7

High-Speed Development

From Missiles Boats to *Iron Dome*

Two missile systems developed five decades apart illustrate how Israel’s acquisition process differs from the normal way of doing such things, chiefly by a much faster pace, as risks are accepted in preference to the high costs and endless delays of adversarial testing and “verification” procedures. The first was the anti-ship *Gabriel*, developed, along with its fire-control radar and guidance system, by the country’s infant military industries from 1962, when Israel had less than half the population of Sicily—and very little by way of electrical or mechanical industry, hardly more than a few small machine-tool shops, repair garages, smithies, and such. The second, Israel’s largest weapon-development failure, was the *Lavi* jet fighter, condemned not by rapid development but by US opposition; begun in 1980, it was canceled in August 1987 because of US pressure after two prototypes had flown.[[1]](#endnote-1)

Aside from poverty, and the country was indeed poor by European, let alone American standards, the other cause of industrial underdevelopment was Zionist ideology: it greatly favored agriculture (“to redeem the neglected land with manual labor,” which would in turn redeem the weakling Jews of the diaspora). A majority of Israel’s political leaders, academics, and opinionmakers despised commerce; from banking to shopkeeping, it was all equally sordid for them, and they disregarded industry because their great dream was to advance Israel’s agriculture. In that they were quickly successful—Israel became a leader in the development of new crops, in the use of bromine for fumigation, and in globally successful drip irrigation. In the meantime, industry lagged, starved of enthusiasm and leadership.

It was in that most unpromising context that the dream of a “missile-boat” (only the Soviet navy had any) had its very uncertain start. At the time, Israel’s Research and Design Directorate‬ amounted to a few engineers in a few ex-British army huts, with little funding or equipment, but it soon embarked on its first attempt to develop a tactical missile, the surface-to-surface *Luz,* which was to be manually command-guided with a joystick and offered to the artillery and the air force.[[2]](#endnote-2) Development was stopped in 1963 as both branches considered it unsuitable for their needs, but in 1964, the IDF’s “sea corps” adopted the project together with the Israel Aviation company, now IAI, when it realized the Egyptian and Syrian navies were acquiring Soviet *Osa*-class missile boats equipped with the powerful P15 *Styx* anti-ship missile.

The start was unpromising because the semiactive radar guidance of what became the *Gabriel*missile required the uninterrupted radar illumination of a target by the launching vessel’s radar, hard to do with both launching vessel and target vessel on the move. At first it could only be done at short ranges, 10 kilometers or less. But the Gabriel's leading artificer, engineer Uri Even-Tov, was a master of improvisations and “go-arounds.”[[3]](#endnote-3)

To build a useful capability against the *Osa* missile boats, two development efforts were launched, each of might be called “major” were it not for the handful of engineers and scant means at hand. The first effort was to improve the missile motor to attain a more useful range of 20 kilometers, a task assigned to its developer, Israel Military Industries (IMI), which amounted to a few workshops with a few engineers. The second effort was to develop an active radar seeker that could keep up with the target even if it maneuvered evasively.

The resulting missile design envisaged three stages: first, for the initial takeoff boost, it was directed manually with left and right commands; second, the missile’s own semi-active radar took over, with its returns processed aboard the launching ship to generate guidance commands; third, a few kilometers from the target, the missile dove down into a sea-skimming trajectory and switched on an active seeker to guide it to the target. That front-mounted radar receiver was to continually detect signals bouncing off the target vessel once it was illuminated (“painted”) by the on-board radar transmitter and feed the inputs to an autopilot that would in turn generate directional signals for the moving fins that sent the missile right or left as needed. Its up or down movement was regulated by an altimeter to achieve the sea-skimming flight profile in order to minimize the missile’s exposure to visual or radar detection. The Israeli Navy had not wanted a large missile like the *Styx* that flew like a dive-bombing airplane and could be shot down like one, so right from the start it insisted on a much smaller sea-skimmer that would be hard to detect in all the sea clutter that shows up on maritime radar scopes.

Initial development of the *Gabriel*was very slow because of lack of funds. The ground-force generals who dominated the General Staff agreed with the airmen, who were themselves convinced they could sink any ship with their fighter-bombers without need of naval missiles. But on 21 October 1967, with a ceasefire in place after the June 1967 war that left Israel in control of the Sinai, the 1944 British-built destroyer escort ex-*MS Zealous*, serving as the flagship of the Israeli navy as the *INS Eilat,* was sunk in international waters off Egypt’s Port Said, hit by three Soviet-made *Styx* missiles launched from *Komar*-class missile boats of the Egyptian navy from inside the harbor. Out of a crew of 199, a total of 47 were killed and more than 90 wounded. Sixty-seven hours after the attack Israel retaliated by shelling Port Suez with mortars, destroying two oil refineries. That episode was enough to change the priorities of the IDF General Staff. With sudden funding, and a furious day-and night effort, the *Gabriel*’s development was largely completed by the end of 1969. Four years later during the Yom Kippur War in October 1973 it was devastatingly effective, rapidly sinking seven Egyptian and Syrian warships and driving others to seek refuge within their ports.

The high-speed development of the Gabriel system—the missile, radar, fire-control system, and an entire suit of electronic countermeasures that largely neutralized the guidance of the Soviet *Styx* missiles of the two Arab navies—was an extraordinary engineering achievement. It reflected a specific operating concept developed beforehand by the chief guiding light of the Israeli navy, Rear Admiral Yohai Ben-Nun, who had become at age 36 commander of the “Sea Corps,” Israel’s navy in 1960.[[4]](#endnote-4)

Yohai Ben-Nun was unimpressed by contemporary warships, destroyers and cruisers that needed large tonnages to carry guns of limited range, with large crews because of operating requirements and more requirements generated by crew needs. Those classic warships were fine to show the flag, but long before the *Eilat* was sunk, Ben-Nun concluded that they were vulnerable to drastically smaller missile boats. He wanted a navy of small, fast boats to sink much larger traditional warships.

One of Israel’s first combat frogmen, originally personally trained in secret under British rule by a veteran of Italy’s world-leading underwater combat force, Ben-Nun founded the “*Shayetet* [flotilla] 13” naval commando force in 1949, for which he secretly imported leftover wartime Italian equipment, including manned torpedoes, with the connivance of the Italian frogmen unit that survived on its traditional base in semi-clandestine fashion, because of postwar political restrictions.[[5]](#endnote-5) Unable to match the larger Arab navies at sea—Israel could not afford proper modern warships—it would instead send the *Shayetet’s* combat frogmen to attack them at their anchorages inside their guarded naval bases, to sink their warships with limpet mines and manned torpedoes, as the Italians had famously done against the Royal Navy in Alexandria and Gibraltar.[[6]](#endnote-6)

By the time the IDF’s Sea Corps came under Ben-Nun’s command in 1960,he had come up with an entirely different way of overcoming its fundamental problem, namely the impossibility of acquiring and operating even a handful of modern warships, given that the air force had to come first in funding, followed by the mechanized forces essential to protect Israel from invasion.

Aside from minesweepers, torpedo boats and other specialized vessels, there was a hierarchy among surface warships, then still very much a function of the power of their guns. It started with corvettes of a thousand tons or so of displacement, rising to 2,000-ton or so destroyer-escorts, 3,000-ton destroyers, and 5,000-6,000-ton cruisers, each class capable of mounting bigger and bigger guns. Above them were even more impossibly large warships, all the way up to aircraft carriers, as well as submarines that might have small displacements but were drastically more expensive per ton.

Given that he could not hope to acquire modern corvettes Ben-Nun’s solution was to give up on conventional warships and their guns altogether to instead build a navy of anti-ship missile boats that could achieve ship-sinking lethality within displacements under 500 tons, even under 300 tons. Unlike the long-established torpedo boats, which were strictly short-range attack vessels, missile boats could have decent range and endurance because their major weapon was not heavy.[[7]](#endnote-7) But Ben-Nun’s problem was that no such missiles or vessels existed. For the missile, the Gabriel program begun in late 1962 would offer the solution, incidentally launching Israel’s missile industry, which started in *Rafael’s* few huts and evolved into today’s supplier of advanced air-to-air, air-to-ground, and surface-to-surface ballistic and anti-ballistic missiles.

But for *Gabriel*’s platform a do-it-yourself vessel was simply impossible. At the time, Israel’s only shipyard could at best repair vessels and build barges. Just as he had done for his frogmen when he had reached out to Italy’s pioneers, Ben-Nun sent a trusted representative to scout shipyards throughout Europe. What he wanted was a vessel that could compress the needed range, speed, and load capacity within a small tonnage, on the order of 200 tons at full displacement, which would allow for the purchase of a dozen such boats for the price of one small destroyer.

A newly revived West German shipbuilder produced the best hull design, and the best engines were also German, but ultimately only the French were willing to supply Israel, so in July 1965 the Israeli order was awarded to a Cherbourg shipyard.[[8]](#endnote-8) They were to build eight vessels based on the German-designed and German-powered *Jaguar* torpedo-boat, but with an Israeli-specified steel hull instead of the original wooden hull, the addition of 2.4 meters (7 feet, 10 inches) to the hull length and revised internal compartments. The *Gabriel* missile launchers and other weapons and related systems of what was designated as the Sa’ar 3 class were to be installed in Israel upon the arrival of the boats.[[9]](#endnote-9)

There was historical irony in the fact that the *Jaguar,* derived from the famously fast S-boot of the wartime German navy, was the most suited to function as a platform for the Israeli navy. Only fifteen years after the end of the war and the Holocaust, Israeli navy officers found themselves engaged in vigorous technical discussions with German officers and engineers who had served in Nazi uniforms, even encountering heavily compromised figures.[[10]](#endnote-10)

Once a development agreement was signed, an Israeli delegation arrived at the German shipyard to discuss needed modifications under conditions of extreme secrecy because diplomatic relations did not start until 1965.[[11]](#endnote-11) The modifications were extensive; in addition to replacing the wood hull with steel, a longer frame was needed to accommodate the weapons and electronic systems, as was a different mast. When the head of the Israeli delegation finished presenting the long list of Israeli requirements to the Germans, there was a moment of silence, after which the German team chief asked, “Sir, please, would you like to also have a grand piano on deck?”[[12]](#endnote-12)

The Germans balked at accommodating all the changes the Israelis wanted but when everything seemed blocked, Israel’s delegation head, Rear Admiral Shlomo Erell, asked to deal directly with the chief engineer. When the reluctant Germans finally agreed, the chemistry between the two men quickly advanced the design to meet Israeli specifications.[[13]](#endnote-13) The shipyard agreed to supply Israel with twelve *Jaguar-*class fast attack craft, but only three had been delivered when in 1964 the German government repudiated the agreement under Arab diplomatic and commercial pressure, though it did agree that its fully engineered design could be built in a foreign yard. With France the only country ready to supply Israel, the choice for the remaining nine boats fell on *Constructions Mécaniques de Normandie*, a small private shipyard in Cherbourg, under the class designation *La Combattante* (designated *Sa'ar-1* by the Israelis). The first boat for Israel left in April 1967 and another a month later. But on June 2, 1967, just a few days before war started on June 5, 1967, President Charles de Gaulle declared that France would no longer supply “offensive” weapons to the Middle East, which meant Israel, there being no Arab buyers of French weapons at the time. All nine boats had been paid for and the remaining seven were in advanced construction, with two almost ready. They duly sailed for Israel in the autumn of 1967, unresisted; many in the French defense establishment had been comrades in arm with the Israelis since the 1950s, and Cherbourg’s population was also strongly supportive.

De Gaulle’s embargo became total after a clamorous Israeli raid on the Beirut airport on December 28, 1967, but Parisian policy decisions were again subverted locally, and three almost completed missile boats embarked with reduced crews on January 4, 1969. As they sailed out to practice, as before, they raised the Israeli flag and continued unchallenged into the English Channel, never to return. It caused a scandal in Paris, which ordered increased vigilance, but construction was allowed to continue on the last five missile boats. However, Israeli crew members allowed aboard to practice were kept under surveillance, and there was a tight control on fuel loadings, with the French navy alerted to stop any escape. De Gaulle resigned on April 28, 1969, but French policy did not change, and it took a full-scale Mossad operation with a Norwegian-purchase cover story to pull off the escape of the five remaining boats over Christmas, December 24-25, 1969. It was not a low-risk operation; that night French vigilance was relaxed due to a dangerous gale in the Bay of Biscay.

Because a helicopter BBC crew later filmed the escaping boats in the Channel, causing much hilarity around the world at this blatant defiance of the imperious De Gaulle, the French minister of defense and De Gaulle supporter Michel Debré ordered the French air force to find and sink the boats, then still at the start of their 3,145 nautical mile (5,825 kilometer) journey to Gibraltar, Crete, and finally Haifa, with refueling along the way from improvised tankers. The French military chiefs, for whom the Israelis had been comrades in arms since 1956, were unwilling to add violence to betrayal and delayed their response to Debré’s order until it was countermanded by Prime Minister Jacques Chaban-Delmas. He could have been overruled in turn by the just-installed president, Georges Pompidou, but Pompidou was not as devoted as Debré to Gaulle, and in any case he was unwilling to challenge Chaban-Delmas, a tennis and rugby champion and an authentic hero of the wartime resistance. It remained for French Foreign Minister Maurice Schumann to warn that if the boats appeared in Israel, “the consequences will be very grave indeed.”[[14]](#endnote-14) But the arrival of the boats in Haifa harbor on New Year’s Eve, December 31, 1969, triggered a memorable citywide party.

Ben-Nun’s foresight was vindicated less than four years later in the October 1973 war, when his missile boats and their *Gabriel* missiles dominated the war at sea.[[15]](#endnote-15) In history’s first battle between missile boats, on the night of October 6-7, 1973, the Israelis sank one Soviet-made *Osa* and two *Komar* missile boats, one torpedo boat, and one minelayer of the Syrian navy near the naval base in Latakia’s harbor. On the next night, they sank three Egyptian *Osa*-class missile boats in Dumayit harborand badly damaged another. It was a baptism of fire for the new boats, plus the Israeli-built *Sa’ar 4*, locally made with a larger displacement and upgraded radar and systems.[[16]](#endnote-16)

Iron Dome

When it comes to rapid development, the ultimate example is the *Iron Dome* *(Kippat Barzel*) the anti-rocket, anti-missile, anti-artillery shell, and potentially, anti-aircraft system whose full-scale development started in 2007, based on a research program begun in 2005. Declared operational in 2011, it achieved global fame by intercepting 421 rockets in the 7-day conflict in November 2012 with Hamas and another 578 rockets during the 50-day confrontation in summer 2014.[[17]](#endnote-17)

Like any weapon system, the *Iron Dome* has its limitations, but compared to the fifteen to twenty or more years of guided-missile projects elsewhere, the sheer rapidity of its development—less than five years—was phenomenal, given that the radar detector and tracker, the remarkable software, and the interceptor missile were all entirely new. The software was the key breakthrough because it made the system economical, allowing Israel to intercept endless rockets, most crudely and cheaply made (approximately 500 US dollars each) yet still potentially destructive and possibly devastating, with missiles that could have cost at least a hundred times as much.[[18]](#endnote-18)

Studying the history of rocket attacks, Israeli planners concluded that about 75% of the rockets would fall in open terrain and therefore did not warrant interception. Therefore, the Iron-Dome’s computer was to plot the trajectory of incoming rockets to assess their final hit-point and launch interceptor missiles only at those computed to fall on residential areas or on important civilian or military infrastructure. Operators needed the ability to override the software because even intercepted rockets can inflict damage; in spite of the mere seconds available, manually controlled intercepts are accomplished routinely, saving many lives as well as preventing much material damage.[[19]](#endnote-19)

The Iron Dome is the ultimate evidence that Israel’s ultra-fast, often risk-taking acquisition process offers two very different benefits. One is obvious: the timely delivery of effective weapons urgently needed for recurring episodes of combat*.* The other is the economy of straightforward programs, amounting to vast savings. And cost is decisive for IDF innovations because in most cases if a new weapon or system cannot be developed on the cheap, it cannot be developed at all.

Haste also makes some waste, of course. To rush ahead with purchasing and fabrication before all the calculations are fully complete results in both false starts and backtracking. But even somewhat wasteful haste is economical compared to the cumulative cost of carefully planned, managed, costed, and executed development programs constantly overtaken by the obsolescence of components, changes in the nature of the threat, or technological change.

The agonizingly detailed procedures obligatory in both the United States and Western Europe, which delay the acquisition of weapon systems for years and even decades, inflict tremendous costs while attempting to limit them by preventing overbilling, waste, technical fraud (fake test results), and mismanagement. Elaborate rules to ensure “arms’ length” contracting practices designed to prevent cozy deals between complaisant acquisition officers and greedy contractors require that everything must be costed out and specified in excruciating detail. That in itself requires a great many working hours by managers, accountants, and lawyers who routinely outnumber the engineers involved. Then there is more of the same for each successive design review, program evaluation, and cost analysis, which also require endless recalculations, often outsourced at great cost, increasing the total expenditure before anything is produced.

But the worst part is that during the years and decades of the development process, more and more components and even sub-systems (in combat aircraft it can be sub-systems as important as radar or even engines) become obsolete, or may even be going out of production in the near future. Each time that happens, the result is an agonizing dilemma: change to a new item, which will usually require redesign and reengineering, typically triggering yet another time-consuming program review. Or else remain with the old, and thus contribute to the problem of obsolescence-on-delivery, which may finally trigger outright cancellation—that being the fate of many a costly weapon system—after huge sums were spent for nought.

Consider for example the costliest of all contemporary weapon acquisitions, the *F-35* jet fighter family, whose development started in 1996. It was declared operational (“initial operational capability” or IOC) some twenty years later, in 2015 for the US Marine version, 2016 for the Air Force version and 2019 for the Navy version – except that these were “political” IOCs to counter criticisms of the slow pace of development, and many inadequacies remained to be corrected.[[20]](#endnote-20) Together with the USAF, the IAF has been spearheading the F-35’s operational use and was the first air force to use the plane in combat.[[21]](#endnote-21) Even then, it flew with unresolved software problems. When an aviation project is so greatly protracted, dragging on for more than two decades, it is bound to be left behind by the rapid advance of microprocessor technology. Any combat aircraft is also a set of computers, while some microprocessors are easily updated, others are embedded in components and subsystems that have to be redesigned, delaying the project once again, while there are bound to be further advances. The F-35 sacrifices speed, maneuverability, and its air-to-ground bomb loads in order to maximize its “stealth” characteristics, which would have been extremely valuable in combat in 1996, but much less now that both lower-frequency and bi-static radars can detect stealth aircraft in varied conditions.[[22]](#endnote-22)

When it came to the development of the *Iron Dome* air-defense system from contract inception in February 2006 to its March 2011 initial operational capability date, Israel was no longer the poor little country that had embarked on the development of its first missiles in the early 1960s. Yet there was extreme scarcity nonetheless, both in time, in the wake of that year’s massive Hezbollah rocket bombardment (the total number of rockets was variously estimated at 3,970 to 4,228 between 12 July and 14 August 2006), and even funds, albeit because of policy priorities rather than national limitations. With a greatly diminished threat of conventional war as compared to previous decades—owing to the withdrawal of Egypt and Jordan from the conflict, Syria’s decline, and the incapacitation of Iraq—the funding needs of the ground forces and even the air force to a degree were less pressing. Nevertheless, their bureaucratic power was undiminished, and while all might acknowledge the need to defeat the rocket threat, no branch of the IDF was willing to cut its own budget to do so.

In any case almost all IDF senior officers were convinced, along with almost all civilian experts, that it would be disastrously uneconomical to intercept rockets that were virtually free for their users, with necessarily costly interceptor missiles.[[23]](#endnote-23) Others argued that the successful protection of its own population would delegitimize Israeli air attacks meant to deter or stop aerial bombardment because the casualties would all be in Gaza, which would result in international pressure against Israeli counteroffensive operations, as duly happened in the summer of 2014 and in May 2021.[[24]](#endnote-24) The result was that the Iron Dome’s development process was at first only minimally funded; indeed it was funded illegally. A timeline best shows how that extraordinary situation came about.

On April 19, 2004, the IDF Deputy Chief of Staff, MG Gabi Ashkenazi assigned responsibility for the overall effort against the medium and long-range surface-to-surface missile threat to the air force. On July 6, 2004, he assigned all staff work to MaFat, the “Administration for the Development of Weapons and Technological Infrastructure.” On October 13, 2004, Deputy Chief of Staff MG Dan Halutz (former commander of the Israeli Air Force), formally directed MaFat to explore possible countermeasures against both the short-range Qassam rockets launched from the Gaza strip, and against longer-range rockets Iran was supplying to Hezbollah in Lebanon.

But Danny Gold, head of MaFat’s research and development unit, was vehemently dissatisfied with mere “exploration.”[[25]](#endnote-25) On or around August 5, 2005, he decided on his own to initiate accelerated development while the airmen were still undecided on how to proceed and the ground-force generals were opposed. In their view, rocket bombardments were not to be tolerated, nor mitigated with expensive attempts at interception—they were to be extinguished at the source by overrunning those who launched rockets. Gold was unimpressed by the argument; rocket attacks were continuing while nobody was doing any overrunning because the potential cost in blood, treasure, and political capital of ground incursions into Gaza outweighed the damage and casualties inflicted by the rockets. Meanwhile, Israeli towns and villages next to the border, such as Sderot, had to live under intermittent bombardment that made life excruciating and inflicted some casualties—90% of the residents experienced a rocket explosion on their or an adjacent street.[[26]](#endnote-26)

Gold did have the authority to pursue any research and development effort he deemed worthy, but only up to the prototype stage, which could be done within his small budget, because all sorts of liberties are allowed in making prototypes without having to worry about future producibility, continuing maintenance, or even reliability.[[27]](#endnote-27) But from the start, he directed his subordinates to pursue the project as an all-out development effort whose costs would soon greatly exceed his budget, with the aim of demonstrating an intercept capability within 18 months and completing the full-scale engineering development of each component—radar, software, and missile—within 36 months. Moreover, he wanted the equally rapid establishment of industrial production facilities, including assembly lines for a missile that did not yet exist and whose full-scale engineering development had not been authorized.

In the absence of miracles, this circle could only be squared with the next-best thing, the engineering equivalent of a commando raid: a “telescopic” project in which everything was done concurrently instead of sequentially, saving much time. But there was a price to be paid, because of the near certainty that the development of the radar, missile and software would keep diverging as work evolved to overcome specific problems, requiring costly fixes that might also upend the desired urgency by imposing their own delays. On top of that was Gold’s entirely unauthorized foray into the preparation of industrial facilities, for which he had no funds at all. Even his engineering development work was unauthorized, because it went far beyond mere prototyping with cheap mockups, brass-boarded components, and such, but the amounts were much smaller.

Invested with his own overwhelming sense of urgency—a determination to have defenses up and running before the next mass rocket bombardment—the charismatic Gold conjured the funds needed out of thin air by persuading the managers and board members of *Rafael,* the state-owned missile company, and *Elta,* the state-owned radar company (almost all of them reserve officers) to advance the money from their own funds. That they did, without having government orders for the work, and therefore without any certainty of repayment soon or ever, even though they were the directors of incorporated companies legally responsible for their financial integrity. They were risking legal retribution, their reputations, and careers by going along with Gold, in order to continue straight into much more costly full-scale development after he had run out of properly authorized prototyping funds.

These highly irregular—indeed prohibited—procedures seem to have favored rather than hindered the project because all concerned were caught up in its overwhelming dynamic momentum. Gold’s own eight-member MaFat team, *Rafael’s* best missile designers, and *Elta’s* top radar engineers all worked as near a 24/7 schedule as human physiology would allow. Everyone gave up private life for the duration, and at least one religious staff member gave up his holy Sabbath, invoking the allowed “saving of lives” exception.[[28]](#endnote-28)

No less important was the question of method. Truly innovative research and development, as opposed to incremental upgrading that uses up most research and development funds, must be a process of trial and error, or rather of rigging up something, testing it properly, and then deciding how to correct or work around the shortcomings or outright defects that emerge. Hence some costs and some delays are unavoidable each time there is enough progress to warrant testing. But when there are commercial contractors are at one end and government servants at the other, civil or military, the contractors’ proper concern with profits and the government’s duty to the taxpayer means that each error must first be analyzed carefully, in order to determine whether the error was caused by overdemanding specifications or excessively demanding testing, the government’s fault, or by the contractor’s inadequate skill, attention, or investment. That takes time, sometimes considerable time to “verify” claims on each side, and it may generate disputes that bring lawyers coming into the process, so that resolution takes up yet more time before work can resume to correct the problem or to come up with an alternative. Also attempts to limit waste, fraud, and mismanagement through elaborately supervised “verification” procedures by an outside testing group, in order to prevent cozy arrangements at the taxpayers’ expense, are a very expensive way of avoiding costs in new weapons development.

Gold and his team acted differently, or rather they acted just as US weapons developers used to do before many thousands of legally mandated regulations were imposed on them since the 1960s. When testing revealed an error, everyone started work right away to overcome the problem without bothering to attribute responsibility, let alone blame. Gold also mandated a “design to cost” method: the 400 or so *Elta*, *Rafael,* and his own staff were divided into 14 teams that functioned as parallel competitive startups: “We came up with various solutions in parallel – everything in the project was done in parallel.”[[29]](#endnote-29)

Any normal project comprises two stages: an R&D phase and an engineering development and production phase. Gold compressed the two stages to keep up with the tight deadline. This too was a decision that exceeded his authority, but he took the chance nevertheless. Actually, the key innovation of the *Iron Dome* system was the low unit cost of its missiles, between US$ 77,000 and 97,000 initially and roughly 50,000 USD (as of 2021).[[30]](#endnote-30) It means that this missile falls into the “ammunition” category, allowing a nonconservative firing doctrine that allows the IDF to take risks with lower-probability missile launches, thereby achieving a higher interception rate.

Paradoxically, the initial reluctance to acquire the system within the IDF greatly aided the project’s development.[[31]](#endnote-31) As a senior participant explained: “Because no Operational Demands or Technical Specifications were imposed on them, the engineers enjoyed total freedom to develop an optimal weapon rapidly…without [junior officers] pouring into it their “wet dreams” derived from *Aviation Week & Space Technology* magazine, and without Generals “overseeing” the program with endless meetings and discussions.”[[32]](#endnote-32) Unintentionally, the disregard for proper bureaucratic procedures, later condemned by the state comptroller, actually saved the day.[[33]](#endnote-33)

In the aftermath, it could be argued that a better performance might have been attained with more R&D prior to production, but the price would have been much higher. Gold's team was ingenious in identifying features where funds could be cut without damaging the final product.[[34]](#endnote-34) Another key to cost control in the engineering phases was that *Rafael’s* managers agreed to a predetermined fixed payment that would not be dependent on the amount of development time.[[35]](#endnote-35) It meant that the company’s managers accepted the full risk of losing money on the project. But it also meant they had full freedom of action because the customer could not intervene to reduce costs, which played a major role in the success of the project. In one case, they diverged radically from established practice by deciding that *Iron Dome*’s missile should have an electrical servo motor, as if it were a large liquid-fuel ballistic missile. This decision ignored the expertise accumulated over the years that favored pneumatic servo motors for (air to air) missiles, but the unusual electrical solution considerably reduced overall costs.[[36]](#endnote-36)

Pursuing low-cost solutions for each part of the system—and the *Iron Dome* is a veritable orchestra of sub-systems—was a high priority because at the outset all the options seemed to lead to astronomical expense. Finding expensive, complex solutions in designing weapons is not hard —it is the realm of $6,000 aircraft toilet seats—but finding simple solutions requires thought and creativity.[[37]](#endnote-37)

In spite of the urgency of finding a solution for the ever-present threat of rocket and missile bombardment, there was no compromise in meeting the fundamental requirement of operating efficacy at a reasonable price. When the developers of the separate components came up with solutions that failed to attain the required standards, they were told to keep working until they found better solutions. “The success of a project always depends on prior success in choosing the right people" was the conclusion of one protagonist. Dr. Ron, one of the development team leaders called the “Fabulous Five,” describes the special atmosphere in the project: “From the first moment, I was driven by the fact that we were dealing with something of a supreme significance… A senior engineer with decades of experience found himself listening to a young engineer with a different opinion.” Indeed, the absence of a hierarchy naturally inclined to favor well-established methods propelled the project. There was no higher authority to override the preference for the quickest, cheapest, and most logical operational system merely because it relied on unusual solutions.[[38]](#endnote-38)

As happened repeatedly and on all sides during the Second World War, groups of engineers and scientists personally committed to an urgent national mission that might avert the deaths of loved ones achieved a critical mass of dynamic creativity otherwise not only unattainable but unimaginable. That is how the British came up with the world’s first centralized air-defense system to defeat the initially much superior *Luftwaffe* with nary a computer in sight, and then forced a crude computer into existence to break German radio traffic cyphers to sink the U-boats starving Britain. That is also how the Germans invented and produced the first rocket-powered fighter, the first jet-fighter, the first cruise missile, the first ballistic missile, the first air-to-surface missile, and even the prototype of the first “stealthy” jet bomber while under increasingly heavy bombing. All those achievements were exceeded by the mostly refugee scientists of the Manhattan project, who feared that German creativity might extend to the fission bomb and therefore stopped at nothing to invent practical ways of separating U-238 and using the resulting fissile material in two different bomb designs, hoping one might work (both did), all done in a little over three years.

In Israel’s case we have the testimony of the head of *Rafael’s* R&D Division, Dr. Ronen: “I was traveling north one day to attend an experiment and when I reached Tel-Aviv an alarm was sounded. My children and grandchildren live there, and I witnessed how the missile intercepted a rocket seemingly right over their house.” David, the project’s chief engineer, explained how the project dynamics worked. Before the *Iron Dome*, the rule within *Rafael* was that after a failed test, everyone would go back to the development facility to return to the proving grounds with a new solution within a few months; the *Iron Dome* project broke that rule. First, the experiments started very early, which is highly irregular in missile development. Right from the first, frustrating experiments, an ethos of “no surrender” was forged. Sometimes a team would remain in the field instead of returning to their desks while the guys at the labs figured out the problems; sometimes the solutions were found on the same night that an obstacle arose, so that the following morning a new experiment could take place as if no mishap had ever occurred. In the process, all barriers to creativity were breached, including the most important, those that are entirely unconscious. A key figure testified: “The [*Iron Dome*] ... missile is the only one in the world that contains components [taken from toys]. One day I brought to work one of my son’s toy cars. We passed it between us and saw that there were components that really suited us; more than that I cannot tell you.”[[39]](#endnote-39)

It is an unfortunate hallmark of military R&D to reinvent what already exists, often to find a use for some new technology that may excite technologists but is not really necessary, or simply too expensive, for the project at hand. The aircraft carrier *USS Gerald R. Ford* CVN-78 attained a total cost of $ 17.5 billion versus the $6 billion of its CVN-77 predecessor, the *USS George H.W. Bush*, in great part because of the irresistible urge to replace the traditional hissing and bumping steam catapults with a soundless Electromagnetic Aircraft Launch System that eliminates all that antique steam generation. When the new $4 billion wizardry kept failing, seriously delaying the commissioning of *USS Ford* month after month, the beleaguered US Navy claimed that the $4-billion wonder would save that amount in operating costs over a 50-year lifespan, indicating that those involved might not do very well as investors. In the *Iron Dome* project by contrast there was no urge at all to reinvent.

Another procedural factor, which ended up accelerating the project, was the involvement of the different participants very early in the development stage. Usually production work starts only after development is completed, but with *Iron Dome* there was cooperative synergy with the Ministry of Defense, which became a participant instead of an arms’-length inspecting and auditing customer (a relationship that would have horrified the valiant fighters against waste, fraud and mismanagement who much prefer adversarial relations without ever computing their tremendous costs). *Iron Dome* offers the counterexample of a project in which the customer practically merged with the project team. In another drastic departure from all normal practice, the *Heyl Avir* personnel who were to operate Iron Dome batteries (no way would airmen allow soldiers to shoot missiles into their sky) also participated in the development work.

That the system be easy to use correctly was an extremely important project goal—the batteries would be operated by young conscripts, not seasoned professionals, so air force anti-aircraft personnel were brought into the process. Then they surprised the developers by coming up with improvements and adjustments of their own, which were duly implemented. That was only possible because of a most unusual move by the development chiefs: “The [anti-aircraft] soldiers who operate the system have our telephone numbers (!) and call us for every problem. [They were] involved in the project from the first moment, from the most basic level of requirements and specifications.”[[40]](#endnote-40)

Operating simplicity was a leading requirement, but there were other considerations: “One of the system's requirements that we defined early on was that a small female soldier should be able to step onto the launcher position and activate it. We also had aesthetic design considerations; I told the launcher designer that I want it to look super modern but also menacing because it is clear that within an hour of its operation, it will appear on CNN and Al Jazeera.”[[41]](#endnote-41) Finally, representatives of the manufacturing staff were also integrated into the development process at a much earlier stage than is customary, which lowered development-to-production risks and accelerated problem solving while reducing costs.[[42]](#endnote-42)

A simple timeline captures the sheer dynamics that propelled the Iron Dome project:

In February 2006, Gold issued his legal and proper contract for a “technology demonstrator,” and no more than that.

August 27, 2006: Minister of Defense Amir Peretz, who happened to be a resident of Sderot, which was very close to Gaza and a prime target of Hamas rockets, declares Iron Dome a “highest priority project” and calls for an “Emergency Plan” to accelerate its completion. But he does not secure a budget or Cabinet support for formal orders though the IDF Chief of Staff.

November 12, 2006: Gold as head of MaFat officially instructs *Rafael’s* to initiate full scale development.

November 16, 2006: the chief of the IDF General Staff Planning directorate, a one-star brigadier-general, assigns responsibility for the development of an “Active Anti-Short Range Rockets Defense for System” to the air force, ignoring and cutting across Danny Gold’s initiative.

December 1, 2006: defense minister Amir Peretz declares that a Short-Range Rocket interception capability is essential, and that the “Iron Dome” is the chosen solution but cannot himself authorize the needed funds.

February 4, 2007: Prime Minister Ehud Olmert asserts that “Iron Dome is inevitable” and most urgent. But no funding was allocated to Gold’s unauthorized venture. Olmert’s statement nevertheless encourages the *Rafael* and *Elta* managers to keep working confident that all would be put right in the end.

June 4, 2007: the IDF Chief of Staff LTG Gabi Ashkenazi withholds his authorization of the Iron Dome project because it still had received no funds from the ministry of defense.

July 3, 2007: the new minister of defense, MG Ret Ehud Barak approves “in principle” the Iron Dome’s development, which Gold had in fact started two years earlier without any ministerial authorization or funding.

December 23, 2007: five months after Barak’s approval, the actual “commander -in-chief” under the Israeli system, the Cabinet Committee on National Security that includes the Minister of Finance, finally endorses Barak’s decision, providing initial funding.

January 1, 2008: The *Iron Dome* has its official start—two years and four months from its actual start in 2005.

July 15, 2009: the *Iron Dome* radar, missile and software are ready to be tested as an integrated system. It successfully intercepts multiple targets.

July 25, 2010: a prototype demonstrates the selective interception of rockets headed to designated “populated places” as opposed to uninhabited places.

March 27, 2011: a first operational battery is deployed near the Gaza Strip, followed by a second battery on April 4, 2011, but the Ministry of Defense issues a disclaimer “confessing” that the Iron Dome is not yet fully operational and that more batteries will be pressed into service nonetheless, as an “operational experiment.” But that excuse was scarcely called for, as on April 7, 2011, a battery successfully intercepted a 122-mm rocket launched from Gaza toward the city of Ashqelon. The radar instantly identified the launch-point, allowing an air force aircraft already airborne on patrol to bomb the launch team, successfully.

August 20, 2011: as the fighting heated up, eleven 122mm rockets were launched in a single salvo at the city of Be’ersheva; the Iron Dome intercepted nine—and the remaining two caused little damage.

March 2012: a total of some 300 rockets and mortar shells were fired against Israeli territory. Out of 73 rockets identified as real threats to populated places, the Iron Dome intercepted 69. A fourth battery is deployed.

May 18, 2012: duly impressed by its success the US House of Representatives votes $680 million for *Iron Dome* funding, in exchange for technology-sharing with US industry, and specifically the major contractor Raytheon.

June 4, 2012: the US Senate Armed Forces Committee approved only $210 million, still requiring full technology sharing, which does not bother the Israelis because they welcome the added production of interception missiles by Raytheon.

June 23, 2012: Iron Dome achieved its 100th intercept.

November 14-21, 2012: Operation “Pillar of Defense”: Iron Dome batteries intercept 428 rockets for an 84% success rate.

November 17, 2012: A fifth battery is deployed in the Tel Aviv area. Intercepts a rocket on the same day.

January 17, 2014: US president Barack Obama approves $235 million for the procurement of ID batteries for the US.

August 1, 2014: the US Congress approves an additional $225 million to replenish the missile inventory.

August 26, 2014: Operation “Protective Edge” begins: nine ID batteries intercept 578 rockets including larger Fajr-5s and M-75s, for an 89.6% total success rate (65 of the intercepts are initiated manually, overriding the ID’s automatic launch program).

May 16, 2016: successful sea trial of the naval version of ID.

September 17, 2016: an ID battery intercepts two mortar shells from Syria in the Golan Heights.

Five years later, with renewed hostilities on May 10-21, 2021, Hamas launched a total of 4,360 rockets against Israel. Of these, 1,661 were intercepted by the *Iron Dome*, 176 were missed and fell in built-up areas, and 1,843 rockets fell as predicted in open areas.[[43]](#endnote-43) About 680 rockets failed to cross the border and fell inside Gaza, causing significant Palestinian casualties. Ten Israeli civilians lost their lives, with many more saved, some because improvements had increased the system’s performance against heavy salvos specifically intended to overwhelm the system.

Strategically, the value of the *Iron Dome* was that it offered the Israeli government an alternative to another ground offensive likely to be both costly and inconclusive. The development and early production costs, moreover, were moderate, a total of some US 2.2 billion (half from the US) from inception to first operational use, in part because of a phenomenally rapid pace of development: the first successful intercept occurred on April 7, 2011, less than six years from the start of the first research efforts in August 2005.

But Michael Lindenstrauss, Israel’s state comptroller and keeper of proper government procedures, including safeguards against waste, fraud, and mismanagement, was not amused by the wholesale violation of rules perpetrated by Gold and his confederates. As far as he was concerned, Gold’s feat, rather than exemplary, was a case of sustained, piratical insubordination, budgetary misappropriation, and administrative irregularity on the largest scale. The comptroller’s report did acknowledge that the circumstances in which Gold made his decisions were far from tranquil and declared his sense of urgency praiseworthy: “The office of the State Comptroller is aware of the decisiveness and fervor of MaFat in producing active defense systems as soon as possible.” But it went on to reiterate that it was nonetheless improper for MaFat to initiate full-scale development before the IDF had even defined the operational requirements, before the IDF and the government had approved the spending of vast sums, and before any exploration of offensive alternatives, and/or of alternative anti-rocket defense system configurations. In other words, Gold had picked a system and charged ahead to engineer it into existence, instead of considering all the alternatives. There followed a very long list of irregularities, ending with: “Brigadier General Dr. Danny Gold started the development of the Iron Dome in August 2005 in an ‘unruly’ manner, violating regulations to order the overlapping of the pre-development stage with the full-scale development stage, thereby overriding the exclusive jurisdiction of the IDF Chief of Staff, the Minister of Defense, and the Israeli Government as a whole.” [needs source]

Along with many more violations by ministry of defense officials and serving officers energized by Gold’s charismatic urgency, the comptroller’s report noted that Gold had violated Ministry of Defense decree no. 20.02 of August 2005 when he ordered the “telescopic” scheduling of the project with overlapping stages, so as to commence (unauthorized) full-scale development under the guise of (authorized) prototype development, a violation only possible because of the indulgence of *Rafael* and *Elta* management. But parenthetically, the state comptroller noted that the MoD had never defined the specific terms it used for R&D projects: Telescopic Development; Spiral Development (seemingly: the sequential reassessment and pursuit of projects); Incremental Development; Specified demonstration program; and Technology demonstration. After the long list of accusations, the report’s final conclusions were (unsurprisingly) mild: “It is advisable that the development and procurement of weapon systems (particularly projects which considerably affect the IDF’s budget, and it force structure), will be executed after the operational requirements have been specified properly, and approved beforehand.” [needs source]

In all of the above Gold had done what Americans used to do. As late as 1956, when the US Navy started the development of the submarine-launched *Polaris 1A* nuclear-armed ballistic missile, there was still room for real project leadership in US defense procurement. Admiral “31-knot” Arleigh Burke (so called because he would steam his ships above their recommended speed) then chief of naval operations, who combined a fine analytical mind with a hard-charging character, appointed Rear Admiral W. F. Raborn, another brainy, hard-charging character to head the project.[[44]](#endnote-44) On 21 January 1961, after 66 days of submerged patrol, the USS George Washington, armed with 16 Polaris missiles, was declared fully operational—just five years after work had started on a weapons system a hundred times more complicated than the *Iron Dome* (and funded with a budget a hundred thousand times as large). At a time when there was much anxiety in the United States about Soviet advances in ballistic missiles, the early arrival of Polaris was very important strategically because it was a “second-strike” weapon, much less vulnerable to surprise attack than bombers on their airfields or Air Force ballistic missiles in their static emplacements on land.

To develop *Polaris* as quickly as they did, Burke and Raborn had to take many risks large and small, because they were developing an entirely new kind of submarine for an entirely new kind of ballistic missile, whose reduced diameter was made possible by an entirely new kind of nuclear warhead. Polaris only became possible because Burke believed the promise of the eccentric genius Edward Teller, “father of the thermonuclear bomb,” that his team could develop a new (W-47) reduced-diameter warhead and do so rapidly. It was on that basis that Burke rejected the “sure thing” Army Jupiter medium-range ballistic missile, which would have required much larger submarines, to instead develop the radically different Polaris.

But all that happened before the arrival of the present US regulatory regime, which entraps everyone in thousands of rules and an endless sequence of program reviews (and agonizing reappraisals by the buying service) in the name of fighting “waste, fraud and mismanagement.” Instead of being honored and praised for bold and successful leadership, these days admirals Burke and Raborn would be hounded out of the service for risk-taking, with every imperfection labeled a scandal.[[45]](#endnote-45)

The 2009 report of Israel’s state comptroller that both praised and condemned BG Daniel “Dany” Gold shows that Israel too has acquired overlapping authorities that issue contradictory instructions, as well as a great many regulations that assure nothing much while impeding dynamic action. But in Israel almost daily enemy attacks keep legalistic and bureaucratic degeneration under some control, and the right signals were sent when Gold was not fined or fired but instead honored with the Defense Prize and promoted head of all research and development in the IDF and Ministry of Defense, with a seat at General Staff meetings.

In 2019 the US Army purchased *Rafael* *Iron Dome* batteries to protect its bases in contested areas. It was a final seal of approval, after ten years of operational activity and the interception of over 2,400 missiles and rockets.[[46]](#endnote-46)

1. Funding the project depended on US assistance. John F. Golan, *Lavi: The United States, Israel, and a Controversial Fighter Jet* (Lincoln, NE: University of Nebraska Press, Potomac Books, 2016). [↑](#endnote-ref-1)
2. Uzi Eilam, *Eilam’s Bow* (Tel-Aviv: Miskal, Yedioth Aharonoth, Chemed Books, 2009), 371. [cite English language book] [↑](#endnote-ref-2)
3. Shlomo Erell, *Facing the Sea* (Tel Aviv: Ministry of Defense, 1998), 217-218. (H) [↑](#endnote-ref-3)
4. Ben-Nun (1924–1994) was founder of Israel’s frogmen-commandos. On October 22, 1948, he drove an explosive boat that sank the 1400-ton sloop *El Amir Farouq* flagship of the Egyptian Navy, jumping off just in time. In 1956 as commander of a destroyer-escort he captured an Egyptian destroyer. Retired in 1966, he fought in 1967 in the Golan Heights as a volunteer. He is commemorated by the Yohai Ben-Nun Foundation for Marine and Freshwater Research. [↑](#endnote-ref-4)
5. Luciano Garibaldi, Gaspare Di Sclafani, *L'incredibile vicenda di Fiorenzo Capriotti eroe della Decima ed eroe di Israele*, in *Così affondammo la Valiant*, 1ª edizione, Torino, Edizioni Lindau, 2010. [↑](#endnote-ref-5)
6. Mike Eldar, *Flotilla 13: The Story of Israel's Naval Commandos* (Tel Aviv: Ma'ariv Book Guild, 1993), 109-162. (H) [↑](#endnote-ref-6)
7. Avner Shur, Aviram Halevi, and Tal Bashan, *Fire and Silence*: *Yohai Bin-Nun*: *The Chief of the Israeli Navy and the Making of the Israeli Navy Commando Unit*, (Ben Shemen: Keter Press 2017), 218. (H) [↑](#endnote-ref-7)
8. The originally wooden-hulled *Jaguar* boat of the Lürssen shipyard in Bremen, Shlomo Erell, *Facing the Sea* (Tel-Aviv: Ministry of Defense, 1998), 217. (H) [↑](#endnote-ref-8)
9. Shur, Halevi, and Bashan, *Fire and Silence*, 221, 225. [needs Hebrew translit. title] [↑](#endnote-ref-9)
10. One was the current chief of German naval intelligence Otto Kretzmer, winner of the Iron Cross, another was Professor Gabler wartime submarine planner. Haim Shahal, the project's chief engineer believed that a German colleague had been in the SS. [↑](#endnote-ref-10)
11. For full diplomatic relations. Israel’s Prime Minister David Ben Gurion and Chancellor Konrad Adenauer of the Federal Republic of Germany had signed a Reparations Agreement in 1952; under a secret 1960 agreement the FRG agreed to provide US $ 60 million worth of weapons, including $ 12 million for torpedo boats. [↑](#endnote-ref-11)
12. Shur, Halevi, and Bashan, *Fire and Silence*, 226. [Hebrew translit. title] [↑](#endnote-ref-12)
13. Shur, Halevi, and Bashan, *Fire and Silence*, *2*26-227*.* [Hebrew translit. title] [↑](#endnote-ref-13)
14. #  He was candid as to French motives: M. Maurice Schumann: notre politique a abouti au regain de notre influence dans le monde arabe, *Le Monde* January 14, 1970.

 [↑](#endnote-ref-14)
15. See Mike Eldar, *The Enemy and the Sea* (Tel-Aviv: Ministry of Defense, 1991), 170-182. (H); Moshe Imbar, *The 3rd Flotila – The Israel Navy Fast Missile Boats* (Tel-Aviv: Ministry of Defense, 2005), 32-33. (H) [↑](#endnote-ref-15)
16. Shlomo Erell, *Facing the Sea* (Tel-Aviv: Ministry of Defense, 1998), 312-313 (H); Imbar, *The 3rd Flotila, 36-7;* Eldar, *Enemy and the Sea*, 191-199. [all need Hebrew translit. titles] [↑](#endnote-ref-16)
17. Uzi Rubin, “Israel’s Air and Missile Defense During the 2014 Gaza War” BESA Center for Strategic Studies, Mideast Security and Policy Studies No. 111 (February 2015), 18. [↑](#endnote-ref-17)
18. Ulrike Putz, “Graveyard Shift for Islamic Jihad: A Visit to a Gaza Rocket Factory,” *Spiegel Online International,* January 29, 2008. At: <http://www.spiegel.de/international/world/graveyard-shift-for-islamic-jihad-a-visit-to-a-gaza-rocket-factory-a-531578.html> [↑](#endnote-ref-18)
19. ##  Theodore A. Postol’s “An Explanation of the Evidence of Weaknesses in the Iron Dome Defense System,” *MIT Technology Review,* July 15, 2014, cited insurance damage claims to depict the system as ineffectual because separated rocket warheads still detonated. That is, *Iron Dome* could not *nullify* the attack, but it displaced the damage to save lives and property even if separated warheads did explode.

 [↑](#endnote-ref-19)
20. Michael Gilmore, Director of Operational Test and Evaluation Department of Defense, as cited in: Bill Sweetman, “Not Combat Ready,” *Aviation Week and Space Technology:* 15-28, February 2016, 34. [↑](#endnote-ref-20)
21. Carmel Liberman, “Israel's Air Force Commander: We are the First to use the F-35 in an Offensive Mission,” *Bamachane'* *Journal,* May 22, 2018. (H) [↑](#endnote-ref-21)
22. From the first, overhead synthetic aperture radars could reveal the outline of any stealthy aircraft below them because their airframes occlude the terrain otherwise detected. [↑](#endnote-ref-22)
23. Eg. Reuven Pedatzur “What happened to Iron Dome,” *Ha’aretz,* August 28, 2013*.* Athttps://www.haaretz.co.il/opinions/.premium-1.2107807. [↑](#endnote-ref-23)
24. Avi Kober, “Iron Dome: has Euphoria been Justified?”BESA Center, BESA Center Perspectives Paper No. 199 (25 February 2013). [↑](#endnote-ref-24)
25. BG (Res.), Dr. Dany Gold served in the air force and then in the Weapons Development Department. After developing the Iron Dome System he was awarded the Israeli Security Prize, retired as Brigadier General and became head of MaFat. [↑](#endnote-ref-25)
26. BBC News, *Q&A: Gaza Conflict*, 18 January 2009, at http://news.bbc.co.uk/2/hi/middle\_east/7818022.stm. [↑](#endnote-ref-26)
27. Uzi Rubin, "Israel Defense Establishments Adaptability to Abrupt Changes in its Strategic Environment: Missile Defense as a Test Case", PhD Thesis, Bar Ilan University, (Ramat – Gan, Israel, 2018), 161-172. (H) [↑](#endnote-ref-27)
28. "Dedication, Zionism and a Few Parts from Toys R Us” *The Expert News*, July 9, 2014. At: <http://tracks.roojoom.com/r/12638#/trek?page=1>. (H); also Ilan Kfir & Danny Dor, *Iron Dome*, (Or-Yehudah, Israel: Kineret Zmura-Bitan 2014), 130. (H). [↑](#endnote-ref-28)
29. “Israel’s Innovations,” *Ynet,* 15. April 2018, at: https://www.ynet.co.il/articles/0,7340,L-5227361,00.html#autoplay (H). [↑](#endnote-ref-29)
30. 2021 interview with BG Ret Dr. Uzi Rubin, Tel Aviv, May 9, 2016. He founded and headed Israel’s Missile Defense Organization *Minhelet Chuma* (1991-1999), overseeing the *Arrow* anti-missile defense system, for which he received the Israel Defense Prize in 1996. [↑](#endnote-ref-30)
31. The IAF never actually endorsed the system. Uzi Rubin, “Iron Dome Versus Grad Rockets Dress Rehearsal for an All-Out War” BEAS Perspectives Papers, No. 173, July 3, 2012. At: https://besacenter.org/perspectives-papers/iron-dome-vs-grad-rocketsa-dress-rehearsal-for-an-all-out-war/ [↑](#endnote-ref-31)
32. Interview with A., Senior Iron Dome Developer in MaFat, Tel Aviv, June 15, 2016. [↑](#endnote-ref-32)
33. Interview with Rubin. [↑](#endnote-ref-33)
34. Senior Developer in MaFat. Personal email correspondence with the authors, 15 August 2016. [↑](#endnote-ref-34)
35. Avigdor Zonnenshain and Shuki Stauber. *From the Concorde to Iron Dome: Managing Technological systems in the 21st Century,* (Haifa, Israel: The Technion Institute for Research & Development, 2014), 92-94. (H) [↑](#endnote-ref-35)
36. Zonnenshain and Stauber, *From the Concorde,* 89. [needs Hebrew translit. title] [↑](#endnote-ref-36)
37. Zonnenshain and Stauber, *From the Concorde*, 95-96. [needs Hebrew translit. title] [↑](#endnote-ref-37)
38. “Dedication, Zionism and a few parts”—interview with the Leading Team developers of Iron Dome Graduates of Technicon on the Secrets of Success of the Project” (H), 124, 125. [↑](#endnote-ref-38)
39. Kfir & Dor, *Iron Dome*, 126, 143. [↑](#endnote-ref-39)
40. “Dedication, Zionism and a few Parts from Toys R Us.” [↑](#endnote-ref-40)
41. Attributed to Hanoch, Zonnenshain and Stauber. [who is Hannoch?, same title as below but diff authors] [↑](#endnote-ref-41)
42. Zonnenshain and Stauber, *From the Concorde*, 97-99. [needs Hebrew translit. title] [↑](#endnote-ref-42)
43. IDF at: <https://www.idf.il/en/articles/defense-and-security/israel-under-fire/> [↑](#endnote-ref-43)
44. Edward Luttwak knew Burke when he inspired a then innovative think-tank best left nameless. [↑](#endnote-ref-44)
45. There were serious “imperfections”: Teller’s [W-47 warhead](https://en.wikipedia.org/wiki/W47) had an unreliable trigger mechanism, and the A2 missile was running late. But Burke and Raborn were not fired. Instead, they lead the corrective efforts, so that by the end of 1961 the A2 version was ready, and the W-47 was successfully modified.   [↑](#endnote-ref-45)
46. Judah Hari Gross, "US Army Receives 1st of 2 Iron Dome Batteries, but Future Unclear" ,*The Times of Israel* , September 30, 2020, at: <https://www.timesofisrael.com/us-army-receives-1st-of-2-iron-dome-batteries-doesnt-plan-to-buy-more/>. During Operation Protective Edge, Iron Dome interceptors executed 735 successful interceptions, Ben Hartman, "50 Days of Israel's Gaza Operation, 'Protective Edge' by the Numbers", *Jerusalem Post* , 28 August, 2014., at: <https://www.jpost.com/Operation-Protective-Edge/50-days-of-Israels-Gaza-operation-Protective-Edge-by-the-numbers-372574> [↑](#endnote-ref-46)