Gun Systems? For Air Defense?

William D. O'Neil

U. S. Naval Institute Proceedings, March, 1971

Most people are now ready to concede that the naval gun serves a useful purpose in shore bombardment. Many will even credit the gun with a significant, if limited, role in dealing with opposing surface ships. But few can imagine the gun challenging the missile's suzerainty in naval air defense.

A conclusion reached from the U. S. Navy's experience during World War II was that AA guns were a vital part of air defense. If the combat air patrol could break up and thin out any massed, coordinated thrusts, the shipboard AA guns generally could be counted upon to deal with the remaining attackers. The kamikazes changed the picture somewhat. Damage which would cause a bomber pilot to break off his attack would not likely deter a man bent on suicide. The Navy's answer to the kamikaze was the 3-inch/50-caliber rapid fire gun, which threw a heavier shell to longer ranges than the 20-mm. and 40-mm. guns which had been the AA mainstays, together with radar-directed fire control systems. These new systems did not see service during World War II.

The Germans worked on a number of surface-to-air missiles (SAMs) as an answer to Allied high-altitude bomber attacks, and came reasonably close to putting two types into service. The U. S. Navy had given some thought to SAMs, but operational experience had shown that ships had less to fear from high altitude bombers than from dive bombers or kamikazes. Then came the atom bomb, and, suddenly, it seemed imperative for the Fleet to have an absolutely "air tight" defense against high altitude bombers.

AA guns could not meet this need. Only a very heavy gun (5- or 6-inch, at least) would fire a projectile to a height of 30,000 to 40,000 feet, and such guns could not be made to fire very rapidly, nor could ships carry large quantities of such heavy ammunition. Moreover, the time of flight to altitude would be at least 20 to 30 seconds. Thus, any miscalculation in upper air winds, any errors in measurement of the target's position or velocity, or any maneuver by the target would cause the projectile to miss its target by a wide margin.

The combination of low volume of fire and low accuracy meant that a gun system effective against high altitude bombers would be enormously costly, if, indeed, one could be perfected at all.

The U. S. Navy decided to take up where the Germans had left off. A SAM with target-seeking (homing) guidance would not lose accuracy over long times of flight. The gain in accuracy would more than compensate for the low rate of fire and high unit cost inherent in a SAM system. Some optimists predicted single shot kill probabilities of virtually 100%, and no one predicted less than 50%. And so the U. S. Navy invested huge sums in developing and producing shipboard SAM systems such as Terrier, Talos, Tartar, and (still on the drawing board) Aegis. The British, French, and Soviet Navies also took up SAM development, on scales appropriate to their more limited resources.

The SAM has indeed proven to be quite efficient against high-flying bombers. It seems quite generally agreed that high-altitude (or even medium-altitude) free-fall bombing attacks against targets well defended by SAMs would inevitably suffer very high losses. It seems unlikely that any air force contemplates such attacks against naval task forces escorted by SAM ships: current thinking on air strikes against naval units emphasizes low altitude attacks by tactical aircraft or antiship missiles. It is no coincidence, of course, that most SAMs are at their weakest in dealing with low level targets.

The performance deficiencies of SAMs might not appear to be too significant if the missiles were inexpensive enough to be mounted in considerable numbers throughout the Fleet. Quite the reverse is true. SAMs cost more than $25 thousand each, and a complete shipboard installation costs as much as a World War II cruiser. The original idea that SAMs would be employed for the defense of individual ships in the manner of World War II AA guns has had to be dropped owing to cost. Thus, the U. S. Navy's Tartar, originally envisioned as an inexpensive SAM system suitable for the main armament on light warships and the secondary armament of larger ships, today forms the primary armament of 10,000-ton, $200-million, nuclear-powered, guided missile frigates.

The Tartar missile is now classed as an area defense weapon, intended to defend an entire task group rather than any individual ship. Whether Tartar can do this when faced with concerted low altitude attacks is very doubtful. SAMs are inherently best-suited to the role for which they were first designed: defense against aircraft flying at high-to-medium altitudes. While a SAM certainly could be designed to deal effectively with multi-wave, low-level, high-speed attacks on ships ten miles away, the costs would be staggering.

Effective low-altitude air defense became a matter of considerable urgency with the advent of the antiship missile. Previously, one had to worry about really effective low-level attack only when the force was within a few hundred miles of an enemy tactical air base or aircraft carrier. Antiship missiles, on the other hand, can be launched from surface ships, submarines, long-range maritime reconnaissance aircraft, shore batteries, or even small patrol boats. These weapons make virtually every enemy unit a potential source of strong air attacks.

The Soviets were the first to develop antiship missiles and have deployed a number of types. Best known is the Styx (NATO code name), a small subsonic rocket missile with a range of at least 13 nautical miles. Styx missiles, launched from a Soviet-supplied patrol boat, were used by the Egyptians to sink the Israeli destroyer *Elath* in 1967. The Saab Rb 08 antiship missile is operational on destroyers of the Swedish Navy, and the Israelis have fitted their Gabriel missile on patrol boats supplied by the French. The French themselves have developed a missile known as the Exocet. The Italian firm of Contraves has two versions of its Sea Killer; the larger Mk-2 has a maximum range in excess of 25,000 yards and is now being produced for several navies. The West German Navy is planning to modify the U. S. Tartar SAM for antiship duties.

Needless to say, antiship missiles come in a wide variety of types. Those designed for launch from a maritime reconnaissance aircraft, which will generally be able to detect its target 200 to 300 miles away, will naturally tend to be larger and of longer range than those intended for firing from a patrol boat with a 20-mile radar horizon distance. But there does seem to be a common pattern. The missile generally receives some sort of mid-course guidance from the launching vehicle (or from a cooperating unit) to get it into the general vicinity of its target. At a suitable range, its own radar is turned on and the missile thereafter homes on the target.

Flight altitudes for antiship missiles tend to be low. The Exocet and Sea Killer are especially sinister in this regard. These "skimmer" missiles fly at a fixed average height over the sea (using a radar altimeter) and are guided in azimuth only. Their flying height is reported to be only 10 feet. This may seem impossibly low, but it must be realized that 10-foot waves are extremely rare even in Sea States as high as 3. Greater operating altitudes can be selected when the weather is rough. The probability of killing such a skimmer antiship missile with any feasible SAM appears small.

Antiship missiles are not without their problems. If they are to be borne by aircraft or patrol boats, or even by larger ships, they must be compact. The laws of aerodynamics decree that small missiles cannot travel as fast or as far as large ones: doubling a missile's speed without reducing its range implies quadrupling its size, all other things remaining constant. Carrying a complete radar aboard the missile assures that it will be expensive. Reliability is likely to be a severe headache. Nevertheless the antiship missile is a weapon system which commands respect; if you do not have a defense against it, it becomes positively terrifying.

The sinking of the *Elath* stirred quite a bit of concern. It suddenly became clear that naval vessels would either have to be able to offer a reasonable defense against air attack or must avoid any contact with the enemy.

One response to the need for self-defense has been acceleration of the development of what might be termed "mini-SAMs." These include the British Sea Cat and American Basic Point Defense Surface Missile System, BPDSMS, popularly known as Sea Sparrow, both of which are operational, as well as a number of systems under study or development. In all cases the idea is to reduce cost and weight of the SAM system by accepting some performance limitation. Whether it is possible to build a system of acceptable weight and cost which still has enough performance to offer adequate defense is another question.

Considerable attention has been given to electronic countermeasures as a defense against radar-guided antiship missiles (and attack by radar-equipped aircraft at night or in foul weather) on the principle that if one can play enough electronic tricks on the guidance radar of the missile, it will then fly off without bothering anyone. Working in favor of the ECM approach is the fact that the sort of electronic "brain" one can cram into an antiship missile to control its flight is likely to be fairly stupid and lacking in powers of discrimination. On the other hand, to trick even a moderately good radar one must know its characteristics in considerable detail. The enemy is unlikely to be so obliging as to reveal these, and one might lose a good many ships while trying to learn them in combat. There are a number of subsidiary factors which weigh heavily against electronic countermeasures ECM, including the facts that antiship missiles typically need to use their radars only briefly, that non-radar guidance is quite possible, and that ECM is an expensive single-purpose system.

The one air defense measure which is scarcely ever given any serious consideration is the anti-aircraft gun. Guns are generally felt to be useful only against targets in the low subsonic (i.e., World War II) speed range. Such a view is perhaps natural when one considers that the vast majority of AA gun systems in the U. S. Navy, for instance, were designed prior to VJ Day. But it neglects entirely the great improvements in gun system technology since 1945.

Table 1 provides data on 13 selected AA guns designed since World War II; all but one of them, number 18, are shipboard weapons. The older U. S. Navy, 5-inch/38-caliber dual-purpose guns (designed in the 1930s) and 3-inch/50-caliber, rapid-fire guns (designed during the latter part of the war) are also included for comparison purposes.

The data for mount weight includes all rotating equipment, mount hoists (one deck high) where necessary, full gunhouses, and control equipment, but excludes magazines and foundations. The rates of fire are peak figures and some of the smaller guns may not be able to sustain their maximums for more than 15 to 30 seconds, owing to ammunition feed and barrel cooling limitations; even among larger guns, reliability may suffer in some guns if they are fired at maximum rate for long periods. (Since the 5-inch/38-caliber guns are manually loaded, firing rates vary with crews, but 15 rounds-per-minute-per-barrel is considered excellent.)

"Ready ammunition" refers to those rounds which can be stored in the feed mechanism over long periods at sea and fired on a moment's notice by a single watchstander. Since an aircraft or a missile flying at low altitude and high speed can reach a ship within a minute or two of crossing its radar horizon, an "instant fire" capability is of considerable importance.

The muzzle velocity given is for a gun with a new barrel or liner, firing service antiaircraft ammunition. "Muzzle energy" represents a basic constant for a gun: projectile weight and muzzle velocity can generally be varied over wide limits, provided their relationship is kept at such a state that muzzle energy is not increased. For instance, the U. S. 5-inch/54-caliber guns would probably have little difficulty in firing 55-pound 5-inch/38-caliber projectiles to a velocity of 2,990 feet per second, although bore erosion would be increased somewhat.

A gun firing at a steady rate is much like the piston engine in an automobile in that it is using chemical energy (from fuel or propellant) to impart momentum to pistons (or projectiles). But the gun, rather than harnessing the pistons to turn a shaft, simply lets them fly on out of the cylinder (or barrel). In either case, engine or gun, the output may be expressed in terms of power. The firepower of a gun is simply the product of the rate of fire and the muzzle energy, divided by a constant of 33,000 to convert the results to units of horsepower.

The firepower figures in Table 1 are given for maximum rates of fire. They really represent firepower at the gun muzzle only; firepower falls off with range as the projectiles lose energy owing to air resistance. This falling off will be more rapid for small-caliber guns than for large calibers.

Firepower is a key indicator of a gun's effectiveness as an antiaircraft weapon, combining as it does the projectile weight, muzzle velocity, and firing rate. Since weight is critical in any shipboard equipment, one measure of a gun's efficiency would be its firepower divided by its weight. This figure is given in the final column of Table 1, where it is called the firepower-to-weight ratio.

One major factor in gun performance—accuracy—is not represented in Table 1. Obviously, this will have a very crucial effect on a gun's ability to shoot down aircraft. Unfortunately, it is expensive to conduct the extensive firing trials necessary to determine a gun's accuracy, and it is difficult to present the results in a compact, understandable, and unambiguous form. In

TABLE 1 CHARACTERISTICS OF SELECTED SHIPBOARD ANTIAIRCRAFT GUN MOUNTS

Gun No.	Mount Manufacturer	Mount Designation	Gun Bore Caliber (inches)	Gun Bore Length (cal.)	No. of Guns	Mount Weight (long tons)
1	FMC Corp., Minneapolis Minnesota	5"/54 Mk. 45, Mod. 0 (U. S. Navy)	5	54	1	22.1
2	FMC Corp., Minneapolis, Minnesota	5"/54 Mk. 42, Mod. 9 (U. S. Navy)	5	54	1	60.4
3	S.p.A. OTO Melara, La Spezia, Italy	127-mm/54 COMPACT	5	54	1	32.0
4	No longer in production	5"/38 Mk. 32, Mod. 2 (U. S. Navy)	5	38	2	52.3
5	No longer in production	5"/38 Mk. 30, Mod. 24 (U. S. Navy)	5	38	1	20.1
6	Aktiebolaget Bofors, Bofors, Sweden	TAK 120 L/50-93	4.7	50	1	49.2
7	Aktiebolaget Bofors, Bofors, Sweden	TAK 120 L/46	4.7	46	1	28.1
8	Vickers Ltd., London, England	Mk. N(R)	4	62	1	30.0
9	Direction Technique des Constructions, Navales, Paris, France	100-mm	3.9	55	1	20.5
10	S.p.A. OTO Melara, La Spezia, Italy	76-mm/62 COMPACT	3	62	1	6.3
11	No longer in production	3"/50 Mk. 33, Mod. 13 (U. S. Navy)	3	50	2	15.2
12	No longer in production	3"/50 Mk. 34 (U. S. Navy)	3	50	1	8.3
13	Aktiebolaget Bofors, Bofors, Sweden	SAK 57 L/70	2.2	70	1	6.4
14	Aktiebolaget Bofors, Bofors, Sweden	SAK 40 L/70-350 P	1.6	70	1	3.0
15	S.p.A. OTO Melara, La Spezia, Italy (Gun by Oerlikon-Buhrle Ltd.)	OE/OTO 35-mm, Model AO	1.4	90	2	5.1
16	Oerlikon-Buhrle Ltd., Zurich, Switzerland	35-mm GDM-A	1.4	90	2	4.2
17	British Mft. & Research Co., Ltd., Grantham, England	30-mm A 32	1.2	70	2	1.5
18	General Electric Co., Burlington, Vermont	20-mm Vulcan turret	0.8	76	1	1.3

general it can be said that: (1) any gun's accuracy will get steadily worse over long times of flight; (2) fast firing guns suffer loss of accuracy, owing to the tendency of the gun and barrel to vibrate; and (3) smaller caliber guns generally have accuracy somewhat inferior to that of larger ones. The accuracy of the gun system as a whole is strongly influenced by the characteristics of the fire control system, which we shall take up presently.

Comparison of the World War II vintage guns in Table 1 (Nos. 4, 5, 11, and 12) with their more modern counterparts reveals some striking improvements. Efficiency (as measured by firepower-to-weight ratio) has more than doubled for both 5- and 3-inch guns. Accuracy has been improved (this is especially true of the smaller guns—20-mm. to 40-mm.). Crew requirements have been reduced dramatically—the OTO Melara 3-inch gun (No. 10) needs only 3 men to outperform the old U. S. Navy 3-inch/50 twin gun (No. 11) with 14. Finally, the introduction of automatic loading systems has led to development of the instant ready ammu-

Total Max. Rate of Fire (rds./min.)	*Ammunition Feed Type*	*Instant Ready Ammo. (rounds)*	*Weight of AA Projectile (pounds)*	*Muzzle Velocity (ft/sec.)*	*Muzzle Energy (ft.-lb.)*	*Max. Firepower (h.p.)*	*Firepower to Weight Ratio (h.p./ton)*	*Gun No.*
20	Drum, under mount	20	70	2,650	7.63×10^6	4,630	210	1
40	2 drums, under mount	40	70	2,650	7.63×10^6	9,260	153	2
45	3 drums, under mount	66	70	2,650	7.63×10^6	10,420	326	3
30	Hand loaded	0	55	2,600	5.77×10^6	5,240	100	4
15	Hand loaded	0	55	2,600	5.77×10^6	2,620	131	5
70	2 multi-row drums, below decks	300	46.3	2,950	6.28×10^6	13,330	271	6
80	2 hoppers, on mount	48	46.3	2,630	4.95×10^6	12,020	429	7
40	2 hoppers, on mount	46	36	2,900	4.70×10^6	5,700	191	8
60	Drum, under mount	35	29.8	2,850	3.76×10^6	6,830	333	9
90	3 revolving rings, under mount	115	13.7	3,040	1.96×10^6	5,350	850	10
90	2 rotary, on mount	0	13.1	2,700	1.48×10^6	4,050	296	11
45	Rotary, on mount	0	13.1	2,700	1.48×10^6	2,030	246	12
200	Hopper, on mount	40	5.3	3,360	9.30×10^5	5,640	883	13
300	Hopper, on mount	18	2.1	3,300	3.58×10^5	3,250	1,102	14
1,100	2 belt magazines, below decks	780	1.2	3,860	2.80×10^5	9,330	1,820	15
1,100	2 hoppers, on mount	112	1.2	3,860	2.80×10^5	9,330	2,210	16
1300	2 belt magazines, on mount	294	0.79	3,540	1.55×10^5	6,120	4,170	17
6,000	Helical drum, on mount	2,000	0.22	3,380	7.81×10^4	6,920	5,480	18

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			Caliber (inches)	*Length (cal.)*										
1	FMC Corp., Minneapolis Minnesota	5"/54 Mk. 45, Mod. 0 (U. S. Navy)	5	54	1	22.1	20	Drum, under mount	20	*70*	2,650	7.63×10^6	4,630	210
2	FMC Corp., Minneapolis, Minnesota	5"/54 Mk. 42, Mod. 9 (U. S. Navy)	5	54	1	60.4	40	2 drums, under mount	40	70	2,650	7.63×10^6	9,260	153
3	S.p.A. OTO Melara, La Spezia, Italy	127-mm/54 COMPACT	5	54	1	32.0	45	3 drums, under mount	66	70	2,650	7.63×10^6	10,420	326
4	No longer in production	5"/38 Mk. 32, Mod. 2 (U. S. Navy)	5	38	2	52.3	30	Hand loaded	0	55	2,600	5.77×10^6	5,240	100
5	No longer in production	5"/38 Mk. 30, Mod. 24 (U. S. Navy)	5	38	1	20.1	15	Hand loaded	0	55	2,600	5.77×10^6	2,620	131
6	Aktiebolaget Bofors, Bofors, Sweden	TAK 120 L/50-93	4.7	50	1	49.2	70	2 multi-row drums, below decks	300	46.3	2,950	6.28×10^6	13,330	271
7	Aktiebolaget Bofors, Bofors, Sweden	TAK 120 L/46	4.7	46	1	28.1	80	2 hoppers, on mount	48	46.3	2,630	4.95×10^6	12,020	429
8	Vickers Ltd., London, England	Mk. N(R)	4	62	1	30.0	40	2 hoppers, on mount	46	36	2,900	4.70×10^6	5,700	191
9	Direction Technique des Constructions, Navales, Paris, France	100-mm	3.9	'55	1	20.5	60	Drum, under mount	35	29.8	2,850	3.76×10^6	6,830	333
10	S.p.A. OTO Melara, La Spezia, Italy	76-mm/62 COMPACT	3	62	1	6.3	90	3 revolving rings, under mount	115	13.7	3,040	1.96×10^6	5,350	850
11	No longer in production	3"/50 Mk. 33, Mod. 13 (U. S. Navy)	3	50	2	15.2	90	2 rotary, on mount	0	13.1	2,700	1.48×10^6	4,050	296
12	No longer in production	3"/50 Mk. 34 (U. S. Navy)	3	50	1	8.3	45	Rotary, on mount	0	13.1	2,700	1.48×10^6	2,030	246
13	Aktiebolaget Bofors, Bofors, Sweden	SAK 57 L/70	2.2	70	1	6.4	200	Hopper, on mount	40	5.3	3,360	9.30×10^5	5,640	883
14	Aktiebolaget Bofors, Bofors, Sweden	SAK 40 L/70-350 P	1.6	70	1	3.0	300	Hopper, on mount	18	2.1	3,300	3.58×10^5	3,250	1,102
15	S.p.A. OTO Melara, La Spezia, Italy (Gun by Oerlikon-Buhrle Ltd.)	OE/OTO 35-mm, Model AO	1.4	90	2	5.1	1,100	2 belt magazines, below decks	780	12	3,860	2.80×10^5	9,330	1,820
16	Oerlikon-Buhrle Ltd., Zurich, Switzerland	35-mm GDM-A	1.4	90	2	4.2	1,100	2 hoppers, on mount	112	12	3,860	2.80×10^5	9,330	2,210
17	British Mft. & Research Co., Ltd., Grantham, England	30-mm A 32	1.2	70	2	1.5	1300	2 belt magazines, on mount	294	0.79	3,540	1.55×10^5	6,120	4,170
18	General Electric Co., Burlington, Vermont	20-mm Vulcan turret	0.8	76	1	1.3	6,000	Helical drum, on mount	2,000	0.22	3,380	7.81×10^4	6,920	5,480

nition concept. Indeed, the AA gun has improved as much since World War II as has its adversary, the attack aircraft.

Improvement has been even more revolutionary in the other major component of AA gun systems, the gun fire control system (GFCS) ; great strides have been made in the three crucial functions of target acquisition, target tracking, and computation and control. It became apparent a decade ago to GFCS designers that gun systems could never deal with really high-speed, low-level air targets unless target acquisition could be greatly improved. The best of current gunfire control systems meet the acquisition challenge with an acquisition radar especially designed to work with (and be a part of) the GFCS. This radar should be fully stabilized (by the same system that stabilizes the GFCS), be able to measure target range and bearing with considerable accuracy, be well protected against ECM, and have special provisions for detection of low altitude aircraft. Ideally, the acquisition radar will automatically detect and track fast-closing targets, greatly reducing reaction-time.

The tracking radar is invariably a "pencil beam" set with the familiar parabolic "dish" antenna. Its purpose is to continuously provide extremely precise elevation, azimuth, and range data on the target currently under fire. It will usually be what is technically described as a monopulse (or simultaneous lobing) radar, although the older conical-scan type can give satisfactory results so long as the enemy does not employ sophisticated ECM measures. Most current GFCS track radars use the Doppler effect to measure the target's instantaneous range rate (closing speed). This is desirable, but ca,n lead to other difficulties if special precautions are not taken in the design of the radar. Special techniques may be employed to improve tracking of low altitude targets. On larger ships, with a number of guns, it is desirable to have several independent tracking radars so that several targets may be taken under fire simultaneously.

GFCS computer development has proceeded along two separate lines. Most manufacturers have replaced the electro-mechanical analog computers of World War II with electronic analog machines, which, while generally more accurate, automatic, and reliable, act in essentially the same way. A few firms, however, have adapted the digital computer to gunfire control. The advantage of the digital machine is not so much in the matter of accuracy as in its flexibility, ability to perform complex control functions, and compatibility with the digital computer tactical data systems now being fitted to warships (such as the U. S. Navy's Tactical Data System NTDS and the Royal Navy's Action Data Automation ADA system). The analog computer, on the other hand, will frequently be less expensive to buy.

N. V. Hollandse Signaalapparaten, of the Netherlands has pioneered the use of digital computers in shipboard gunfire control. They currently offer the M-22 system, used by quite a number of navies, including those of Canada (on order), Finland, Malaysia, Norway, Sweden, and the United States (where it has been manufactured under license and is known as GFCS Mk-87). Its acquisition radar, whose antenna is mounted on the same stabilized platform as the tracking sets, can give rough elevation angles, thus reducing tracker lock-on time. It searches 360° in azimuth and from the horizon to an elevation angle of more than 20° every 4½ seconds. Detection range, against a jet attack aircraft, is about 35,000 yards.

Contraves A. G., of Zurich, Switzerland, has recently introduced a light AA GFCS designated Sea Hunter 4 A broad range of options is offered, including radars of various degrees of sophistication (and cost) and a choice of a very advanced analog computer or a digitized version. The acquisition radar is fully stabilized and rotates every 1.2 to 2.0 seconds, depending on the model selected. The most significant advantage of the more sophisticated radars is their resistance to ECM.

The Vega-Castor is a GFCS recently developed by Thompson-CSF in Bagneux, France. Its Triton surveillance radar is stabilized in roll only and can detect small attack aircraft at 50,000-yard ranges. Vega-Pollux, a version with a less sophisticated tracking radar, is also available. Analog computation is used.

Strangely enough, several recently developed GFCSs do not have integrated air target acquisition radar systems. These include the Italian Argo, the British "Gun System Automation GSA4/GWS24," and the U. S. Mk-86 GFCS. The Mk-86 is unique in having been originally designed for use against surface targets only. An AA capability has been added, but the system cannot be considered ideal for AA purposes and its cost is very high.

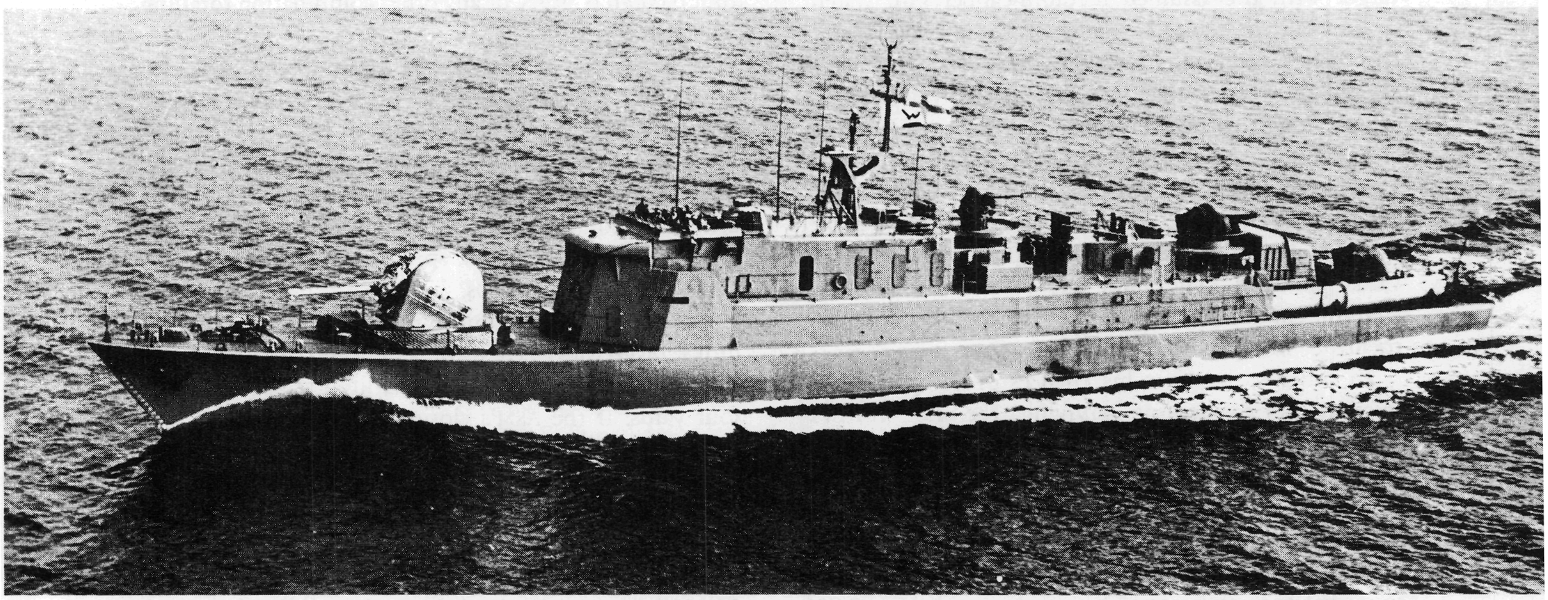
Most of these systems are capable of controlling guns of up to 5-inch caliber (although of course the computer must be adapted to the ballistics of the particular weapons used) in firing against surface ships and shore targets as well as aircraft. All of the systems, in modified versions, can control short-range SAMs as well as guns, and the first three mentioned have variants which control antiship missiles. Some can even be tied in with antisubmarine and torpedo weapon control systems.

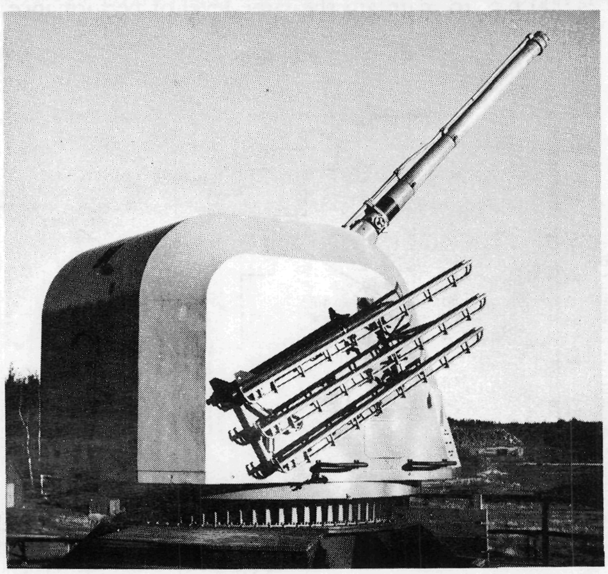
All of these systems are far ahead of anything available during World War II. Accuracies have been vastly improved and reaction times have been cut to less than ten seconds. Moreover, the modern GFCS is equally efficient in all weather and can be brought into action by a single watchstander. New computer designs and improvements in radar have greatly increased reliability and reduced maintenance requirements.

The really important question about an AA gun system, of course, is: "How well can it shoot down aircraft and missiles?" Let us attempt to sketch an answer for typical modern systems. Consider a gun system comprising one or more medium-caliber (4- to 5-inch) guns and a GFCS. For the short times of flight typical of AA fire, a good system will ordinarily have a dispersion standard deviation of about 2.5 mils. In more concrete terms, this amounts to saying that 50% of all rounds fired will come within about 3 mils of the mean point of impact (MPI). If the target does not maneuver between the time of firing and the time of intercept (the time at which the projectile hits or comes closest to the target) then, again assuming a good system, the MPI should be within one mil or so of the target's actual position at intercept. These figures are subject to considerable variation with type of target and environmental conditions.

A projectile in this size range would normally weigh from 35 to 70 pounds and, with a proximity-fuzed, controlled fragmentation warhead, should be able to destroy most aircraft or missile targets at a considerable distance. We will suppose that the projectile's effective lethal radius against a light attack aircraft is four yards, measured from the center of the projectile to the center of the aircraft. On this assumption, the laws of mathematical probability theory determine the probability of hitting a target to be, for example, about 50% at a range of 1,300 yards and virtually 100% at a range of 500 yards.

The relatively low rate of fire characteristic of the medium-caliber gun makes it relatively easy to calculate





The Bofors 120-mm. L/46 (#7 in Table 1) is seen on the test stand at left—the racks on the side of the gunhouse are for the launching of flare rockets—and, above, mounted forward on the Finnish gunboat Turunmaa. *Aft, under covers, are two 40-mm. L/70 guns (#14 in Table 1) while amidships may be seen an older 40-mm. L/60.*

precisely the probability of actually shooting down an aircraft in a particular engagement. For this purpose, suppose that the gun system has a total firepower of 12,000 and fires at a rate of 60 rounds per minute. (It is immaterial whether this is done with one 12,000-h.p. gun, two 6,000-h.p. guns, or even twelve 1,000-h.p. guns.) A muzzle velocity of 3,000 feet per second is assumed. Proximity-fuzed projectiles cannot be expected to function with complete reliability: it will be supposed that 20% of the projectiles fail to detonate for one reason or another.

The target will be assumed to be closing at low altitude and with a speed of 500 yards per second. This speed, equivalent to about 890 knots or Mach 1.35 at sea level, represents low altitude performance unlikely to be exceeded by attack aircraft for some time. Figure 1 shows the kill probability obtainable against such a target with the assumed medium-caliber gun system.

To evaluate Figure 1, one needs some knowledge of the tactics and limitations of attack aircraft. First, it should be realized that it is not presently feasible for attack aircraft to release ordnance at supersonic speeds, as has been assumed here. (If the aircraft approached at subsonic speed, the kill probability would be significantly higher.) The maximum range for accurate rocket firing or bomb release is about 1,000 yards, with 500 yards preferred. The pilot must fly on a relatively straight course for at least four or five seconds prior to firing, in order to line up his sights.

In order to improve his chances of completing his mission (not to mention surviving) the pilot will normally take evasive action—"jink"—from the time he first comes within gun range until he must begin his aiming run. He is very unlikely to be hit while jinking. But, if he straightens out at a range of 4,500 yards (to give an aiming run of 7 to 8 seconds), he will begin to receive accurately-aimed fire at a range of about 2,800 or 3,000 yards, as indicated by the middle stepped-line in Figure 2. If he does not straighten out until reaching 3,000 yards (leaving only 4 to 5 seconds for aiming) the first accurate round will intercept at about 1,800 to 2,000 yards, shown by the bottom (interrupted) stepped line in Figure 1.

It is evident that an eight-second aiming run followed by weapon release at 500 yards gives the pilot less than a 2% chance of mission accomplishment—clearly unsatisfactory from his standpoint. If a four-second run-in is used, with weapon release at 1,000 yards, survival chances rise to nearly 30%. An attrition of 70% would normally be considered unacceptable by an attacker, but the defender may very reasonably crave better protection. Figure 2 shows that a very high degree of protection can be achieved by doubling the gun system's firepower (by using two 12,000-h.p. guns, four 6,000-h.p. guns, or any other combination totalling 24,000 h.p.).

It is becoming increasingly common, however, for attack aircraft to be equipped with air-to-surface missiles (ASMs) which can be launched from beyond the maximum effective range of AA guns and home-in on the ship. Most current versions cannot touch Mach 2, even after supersonic launch, but improved materials and rocket fuels make higher speeds a possibility for the late 1970s or early 1980s.

Let us suppose that our hypothetical medium-caliber gun's projectiles have the same effective kill radius against ASMs that they do against light attack aircraft-four yards. If the ASM's closing speed is 750 yards per second (about 1,340 knots, or Mach 2.0 at sea level), Figure 1 gives the kill probability for an 18,000-h.p. gun system. If the ASM's speed is raised to 1,000 yards per second (about 1,775 knots, or Mach 2.7 at sea level), then the system's ballistic power must be raised to 24,000 h.p. to maintain the same level of performance.

Figure 1

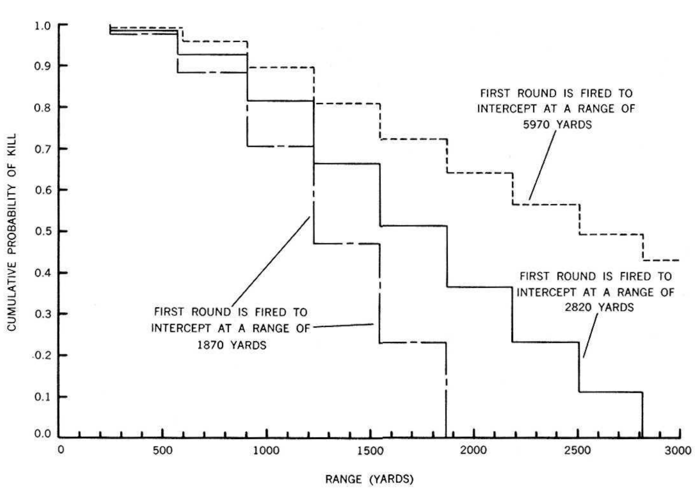


Figure 2

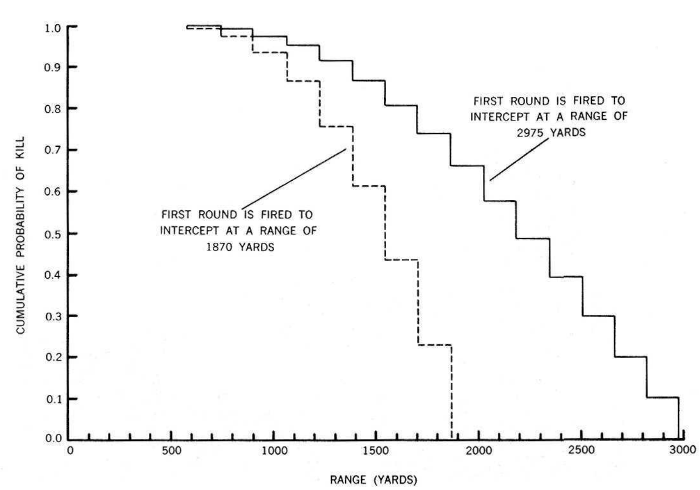


Figure 1

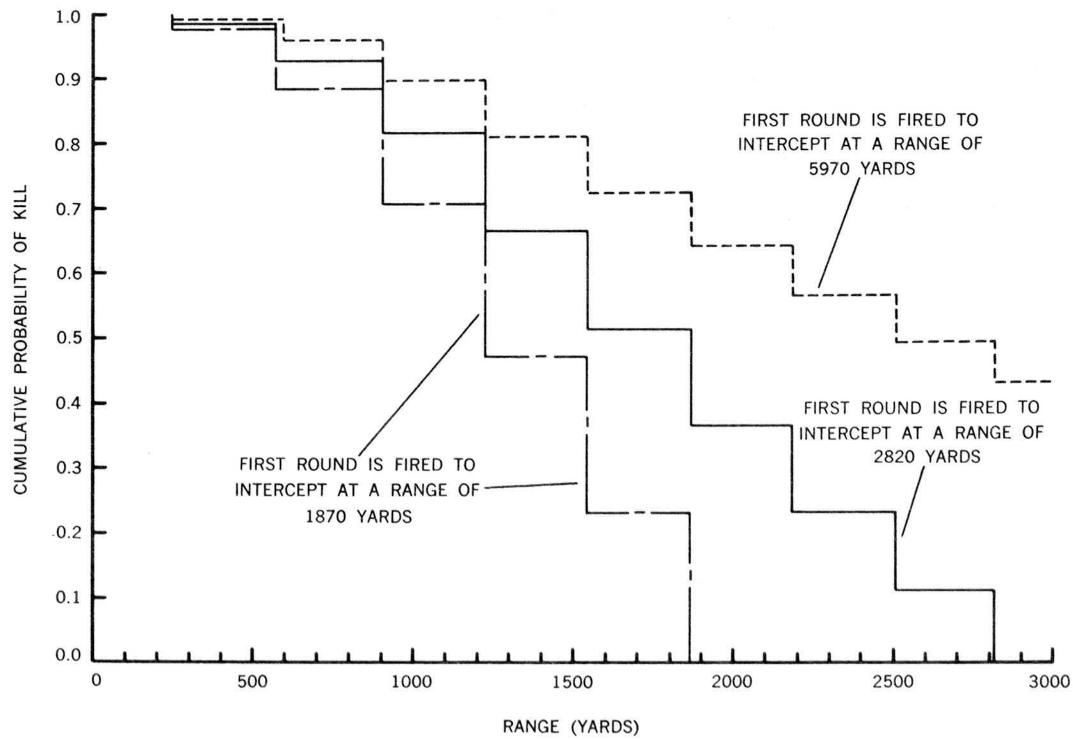
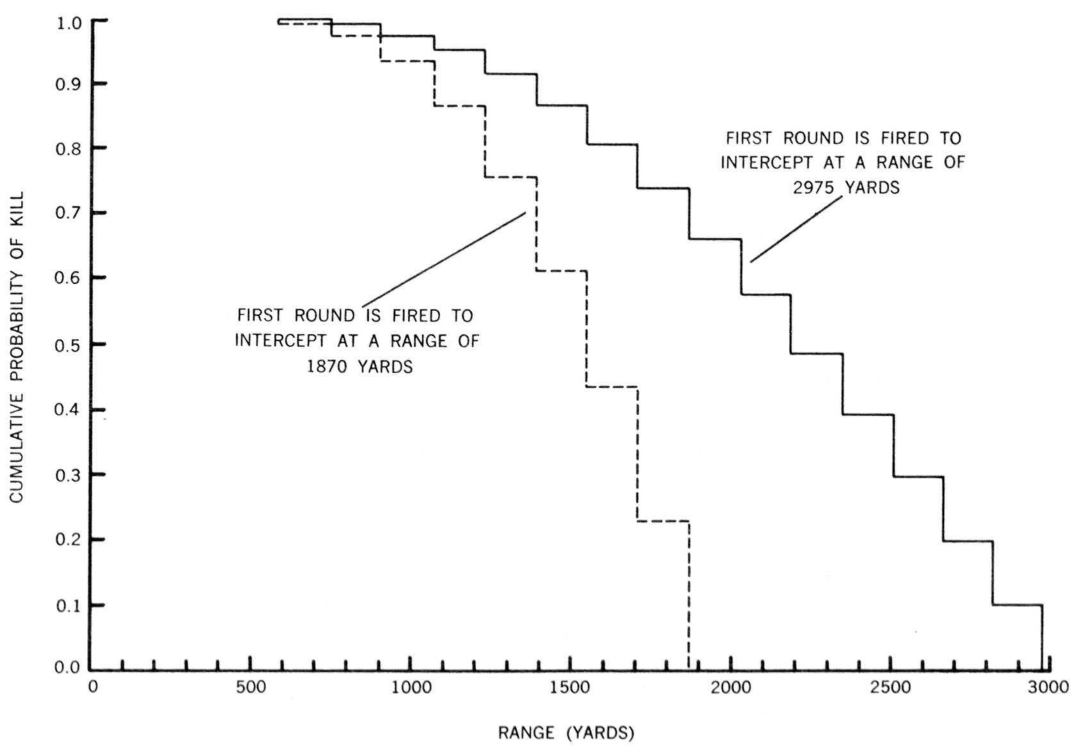
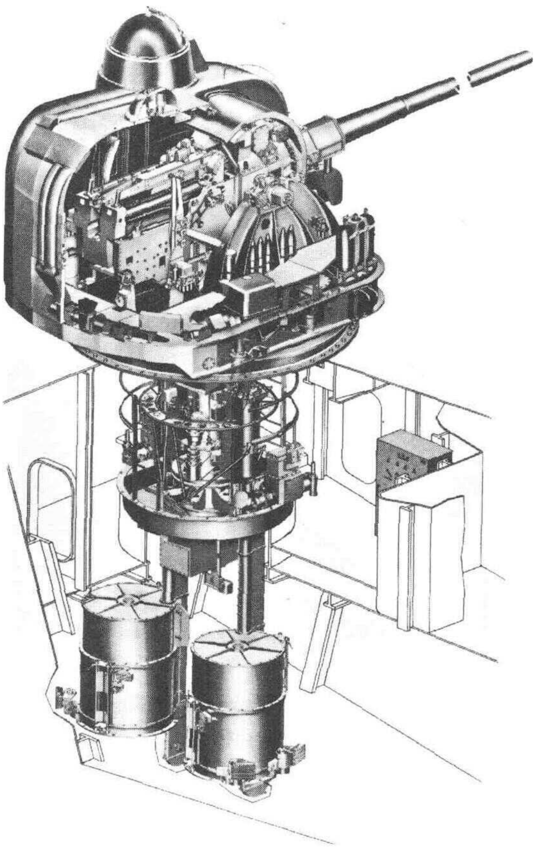
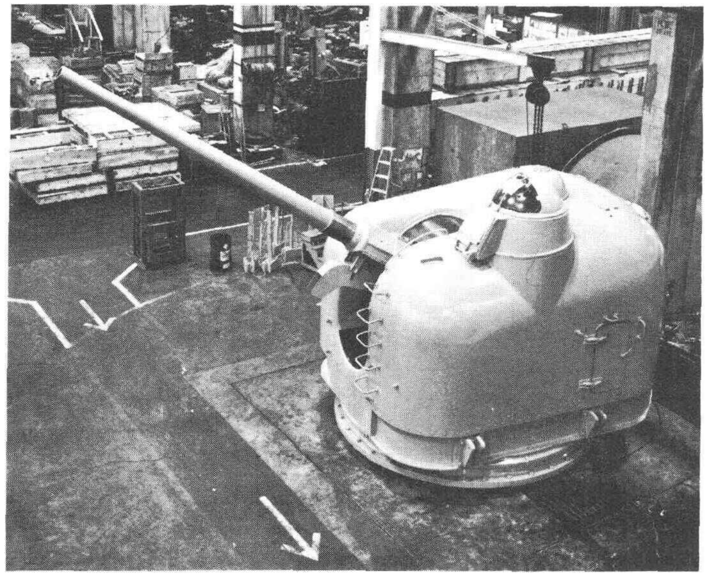


Figure 2







The U. S. Navy's 5-incb/54 Mk.42, Mod.9 "rapid fire" gun (#2 in Table 1) is seen on the production line at FMC Corporation and, left, in a cutaway view which shows its undermount ammunition drums.

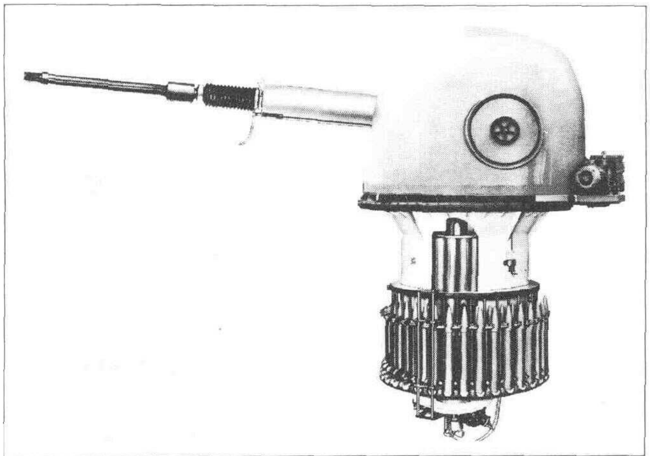
Since ASMs are cheaper than attack aircraft (and available in larger numbers), one needs a better defense against them. It seems clear, however, that the performance level represented in Figure 2 is more than adequate. An ASM's chances of getting within 250 yards of the ship are virtually nil. Detonation of an ASM warhead at this range will produce shrapnel hits on the ship, but is unlikely to do significant damage.

Most of the larger antiship missiles have speeds of less than 500 yards per second. (Styx cannot exceed 350 yards per second.) Since jinking is impractical for guided missiles, these "birds" are clearly sitting ducks for our medium-caliber gun system.

Of course, there are other considerations which bear heavily on the gun system's overall effectiveness. A high kill probability is of little use unless the guns can be brought into action in time to destroy the attacker prior to weapon release. The gun itself should pose little problem in this respect. Table 1 shows that all of the modern guns (with the partial exception of the Bofors 40-mm. gun) have sufficient ready ammunition to carry out at least one AA engagement before the full gun crew reaches its station. In the typical modern design, all of the guns in a battery could be fired at full effectiveness under the control of a single man on watch.

If a good acquisition radar is fitted, and well integrated with the rest of the GFCS, the target should be detected and handed over to the tracking radar within 10 or 15 seconds after it first comes in radar range (usually at least 20,000 yards distant). With modern "Kalman filter" tracking techniques the tracking should settle within a few seconds.

The major problem in reaction time may be simply in making the decision to fire. As a practical matter it may very well be necessary to adopt a policy of opening fire on any target which closes to 5,000 yards at high speed without responding to IFF interrogation. The gun's short range is an advantage of sorts in this situation, since the corresponding policy for a missile system might require one to fire at any target closing to 40 miles. Chances of an unpleasant mistake are clearly less. In any event, the decision must be made, and quickly—any significant hesitation is a de facto decision not to fire, and risks destruction of the ship. Since some degree of trigger-happiness is likely under the stresses of combat, planes unexpectedly encountering friendly ships would be well-advised to turn sharply away and start jinking.



The Italian Navy's OTO Melara 76-mm/62-caliber "compact" gun (#10 in Table 1), seen in a cutaway view and mounted in the patrol boat Fulmine, *needs only a three-man crew to outperform the U. S. Navy's old 3-inch/50-caliber (#11 in Table 1) which requires a crew of 14.*

While the best of modern gun systems have a combination of acquisition range and reaction time sufficient to deal with targets approaching at any likely speed, any single gun system can be "saturated" if two or more targets appear at exactly the same instant. But a gun system can be expected to do very well against multiple attackers that are separated by intervals of 10 to 20 seconds. This of course emphasizes the importance of the combat air patrol's ability to scatter incoming raids, even when it cannot shoot down all of the attackers. Larger ships, such as aircraft carriers and cruisers, which must expect to become the targets of multiple attacks despite the combat air patrol's best efforts, can be fitted with a number of guns arranged in two or more batteries, each controlled by its own tracking radar and able to engage targets independently of the others.

It should be clear by now that a well-conceived AA gun system can provide a ship with a considerable measure of defense against missile and low altitude aircraft attacks. It is natural to ask: "What gun system is best?" and, "What will it cost?" Although neither of these questions can be answered definitively here, some general observations may be useful.

A look again at Table 1 shows an astonishing variety of guns—and this is by no means a complete listing of available AA guns. The most obvious evidence of diversity lies in the wide spectrum of gun calibers: from 5-inch down to 20-mm. (about 0.8-inch). Indeed, many of the major features which distinguish one gun from another are closely associated with caliber.

The effectiveness analysis sketched above stipulated a gun of about 4.5-inch caliber. This was a matter of ease of calculation, however, rather than a reflection of any special virtue of relatively large-caliber guns. A larger caliber does have its advantages, particularly in the matter of accuracy. At typical AA ranges, a 1.5-inch caliber gun system is likely to have dispersion 50% greater than that of a 5-inch system.

Small-caliber guns, on the other hand, generally give a lot more firepower per ton of gun weight, as can be seen from the final column of Table 1. In general, guns of 1- to 2-inch caliber have firepower-to-weight ratios about ten times those of 4- to 5-inch guns. This disparity is somewhat reduced when the weights of ammunition and crew are considered, but one will still be able to cram something like three times as much firepower into a given ship using small guns. This can make up for quite a bit of inaccuracy. Unfortunately, the small guns will not be of much use if shore bombardment or long-range surface ship engagements are called for, as their firepower decreases drastically at longer ranges because of air resistance.

The most significant difference between larger and smaller caliber guns is the most difficult to assess: fuzing. Large-caliber guns generally fire proximity-fuzed fragmentation projectiles which can kill or seriously damage an aircraft even if they "miss" by several yards. While it is possible nowadays to fit proximity fuzes in 3½-ounce/20-mm. projectiles, it is quite otiose: such a projectile cannot possibly do any serious harm to an aircraft without scoring a direct hit, so that the proximity fuze is simply wasted expense. As a practical matter, proximity fuzes are rarely used with projectiles that have a caliber smaller than 3-inch.

Whether proximity fuzes are advantageous depends on a number of factors. Proximity-fuzed projectiles rely on the kinetic energy of their fragments to damage the target, whereas a contact-fuzed, small-caliber projectile will actually explode within its structure. On the other hand, the contact-fuzed projectile's probability of hitting will go down in proportion as target size shrinks; a well-designed, proximity-fuzed projectile's effective kill radius will not change much with target size, all other things being equal. Thus, and strangely enough, we may find that small-caliber guns are more effective against larger targets (e.g., attack aircraft) but that large-caliber guns are more effective against smaller targets (e.g., ASMs).

A good medium-caliber gun system with a total firepower in excess of 18,000 h.p. can be had (including GFCS) for about five million dollars, exclusive of installation costs, and would weigh from 65 to 150 tons. A small-caliber system of roughly comparable performance might cost somewhat less and could weigh as little as 20 tons, but would lack the multipurpose capabilities of the larger-caliber system. It may be most economical to combine both small and medium-caliber guns, using the same GFCS for both.

It would take an absolute minimum of five years and $25 million to develop a complete high-performance gun system from scratch. And success is by no means assured unless one has design teams experienced in gun and GFCS development. Slippage, "cost growth," and failure to meet performance and reliability goals have marked many past projects.

Fortunately, there is very little need to embark on a costly development program of uncertain outcome. One or more of the guns and fire control systems discussed above can economically meet almost any reasonable requirement. Most of these systems are available to virtually any nation, and license manufacture can generally be arranged if no suitable system is manufactured domestically. (Only the most highly industrialized nations will be able to construct fire control systems, however.)

Selection of existing guns and fire control systems will almost always be the wisest choice. Most of the systems discussed here have considerable margin for growth and a navy will get the largest performance return for its development money by spending it on improvement of components for such a system. Ammunition and fuzing appears to be an especially promising area for research and development effort.

Of course, before investing many millions of dollars in procurement of gun systems, a navy will wish to give careful thought to its needs. Studies do not defend ships, however, and one must beware of several frequently encountered pitfalls. One is the making of outwardly plausible assumptions which will have the effect of raising the requirements which the system must meet without contributing anything of significance to performance in service, or which focus attention on what are really subsidiary requirements.

Another common pitfall is to reject a good, obtainable system in favor of a seemingly better system which is "just around the corner." Many people have been led astray by a siren song, usually from some well-intentioned soul enamored of a particular type weapon system who opines: "Oh sure, our current model is only 5% effective against low altitude targets, but wait until we get out relativator, with its 20,000-MTBF, 400-second specific impulse, and gigawatt CW laser; then we'll show them!"

On closer examination, it is usually found that such enthusiasts are speaking of technology on someone's laboratory bench, or in the back of some physicist's mind, rather than what is currently available. What this technology will look like when (and if) it is incorporated into an operational weapon system is quite another matter. And who will defend your ships in the meantime?

It is not the intent of this article to argue that guns should be a fleet's sole, or even primary, defense against aircraft and missile attack. Combat air patrol is definitely the most important and effective single air defense measure. And SAM ships certainly have a place in a modern fleet, if only to ward off high and medium-altitude attackers. But every ship exposed to attack from the air should have an adequate gun system as a means of dealing with low-altitude threats which the combat air patrol is not able, or not available to intercept.

After graduating from UCLA in 1960, Mr. O'Neil spent four and a half years on active duty with the Navy, serving as an officer candidate, as Navigator of the USS *Vesuvius* (AE-15), and as a systems analyst at the U. S. Navy Electronics Laboratory.

From 1964 to 1969, he worked in the Los Angeles area as an operations analyst and applied mathematician for Planning Research Corporation, Bissett-Berman Corporation, and the Advanced Marine Technology Division of Litton Systems, Inc. During this period, Mr. O'Neil also did graduate work at UCLA, receiving his Master of Science degree in 1968. He has been employed in the Office of Program Appraisal, Department of the Navy, Washington, D.C., since June 1969. As a lieutenant commander, USNR-R, he serves on the staff of Naval Reserve Officers School 5-7.