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Hypersonic Aerial Gunnery: New Missions, Aircraft Design Opportunities

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This paper describes a host of new combat aircraft design opportunities that are being made possible by a new class of weapon systems: Hypersonic Aerial Gunnery. It starts with a brief overview of the underpinning technologies enabling HAG including a long-running, but unsuccessful USAF effort to develop flight-safe discarding sabot (FSDS) ammunition which took place from the 1950's through the 1990's. The FSDS RDT&E effort was capped with a series of experiments that led to the development of hypersonic munitions and guided aerial gunnery proof-of-concept projectiles. Although the DoD effectively divested itself from advanced, guided aerial gunnery for the past quarter-century, successful inventions in academia and private efforts to finally develop both guided hard-launch munitions and FSDS ammunition have borne fruit. Because FSDS ammunition decouples the gun caliber from the munition caliber, extremely high speeds can be achieved. Given very low drag profiles, it is shown that hypersonic rounds maintain these high speeds throughout most of their flights, rather than rapidly bleeding them off like conventional rounds. Because the times of flight, tip-off angles, circular errors probable and gust sensitivities are reduced while speed and kinetic energy on target is boosted, HAG projectiles are especially potent at extended ranges. What is more is that smaller calibers can successfully engage targets that were formerly only vulnerable to larger calibers. This means that 20mm FSDS ammunition can do the job of 30mm conventional ammunition, .50 cal can do the job of 20mm and so on. Because gun and ammunition weight and recoil forces drop with reduced caliber, smaller guns can now be placed on slewing pods and integrated into aircraft which were formerly not known for gunnery attacks. The paper concludes with several notional new attack fixed-wing designs which take advantage of this dynamic as well as potential integration mechanisms on uninhabited aerial vehicles of several classes.

I. Nomenclature

AP	=	*Armor Piercing*
APDS	=	*Armor-Piercing Discarding Sabot*
APFSDS	=	*Armor-Piercing Fin Stabilized Discarding Sabot*
API	=	*Armor-Piercing Incendiary*
ARDEC	=	*Armament Research, Development and Engineering Center*
ARF	=	*Aeroballistics Research Facility*
BAA	=	*Broad Agency Announcement*
BASS	=	*Ballistic Aeromechanically Stable Sabot*
BEF	=	*Ballistic Experimentation Facility*
BLAM	=	*Barrel-Launched Adaptive Munition*
CAS	=	*Close-Air Support*
CEP	=	*Circular Error Probable*
CEW	=	*Cost-Effective Warfare*
CIWS	=	*Close-In Weapon System*
EXACTO	=	*Extremely Accurate Tasked Ordnance*
FOIA	=	*Freedom of Information Act*
F_{recoil}	=	*Gun Recoil Force*

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FSDS	=	*Flight-Safe Discarding Sabot*
GDS	=	*Gun Director Sight*
GE	=	*General Electric*
GOT	=	*Go onto Target*
HE	=	*High Explosive*
HEI	=	*High Explosive Incendiary*
HEAT	=	*High Explosive Anti-Tank*
LCC	=	*Life-Cycle Cost*
Mcart	=	*Cartridge Mass*
MASS	=	*Maneuvering Aeromechanically Stable Sabot*
P_k	=	*Probability of a Kill*
RDT&E	=	*Research, Development, Test, and Evaluation*
REAM	=	*Range-Extended Adaptive Munition*
SAPHEI	=	*Semi-Armor Piercing High Explosive Incendiary*
SCREAM	=	*Shipborne Countermeasure Range Extended Adaptive Munition*
UAV	=	*Uninhabited Aerial Vehicle*
W_g	=	*Gun Weight*
ø	=	*Caliber*

II. Introduction: The Critical Importance of Sabots

In 1326 a secret document would be penned for the eyes of rulers and leaders of medieval armies. Walter de Milemete's *de Nobilitatibus, Sapientiis, et Prudentilis Regum* (On the Nobility, Wisdom, and Prudence of Kings) was to many medieval tacticians and strategists what 孫子 (Sun Tzu's) 孫子兵法 (The Art of War) were to the Qin, Han, and Xin rulers of China. [1] [2] [3] Among many admonitions for general conduct, international relations, and scholarship were pages describing the latest on weaponry and tactics. The earliest archival depiction of a cannon in the West shows a large arrow emerging from a "pot-de-fer" (fire pot).

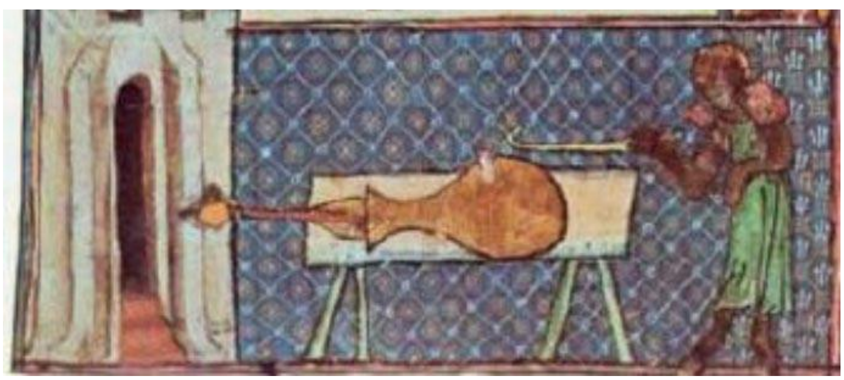

Fig. 1 The First Depiction of a Cannon and Saboted Flechette Projectile (1326) [1]

The term *sabot* means "wooden shoe" in French and comes from the time when Renaissance cannon balls needed wood alignment blocks placed at their base to mitigate the introduction of spin (which would cause them to veer off a ballistic arc, thereby reducing accuracy) and help seal gun gasses to mitigate blow-by and increase muzzle velocity and range. [4] [5] [6] Sabots continued to develop steadily for hundreds of years and are evolving today. During this time, conventional ammunition evolved as well from gravel to balls to aerodynamic shapes which eventually used body longitudinal axis spin stabilization. During WWI, flechette ammunition was most often not fired, but dropped. Steel darts (flechettes) were lofted by aircraft, flown over trenches, then dropped. The aeromechanically stable darts rained down like deadly spike showers, penetrating helmets, car bodies, tree trunks and human bodies as the horrors of the war raged all around. They were used by all sides and lofted by bombers and fighters alike, to be dropped as targets of opportunity presented themselves. Their terminal velocities were so high and the steel hard enough that the top skins of tanks were even breached. [5] Subscale antipersonnel flechettes are used today as submunitions in exploding rounds of many calibers (lower left, below).

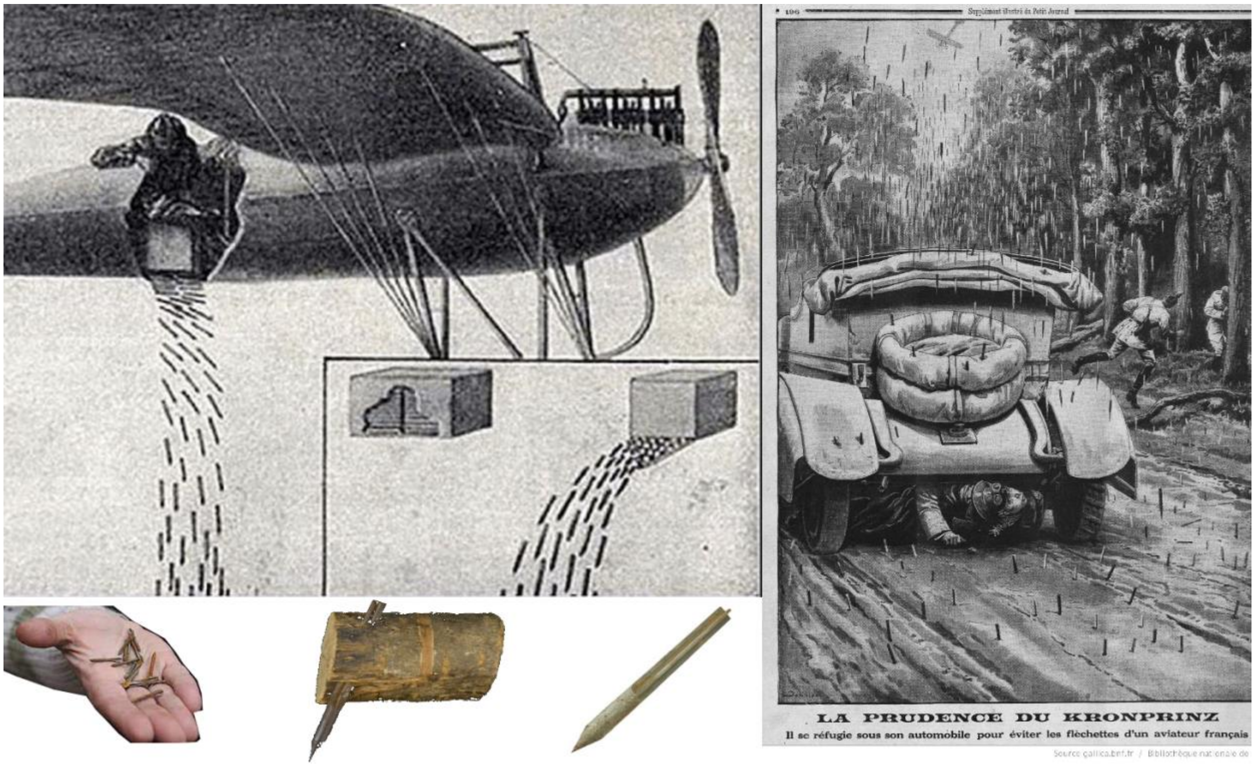

Fig. 2 Air-Dropped Flechettes from WWI and Modern Subscale Flechettes (1326) [5]

Saboted flechette ammunition would see use in modern warfare as the British QF-6 Pounder (US 57mm M1) was fielded near the end of WWII. The basic operation of the ammunition is obvious as the force of the in-barrel acceleration is accepted by the full-bore base of the comparatively light sabot which is then transferred to the projectile. The smaller, high density, sub-caliber caliber projectile in turn exits the muzzle with higher velocity than could otherwise be achieved by a full-bore projectile with the same projectile density. The figure below shows the entire cartridge and sabot-projectile assembly outside of the cartridge. The tungsten slug is located within an aerodynamic shell. The pusher plate distributes the base pressure to the penetrator-sabot assembly. As the round exits the barrel, the pusher plate and sabot pieces fall away, leaving the penetrator to fly towards the target at high speeds. The discarding sabot assembly of the QF-6 shell is shown below.

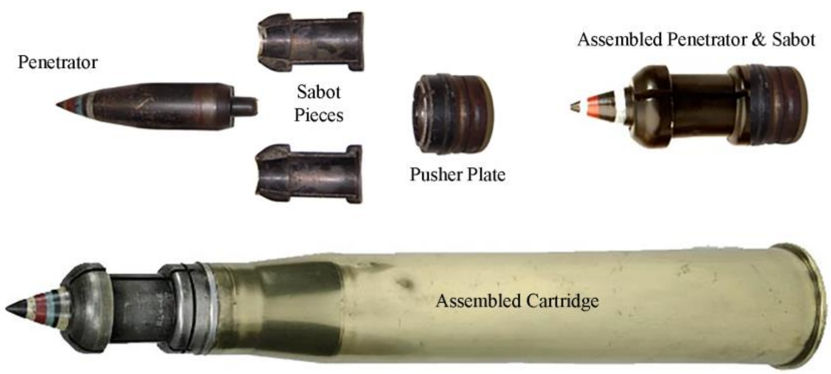

Fig. 3 QF-6 Armor-Piercing Discarding Sabot Penetrator and Assembled Cartridge (1944) [4] [5]

Modern saboted ammunition has evolved to possess higher fineness ratios as they are shaped more like darts than splitting wedges. Penetrators have become longer and often fin sets protrude into the powder base of the cartridge to accommodate the increased fineness ratios and total projectile lengths. Often the sabots themselves are made principally of materials like graphite-epoxy composites so as to increase the weight fraction of the penetrator. Because the penetrators are not spin-stabilized, they must be made inherently aeromechanically stable. To maintain aeromechanical stability, they typically have a nontrivial fin set far behind the center of gravity as shown below which drives the aerodynamic center one or more calibers aft of the center of gravity as shown below.

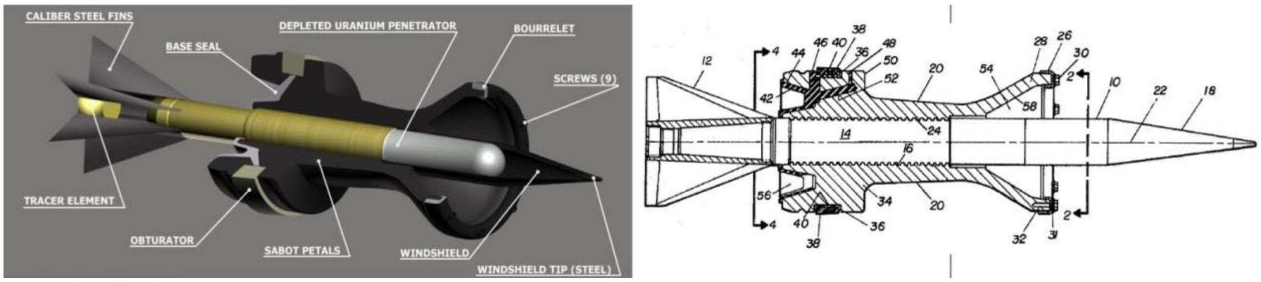

Fig. 4 Modern Armor-Piercing Discarding Sabot Munitions [4] [5]

While armies developed discarding sabot ammunition, the USAF tried to do the same. From 1952 through 1998 a nontrivial number of programs were undertaken by the USAF Munitions Directorate to do just that. Unfortunately, problem proved too challenging. Director Dale Davis put it succinctly:

Flechette ammunition by its nature must be sabot launched. Herein lies another advantage and its major disadvantage. The advantage of sabot launch is, of course, that the projectile has a low sectional density while in the gun bore and can be easily accelerated to velocities not readily attainable with conventional shot. The disadvantage of sabots is that they must be discarded at muzzle exit, and these rapidly decelerating sabots pose an unacceptable hazard to launching aircraft.

-***Dale Davis***, *Director, USAF Munitions Directorate 1984* [7]

From 1995 through 1998, the Munitions Directorate explored a most ambitious program which was poised to usher in a new era of aerial gunnery. The Barrel-Launched Adaptive Munition (BLAM) program was centered on a 10° half-angle 37mm articulated conical projectile. By the end of 1998, the program had demonstrated high control authority levels at high rates and high setback accelerations. In short, the BLAM program was poised to revolutionize aerial gunnery. In late 1998, the program was cancelled. [8] Research on guided munitions programs for infantry and artillery and naval surface fire continued at a robust pace for the following 25 years. [5] [4] [8] [9] While robust guided ammunition programs were found serving many combat modalities, aerial gunnery was effectively orphaned. Not a single DoD RFP, BAA or program from the past 25 years has supported advanced guided aerial gunnery.

Although unfortunate and decidedly harmful to the US defense posture and readiness, guided aerial gunnery efforts have continued in private companies and academia. In 2019 after three years of research, the world's first Flight Safe Discarding Sabot (FSDS) designs were submitted to the US Patent and Trademark Office. [10] This has since been converted to a PCT filing. [11]

The FSDS ammunition is seen as coming in two major families: Ballistic Aeromechanically Stable Sabot (BASS) and Maneuvering Aeromechanically Stable Sabot (MASS). [12] Schumacher's BASS and MASS ammunition featured high fineness ratio flechette ammunition. [13] [14] [15] [16] [17] [18] [19] More than 54 families of BASS and MASS projectiles and associated sabots (representing more than 500 species) were approved by the USPTO for export. [10] A typical sabot projectile looks like the figure below. The BASS projectile shown below is clearly shaped very much like the flechettes of yesteryear as form dictates function. The projectile (430E) is specifically designed to have several calibers of longitudinal and directional stability and not rely upon spin stabilization. The aerodynamic center is moved aft by fin strakes that clearly seat well within the powder bed of the cartridge. The sabot (410E) is designed to be aeromechanically stable. The nose of the sabot (415E) is fashioned from a comparatively heavy material. This moves the center of gravity (21) ahead of the aerodynamic center (22). This arrangement leads to an aeromechanically stable sabot which is designed to clear the airframe of the launching aircraft by flying away in a stable and controlled manner. The BASS sabots are particularly well suited for air-to-ground combat as they are weighted to head straight for the ground. MASS sabots are better suited for air-to-air combat as they are designed with flight control mechanisms which allows them to actively maneuver out of the way of the launching aircraft and steer clear of wingmen.

Fig. 5 One Species of Ballistic Aeromechanically Stable Sabot (BASS) Flechette and Sabot [10] [11]

Because the flechettes of [10] and [11] are substantially lower in caliber than the bore, they have significantly lower drag than the conventional ammunition they are intended to replace. Given that they are inherently aeromechanically stable, they are also shown to survive wind shear and gust layers with far lower disturbance levels which cuts dispersion as well.

III. Supersonic to Hypersonic: Boosting Flechette Performance

The BASS and Maneuvering Aeromechanically Stable Sabot (MASS) flechettes represent a major change in projectile properties. When one examines commonly fielded ammunition which is used for aerial gunnery like the M50, PGU-27/28/47 and M789 families as well as APIDSFS rounds fielded by the Army and CIWS rounds used by the Navy, then BASS and MASS mid-caliber ammunition compares very favorably. Fig. 6 shows the relative ballistic coefficients of the first aerial gunnery ammunition as well as commonly fielded aerial gunnery rounds and the highest ballistic coefficient rounds of today used by the US armed forces.

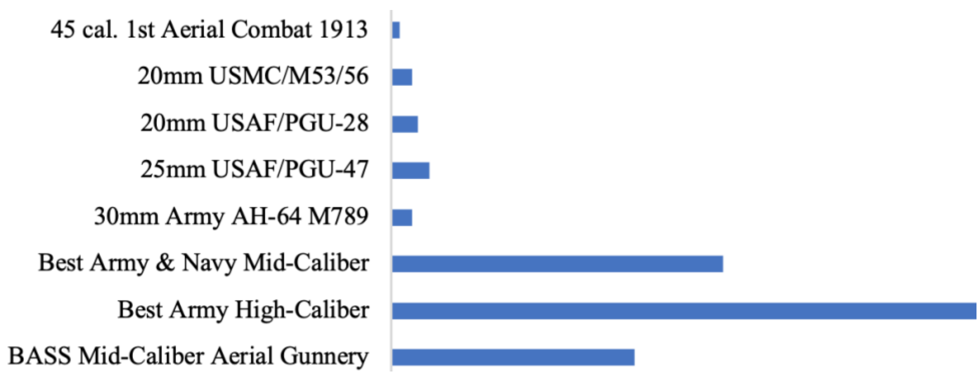

Fig. 6 Relative Ballistic Coefficients of Common Aerial Gunnery Rounds, Discarding Sabot Ammunition for Surface Gunnery and BASS Ammunition

One of the most important characteristics of any weapon system in combat is related to the timeliness of fire. At the core of rendering timely fire is the total time of flight (TOF). Given the range of ammunition above used in aerial gunnery, it is easy to see that several challenges currently exist: i.) conventional ammunition loses speed and kinetic rapidly with range, ii.) missile systems take several seconds to acquire, lock on and fire, then leave the airframe with zero relative speed, iii.) high caliber guns are heavy and large and impart high recoil forces to the airframe. Conversely, BASS rounds are relatively light as are the gun systems that use them. The extremely low drag coefficient of the BASS ammunition means that the BASS projectiles do not bleed off kinetic energy very rapidly as is the case with conventional rounds. An extremely beneficial characteristic of all discarding sabot ammunition (like BASS rounds) is that the barrel bore and the projectile caliber are fundamentally decoupled. This means that the BASS flechettes can be changed in form factor and dimension independent of the bore. If one matches the conventional ammunition mass and muzzle velocity, then outstanding performance is seen; however, if the BASS flechettes are reduced further in size, then for the same muzzle energy (recoil on the airframe and cartridge powder volume), then large gains in muzzle velocity are possible. Indeed, if the mass if dropped by a factor of 4, then the speed roughly doubles at the muzzle as the flechette enters the hypersonic flight regime. Drag trends and aeromechanics are different between supersonic and hypersonic flight, but the aerodynamic and aeromechanical properties at the lower bound of hypersonic flight (Mach 5) are not that far from properties at typical muzzle velocities (between Mach 2 and 3).

The Supersonic-to-Supersonic Boost: Traveling Charge

To reach hypersonic muzzle velocities a number of different approaches have been successfully evolved through the years. The fundamental challenge experienced by hard-launched munitions is that for conventionally configured cartridges, the farther a projectile travels away from the breech, the lower the overall chamber and base pressure. This is typified by the chart below:

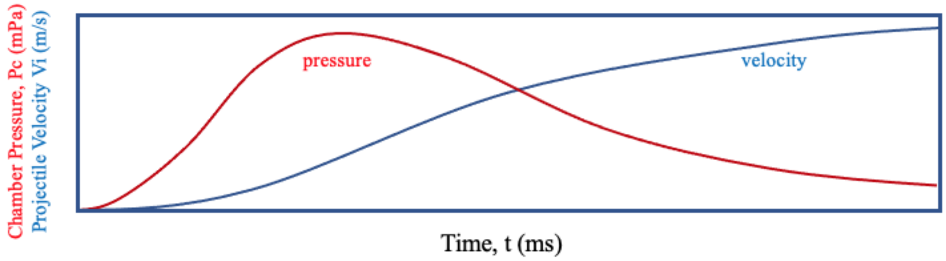

Fig. 7 Typical Chamber Pressure and Projectile vs Time Profile for Normal Cartridged Ammunition

When one considers cannon barrels for various missions, it is easy to see a strong correlation between barrel length-to-diameter ratio (l/d) and muzzle velocity (Vm) among higher caliber weapons. Tracking various ground-based artillery pieces and aerial gunnery cannon yields an unremarkable trend:

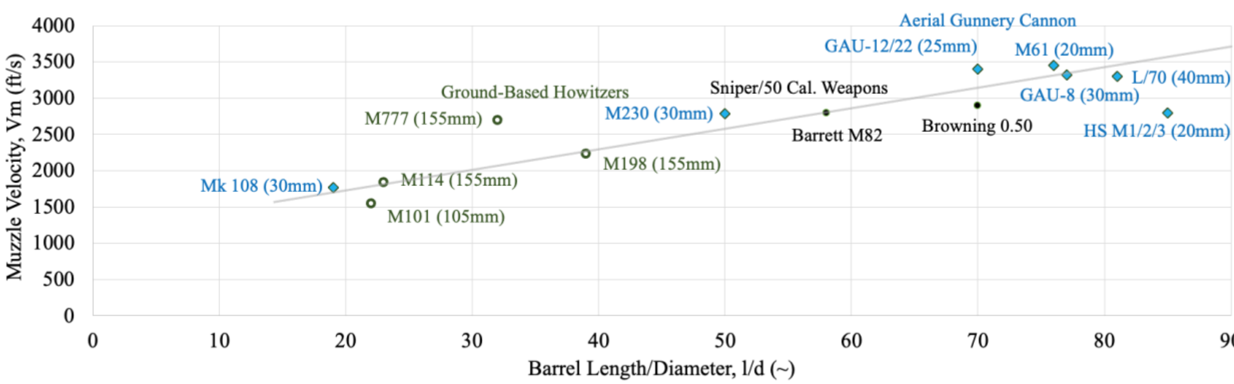

Fig. 8 Cannon Projectile Muzzle Velocity as a Function of Barrel Length-to-Diameter [20] [21]

Bottoming out the general range of cannon

One will certainly observe the Mk 108 as an outlier on several accounts: First, it was one of the earliest autocannon fitted to an operational jet fighter; Second, it was intended for close-in jet-on-propeller-driven bomber aerial interception. Ground based artillery of 105 - 155mm have intermediate muzzle velocities ranging from just over 1500 ft/s to nearly 2700 ft/s as well as l/d values. An intermediate l/d and muzzle velocity for aerial gunnery autocannon is seen in the M230 which is currently fielded on the AH-64 Apache. These guns typically fire combined effects HEDP M788/M789 30 x 113mm rounds. Given very low ballistic coefficients, and severe restrictions of recoil impulse transferred to the airframe, these rounds are effective at only very limited ranges with comparatively high times of flight. Lower times of flight are seen in the M197 20mm guns sported on the AH-1 Apaches which are essentially three-barreled versions of the M61 Vulcan Gatling guns used on fixed wing aircraft.

Many fixed-wing attack and fighter aircraft are specifically designed to accommodate far higher recoil loads than are seen on similarly sized rotorcraft; accordingly, their rates of fire and muzzle velocities are often far greater. Since the inception of autocannon for aerial gunnery, it became very clear to those engaging in air-to-air combat and fixed-wing air-to-ground combat that muzzle high velocities were paramount. Boosts in l/d were one of the more efficient ways to enhance muzzle velocity. Indeed, the famous Hispano-Suiza M1/M2/M3/M24 20mm cannon used in so many WWII through Viet Nam era combat aircraft sported l/d values of 85:1 in an effort to boost muzzle velocities while maintaining a reasonable weight and otherwise compact form factor. The ammunition and gun metallurgy technology of the day limited the muzzle velocity to just 2900 ft/s, but given that the gun and ammunition were developed eighty years ago, these are impressive numbers. Since the end of WWII, higher l/d's have been the norm, especially for fixed-wing combat aircraft. The ubiquitous M61, GAU-12/22 and famous GAU-8 of A-10 fame are all in the 70 - 80 l/d range with 3300 - 3500 ft/s muzzle velocities. While increases in l/d would be taken to absurd extremes of nearly 500:1 during WWII in the V3 Vergeltungswaffe program, practical issues with the gun, projectile stability and Allied bombing rendered the program fundamentally ineffective.

One noteworthy hypersonic projectile program which is nearly lost to history is the "Hypervelocity Weapon System" which was pioneered 30 years ago. This effort showed that 105mm cannon shells could be accelerated to speeds ranging up to 6720 ft/s (Mach 6) by conventional powder charges from guns with l/d values of 90 and the use of traveling charges propelling saboted rounds. [22]

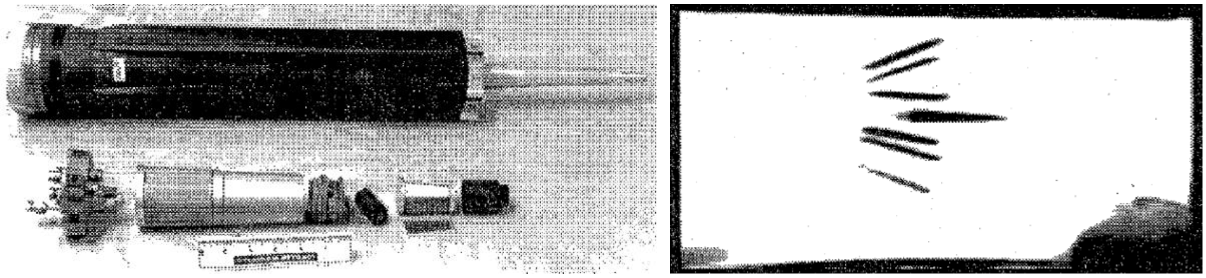

Fig. 8 Hypervelocity Weapon System (HVWS) Projectile & Sabot Separation (1993) [22]

The reader will note the unusual conical shape of the HVWS round on the LHS of Fig. 8. This is to accommodate GNC assemblies which were being matured in other programs like the Barrel-Launched Adaptive Munition (BLAM) effort. [23] [24] It was clear that by the middle 1990's the USAF was well on its way to making guided hypersonic ammunition for aerial gunnery. Although the pieces were coming together, the great problem at the time can be seen in the RHS of Fig. 8: The separating sabot pieces. As noted so famously by Dale Davis [7], this issue would render the entire system to only ground-based systems till a solution could be found. By the time the entire USAF advanced aerial gunnery program was shut down in 1998, that problem had not been solved. The lack of funding and vision would relegate that problem to civilian researchers who would finally solve it 18 years later. [6] [19] [25] [10] [4] [5]

Clearly invention of the BASS round configuration enabled flight-safe saboted aerial gunnery. While this is a nontrivial advancement, the BASS round configuration is particularly well suited for accommodation of traveling charges. As noted in Ref. [10] [11], the traveling charge leads to a substantially different base pressure profile as the projectile travels down the barrel as can be seen below in Fig. 9:

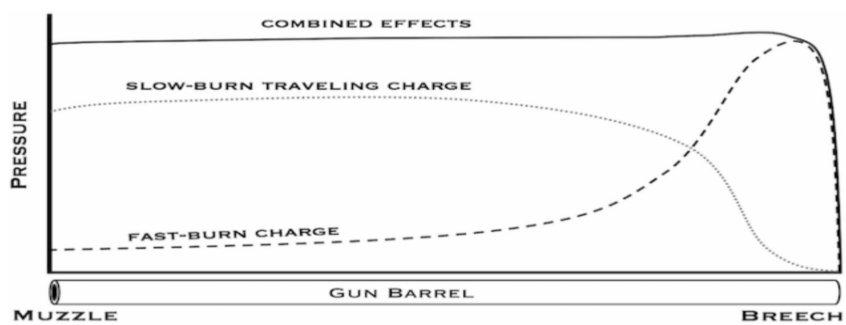

Fig. 9 Effects of Traveling Charge on Projectile Base Pressure [11] [10]

Given base pressure profiles as such saboted projectiles can be accelerated to very high speeds, well into the hypersonic for reasonable barrel pressures as more total energy of combustion products are transferred to the projectile as it travels down the barrel.

By using a traveling charge profile, the muzzle velocities can be boosted to between 1 and 2 mi/s, as was the case in the HVWS. The big difference, of course, is that the BASS system is not just hypersonic and uses saboted flechettes, but the entire configuration is flight safe. This has profound implications for aerial gunnery of all missions and launching aircraft types -- rotary and fixed. The figure below shows that the energy maintained with range for hypersonic BASS rounds (HBASS) very closely matches conventional BASS rounds; however, the TOF is nearly half that of conventional BASS rounds. Because the HBASS flechette configuration is aeromechanically stable, it is also highly compatible with adaptive guidance and control systems like those described in Ref. [26]. In short, the technical community now has available for license all of the technologies enabling hypersonic, guided hard-launched ammunition for use in air-to-air and air-to-ground combat.

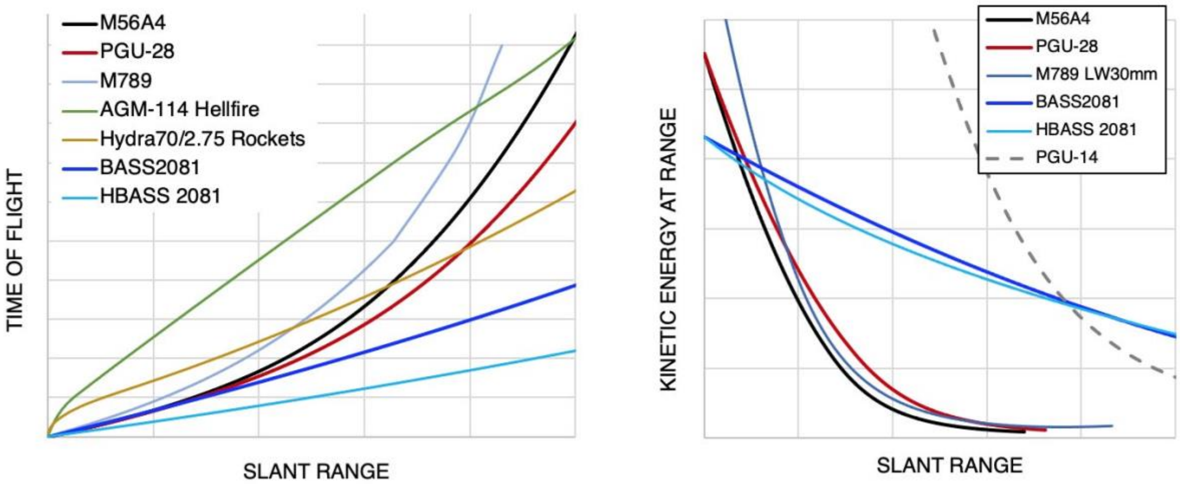

Fig. 10 Hypersonic BASS Rounds and Conventional US Attack Aircraft Weapon Systems Times of Flight and Kinetic Energy

Given typical engagement ranges for many ground targets, it is clear that HBASS rounds arrive on target in a tiny fraction of the time that missile systems and conventional ammunition takes. From a combat perspective this means that targets move just a fraction of the distance between trigger pull and engagement, increasing the probability of a hit. At hypersonic and high supersonic flight speeds which the BASS rounds maintain, the probability of a kill is also preserved.

If one considers air-to-air combat, especially given aircraft with internal stores like the F-35 and F-22, then the time between trigger pull and missile airframe clearance is considerable. If one compares a typical air-to-air missile with the full range of 20mm ammunition, it is easy to see that for the first increment in time, all of the various gunnery options provide more timely fire than the missile. The internally stored missile is only good at extended range combat with respect to gunnery, not close-in in great part because of the pull-to-clearance lag. Not surprisingly, the BASS rounds with their extremely high ballistic coefficients are substantially better than the conventional rounds, and the hypersonic BASS rounds are better still as seen below. It is easy to show that at higher altitudes, and certain Mach numbers, some air-to-air missiles simply do not ever catch up with the HBASS flechettes.

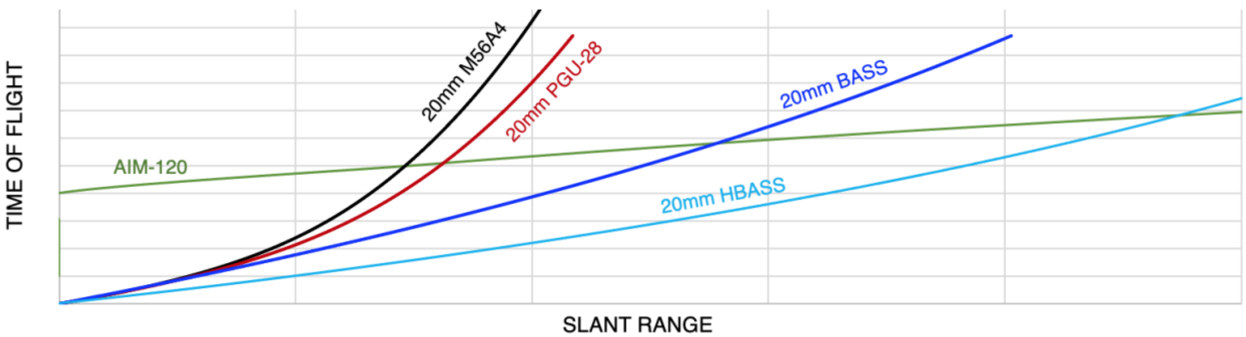

Fig. 11 Hypersonic BASS Rounds, Conventional Aerial Gunnery Rounds and AIM-120 Times of Flight and Kinetic Energy in Air-to-Air Engagements

Considering timeliness of fire, it is hard to do much better than a projectile that moves 1 - 2mi/s (1.6 - 3.2km/s) over most of its flight. Current USAF tacticians and weaponeers hold to the philosophy that "If you're using your gun, you've done something wrong." It is easy to argue that this philosophy is more than slightly antiquated.

IV. BASS/MASS Gun-Airframe Integration

The above discussion clearly indicates that nontrivial benefits can come to aerial gunnery systems from the use of BASS and MASS ammunition. Because the combat effectiveness of a BASS round of a given caliber is similar to the a conventional round of larger caliber fired from a larger gun, a look at gun systems is prudent. When considering gun integration, several characteristics are paramount, including: i.) weight of gun, ii.) cartridge mass, iii.) recoil forces, iv.) gun form factor and dimensions, v.) gun gas generation. The figure below examines four families of commonly fielded aircraft guns, tracking the aforementioned. From Ref. [7] and [27] it can be seen that gun gasses are roughly proportional to the volume of propellant.

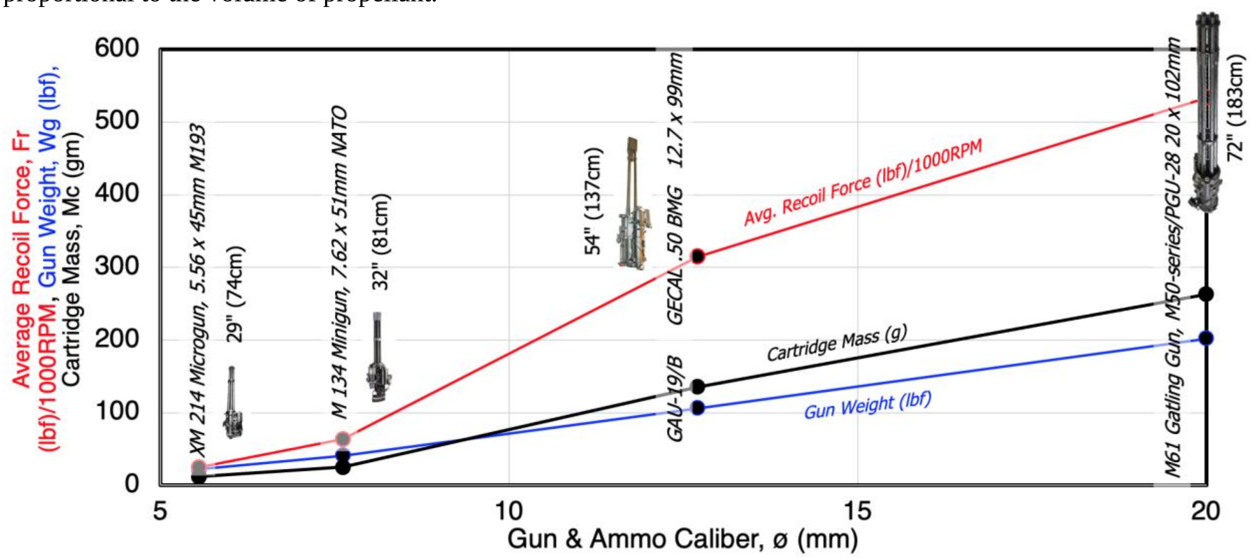

Fig. 12 Effects of Caliber on Recoil Forces, Weights and Cartridge Masses for Various Aerial Gun and Conventional Ammunition Calibers [28]

From the data above three important curve fits can be established with R^2 values in excess of 98%:

Three trends are seen to roughly hold with R values in excess of 98%:

F_{recoil}(lb)/1000rounds/min = 36.7ø(mm) - 187 (R^2 = 0.986) (eq. 1)

M_{cart}(g) = 18.07ø(mm) - 98.4 (R^2 = 0.9925) (eq. 2)

W_g(lb) = 12.62ø(mm) - 52.0 (R^2 = 0.9984) (eq. 3)

The recoil forces, F_{recoil}, are measured per 1000rounds/min fired, indicating that at higher rates, the recoil forces (necessarily) increase. The cartridge masses, M_{cart} include the cartridge case, propellant, typical conventional ammunition mass indicated and projectile. The mass of the belt and/or links, conveyance system and storage drum are not included. The weight of the gun (Wg) includes the "dry" weight, not accounting for the many associated attachments and mounts that are often included.

From the figure above, it is clear that new applications for gunnery are possible. For instance, the F-35 can down-gun to 20mm, which would save roughly 100lb in gun weight, reduce the recoil 388lb/(1000rounds/min) and cut ammunition weight roughly 20 lb. Holding the system weight constant, the amount of ammunition it could hold in a down-gunned configuration would go up from 191rounds to 307, given constant system weight. Considering the volumetric savings, it could hold 522 rounds, which slightly overmatches the F-15.

What is more is that different attack modes can be considered given dramatically reduced times of flight. If one considers the threat dome posed by most MANPADS, especially the SA-25 going through 15,000 ft, then it is obvious that attack modes outside of that zone are preferable. Currently, many attack aircraft, UAVs included engage targets outside of the threat dome. Given that hypersonic BASS rounds move at roughly 1 mi/sec., the time to engage targets from above the dome is roughly 3 sec. From Ref. [29] it can be seen that the Hellfire max. range of 8km (5mi/4.3nmi) is just barely beyond the SA-25 threat zone of 4 mi (below, less than half of the BASS range). What is more is that at that range, the AGM-114 Hellfire takes 36 sec. to engage the target. Conversely, the HBASS rounds take only around 5 sec. to engage the target. When fired from overhead, HBASS rounds can make contact in only 3 sec. Accordingly, this dynamic can be used to advise future attack aircraft and tacticians in the prosecution of various targets. From the figure below, two families of BASS rounds are examined, the API variant (2581) and the SAPHEI 2583 which is essentially a cargo round. Both families of rounds are shown to bracket the given target with direct fire capability. Indeed, the BASS rounds perform so well that at altitude, their effective air-to-ground engagement ranges are significantly more than double those of conventional munitions like the 30mm PGU-13/14 and even the 105mm. This is critically important to note as BASS and HBASS rounds that are designed to destroy armor are expected to cost between $54 and $80 each while the AGM-114 Hellfire can cost as much as $100,000 each depending on variant. [30] Assuming a load of 10 rounds are expended for each kill, a hundred-fold savings per kill is hard to ignore and speaks directly to the concept of Cost Effective Warfare.

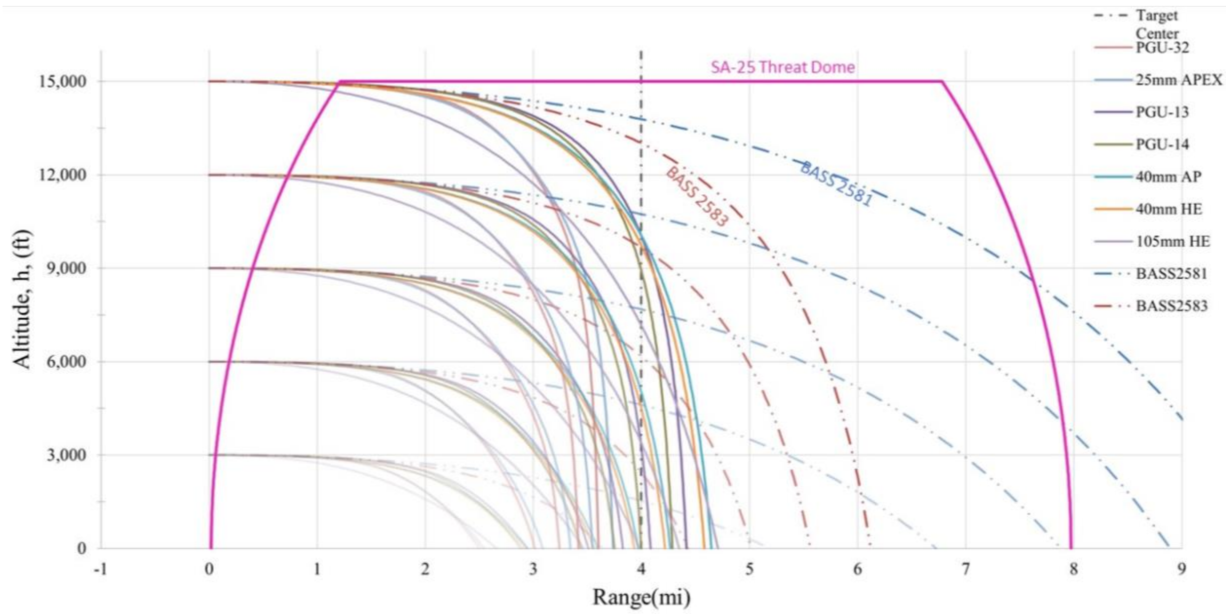

Fig. 13 SA-25 MANPADS Thread Dome and BASS Round Strike Patterns [31]

Engagement modeling of 20mm BASS and HBASS rounds show good armor penetrations through thicknesses higher than that found on the tops of the T-72 tanks at high obliquity angles. The figure below shows one such penetration model of a BASS round interacting with high strength armor steel.

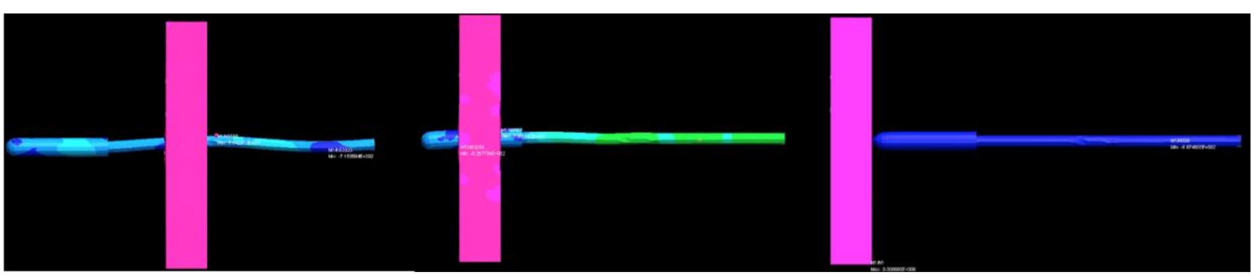

Fig. 14 20mm BASS Round Interacting with T-72 Top Armor at Ranges Beyond MANPADS Threat

Clearly, BASS rounds have the range and armor piercing capability to be productive assets in today's battlefield. New aircraft designs enabled from the aforementioned considerations can easily employ articulated, lower caliber gun systems. If one considers an attack aircraft to rival the A-10 in anti-armor capability, AC-130 in suppressive persistence and the AT-6 in cost, then an aircraft like the one shown below will result. This OV-10 Bronco-sized aircraft can orbit or strafe with advanced BASS rounds that are large enough to engage armor like the T-72. If equipped with SAPHEI HBASS rounds, then soft targets can very effectively be engaged and anti-personnel missions can be undertaken. The aircraft below, the "Swift Dragoon" was designed to provide high loiter times in both orbiting fire and strafing attack with twice the number of rounds of the A-10 and the same anti-armor capability. The figure below shows the side-mounted autocannon in two positions: i.) strafe, ii.) orbit. What is more is that the gun also has the ability to engage targets that are directly beneath the aircraft. When fired from above SA-25 threat altitudes, dispersions are still tight even under 99% gust profiles and gravity itself counteracts many of the effects of drag. Like the deadly flechette rainstorm shown in Fig. 2, the Swift Dragoon has the capability to do the same thing, but with even higher levels of lethality.

Fig. 15 Example Ground Attack Aircraft Designed to Loft and Fire HBASS Rounds with Strafing Fire (L) and Direct Orbiting Fire (R)

Because the individual rounds are compatible with a multitude of guidance systems, new engagement scenarios are conceived. Fig. 16 shows several defensive applications of MASS rounds against both IR and RF guided incoming missiles. These are anticipated to be particularly effective as the round guides on the missile and by tailoring various signatures, the missile would guide on the round.

Fig. 16 Examples of Defensive Applications of MASS Rounds

With such defensive capabilities, the implications for defending against both air-to-air and surface-to-air missiles would significantly change aerial combat doctrines and techniques. Because ballistic shots could easily reach more than 100nmi, augmenting (or more appropriately), replacing long-range air-to-air missiles is certainly possible. When one considers that large missiles like AAMRAAMs and BVRAAMs and considers that less than 15% of the F-35's weapon bay volume is actually devoted to missile and of that 15%, nearly 80% is devoted to propulsion, leaving just a tiny fraction for warhead and GNC packages. If one were to fit an appropriate warhead and GNC package into a MASS configured 40mm round and eliminated wasted volume, then it can be seen that the volume of an aircraft like the F-35 would shrink dramatically. The loss of volume lowers not just the weight, but the wave drag, interference drag and excrescence drag. Additionally the RCS of the aircraft would be suppressed substantially as missile bay doors would be eliminated. Given the lack of large structural cut-outs, the weight of the aircraft would be reduced still further.

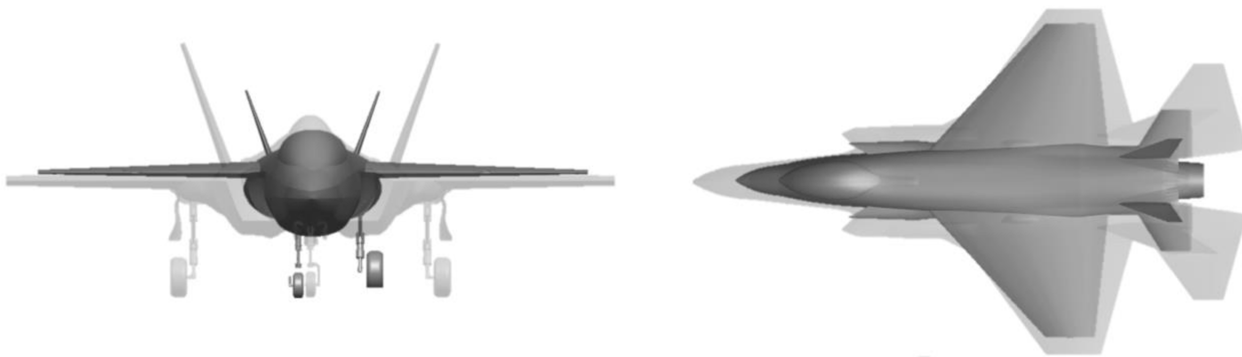

Fig. 17 Representative Shrinkage of the F-35 Considering Appropriate Integration of MASS Weapons

The life cycle cost savings of aircraft programs like the F-35 should be argument enough to license and integrate MASS technologies in combat aircraft. Using raw acquisition cost per pound, then the F-35 has a cost-to-weight sensitivity of $4,533/lb. If one examines Ref. [32], it can be seen that the AMP cost sensitivity of aircraft the size of the F-35 is roughly $9,850/lb. Given large weight, volume, acquisition, direct operating and life cycle cost potentials, it would be wise for the DoD to at the very least investigate the technology and preemptively license the technologies.

V. Conclusions

It was shown that BASS and MASS ammunition have some decidedly superior properties with respect to conventional aerial gunnery ammunition. Foremost among them is far lower drag due to the use of FSDS configurations which allows for flechette-configured projectiles. These flechette projectiles maintain far flatter trajectories, much lower TOF and CEP than conventional ammunition and missile systems. Their low drag profile allows them to exit the muzzle at high speeds up through hypersonic flight regimes and hold high supersonic flight speeds for extended ranges. TOF estimates show that the HBASS rounds can reach targets in a fraction of the time that it takes current air-to-ground weapon systems. Against air targets, HBASS rounds leave the muzzle at speeds in excess of 1mi/s which allows them to engage aerial adversaries in a fraction of the time that it takes a missile to be swung out on a trapeze after bay door opening, then fire only after clearing the boundary layer of aircraft like the F-22 and F-35. New engagement modes are shown to be possible outside of typical MANPADS engagement domes. These engagement modes include run-on strafe, direct fire orbiting fire and indirect orbiting fire. New inhabited aircraft are laid out supporting these engagement modes and new ones including a direct overhead downward shot. 20mm HBASS rounds are also shown to possess enough kinetic energy to penetrate the top armor of T-72 tanks when fired from an altitude outside of the SA-25 thread dome. The full paper will include conclusions regarding families of UAVs armed with HBASS rounds and specially tailored guns as well as cost reduction estimates and conclusions regarding prosecution of Cost-Effective Warfare.

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