STEEL SHOT: RECENT DEVELOPMENTS AND GAINING AN UNDERSTANDING

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Abstract.

Dozens of non-toxic lead shot substitues suitable for waterfowl hunting have been researched and explored for decades. In this time only steel shot has proven non-toxic, ballistically acceptable, and exonomically feasible. Despite the fact that when taken as a whole available research to compare steel vs. lead's ability to bag ducks tends to indicate no significant differences, the belief that steel shot will cripple a greater percentage of waterfowl, besides damaging shotguns, still receives strong support. These beliefs stem from ignorance of facts concerning gun-barrel-damage tests and history, and of the ballistic characteristics and potential of steel shot loads. Ballistically, steel shot can be loaded to perform as well to 70 yards in bagging waterfowl as popular lead shot loads. Steel shot maintains a better form factor than lead shot, and compensations can be made for its lighter weight to enable it to deliver values of retained energy equal to popular lead shot sizes. Improved factory loads and steel shot handloads are forthcoming in the fall of 1978.

INTRODUCTION

While the public seems generally to understand the lead poisoning issue, there is less evidence of its understanding of the successful and unsuccessful non-toxic substitutes for lead shot, results of the controlled shooting tests, and the ballistic properties and potentials of what remains currently as the only available non-toxic substitute for lead shot—soft iron or steel shot. A brief summary and update of the various non-toxic substitutes for lead shot, and the conclusions of the completed controlled shooting tests will serve here, before examining the ballistic properties and potentials of steel shot. Research to find a suitable substitute for lead shot has been reported by Andrews and Longcore (1969), the Mississippi Flyway Council (1965), Kozicky and Madson (1973), Irwin et al. (1973) and Kimbell (1974).

Controlled shooting tests of lead vs. steel shot have been conducted by Bellrose in 1953 (Bellrose 1953, 1959), by the Bureau of Sport Fisheries and Wildlife at the Patuxent Wildlife Research Center in Laurel, Maryland, in 1969 (Andrews and Longcore, 1969), and by Winchester-Western at Nilo Farms near Alton, Illinois in 1972-73 (Madson and Kozicky, 1973).

Field tests comparing lead shotshell load to steel shotshell load performance have been conducted among others by the Mississippi Flyway Council at Nilo Farms in 1964 (Mikula, 1965), by the Bureau of Sport Fisheries and Wildlife on federal refuges in 1973-75 (USFWS FES: Proposed Use of Steel Shot, etc., 1976), at McGraw Wildlife Foundation shooting preserve near Dundee, Illinois in 1971-72 (Nicklaus, 1976), and by the state of Michigan at their Shiawassee River State Game Management Area near

Saginaw in 1973 (Mikula, et al. 1977). All of these tests have been confined to measuring the effectiveness of lead vs. steel in bagging ducks. Most recently in 1977-78 the U.S. Fish and Wildlife Service has been conducting a semi-controlled field test (for which I serve as Principal Research Consultant) on medium-sized geese, rather than ducks, at Tulelake NWR at Tulelake, California.

LEAD SHOT SUBSTITUTES

History

Without citing precise historical development, research and chronology of non-toxic lead shot substitutes, their history can be summarized as follows. Protective coatings applied to lead pellets to prevent the grinding action of the gizzard from exposing the toxic lead core have been tried, tested, and proven failures. This includes jackets of copper, nickel, tin, steel, other metals and metal alloys, epoxy resin, nylon and plastic. All attempts to date to alloy lead with other metals in order to preclude or to render less potent lead's inherent toxicity, have either failed or proven economically unfeasible. These have included alloys of lead-magnesium, lead-calcium, lead-phosphorous-tin (Remington Arms Co. patent), lead-selenium, and lead-tin. Attempts to add 15 different biochemical additives to lead shot to convert lead as it is being eroded into a chemical state that can't be absorbed have failed. Efforts to combine lead powder with water soluble binders and other bonding metals, and to fabricate lead pellets as composites of iron, lead, and plastic have failed. Leaded glass has been considered but does not meet ballistic requirements. The use of materials other than lead such as pure tin, pure zinc, pure copper and pure nickel have been tried and found to be ballistically unacceptable, economically unfeasible, or to create their own toxicity problems (USFWS FES: Proposed Use of Steel Shot, etc., 1976).

Recent Developments

Recent efforts have been made to combine lead and iron in various percentages to produce a non-toxic shot. This so-called "sintered shot" agglomeration process whereby lead is infiltrated into porous iron spheres has been tested for toxicity by the Illinois Natural History Survey in 1975 and 1976, and results reported by Sanderson and Irwin in 1976. Sanderson concluded that a sintered shot pellet of no more than 40 percent lead and 60 percent iron is relatively non-toxic for captive game-farm mallards on a diet of corn (Sanderson et al. 1976).

However, only limited information has been available to indicate the ballistic value of a 40 percent lead 60 percent iron pellet. Current indications are that problems exist in the available technology to render pellets consistent in percentages of the two sintering metals, of preventing the pellets from breaking apart during bore and choke passage in shotguns, of producing successful pellets at an economically feasible cost, and of the pellets performing ballistically more like steel than like lead, (Lowry and Smith, pers. comm.). Sintered shot has within the arms industry slipped quietly into the cloudy world of the unknown, the unfeasible and the impractical.

Finally, a news item has recently appeared in the November 1977 issue of Olin, indicating that John M. Olin, Chairman of the Board of Olin Corporation, and Dr. S. V. Urs, Senior Engineering Associate at the Winchester-Western operation at East Alton, Illinois, has been jointly granted a U.S. patent entitled Disintegrating Lead Shot.

The patent protects a process whereby particles of lead are held together in pellet form by a resinous binder which decomposes in an acid environment as found in the digestive tract of waterfowl, but is stable in less acid environments. Such pellets, it is claimed, would maintain their pellet form in water, the flesh of waterfowl, and other such mediums, but would disintegrate when eaten and quickly pass through the digestive tract, thus reducing or precluding lead poisoning from ingestion. However, no information is available on problems with such pellets fragmenting during bore or choke passage or when striking the target medium, nor on how they would behave ballistically. It is believed that even if these problems were overcome, the cost of manufacture would preclude successful marketing (Lowry and Smith, pers. comm.).

To date only one non-toxic and practical, viable substitute for lead shot remains: soft iron, more popularly called steel shot. Commercially loaded steel shot loads have been used in the United States since 1973.

STEEL SHOT LOAD EFFICIENCY

Despite research and field data to the contrary, the belief that steel shot loads are not an effective substitute for lead shot loads persists. Reality is that all available research when taken together tends to indicate no significant difference in the ability of steel shot loads to bag ducks when compared to lead shot loads under similar circumstances and conditions.

Controlled Test Results

In controlled tests Bellrose found that steel shot performed as well as lead shot of the same size out to 40 yards. At 50 and 60 yards lead proved more lethal than steel (Bellrose, 1959). The Patuxent controlled test of 1 ounce loads of No. 4 steel shot vs. 1¼ ounce loads of No. 4 and No. 6 lead showed lead more efficient than steel, but only when considering consistency of performance (Andrews and Longcore, 1969). The Nilo controlled test compared a 1½ ounce grex-filled load of No. 4 lead to 1 1/8 ounce loads of No. 4 steel and No. 6 steel. The test showed increased crippling losses with either steel load over the lead load at ranges beyond 40 yards (Madson and Kozicky, 1973).

However, Cochrane when comparing the results of both the Patuxent and Nilo controlled tests under a set of common criteria which smoothed out the differences in experimental technique and loads used, found the No. 6 lead load at Patuxent superior to the No. 4 lead loads used at both Patuxent and Nilo, and superior to all steel loads used at Patuxent and Nilo from ranges of 30 to 60 yards (Cochrane, 1976).

Field Test Results

When field test and semi-controlled field test data is examined, a still different picture emerges. At Nilo in 1964 Mikula found that 1 ounce loads of No. 2 steel shot exceeded the performance of 1¼ ounce loads of No. 4 lead shot. The Bureau of Sport Fisheries and Wildlife tests and questionnaires on federal refuges in 1963-75 where 1 1/8 ounces of No. 1 or No. 4 steel shot loads were compared for effectiveness against 1¼ ounce lead loads of No. 2, 4 or 6, reveal the two load types were very similar with respect to effectiveness and loss rates. The semi-controlled field test at the McGraw Foundation in 1971-72 showed no significant difference in bagging or crippling rates between the

$1\frac{1}{4}$ ounce load of No. 6 lead vs. the 1 1/8 ounce load of No. 4 steel at distances of 40 to 60 yards (Nicklaus, 1976). The same was found at Shiawassee in 1973 when the effectiveness of 1 1/8 ounce loads of No. 4 steel were compared to $1\frac{1}{4}$ ounce loads of No. 4 lead (Mikula et al. 1977).

Damage to Gun Barrels

The fear that steel shot will damage shotgun barrels continues to linger despite all indications that it will not. In the five years of usage and field tests of steel shot on state game management areas and federal refuges involving the hunting public, the fact remains that not a single documented case exists of barrel damage or choke erosion directly attributable to steel shot. In addition, the three major arms and ammunition manufacturers have issued public statements and statistics in the USFWS Final EIS on steel shot that currently available steel shot loads containing steel shot of no greater hardness than 95 diamond pyramid hardness (DPH) would cause no significant reduction in the life of most American full-choke shotguns. Their statements and statistics supported the conclusion that only superficial damage to full-choked shotguns such as minor choke expansion might occur, that such expansion might actually improve pattern values, and that only owners of thin-walled, soft-steel shotguns, some Brownings of early serial number vintage, and shotguns with sharpangled or swedged full chokes need worry at all (Roster, 1977). After 18,000 rounds have been expended by hunters during the Tulelake test in 1977, we have no reports or claims of barrel damage.

Popular Attitudes Toward Steel

While barrel damage fears from steel shot may be waning, the belief that steel shot is an inefficient projectile that will increase crippling losses continues. One only need examine such pieces as "Steel Shot Advocates Ignore Nature's Laws" by Robert N. Sears, in the January 1975 issue of The American Rifleman; "Steel Shot Evaluated" by Nick Karras in the December 2, 1977, issue of Newsday; the entire chapter entitled "Stuffing Steel Shot" in Don Zutz's book Handloading for Hunters, copyright 1977, published by Winchester Press (319 pp), or any in a series of "News from Nilo" news releases from Winchester-Western in recent years to see that many outdoor writers and some manufacturers still believe that steel shot is ineffective past 35 yards and will increase crippling losses of waterfowl. This despite the aforementioned cited research which when taken as a whole indicates steel shot can be as efficient as lead in bagging ducks.

The Nilo Test Discussed

The most frequently cited data base for the belief that steel shot must necessarily increase crippling losses is the controlled test study done at Nilo. Unfortunately, those who look to Nilo for support of their belief that steel shot is inefficient beyond 35 yards fail to recognize that the Nilo test was in many ways an unfair comparison. The Nilo test compared the very best available 2-3/4" lead shot loads—the Super-X Double X magnum, a 1-1/2 ounce load of very hard No. 4 lead shot buffered with a granulated plastic filler, which results in abnormally high pattern performance above 90 percent in most full-choke shotguns—against a quite primitive 1 1/8 ounce load of No. 4 steel and another of No. 6 steel. Ballistically, the No. 6 steel load never had a chance, and while the No. 4 steel load contained nearly the same number of pellets as the No. 4 lead load, that is, they were volumetrically equivalent, the steel load did not pattern as well, nor could the size of steel pellets used ever compare to the size of lead pellets used in terms of retained energy. Ballistically, a steel pellet must be nearly two sizes larger than a lead pellet to retain similar energy over distance. Thus, a fair ballistic comparison can occur only when No. 4 lead is tested against No. 2 steel.

In addition, the XX Magnum load tested at Nilo is not one that is frequently shot by the public for the majority of this nation's duck hunting. The standard 1¼ ounce lead load, together with the "baby magnum," 1½ ounce, non-buffered lead load easily comprise 95 percent of all the 2-3/4" 12 guage lead shot loads used to hunt ducks. Thus, the Nilo project tested the Cadillac of lead loads, used by no more than 5 percent of this country's waterfowlers, against a mediocre steel load, loaded with a shot size that could never compare ballistically to the lead shot of the size and quality loaded in the "Cadillac" load.

Had the Nilo project compared a 1¼ ounce load of No. 4 lead possessing a lower antimony level which renders a softer pellet more closely approximating the quality of lead shot found in many of the 1¼ ounce and 1½ ounce lead loads used by most waterfowlers, against a ballistically equivalent No. 2 steel pellet in a 1-1/8 ounce steel load which had been tested, altered and refined as long as the decades-old 1¼ ounce and 1½ ounce loads results would be much different. In fact, I submit, results might have been very similar to what Mikula found in 1964—that a steel shot load truly equivalent to a given lead shot load, cannot only hold its own, but often times can exceed lead shot performance.

As a ballistics expert, I view the Nilo controlled test as serving chiefly to instruct us about one point—that most lead shot load performance can be greatly improved by the loading of very hard shot and by the addition of a filler material to the shot column. Hard shot and a filler added to the shot column interstices help preclude lead pellet deformation.

Thus, the major ballistic conclusion arising from the Nilo project is <u>not</u> that steel shot in total is inferior to lead shot and therefore will increase crippling losses of waterfowl. Rather, Nilo taught us a more modest ballistic fact: that an essentially undeformed lead projectile of the same size as a steel projectile will tend to be ballistically superior to the steel projectile.

UNDERSTANDING STEEL SHOT

However, just because steel, shot size for size, is lighter than lead shot and therefore suffers ballistically, does not necessarily mean that it cannot be loaded in such a manner as to compensate for its lightness so that steel can serve as an acceptable, even desirable, ballistic projectile for waterfowl hunting. To understand steeel shot, one must first recognize and admit the inherent deficiencies in lead shot and lead shot loads. Secondly, one must recognize that steel shot inherently overcomes lead shot's major ballistic flaw. Thirdly, to understand steel shot, attention must be paid to the reality that steel shot's only ballistic problem is its light weight but merits of a shotshell load.

Hunters Performance with Lead Shot Loads

Since for centuries lead shot has been used almost exclusively for waterfowl hunting, and since many millions of waterfowl have been successfully bagged with lead shot, there is a tendency to believe that only lead shot can successfully bag waterfowl.

This belief seems especially strong in a large percentage of waterfowl hunters, but fails to recognize that the average American hunter has been something less than impressive in bagging waterfowl with lead. Bellrose (1953) summarized a large sample of observations of hunter performance with lead shot obtained between 1945 and 1951 at 11 locations in the eastern half of the United States. Twenty-two and one-half percent of approximately 80,000 ducks downed were not retrieved (assumed cripples). Each year since 1952 a portion of the duck stamp purchasers have been contacted by the USFWS and asked to report their hunting kill or number of birds downed but not retrieved. For the period 1952-71 these hunter reports indicate that throughout the U.S. slightly less than 19 percent of birds downed with lead shot were not retrieved (USFWS DES on Steel Shot, 1976). Crippling losses with lead shot, then, have been measurably higher than desirable. Hunters also display less than desirable ability to hit waterfowl (shooting ability) with lead shot. Current estimates indicate that the average hunter fires six shells for each duck he bags and nine shells for each goose (Roster, 1976).

Lead Shot Problems

While lead shot is desirable ballistically from the standpoint of its outstanding pellet density, lead shot suffers from its inability to remain round under the forces of combustion in shotshell loads, and during forcing cone, bore and choke passage. Thus, depending upon the load and loading technique, a high percentage of the pellets in any given lead shot load are deformed before they leave the muzzle. Deformed pellets expose more surface area to air resistance (drag) than round pellets, and therefore diverge from the point of aim as flyer shot and these in turn reduce pattern values. In addition, deformed shot do not retain as much energy over distance as round shot, and tend to fall behind round shot excessively lengthening the shot string. Deformed lead shot pellets and excessive shot stringing increase crippling losses (Roster, 1976, 1977: Brister, 1976).

Because the hardness of lead pellets in unbuffered lead shot loads becomes the principal factor in their ability to pattern well, as shot hardness goes, so goes patterning values. It is a common myth among hunters that shot quality in all factory loads and even reloads is the same. In fact, this is not true. As price goes down for a given load of factory lead shot ammunition for a given gauge, so usually does the amount of antimony added to the shot. Since antimony is the chief hardening agent in lead shot, as antimony decreases so does shot hardness. Thus, the least expensive factory loads and the least expensive bagged shot sold to reloaders tend to contain the softest shot (Roster, 1975a; 1977b; Brister, 1976).

Lead Shot Load Patterning Performance

The ammunition industry has traditionally attempted to overcome lead shot's proclivity for deformation and low pattern values, by loading larger shot charges per gauge, popularly called "magnum loads." Hunters commonly believe that magnum loads pattern the best of all shotshell loads and are the most lethal of all loads especially for goose hunting. This currently accounts for the unbuffered 1½ ounce "baby magnum" 12 gauge load comprising the largest percentage of goose loads sold by the three leading ammunition manufacturers (Bussard, Dietz, and Falk pers. comm.).

In reality, both Brister and I have found that when subjected to arduous pattern testing, unbuffered magnum lead shot loads consistently pattern the poorest of all shotshell loads currently used, and that lighter, less popular loads actually produce better patterns at long range (Roster, 1975a, 1975b, 1976, 1977b; Brister, 1976).

Recent efforts (since 1973) to improve lead shot load patterning performance have concentrated on loading hard lead shot, plated lead shot, and the addition of a filler material (a buffering agent) to the shot column to reduce pellet deformation. These loads tend to pattern the most densely of all shotshell loads, with factory buffered loads producing pattern values at 40 yards through most full-choke shotguns of 80 to 92 percent, and in the case of the buffered loads I developed, as high as 100 percent (Roster, 1975a, 1976, 1977b, 1977c; Brister 1976). However, even though these loads pattern extremely well and have shorter shot strings than unbuffered lead loads, they are more difficult to load, more costly, and are employed for probably less than 10 percent of all the shots fired at waterfowl (Brister, 1976; Roster, unpubl.).

As a consequence of magnum loads tendency to pattern poorly (especially at long range) of popular inexpensive lead loads containing low antimony shot and thus also tending to pattern poorly, it is a ballistic fact that these loads—the lead loads currently being used by the vast majority of waterfowl hunters in this country—struggle to achieve 70 percent pattern values at 40 yards and 30-35 percent pattern values at 60 yards through most full-choke shotguns (Roster 1975a, 1976b, 1976, 1977b; Brister 1976).

Steel Shot's Form Factor

Unlike lead, steel shot of 75 DPH or harder tends to be extremely resistant to deformation, emerging from the barrel in an essentially spheric shape. Currently manufactured steel shot loads contain pellets at or near the 90 DPH level of hardness. While working on the Nilo project, E. D. Lowry (1973) who had participated in the Patuxent test and played a major role in developing the Nilo lethality formula, found during a Sporting Arms and Ammunition Manufacturers' Institute (SAAMI) funded grant to Winchester-Western in 1969 that steel shot maintains a minimum of a 12 percent higher form factor than lead shot. A projectile's form is one of three major factors used to rate the ballistic effectiveness of shotshell pellets, the other two being the density of the pellet and its original velocity. Thus steel pellets, due to their high form factor, are capable of traveling through atmospheric resistance at a higher degree of efficiency than their density would indicate.

A new set of tables for lead and steel completed by Lowry on February 26, 1970, were turned over to SAAMI to be incorporated into the SAAMI Technical Committee Manual (Revised). The new tables, relatively unknown to the bulk of America's shooters and hunters, take into account lead's poor form factor, and thus adjusts the performance of lead shot pellets downward in terms of retained energy and time in flight. The old SAAMI shotshell ballistics table for lead shot, believed for years as gospel, was based on mathematical projection rather than actual down-range testing. It assumed a spheric shape for the lead projectile, and thus an inflated form factor, which also produced an inflated set of retained energy and time in flight values for lead shot.

A brief examination of Table 1 which incorporates the new and old tables, helps explain why Mikula (1974) found No. 2 steel outperforming No. 4 lead and why the primitive 1 ounce steel load used at Patuxent (Andrews et al., 1969) was capable of bagging ducks as effectively at 40 yards and nearly as effectively at 60 yards as the 1¼ ounce lead load.

Steel Shot Load Patterning Performance

A direct result of steel's higher form factor is its tendency to pattern better than lead shot. While most unbuffered lead loads through full-choke guns struggle to achieve 70 percent patterns at 40 yards and 30-35 percent patterns at 60 yards, current steel shot loads typically pattern 80-92 percent at 40 yards and 45-60 percent at 60 yards, depending on shot size, load and gun used. Thus, current steel shot loads, even though they are in the infancy of their development, pattern consistently as well as the most modern of lead loads—those buffered with a filler material added to the shot column (Brister, 1976; Roster unpubl.). Typical steel shot loads, then, outpattern by a wide margin the popular lead shot loads used for the majority of waterfowl hunting.

In addition, steel shot load shot strings, are much shorter than lead shot loadshot strings. Brister (1976) found during moving pattern tests to measure shot stringing at speeds equivalent to flighted waterfowl -40-50 MPH- that steel shot loads produced shot strings significantly shorter than non-buffered (popular) lead shot loads at ranges of 40 to 60 yards.

Steel Shot Retained Energy

Of the three major factors used to determine a pellet's ballistic effectiveness, steel shot is inferior to lead in regard to only one-pellet density (weight). Steel is only 68 percent as heavy as lead. The popular belief is that this factor alone makes steel inherently inferior to lead, and therefore, never as effective as lead. This is true, however, only when comparing steel and lead pellets of the same size.

But what hard and fast rule requires that the same size pellets of steel be used for the same tasks required of lead pellets? While 6's and 5's have been traditionally popular with duck hunters, and 4's and 2's with goose hunters, for example, what law or constraint prevents the use of No. 4's or 2's for ducks or No. 1's or BB's for geese? (Table 2). There is none ballistically. Shot size choice is largely a matter of preference governed to a certain extent by desired pattern density. Current popular lead shot sizes are used as a matter of tradition more than ballistic necessity.

A steel shot pellet two sizes larger than a lead shot pellet performs in a similar ballistic manner and is therefore, ballistically comparable (Lowry, 1973; Brister, 1976; Roster, 1977a). The simple switch from a given lead shot pellet size to a steel shot pellet two sizes larger immediately compensates for steel's lightness (Table 3). With steel, then replacement shot sizes for ducks could be 4's, 3's or even 2's. Replacement steel shot sizes for geese could be 2's, 1's, B's or BB's.

Since retained energy is a function of mass and velocity ($KE = 1/2\ MV^2$), steel's lighter mass can be further compensated by increasing velocity. Table 4 reveals that a 1365 fps steel shot load (average instrumental velocity of currently available commercial

Table 1. Comparison in part of the old SAAMI shotshell ballistics table for lead and the table completed and submitted to SAAMI in 1970 (new), and a current down-range ballistics table for steel, run for Roster by E. Lowry on 1/14/78.

Pellet Type	Ballistic Table	Pellet Size	Instrumental Velocity	Velocity (fps)		Energy Per Pellet (ft./lbs.)		Time in Flight (sec.)	
				40 yds.	60 yds.	40 yds.	60 yds.	40 yds.	60 yds.
Lead	Old	4	1330	815	685	4.77	3.35	.1187	.1993
Lead	New	4	1330	740	590	3.91	2.49	.1235	.2147
Lead	Old	2	1330	860	730	7.98	5.76	.1148	.1908
Lead	New	2	1330	770	630	6.39	4.28	.1204	.2071
Lead	Old	BB	1330	915	790	16.27	12.23	.1107	.1815
Lead	New	BB	1330	815	675	12.89	8.84	.1167	.1980
Lead	Old	6	1330	765	630	2.50	1.70	.1238	.2108
Lead	New	6	1330	700	550	2.11	1.30	.1278	.2252
Lead	Old	66	1255	740	610	2.34	1.61	.1292	.2189
Lead	New	6	1255	680	535	1.99	1.23	.1327	.2328
Lead	Old	4	1255	785	665	4.45	3.16	.1240	.2074
Lead	New	4	1255	715	575	3.65	2.36	.1288	.2228
Lead	Old	2	1255	830	705	7.43	5.36	.1201	.1994
Lead	New	2	1255	745	610	5.98	4.01	.1255	.2148
Lead	Old	BB	1255	880	765	15.05	11.37	.1160	.1894
Lead	New	BB	1255	785	655	11.96	8.33	.1219	.2059
Lead	Old	6	1185	715	595	2.18	1.52	.1348	.2274
Lead	Old	4	1185	760	645	4.13	2.97	.1297	.2159
Lead	Old	2	1185	795	685	6.81	5.06	.1259	.2073
Steel	-	4	1500	700	532	2.48	1.43	.1216	.2204
Steel	-	2	1500	739	575	4.25	2.57	.1175	.2100
Steel	-	1	1500	769	602	5.58	3.42	.1133	.2021
Steel	-	BB	1500	790	628	8.39	5.31	.1128	.1985
Steel	-	4	1450	689	601	2.40	1.40	.1242	.2243
Steel	-	2	1450	728	567	4.12	2.50	.1201	.2139
Steel	-	1	1450	745	586	5.24	3.24	.1183	.2096
Steel	-	BB	1450	777	620	8.11	5.16	.1154	.2024
Steel	-	4	1400	679	517	2.33	1.35	.1269	.2285
Steel	-	2	1400	716	559	3.98	2.43	.1228	.2181
Steel	-	1	1400	732	577	5.06	3.14	.1211	.2138
Steel	-	BB	1400	763	610	7.83	5.00	.1182	.2066
Steel	-	4	1365	671	512	2.28	1.33	.1290	.2317
Steel	-	2	1365	707	552	3.88	2.37	.1249	.2213
Steel	-	1	1365	723	571	4.94	3.07	.1232	.2170
Steel	-	BB	1365	753	603	7.62	4.69	.1203	.2098
Steel	-	4	1300	656	500	2.18	1.27	.1330	.2381
Steel	-	2	1300	690	540	3.70	2.27	.1290	.2276
Steel	-	1	1300	706	558	4.70	2.94	.1273	.2233
Steel	-	BB	1300	734	590	7.24	4.68	.1245	.2160
Steel	-	4	1250	644	491	2.10	1.22	.1365	.2435
Steel	-	2	1250	677	530	3.56	2.19	.1324	.2329
Steel	-	1	1250	692	548	4.51	2.83	.1308	.2286
Steel	-	BB	1250	719	579	6.94	4.50	.1280	.2213
Steel	-	4	1200	631	482	2.02	1.17	.1402	.2494
Steel	-	2	1200	663	520	3.41	2.10	.1362	.2387
Steel	-	1	1200	677	537	4.32	2.72	.1345	.2343
Steel	-	BB	1200	703	567	6.63	4.32	.1318	.2271
Steel	-	4	1100	603	460	1.84	1.07	.1486	.2629
Steel	-	2	1100	633	496	3.11	1.91	.1447	.2520
Steel	-	1	1100	646	512	3.94	2.48	.1431	.2476
Steel	-	BB	1100	669	541	6.01	3.94	.1404	.2403

Table 2. Standard American steel and lead shot size designations by diameter.

Shot Size Designation (American)	Diameter (Inches)
BB	.180
Air Rifle	.175
B	.170
1	.160
2	.150
3	.140
4	.130
5	.120
6	.110

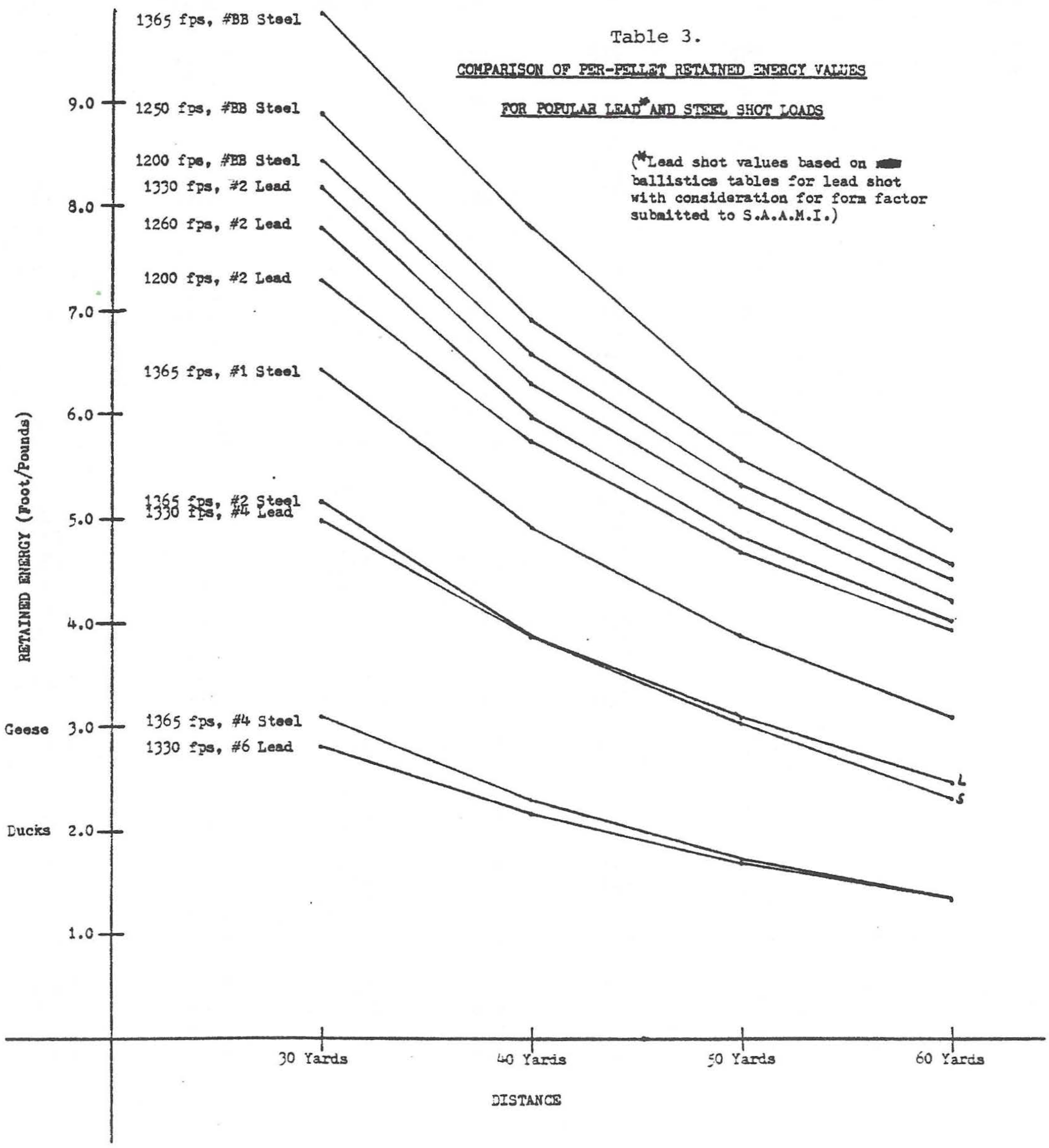

Table 3.

COMPARISON OF PER-PELLET RETAINED ENERGY VALUES FOR POPULAR LEAD* AND STEEL SHOT LOADS

(*Lead shot values based on [redacted] ballistics tables for lead shot with consideration for form factor submitted to S.A.A.M.I.)

1-1/8 oz., 2-3/4" 12 gauge steel shot loads) of No. 2 steel retains almost identical per-pellet energy at 60 yards (2.37 ft/lbs) as a 1255 fps (average instrumental velocity of currently available commercial 2-3/4", 1½ ounce lead loads) of No. 4 lead (2.36 ft/lbs). A similar ballistic comparison exists between even the fastest available lead load of No. 6 shot (average instrumental velocity of currently available 3-3/4 dram equivalent commercial 2-3/4", 12 ga., 1¼ ounce lead loads) which retains 2.11 ft/lbs and 1.30 ft/lbs of energy per pellet at 40 and 60 yards, and the commercially loaded 2-3/4", 12 ga. 1 1/8 oz. No. 4 steel shot load—2.28 ft/lbs and 1.33 ft/lbs of retained energy per pellet at 40 and 60 yards respectively. For geese the 2-3/4" 12 ga., 1-1/8 oz. load of steel 1's retains 3.07 ft/lbs of energy per pellet at 60 yards and steel BB's in the same loading would retain 4.69 ft/lbs per pellet at the same range. This slightly exceeds the per-pellet retained energy values of the most popular American goose load, the 2-3/4", 12 guage "baby magnum" load (1255 fps average instrumental velocity) of lead 4's which retain 2.36 ft/lbs of energy per pellet and lead 2's which retain 4.01 ft/lbs of energy per pellet at the same distances.

Since retained energy and it derivative, delivered pellet energy density—$\left(\frac{\text{retained energy-threshold energy}}{\text{cross-sectional area of pellet}}\right)$ is the factor most closely correlated with percentage of bagged birds (Lowry 1974), steel shot's ability to retain energy in a manner equivalent to lead shot (given proper shot size selection and velocity compensations) enables steel shot to be as capable as lead shot up to size No. 2 of being ballistically efficient in bagging waterfowl.

Steel Shot Load Pellet Counts and Pattern Density

The only factor steel might still give up to lead is pattern density. This cannot be true when comparing lighter steel loads to heavier lead loads of the same shot size for frequently certain lead and steel loads would contain the same pellet counts. Since steel loads tend to pattern more densely than lead shot loads, a steel load volumetrically equivalent to a lead shot load of the same shot size would produce a superior pattern density. Thus, for example, a 1-1/8 ounce load of No. 2 steel shot would be expected to produce higher pattern values and a shorter shot string than a 1½ ounce unbuffered load of No. 2 lead. This fact also offers compensation when having to go up in pellet size steel to gain equivalent retained energy values to lead. Because steel patterns more densely than lead with less stringing than unbuffered lead, a larger shot size can be employed to deliver similar on-target pattern density, especially as range increases.

In addition, sight must not be lost of the fact that delivered pellet energy density is the factor most closely correlated with bagged birds, not pattern density (Lowry 1974; Roster unpubl.). The belief that pattern density, i.e., that a pattern made up of many pellets of a smaller size is more lethal than one made of of a fewer pellets of larger size, is not grounded in ballistic fact and has never been convincingly proven by research. This explains why, again, Mikula (1964) found that a 1 ounce load of No. 2 steel outperformed a 1¼ ounce load of No. 4 lead in bagging ducks.

Current and Past Steel Shot Loads

To date three manufacturers offer steel shot ammunition in 12 guage only (Table 4). Federal and Remington currently offer a 2-3/4", 12 ga. 1-1/8 ounce steel load in sizes No. 1, 2, 4 and No. 1 and 4 respectively. These 1-1/8 ounce steel loads are the lightest steel loads available and are also currently loaded to the highest velocity

Table 4. Comparison of popular commercial lead and steel shot load retained per-pellet energy values.

Load	Shot Type	Nominal Instrumental Velocity	Shot Size Available and/or Popular for Waterfowl	Retained Energy Per-Pellet (Ft./lbs.) 40 yds.	60 yds.
3" 12 ga. 1-7/8 oz. Magnum	Lead	----	BB	---	---
	Lead	1220	2	7.13 (old)*	5.23 (old)
	Lead	1220	4	4.29 (old)	3.06 (old)
3" 20 ga. 1-1/4 oz. Magnum	Lead	1185	2	6.81 (old)*	5.06 (old)
	Lead	1185	4	4.13 (old)*	2.97 (old)
	Lead	1185	6	2.18 (old)*	1.52 (old)
2-3/4" 12 ga. 1-1/2 oz. Magnum	Lead	1255	BB	11.96 (new)	8.33 (new)
	Lead	1255	2	5.98 (new)	4.01 (new)
	Lead	1255	4	3.65 (new)	2.36 (new)
	Lead	1255	6	1.99 (new)	1.23 (new)
2-3/4" 12 ga. 3-1/4 DE 1-1/4 oz.	Lead	1330	4	3.91 (new)	2.49 (new)
	Lead	1330	6	2.11 (new)	1.30 (new)
2-3/4" 12 ga. 1-1/8 oz. Federal and Remington 3" 12 ga. 1-1/4 oz. Remington (new)	Steel	1365	BB	7.62	4.69
	Steel	1365	1	4.94	3.09
	Steel	1365	2	3.88	2.37
	Steel	1365	4	2.28	1.33
2-3/4" 12 ga. 1-1/4 oz. Winchester (new and old); Federal (new)	Steel	1250	BB	6.94	4.50
	Steel	1250**	1	4.51	2.83
	Steel	1250**	2	3.56	2.19
	Steel	1250**	4	2.10	1.22
3" 12 ga. 1-3/8 oz. Federal (new) and 3" 12 ga. 1-1/2 oz. Winchester (new)	Steel	1200	BB	6.63	4.32
	Steel	1200	1	4.32	2.72
	Steel	1200	2	3.41	2.10
	Steel	1200	4	2.02	1.17
3" 12 ga. 1-1/2 oz. Winchester (old)	Steel	1100**	1	3.94	2.48
	Steel	1100**	2	3.11	1.91
	Steel	1100**	4	1.84	1.07

* New retained energy values for lead consideration for form factor not available below 1255 fps.

** Chronographed by Roster.

levels. Light hunting loads for any given gauge and shell length have always been the fastest available, and this will probably remain true for steel shot loads. Increased ejecta weight always compounds velocity development, for as ejecta weight increases in a given shell length and gauge, so does chamber pressure.

Thus, the heavier steel shot loads currently available have lower velocity levels. Winchester-Western's 2-3/4" 12 guage, 1¼ ounce newer fold crimp steel load attains a velocity of 1250 fps as did its older, now discontinued, roll crimp 1¼ ounce steel load. Winchester's newest currently available 3", 12 ga. 1½ ounce fold crimp steel load attains an instrumental velocity of 1200 fps, but this is significantly better than its old, now discontinued, roll crimped, 3" 12 gauge, 1½ ounce steel load which traveled at only 1100 fps.

Discussion of Old Commercial Steel Loads

Of the three steel loads available, the fastest yet lightest steel load, the 1-1/8 ounce load, is still the most desirable ballistically. The Winchester 3", 12 gauge steel loads not only caused gun malfunctions in popular 3", 12 ga. autoloaders such as Remington's Model 1100 (Dietz and McCawley, pers. comm.), but also delivered very low per pellet energy values. The discontinued 1100 fps W-W 3", 12 ga., 1½ ounce steel load actually delivered undesirably low per pellet energy values. In addition, the old W-W 1¼ ounce and 1½ ounce steel loads displayed erratic pattern performance (Roster unpubl.).

Since it is generally considered necessary to deliver a minimum of 2.0 ft/lbs. of retained energy per pellet for clean kills on ducks, and 3.0 ft/lbs. minimum per pellet energy for clean kills on geese (Roster 1975a, 1976 and others), it is difficult to maintain these levels at normal duck and goose shooting ranges with steel shot with loads having instrumental muzzle velocities below 1300 fps. Examination of Table 4 reveals that W-W's old 1100 fps, 3", 12 gauge, 1½ ounce steel load would be below the 2.0 ft/lbs. minimum needed for ducks with 4's beyond 40 yards and the 3.0 ft/lbs. needed for geese with 2's beyond 40 yards, and with 1's beyond 50 yards. Even the 1200 fps velocity level of current W-W 3", 12 gauge, 1½ ounce steel loads, while an improvement, must still be considered ballistically undesirable. And, there is a high incidence of reported crippling loss problems with steel shot and the use of this load during the 1977 waterfowl season (Smith, pers. comm.).

New Developments In Steel Shot Loads

Both Federal Cartridge Corporation and Remington Arms Co. plan to market heavier fold crimp, 2-3/4" 12 ga. steel loads by the fall of 1978. The Federal steel load will be 1¼ oz. in weight and available in No. BB, 1, 2, and 4 with a targeted minimum velocity level of 1330 fps. Still in the developmental stages, Federal has been able to achieve only 1260 fps velocity levels at a safe chamber pressure as of this writing. The higher muzzle velocity is pending receipt of a new Hercules, Inc., double base, flake powder containing a higher energy level (Bussard pers. comm.).

The Remington heavier 2-3/4" 12 ga. steel load weight has not been decided as of this writing, but the targeted velocity level is 1350 fps. Shot sizes available will include 1's, 2 and 4's. I had an opportunity to field test an experimental 1300 fps, 1¼ oz. version of this load (loaded in a new fold-crimp, one-piece plastic hull of increased volumetric capacity) at Remington Farms in November of 1977. Shooting the experimental $1\frac{1}{4}$ oz. steel load in No. 1 shot with Bob Brister of Field and Stream and Jim Carmichael of Outdoor Life, we made six, one-shot kills with nine shells on Canadensis at ranges of 45 to 65 yards. Autopsies revealed a range of eight to eighteen pellet hits per bird at these ranges, and frequent penetration completely through the goose.

Remington will also have available in fall of 1978 a 3" 12 ga. $1\frac{1}{4}$ ounce steel load in 1's 2's and 4's with a targeted velocity in excess of 1350 fps. Federal currently has a 1-3/8 oz., 3" 12 gauge load developed, capable of 1210 fps velocities. However, pending the arrival of new powders from Hercules, Inc., Federal hopes to increase the muzzle velocity to 1290 fps, with 1250 fps the minimum desired. This load will be available by the fall of 1978 in shot sizes No. BB, 1, 2, and 4 (Bussard, pers. comm.).

In addition, Federal will be adding No. BB shot to its 2-3/4", 12 ga., 1-1/8 ounce steel load offering and Remington No. 2 steel to its 2-3/4", 12 ga., 1-1/8 ounce steel load offering for the fall of 1978. No steel loads are planned by either company for the 16 and 20 guage as of this writing (Bussard and McCawley pers. comm.). For a comparison of steel shot load and lead shot load weights and pellet counts, see Table 5.

Finally, I will be publishing by early summer of 1979, data I have developed after $1\frac{1}{2}$ years of research for reloading steel shot. The data will include loads for the 2-3/4" and 3", 12 gauge and both a $1\frac{1}{2}$ ounce and 1-5/8 ounce, $3\frac{1}{2}$", 10 gauge steel load. All components (including steel shot and wads suitable for loading steel shot) used to assemble the loads will be available to the consumer at a date coinciding with the publication of the data. The loads achieve a velocity level meeting or exceeding current and planned commercially loaded steel shot load velocity levels for respective loads. Reloaders will be able to assemble these loads at approximately one-third to one-half the cost of equivalent commercially loaded steel shot ammunition.

CONCLUSIONS

Steel shot remains the only ballistically acceptable and economically feasible non-toxic substitute for lead shot. Current field research tends to indicate no significant differences in the ability of steel to bag ducks when compared to lead. Research is currently being undertaken at Tulelake NWR to compare the effectiveness of steel vs. lead in bagging geese. Current data indicates that steel shot will not harm the majority of shotguns and that the possiblity of choke erosion exists only for a very limited number of full-choke guns.

The best of lead loads (buffered lead loads) will always outperform the best of steel loads of the same shot size. However, buffered lead loads are a recent development in lead shot loads and are currently used by only about 10 percent of the hunting public. Therefore, steel shot load performance should more properly be compared to popular lead shot loads—unbuffered lead loads. When this comparison is made, steel shot loads perform favorably with lead shot loads, due to lead shot's poor form factor and lower pattern values.

Steel shot is lighter than lead, but maintains a higher form factor. Compensations can be made for steel's light weight by employing pellets two sizes larger than lead,

Table 5. Comparison of volumetrically equivalent steel and lead shot loads of the same shot size.

STEEL VS. LEAD

PELLET COUNT/SHOT CHARGE WEIGHT

Approximate Number of Pellets Per load

	1-1/8 Oz. Steel (492.2 grs.)	1-1/2 Oz. Lead (656.3 grs.)	1-1/4 Oz. Steel (546.9 grs.)	1-3/4 Oz. Lead (765.6 grs.)	1-3/8 Oz. Steel (601.6 grs.)	1-7/8 Oz. Lead (820.3 grs.)	1-1/2 Oz. Steel (656.3 grs.)	2-1/8 Oz. Lead (929.7 grs.)	1-5/8 Steel (710.9 g
#BB .180	80	75	93	88	99	94	107	106	119
#1 .160"	116 Federal 119 mine	--	133	--	146	--	159	--	172
#2 .150"	140 Federal 137 mine	132	153	154	168	165	189	187	199
#4 .130"	216	204	241	238	267	259	291	289	315

Approximate Number of Pellets Per Load (cont.)

	2-1/4 Oz. Lead (984.4 grs.)
#BB .180	113
#1 .160"	--
#2 .150"	198
#4 .130"	307

and by driving steel at higher velocity levels than lead. When this is done, steel shot loads become ballistically similar to lead shot loads, and are capable of performing as well to ranges of 70 yards in bagging waterfowl as lead shot loads.

Some old commercial steel shot loads have been dropped. Improved factory steel shot loads and reloading data for steel shot loads will be forthcoming in 1978. Those steel shot loads possessing the highest muzzle velocities tend to be the most desirable ballistically.

Steel shot loads are still in their infancy and further development is needed. Current development is hampered by the unavailability of high energy, low bulk powders as yet unused in shotshell loading. As new powders are developed, so will new steel shot loads. Steel shot loads possessing velocity levels in the 1375-1500 fps range need to be researched and developed.

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