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A Look at the J-20 AESA Radar

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There is a contrasting or somewhat paradoxical component to available information about the People's Liberation Army Air Force J-20 Mighty Dragon's performance parameters, because while much can be observed and learned regarding the aircraft's external configuration and domestically built WS-15 engine, information about its mission systems, computing, sensing and radar seem comparatively far more difficult to locate. This may indeed be by design, because despite general claims regarding its purported capabilities, the PLA seems to publish little data about key elements of its internal technological composition. The J-20's Active Electronically Scanned Array (AESA) radar is a key element of this, given that some published detail suggests it may operate with unprecedented detection range. This possibility, if accurate, may raise more questions than answers, given that organic "detection range" is only one of many variables fundamental to AESA integration. Nevertheless, PLA writings seem to indicate that its engineers benefitted from a "latecomer" advantage of being able to integrate lessons learned from previously built AESA systems and purportedly surpass or improve upon them.

J-20 AESA Radar

Available recent information cited in Chinese state-affiliated industry writings seems to suggest that China's J-20 AESA radar may have been upgraded beyond the known capacity of the PRC's Type 1475 (KLJ-5) radar designed initially for upgraded versions of the J-11D. This Type 1475 (KLJ-5) contains 1,856 transmit/receive modules, a number that would place its power capacity beyond the 1,676 T/R reception module performance of the F-35s APG-81 AESA radar. The F-22 APG-77 AESA, by contrast, operates with as many as 1,900 T/R modules, giving it a one-third longer detection range than an F-35.[1]

Although T/R module volume and density alone might not fully determine the overall effectiveness of an AESA system, the presence of "more" modules does equate directly to the detection range and signal resolution of a nose-radome integrated AESA system. PLA writings, expert blogs and analytical essays published about the J-20 radar do, perhaps even disproportionately, place a premium on T/R module volume.[2]

According to a 2016 essay in Sina Military News, the J-20 radar achieves 50-percent more power than the F-22 and reaches a comparatively longer detection range. The essay further establishes a direct and clear connection between T/R modules and detection distance; "it can be seen that the number of T/R modules directly determines the size of the transmission power and the distance of the detection distance…..the TR module is equivalent to a relay station and signal amplifier."[3]

> The front end of a T/R component connects to a radar antenna and the back end connects to radar signal transmission and processing equipment, according to the research paper. "The TR component is in the middle to amplify the radar wave emitted by the

transmitter and send it through the antenna, and then receive the radar echo and transmit it to the signal processing computer. The TR component is equivalent to the optic nerve on the human retina. The more there are, the clearer the received signal and the longer the detection distance," the Sina essay adds.[4]

J-20 and F-35 Detection Range

The actual margin of difference between the J-20 and F-35 AESA radar detection range may be even larger than these preliminary indications suggest. While some research suggests that the Type 1475 AESA may have provided the technological foundation for the J-20, more recent, subsequent analysis now suggests that the J-20 may, in fact, operate with an ability to integrate as many as 2,200 T/R modules.[5] According to the Sina essay, "other analysts point out that, based on nose cross-section of J-20 and known data about a single transmit/receive module surface in the J-16's AESA radar-system, J-20s likely fit 2000–2200 transmit/receive modules."

Extending this analysis, research therefore reveals that the F-35 AESA operates at a significant range-detection "deficit" when compared with the J-20 AESA; the F-35 AESA can reportedly "see" targets at ranges out to 80 miles, whereas the PRC J-20 can "see" targets out to 120 miles.[6]

Although this research specifies detection ranges, it does not seem to specify the size and shape of a particular target detectable at this range; there are additional variables impacting this equation, such as the size and cross-section of any given target, according to an interesting 2025 Swiss academic essay called "Understanding Detection Range of Radar Sensors," in "RFBeamMicrowave." Detection range, therefore, depends heavily upon the cross section of the target. According to the article, "the Radar Cross Section (RCS) of an object defines how detectable it is by radar. It quantifies the amount of radar power scattered back to the receiver and is dependent on the target's size, shape, material and orientation relative to the radar."[7]

A smaller target with a less discernible radar cross section might not be detectable at the ranges cited in the Chinese research essay, yet it seems pertinent to take the assessment seriously with respect to larger targets.

Yet another factor relevant to detection range, image return fidelity, can be described in relation to the relative extent of "system losses." According to the Swiss article, "System losses include environmental factors like atmospheric absorption, rain, fog and other conditions, as well as component-related losses in the system itself. These factors collectively reduce the radar's effective range."[8]

While much of this Chinese-industry driven writing about the J-20 appears very technical and sourced with an apparent measure of expertise, it seems important to balance these findings with additional available research about RF detection and RCS variables, as described by the Swiss paper. Recognizing some of these factors, it seems one should naturally view such comparative claims about J-20 detection range with a measure of skepticism. It might not be fully accurate that a J-20 AESA can see targets 40 miles further than an F-35, yet some of the apparent logic about the aircraft having a larger "area" or "space" for T/R modules seems feasible.

AESA Combat Performance

Regardless of this factor, simple detection range is by no means the sole determining factor in "lock-on" targeting and air combat superiority. Actual AESA combat superiority is likely to be determined by a range of additional factors such as the power density of the modules themselves and the size, configuration and mission intent of the aircraft itself. The J-20, for example, is larger, heavier and about 20-feet longer than a US F-35, attributes which increase its RCS and make it potentially more vulnerable to detection.

At the same time, it would also be prudent to consider additional technical variables, such as stealth coating, the possible existence of external payloads or protruding vertical structures more likely to generate a return "rendering" or image to a radar system. For instance, a 2022 essay written in the Modern Strategic Deterrence Alliance further elaborates by stating that while the B-2 and B-21 may be much larger than an F-35, they are far more stealthy.[9] Size alone does not translate into stealth effectiveness in a strictly linear or one-dimensional fashion.

Nonetheless, configuration, size and form factors clearly impact the amount of T/R modules that can be built into an aircraft. The nose radome of the J-20, or pointed front area in which radar modules are encased by composite materials engineered to enable RF signals to "pass through," is larger than that of an F-22 and F-35, a circumstance which enables it to operate with a larger number of T/R modules.

The number of T/R modules in an AESA radar system appears to be a "findable" quantity when reviewing available public information about the J-20 radar, yet a more operative and impactful question may relate to less discernible variables related to T/R "packaging technology." According to an article in *Air Power Australia*, "packaging technology refers to how many individual T/R modules can be installed within the finite space usually accomplished by reductions in size of the individual T/R modules. The more technologically advanced a firm's T/R packaging technology is, the smaller the individual T/R modules will be resulting in an increase density of the layout of T/R modules within the array."[10]

While the nose radome of the J-20 may contain a larger volume creating space for additional T/R modules as described, other variables relate to the relative power density of the "layout of T/R modules within the array" and the size of the individual modules themselves according to much of the research. Upon analysis of the technical descriptions, it would appear that AESA performance in terms of signal fidelity likely pertains greatly to the "packaging" of the modules, something more difficult to determine with the J-20.

It would appear that this question of packaging relates to power density, signal resolution and available research about Gallium Arsenide Microwave Monolithic Integrated Circuit (GaAs MMIC). Carlo Kopp's research identifies two key elements of this fundamental to the distinguishing characteristics of successful AESA radar, one of which simply pertains to the established understanding that GaAs has around six times the electron mobility of Silicon, proving the "potential for significantly faster transistors." According to Kopp, **"**GaAs also proved to be better from a noise performance perspective, so the two key problems in an RF transistor, speed and noisiness, were ostensibly solved by the GaAs transistor."[11]

Kopp further identifies the breakthrough elements of GaAs as it pertains to AESA radar is the ability to integrate many GaAs transistors onto a single chip, thus the Microwave Monolithic Integrated Circuit (MMIC). "The only technology which could possibly allow the manufacture of the densely packed AESA TR modules was the GaAs MMIC," Kopp writes.

These kinds of packaging questions would seem to bear significantly upon the relative effectiveness or successful extent to which the PLA has been able to develop an AESA radar for the J-20 capable of integrating as many as 2,200 T/R modules. Should the packaging and GaAs MMIC be sufficiently effective on the J-20's Type 1475 (KLJ-5) AESA, then the Mighty Dragon may indeed operate with unprecedented range without necessarily compromising precise detection capability. "The more technologically advanced a firm's T/R packaging technology is, the smaller the individual T/R modules will be, resulting in an increased density of the layout of T/R modules within the array. Thus, advancements in packaging technology enable engineers to accommodate more T/R modules within the fixed volume of the aircraft's nose," Kopp writes.

AESA Satellite Networking

Yet another critical variable relevant to the J-20's AESA performance would pertain to its ability to "transmit" data across otherwise dispersed or disconnected nodes, such as satellites. A significant 2006 technical essay in *Avionics International* titled "Radar Transmitting Data" posits that densely packaged T/R modules built into AESA radar could introduce new "networking" and data transmission functionality.

According to a 2006 Avionics International article, "the active electronically scanned array (AESA) radars developed for today's combat aircraft contain hundreds of small transmit/receive (T/R) modules that, in addition to gathering targeting data from a radar beam, could be modified to perform other tasks, including transmitting that data, employing a wide-bandwidth data link. In a directional environment— i.e., steering the RF signal—radar imagery and other data could be transferred throughout the battle space, to other aircraft, a ground station, even to a satellite. Likewise, with a bidirectional link, this versatile radar array also could be used to receive data critical to the combat mission. Any information put into an RF signal could be transmitted or received, including electronic intelligence data, maps, streaming video, positional or vector data, updated mission plans and raw (unprocessed) data."[12]

Therefore, should the J-20 AESA operate with this kind of technical versatility, its targeting fidelity, detection aperture and data transmission aperture could be substantially expanded, yet at the same time, connecting AESA radar with satellites is not without challenges and complications as well. Some of these challenges are raised in an interesting 2024 essay in Orbitshub called "A Closer Look at Satellite-Based Military Aircraft Tracking Systems," a paper which suggests fighter-jet AESA-satellite data transmission can improve accuracy, generate improved real-time tracking and enable weather independence.[13]

At the same time, there are likely areas of potential signal transmission difficulty between fighter-jet integrated AESA radar and satellites regarding the extent to which RF signal transmission, detection and image fidelity can operate effectively at much longer distances. There are also likely questions regarding whether there would be sufficient power generation to enable and sustain extended AESA-satellite long-range connectivity. Finally, the prospect of AESA-satellite connectivity seems to present a known paradox to an extent, given that the tactical advantages of this kind of data sharing and added combat awareness could be offset by added security vulnerabilities. It might prove difficult to sufficiently "harden" high volumes of data traveling long distances against jamming, spoofing and other kinds of interference. Given this, it seems unclear if the PLAAF J-20 is sufficiently engineered to address or mitigate these potential areas of complication. Nonetheless, the prospect of AESA-satellite connectivity could without question increase the threat equation regarding the detection and transmission performance parameters of the J-20.

Pace of Modernization

Research from roughly 10 years ago articulates clear findings that Chinese AESA technology was far behind the U.S. and, according to Kopp, "unlikely that China has been able to reach parity with the United States in terms of packaging technology on their first-generation

AESA design." However, the pace of Chinese modernization has continued to capture global attention, and it seems just unclear how quickly or how fully the PRC has narrowed or closed this apparent gap.

"The first-generation AESA produced by China is likely not on par with the US which is generally recognized as having the most technological mature T/R packaging technology," Kopp writes.

AESA Tactical Supremacy

Tactical supremacy in air combat naturally pertains to a number of variables beyond mere "detection" range of an AESA radar system, things which doubtless complicate any effort to establish clearly defined criteria through which to ultimately determine superior AESA performance.

The tactical efficacy or ultimate combat superiority of 5th-generation stealth fighter jet radar technology involves an intricate and extremely complex mix of variables, such as the form factor or sheer "size" or configuration of a nose radome, thermal signature management, stealth effectiveness and the balance of RF signal aperture and direction. The mixture of these interwoven technological parameters generates an overall combat "effect" characterized by both advantages and limitations.

J-20 Detection Range

Available information seems to suggest that it would appear accurate to posit that, while the Chinese J-20 AESA radar may incorporate superior linear or "straight on" radar detection range when compared with a U.S. F-22 or F-35, the smaller RCS and RF signal "aperture" or "radar angle" versatility enabled by the U.S. platforms might nonetheless prove superior in certain operational circumstances.

Much of this would pertain to the size, scope or tactical combat envelope of a given mission. For instance, the PLA may have intended to engineer the J-20 long-range detection radar to form a protective "wall" or range-enabled radar "barrier" preventing any attacking aircraft from getting close enough to "detect" and "attack" without themselves being detected. Should the J-20 operate with the largest amount of T/R modules in the world capable of a 120-mile detection range, it would position a J-20 with the distinct advantage of "seeing" before "being seen." As previously cited, however, thermal signature factors as well as packaging technology and signal fidelity are all variables which would greatly impact this equation.

Should the J-20 have been "optimized" for a longer "detection" range, the PRC's engineering and technological modernization strategy would align to a clear extent with its well-known larger strategic counter-interventionist posture in the Pacific theater. While the PLA has in recent years been ambitious with its accelerated effort to expand political and military influence beyond the Pacific, its primary concept of operation has for decades been woven into an effort to properly "defend" its coastline and accomplish and sustain dominance in the Pacific theater. It would therefore make sense if PLA engineers sought to architect a 5th-generation fighter with what might be the longest AESA detection range in existence.

However, longer AESA detection range by itself, might not translate into consistent early detection or combat superiority, depending upon the stealth attributes, radar angle or approach vector of an attacking aircraft. Essentially, an examination of the research might suggest that while the J-20 might operate with a longer-range "straight ahead" radar detection range designed to “defend” the Chinese coastline, the aircraft may lack the agility or RCS necessary to prevail in actual air-to-air combat.

The Chinese language “Sina” essay as far back as 2016 from Sina Military Weibo argues that PRC engineers leveraged what it calls “latecomer” advantages to build a breakthrough AESA radar for the J-20 with 50 percent higher power and a longer detection range than an F-22. Accrording to the Sina article, “The J-20 benefits from sufficient head space. The TR components of the AESA radar are as high as 2,000 to 2,200, and the transmission power is 24KW, the largest in the world! It can fully guarantee that the F-22 fighter will be found first outside its detection range. I believe that the Americans now regret not making the F-22 bigger. Although the F-22 leaves room for the distributed synthetic aperture system, if you want to change the large radar, you have to work hard. The embodiment of our country's latecomer advantage lies in learning from the lessons of the other side and taking our own path, and we can do better.”[14]

The 120-mile detection range of the J-20 radar has its origins in a Chinese military study as far back as 2003, which specified requirements for a radar capable of reaching a 200 kilometer tracking range, yet the Sina essay’s suggestion that the PRC J-20 benefits from a “latecomer advantage” may make sense to a certain extent, given that F-35 and F-22 radars were somewhat mature at the time. At the same time, many AESA performance enhancements have been integrated in years since the essay was written in 2016; also the Sina analysis may not have fully analyzed the trade-offs and mix of variables associated with actual AESA performance in a tactical environment.

Specifically, a larger nose radome accommodating a higher number of T/R modules can introduce thermal signature management challenges of great relevance to IR sensor detectability. An essay posted in a blog publication called “Pakistan Defense” forum called the “Technological Maturity of Chinese AESA Technology Strategic Impacts”[15] says high-density T/R module “packaging” can create radar warning receiver detection and “cooling problems.”[16]

“With a high number of T/R modules, the Type 1475 would be vulnerable to radar warning receiver (RWR) systems such as the ALR-94 without a very capable low probability intercept (LPI) mode.… Even if the Nanjing Research Institute of Electronics Technology (NRIET) or the China Leihua Electronic Technology Research Institute (607 Institute) was able to develop sufficient packaging technology that would enable 1,856 T/R modules within the J-20's nose, the density of the T/R modules would create significant cooling problems,” the essay states.

There is also a potential survivability challenge simply related to electromagnetic signature, meaning the greater the number of T/R modules generating RF signals, the larger and therefore more “detectable” a signature is. What this suggests is that should the J-20’s larger nose radome truly allow for as many as 2,200 T/R modules, it may emit a larger and more detectable signature in addition to simply being less stealthy.

Conclusions

Should some of various T/R module analyses of the J-20 be correct, meaning the “detection” range of the Type 1475 (KJL-5) be 40-miles longer than the F-35’s APG-81, then the Mighty Dragon might indeed operate with early detection capability enabling a potential “first-launch” opportunity. It is therefore not surprising that the J-20 is reportedly armed with a long-range air-to-air missile capable of traveling 180 miles. Longer “straight ahead” radar detection, however, as may be the case with the J-20, does not instantly translate into air combat supremacy for many reasons. In a clear, simple sense, a larger nose radome is a larger and therefore more detectable object increasing RCS. Aircraft with a smaller RCS or advanced EW "jamming system," such as the F-35, might be positioned to successfully elude long-range detection otherwise enabled by a J-20 AESA.

It would also be difficult to assess the merits of a J-20 AESA without better understanding the J-20s EO/IR targeting and sensor systems, given that they are operationally and technically "linked" to an extent. Multiple open source essays and accounts of the J-20 specifically express widespread consensus that the PLA Air Force may have copied or simply "stolen" the F-35s system in an effort to replicate its effectiveness. The PLA is reported to have copied the F-35s 360-degree Distributed Aperture System sensors and its Electro-Optical Targeting Systems. Therefore, the operative question or unknown component here relates to the extent to which the J-20's copied technologies successfully replicate the F-35's performance parameters, as the answer to the question would heavily impact the effectiveness of its AESA radar. There is widespread reporting that the PLA is believed to have stolen F-35 specifications and other weapons designs through extensive cyber intrusions; A 2014 "U.S.-China Economic and Security Review Commission"[17] Congressional report specifically cites a Defense Science Board finding citing numerous press reports that Chinese cyber-attacks resulted in the theft of significant specs and technical details of a range of U.S. weapons systems—including the F-35.[18] Given this, it stands to reason that the PLA may have also borrowed or copied some elements of the F-35s AESA radar as well, yet the extent or effectiveness of this may be difficult to discern.

Concepts of Operation

There are Concepts of Operation informing this equation as well, meaning a less-stealthy J-20 with a longer-range AESA makes strategic sense should the PRC wish to form a protective or "defensively-oriented" envelope beyond its borders. This makes great sense with particular regard to the J-20, as it is purely a land-launched platform unable to project power and take-off from the ocean. This means that, in the absence of a non-stealthy refueler, the operational combat range of the land-launched J-20 would be limited to roughly 500-to-600 miles off of the Chinese coastline. While this range could prove formidable in the Pacific, and certainly allow for operations around Taiwan, it would limit the J-20s ability to conduct extensive offensive operations more than 500 miles offshore against US Navy warships or airspace over part of Japan and the Philippines. The Philippines are roughly 600 miles from the Chinese coastline and Japan is anywhere from 1,000 to 1,900 miles from mainland China. What all of this suggests is that perhaps the PRC developed the J-20 radar with defensively oriented concepts of operation, knowing the aircraft would be ill suited for longer-range offensive attack in the Pacific against US 5th-generation aircraft.

Refuelers

The PLA is likely well aware of this limitation, given the large-scale ongoing PLAAF effort to convert many of its Y-20 Cargo planes into refuelers. Accoding to the Defense Departments's 2021 "Report on Military and Security Developments involving the People's Republic of China," "The PLAAF is developing the Y-20U, a new tanker variant of its large Y-20 heavy-lift transport, which will enable the PLAAF to significantly expand its tanker fleet and improve its power," DoD's 2021 [19]

China has for years been operating with a large tanker deficit when compared with the U.S., yet the rapid emergence of a larger tanker fleet would clearly complicate the idea of a purely “defensive” J-20. Sufficient Y-20 tanker support would enable the J-20 to fully reach and operate with dwell time out to the first island chain, something it would currently seem ill-equipped to accomplish. The pace at which tankers could be added appears to be the operative question, as it may be many years until the PLAAF can operate with a fleet of tankers sufficient to sustain a large-scale forward air attack campaign, and cargo-plane-type tankers are of course non-stealthy and highly vulnerable platforms.

Although it seems likely that the PLAAF may have deliberately designed the J-20 with a larger nose radome for the specific purpose of enabling long-range AESA detection, it would also seem inaccurate to posit that the J-20 is not also designed for forward attack as well. The aircraft is quite fast, reaching speeds of Mach 2.0. It also naturally appears stealthy, and can operate with a large “bomb-truck” like weapons payload. While not as fast as the US F-22 capable of Mach 2.25 speeds, the J-20 does operate with a comparable dual-engine thrust and is reportedly capable of F-22-like supercruise, meaning it can sustain Mach speeds without needing afterburner. This would suggest that PLA engineers chose to slightly compromise stealth for the purpose of building a large, fast, heavily armed fighter with long-range AESA detection.

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Endnotes

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