Cheaper precision weapons: an exploratory study about the HESA Shahed 136.

Armas de precisão de baixo custo: um estudo exploratório sobre o HESA Shahed 136.

Daniel Zampronha[1]

Resumo

A capacidade de acertar um alvo com precisão e à distância vinha sendo reservada para as superpotências mundiais. Porém, tal reserva, cada vez mais, vem sendo ameaçada uma vez que drones com essa capacidade estão se tornando acessíveis aos que não contavam com esse recurso estratégico. Este artigo parte do drone iraniano HESA Shahed 136 para discutir as últimas inovações em relação a armas de precisão de longa distância de baixo custo, mais precisamente, o uso de drones kamikaze e loitering munitions (munição vagante). Trata-se de uma pesquisa exploratória que parte da discussão da noção de drone kamikaze e, em seguida, analisam-se as opções de design do Shahed 136, com o propósito de refletir sobre o futuro desse novo tipo de armamento e suas implicações para a relação econômica e política entre armamento e custo. Conclui-se que o HESA Shahed 136 revoluciona o conceito de ataques precisos de longo alcance, uma função que até agora era reservada a mísseis táticos e aeronaves caras e tecnologicamente exigentes, e que agora pode ser realizada com drones de baixo custo. Cria-se, portanto, uma corrida armamentista não apenas para produzir o armamento mais tecnológico e preciso, mas também o de menor custo.

Palavras-chave: armas de precisão, drones, loitering munition, ética.

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Abstract

The ability to hit a target with precision and from a great distance has been reserved for the world's superpowers. However, this resource is increasingly being threatened as drones with this long-range and precision capability are becoming more accessible to those who didn't have this strategic ability. This article starts with an analysis of the Iranian HESA Shahed 136 drone to discuss the latest innovations in low-cost long-range precision weapons, specifically the use of kamikaze drones and loitering munitions. This is an exploratory study that starts by discussing the notion of a kamikaze drone and then analyses the design options for the Shahed 136, with the aim of reflecting on the future of this new type of weapon and its implications for the economic and political relationship between weapon and cost. The conclusion is that the HESA Shahed 136 revolutionises the concept of precise long-range strikes, a function that until now was reserved for expensive and technologically demanding tactical missiles and aircraft, and which can now be carried out with cheap drones. This creates an arms race not only in the production of the most technological and precise weaponry, but also the least expensive.

Keywords: *Drones, loitering munition, ethic*

1. Introduction

Loitering munitions are remote-controlled systems being a niche between guided missiles and conventional reconnaissance and bombardment UAVs, that combine the advantages of both (GILLI; GILLI, 2016). Engaging ground targets with an explosive warhead, they are a single use, highly precise airstrike that can track and engage time-sensitive targets. Kamikaze drones and loitering munitions are cutting-edge technologies and utmost necessities in the modern battlefield (RHEINMETALL, 2023). Loitering munitions can be used to target infantry targets, tanks and military vehicles, but recent events have revolutionised the concepts and limitations of this new weapon program, which has attracted much recent technological interest. This level of innovation and quick progress has been, for the most part, unparalleled in recent military history. Having been used in the Nagorno-Karabakh conflict, kamikaze drones are combat-proven and are an expanding new technology. Most modern superpowers have some kind of suicide drones in their arsenal (YENNE, 2017) (GETTINGER; MICHEL, 2017). In the present conflict in Yemen and the ongoing Ukraine-Russian war, kamikaze drones experienced ground-breaking progress, rethinking the entire concept, going from specialised weapons to cheap and strategic platforms. Following this new development, a new approach to the classification and regulation of the use of these weapons is indispensable.

The response of the first Surface-to-Air Missiles[2] (SAM) was the creation of the first anti-radiation missiles. Anti-radiation missiles are missiles that can target the RADAR emission of enemy SAM sites. These were most effectively used in fighter jets, which would fly over a contested area and constantly target any RADAR emission. The counter-response was the use of mobile SAMs such as 2k12 Krub, with intermittent use of radar. Thus, the SAM battery was only visible for a small period, during which it was also a significant threat to the Suppression of Enemy Air Defences (SEAD) doctrine (RICHARDS; SCHEER; HOLM, 2010). The logical response was the use of cheaper munitions than the expensive aircraft carrying anti-radiation missiles. Hovering and loitering over suspected SAMs sites, armed with radar detection, the first loitering munitions and drones were created with the intent to hunt and wear down enemy anti-air defences.

Following this development, loitering weapons have been expanded to tactical level fire support equipment, such as the AeroVironment Switchblade or the Israeli IAI Harpy. Most kamikaze drones in recent years have been categorized as highly sophisticated weapons reserved for special forces, an advanced squad weapon or specialised tank killers (EVERSDEN, A, 2022).

But the current Yemen conflict has seen the use of a new type of weapon, as Iranian supplied drones to the Houthi rebel movement, which were used as slow flying long-range suicide drones to target Saudi Arabian oil refineries (VOSKUIJL;

[2] SAM are missiles launched from the ground aimed at a target aircraft or other missiles, most commonly using RADAR as guidance.

DEKKERS; SAVELSBERG. 2020). In the most recent Russo-Ukrainian war, it was seen the demployment of the Geran-2 (DANGWAL. 2022a), which is believed to be the Russian version of the Iranian HESA Shahed 136. This drone was deployed as a hard-hitting, strategic and infrastructure attacker (KNIPP, K. 2022) (MALSIN; COLES. 2022), a role traditionally exclusive to expensive and valuable long range guided missiles and cruise missiles. This new use has been pushing the boundaries of the suicide drone's use, attracting large quantities of military, economic, political and international commotion (TROFIMOV; NISSENBAUM, 2022), (TROFIMOV, 2022) (STERN; DIXON, 2022) (NEWMAN, 2022) (HARRIS, LAMOTHE, HORTON, DEYOUNG, 2022).

Usually a sophisticated and tactical weapon, this new design focuses on manufacturing costs and simple construction, to overwhelm and expend enemies' air defense munitions, attacking critical infrastructure behind enemy lines. Not having a computer visor and modern military flight control systems, these drones are mostly inefficient against moving targets or positions with anti-air defenses. This new approach drastically changes the stated view of suicide drones, being a total reimagination of the concept.

Most academic research regarding drones explores guidance, tracking and control systems, mostly for civilian use. Recently, a broader technical analysis of the design choices and overall engineering construction of loitering munitions has been explored in recent literature, as the research made by Voskuil (2022), which serves as the main basis for the propositions in this article.

This article starts with a general theoretical drone engineering overview, with an eye to analyse the HESA Shahed 136 through a study of the design mentality, engineering aspects and the economic choices with the objective of providing an understanding of this new type of technology.

Going against the initial analysis of loitering munitions, the new Shahed 136 uses the logic of asymmetric warfare, using consumer-grade technology, to wage an economic war. Not relying on time-sensitiveness, it explores firepower, range and endurance, while pushing the utmost cheap design. This article expands on the mechanical construction and engineering philosophy of the Shahed 136, and to question the economical and political repercussions of this new type of long-range suicide drone as a precise, cheap and highly destructive armament.

2. Overall theoretical concepts of drone designs.

As far as the design of loitering munitions is concerned, some critical aspects should be well analysed: The type of task, the warhead used to complete this particular task, the total time of the mission (endurance), and in this sense, the distance to the target (range). The attack approach, the ability to hover over targets and target acquisition, as well as launch and weight characteristics. All these aspects will be covered for the HESA Shahed 136, with available public domain information, for an overall analysis and understanding.

As it will be explained, when engineering the Shahed 136, some aspects and others were strongly highlighted as crucial or not crucial, creating such a new weapon. The design was pushed in range, endurance, weight capacity, and using broad, not sophisticated and consumer-grade target acquisition and flight control modules and communications. For a better comprehension of this platform and complementing future development and choices in this technology, this study primarily follows a theoretical approach, although rather superficially. The equation and mathematical theoretical equations used in this article are to demonstrate the intrinsic complexity and multidisciplinary nature of the subject. A more in-depth engineering analysis of loitering munitions was made by Voskuijl (2022).

2.1. Endurance

Endurance, as one of the most critical design choices of the Shahed 136, was defined by Voskuijl (2022) as the total flight time in cruise flight and in the equation, for both piston and battery powered drones:

$$E_{\text{piston}} = \frac{\eta_{\text{prop}}}{c_{\text{P}}} \sqrt{\frac{54}{256} \frac{\rho(\pi A e)^3}{C_{D_0}}} \left[\frac{1}{\sqrt{(W/S)_{\text{final}}}} - \frac{1}{\sqrt{(W/S)_{\text{start}}}} \right] \tag{1}$$

$$E_{\text{battery}} = \eta_{\text{elec}} \eta_{\text{prop}} \sqrt{\frac{27}{512} \frac{1}{(W/S)} \frac{1}{W^2} \frac{\rho(\pi A e)^3}{C_{D_0}}} U_{\text{bat}} \tag{2}$$

These equations are taken as assuming the Endurance is the integral of the total time of the mission, from tstart to tend. The overall derivation of the equation is included by Voskuijl (2022, p. 326).

Even though the equations do not take into account energy and fuel-consuming activities that will be present in the overall mission of a drone, such as take-off, climb and descent, these equations are still useful to determine which design choices have the most overall impact in the endurance of loitering munitions. As stated by Voskuijl (2022):

> *The propulsion system should have a low power-specific fuel consumption (C_P) and a high propeller efficiency (η_{prop}) at the airspeed at which the aircraft loiters. The aspect ratio (A) and Ostwald factor (e) are important aerodynamic design parameters. Furthermore, low altitude flights lead to*

longer endurance. The zero lift drag coefficient (CDo) should be as small as possible. Finally, a low wing loading defined as aircraft weight divided by wing surface area (W/S) and a large fuel fraction (ratio of fuel weight over maximum take-off weight) are design parameters in case of aircraft equipped with internal combustion engines.

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2.2. Precision guided control systems and attack method

As a crucial part of a drone's overall construction, how it approaches the target in the most efficient and precise way, takes a huge toll on its design characteristics. In this final phase, the drone may suffer its biggest external influences, such as turbulence and gust, while the target can be small or moving. The dive and attack velocity are also of great importance. Most loitering munitions emphasise this aspect and benefit from a power shaft with high efficiency at maximum airspeed and low value of the combined zero-lift drag coefficient and wing area. Adding additional controllability to a drone can increase its response to external forces in this critical phase of attack. The load factor (Δn) is given by Voskuijl (2022):

$$\Delta n = K \frac{dC_L}{d\alpha} \frac{\rho U V}{W/S} \quad (3)$$

Thus, the main design parameters that influence the sensitivity of an aircraft to a gust are the wing loading (W/S) and the lift curve slope $(\frac{dC_L}{d\alpha})$.

The delta wing present in the Shahed is also justified by the increased stability of the drone in the pivotal moment of attack. In general, delta wings tend to have a higher wing load compared to a conventional wing configuration. The choice for a delta wing is going to be explained in chapter 3. Having a stable attack phase increases the precision of the dive without relying on increasing the software sophistication.

The Shahed 136 is sometimes called a drone with “autonomy”, understood as “the ability of a machine to execute a task, or tasks, without human input, using interaction of computer programming with the environment.” (WILLIAMS, A., 2015, apud BOULANIN, VERBRUGGEN, 2017, p. 12). In this sense, a drone launched in a “fire and forget” mode can be considered autonomous. After it has been launched from the platform, it does not need additional human inputs to execute its task, although the Shahed might still receive new GPS target coordinates mid-flight (LATYNINA, 2022).

Despite the fact that 'fire and forget' systems have been used since the 1960s, their launch intent and target are usually human-defined, and only the flight trajectory is autonomously defined by the computer. This is the case of the Shahed 136, which functions similar to a conventional direct-attack guided ammunition. This definition contrasts with 'autonomous' loitering munition, which can potentially determine its target autonomously while hovering a suspected area for hours. For example, Bai, Luo and Ling (2021) explore in-depth the algorithm for the control and target acquisition of anti-radiation loitering munition, even with disturbance or in unfavorable conditions. In this regard, the IAI Harpy, the Israeli state-of-the-art anti-radiation loitering drone, can hover in areas in search of the radar signature emission and target it. This has caused a lot of academic interest and ethical debates, as potentially a precursor of fully 'automated' weapons and algorithms (WALLACH, THOMAS, 2016) (MCFARLAND, 2022). The Shahed 136 does not have the properties of autonomously identifying its target as its Israeli counterpart and is comparable to a conventional 'fire and forget' system used in guided missiles.

2.3. Size, weight and launch

The size and weight of the kamikaze drone is another focus when analysing engineering and aerospace technology. Drone weight and design can vary drastically from the intent of the construction.

Small drones with low endurance are designed to deliver grenade-sized warheads in a quick and tactical concept, like the Switchblade 300. While heavy and carrying a more significant payload, drones such as the IAI Harop, can be used as tank killers or an infantry position striker.

Combined with this, are the available launch platforms. Some low-weight and small drones can be launched with hands. It can also be launched with canisters, normally designed with folded wings. Being small in volume and practical, the canisters can be deployed in a wide variety of scenarios, usually in quick succession and in big quantities. They can be used while mounted in helicopters, aircraft, tanks or carried in soldiers' backpacks, which adds more versatility. The drawback is designing a munition that can be fit into this canister, adding more design constraints.

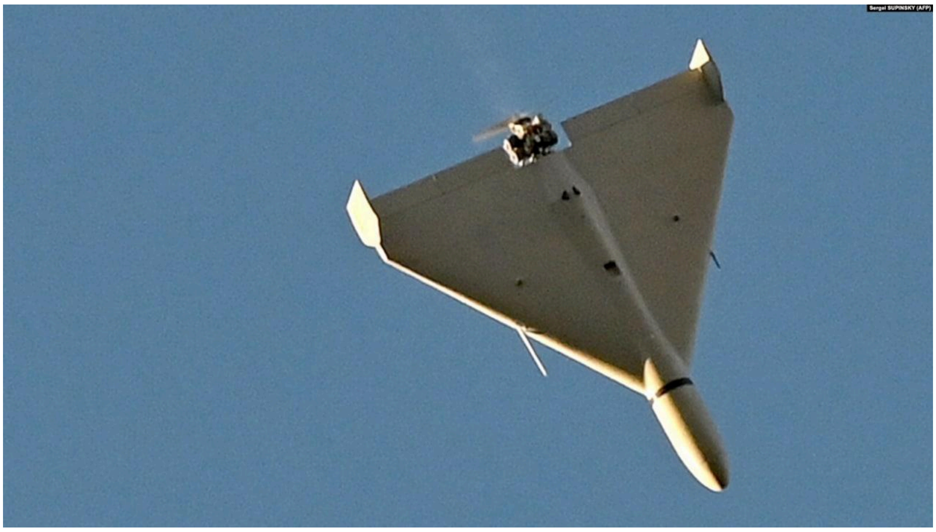
Another option is deploying in rails. Small UAVs can be launched using quickly mounted rails, while bigger drones use fixed rails. It can also be deployed using the Rocket Assisted Take-Off (RATO) technology and rails, small rocket boosters aiding a drone in its launch, reducing design constraints and requiring a smaller runway for take-off (EYMANN, MARTEL, 2012).

3. Engineering of the HESA Shahed 136

A disclaimer concerning the nature of the information used in this article is necessary. Considering the secrecy and recency of the subject, the data used for the Shahed 136 are estimates and may contain mistakes or be unavailable at all.

3.1. Aerodynamics

While most heavy and long-range drones use a traditional conventional fixed-wing configuration, like the Hero 900, Hero 1250 and Samad 3, the Shahed 136 uses a delta wing configuration, more like the IAI designs. This choice is due to various factors.



Open-source photo

The drone has a wingspan of approximately 2.5 metres and a length of 3.5 metres. It weighs approximately 200 kilograms. The flaps and elevons are located at the back of the drone, next to the engine (RUBIN, 2023).

The Delta-wing configuration is structurally efficient and has a large internal volume for a given wing area, increasing lift and resulting in the possibility of a heavier payload. The Delta wing also avoids stalls at slow airspeeds, a key point, considering the low speed of the Shahed.

Another strong point for the Delta wing is that it has a high volume efficiency, meaning more can be held giving a certain storage volume, facilitating transportations and logistics to overwhelm enemies defences by sheer number.

Most importantly, conventionally designed aircraft are well more susceptible to wind gusts than the delta configuration. The delta wing has a relatively high wing loading and is known to have a small lift curve slope compared to other configurations (VOSKUIJL, 2022). As such, for an aircraft like the Shahed 136 that does not have complex flight control systems and controllability, it is crucial to focus on its overall flight stability. In this regard, combined with a low-wetted area, a significantly higher maximum airspeed is expected when compared to conventionally designed wings.

Flight path calculation with respect to wind gusts is easier using delta wings than conventional wings and considering the drones limitation in its guidance system, as previously discussed, the use of a delta configuration makes absolute sense. A more in-depth analysis between conventional and delta wing flight designs in drones was detailed by Voskuijl (2022).

3.2. Propulsion

Engine of a destroyed Shahed-136 / Open-source photo

The Shahed 136 uses a conventional piston engine, driving a two-bladed propeller at the rear fuselage of the drone, in a pusher configuration (RUBIN, 2023). Believed to be an Iranian made MADO MD-550 four-cylinder piston engine, speculated to be a reverse engineering of the Limbach L550E. These engines have a high power-to-weight ratio and provide the drone an estimated range of 1500 to 2500 kilometres.

Although this range is still being disputed and can still be lower than the initial thought, it is nevertheless an incredible range and endurance. This range makes the Shahed on par with most state-of-the-art loitering munition, such as the Hero family and long-range IAI Harop. For comparison, some cruise missiles currently deployed by Russia, for instance the 3M-14 Kalibir and Kh-55, have respectively 2000 and 2500 km in range (CSIS MISSILE DEFENCE PROJECT, 2016).

A peculiar characteristic of this engine is the obnoxious sound the engine produces. Ukrainian sources stated that the sound the engine makes is a weak point of the HESA Shahed 136, alerting troops and defences to the approach of the vehicle. This has been explored against the Iranian drone (MORDOWANEC, 2022).

The choice for a piston engine is expected, as almost all drone designs above 40kg take-off mass uses a piston engine (GETTINGER; MICHEL, 2017) (VOSKUIJL, 2022). Gasoline has an energy density much larger than most modern Lithium-ion batteries. Even though the energy efficiency of electrical motors is higher than gasoline ones, this fact does not compensate for the energy density of gasoline. A good point of electric motors is the sound reduction it can possibly provide, as electric motors are generally quieter than combustion engines. The use of electric motors and their advantages can be increased in the future, as the development of batteries advances.

The choice of a combustion engine follows the general equation 1. Voskuijl (2021) made an extensive database concerning different configurations and a detailed overview of engine choices concerning loitering munitions. Overall, for drones with high endurance and weight, diesel engines are preferable.

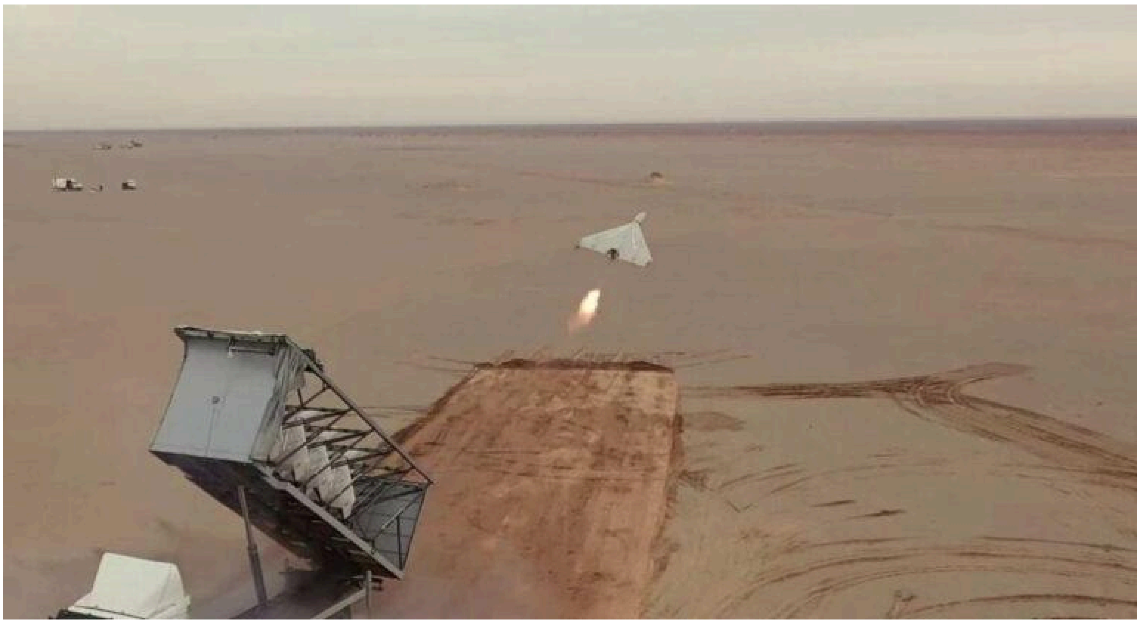
A standard fuel pump found in the debris of a Shahed 136 has supposedly Polish and British origin (MILMO; KIRBY. 2022) Although difficult to pinpoint exactly the origin of the pieces of the Shahed 136, these low-spec parts are well distributed and available around the world, and it is not realistic to control the movement of all these components that can be smuggled through Iran's neighbours, specially China. (OZKARASAHIN, 2022.). Nowadays, it is politically and diplomatically unfeasible to track and regulate the distribution of such ubiquitous components across the globe.

3.3. Launch

The launch is using a rail combined with a rocket-assisted take off (RATO), whereupon the drone's combustion engine takes over. This method includes a quick and compact launch platform, without putting design constraints like the more advanced canister drone launch option. RATO is a well-known method of assisted take-off and is well documented in ammunition-related literature as far as drones are concerned, as it is present in civilian designs as well. While canister launch is more suitable for small drones, it implements more engineering constraints and is more complex in heavy drones, albeit it has its use and qualities, like the IAI Harop (IAI, 2020).

The railway method launch can be placed in the cargo bed of a common pickup truck in order to make it a highly-mobile and hard-to-track long-range artillery. A military vehicle can store multiple drones. The Shahed can be deployed in batches, firing multiple drones simultaneously. This can help overwhelm enemies' defences and increase the intensity of the attack.

This launch option puts serious difficulties in tracking the drone's origin and limits the counter-attacks capabilities. The Shahed 136 is stealthy and efficient, unlike other ordinary long-range missile launches which are easily detectable and often rely on bigger and more sophisticated launch platforms.

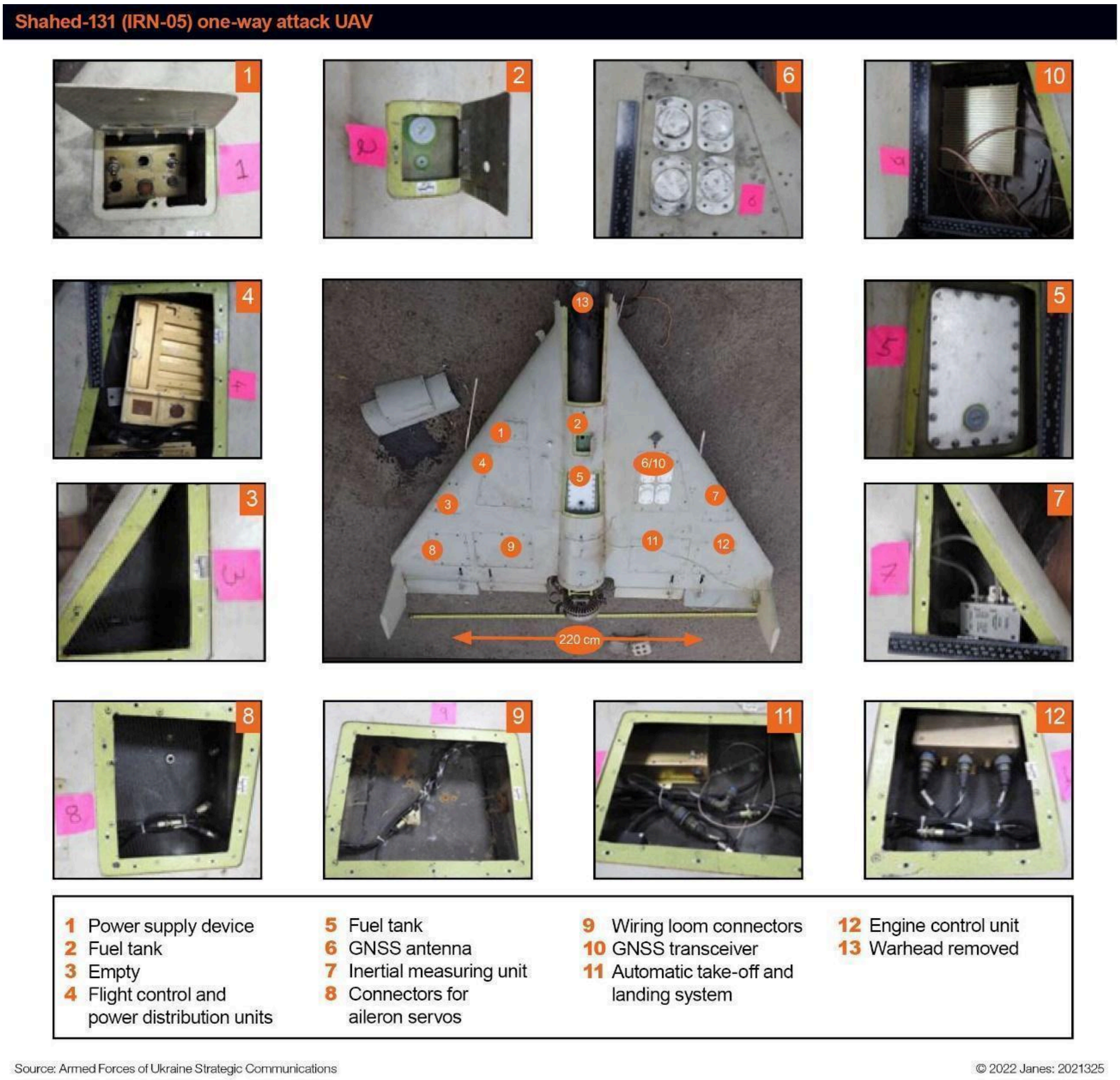


An Iranian HESA Shahed 131 being launched with RATO, from a rail storing multiple drones.
Open-source photo

3.4. Avionics, control systems and guidance:

The HESA Shahed 136 relies on the use of a global positional system (GPS) or a global navigation system (GNSS) similar to the smaller Shahed 131. It is believed the Shahed 136 does not have the capability of targeting radar emissions, as in the IAI Harpy. It flies too low and slow, has no cameras and has no records of targeting radar stations or moving targets with precision (LATYNINA, 2022).

Even though the electronic components of the Shahed 136 are still not fully available, a thorough study on the Shahed 131 was released by the Armed Forces of Ukraine's Strategic Communications Service (JANES, 2022). The smaller version of the Shahed 136, the study on the HESA Shahed 131 has given plenty of information on the drone's design, specifically its electronic components, which is the most valuable and puzzling part of the aircraft. As predicted, all components of the guidance system are from civilian grade, despite afeature added to the GPS that prevents GPS signals from being changed by electronic warfare (JANES, 2022).


Shahed-131 (IRN-05) one-way attack UAV
220 cm
1 Power supply device
2 Fuel tank
3 Empty
4 Flight control and power distribution units
5 Fuel tank
6 GNSS antenna
7 Inertial measuring unit
8 Connectors for aileron servos
9 Wiring loom connectors
10 GNSS transceiver
11 Automatic take-off and landing system
12 Engine control unit
13 Warhead removed
Source: Armed Forces of Ukraine Strategic Communications
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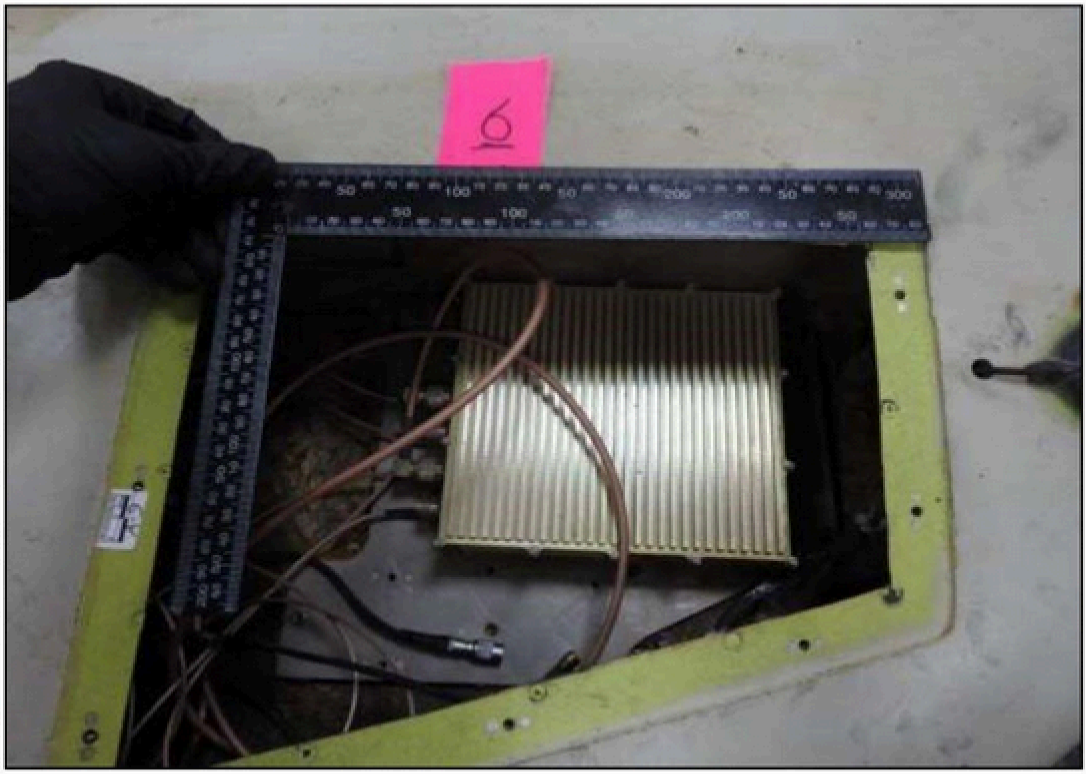

GNSS antenna construction of the Shahed 131 – JANES (2022)

The electronics used in the Shahed 136, including microchips, communications blocks and GPS antennas all come from different international companies, including the USA, China, Switzerland and Taiwan. In fact, despite all sanctions imposed by

America on Iran, the vast majority of electronics found in the Shahed 136 and the Shahed 131 have American origin. (BERTRAND, 2023). In fact, a recent investigation has stated by Conflict Armament Research (2022) stated that:

> *More than 70 manufacturers based in 13 different countries and territories produced these components, with 82 percent of them manufactured by companies based in the United States.*

In the Shahed 136, for instance, it is believed the GPS module was made by Hemisphere GNSS based in Arizona and chips by the company Texas Instruments (USIP, 2023) (BERTRAND, 2023). American electronics companies, most of which have ties with the Pentagon, are finding their chips powering up weapons on both sides of the conflict. A Task Force was launched by the Biden administration to investigate how these crucial chips were being leaked to the Iranians, undeterred by extensive export control. (BERTRANS, 2022).

The history of our current chip-powered world was explored by Chris Miller (2022). His book explored not just the spate of technological progress in the fabrication of chips was increasing at a staggering rate by Moore's Law, but also the production and availability of microchips across the globe. Although it is still unclear how Iran manages to obtain these low-grade Western parts, it is currently unfeasible to control Iran's capabilities to import chips, and China might be playing an even bigger role in supplying Iran with copies of Western commodities. (ALBRIGHT; BURKHARD; FARAGASSO, 2022).

While World War Two was defined by raw industrial power, pumping out steel, tanks and planes non-stop, a twenty-first century conflict is going to be defined by computational power and precision. Deadly accuracy and long-range made possible by microchips invert the axis from quantity back to quality, as intelligent and guided munitions are proven to be more effective than cheap and massed armaments (MILLER, 2022). Without Iran's capacity to bypass sanctions and to acquire microchips, Iran's military industry wouldn't be able to compete against their geopolitical rivals.

Economic sanctions are crucial geopolitical tools used to influence other countries without armed conflict, however, as Iran has shown rather economic resilience, it has sparked increasing debate and reflections about the effectiveness and results of sanctions in this epoch of globalization. Iran is an important case study, both in the short-run and long-run effect, as creation for new sanctions itself, as sanctions imposed on Russia were modeled on Iran's (NEPHEW; FISHMAN. 2022). Also, as coercive sanctions fail to reach their objective, Iran's resilient economy could be a role model for other sanctioned countries, as Russia has increased its political, economic and diplomatic bilateral ties with Iran. (FARZANEGAN. 2022).

As sanctions fail to be particularly ‘on target’ against the elite policymakers of Iran and fail to demoralize Iran’s military production and advancement, as shown with the HESA Shahed 136, it has nonetheless shown a devastating effect against the overall population, especially regarding medical patients. As shown in Gorji (2014), even though the objective of the sanctions are rarely met, these sanctions have created massive humanitarian crises such as declining hospital capacity and the unavailability of medical supplies in the target countries. Consequently, the pervasive use of sanctions in this era of globalization, their effectiveness and consequences are an expanding and important socio-economic discourse.

The low-grade quality found on the smuggled American chips used in the Shahed have contributed to the initial theory of using the drone for targeting only static targets, and not targeting precise nor time-sensitive objectives, as opposed to the initial kamikaze drone concept. This is because of the limits imposed by the grade of the technology used, and the lack of cameras and sensors on the drones.

In a recent development, it has been shown that the Russian forces and engineers have increased the initial Shahed 136’s accuracy by replacing the initial guidance system with a Russian GLONASS unit, which is more precise than the initial one used by the Iranians (DANGWAL, 2022b). This shows a potential increased efficiency in this technology, since more expensive and advanced systems are used to guide suicide drones.

Even though these drones currently don’t benefit from the use of cameras, future designs can be expanded to use low-resolution cameras and sensors, Wang and Han (2021) have shown that even low-grade and cheap technology can still be used effectively in target acquisition using image matching. This could be applied to a newer version of the HESA Shahed.

3.5. Use and cost:

The design choices discussed previously state clearly the engineering philosophy of the HESA Shahed 136: to push the most cost-effective design.

Its estimated price ranges from 10000 to 30000 dollars (RUBIN, 2023). Most weapons that have the same long-range capabilities, for instance cruise and tactical missiles, have prices ranging from 1.5 million to 3 million dollars, carrying on average a 500 kg warhead. The IAI Harop prices aren’t open source but are estimated to be more than 700000 dollars per unit (AHRONHEIM, 2019). The smaller IAI Harpy is valued at 500,000 dollars (FIGHT GLOBAL, 2000). Both carry a small warhead design to target small and time-sensitive targets,with a 4 kg warhead (FIGHT GLOBAL, 2000).

This abysmal price gap is obviously one of the main strong points of the HESA project, if not the main strong point. Affordable and low-cost long-range munitions were unfeasible before the development of the Shahed 136. The sheer price gap between the Shahed and the other similar equipment is what caused this revolution in kamikaze drone technology. The sanction imposed on Iran fuelled one of the most developed and autonomous industries (BARRIE, 2021). The price for such a long-range and precise weapon is unparalleled.

The Shahed 136 carries an estimated 40 kg warhead, which is heavier than most loitering munitions. This is because of its lack of precision and the targeting of bigger and static targets that require more explosive power.

The Shahed 136 flies at low altitudes. This increases its endurance, as stated in equation 1, and makes it harder to track using RADAR.

Because of the low velocity and lack of precision compared to other loitering munitions, the Shahed 136 is not expected to attack highly mobile targets, and it is best suited to attack critical infrastructure and other static objectives. Due to its raw cost-effectiveness, the HESA Shahed 136 puts significant stress on enemy defences, as most times the cost of intercepting the drone is more expensive than the drone itself. Most MANPADs and anti-aircraft missiles are more expensive and sophisticated than the Shahed 136. MANPADs prices are estimated at 20000 to 100000 thousand dollars, while air-to-air and surface-to-air missiles are all above 100000 thousand dollars (MISSILE DEFENCE ADVOCACY, 2022). In addition to the price of the missiles themselfs, it is also necessary to consider the price of operating the platforms of the missiles, which must utilise proper RADAR stations and qualified military personnel.

Complementing this fact, the drone can bypass the existent frontline defence and target infrastructure well into enemy territory. Its low profile and long range can be a problem to enemy airspace, as there is no available economic means to target this type of suicide drone in long range.

As the Shahed 136 design choices presented in this article favours targeting static objectives and infrastructure, with little to no protection. The HESA Shahed lack of speed and precision makes its use on the battlefield tricky, as usually tactical level operations require advanced precision and time-sensitiveness, an example is the Israeli IAI platform's drones. The weapon’s potential effectiveness in targeting civilian or non protected objectives should be taken into consideration, as Ukraine has called the Shahed a terrorist drone (STERN; DIXON, 2022). International authorities need to keep increasing attention to the development and use of this new type of weapon, as targeting civilian and non-combatant areas could be considered a war crime.

It has been reported that small-range anti-aircraft guns, once considered obsolete in today’s warfare, have taken down the Shahed 136 with moderate success (RUBIN, 2023). These weapons take the shift from conventional, more sophisticated anti-aircraft missiles. Due to its small size, low-temperature profile and discrete radar signature, it has proven to be a challenge to track the Shahed with high-tech equipment.

All these breakthroughs made by the Shahed 136 have shifted the focus from technological and sophisticated weapons to a competition for more cost-efficient weapons. This approach might prove a challenge to most Western military industries, as cheap weapons can be used to engage in economic warfare against the overall most well-equipped and expensive Western armies.

Because of the incapability of the drone to loiter and autonomously wait for its target, and because the drone only targets static and long-range objectives, the Shahed 136 is more similar to a cruise missile and may not be called a loitering munition anymore, thus another definition might be suitable. Although it can still receive GPS coordinates mid-flight and change its target.

The HESA Shahed 136 is not an autonomous weapon system, as it cannot independently search and engage targets on its own, the Shahed 136 might introduce another ethical and legal question as extremely precise and lethal weapons become cheaper to produce. The ability to strike from long-range and with precision has been until now exclusive to highly sophisticated and expensive equipment. The sheer affordability and ease of production might be a new problem for the modern world, as novel weapons have not only become more precise and lethal, but more afordable as well.

4. Conclusion and future advancements

The HESA Shahed might implement features to increase its lethality such as the use of an engine with a lower sound emission, the use of a more potent engine, the use of more sophisticated GPS modules to increase its precision and resistance to electronic countermeasures, the use of more stealth materials and stealth painting. All these should be expected and carefully monitored.

The use of American chips in the Shahed 136 highlights the importance and centrality of chips in the modern world. The American government ought to strengthen and expand its sanctions in the electronics sectors, and will promptly escalate the controllability of its chips exports, as seen by recent developments. This is a step in the surge of the new economic and geopolitical conflict for one of the world's most important resources.

In addition, future armies should acquire low-cost anti-air defences, which were replaced by more modern and sophisticated technology nowadays. These low-cost defences can be an additional protection that do not rely on expensive guided missiles. An overall change in scope from technological and sophisticated to more cost-efficient anti-aircraft armaments can also be expected as the use of cheap drones expands.

While the advancement of technology has caused the modern battlefield to be highly deadly and precise, it has also increased the economic and technological demands. Only a few countries were able to keep the pace of this economic and technological race, but the HESA Shahed 136 identifies a new problem, of not only causing the modern battlefield to be deadly and precise, but also cheap, affordable and accessible.

The HESA Shahed 136 revolutionises the concept of long-range precise strikes, a role that until now was reserved for expensive and technologic demanding tactical missiles and aircraft, which can now be achieved using cheap drones. Attacking an enemy from a far way distance, with precision and lethality, has been mostly exclusive to advanced technology, reserved for the most superpowers in the world until now.

This development has introduced a new variable to the twenty-first century arms struggle, of not only producing the most technological and precise, but also cheaper weaponry. Defence companies of superpowers must now take into account cheaper design choices, as more efficient and cheap armament are developed, while other countries might take suicide drones into consideration when building an modern arsenal. Another serious concern is the proliferation of precise long-range weapons in guerrilla and asymmetrical conflicts, with deadly results. International oversight and regulation of kamikaze drones is of utmost importance.

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