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# New Adaptive Engine Needed to Preserve Dominant Qualities of the F-35 Joint Strike Fighter

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## KEY TAKEAWAYS

The F-35's thrust, fuel efficiency, and cooling demands already exceed the F135 engine's capabilities, and updating it will not support future system requirements.

The Adaptive Engine Test Program has demonstrated the ability to support every current and projected weapons system demand of the F-35 power plant.

The Defense Department should move immediately to acquire and field an adaptive engine that can meet F-35 system demands through at least 2040.

The original design requirements for the F-35's Pratt and Whitney (Pratt) F135 engine were crafted in late 1990s[1] for the conceptual dimensions, weight, and other requirements of the three variants of the Joint Strike Fighter (JSF).[2] While the F135 has been very reliable, it produces roughly the same thrust that it was originally designed to deliver.[3] Unfortunately, the JSF's dimensions and weight grew significantly from concept through fielding of the F-35's three variants. Those jets are now 13 percent longer, have wingspans that are 17 percent to 19 percent wider, and are at least 30 percent heavier than their original JSF designs.[4] In other words, the engine is pushing a much bigger jet through the air than it was designed to handle.

Because of this mismatch, all three variants have fallen well short of the JSF key performance parameters for sustained "g" in turns and ability to regain airspeed after an engagement. The time it takes to accelerate from Mach 0.8 to Mach 1.2 can mean life or death for pilots attempting to gain separation from an engagement, but the additional girth of the F-35A, F-35B, and F-35C fighters, paired with the available thrust of the F135 engine, means that those jets require eight seconds, 16 seconds, and a crippling 43 seconds more time, respectively, to reach that safe separation speed.[5]

The deficiency in thrust will become even more pronounced when the Air Force follows the U.S. Marine Corps' lead and adds external pylons to the F-35A so that it can carry external munitions when stealth is not required. There is therefore little question that the jet needs much more thrust than the F135 can deliver.

The longest distance an aircraft can travel from takeoff to a target and return home is known as its combat radius. JSF design objectives took the need for significant combat range into account, but the jet's expanded dimensions and weight, coupled with increased demands for electronic component cooling, have significantly reduced the F-35's combat radius. Cooling air is generated primarily by pulling bleed air from the engine and running it through heat exchangers.

Like electricity, the demand for subsystem cooling is measured in kilowatts (kW). The F135 was designed to handle a 15 kW cooling demand, but that requirement has already doubled to an estimated 30 kW. The F135 meets the 30 kW demand by pulling more bleed air from the engine, which further reduces both thrust and range.

The higher cooling demands (higher bleed air linkage) is where the zero-sum game raises its ugly head with this engine. As more bleed air is pulled for cooling, the engine burns more fuel and runs hotter than it was designed to operate. The higher fuel burn ratio and higher gross weights together have decreased the range of all variants by some 15 percent,[6] and the higher temperatures have resulted in markedly higher engine wear, failure rates, and repair cycles for the F135, reducing engine life span.[7]

An even greater concern is that by 2028, the upgraded subsystems of F-35 Block 4 will need a minimum of 47 kW of cooling,[8] and estimates for the amount required to meet follow-on capability demands range as high as 60 kW. The design of the F135 power plant may allow a few more kilowatts of cooling but it is hard to fathom how it could meet a cooling demand that is four-fold greater than the 15 kW it was designed to sustain.

The supply of electrical power is also a growing issue for the weapons systems onboard the JSF. The voltage generation specification designed into the JSF was 160 kW of 270 volt direct current (Vdc) of power.[9] That was wholly sufficient for the subsystems envisioned 20 years ago, but the performance and effective range of Block 4 subsystems like electronic warfare upgrades and a new APG-85 radar[10] will require more electrical power than the F135 can produce. When coupled with the electrical power requirements for future systems like directed energy weapons, it is no wonder that the F-35 Joint Program Office has signaled the need for an engine that produces more electrical power.[11]

The F-35 will need more thrust, range, thermal management, and electrical power than the F135 can currently deliver. The options being considered to resolve those challenges are to upgrade the jet's current F135 engine or to develop and field a new power plant.

## Upgrading the Current Engine

Pratt has proposed a scalable and incremental F135 engine upgrade opportunity called the Enhanced Engine Program (EEP) to work through some of those challenges.[12] Estimates for the latest version of the EEP, known as Growth Option 2.0, project a 6 percent–10 percent increase in thrust, or a 5 percent–6 percent savings in fuel efficiency, and an increase in thermal management that will enable an "upgraded range of offensive and defensive weapon system technologies."[13]

While it is hard to know how much more cooling that entails, even an additional 50 percent increase would fall short of F-35 Block 4 requirements by the time that EEP patch is fielded. Follow-on growth in the F-35 capabilities would necessitate an even more significant "incremental" engine upgrade to meet the increased demand for thermal management. While the estimated $2.0 billion initial cost of Growth Option 2.0 is appealing, it is not sufficient to meet the Block 4 capabilities that will be fielded this decade, and the bill for "follow-on" upgrades or what those increments will deliver remains undefined.

Pratt executed a similar effort in the 1980s for engines that powered the F-15 and F-16. The "upgrade" delivered an increase in reliability, but the engine also weighed more and actually produced less thrust. F-16Cs powered by that "upgraded" F-100-PW-220 engine performed so poorly that the Air Force decertified them for combat operations.[14]

With no plan to build and test a Growth Option 2.0 prototype, the Air Force will not know whether the EEP measures up to these modest expectations until after the program is bought and fielded. If Pratt's own estimates and track record for previous upgrades are any guide, the EEP will likely do more to constrain the F-35 weapons system than to propel it forward. The only way to meet the F-35's future power plant requirements reliably is to develop a new motor. Fortunately, two competitive alternatives are almost ripe for the picking.

## Developing and Fielding a New Adaptive Engine for the F-35

The Adaptive Engine Test Program (AETP) was formally initiated in 2016 with three goals:

- Bring a three-stream airflow architecture to life to improve engine fuel efficiency by 25 percent,
- Increase thrust by 10 percent, and
- Significantly improve thermal management over two-stream fighter engines.[15]

Pratt and General Electric (GE) were selected to build AETP prototypes, and while the Pratt AETP entry, designated the XA101, is still under development, GE's XA100 has completed testing and has proven to increase fuel efficiency by 25 percent (enabling 30 percent greater range) and thrust by between 10 percent and 20 percent. It also delivers 20 percent more acceleration than the F135 and provides twice the cooling capacity, and its ceramic matrix composite turbine blades can withstand 500 degrees Fahrenheit more heat than the F135 can withstand.[16] While the engine technology developed through the AETP program is essential for the Next Generation Air Dominance (NGAD) family of systems, it could readily be incorporated into all three variants of the F-35.[17]

GE is now awaiting a program decision on the AETP and, should it be selected, is ready to move immediately into the engineering and manufacturing development (EMD) phase of acquisition with fielding for the F-35 expected before the end of the decade.[18] Pratt's XA101 also shows promise and is currently moving back and forth to the testing facility at Arnold Air Force Base.[19] There is every reason to believe that at the end of its testing, the Air Force will have two great options that will support every Block 4 upgrade that is currently envisioned for the jet, and the F-35 desperately needs those two competitors running neck and neck on the track.

Competition has been missing from the JSF engine program since the cancellation of GE's F136 in 2011, leaving Pratt with the F-35 engine monopoly and no compelling reason to compete on price. The F135 was the only major F-35 sub-system that failed to cut its acquisition costs to meet programed targets, which made bringing the F-35A's cost below its $80 million target that much more challenging. While Lockheed Martin was able to bring the price per jet below $80 million in fiscal year (FY) 2021,[20] it had to overcome Pratt's pricing for the F135 to do it. Having Pratt and GE competing for future engine contracts would force both to maximize the performance and minimize the cost of their engines.

Cost is obviously always a consideration, but capability should take precedence in the decisions surrounding future F-35 propulsion. Yet thus far, price has been the focal point of discussions on this topic. In addressing the F-35 engine decision, Secretary of the Air Force Frank Kendall has estimated that development and production costs for the AETP follow-on engine could reach $6 billion[21]—and that's on top of the $4-plus billion cost of the adaptive engine test program.

If cost were the only driver, the EEP's $2 billion price tag would win hands down, at least at first glance, but the EEP is a band-aid approach to addressing the F-35's power plant challenges, and to be successful, additional *incremental* band-aids will be required to enable future capabilities. Selecting the EEP would mean turning a blind eye to the costs of follow-on upgrades, and the incremental nature of those upgrades would do more to constrain the F-35 weapons system's capabilities than it would do to propel them forward. Selecting the EEP over an adaptive engine for the F-35 would mean ignoring the performance issues that drove competition back into fighter engine procurement in the 1970s.

Additionally, any argument that claims the cheaper option is more practical and would meet the F-35's needs ignores the history of that engine war and the adverse operational impacts that such a choice would have on the F-35.[22] By design, the AETP program would reinvigorate competition and elevate the F-35's trajectory for the foreseeable future.

## What Congress and the Air Force Should Do

At a time when the U.S. is likely to be outnumbered by our adversaries, particularly in a fight in the Indo-Pacific, it is important that our pilots have the best fighters America can provide. Air combat is unforgiving when it comes to second best. Putting the AETP engine in the F-35 is clearly the best choice for U.S. national security.

With this firmly in mind, Congress should:

- Direct the Defense Department to provide a report to Congress that documents and objectively evaluates the alternatives for the F-35's future propulsion requirements, to include the two AETP candidates and the EEP.

- Direct the Defense Department to issue a request for Proposal (RFP) for a follow-on propulsion system that meets, at a minimum, the JSF's original performance criteria for acceleration and range and the programmed F-35 upgrade requirements for thermal management, voltage, and durability through 2040 (initial fielding plus 10 years).

For its part, the Air Force should:

- Conduct and complete a competition for the next F-35 propulsion system by the end of FY 2023, based on the JSF's original performance criteria for acceleration and range and the programmed F-35 upgrade requirements for thermal management, voltage, and durability through 2040.

## Conclusion

The demands on the F-35 have outpaced the capabilities of the jet's current engine, and the weapons system will need more thrust, range, thermal management, and electrical power than the F135 can deliver. The potential for squeezing more capability out of the F135's engine core that was designed in the late 1990s will fall well short of what will be required to support Block 4, and the Defense Department should move immediately to acquire and field an adaptive engine than can meet F-35 system demands through at least 2040.

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