

Prof. Ted Postol: Israel's Air Defense Crisis: The Tipping Point

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#Nima

Ted, when it comes to the numbers on the battlefield—the equipment, the drones, the way this war is unfolding—what can you tell us about the situation?

#Ted

Well, I think the situation for Israel relative to Iran is going to continue to get worse. And there are a bunch of reasons for this. I can talk a little bit about the technology issues, and I'd like to do that. It's relevant in the sense of providing a foundation of understanding for the audience. It's not immediately relevant to the situation at the moment, but it sheds light on it, so it's important to contemplate. So, if we go to the slides—why don't we take slide two, for example. There's been an... and this is a very interesting thing—an extraordinary mismanagement by Israel of its air defenses.

Let's go to the next slide. I'll show you that. Here's a—this slide is... You may want to click on the PDF screen and see if you can get it—it's not showing clearly. Whatever you've got. Okay, this is a time-lapse photo of Iron Dome interceptors being shot into the air. You can see tens of interceptors. Now, what you're seeing is from a photographic camera, and the shutter is open for maybe 10 or 15 seconds. As the rocket motor drives the interceptor along its trajectory, it produces a point of light. If you were taking instant photographs, you'd just see a point of light—but because the point of light is moving, it traces out a line.

So the lines you see are the trails of the interceptors as they rise, because that bright point of light, as it moves, produces a line that shows the motion of the interceptor. Now, you see these interceptors all climbing up—and then they're turning downward. They should never turn downward. The only way to have a chance of intercepting a ballistic missile target is to be flying up the expected trajectory. At the end of almost all of these lines, you see little points of light. Those points of light are the warheads on the Iron Dome interceptors—relatively small warheads—detonating.

But there's no target there for them to detonate on. So it's the interceptors flying up and just exploding in the air—probably because the system wants to destroy the interceptors so you don't get

a full interceptor falling to the ground. The ground damage is lower, though still significant. Now, this should never have happened, because those interceptors have no capability against ballistic missiles, but they are very capable against drones and cruise missiles. So this shows that the air defense operations were throwing away interceptors against targets they had no possibility of hitting—zero chance of hitting.

And instead, you could have saved these interceptors for the drone attacks that are now occurring. This is the kind of mismanagement of the air defenses that I find astonishing. The reason I say that is because a lot of the people I've known over the decades in Israel are incredibly capable—people who worked on air defenses. I know how smart they are, so I can't understand it. I had a discussion with one friend of mine, and he couldn't explain it to me. He said, "I'm not part of the operations these days," but he also said, "I agree with you. I have no idea. I have no understanding."

So they've thrown away these interceptors, and that's a real problem the Israelis are facing now. The next slide shows another problem they should have anticipated but didn't. This shows several frames from a video of one of these Al Fatah ballistic missiles coming into the atmosphere at a fantastic speed. The speed of this warhead is probably Mach 10 or 11, or even higher. Now, the reason the speed is so high—if you look carefully, at the upper-left inset—you see something to the right of the main image. That's a reflection off the lens of the camera; it's not real.

That's just an artifact of the camera—reflection from the bright part of the contrail to the left. But you can see the front end of the contrail is much brighter than the rest of it. That's because it's a rocket motor, thrusting the warhead forward against aerodynamic drag. Normally, the warhead would slow down, maybe to one and a half or two kilometers per second if you do the drag calculation. But the rocket motor keeps the speed high, so when it hits the ground, it hits at Mach 10 or higher. Now, if you look at the last slide, lower right, you can see the bright flash from the detonation, and the sky is blue.

And the reason the sky is blue is because the energy at the detonation point is so high that the temperature is higher than you'd normally see from an explosion. If you look at most explosions on the ground, when you don't have this highly energetic warhead coming in, the color tends to be red or yellow, which indicates a lower temperature at the peak of the explosive energy output. This one is higher because you have the kinetic energy of the impact, which contributes as much energy as the equivalent weight of high explosive. So if there were no explosive in this warhead at all, it would still have the explosive energy of its weight in TNT—but it also has TNT in it, high explosive.

So you have twice the explosive density of what you'd get from just TNT or just the kinetic impact. This causes a much more violent explosion, which does much more damage at the endpoint—the target point. And when you look at some of the damaged areas—unfortunately, I didn't have time to include them here—you can see the effects of these much more energetic explosives. They're doing

tremendous damage to very highly reinforced buildings. But these two effects, which have been going on for a large part of the war—during the forty days of this war—have resulted in the depletion of interceptors.

If we look at the next slide, this is taken from a Royal United Services Institute report published at the end of March—so basically a week and a half ago. This is their estimate, based on their best guess of how quickly interceptors are being used up. You can see in the last column they're projecting that all of the Iron Dome interceptors would be used up by the end of April, or maybe May. That's not correct, I'm sure. I think we're already nearly at the end of the Iron Dome interceptors being available, and we're also nearly out of the air-to-air missiles that can be fired from aircraft against drones.

So these are the missiles that could be used against drones. The capability of intercepting ballistic missiles is near zero, no matter what you have left. In other words, the Arrow 2, Arrow 3, David's Sling, and THAAD systems have a very low intercept rate against ballistic missiles. They've always had a low intercept rate. So what you have, roughly speaking—we don't know for sure—is a depletion of air defenses against drones, and an ongoing inability to shoot down ballistic missiles. But the ballistic missiles are even more difficult to hit and even more damaging when they reach the ground, and they reach the ground with higher efficiency.

The percentage of launched missiles reaching the ground is much higher, not only because the intercept rates are low, but also because the missiles are more reliable. Their technical features make them more reliable during reentry. So the warheads essentially always detonate, which wasn't always the case before, because the Iranians were firing older missiles where the warheads sometimes tumbled, broke up, and sometimes didn't detonate. So the situation we're now facing is summarized in the next slide—and by "we," I mean the Israelis and the Americans. First of all, they've mismanaged their Iron Dome defense system, and that's serious because the Iron Dome is very effective at shooting down drones.

But they've expended most of them, and they'll be out of Iron Dome interceptors against drones. And the drones are very, very problematic, as I've explained. The availability of timely, high-resolution satellite reconnaissance data is now coming from China and Russia to Iran. So the Iranians have information on the locations of air defense units—which you try to move around—air defense radars, and this allows them to target those radars with their drones. We saw a tremendously effective attack on the ballistic missile defense radars in the first two days of the war. That was carried out using strategic reconnaissance from the Chinese and the Russians, provided to the Iranians.

The Iranians, very cleverly—and I want to underscore this—have executed their military planning superbly well. There have been no mistakes that I can find, unlike the Israelis, who I didn't expect to make the kinds of mistakes they've made with their air defenses. I think what happened with their air defenses is that they've been lying about the capability of Iron Dome against ballistic missiles.

They became victims of their own propaganda and wasted all these interceptors on targets they had no chance of hitting. And now they don't have interceptors left to shoot at targets they actually have a good chance of hitting.

That was a strategic blunder of a non-minor level. The Iranians have made no such blunders. They had these extremely accurate drones and were able to use them to destroy the fantastically expensive and limited number of ballistic missile defense radars that the Americans and Israelis had. In particular, there were four THAAD radars. I have a picture of one of them later on in the discussion, if we get to it. And there was a giant radar in Qatar that was critical for the overall defense of Israel against ballistic missiles. This giant radar was crucial because it could see almost everything launched from Iran as soon as it was launched, and then tell the smaller, less capable THAAD radars where to look for the incoming ballistic missiles.

So these radars could then manage the defensive interceptors—the THAAD, Arrow 1, Arrow 2, and David's Sling interceptors—because the radars operated by those systems were less capable in terms of range and their ability to acquire large numbers of incoming warheads. So Iran took that capability away from Israel and the United States literally in the first day of the war—first day, or maybe two. That was an amazing accomplishment. I did not expect it. I knew the drones were going to be a problem for the Americans and the Israelis, but I did not expect that level of precision in finding targets of great effect.

In other words, the satellites gave the Iranians key data about the exact locations of these radars—almost all of which could have been moved, except for the big radar in Qatar. That allowed the Iranians to target those radars with drones, and they did it very quickly. What I don't know, but I'm pretty sure is the case, is how many smaller air defense radars have also been destroyed, because the Iranians likely got information about those too. It's not as certain, though, since the smaller radars are harder to locate—but they can still be found with some efficiency by Chinese and Russian reconnaissance satellites.

And those radars are certainly also being destroyed. You know that has to be the case because the air defenses at the American bases in the Persian Gulf have hardly been operating. You see videos of these drones coming in and no interceptors being fired at them. Some of it may simply be because the Americans have run out of interceptors—which, of course, is an incredible oversight on their part. And the other part could easily be that the radars guiding those interceptors no longer exist; they've been destroyed or damaged. So the increasing losses of all these air defense radars are significant and will continue as the war goes on.

As the war goes on, Iranian drones will have an easier and easier time damaging and going after critical targets that the Americans and Israelis have. The drones don't have as large a warhead as you get with ballistic missiles—you might have a one-ton warhead on a ballistic missile, whereas a drone might carry only a tenth of a ton. But you don't need ten 100-kilogram warheads if you have precision. If you want to bring down a building, a 100-kilogram warhead is more than enough if you

can place it within meters of accuracy. So the fact that the drones have smaller warheads doesn't mean tremendous damage can't be inflicted.

Plus, of course, the number of drones you can bring to bear against targets of interest is enormous—thousands, tens of thousands of these drones. And we know that the Iranians can keep producing them, and they'll be unstoppable. So if we look at slide seven, I can begin to show how, even if they manage to preserve the radars, it's going to be nearly impossible to stop the drones. That's another factor. I'm not only saying the drones will be more capable of doing damage because they have high accuracy, but also that Iran has data from China and Russia that allows them to locate the targets. So they can find the targets, and they can hit them. But even when some radars are preserved, those radars won't be able to detect the drones, because the drones are increasingly able to fly very low.

And when they fly very low, they're in what's called ground clutter. So, for example, when you talk about AWACS—airborne warning and control system aircraft—those radars are going to have only very limited capability against drones. They've already destroyed at least one AWACS on the ground, and there will probably be others destroyed as time goes on. But there will still be some airborne warning and control system radars operating. Of course, they can't operate 24 hours a day, seven days a week. I think there may be five or six of these, so you can have them on a 12-hour mission. You'd need maybe three aircraft to keep two on station 24 hours a day, because it takes time to refuel and repair the aircraft.

So they do have airborne warning and control systems. But if we look at the next slide, we can see why those systems have very limited capability. First of all, the Earth is round, and there are two phenomena that are extremely important. If we look to the left, we see an icon of a radar dish. The radar is looking straight out, and there's a shadow—the Earth is curved, so there's a shadow region below which the radar cannot see. That shadow region can be many tens of kilometers, even up to a hundred kilometers, if the airplane is in the air, like an airborne warning and control system.

But notice there's an area called the clutter zone. That clutter zone actually extends out quite a distance and basically makes it impossible to see the drones. I'm going to explain very briefly what clutter is, because clutter is very important. The clutter hides the drone and makes it, even when the radar has a line of sight to it, impossible to see. So, if we go to slide nine—the next slide—if we have an airplane flying at high altitude, we can potentially see the targets and have a line of sight to them, even 50 or 100 kilometers away. But that's misleading, because if we go to the next slide, we see what the clutter problem really is. Did I do that?

#Nima

Okay.

#Ted

The next slide shows the actual radar reflectivity of a drone. If we look at the upper left corner, we can see the radar cross section of an insect—that's about one-thousandth of a square meter. The next one, just below and to the left—go back, there you go—shows the radar cross section of a drone. To the right, we see that the radar cross section of a drone is about one-hundredth of a square meter. That's really very small. To get a sense of how small it is, if we look below the drone radar cross section, the radar cross section of a bird is comparable. So how do you tell the difference between a bird and a drone? You know, this is a problem.

Now, it turns out there is technology for doing this, but the technology is limited in its precision. So the bottom line is, you cannot tell the difference—you cannot see the drone in the clutter. I'm going to explain what clutter is, just so your audience has a rough sense of it. The reason this is important is that, basically, even with radar aircraft, those radar aircraft are not going to contribute to an air defense warning system against these drones. Of course, you're also going to run out of interceptors as well. So even if you have some interceptors, the radar-borne system won't be able to guide them, because you still need radar for the air defense—and those radars are being launched or destroyed.

So if we go to the next slide, we see an illustration of what clutter is. Imagine you're in an airplane, looking down at the surface of the Earth, and you illuminate a patch of that surface. Now, imagine that surface acts like a perfect mirror. In that case, you'd see no backscattered or reflected signal. So if there were a radar reflection from a drone, you'd get that signal—it would be very small because the radar cross section is very small—but you wouldn't get a competing signal from the illuminated ground. But instead, think of a flashlight. Imagine you have a flashlight, you're in an open area, and you shine it down on a mirror at an angle.

You would see no reflection from the mirror. So if you saw an insect flying above the mirror, you might actually see the insect above this black surface, because you don't see your own reflection. But imagine that the surface is made up of trees, or mountains, or rolling hills, or grass. Then you're seeing a big reflected signal, because you're illuminating a very large area compared to the area you're illuminating when you're looking at the drone. So the drone is going to get hidden in the clutter. And clutter comes from all kinds of sources. The big problem is not simply seeing the small radar cross-section target—which is a gigantic problem by itself—but also seeing it against the interfering reflected signals from other sources.

So if we go to the next slide, we see that there are all kinds of contributions to clutter. You have weather clutter, you have rain, you have ground reflections. If you look at this particular drawing, to the right and below, you see an aircraft in a shadowing region. The shadowing region can be caused not only by the curvature of the Earth, but also by objects between the radar—mountains, trees, or whatever—and the target you're trying to see. All of that limits your ability to see targets. So if I go to the next two slides, you'll see that this one is just depicting birds, trees, and other things giving me false or interfering signals.

If I go to the next slide, you can see a radar target area. Near the radar, there's all kinds of clutter from buildings, trees, or whatever. Further out, if you look at the upper right corner, you can have rain clouds or echoes from buildings—because you might have a cluster of buildings in some areas that sets up an echo. You can see one of these is called an “urban spike.” When the Iranians attacked the Abqaiq oil field in Saudi Arabia, the drones came in—well, in this case, they weren't drones, they were cruise missiles—and they came in over buildings. So you have these buildings, and then you have this drone, and it reflects only a very small amount of radio signal.

And the building is reflecting a tremendous radio signal. So I'm trying to see this drone—it's a small signal from the drone against the radar reflection from the building. Let me give you one very simplified idea of how the radar tries to see the drone. There are these very exotic radio technologies that are used. If we go to slide 16, we see a depiction of how the radar tries to see it. The signal from the ground is tremendously large, so the radar, shown in blue, sends a signal out trying to detect a low-flying drone. The only thing that makes the drone's reflection different from the reflection from the ground is that the drone is moving toward the radar.

So the reflected signal, shown in green, is at a slightly higher frequency than the signal from the ground. The ground return is a tremendous signal. The processed signal, shown in red here, is the one where I intentionally mix the signal I'm receiving with the low-flying signal from the target. What I get is a beat frequency, which is depicted here. If I go to the next slide, I know the frequency of that signal. For a drone, the shift is going to be about 300 hertz, while the radar's frequency is in the gigahertz range—a billion hertz. So I have to maintain very high frequency stability.

If the frequency of the radar is moving by a few hundred hertz, then I won't be able to see the 300-hertz beat frequency. I'll be seeing a beat frequency, but it'll just come from the oscillation of my own signal. So you can see how precisely the radar's primary signal has to be controlled. What I've shown in the next slide are the beat frequencies for one- and two-hertz changes in frequency. If I have a one-hertz change, I get a beat frequency of one hertz—it would be 100 hertz in this case. And if it's two hertz, you can see I get twice the beat frequency.

And in the next slide, I show that the beat frequencies are the same, even if I assume twice the frequency. The beat frequencies stay the same. So no matter what the radar frequency is, I get the same beat frequency. The problem is, if I use a higher-frequency radar—like an X-band radar, which is the type I'd want for high-precision tracking—then the radar frequency is ten times higher. That means I have to control the base frequency ten times more precisely. So the net result is, when I look at the problem of controlling the radar's frequency and also the frequency changes, it becomes very challenging because it's an airborne radar.

So there's a change in the frequency of the ground clutter from the airborne movement. I have methods for controlling that as well. It turns out I just cannot see these low-flying, very low radar

cross-section targets. So now I have the problem of drones that can home in. If we look at slide 21—yes, slide 21—this is actually an American drone that uses the Iranian design, because the Iranian design is perfect. So Iran can take credit for designing the perfect drone that everybody uses. This is a Shahed; I had it incorrectly marked. The Gen-2 version is a Russian drone, which, as an airframe, looks exactly like the original Iranian design. The Shahed drone is the original Iranian drone.

And this is an American design that uses the same Iranian airframe. So Iran is the inventor of the kamikaze drone that's wreaking havoc on the United States and Israel now, and it's leading to Iran becoming the dominant military power in this current war. Iran's dominant military influence is now due to several factors. First of all, Iran controls the Strait of Hormuz, giving it a stranglehold on the world economy, including the American economy and those of other nations. Iran has been able to preferentially supply oil to countries it considers non-hostile—not necessarily supportive, but simply non-hostile.

So Iran has very cleverly thought through the idea: "Well, we're not going to just stop it for everybody. If you're not hostile to us, we're going to leave it open." And by the way, even the United States realizes that Iranian oil is critical for keeping the world economy from collapsing. So now Iran is selling oil, not at the reduced rate of \$45 per barrel—because Iranian oil was sanctioned by the United States—but at \$120 a barrel. So Iran is raking in money. I mean, it's almost... it's almost a comedy that the Americans have now removed the sanctions on Iranian oil. All of a sudden, the Iranians are getting full price for their oil because of their control of the Strait of Hormuz.

And of course, they're able to provide oil to non-hostile states. That's a tremendously favorable situation for Iran in this war. The next issue they have is these ballistic missiles, which are doing far more damage per impact than they were doing earlier. And the next point is that Iran has precision information on the targets. Some of this precision information could have come from other sources. Let's go back to slide 22. This is from the original attack in September 2019 that Iran carried out against the Abqaiq oil fields in Saudi Arabia. At the bottom of this drawing, I've shown a satellite photograph of one of these oil processing tanks.

And notice that what's shown in the satellite photograph are the holes in the oil processing tank that were produced by Iranian cruise missiles hitting those tanks. The precision of those holes is within meters. It's incredible how accurately the Iranian cruise missiles were able to hit these processing tanks. Well, I don't know exactly what specific technology the Iranians used, but I can give you a speculation. If you look at the next slide, what the Iranians could have done is taken a satellite photograph of those tanks. In other words, they didn't have to get help from China or Russia. All they needed was a commercial photograph of those tanks. In the upper left corner here, what they did is a cross—so the cruise missiles have an image of what they're looking for. Here's the image—it's my hand. And now what I have is the image, and what I do is I cross the image with the image of my hand. I do it electronically. So when I line them up, all the light gets passed through; none of the light gets passed through when I'm not lined up properly. So you see these three peaks. This is a simulation I actually did—my simulation. It's a guess. And what I've done, if you look to the right, I

show you the peaks of the cross-correlation. And then in the bottom image, I show you the peaks of the cross-correlation overlaid on the targets. So this could have been done with satellite imagery and cross-correlation, which we know the Iranians are well up to the job. So here's an example where it's not a drone necessarily being homed by what's called first-person guidance.

In other words, this isn't necessarily a drone operator sitting far away, receiving a television signal from the drone and guiding it into the target. This could simply be a drone that's a robot. It already knows where to go before it "opens its eyes," takes a photograph of what's in front of it, and cross-correlates that photograph with the target. So you can see how problematic these drones can become, because now I have the ability to do real-time homing. In other words—well, maybe I'll talk about that next, because we're now coming to... But the simplest, conceptually simplest idea is that I have a drone, and I'm looking through a television camera, which means the drone has to be sending a television image back to me.

I might be thousands of kilometers away, and then I have to give the drone signals. I don't need to do that in this particular case. So now—so Iran... The indications are, at least to me, that Iran has drones that can do cross-correlation with images of the targets, as well as drones that can home directly on signals from television cameras inside the drones. That's a big innovation. Maybe I should stop here, and I can talk about how they do it some other time—how Iran is doing this. But the availability of the Starlink system is now making it possible for Iran to use drones to do real-time homing on targets. So what happens? They get an image of the real-time situation. Actually, let's go to slide 33 for a quick second—go to slide 33. If you look at slide 33, here's before and after. I have an image of where these radar domes are, so I can destroy them in two ways. I can have an image of the radar dome and cross-correlate it with the drone as it comes in, as I described earlier, or I can simply home on the radar dome using a video camera. And the video camera can get its information from a Starlink signal. Let me just show you—let's go to slide 38, and I'll stop after this. This particular square on the right, this is a Starlink radio terminal. Let's just go one more slide forward—one more slide.

And here you see this little dog—a cute little dog—next to the Starlink communication system. That Starlink system weighs only a pound or two. Let's go one more slide. There it is, in a box you can order. Notice the box has instructions for how to use it. You can go out—Nima can go out—and he can order one from Amazon for about \$250, and you'll get it in the mail in a few days. Then you can modify it and put it on your drone, if you know how to use the signal. After that, you can send your drone out looking for a target, using the drone communications through your Starlink satellite connection.

Now, let's say I'm the United States. I say, I don't want Nima out there using that drone. Well, how am I supposed to know Nima is out there using the drone? I've just sold them a terminal. The terminal has encrypted communications, because that's how you keep the signals secure for people

who just want to communicate normally. So how do I know it's Nima with his drone flying around looking for something to hit? I have no way of selectively turning off the drone signal to Nima. All I can do is turn off all the Starlink satellites that are functioning over, let's say, the airbase.

But if I do that, then I turn off all the Starlink communications that the airbase is using. So I have a dilemma. The problem is very serious. Now we see how modern technologies—navigation technology, GPS, the Chinese Baidu system—are widely available. These are very high-technology systems, but they're universally accessible. You don't need to understand the system or be able to build it yourself; you just need access to its service. So you have the service, you have high-precision, real-time satellite imagery from the Russian and Chinese satellites, and you're in business. And you have Russia, which has been attacked using American weapons—the Americans have attacked Russia via Ukraine by giving Ukraine missiles to attack Russia.

And Russia told the United States—when the U.S. did this—that if you do this, then at some future time we'll be giving information to someone else to attack you. All right. You did this in Kursk, you did this in Russia, and you gave the Ukrainians all this information. You gave them satellite surveillance data, you gave them communication information so the drones could attack our strategic bombers, for example. Okay, you want to play that game? That's fine, because we're going to attack your AWACS. We're going to make sure the Iranians know where those AWACS are parked.

We're going to make sure the Iranians know where the radars are, and we're going to give them that information. They'll have the navigation resources they can just buy commercially—and good luck, you know. Now Iran is benefiting from these services, and so, incidentally, are China and Russia, because those countries want Iran to prevail. And I think Iran will prevail in this. I think the war is going to get worse and worse for the Americans. My gravest concern is that as Israel gets into a more and more desperate situation, they might be foolish enough to use nuclear weapons. And the American political decision-makers had better make sure that Israel understands they are on their own if they ever use nuclear weapons against anyone.

#Nima

You know,

#Ted

They are absolutely on their own—forever. Completely. Because I'm concerned that this crazy guy, Netanyahu, who definitely has the same mentality Adolf Hitler had, might do something that brings down Israel along with everybody else. And Adolf Hitler would have brought down Germany—we have every reason to believe he would have—if he'd had the ability to do it with nuclear weapons, because he was suicidal. It only took an intervention like the one Albert Speer made. Speer was his architect, and when Hitler told him, as the man running the German economy, to destroy Germany, he refused.

And Speer failed to follow his order because he didn't want Germany completely destroyed. Otherwise, Germany would have been wiped out if that order had been carried out. So you have to hope that either Netanyahu isn't as crazy as he looks, or that the people he would order to do the job will refuse to do it. And I sincerely hope that the kind of Israelis I know are in the loop, and that they would refuse to do it, because they're smart enough to know it would be the end of Israel along with a lot of other things. But I don't know how much control this man—this lunatic—has taken. So anyway, I'll leave it there.