320A—body-caliber fins or strakes 330A, and aft body or fuselage 340A. Such penetrators may be made of any suitably dense material, ranging from steel to brass to tungsten and DU. Also, the penetrator 300A need not be made from a single material, but may be made from a plurality of materials. The projectile 320A is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00100] FIG. 4B depicts a polygonal cross-section penetrator 300B with a nose and main body 310B, stepped grapple which allows the presently disclosed sabot to transfer launch forces to the projectile 320B, corner caliber fins or strakes 330B, and aft body or fuselage 340B. Such penetrators may be made of any suitably dense material, ranging from steel to brass to tungsten and DU. Also, the penetrator 300B need not be made from a single material, but may be made from a plurality of materials. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00101] FIG. 4C depicts a polygonal cross-section penetrator 300C with a nose and main body 310C, stepped grapple which allows the presently disclosed sabot to transfer launch forces to the projectile 320C, super-corner caliber fins or strakes 330C, and aft body or fuselage 340C. Such penetrators may be made of any suitably dense material, ranging from steel to brass to tungsten and DU. Also, the penetrator 300C need not be made from a single material, but may be made from a plurality of materials. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00102] FIG. 4D depicts a polygonal cross-section penetrator 300D with a nose and main body 310D, stepped grapple which allows the presently disclosed sabot to transfer launch forces to the projectile 320D, super-corner caliber fins 330D and aft body or fuselage 340D. Such penetrators may be made of any suitably dense material, ranging from steel to brass to tungsten and DU. Also, the penetrator 300D need not be made from a single material, but may be made from a plurality of materials. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00103] FIG. 4E depicts a polygonal cross-section cargo round 300E with a nose and main body 310E, stepped grapple which allows the presently disclosed sabot to transfer launch forces to the projectile 321E, and flared back end (322) which may or may not carry a cargo such as high explosive. The round may be constructed from a plurality of materials and may include a variety of fuses. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00104] FIG. 4F depicts a guided polygonal cross-section cargo round 300F with a nose and main body 310F. Protruding laterally from the sides of the round are at least one set of control surfaces 340F. The round may also have a cargo section 321F which has grapple features on the sides to allow the transfer of launch loads from the presently disclosed sabot to the projectile, as well as an empennage assembly 330F. The guidance and control section will command the flight control surfaces 340F to deflect in response to internal or externally directed guidance commands which may come from any electromagnetic wavelength. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00105] FIG. 4G depicts a guided circular cross-section cargo round 300G with a nose and main body 310G. Protruding laterally from the sides of the round are at least one set of control surfaces 340G. The round may also have body strakes, 330G as well as an empennage assembly 330G. The guidance and control section will command the flight control surfaces 340G to deflect in response to internal or externally directed guidance commands which may come from any electromagnetic wavelength. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00106] FIG. 4H depicts a guided polygonal cross-section cargo round 300H with a nose and main body 310H. Protruding laterally from the sides of the round are at least one set of control surfaces 340H. The round may also have an empennage assembly 330H at the end of a comparatively narrow aft fuselage. The guidance and control section will command the flight control surfaces 340H to deflect in response to internal or externally directed guidance commands which may come from any electromagnetic wavelength. The projectile is longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00107] The projectiles which are compatible with the presently disclosed sabots may have any of the aforementioned features. In some implementations, the projectiles include: i.) a mechanism and/or geometric feature to transfer loads from the presently disclosed sabot to the projectile; ii.) be configured such that the presently disclosed sabot can release from the projectile following barrel-exit; and iii.) will be longitudinally and directionally aeromechanically stable, such that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$.

[00108] Given the range of projectiles which may be used with the presently disclosed sabots, a basic assembly including those projectiles and the presently disclosed sabots is shown in FIGS. 5A-5F. Referring to FIG. 5A, shell 100 includes a number of components. A casing 102 of the shell 100 is full of propelling charge as illustrated in view 101, and view 101 shows that the projectile 430 sits deep within the propellant, almost all the way to the aft end of the shell casing, far past the aft end of the presently disclosed sabot 401. The projectile assembly 400 is joined to the shell casing with at least one groove, crimp, swage, bond, or interference fit. After firing, the projectile assembly 400 is expelled from the filled casing 101 as the propellant charge within the casing is converted to high temperature, high pressure gas within the firing chamber and barrel. The empty casing 102 is then discarded. The presently disclosed sabot 401 then separates from the projectile 430.

[00109] FIGS. 5A-5F show one of many kinds of projectiles that may be launched by the presently disclosed sabot. As an example, a circular cross-section projectile 430A that happens to have projectile-caliber aft-body strakes, is launched by the presently disclosed sabot 401. FIG. 5A shows a comparatively lightweight main body of the presently disclosed sabot, 410A/B, comparatively heavy counterweight and load transfer assembly of the presently disclosed sabot 415A/B, and segmented nose seals 420A/B. These components 410A/B, 415A/B, 420A/B, 430A/B all form the projectile assembly 400A which includes the presently disclosed sabot and a projectile. It should also be clear that the presently disclosed sabot 401 contains at least two components of dissimilar materials that are intimately bonded together as shown in the cut-away 410C, 415C. Materials of higher density will be placed forward while lower density materials will be present in the back to shift the presently disclosed sabot center of gravity forward.

[00110] The individual sections of the nose seals of the projectile assembly are shown as components (410C1, 420C2, 420C3, 420C4). The nose seal components are made from materials which facilitate storage and handling of the entire assembly, protecting the munition from damage caused by moisture, corrosion and other accidental damage. However, the nose seal components (410C1, 420C2, 420C3, 420C4) are made of a material which is compliant and frangible enough that it can be ingested into aircraft engine inlets without inducing damage. The nose seal components are also compliant and frangible enough that they will not induce damage on airframe components should they strike an airframe.

[00111] As the projectile assembly (400B) goes down the launching barrel (440B) as shown in FIG. 5B, the assembly accelerates but stays together as a single unit till barrel exit. As shown in FIG. 5D, upon barrel exit, the projectile assembly changes configuration. The presently disclosed sabot (401) begins to slide backwards, longitudinally along the length of the projectile, 430. This releases the nose seal components, 420, which are then free to fly away from both the projectile and the presently disclosed sabot.

[00112] FIG. 5E shows these nose seal components, (410E1, 420E2, 420E3, 420E4) flying away from both the projectile and the presently disclosed sabot (401) in a tumbling motion. Because the nose seal components are neither aeromechanically stable nor exhibit near zero inherent pitching and yawing moment coefficients, they will inherently tumble. By doing so, they will lose airspeed and energy and they will not follow the trajectory of the projectile or the presently disclosed sabot. FIG. 5E very clearly shows the presently disclosed sabot (401) in free flight. The free flight sabot (401) is composed of a comparatively heavy nose section, light tail section, and load transfer assembly (415E) coupled to a light aftbody, (410E). Because of the prescribed component form factors and mass distribution, the center of gravity (21) is positioned forward of the aerodynamic center (22). This positioning of the center of gravity relative to the aerodynamic center ensures that $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$. Accordingly, both inherent longitudinal and directional static stability is assured. The mass distribution and length of the presently disclosed sabot (401) are also tailored such that stability in both axes with respect to Mach Tuck and short period modes are maintained. By doing so, precession and nutation modes will be inherently suppressed, as illustrated by the following equations, set of Equations 10:

[00113] $S.M._{long} = \bar{X}_{aclong} - \bar{X}_{cg} > \left|\frac{C_{mcgu}}{C_{Lu}+2C_{L1}}\right|$

[00114] $S.M._{dir} = \bar{X}_{acdir} - \bar{X}_{cg} > \left|\frac{C_{ncgu}}{C_{Yu}+2C_{Y1}}\right|$

[00115] $S.M._{long} = \bar{X}_{aclong} - \bar{X}_{cg} > \left|\frac{C_{mq}\rho S\bar{D}g}{4W}\right|$

[00116] $S.M._{dir} = \bar{X}_{acdir} - \bar{X}_{cg} > \left|\frac{C_{nr}\rho S\bar{D}g}{4W}\right|$.

[00117] Because the presently disclosed sabot (401) is designed to execute a maneuver after barrel exit and projectile release, slight asymmetries in mass and/or body geometry are employed. These asymmetries may include a mass distribution which is not collocated with the body x-axis or longitudinal centerline, chamfers, bevels, ridges, divots or any other geometric imperfection, flap, surface, or deviation from the inner or outer mold lines. These geometric features may also include a non-axial bend in the geometry of the forward or aft end of the central body hole through which the projectile slides. No matter how these asymmetries are achieved, they will induce a pitching and/or yawing moment about the center of gravity of the presently disclosed sabot (23). This moment is critical for the functionality of the presently disclosed sabot (401) as it will be prescribed to induce a trimmed body of attack and/or sideslip angle that generates more g's of acceleration normal to the flight path than may be achieved by the launching aircraft during its hardest maneuver. It should also be noted that this asymmetry will not be great enough to induce a tumbling motion of the presently disclosed sabot (401), instead only generating a trimmed angle of attack sufficient to generate the aforementioned acceleration.

[00118] The result of this acceleration normal to the flight path of the presently disclosed sabot is seen in FIG. 5F. The launching aircraft (500) launches the projectile assembly (400) from the aircraft gun barrel (440). Extending forward the projectile (430) separates from the presently disclosed sabot (410, 415). The projectile then travels principally straight, along the projectile flight path (510) at high speed towards the intended target. The launching aircraft then maneuvers (500A to 500B) along its flight path (520). Because it is imperative that the presently disclosed sabot (401) clear the launching aircraft in all maneuver states, it is designed to execute a maneuver of more g's of normal force than may be achieved by the launching aircraft. Uninhabited aircraft may have higher limits than piloted aircraft. This hard maneuver will as a minimum generate an arc (530) which clears the tightest maneuver the launching aircraft can achieve.

[00119] Similarly, it is conceivable that a highly maneuverable variant of the presently disclosed sabot (401) will be able to achieve high turning rates. The tightest turn of the presently disclosed sabot (401) will be no tighter than the minimum turn radius flight path (540). This minimum turn radius flight path will clear the maximum extent of the aircraft and all of the aircraft in the attacking formation by no less than one entire wing span in all dimensions. Between the minimum and maximum turn radius flight paths of the presently disclosed sabot (530, 540), there exists a zone of possible flight paths in which the presently disclosed sabot (401) may fly. By matching the aeromechanics of the presently disclosed sabot (401), the launching aircraft, and associated formation of friendly aircraft, a range of flight paths (530, 540) can be designed. These flight paths (530, 540) can be laid out such that the probability of sabot ingestion by launching aircraft, friendly aircraft, or both satisfies one or more FAA standards. Examples of such probability are less than 1 in 10^{-6}, 1 in 10^{-9}, 1 in 10^{-11}, etc. Accordingly, flight operations with the presently disclosed sabots, such as sabot 401 can be rendered as flight safe per aviation safety regulations (commercial and/or military).

[00120] FIGS. 6A-6F shows a bluff-body variant of the presently disclosed sabot. As shown in FIG. 5, the assembly shown in FIGS. 6A-6F depicts a projectile assembly (400) which is fired from a separated shell casing (101/102) as shown in FIG. 5. FIG. 6A depicts a monolithic configuration of the presently disclosed sabot (401) with a bluff forward section. The lightweight main body (410) is firmly affixed and otherwise bonded to the load transfer assembly (415) which also includes a nose counterweight section. The main body (410) may have any number of features which allow it to be connected to the forward part of the shell casing (101/102) including: ridges, bumps, grooves, straps, fibers, screws, rivets, fasteners and/or grapples of any given geometry. A swage fit may also be employed so as to keep the main body (410) of the presently disclosed sabot (401) attached to the shell casing (101/102) prior to the firing event. The main body (410) may also be fitted with any number of bands, sheathes, coverings, and/or shields which allow the projectile assembly (400) and presently disclosed sabot (401) to be hermetically sealed against the elements and/or allow for better gun gas sealing during the firing event and/or lubricate the projectile assembly as it travels down the barrel during firing.

[00121] The load transfer assembly (415) is made from a high strength material which is capable of transferring loads imparted by the projectile on the presently disclosed sabot (401) due to setback accelerations during launch. The net result of the use of a nose weight in the load transfer assembly (415) and comparatively low-density body (410) is that the center of gravity (21) is displaced forward of the aerodynamic center (22) of the presently disclosed sabot (401). A favorable characteristic of the bluff-body configuration of the presently disclosed sabot is that the aerodynamic center is shifted aftwards during both subsonic and supersonic flight regimes. This tends to reduce the amount of nose weight required to make $C_{mcg\alpha} < 0$ and $C_{ncg\beta} > 0$ and the static margins sufficiently great enough to suppress Mach Tuck, short period, nutation, and precession as previously described.

[00122] FIG. 6B shows the halved presently disclosed sabot (401) in its bluff body configuration. The load transfer assembly (415) features a stepped load transfer grapple on the aft body (416). This grapple is fabricated from high strength materials and transfers loads from the presently disclosed sabot to the projectile (430) during setback. However, following barrel exit, it allows the presently disclosed sabot (401) to slide aftward along the x-body axis of the projectile (430) until it is sufficiently separated from the projectile and experiencing freeflight. The load transfer grapple (416) may have a mirroring surface which is co-cured or bonded to the main body (410) to enhance load transfer within the presently disclosed sabot (401). The load transfer grapple is also geometrically matched to the projectile load-transfer neck (431).

[00123] FIG. 6C shows the entire projectile assembly (400) in the bluff-body configuration with a number of protective nose seals (420) in place. These seals protect the nose of the projectile assembly (400) during handling up through the firing event, and lie within the main body of the presently disclosed sabot (401). Moments after the firing event, just after barrel-exit, the projectile assembly (400) changes configuration as the presently disclosed sabot (401) slides aftwards along the length of the projectile, as shown in FIG. 6D. Immediately following the aftward motion of the disclosed sabot, the protective nose seals (420) are exposed as they remain adjacent to the nose surfaces.

[00124] As the nose seals (420) are exposed to airflow, they separate from the projectile forebody and tumble downstream as shown in FIG. 6E. These nose seals are made from frangible highly compliant material that can harmlessly be ingested into jet engines and will pose no threat to the launching airframe. FIG. 6E shows the aftward separation of the load transfer grapple (416) which is on the inside of the presently disclosed sabot (401) and the projectile load-transfer neck (431). The presently disclosed sabot (401) is also shown sliding completely off the aft of the projectile (430) in FIG. 6E. Following the aftward separation of the presently disclosed sabot (401), the projectile (430) then flies towards its target while the presently disclosed sabot flies between maximum and minimum turn radii flight paths (530, 540) as shown in FIG. 5F.

[00125] FIGS. 7A-7F show a segmented variant of the bluff-body configuration of the presently disclosed sabot (401). FIG. 7A shows a bluff-body combination of the lightweight, low-density aft body (410) and the higher-density nose counterweight and load transfer assembly (415) making up this variant of the presently disclosed sabot (401). Because the segmented variant of the presently disclosed sabot (401) separates from the projectile (430) by flying away from the projectile laterally, there is no aftwards sliding motion as shown in FIGS. 6A-6F. Accordingly, the grapple configuration between the presently disclosed sabot (401) and the projectile (430) differs from the grapple-to-load transfer neck shown in FIG. 6 (416, 431). FIG. 7A shows a plurality of segments of the presently disclosed sabot (401) together in the firing configuration including: the low-density body (410), load transfer assembly (415), and a special bevel placed on the inside of both of the aforementioned components (417).

[00126] FIG. 7B shows that the segmented variant of the presently disclosed sabot (401) may be divided into two or more segments. Each of these individual segments possesses aeromechanical stability both collectively and separately as exemplified by the relative positions of the forward-displaced center of gravity (21) and the aft-displaced aerodynamic center (22) of the presently disclosed sabot (401). The inner surface of this segmented bluff-body variant of the presently disclosed sabot (401) is composed of a plurality of ridges (418). These ridges transfer loads from the presently disclosed sabot (401) to the projectile (430) by mating with their counterparts on the projectile (432).

[00127] FIG. 7C shows an individual segment configuration of the presently disclosed sabot (401). The lightweight main body (410) is attached to the comparatively heavy load transfer assembly and nose weight (415). Because of the density difference between the two components, (410, 415) the center of gravity of the presently disclosed sabot, (21) is shifted forward with respect to the aerodynamic center (22). The forward shift in c.g. with respect to a.c. is such that the presently disclosed sabot (401) will not tumble and will maintain stable flight following separation from the sides of the projectile (430). The nose chamfer (417) is designed to induce a finite angle of attack such that normal forces perpendicular to the flight path will induce the range of flight paths as described for features 530 and 540 of FIG. 5.

[00128] FIG. 7D shows the assembled segmented configuration of the projectile assembly (400) prior to and during the firing event. This includes the presently disclosed sabot (401) with its constituent components (410, 415) and projectile. In this configuration, the inner faces of the load transfer ridges (418) on the presently disclosed sabot (401) make contact with the outer faces of the load transfer ridges (432) of the projectile (430).

[00129] FIG. 7E shows the separation of the presently disclosed sabot (401) from the body of the projectile just after barrel exit. This includes the separation of the matched sets of load transfer ridges (418, 432). As previously described, the presently disclosed sabot (401) does not tumble, but rather flies away from the projectile (430) after barrel exit, achieving a stable trimmed angle of attack and/or sideslip angle. FIG. 7F shows the flight of the individual segments of the present disclosure (401) as they pitch and yaw away from the projectile, ultimately following flight paths as described by maximum and minimum turn radii (530, 540) of FIG. 5.

[00130] FIGS. 8A-8E show a skirted configuration of the presently disclosed sabot (401). FIG. 8A shows the projectile assembly (430) containing the disclosed sabot (401), protective nose seals (420), and a folded aft skirt (450A). As the presently disclosed sabot (401) is located within the cartridge (101) for storage and during the launching event, the aft skirt of this incarnation of the presently disclosed sabot (401) will stay folded as shown in FIG. 8A. After barrel exit, the skirt on the aft end of the presently disclosed sabot (401) will unfold, forming a conical flare (450B). This conically flared skirt may be asymmetric so as to execute prescribed maneuvers as described by flight paths 530 and 540 in FIG. 5F.

[00131] FIGS. 8A-8E also show a monolithic configuration of the presently disclosed sabot (401) that is designed to accommodate a projectile with a regular polygon cross-section and aft strakes that span the corner caliber of the polygonal cross-section. FIG. 8C shows the load transfer neck (431) of the projectile (300). FIG. 8D shows the multiple low compliance protective nose seals (420) both installed and egressed following projectile expulsion from the gun barrel. The load transfer grapple within the monolithic variant of the presently disclosed sabot (401) and folded stabilizing skirt is shown (450A). Because the presently disclosed sabot employs a variety of different density materials which are intended to properly stabilize the device, the center of gravity (21) is positioned ahead of the longitudinal and directional aerodynamic center (22). Following skirt deployment (450B), the aerodynamic center (22) of the presently disclosed sabot (401) will, necessarily, shift further aftward as shown in FIG. 8E.

[00132] FIGS. 9A-9E show a skirtless configuration of the presently disclosed sabot (401) which is designed to accelerate a regular polygonal projectile (300) with corner-caliber aft body strakes. As was the case with the sabot configuration shown in FIGS. 8A-8E, the disclosure shown in FIGS. 9A-9E is aeromechanically stable with a center of gravity (21) ahead of the longitudinal and directional aerodynamic center (22). Unlike the configuration disclosed in FIGS. 8A-8E, however, the configuration of the present sabot takes advantage of the forward mass placement within the sabot to achieve proper amounts of longitudinal and directional stability.

[00133] FIGS. 10A-10F disclose a projectile as shown in FIGS. 9A-9E but with a spanwise growth in aft-body strake (330). These larger strakes are accommodated in a series of slots (455) that are important for the maintenance of clocking and clearance as the presently disclosed sabot (401) slides aftward along the projectile (300) following the launch event and barrel exit. During the launch event, the presence of the strakes (330) in the slots (455) form a seal against gun gasses. If an empennage assembly of the projectile possesses a span which is larger than the aft-body strakes, then flapper-valve seals are used on the back of the sabot as shown in FIG. 10F (456).

[00134] FIGS. 11A-11E show several incarnations of the presently disclosed sabot (401) that are designed to accommodate fin sets that extend to the full gun bore (300). These bore riding fins preclude completely monolithic designs for the presently disclosed sabot (401). Rather, for the presently disclosed sabot to clear the fins following barrel exit, the sabot itself must either expand to open up slots through which the fins can pass or separate off the sides of the projectile (300). To hold the segments of the presently disclosed sabot (401) together, segment clips (560) may be used if the sabot is to stay in a monolithic configuration. These clips fold down and together during storage, chambering and firing (560A). After barrel exit, the clips expand (560B) to push the individual segments away from each other. As shown in FIGS. 9A-9E, FIGS. 10A-10F, and previous illustrations, the launch loads are transferred between the load transfer grapple-to-load transfer neck shown in (416, 431). As the monolithic, full-bore fin accommodating variant of the presently disclosed sabot (401) shown in FIGS. 11A and 11B, the sabot stays together even after sliding down the length of the projectile, flying freely. As is the case with all incarnations of this presently disclosed sabot (401), the center of gravity (21) is designed to be forward of the longitudinal and directional aerodynamic center (22).

[00135] FIG. 11C shows the presently disclosed sabot (401) on a projectile with full-bore fins (300), but in a multi-segmented configuration. The presently disclosed sabot in this segmented configuration (401) may be held together by any number of pins, bands or straps such that upon barrel exit, after exiting the muzzle blast, the retaining mechanism releases the segments of the sabot. These bands may be made of Teflon, PTFE, or other polymer systems which may form an obturating band. FIG. 11D depicts the same assembly immediately following launch and barrel exit. Clearly, the individual pieces of the presently disclosed sabot (401) are moving aftwards down the length of the projectile (300). FIG. 11E shows the pieces of the presently disclosed sabot (401) clearing the fin set after release along with the protective nose seals (420). As is the case with all other incarnations of the presently disclosed sabot, the center of gravity (21) is positioned ahead of the longitudinal and directional aerodynamic center (22). Also included are geometric features which allow the sabot pieces to achieve trim angles without tumbling and execute high-g maneuvers that are normal to the sabot flight path as described for the sabots depicted in FIG. 5F.

[00136] FIGS. 12A-12E show a rocket assisted variant of the presently disclosed sabot (401). As the projectile assembly (400) travels down the barrel as seen in FIG. 12A and then is ejected in FIGS. 12B and 12C, the configuration of the projectile is very similar to the configuration presented in FIG. 5. As is the case in the variant of the presently disclosed sabot shown in FIG. 5, the center of gravity (21) is designed to be ahead of the longitudinal and directional aerodynamic center (22) as shown in FIG. 12D. However, in this variant, the central body of the presently disclosed sabot (410) is filled with rocket fuel (475) which has been triggered at a predetermined time and/or distance from the barrel exit by any means including electronic triggering and/or pyrotechnic fuse mechanisms. Rocket motor orifices or nozzles (480) may be placed on the side of the sabot, front or back of the sabot. The purpose of these nozzles and associated rocket motor ejecta (485) are to enhance the maneuvering capability of the presently disclosed sabot so as to execute a range of maneuvers as shown in FIG. 5F.

[00137] FIGS. 13A-13E show an articulated, finned variant of the presently disclosed sabot. FIG. 13A shows the sabot assembly with fins (451) that are pivoted around either discrete or solid-state hinge mechanisms (452) and sprung outwards. During storage, chambering, and the firing event, the teeth on the inner faces of the fins lock into the interior grooves of the sabot aft body and transfer loads to the projectile body with matched grooves. The configuration of sabot is compatible with projectiles equipped with fin sets that do not extend to the full bore (300). FIG. 13B shows the sabot just after barrel exit with sprung fins extending outwards. Just after barrel exit, the sprung fins are flung outwards, unlocking the projectile and sabot, allowing the sabot to travel aftwards along the length of the penetrator (300) as shown in FIG. 13C. The penetrator fins move forward underneath the sabot fins (451), then through a slot that formerly accommodated the fins themselves. Eventually the presently disclosed sabot (401) and nose seals (420) completely slide off the back of the projectile. Because the presence of fins dramatically shifts the aerodynamic center of the presently disclosed sabot aftwards (422), the distance from the forward displaced center of gravity (421) is great, lending a very high level of longitudinal and directional stability.

[00138] FIGS. 14A-14H show guided variants of the presently disclosed sabot (401). FIG. 14A shows an aeromechanically stable sabot as described earlier with a center of gravity (21) positioned ahead of the longitudinal and directional aerodynamic center (22). Ringing the sabot is a series of sensors (490). These sensors are sensitive to differences between earth and sky and may respond to differences in a variety of electromagnetic spectra including visual, infrared, and ultraviolet bands. These sensors (490) act to determine the orientation of the sabot about the body x-axis relative to the earth and sky. A flight controller within the round then determines how and when to fire rocket motors as shown in FIGS. 14A, 14B and 14C to execute a prescribed maneuver.

[00139] FIG. 14D shows a variant of the presently disclosed sabot (401) with a set of controllable canards (452) in addition to the sensors (490). This variant is designed so that the canards are deployed after barrel exit, then pitched so as to control the sabot in both pitch and roll. FIG. 14E shows a variant of the presently disclosed sabot (401) with canards as previously described, but also fins with permanent cants set in the ends of at least two orthogonal fins (453). FIG. 14F shows a canard-controlled sabot, but with a series of tabs (450) that are set to enhance maneuvers. FIG. 14G shows a canard-equipped sabot as previously described, but with one fin that is significantly more deployed than the others. This asymmetric deflection allows the canards to be used principally for roll, while the steady state maneuver is accomplished by tabs or excessive tail fin deflections. The purpose of lending guidance to the presently disclosed sabot is to provide an increased amount of flight safety to the launching aircraft and friendly cooperative aircraft, as compared to conventional sabots. To accomplish this, FIG. 14H shows the launching aircraft (500) firing a projectile along a mostly straight trajectory aligned principally with the body x-axis of the launching aircraft (510). As the launching aircraft maneuvers along another flight path (520), increasing the distance between the launching aircraft and friendly aircraft is important for maintenance of flight safety; accordingly, the trajectory (530) of the guided variant of the presently disclosed sabot (401) is highly tailored. The trajectory is designed around a high-g turn straight towards the earth. This means that the sabot will fly downwards as quickly as possible and impact the earth rather than staying airborne and posing potential risk to friendly airborne forces.

[00140] FIGS. 15A-15E show a reversed variant of the presently disclosed sabot (401). Although the components of this variant of the presently disclosed sabot are essentially the same as shown in FIGS. 13A-13E, the disposition of the sabot is such that the fin set is facing forward and the comparatively heavy nose is facing towards the aft of the projectile as shown in FIGS. 15A and 15B. The utility of this configuration is to allow the projectile assembly to not only exit the muzzle, but survive the muzzle blast and not initiate a high tip-off angle in clearing the blast while not incurring additional weight penalties in the aftmost portion of the sabot to survive these launch loads when in the freeflight configuration. This configuration may therefore, afford a lower total weight solution by allowing for the reduction in mass in the forward section of the projectile when stowed or before the launch event. FIG. 15C shows the presently disclosed sabot (401) sliding aftwards towards the tail of the projectile after the fins (451) unlock against the sides of the projectile. The projectile (300) then clears the fins of the presently disclosed sabot (401) with the two noses headed in opposite directions. FIG. 15E shows that following separation, the extremely high degree of longitudinal and directional stability will dynamically rotate the sabot from the positions shown in various states of rotation through 180 deg. (401C, 401D, 401E), ending up with a flight attitude depicted by stable nose-into-the-wind flight (401F). While a 180 deg. rotation about the body y and/or z-axis is indeed extreme, the static margins of the sabot both directionally and longitudinally is high enough that tumbling will not take place and maneuvers as depicted in FIGS. 5F or 14H may then be executed.

[00141] FIGS. 16A-16H show a bluff-body configuration of aeromechanically stable sabot which possesses dynamics that are similar to the sabot depicted in FIGS. 15A-15E. FIG. 15A shows the present disclosure in a segmented bluff-body sabot configuration (401). The sabot is constructed with a lightweight body (410), capped with a heavy nose weight (415). The center of gravity (21) is accordingly shifted closer to the nose weight (415). This shifts the center of gravity (21) away from the aerodynamic center (22). A geometric chamfer (417) aids sabot separation from the projectile. FIG. (16B) shows a sectioned sabot exposing the internal grappling grooves (418), lightweight body (410), chamfers on either end (417) and the nose weight (415). FIG. 16C shows the present disclosure (401) segment. FIG. 16D shows the projectile assembly (400) with the present disclosure (401) composed of a lightweight body (410) and comparatively heavy end (415) attached to the projectile (430). This configuration of the present disclosure (401) shows the sabot aerodynamic center (22) as being ahead of the center of gravity (21).

[00142] FIG. 16E shows the initial separation of the projectile assembly (400) just after barrel exit including the present disclosure (401) peeling away from the projectile (430). The internal grappling grooves inside of the present disclosure (418) are shown breaking away from load transfer grooves (432) on the sides of the projectile (430). The shape of the present disclosure and relative positions of the aerodynamic center (22) and center of gravity (21) induce the present disclosure (401) to pitch up rapidly and away from the projectile. FIG. 16F shows the present disclosure (401) continuing to diverge away from the projectile (430) a split second farther in time. FIG. 16G shows the next split second with the present disclosure (401) flying yet farther away from the projectile (430) as the aerodynamic center (22) forces the present disclosure (401) to flip over and around the projectile. FIG. 16H shows the stable, free-flight configuration of the components associated with the projectile assembly including a straight-flying projectile (430) and the present disclosure (401) with a center of gravity (21) ahead of the aerodynamic center (22), at a trimmed angle of attack and sideslip angle forcing the present disclosure (401) away from the projectile body x-axis. As the present disclosure (401) flies away from the projectile body x-axis, it will follow a trajectory between maximum and minimum normal accelerations (530, 540) seen in FIG. 5F.

[00143] FIGS. 17A-17C show a more finely segmented variant of the present sabot disclosure (401). The present disclosure (401) as seen in FIG. 17A will exhibit a center of gravity (21) that is displaced closer to the free-flight configuration nose which accommodates the load transfer ring and nose weight (415). The aerodynamic center (22) will be comparatively behind center of gravity in the free-flight configuration. As the present disclosure separates from one unitary member (shown in FIG. 17A) to many individual components (shown in FIG. 17B) the center of gravity of the collective and individual pieces will shift neither forward nor aft in absolute dimension. However, by examining FIG. 17C, it is apparent that the segmented present disclosure (401) has a much smaller hydraulic diameter or effective caliber. Accordingly, the hydraulic diameter normalized static margin longitudinally and directionally will be far greater for the individual segment configuration of the present disclosure shown in FIG. 17C than the combined configuration shown in FIG. 17A. Because the surface area per unit mass will be increased in the individual segment configuration shown in FIG. 17C, the magnitudes of the normal force coefficient with respect to angle of attack, $C_{N\alpha}$ and the side force coefficient with respect to yaw angle, $C_{Y\beta}$, will also be increased with respect to the combined configuration shown in FIG. 17A. This in turn increases the total amount of acceleration along the body y and z axes that can be generated per unit angle of attack.

[00144] Adding to the stabilization will be the inevitable increase in magnitude of stabilizing pitching moment coefficient about the center of gravity with respect to pitch rate C_{mcgq} and the yawing moment coefficient about the center of gravity with respect to yaw rate C_{ncgr}. Increases in the magnitudes of both of these values will aid in damping out adverse aeromechanical modes which affect flight path tailoring by increasing scatter. Of critical importance in this design will be the ability of the present disclosure to achieve a particular trimmed angle of attack, α, and sideslip angle, β. To achieve this, the tailoring of the chamfers (417) is important such that the angle of attack and angle of sideslip in free flight produces the prescribed amount of normal force and side force in the given flight state.

[00145] FIGS. 18A-18C show a similar increase in segmentation and greater detail on the chamfers. FIG. 18A shows a more finely segmented variant of the present disclosure with all segments combined in the unitary or storage and launch configuration. The center of gravity of the present disclosure (21) is displaced towards the load transfer mechanism and nose weight (415) which results in the many benefits listed for the variant shown in FIG. 17A. The variants of the present disclosure shown in FIGS. 17A-17C and 18A-18C are stable and will tend to inherently stay together just after barrel exit as the muzzle blast washes over the projectile assembly (400), starting at the load transfer ring (415), then moving towards the body (410) and chamfers in the tail (417). However, just after clearing the muzzle blast zone, the opposite dynamic occurs as the present disclosure (401) is designed to separate rapidly and peel away from the projectile quickly and cleanly.

[00146] The large chamfers shown in FIG. 18A (417) form a pocket of low-pressure air during while being exposed to muzzle blast. This low-pressure air tends to hold the pieces of the present disclosure tightly against the sides of the projectile. However, the chamfers on the present disclosure (417) are also designed such that as the projectile assembly (400) clears the muzzle blast zone, the pocket of air in the middle of the chamfers shown in FIG. 18A goes from low pressure to high pressure as the pocket of air reaches full stagnation pressure for a split second before segment separation. This high pressure air pocket in the middle of the chamfers of FIG. 18A (417) will act as a wedge and rapidly rotate and translate the present disclosure (401) away from the projectile body. This process may be aided by the addition of small explosive charges placed between the segments and/or the projectile (430). FIG. 18B shows the individual segments of the present disclosure separating.

[00147] FIG. 18C shows the load transfer grooves (418), segmented load transfer ring and nose weight (415), lightweight body section (410) and center of gravity (21) displaced closer to the nose weight (415) than the aerodynamic center (22). The chamfers (417) at the free-flight aft of the present disclosure are tailored along with lengthwise curvature to achieve a particular trimmed angle of attack α, and sideslip angle, β to produce the prescribed amount of normal force and side force in a given flight state. The chamfers shown in FIG. 18C may also be augmented with any number of aerodynamic devices or excrescences to achieve the proper trim state and desired aeromechanical properties. Also of importance in chamfer tailoring shown in FIG. 18C is the recovery of base pressure which can be used to tailor the drag and/or axial force coefficients.

[00148] Referring to FIG. 19, a block diagram of a munition 1900 is shown. Munition 1900 may include or correspond to a round of munition, such as described with reference to FIGS. 5A-18C. Multiple portions of munition 1900 are be configured to achieve stable flight, e.g., non-tumbling flight, after launching from a weapon. For example, after separation of sabot system 1902 from projectile 1904, sabot system 1902 (i.e., one or more pieces thereof) achieves stable flight.

[00149] As illustrated in FIG. 19, munition 1900 includes sabot system 1902, projectile 1904, and propellant 1906. Sabot system 1902 is removably coupled to projectile 1904 and is configured to accelerate projectile 1904 and guide projectile 1904 prior to separation. Sabot system 1902 may include or correspond to one or more projectiles described above. Additionally, sabot system 1902 may include one or more features of different sabots described with reference to FIGS. 5A-18C.

[00150] Sabot system 1902 may optionally include one or more sections, i.e., a sabot assembly, in some implementations. In other implementations, sabot system 1902 includes a single section coupled together, i.e., a monolithic sabot. As illustrated in the example of FIG. 19, sabot system 1902, includes a nose cone.

[00151] Sabot system 1902 includes a center of gravity 1932 and an aerodynamic center 1934. The center of gravity 1932 is forward of the aerodynamic center 1934. The center of gravity 1932 may be reward of the aerodynamic center 1934 prior to release from the projectile 1904, in some implementations. However, after release of sabot system 1902 from the projectile 1904, the center of gravity 1932 is forward of the aerodynamic center 1934 and the sabot system 1902 achieves stable flight, as described above.

[00152] Projectile 1904 may include or correspond to one or more projectiles described above. Additionally, projectile 1904 may include one or more features of different projectiles described with reference to FIGS. 5A-18C. Propellant 1906 may include explosive charges, powders, gasses, etc., or another substance for launching projectiles.

[00153] Referring to FIG. 20, a block diagram of an example of a control system 2000 of a sabot system 1902 is shown. Control system 2000 may include or correspond to an electronic device or system. Control system 2000 may be configured to orient and direct sabot system 1902 such that sabot system 1902 achieves stable flight.

[00154] As shown in FIG. 20, control system 2000 includes one or more interfaces 2012 and one or more controllers, such as a representative controller 2016. Interfaces 2012 may include a network interface and/or a device interface configured to be communicatively coupled to one or more other devices, such as sensors 2070, control surfaces 2080, and/or motors 2078. For example, interfaces 2012 may include a transmitter, a receiver, or a combination thereof (e.g., a transceiver), and may enable wired communication, wireless communication, or a combination thereof.

[00155] The one or more controllers (e.g., controller 2016) include one or more processors and one or more memories, such as representative processor 2020 and memory 2022. Memory 2022 may include executable instructions 2032. The one or more sets of instructions 2032 may be further based on thresholds 2034, data set(s) 2036 stored in memory 2022 that aid in determining control signals 2082 (e.g., one or more output settings), and/or one or more translation algorithms for generating control signals 2082. For example, instructions 2032 may be based on thresholds 2034 and/or data set(s) 2036 stored in memory 2022 that aid in determining the one or more control signals 2082 (e.g., dimensions, measurements, and/or other parameters control surface 2080 alignment or orientation). To illustrate, the instructions 2032 may execute when thresholds 2034 for sensor data 2084 stored in memory 2022 are reached.

[00156] As shown in FIG. 20, processor 2020 is coupled to the memory 2022 and configured to execute the one or more instructions. Processor 2020 may include or correspond to a microcontroller/microprocessor, a central processing unit (CPU), a field-programmable gate array (FPGA) device, an application-specific integrated circuits (ASIC), another hardware device, a firmware device, or any combination thereof. Processor 2020 may be configured to execute instructions to initiate or perform one or more operations described with reference to FIGS. 5A-18C or 23-25.

[00157] In some implementations, control system 2000 may be configured to receive sensor data 2084 and generate and/or communicate control signals 2082 (e.g., one or more output settings) for control surfaces 2080 and/or motors 2078, based on the sensor data 2084. The one or more sets of instructions 2032 may be further based on thresholds 2034 and/or data set(s) 2036 stored in memory 2022 that aid in determining the one or more output settings indicated by control signals 2082.

[00158] Referring to FIG. 21, a block diagram of vehicle is shown. In the example of FIG. 21, the vehicle is an aircraft 2100. Aircraft 2100 may include or correspond to an such as described above with reference to FIGS. 5A-18C, and including a sabot as described above. In FIG. 21, aircraft 2100 include one or more propulsion system 2102, control systems 2104, a body 2106, and one or more weapons systems 2108. As illustrated in FIG. 21, the one or more weapons systems includes a cannon 2112 configured to launch munitions, such as munition 2114. Munitions 2114 may include or correspond to munitions 1900, sabot system 1902, or a sabot as described above with reference to FIGS. 5A-18C. In FIG. 21 Munitions 2114 include projectiles 2122 and sabots 2124 (e.g., 1902 or another sabot as described above with reference to FIGS. 5A-18C).

[00159] In a particular implementation, aircraft 2100 further includes a sensor, such as sensors 2070, and a controller, such as controller 2016. Aircraft 2100 may be configured to send control signals, such as 2082, to sabots 2124 of munitions 1900 to control or guide flight of sabots 2124 based on sensor data (e.g., 2084, such as orientation data) from the sensors. The orientations may include or correspond to an Earth orientation, a horizon orientation, a launching aircraft orientation, a friendly aircraft orientation, or any combination thereof. To illustrate, aircraft 2100 sends control signals (e.g., 2082) via an interface (e.g., 2012) to sabots 2124 to activate control surfaces (e.g., 2080) or motors (e.g., 2078, such as rocket motors) thereof.

[00160] Referring to FIG. 22, a block diagram of a cannon 2210 is shown. Cannon 2210 may include or correspond to cannon 2112. As illustrated in FIG. 22, cannon 2210 may be included in a ground installation 2200.

[00161] Referring to FIGS. 23-25, exemplary methods are illustrated. Method 2300 of FIG. 23 may be performed by a sabot, such as any of the sabots described herein. Method 2300 includes increasing, by a sabot coupled to a projectile, a velocity of the projectile responsive to expansion of propellant, at 2310. Method 2300 also includes, after exiting barrel, separating, by the sabot, from the projectile, at 2312. Method 2300 further includes achieving, by the sabot, stable flight after separation from the projectile, at 2314. Thus, method 2300 describes operation of a sabot which can be incorporated into a vehicle (e.g., an aerial vehicle) without the sabot entering the movement path of the vehicle and causing damage to the vehicle.

[00162] Method 2400 of FIG. 24 may be performed by a controller, such as any of the controllers or control systems described herein. As an illustrative example, the method 2400 of FIG. 24 may be performed by a control system 2000 or a controller 2016. The control system 2000 or the controller 2016 may be including in a sabot (e.g., a guided sabot), an aircraft (e.g., 2100), or both. Method 2400 includes receiving sensor data, at 2410. Method 2400 also includes determining whether to activate corrective flight path action based on the sensor data, at 2412. Method 2400 further includes initiating corrective flight path action, at 2414. Thus, method 2400 describes operation of a sabot which can be incorporated into a vehicle (e.g., an aerial vehicle) without the sabot entering the movement path of the vehicle and causing damage to the vehicle.

[00163] Method 2500 of FIG. 25 may be performed by a vehicle, such as any of the vehicles or aircraft described herein. As an illustrative example, the method 2500 of FIG. 25 may be performed by aircraft 2100. Method 2500 includes loading a round of ammunition into a barrel, the ammunition included a sabot having positive stability, at 2510. Method 2500 further includes firing the round of ammunition, wherein the sabot decouples from a projectile of the round of ammunition and exits a movement path of a vehicle, at 2512. Thus, method 2500 describes operation of a vehicle (e.g., an aerial vehicle) which can incorporate sabots, and their accompanying benefits, without the sabots entering the movement path of the vehicle and causing damage to the vehicle.

[00164] It is noted that one or more operations described with reference to one of the methods of FIGS. 23-25 may be combined with one or more operations of another of FIGS. 23-24. For example, one or more operations of method 2400 may be combined with one or more operations of method 2500. Additionally, or alternatively, one or more operations described above with reference to FIGS. 5A-22 may be combined with one or more operations of FIGS. 23-25, or a combination of FIGS. 23-25.

[00165] Although the embodiments of the present disclosure and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the appended claims. Further, although the drawings may illustrate some of the concepts disclosed herein as logical or functional blocks, it is to be understood that each of those blocks may be implemented in hardware, software, or a combination of hardware and software. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the present disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

CLAIMS

What is claimed is:

1. An aeromechanically stable sabot comprising:

a sabot assembly which is lower in mass than a projectile that the sabot assembly is configured to accelerate and release;

means of transferring launch pressures and loads when inside a barrel during a firing event to the projectile as the projectile is accelerated down a length of the barrel;

means of accommodating projectiles that are smaller in caliber than a bore of the barrel and longer than the sabot assembly; and

means of separating from the projectile such that the sabot assembly and the projectile will fly in stable free flight upon separation without pitching or yawing more than 360 degrees about the sabot assembly in pitch or yaw axes after exiting the barrel;

wherein the sabot assembly has a center of gravity location that is displaced forward of longitudinal and directional aerodynamic centers that the sabot assembly will not tumble about the sabot pitch and yaw axes after exiting the barrel and projectile release;

wherein the sabot assembly has a center of gravity position, prior to launch and during launch from the barrel, which is ahead of the longitudinal and directional aerodynamic centers of the sabot or behind the longitudinal and directional aerodynamic centers of the sabot during the launch event, but following sabot launch and separation from the projectile, will fly in a stable configuration such that the sabot assembly center of gravity will be ahead of the sabot assembly longitudinal and directional aerodynamic centers;

wherein the sabot assembly has a lower density aft section and higher density forward section such that the center of gravity of the sabot assembly is shifted farther forward than the free-flight longitudinal and directional aerodynamic centers such that the pitching moment coefficient about the center of gravity with respect to angle of attack is less than zero ($C_{mcg\alpha} < 0$) and the yawing moment coefficient about the center of gravity with respect to sideslip angle is greater than zero ($C_{ncg\beta} > 0$); and a geometric feature, a functional feature, mass asymmetry or any combination thereof, configured to establish a trimmed angle of attack (α) and/or slideslip angle (β) of the sabot assembly to execute a maneuver such that a collision between the sabot assembly and the launching aircraft and/or associated friendly aircraft is avoided.

2. The aeromechanically stable sabot of claim 1, wherein the assembly includes at least one aeromechanically stable segment.

3. The aeromechanically stable sabot of claim 1, further comprising one or more section having a bourrelet configuration.

4. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate a projectile nose cone, a body, canards, wings, fins and strakes via a series of suitable slots, holes and/or geometric accommodations through which they can pass.

5. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate at least one band, strap or seal that mitigates intrusion of water or other adverse conditions during storage, transportation and handling and may function as in-bore lubricant and/or obturating bands.

6. The aeromechanically stable sabot of claim 1, further comprising a series of baffles and/or valves that prevent gun gas backflow through and/or around the sabot during the firing event.

7. The aeromechanically stable sabot of claim 1, wherein the assembly includes one or more materials configured to biodegrade, deflagrate, disassociate, sublimate, evaporate, dissolve, combust or otherwise mechanically break down after launch and projectile separation.

8. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to transfer launch loads to the projectile via a series of grooves or ridges.

9. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate projectiles that can be as long as 99% of the entire shell length.

10. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate a projectile, wherein the projectile comprises a dart, a flechette, or a cargo round, wherein the projectile has a circular shape, a regular polygon shape, or an irregular prism shape , wherein the projectile include one or more strakes, one or more canards, one or more wings, one or more fins, or any combination thereof.

11. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate one or more fixed or movable aerodynamic stabilizers, the one or more fixed or movable aerodynamic stabilizers configured to increase static stability margins, enable commanded maneuvers, or both, wherein the aerodynamic stabilizers comprise one or more canards, one or more wings, one or more fins, or any combination thereof.

12. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate a plurality of sensors, the configured plurality of sensors to determine an orientation of the assembly relative to one or more reference orientations, wherein the one or more reference orientations include an Earth orientation, a horizon orientation, a launching aircraft orientation, a friendly aircraft orientation, or any combination thereof.

13. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate one or more extendable flight control surfaces mounted on or within the assembly, the one or more extendable flight control surfaces configured to be extended after launch, wherein the one or more extendable flight control surfaces comprise one or more canards, one or more wings, one or more fins, or any combination thereof.

14. The aeromechanically stable sabot of claim 1, further comprising a flight control system configured to execute avoidance maneuvers, control flight of one or more components of the assembly to ground, or both.

15. The aeromechanically stable sabot of claim 1, further comprising a rocket motor including at least one nozzle configured to execute a controlled maneuver.

16. The aeromechanically stable sabot of claim 1, further comprising a separation/explosive charge configured to induce rapid subcomponent separation upon muzzle exit.

17. The aeromechanically stable sabot of claim 1, further comprising nose seals and/or handling guards which are made from compliant, frangible materials, and wherein the compliant, frangible materials be ingested by launching aircraft engines or strike the launching aircraft airframe without inducing adverse harm or damage.

18. The aeromechanically stable sabot of claim 1, wherein the assembly is configured to accommodate projectile full-bore fins by expanding via clip assemblies between segments or by breaking into aeromechanically stable segments.

19. An apparatus comprising:

a monolithic sabot configured to support a projectile in a barrel,

wherein a center of gravity of the monolithic sabot is positioned forward an aerodynamic center of the monolithic sabot.

20. The apparatus of claim 19, further comprising a nose seal coupled to the monolithic sabot.

21. The apparatus of claim 20, wherein the nose seal is configured to separate from the monolithic sabot.

22. The apparatus of claim 21, wherein the nose seal is made from compliant, frangible materials, and wherein the compliant, frangible materials are configured to be ingested by a launching aircraft engine or strike a launching aircraft airframe without inducing adverse harm or damage.

23. The apparatus of claim 19, wherein the monolithic sabot is configured to stay in one piece after separating from the projectile.

24. The apparatus of claim 19, wherein the monolithic sabot includes one or more fixed aerodynamic stabilizers configured to increase static stability of the monolithic sabot.

25. The apparatus of claim 24, wherein the one or more fixed aerodynamic stabilizers include one or more strakes, one or more canards, one or more wings, one or more fins, or any combination thereof.

26. The apparatus of claim 19, wherein the monolithic sabot includes:

one or more control surfaces; and

a controller configured to adjust the one or more control surfaces.

27. The apparatus of claim 26, wherein the one or more control surfaces are configured to extend away from a body of the monolithic sabot.

28. The apparatus of claim 26, further comprising one or more sensors configured to generate sensor data, wherein the controller is configured to adjust the one or more control surfaces based on the sensor data.

29. The apparatus of claim 28, wherein the one or more sensors comprise velocity sensors, attitude sensors, or any combination thereof.

30. The apparatus of claim 26, wherein the one or more sensors or the controller is configured to determine an orientation of the monolithic sabot relative to one or more reference orientations, and wherein the one or more reference orientations include an Earth orientation, a horizon orientation, a launch orientation, a barrel exit orientation, a launching aircraft orientation, a friendly aircraft orientation, or any combination thereof.

31. The apparatus of claim 19, wherein the center of gravity is forward of longitudinal and directional aerodynamic centers of the monolithic sabot such that the monolithic sabot will not tumble about pitch and yaw axes after releasing the projectile.

32. The apparatus of claim 19, wherein the center of gravity is behind a longitudinal and directional aerodynamic centers of the monolithic sabot prior to a launch event, and wherein following the launch event and separation from the projectile the center of gravity of the monolithic sabot is forward of the longitudinal and directional aerodynamic centers of the monolithic sabot.

34. The apparatus of claim 19, wherein the monolithic sabot has a lower density aft section and a higher density forward section such that the center of gravity of the monolithic sabot is forward of free-flight longitudinal and directional aerodynamic centers such that a pitching moment coefficient about the center of gravity with respect to angle of attack is less than zero

($C_{mcg\alpha} < 0$) and a yawing moment coefficient about the center of gravity with respect to sideslip angle is greater than zero ($C_{ncg\beta} > 0$.

35. The apparatus of claim 19, wherein the monolithic sabot includes or is configured to be coupled to at least one band, strap or seal that mitigates intrusion of water or other adverse conditions during storage, transportation and handling and may function as in-bore lubricant and/or obturating bands.

36. The apparatus of claim 19, wherein the monolithic sabot includes a series of baffles and/or valves that prevent propellant backflow through and/or around the monolithic sabot during a firing event.

37. The apparatus of claim 19, wherein the monolithic sabot includes one or more materials configured to biodegrade, deflagrate, disassociate, sublimate, evaporate, dissolve, combust or otherwise mechanically break down after launch and projectile separation.

38. The apparatus of claim 19, wherein the monolithic sabot is configured to transfer launch loads to the projectile via a series of grooves or ridges of the monolithic sabot.

39. The apparatus of claim 19, further comprising a rocket motor coupled to the monolithic sabot, the rocket motor configured to propel the monolithic sabot.

40. An apparatus comprising:

a sabot assembly including a plurality of pieces and configured to support a projectile in a barrel,

wherein a center of gravity of at least one piece of the plurality of pieces of the sabot assembly is positioned forward an aerodynamic center of the at least one piece.

41. The apparatus of claim 40, wherein a center of gravity of each piece of the plurality of pieces the sabot assembly is positioned forward a corresponding aerodynamic center of each piece.

42 The apparatus of claim 40, wherein the sabot assembly includes one or more sections having a bourrelet configuration.

43. The apparatus of claim 40, further comprising a separation charge configured to induce separation of the pieces of the sabot assembly after exiting the barrel.

44. The apparatus of claim 40, further comprising one or more clips configured to decouple the pieces of the sabot assembly after exiting the barrel.

45. The apparatus of claim 40, further comprising a nose seal coupled to the sabot assembly.

46. The apparatus of claim 45, wherein the nose seal is configured to separate from the sabot assembly.

47. The apparatus of claim 46, wherein the nose seal is made from compliant, frangible materials, and wherein the compliant, frangible materials are configured to be ingested by a launching aircraft engine or strike a launching aircraft airframe without inducing adverse harm or damage.

48. The apparatus of claim 40, wherein the pieces of the sabot assembly are configured to separate from each other after separation of the sabot assembly from the projectile.

49. The apparatus of claim 40, wherein the sabot assembly includes one or more fixed aerodynamic stabilizers configured to increase static stability of the sabot assembly.

50. The apparatus of claim 49, wherein the one or more fixed aerodynamic stabilizers include one or more strakes, one or more canards, one or more wings, one or more fins, or any combination thereof.

51. The apparatus of claim 40, wherein the sabot assembly includes:

one or more control surfaces; and

a controller configured to adjust the one or more control surfaces.

52. The apparatus of claim 51, wherein the one or more control surfaces are configured to extend away from a body of the sabot assembly.

53. The apparatus of claim 51, further comprising one or more sensors configured to generate sensor data, wherein the controller is configured to adjust the one or more control surfaces based on the sensor data.

54. The apparatus of claim 51, wherein the one or more sensors comprise velocity sensors, attitude sensors, or any combination thereof.

55. The apparatus of claim 51, wherein the one or more sensors or the controller is configured to determine an orientation of the sabot assembly relative to one or more reference orientations, and wherein the one or more reference orientations include an Earth orientation, a horizon orientation, a launch orientation, a barrel exit orientation, a launching aircraft orientation, a friendly aircraft orientation, or any combination thereof.

56. The apparatus of claim 40, wherein the center of gravity is forward of longitudinal and directional aerodynamic centers of the sabot assembly such that the sabot assembly will not tumble about pitch and yaw axes after releasing the projectile.

57. The apparatus of claim 40, wherein the center of gravity is behind a longitudinal and directional aerodynamic centers of the sabot assembly prior to a launch event, and wherein following the launch event and separation from the projectile the center of gravity of the sabot assembly is forward of the longitudinal and directional aerodynamic centers of the sabot assembly.

58. The apparatus of claim 40, wherein the sabot assembly has a lower density aft section and a higher density forward section such that the center of gravity of the sabot assembly is forward of free-flight longitudinal and directional aerodynamic centers such that a pitching moment coefficient about the center of gravity with respect to angle of attack is less than zero ($C_{mcg\alpha} < 0$) and a yawing moment coefficient about the center of gravity with respect to sideslip angle is greater than zero ($C_{ncg\beta} > 0$.

59. The apparatus of claim 40, wherein the sabot assembly includes or is configured to be coupled to a projectile nose cone, a body, canards, wings, fins and strakes via a series of suitable slots, holes and/or geometric accommodations.

60. The apparatus of claim 40, wherein the sabot assembly includes or is configured to be coupled to at least one band, strap or seal that mitigates intrusion of water or other adverse conditions during storage, transportation and handling and may function as in-bore lubricant and/or obturating bands.

61. The apparatus of claim 40, wherein the sabot assembly includes a series of baffles and/or valves that prevent propellant backflow through and/or around the sabot assembly during a firing event.

62. The apparatus of claim 40, wherein the sabot assembly includes one or more materials configured to biodegrade, deflagrate, disassociate, sublimate, evaporate, dissolve, combust or otherwise mechanically break down after launch and projectile separation.

63. The apparatus of claim 40, wherein the sabot assembly is configured to transfer launch loads to the projectile via a series of grooves or ridges of the sabot assembly.

64. The apparatus of claim 40, further comprising a rocket motor coupled to the sabot assembly, the rocket motor configured to propel the sabot assembly.

65. A munition comprising:
the apparatus of claims 19-64; and
the projectile.

66. The munition of claim 65, wherein the projectile comprises a dart, a flechette, or a cargo round.

67. The munition of claim 65, wherein the projectile has a circular shape, a regular polygon shape, or an irregular prism shape.

68. The munition of claim 65, wherein the projectile include one or more strakes, one or more canards, one or more wings, one or more fins, or any combination thereof.

69. An vehicle comprising:
the munition of claims 19-64; and

a weapon configured to launch the munition.

70. The vehicle of claim 69, wherein the vehicle comprises an aircraft and wherein the apparatus is an aeromechanically stable sabot which is configured to exit a flight path of the aircraft after exiting the weapon.

71. The vehicle stable sabot of claim 69, wherein the vehicle comprises an aircraft and wherein the apparatus is a guided sabot which is configured to activate a control surface, a motor, or both, to move the guided sabot away from a flight path of the aircraft after exiting the weapon.

72. An system comprising:
the munition of claims 65-68; and
a weapon configured to launch the munition.

73. A method achieving stable flight, the method comprising:
increasing, by a sabot coupled to a projectile, a velocity of the projectile responsive to receiving force from a propellant;
after exiting a barrel, separating, by the sabot, from the projectile; and
achieving, by the sabot, stable flight after separation from the projectile.

74. The method of claim 73, further comprising exiting a flight path of an aircraft after exiting the barrel.

75. The method of claim 73, activating a control surface, a motor, or both, to move the sabot away from a flight path of an aircraft after exiting the barrel.

76. A method operating a guided sabot, the method comprising:
receiving, at a sabot, sensor data;
determining, at the sabot, whether to activate corrective flight path action; and
responsive to determining to activate corrective flight path action, initiating, at the sabot, corrective flight path action.

77. The method of claim 76, wherein initiating corrective flight path action includes exiting, by the sabot, a flight path of an aircraft.

78. The method of claim 76, wherein initiating corrective flight path action includes activating, at the sabot, a control surface, a motor, or both, to move the sabot away from a flight path of an aircraft.

79. A method of operating a vehicle, the method comprising:

loading a round of ammunition into a barrel, the ammunition including a sabot having positive stability; and

firing the round of ammunition, wherein the sabot decouples from a projectile of the round of ammunition and the sabot exits a movement path of the vehicle.

80. The method of claim 79, executing, by the vehicle, a turn, wherein the sabot is outside of a second movement path of the vehicle during the turn.

81. The method of claim 79, further comprising transmitting, by the vehicle, commands to the sabot, the commands configured to activate a control surface of the sabot, a motor of the sabot, or both, to move the sabot away from the movement path of the vehicle.

82. A non-transitory computer-readable medium comprising instructions, that when executed by a processor, cause the processor to perform the method of any of claims 76-81.

83. An apparatus comprising:

at least one processor; and

a memory coupled to the at least one processor,

wherein the at least one processor is configured to perform the method of any of claims 76-81.

ABSTRACT

An aeromechanically stable sabot system that includes a center of gravity that is placed forward of an aerodynamic center of the aeromechanically stable sabot system. By placing the center of gravity forwards of the aerodynamic center, the sabot system exhibits positive stability. To illustrate, the sabot system and/or portions thereof will return to stable flight after being disturbed in pitch (vertically or about a transverse axis) or yaw (side to side or about a vertical axis).

PRIOR ART

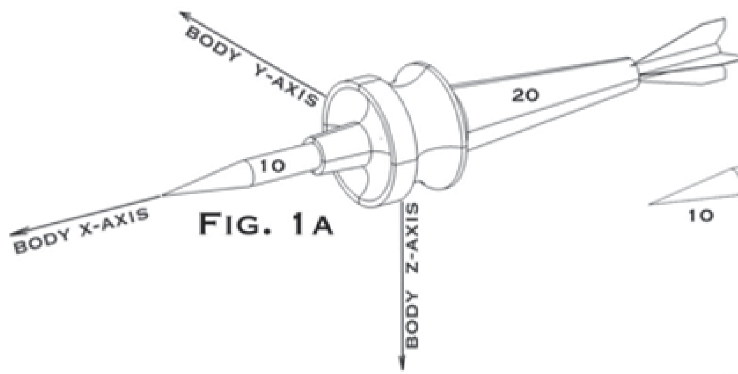


FIG. 1A

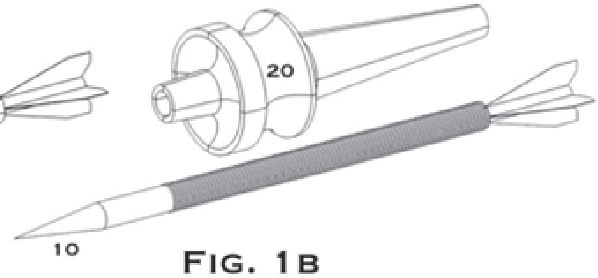


FIG. 1B

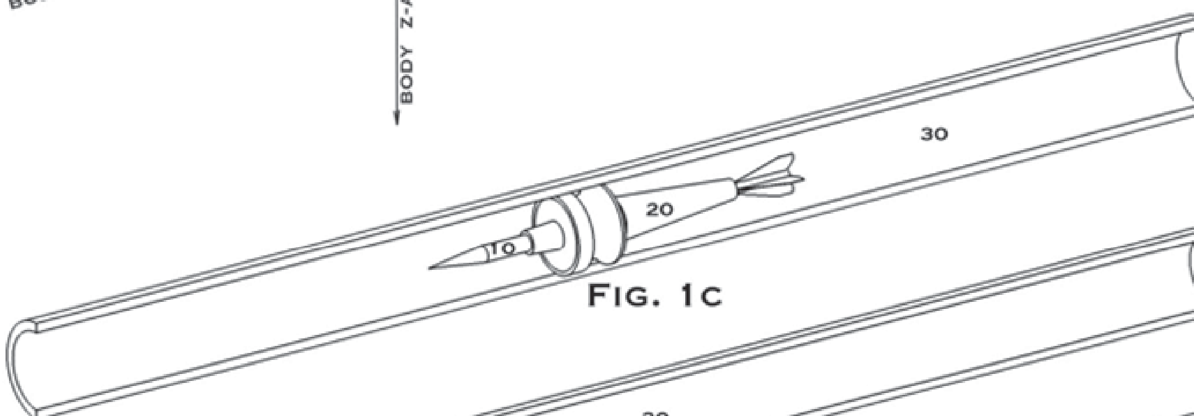


FIG. 1C

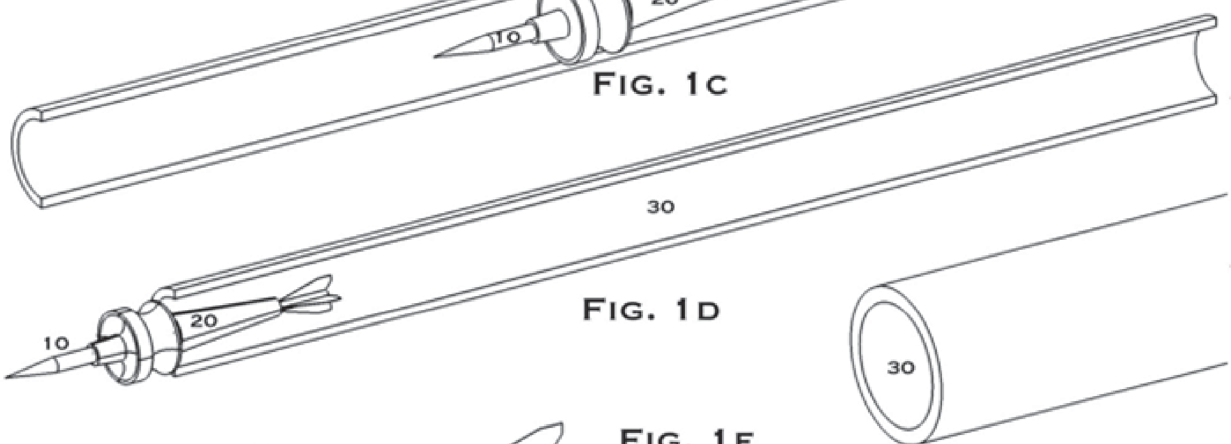
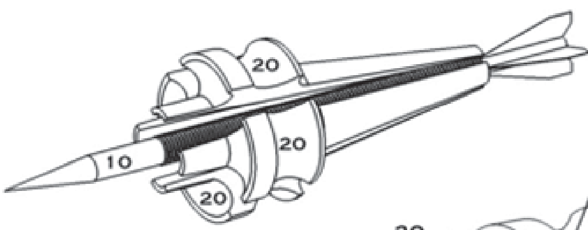


FIG. 1D

FIG. 1E



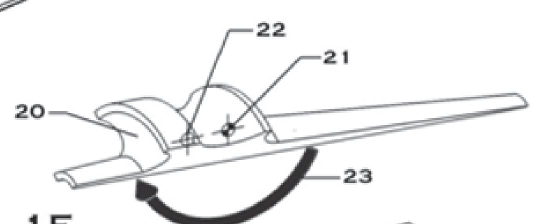


FIG. 1F

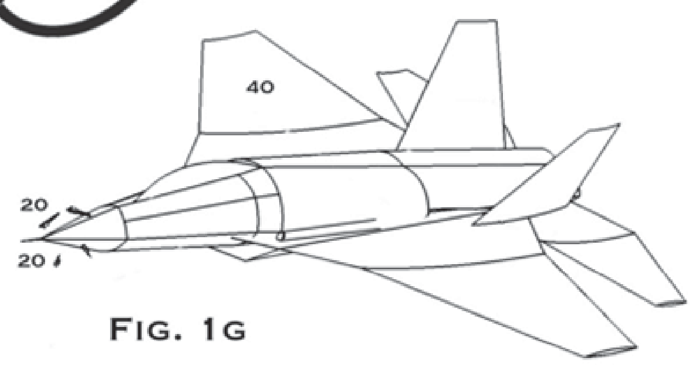


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FIG. 1G

PRIOR ART

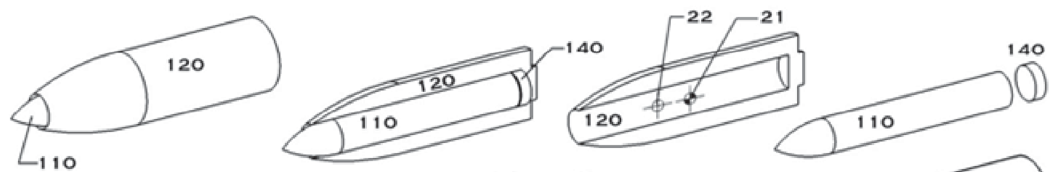


FIG. 2A

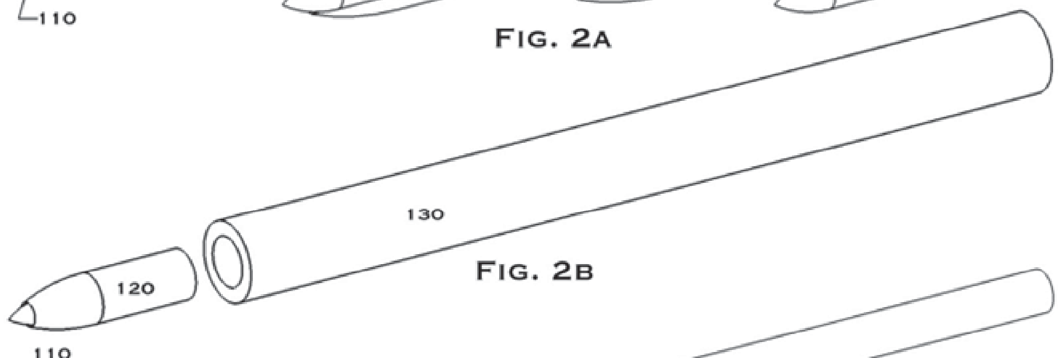


FIG. 2B

FIG. 2C

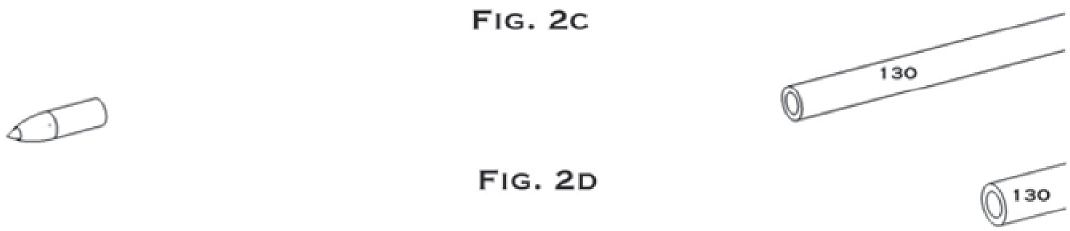


FIG. 2D

FIG. 2E

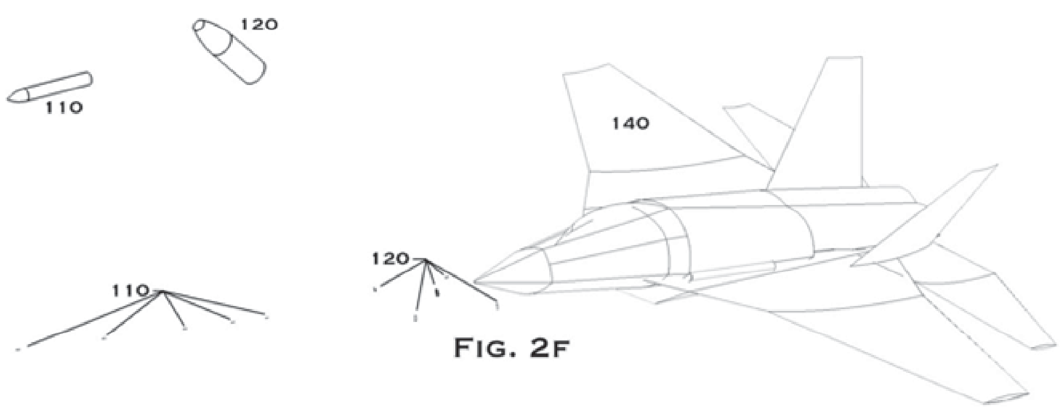


FIG. 2F

PRIOR ART

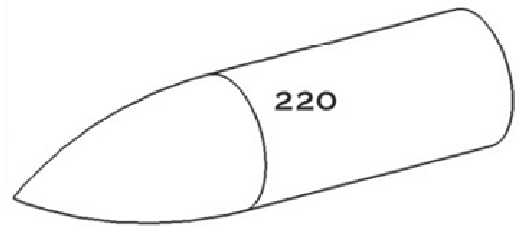


FIG. 3A

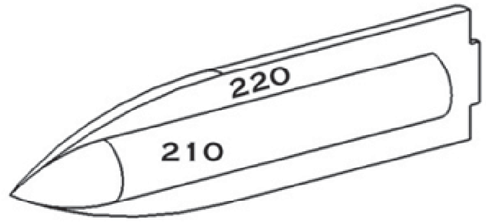


FIG. 3B

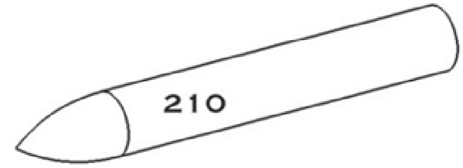


FIG. 3C

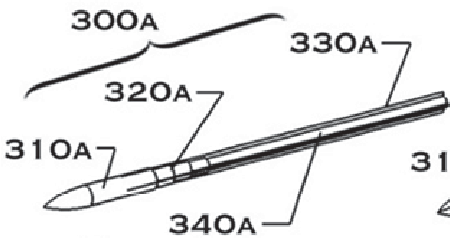


FIG. 4A

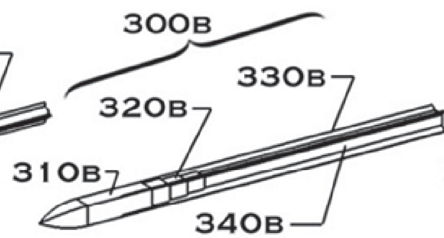


FIG. 4B

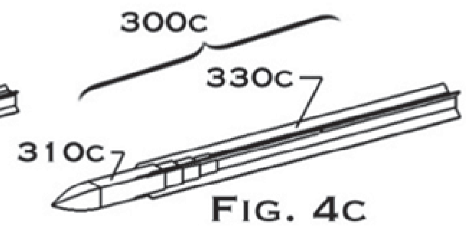


FIG. 4C

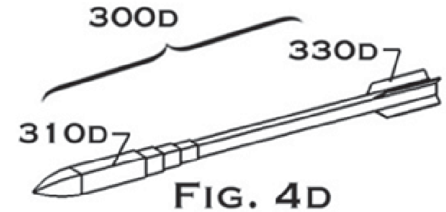


FIG. 4D

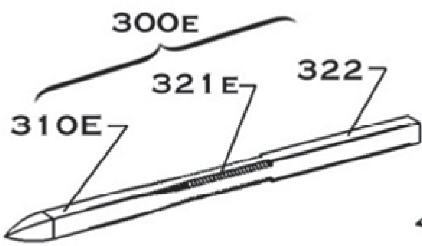


FIG. 4E

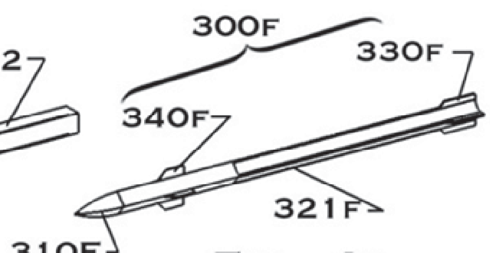


FIG. 4F

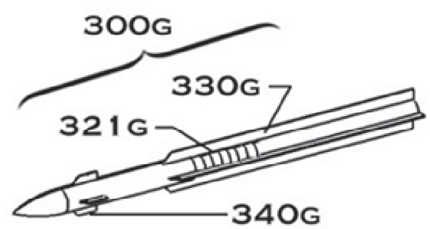


FIG. 4G

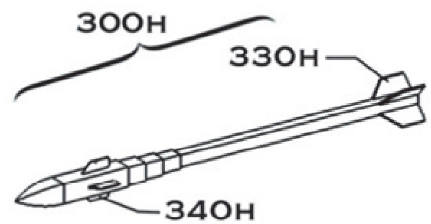


FIG. 4H

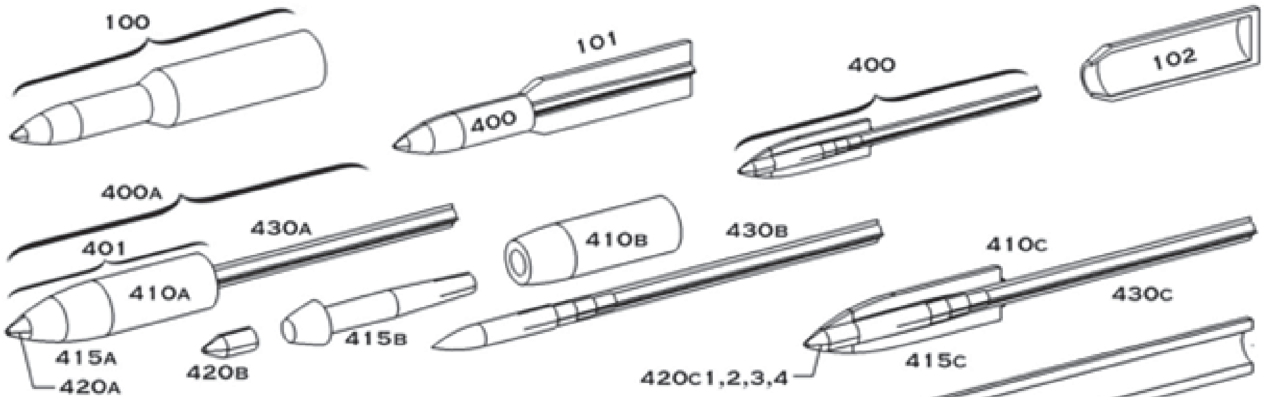


FIG.5A

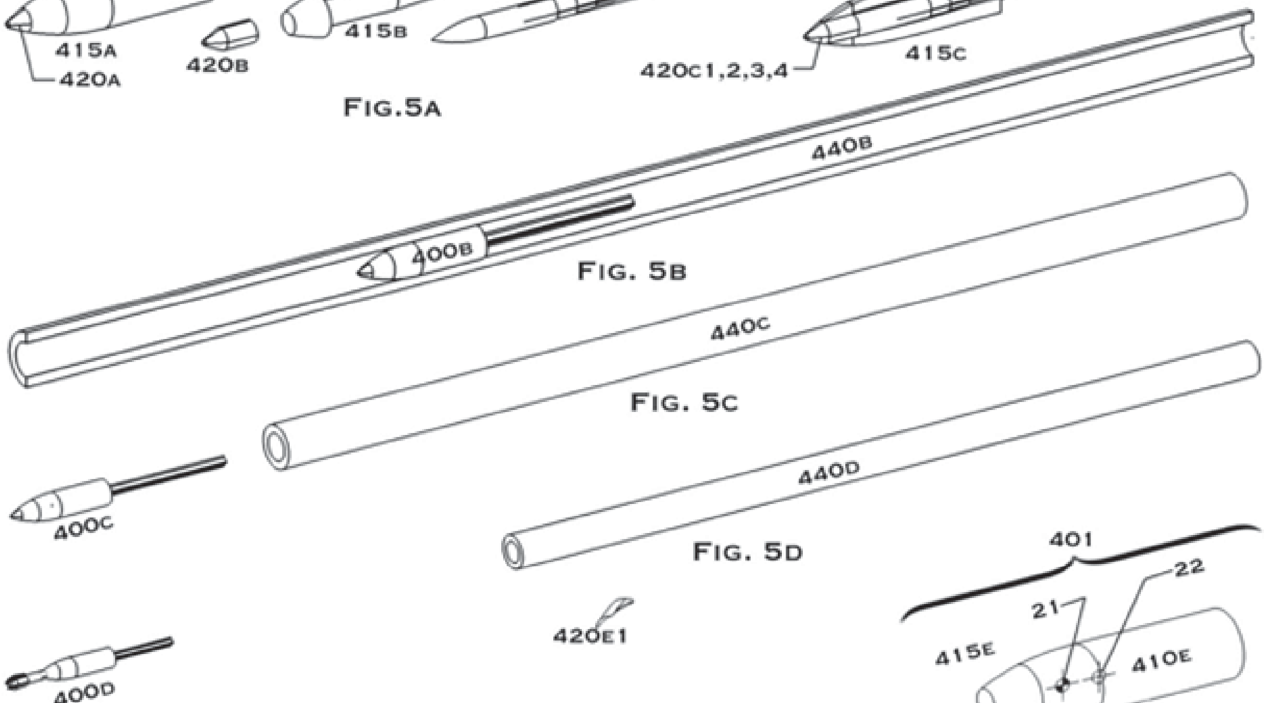


FIG. 5B

FIG. 5C

FIG. 5D

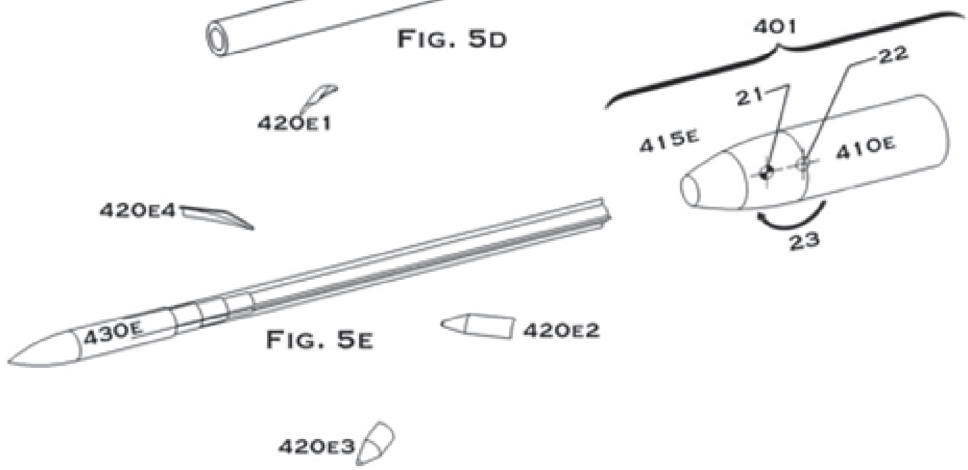


FIG. 5E

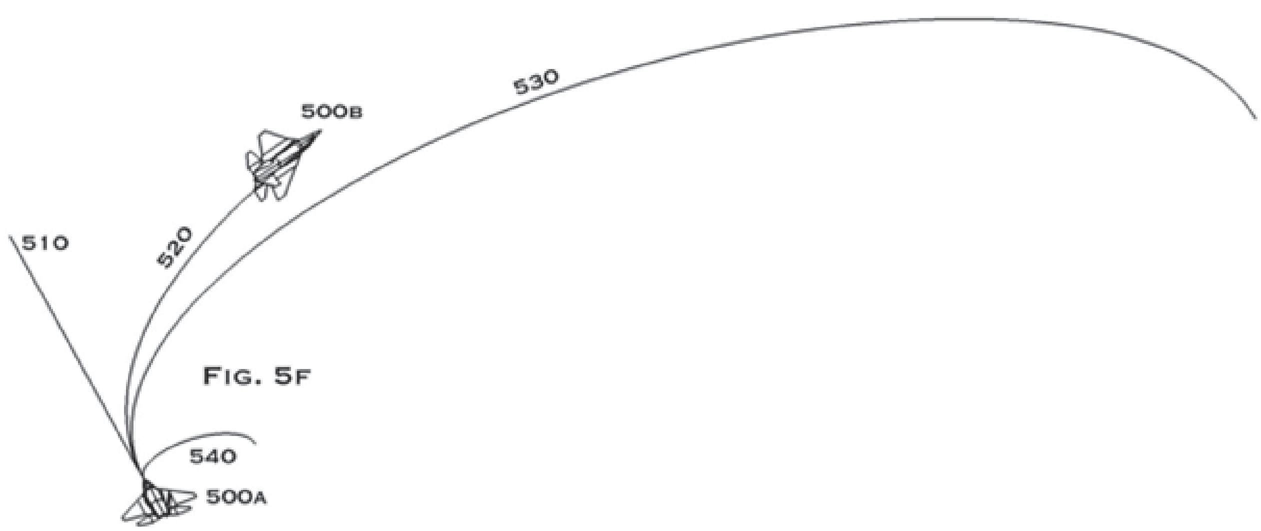


FIG. 5F

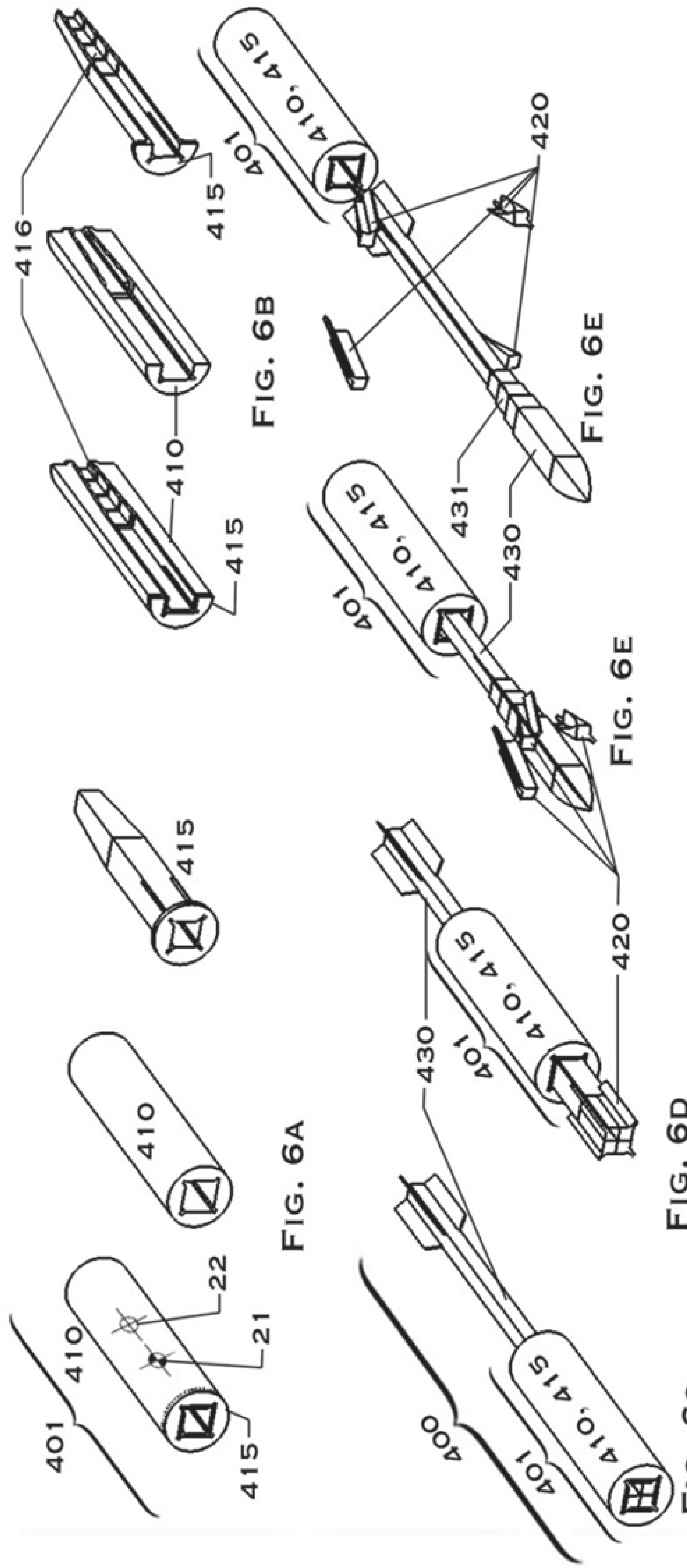


FIG. 6A

FIG. 6B

FIG. 6C

FIG. 6D

FIG. 6E

FIG. 6E

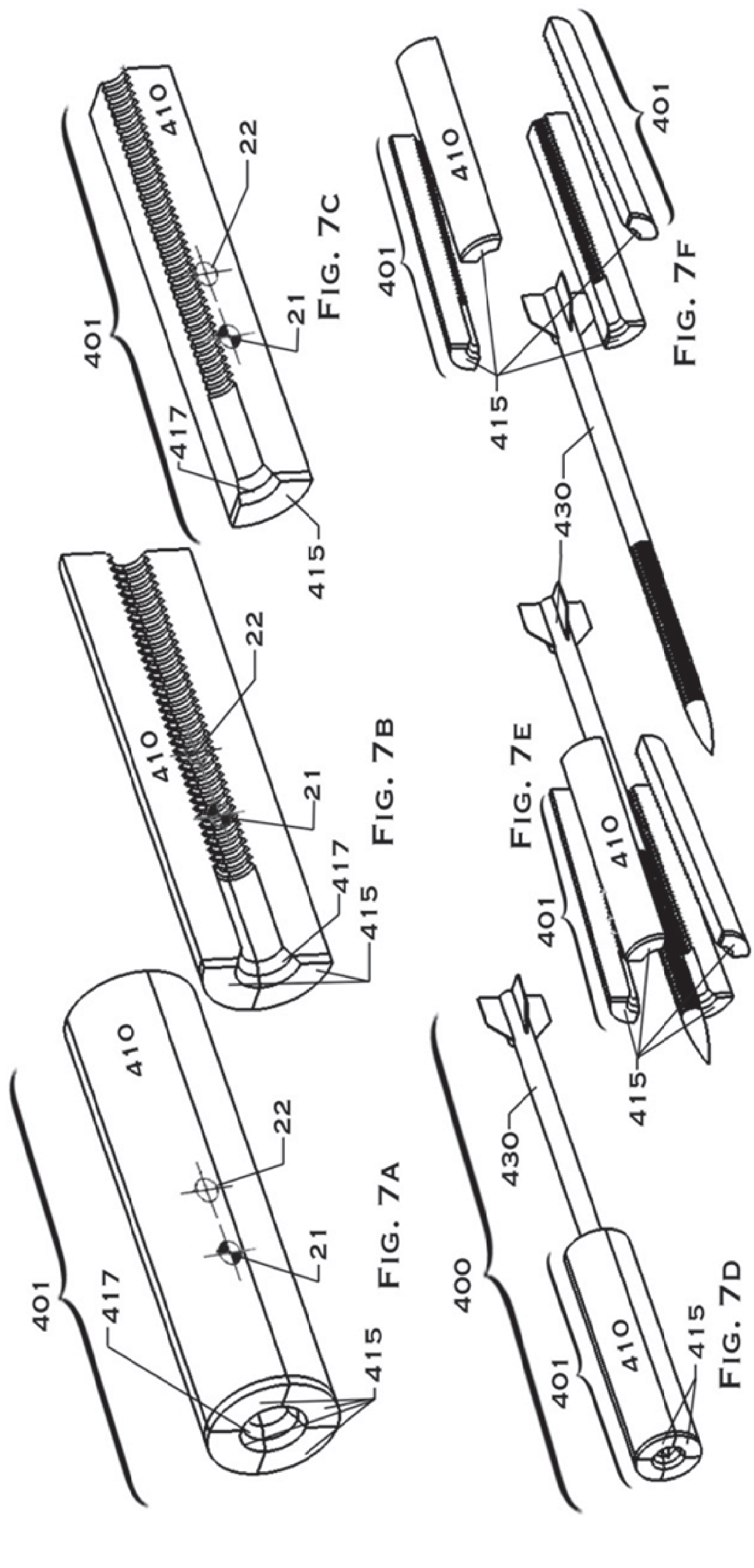


FIG. 7A
FIG. 7B
FIG. 7C
FIG. 7D
FIG. 7E
FIG. 7F

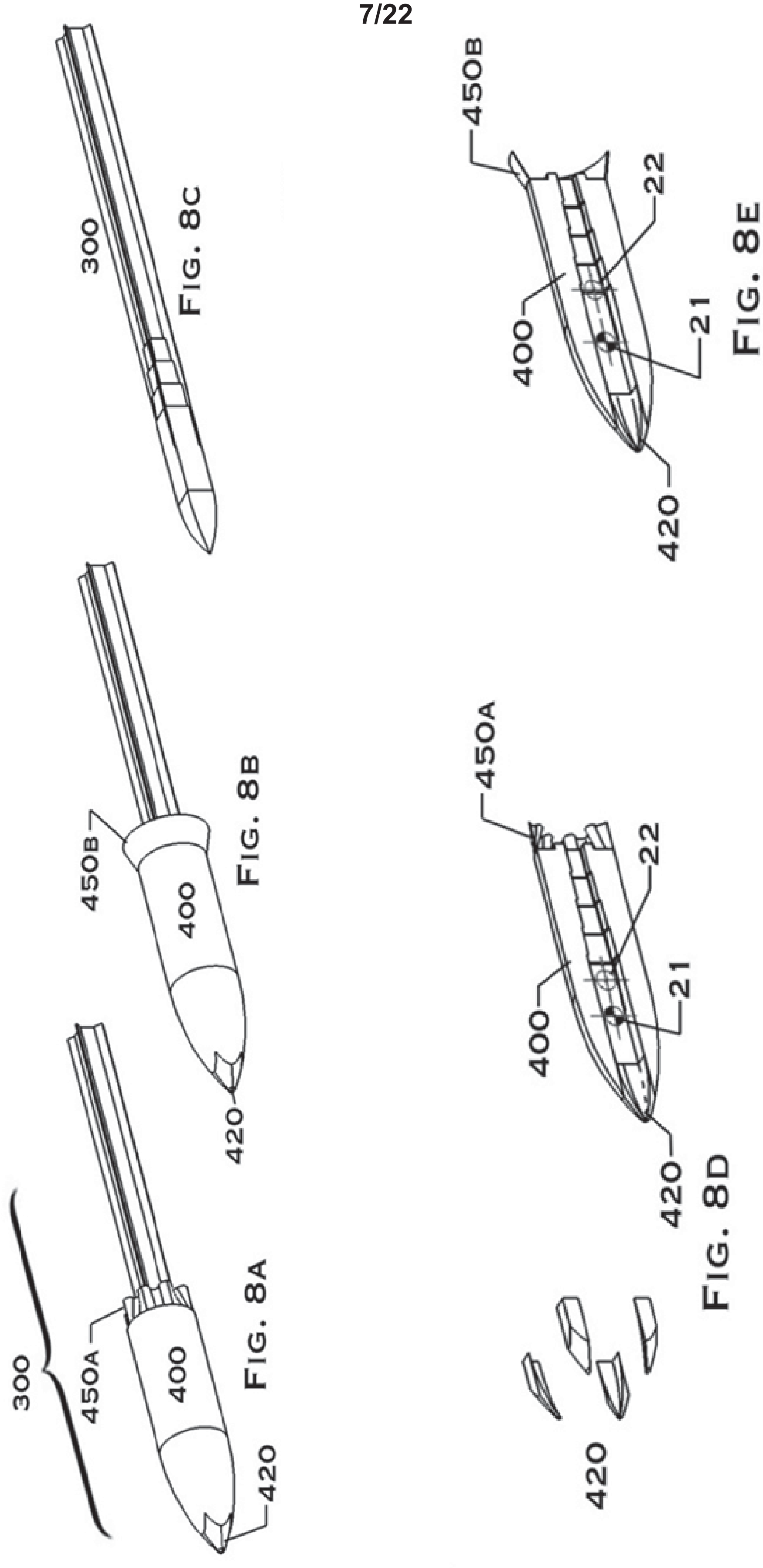


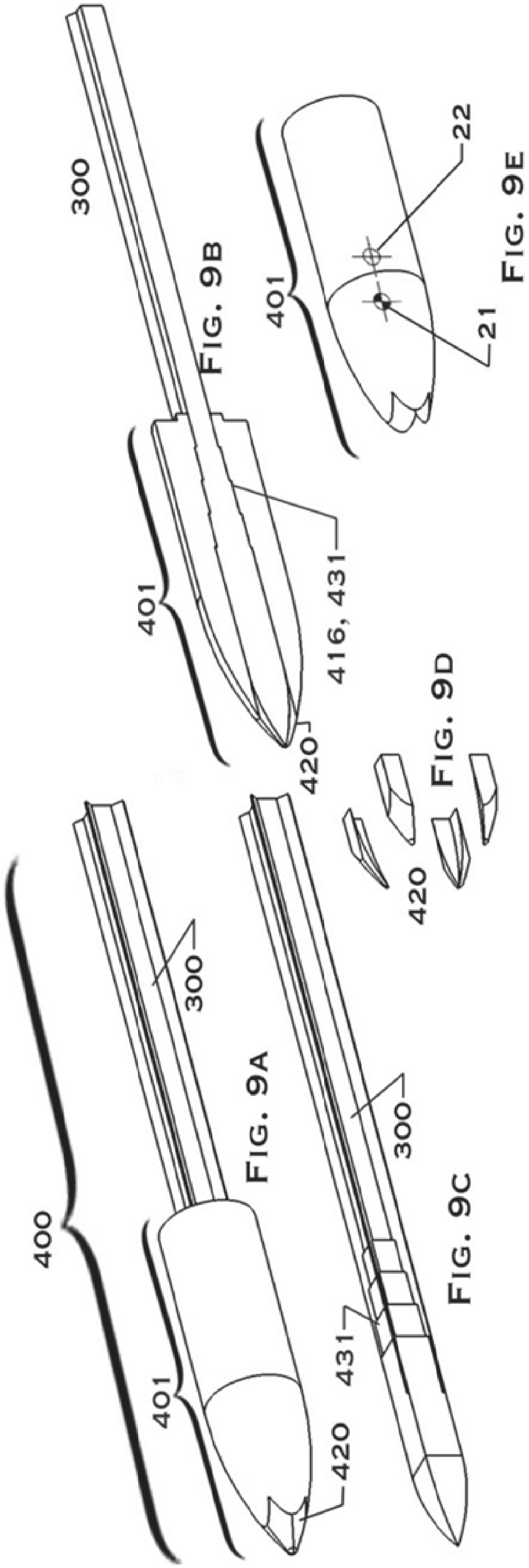
Fig. 8A

Fig. 8B

Fig. 8C

Fig. 8D

Fig. 8E


300
FIG. 9B
401
416, 431
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22
21
FIG. 9E
FIG. 9D
420
400
401
420
300
FIG. 9A
300
431
FIG. 9C

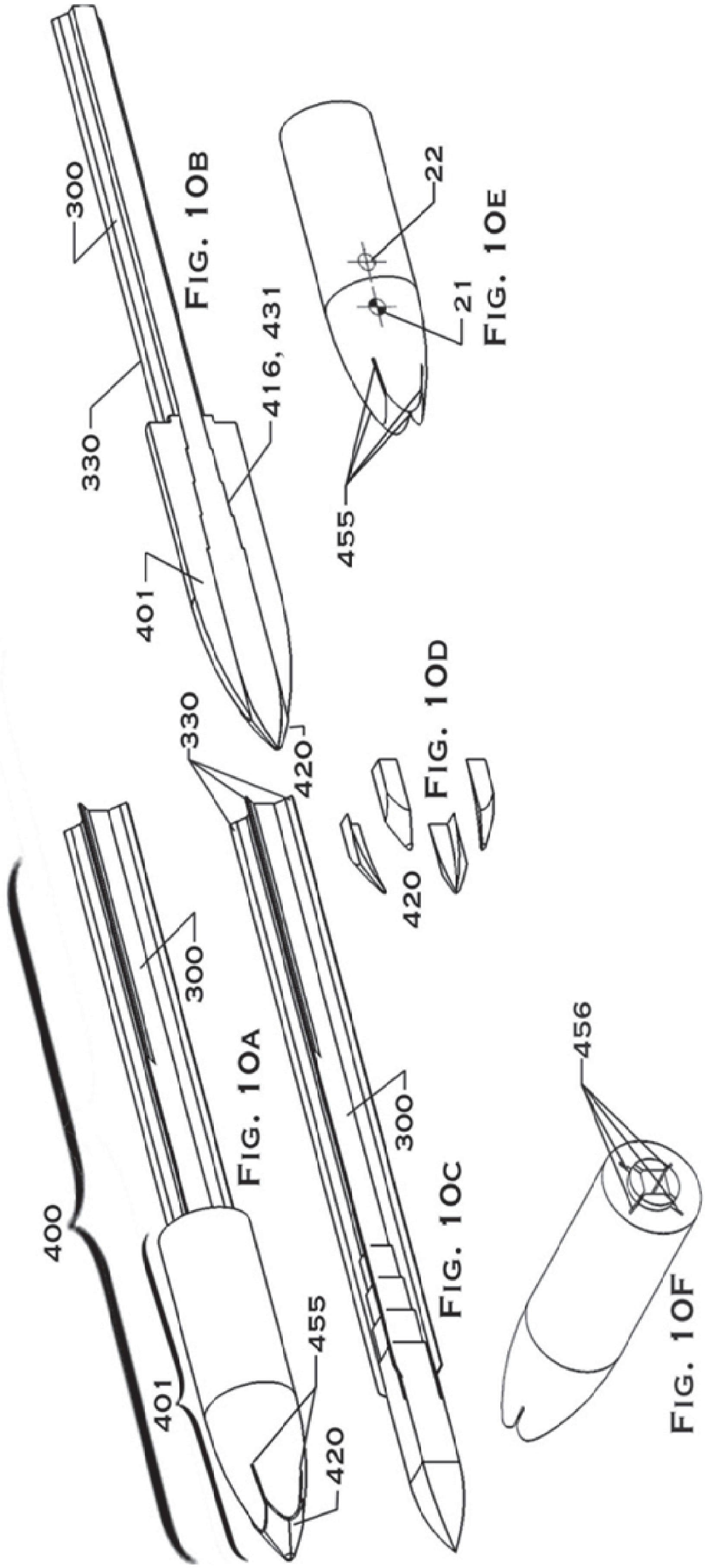

FIG. 10A FIG. 10B FIG. 10C FIG. 10D FIG. 10E FIG. 10F

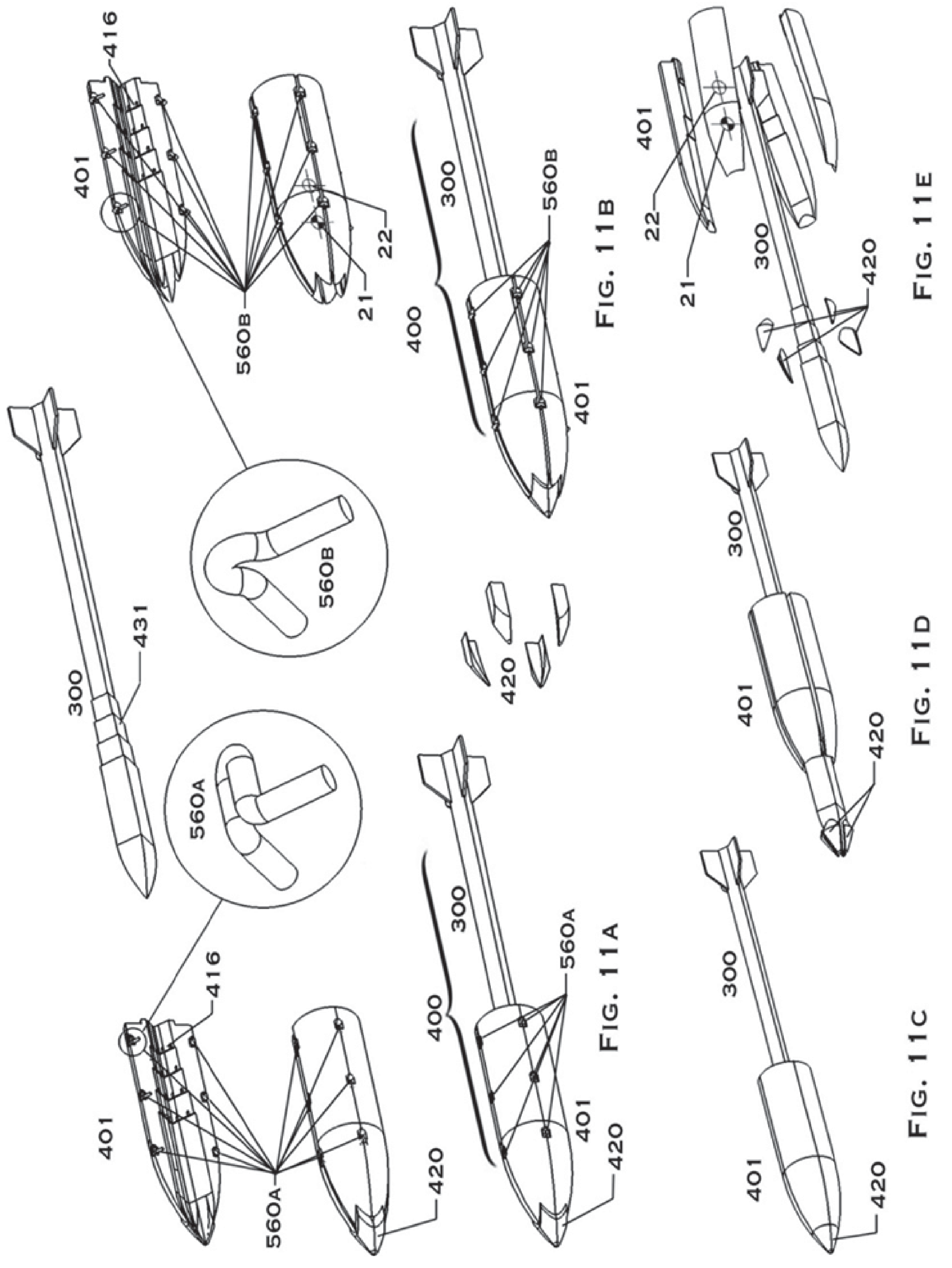

FIG. 11A

FIG. 11B

FIG. 11C

FIG. 11D

FIG. 11E

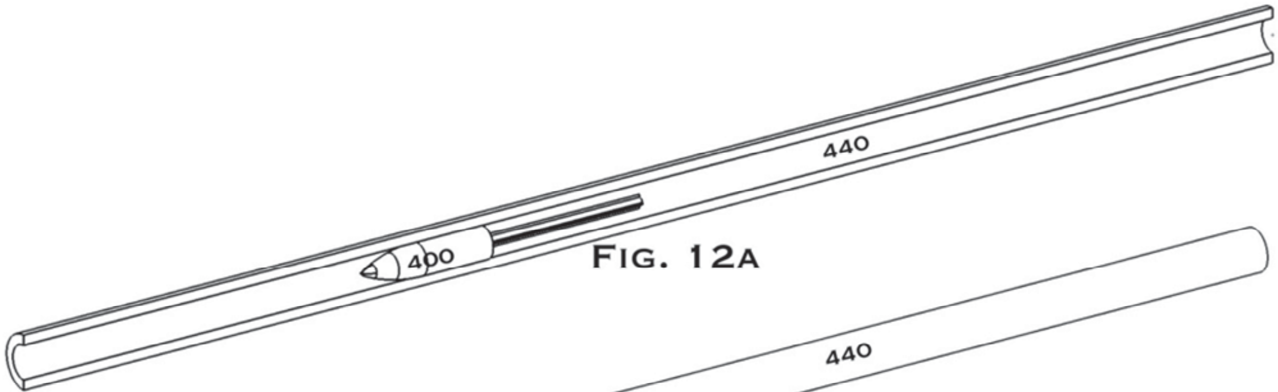

FIG. 12A

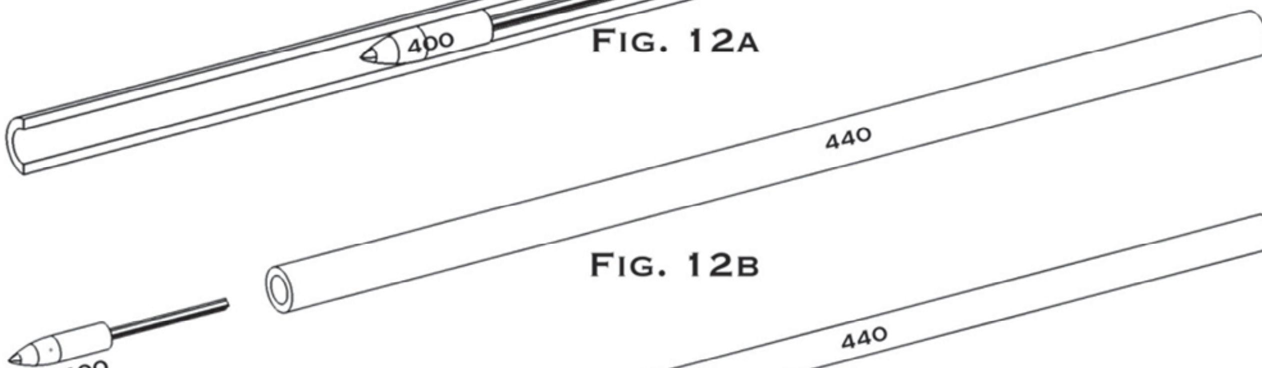

FIG. 12B

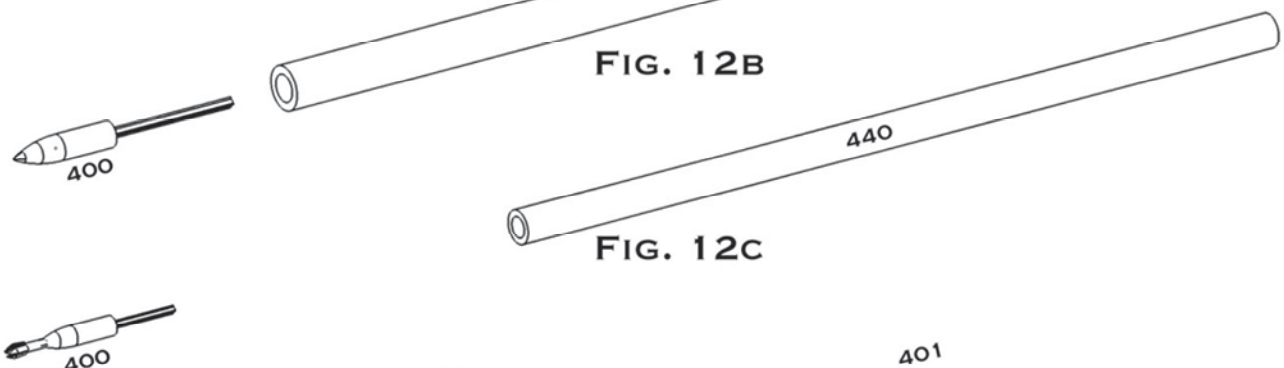

FIG. 12C

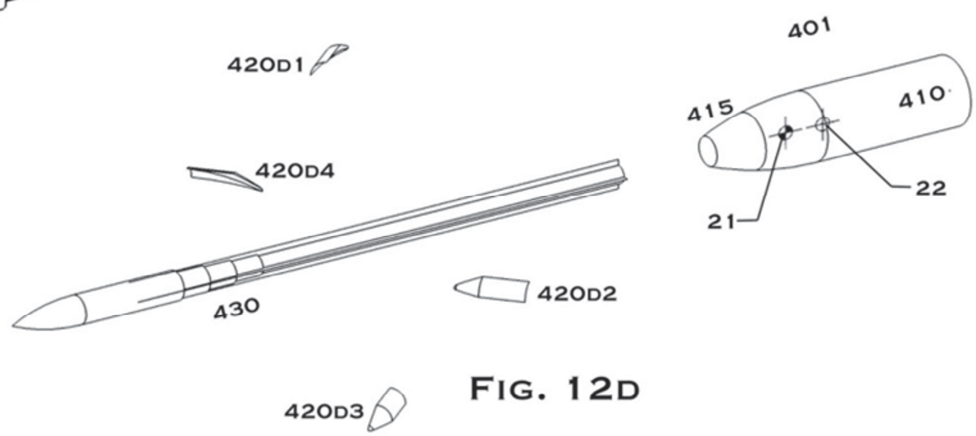

FIG. 12D

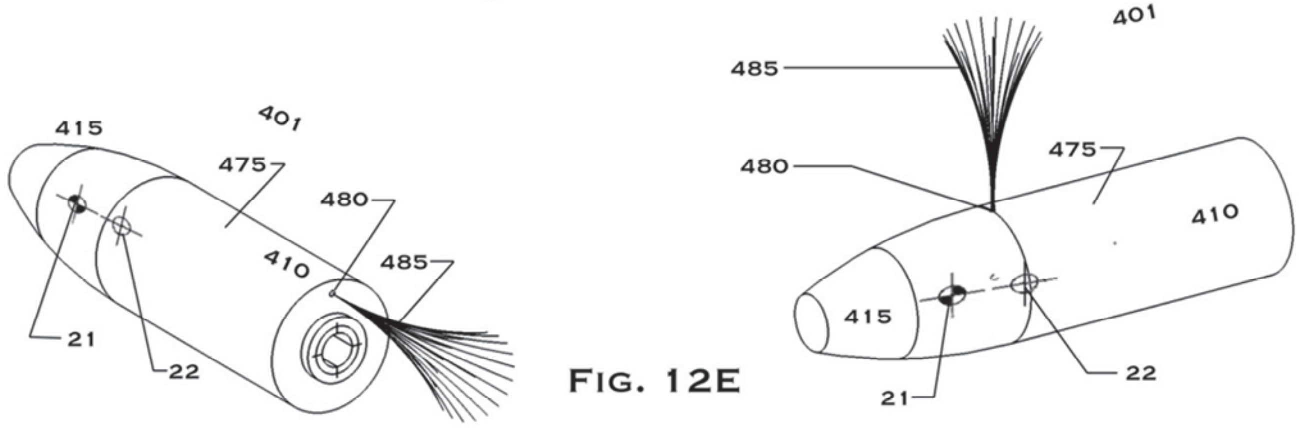

FIG. 12E

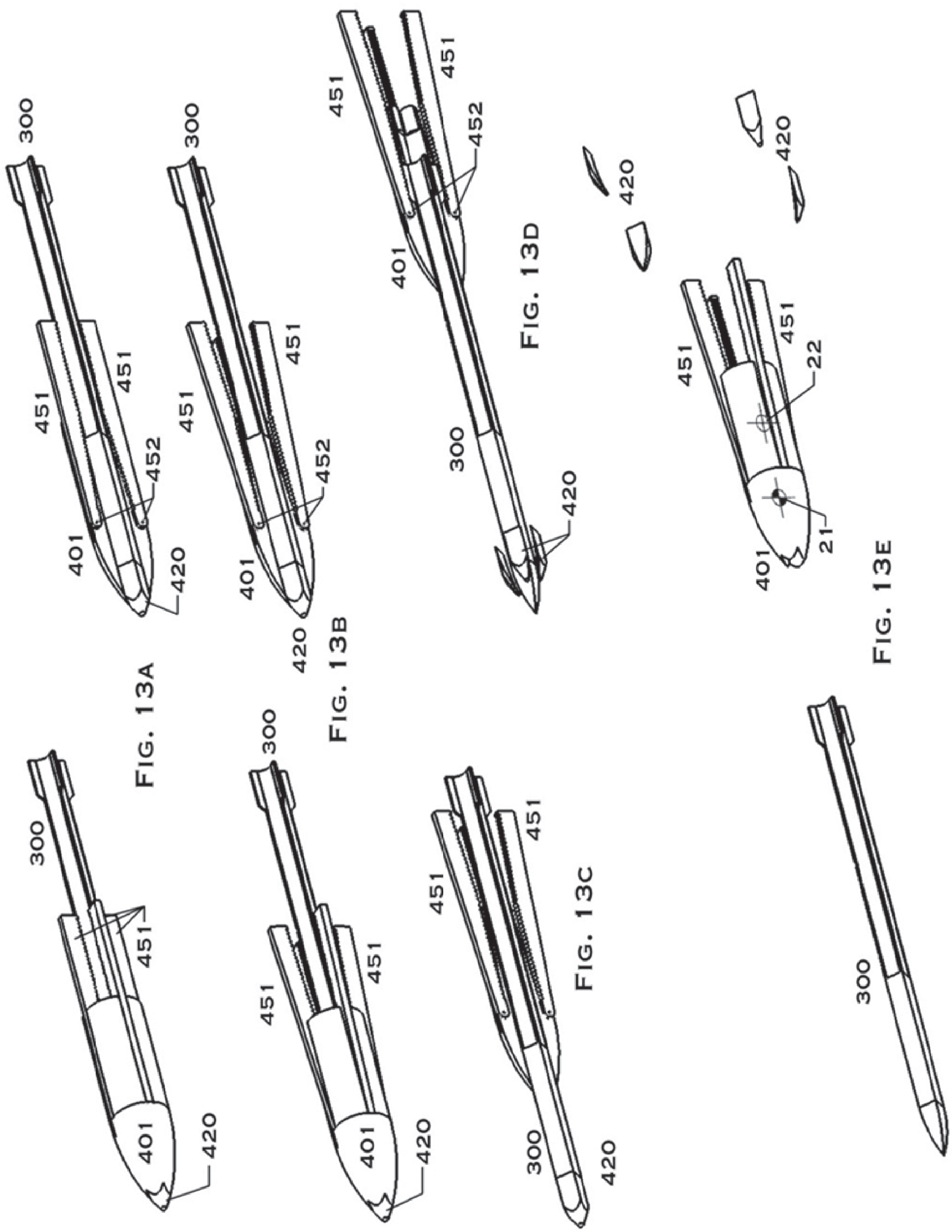

FIG. 13A

FIG. 13B

FIG. 13C

FIG. 13D

FIG. 13E

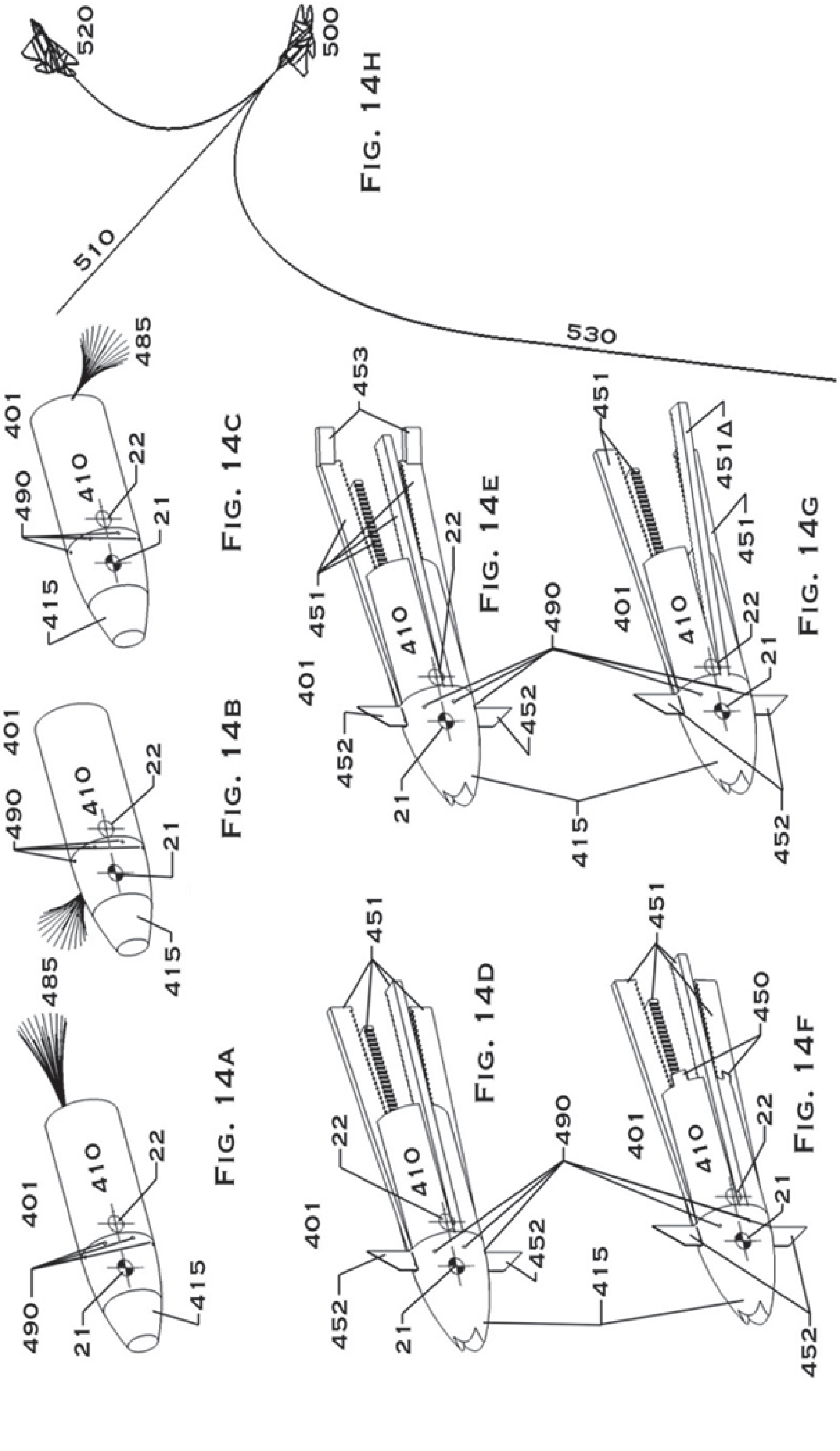

FIG. 14A

FIG. 14B

FIG. 14C

FIG. 14D

FIG. 14E

FIG. 14F

FIG. 14G

FIG. 14H

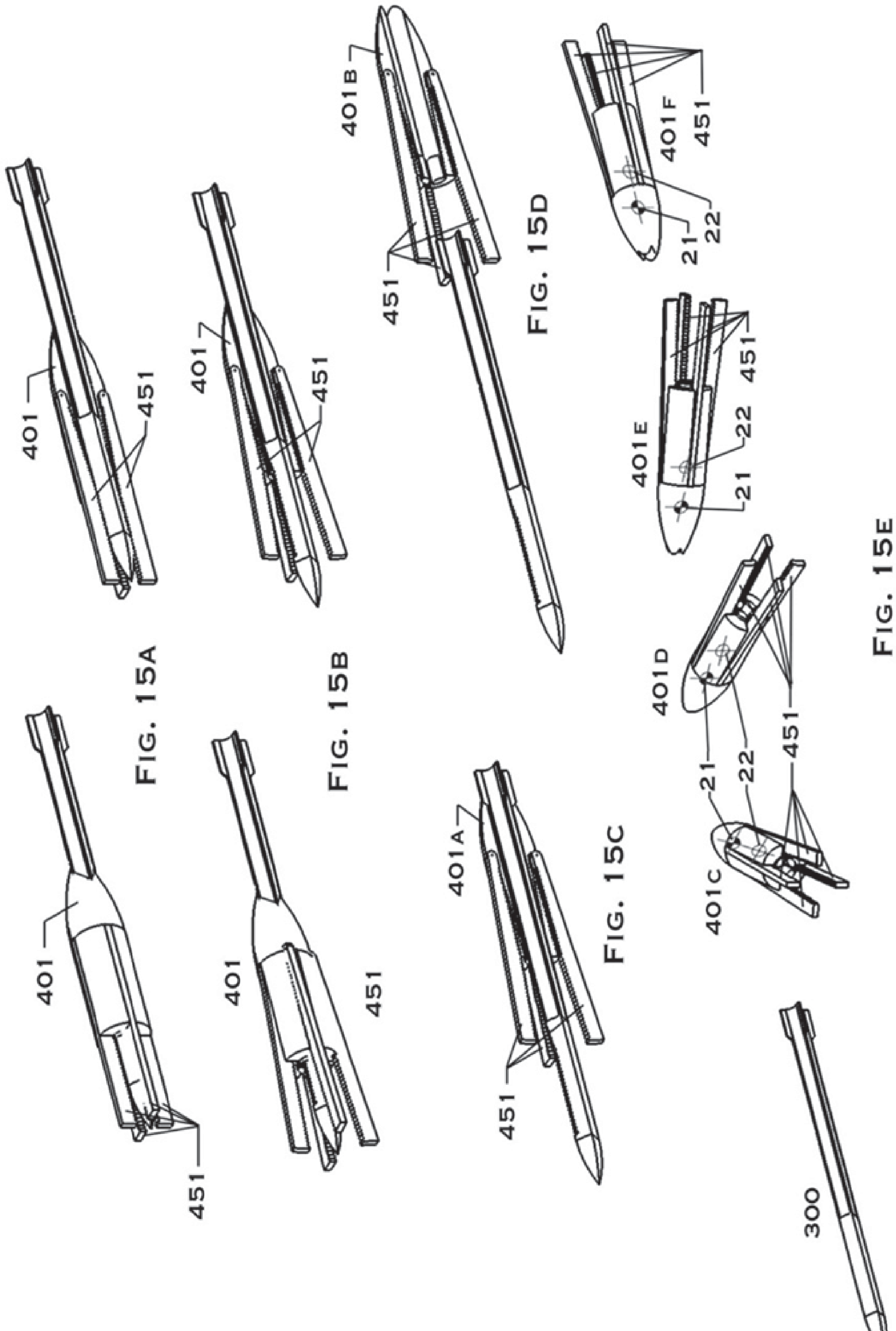

FIG. 15A

FIG. 15B

FIG. 15C

FIG. 15D

FIG. 15E

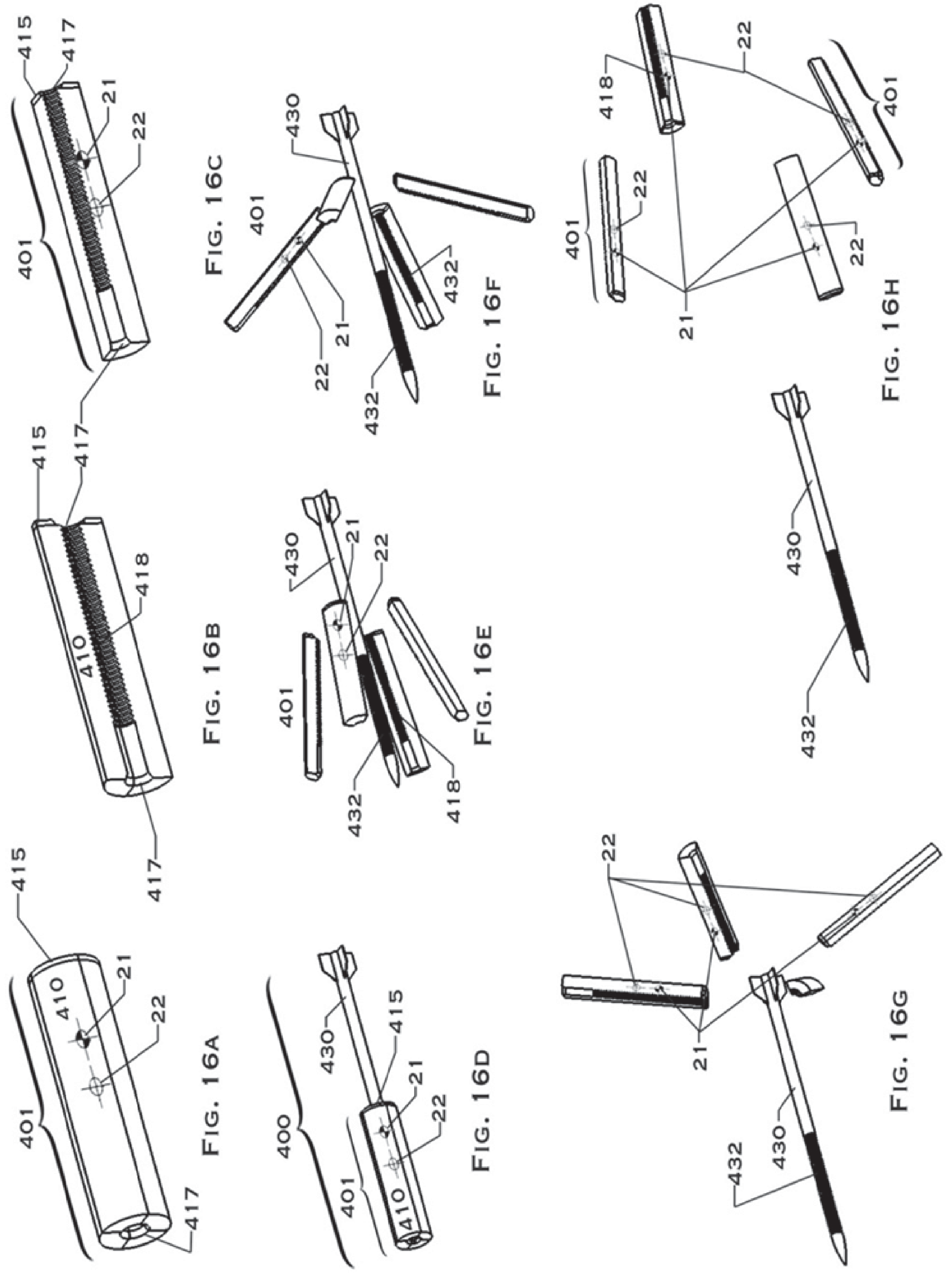

FIG. 16A FIG. 16B FIG. 16C FIG. 16D FIG. 16E FIG. 16F FIG. 16G FIG. 16H

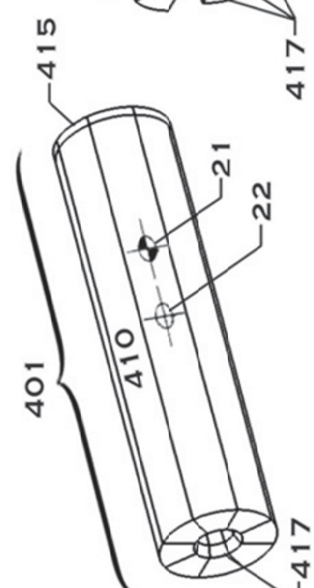

FIG. 17A

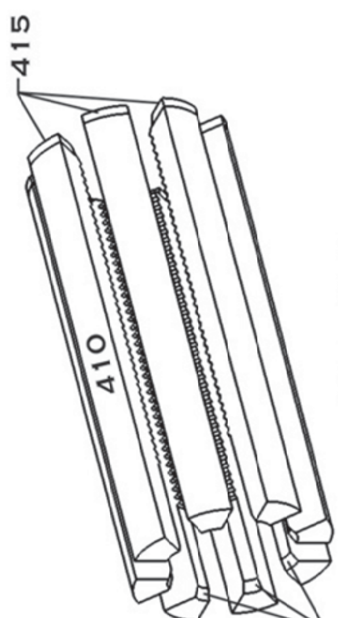

FIG. 17B

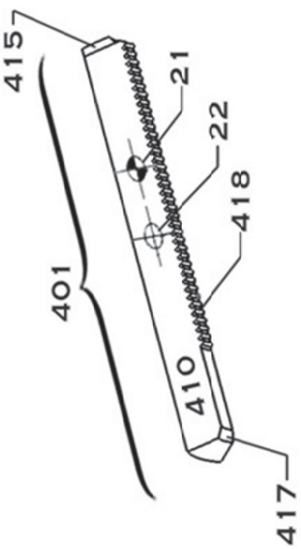

FIG. 17C

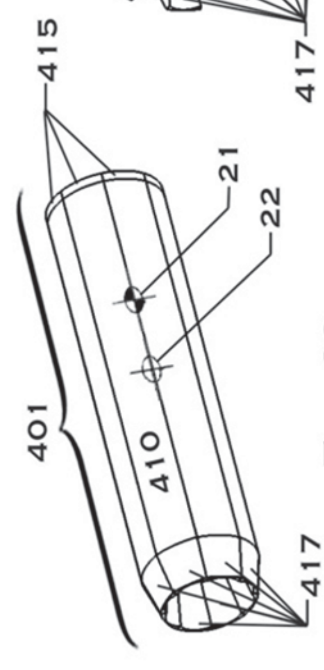

FIG. 18A

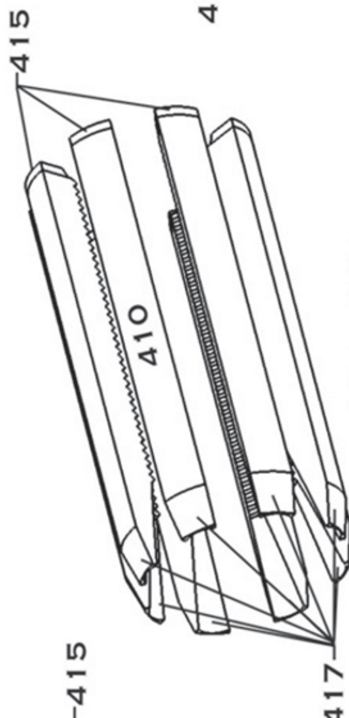

FIG. 18B

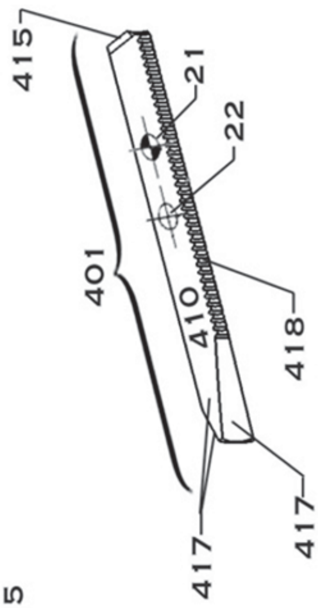

FIG. 18C

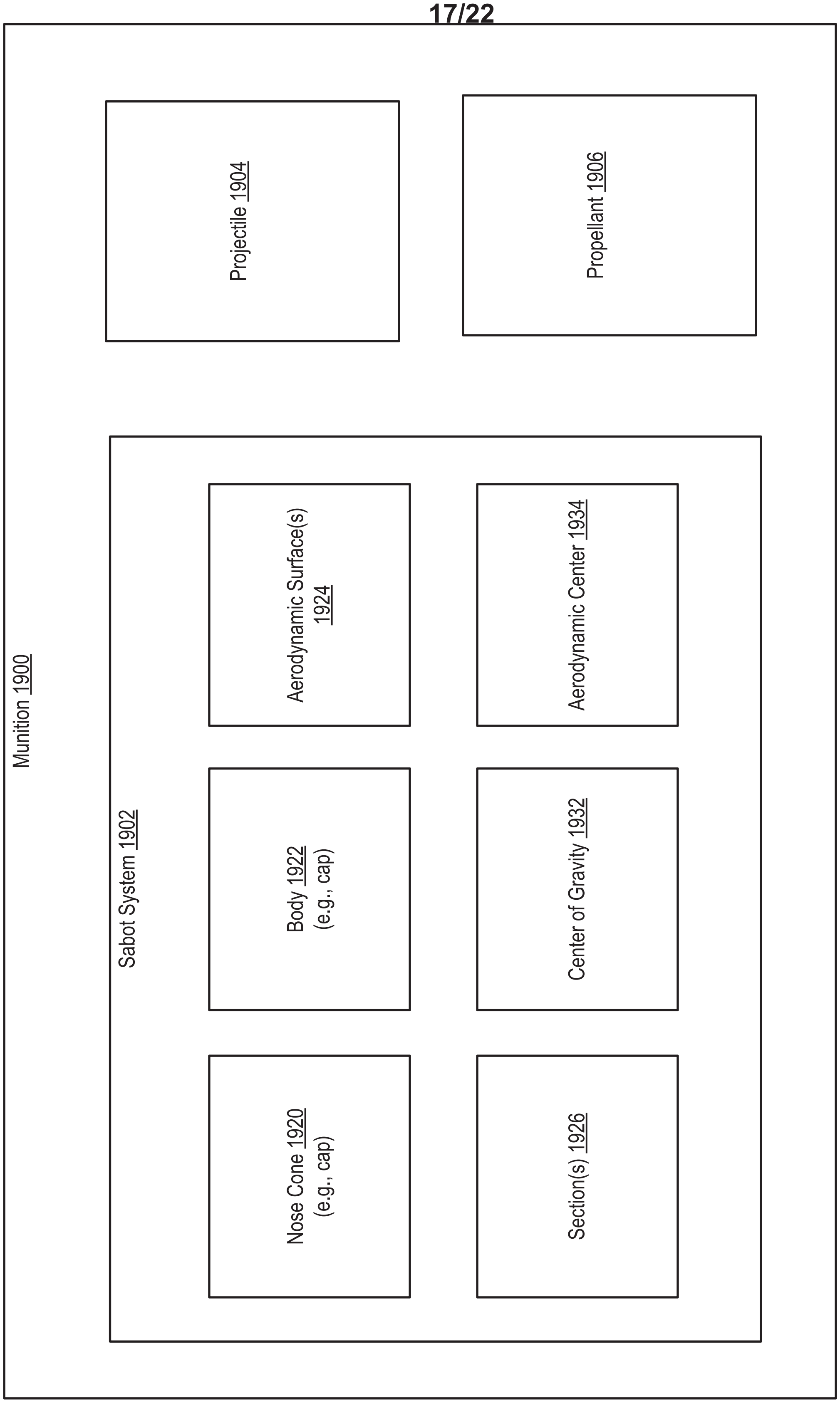
Munition 1900
Projectile 1904
Propellant 1906
Sabot System 1902
Nose Cone 1920 (e.g., cap)
Body 1922 (e.g., cap)
Aerodynamic Surface(s) 1924
Section(s) 1926
Center of Gravity 1932
Aerodynamic Center 1934

FIG. 19

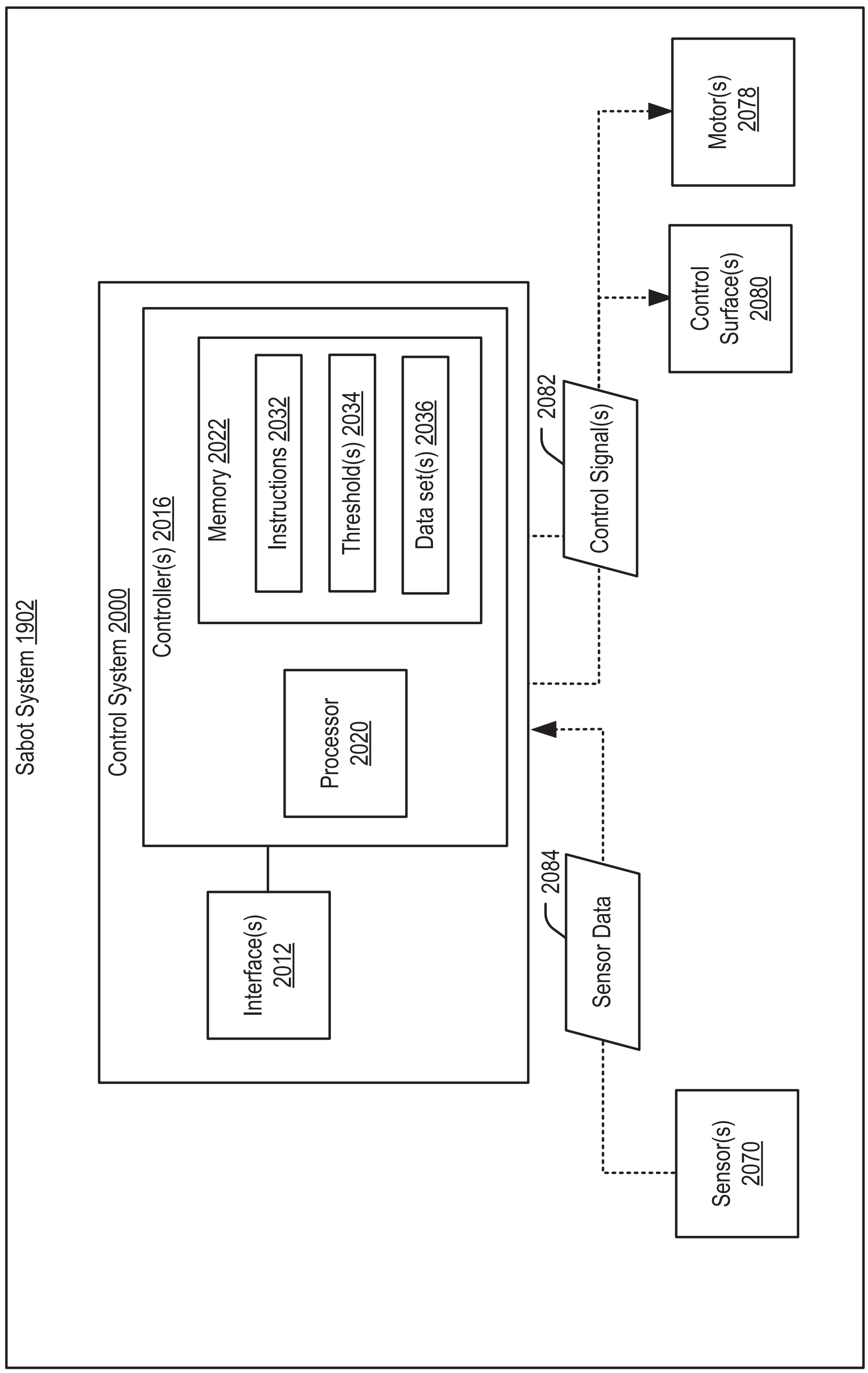
Sabot System 1902
Control System 2000
Controller(s) 2016
Memory 2022
Instructions 2032
Threshold(s) 2034
Data set(s) 2036
Processor 2020
Interface(s) 2012
2082
Control Signal(s)
2084
Sensor Data
Motor(s) 2078
Control Surface(s) 2080
Sensor(s) 2070

FIG. 20

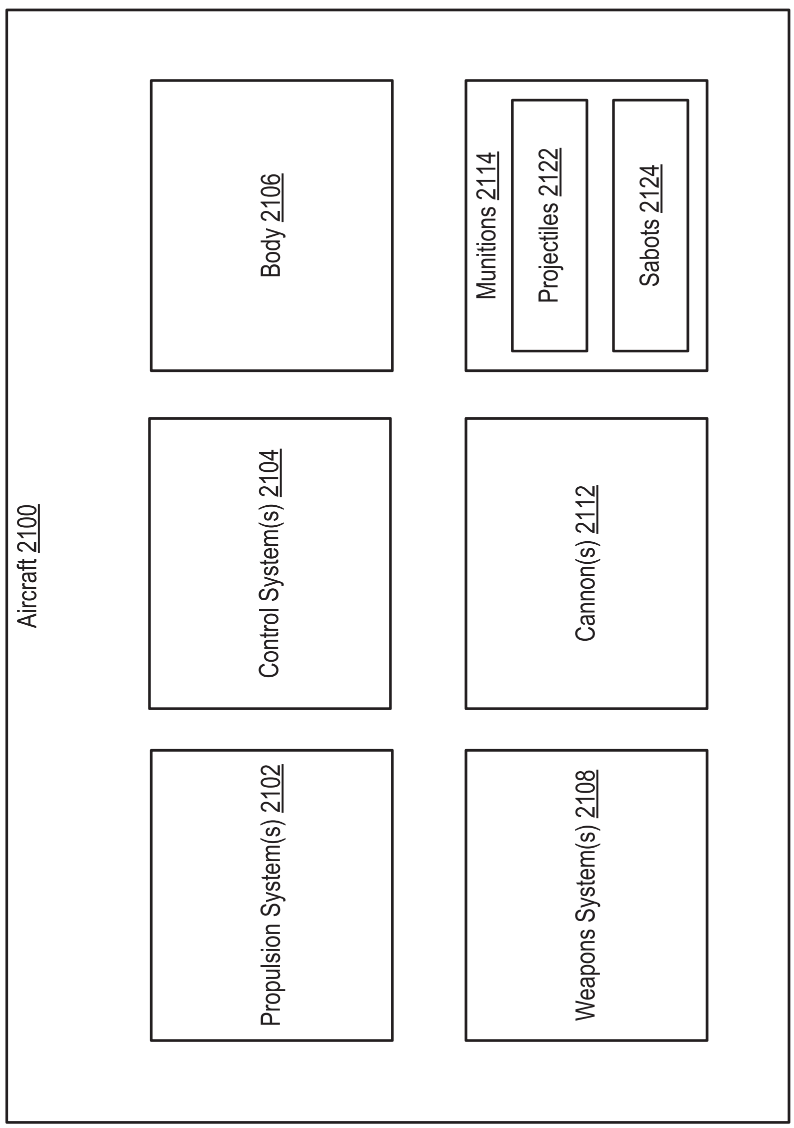
Aircraft 2100
Propulsion System(s) 2102
Control System(s) 2104
Body 2106
Weapons System(s) 2108
Cannon(s) 2112
Munitions 2114
Projectiles 2122
Sabots 2124

FIG. 21

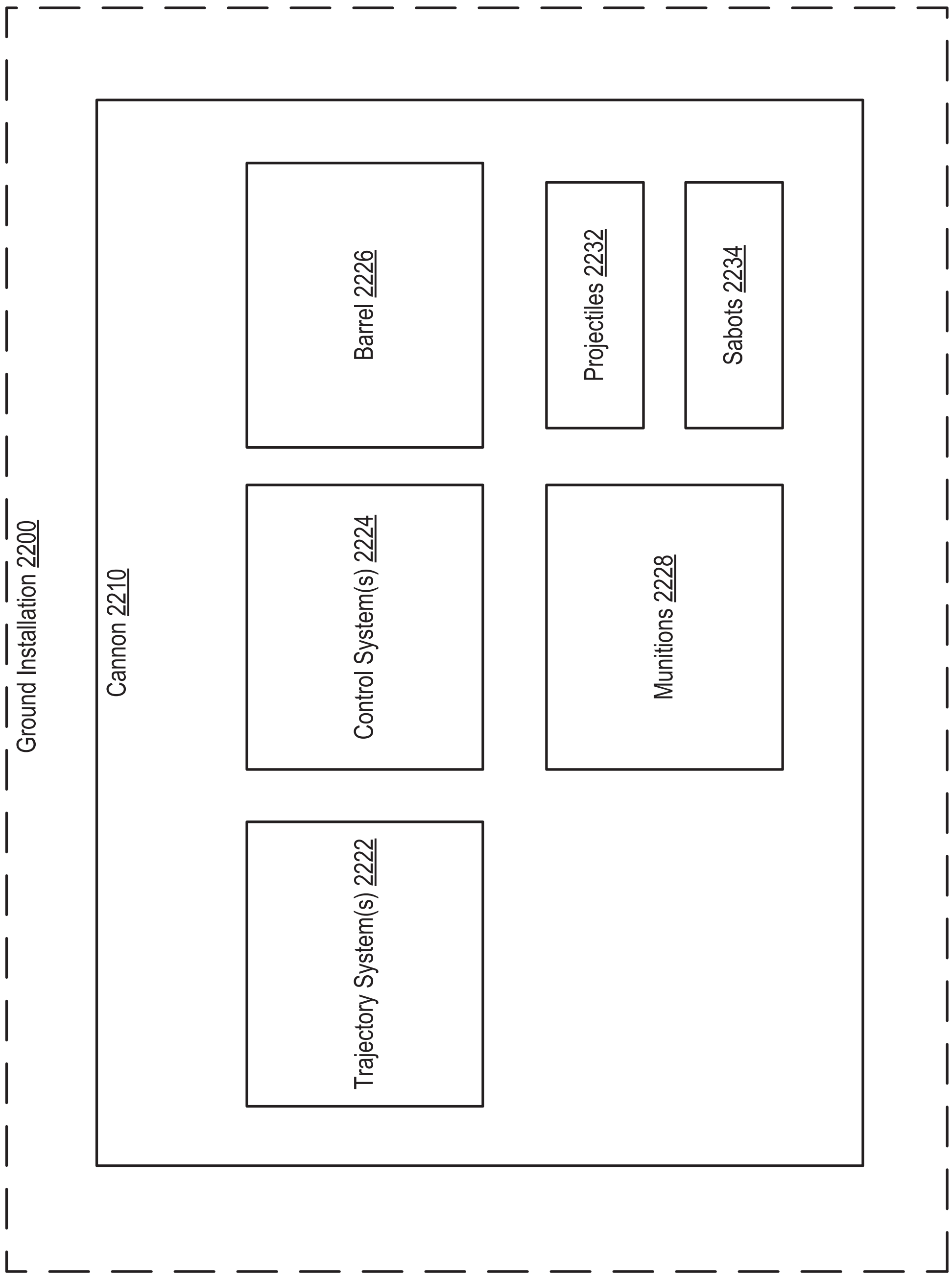
Ground Installation 2200
Cannon 2210
Barrel 2226
Control System(s) 2224
Trajectory System(s) 2222
Projectiles 2232
Sabots 2234
Munitions 2228

FIG. 22

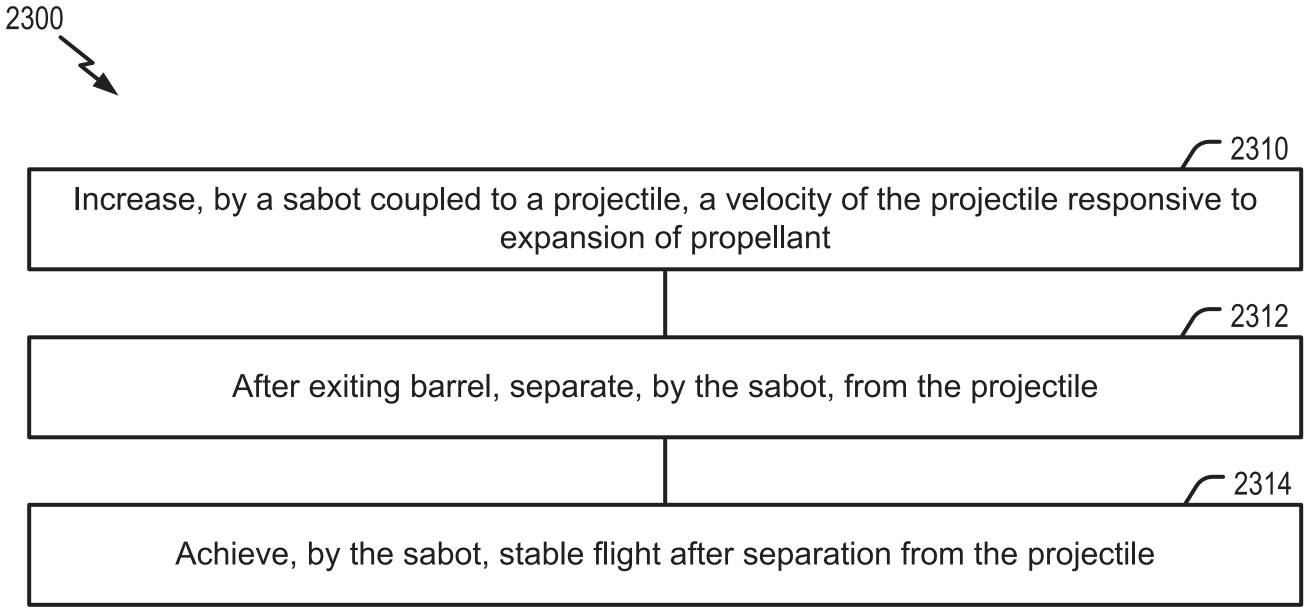
2300
2310
Increase, by a sabot coupled to a projectile, a velocity of the projectile responsive to expansion of propellant
2312
After exiting barrel, separate, by the sabot, from the projectile
2314
Achieve, by the sabot, stable flight after separation from the projectile

FIG. 23

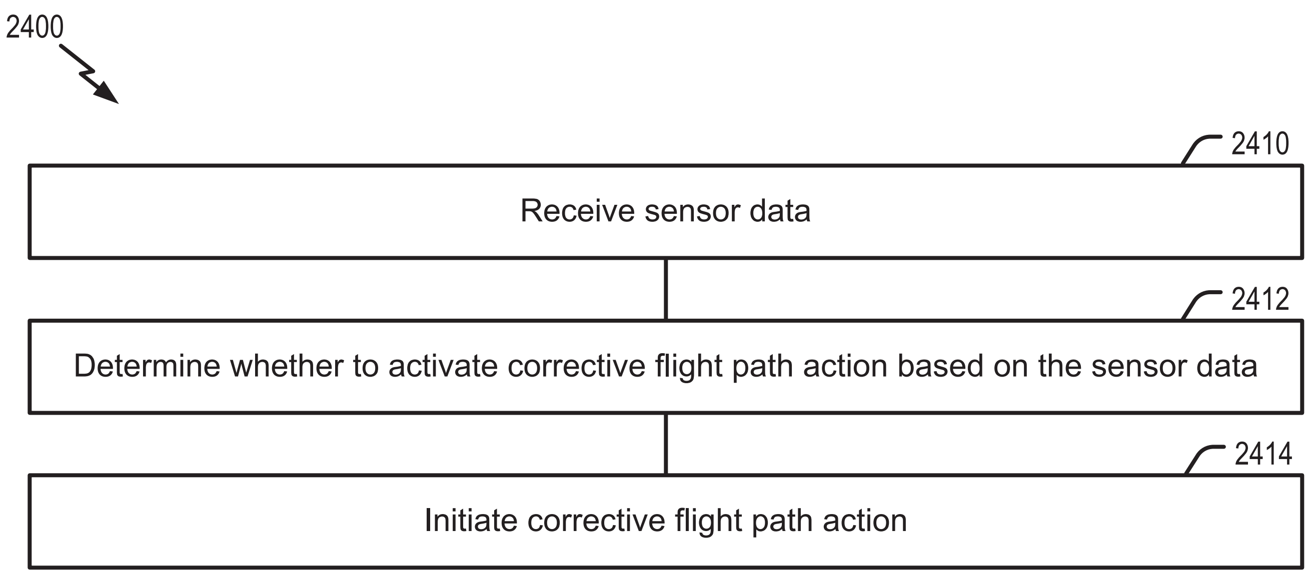
2400
2410
Receive sensor data
2412
Determine whether to activate corrective flight path action based on the sensor data
2414
Initiate corrective flight path action

FIG. 24

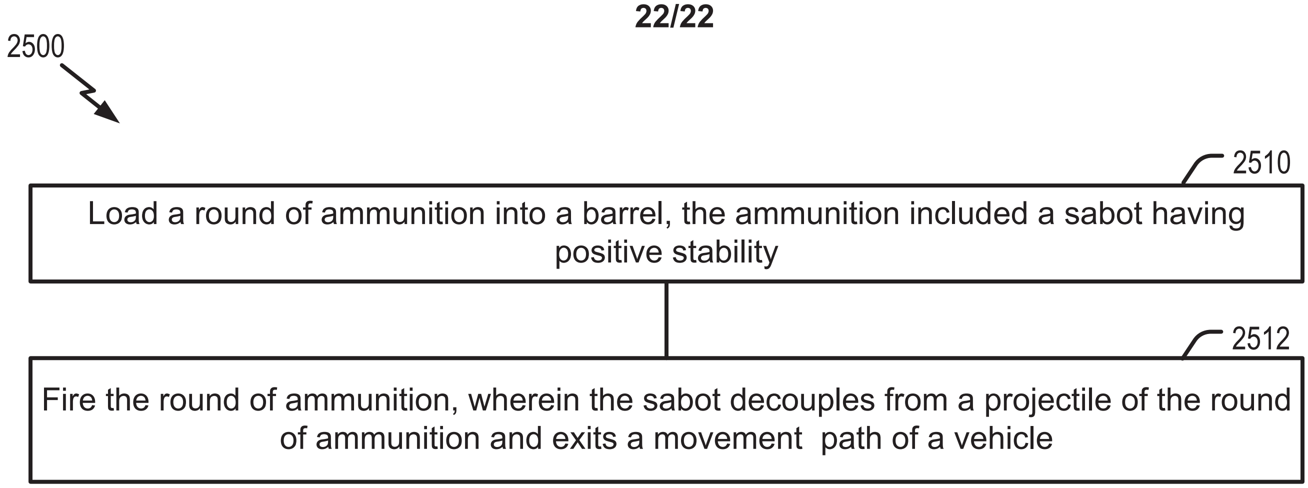
2500
2510
Load a round of ammunition into a barrel, the ammunition included a sabot having positive stability
2512
Fire the round of ammunition, wherein the sabot decouples from a projectile of the round of ammunition and exits a movement path of a vehicle

FIG. 25

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	

Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Ronald	M.	Barrett	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Lawrence	State/Province	KS	Country of Residence i	US

Mailing Address of Inventor:

Address 1	823 Missouri St.
Address 2	
City	Lawrence
State/Province	KS
Postal Code	66044
Country i	US

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Lauren	Nicole	Schumacher	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Rolla	State/Province	MO	Country of Residence i	US

Mailing Address of Inventor:

Address 1	14000 Hwy. 72
Address 2	
City	Rolla
State/Province	MO
Postal Code	65401
Country i	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	

Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	29053	
Email Address		Add Email / Remove Email

Application Information:

Title of the Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM		
Attorney Docket Number	UKAN.P0022USP1/1001071694	**Small Entity Status Claimed** ☐	
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)		**Suggested Figure for Publication (if any)**	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., “Domestic Benefit/National Stage Information” and “Foreign Priority Information”).

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	29053		

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	

Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	
Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	
Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

○ Assignee ○ Legal Representative under 35 U.S.C. 117 ○ Joint Inventor

○ Person to whom the inventor is obligated to assign. ○ Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	University of Kansas		
Mailing Address Information For Applicant:			
Address 1	1450 Jayhawk Boulevard		
Address 2			
City	Lawrence	**State/Province**	KS
Country	US	Postal Code	66045
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button.

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	
Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM	

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Allan Braxdale/			Date (YYYY-MM-DD)	2019-04-26
First Name	Allan	Last Name	Braxdale	Registration Number	64,276

Additional Signature may be generated within this form by selecting the Add button.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	UKAN.P0022USP1/1001071694
	Application Number	

Title of Invention	MANEUVERING AEROMECHANICALLY STABLE SABOT SYSTEM