

Background

No. 2494
December 1, 2010



Published by The Heritage Foundation

What Russia's Stealth Fighter Developments Mean for America

Mackenzie Eaglen and Lajos F. Szaszdi, Ph.D.

Abstract: *Russia's development of the PAK FA fifth-generation stealth fighter could challenge American air supremacy, especially if Russia sells the PAK FA to its usual buyers of military equipment. In the U.S., closure of the F-22 production line has severely limited America's ability to respond to PAK FA proliferation by building more F-22s and potentially selling them to U.S. allies. The U.S. needs to revise its assessment of U.S. air superiority needs and then explore ways to modernize and strengthen the U.S. tactical fighter force.*

With America's closure of the F-22 production line and the recent debut of Russia's PAK FA fifth-generation stealth fighter, American air supremacy for the foreseeable future is not as assured as the U.S. Department of Defense once predicted. Indeed, Lieutenant General David A. Deptula, recently departed Deputy Chief of Staff for Intelligence, Surveillance and Reconnaissance in the U.S. Air Force, recently made the startling announcement: "For the first time, our claim to air supremacy is in jeopardy.... The dominance we've enjoyed in the aerial domain is no longer ours for the taking."¹

To preserve traditional U.S. margins of military technological superiority, Congress should review potentially outdated requirements and projections, and policymakers should push defense officials to enact more forward-looking budgeting and acquisition strategies for U.S. fighter fleets. Increased investment in modernization and new partnerships with

Talking Points

- Russia recently unveiled its PAK FA stealth fighter, which may prove superior to all fighters except the U.S. F-22.
- Russia will develop the PAK FA in partnership with India and could sell it to China, Libya, Venezuela, Algeria, Syria, and Iran, which would be destabilizing and have unintended consequences.
- With the closure of the F-22 production line underway, the U.S. has effectively lost its ability to hedge against PAK FA proliferation.
- Delays and other problems plaguing the F-35 Joint Strike Fighter program are worrisome because the F-35 may be less effective as a force multiplier for the F-22 if it is built in insufficient numbers.
- American air supremacy is no longer as assured as the U.S. Department of Defense once predicted.
- To preserve a favorable balance of power in the skies, the U.S. will need to increase investment in modernization and explore new partnerships with its allies, such as Japan and Israel.

This paper, in its entirety, can be found at:
<http://report.heritage.org/bg2494>

Produced by the Douglas and Sarah Allison
Center for Foreign Policy Studies
of the
Kathryn and Shelby Cullom Davis
Institute for International Studies

Published by The Heritage Foundation
214 Massachusetts Avenue, NE
Washington, DC 20002-4999
(202) 546-4400 • heritage.org

Nothing written here is to be construed as necessarily reflecting the views of The Heritage Foundation or as an attempt to aid or hinder the passage of any bill before Congress.

allies like Japan and Israel will be necessary to prevent the airpower balance from tilting in favor of the Russian and Chinese air forces and to hedge against the potentially destabilizing proliferation of Russia's PAK FA fighter to unstable actors, non-state groups, and/or terrorism-sponsoring rogue states around the world. For example, if Syria or Iran acquires the PAK FA, it could provide the fighter to the non-state group Hezbollah to form a proxy air force against Israel.¹

U.S. Air Power Assumptions Challenged

Defense analysts, officials, and industry personnel have long believed that the U.S. F-22 Raptor and the F-35 Lightning II Joint Strike Fighter would not face serious threats from foreign fifth-generation fighters for the next 20 years.² In September 2009, Secretary of Defense Robert Gates repudiated claims of a looming "fighter gap"—a deficit between the services' fighter aircraft inventories and their operational requirements. "[T]he more compelling gap," he argued, "is the deep chasm between the air capabilities of the United States and those of other nations."³ In an earlier speech, he argued:

China... is projected to have no fifth generation aircraft by 2020. And by 2025, the gap only widens. The U.S. will have approximately 1,700 of the most advanced fifth generation fighters versus a handful of comparable aircraft for the Chinese.⁴

The Secretary's claims may now be in doubt. With the cancellation of the F-22 and closure of its production line combined with various development delays in the F-35 program—the mainstay of America's future fighter fleets—U.S. fighter inventories may be significantly smaller in coming years than

initially planned. For example, initial operational capability for the F-35A, the U.S. Air Force version of the F-35, was recently pushed back two years to the end of 2015, now changed to 2016 for both the F-35A and the Navy's F-35C.⁵ These delays often increase production costs, forcing reductions in the overall buy. Regrettably, other fiscal pressures will likely squeeze procurement budgets further in the coming years and prevent the expenditures needed to reach planned F-35 force levels.

Meanwhile, Russian fighter and military modernization efforts are proceeding rapidly, defying the expectations of many. In August, Russia undertook the largest airborne military exercises since the collapse of the Soviet Union, making "use of automated command and control systems."⁶ On January 29, 2010, Russia conducted the first test flight of the T-50, a prototype of the PAK FA, Russia's fifth-generation fighter jet, which was designed to rival the

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American F-22. With advanced stealth technology and high-tech avionics, the PAK FA could eventually—as Moscow has repeatedly proclaimed—seriously challenge U.S. air supremacy. Russia is also selling modern fourth-generation fighter aircraft to the Indian, Chinese, Algerian, Vietnamese, and Libyan militaries.

The air forces of Russian defense trade partners—including India, China, Algeria, Vietnam, and Libya—could also pose growing challenges.

1. Kevin Baron, "Exiting AF Intel Chief: No US Air Superiority," *Stars and Stripes*, September 15, 2010, at <http://www.military.com/news/article/exiting-af-intel-chief-no-us-air-superiority.html> (September 23, 2010).
2. A&E Home Video, *Dogfights of the Future*, DVD, 2007.
3. Robert M. Gates, speech at the Air Force Association Convention, National Harbor, Maryland, September 16, 2009, at <http://www.defense.gov/speeches/speech.aspx?speechid=1379> (September 23, 2010).
4. Robert M. Gates, speech at the Economic Club of Chicago, July 16, 2009, at <http://www.defense.gov/speeches/speech.aspx?speechid=1369> (September 23, 2010).
5. Amy Butler and Graham Warwick, "More Clouds for JSF," *Aviation Week & Space Technology*, November 15, 2010, p. 36, and Caitlin Harrington, "USAF Slips F-35 IOC by Two Years," *Jane's Defence Weekly*, March 10, 2010, p. 8.
6. RIA Novosti, "Largest Airborne Military Exercises Since Sov. Union Begin in Central Russia," August 24, 2010, at http://en.rian.ru/military_news/20100824/160321679.html (September 23, 2010).

Russia has already sold hundreds of its best fighter aircraft to China, and may sell China the PAK FA as well. China is Russia's largest purchaser of Su-27/Su-30 Flanker fighters, including the more advanced Su-30MKK and Su-30MK2, buying or ordering up to 624 as of 2009.⁷ The Su-27/Su-30 fighters are produced by Sukhoi, the same firm that is developing the PAK FA. Indeed, the Komsomolsk-on-Amur KNAAPO factory, which is producing the Su-27/Su-30 fighters, is located in Khabarovsk, a region that borders China. By 2025, China could have up to 120 PAK FA fighters, compared to America's 187 F-22As.⁸

PAK FA Program and Potential Foreign Exports

While reduced resources and growing internal defense budget imbalances imperil U.S. defense procurement plans, Russian defense spending is getting a boost from oil and gas export revenues, even after the 2008–2010 slump in oil prices.⁹ Russia has the third largest gold and hard currency reserves after China and Japan. State coffers have been expanding

quickly, with Russia's foreign reserves increasing from \$437 billion at the end of January 2010 to \$503.7 billion by October.¹⁰ Although the Russian economy relies heavily on exports of raw materials, the government is unlikely to encounter much difficulty funding the PAK FA program, especially with significant assistance from India, which plans to inject \$30 billion into the program.¹¹

Furthermore, the PAK FA is expected to be cheaper to produce than the F-22. Russian Prime Minister Vladimir Putin has recently claimed that the PAK FA "would be 2.5 to 3 times cheaper."¹² Currently, the PAK FA is expected to cost less than \$100 million per plane,¹³ while the F-35 is projected to cost between \$100 million and \$112 million, and the F-22 will cost around \$140 million.¹⁴

The Russian Defense Ministry initially planned to buy 300 PAK FA fighters, but has since reduced its stated requirement to 250 planes, with a preference for the single-seat version. Whether Russia will meet this target is unclear. As part of the "2011–2020 state arms procurement program," the ministry is budget-

7. Mackenzie M. Eaglen and Lajos F. Szaszdi, "The Growing Air Power Fighter Gap: Implications for U.S. National Security," Heritage Foundation *Background* No. 2295, July 7, 2009, at <http://www.heritage.org/research/reports/2009/07/the-growing-air-power-fighter-gap-implications-for-us-national-security>. See also Yefim Gordon, *Chinese Air Power: Current Organization and Aircraft of all Chinese Air Forces* (Hersham, U.K.: Midland Publishing, 2010), p. 66.
8. These estimates are based on the annual production rates of Su-30MKK and Su-30MK2 at KNAAPO from 2001 to 2004. See Gordon, *Chinese Air Power*, pp. 86 and 237.
9. Ajai Shukla, "India, Russia Close to PACT on Next Generation Fighter," *Business Standard*, January 5, 2010, at <http://www.business-standard.com/india/news/india-russia-close-to-pactnext-generation-fighter/381718> (September 23, 2010).
10. Reuters, "Russian Gold/Fx Reserves Rise to \$494.4bln," XE.com, October 7, 2010, at <http://www.xe.com/news/2010-10-07%2002:08:00.0/1443713.htm> (October 27, 2010), and RT, "Russia's International Reserves Pass \$500-Billion Mark," October 21, 2010, at <http://rt.com/prime-time/2010-10-21/russia-international-reserves-record.html> (October 22, 2010).
11. Rahul Bedi, "India Set to Spend More than \$30bn on FGFA Programme," *Jane's Defence Weekly*, October 13, 2010, p. 5.
12. Press Trust of India, "Russian 5th Gen Fighter Will Be Cheaper, Superior: Putin," *ZeeNews.com*, June 20, 2010, at <http://www.zeenews.com/news635381.html> (September 23, 2010).
13. RIA Novosti, "The T-50 Fifth-Generation Fighter," February 19, 2010, at <http://en.rian.ru/infographics/20100219/157939986.html> (September 23, 2010), and Ajai Shukla, "India to Develop 25% of Fifth Generation Fighter," *Business Standard*, January 6, 2010, at <http://www.business-standard.com/india/news/india-to-develop-25fifth-generation-fighter/381786> (September 23, 2010).
14. The potential Israeli variant of the F-35 will cost \$130 million per plane. ARMS-TASS, "Sredniaia stoimost' amerikanskogo istrebitelia 5-go pokoleniia JSF mozhnet previsit' 80 mln dollarov," February 26, 2010, at <http://arms-tass.ru/?page=article&aid=81510&cid=25> (September 23, 2010); Amy Butler et al., "Going Vertical: As Price Soars, JSF Comes Down for Its Vertical Landing," *Aviation Week & Space Technology*, March 22, 2010, p. 33; United Press International, "Israel Presses U.S. for F-35 Deal," February 12, 2010, at http://www.upi.com/Business_News/Security-Industry/2010/02/12/Israel-presses-US-for-F-35-deal/UPI-44751266002107 (September 23, 2010); and Rajat Pandit, "Russia Conducts First Test of Fifth-Generation Sukhoi," *The Times of India*, January 30, 2010, at <http://timesofindia.indiatimes.com/india/Russia-conducts-first-test-of-fifth-generation-Sukhoi/articleshow/5514549.cms> (September 23, 2010).

ing \$656 billion, which includes funding to produce 10 PAK FAs between 2013 and 2015 and 60 additional fighters between 2016 and 2020.¹⁵

Although Russia is leading the program and shouldering the bulk of the cost, India is set to provide significant assistance, aiming to have a 25 percent stake in designing and developing the fighter.¹⁶ India is currently negotiating with Sukhoi to build an Indian variant called the Fifth-Generation Fighter Aircraft (FGFA). India reportedly plans to purchase 250 of these fighters: 200 twin-seaters and 50 single-seaters, with an option for future orders that could increase the total to 300.¹⁷

Mikhail Pogosyan, General Director of the Sukhoi Design Bureau, has stated: “I am strongly convinced that our joint project will excel its Western rivals in cost-effectiveness and will not only allow strengthening the defense power of Russian and Indian air forces, but also gain a significant share of the world market.”¹⁸ Pogosyan calculates that there could be a world market for 1,000 PAK FAs in the next 40 years.¹⁹

One likely buyer is China. Although Beijing is reportedly developing its own fifth-generation fighter aircraft (the J-12), the Chinese military could conceivably buy up to 250 PAK FA planes, espe-

cially if its own program encounters delays.²⁰ In addition, Russia would likely seek to export the PAK FA to Algeria, Libya, Iran, Syria, and Venezuela. Kazakhstan may also purchase the aircraft, as could Malaysia and Vietnam, thanks to their gas and oil revenues. Indonesia may want to buy limited numbers to counterbalance the 100 F-35s that Australia plans to acquire.²¹ America’s oil-rich Arab allies may also order PAK FA aircraft if Washington refuses, as expected, to sell them F-35s and instead exports up to 100 F-35s to Israel.²²

Russia would likely seek to export the PAK FA to Algeria, Libya, Iran, Syria, and Venezuela.

The PAK FA will likely form the basis for several foreign variants, in the same way that the Russian Su-27 Flanker fighter spawned the Su-30MKI multirole fighter for India, the Su-30MKK multirole fighter and Su-30MK2 naval strike fighter for China, the Su-30MKA for Algeria, and the more advanced Su-34 strike aircraft and Su-35 multirole fighter. One possible PAK FA variant is a twin-seat long-range strike version similar to the Su-34 or the proposed (and now shelved) FB-22 bomber version of the F-22.

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15. RIA Novosti, “Russian State Arms Procurement Program to Be Significantly Increased (Update 1),” July 19, 2010, at <http://en.rian.ru/russia/20100719/159868060.html> (September 23, 2010), and Bill Sweetman, “PAK FA Will Be Operational in 2015: Executive,” *Aviation Week*, July 21, 2010, at http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/awx/2010/07/21/awx_07_21_2010_p0-242633.xml (September 23, 2010).
 16. RIA Novosti, “Russia’s Future Fighter Conquers the Skies,” January 29, 2010, at http://en.rian.ru/military_news/20100129/157712091.html (September 23, 2010), and Shukla, “India to Develop 25% of Fifth Generation Fighter.”
 17. Shukla, “India to Develop 25% of Fifth Generation Fighter”; Ajai Shukla, “India, Russia Close to PACT on Next Generation Fighter,” *Business Standard*, January 5, 2010, at <http://www.business-standard.com/india/news/india-russia-close-to-pactnext-generation-fighter/381718> (October 27, 2010); Agence France-Presse, “India to Buy 250–300 Fighter Jets from Russia,” *Free Malaysia Today*, October 7, 2010, at <http://freemalaysiatoday.com/fmt-english/world/world-news/11279-india-to-buy-250-300-fighter-jets-from-russia> (October 7, 2010); RIA Novosti, “India Set to Buy Around 300 5th Generation Fighters from Russia,” October 7, 2010, at <http://en.rian.ru/news/20101007/160867582.html> (October 22, 2010).
 18. ITAR-TASS, “Russia, India to Sign Contract for Sketching 5th Generation Jet Soon,” March 13, 2010, and Sukhoi Company, “Sukhoi Company Launches Flight Tests of PAK FA Advanced Tactical Frontline Fighter,” January 29, 2010, at <http://www.sukhoi.org/eng/news/company/?id=3143> (September 23, 2010).
 19. David A. Fulghum and Douglas Barrie, “Sukhoi T-50 Prototype Demonstrated for Putin,” *Aviation Week*, June 29, 2010, at http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/awst/2010/06/28/AW_06_28_2010_p34-236434.xml (September 23, 2010).
 20. Gordon, *Chinese Air Power*, p. 379.
 21. Gerard Keijsper, *Joint Strike Fighter: Design and Development of the International Aircraft* (Barnsley, U.K.: Pen and Sword, 2007), p. 260.
 22. United Press International, “Israel Presses U.S. for F-35 Deal.”

With its stealth technology, supercruise capability, and sensor fusion, the F-22 was designed to prevail in present and future air battles. It also has the ability to carry smart bombs for precision strike missions in heavily defended battle spaces. Due to its supercruise ability, the F-22 is capable of covering long distances in regions like the Arctic Ocean, the continental U.S., the Western Pacific, and the Persian Gulf with supersonic flight without the need to engage afterburners. Since the PAK FA is planned to have similar capabilities, only the F-22 would be capable of matching the future Russian fighter, if not prevailing over it.

The FB-22 would possess the stealth and supercruise characteristics of the F-22A, and it would provide a stealth and supersonic medium-range bomber capability for the Air Force, filling a niche between the F-35 fighter-bomber and the proposed 2018 long-range bomber.²³ The FB-22 would be able to carry 30 Small Diameter Bombs and have 50 percent more range than the F-22.²⁴ In the future, Russia may deploy a medium-bomber version of the PAK FA while the U.S. Air Force may be left without such a bomber capability.

According to Russian officials, the joint Russo-Indian PAK FA/FGFA fighter should be ready by 2015 or 2016. It may also incorporate equipment from third countries, just as Russia has previously integrated French and Israeli technology into its weapons systems.²⁵ Indian officials hope the FGFA

will be fully developed by 2016 so that it can enter service in 2017.²⁶

With a planned price tag of about \$100 million per aircraft, the PAK FA will not be cheap, but it will likely find a market among those countries that have purchased Russia's Su-27/30 fighters. Many of these countries have substantial foreign currency reserves. Those that want to modernize and expand their militaries, expand their global presence, and become increasingly assertive on the world stage or in their regions will be interested in the PAK FA. If the PAK FA proves to be a success, the U.S. should expect it to proliferate among countries with the means to acquire it and with foreign policies that potentially defy Washington or look toward Moscow.

Understanding the Potential for Trouble

After successful test flights on January 29 and February 12, 2010, the T-50 began standard tests in April. Testing could take several more years, according to sources from Sukhoi²⁷ and statements by Prime Minister Putin,²⁸ but some planes could conceivably be deployed in operational units before testing is completed. This would not be unusual. The first operational F-22s were delivered in September 2003, even though testing continued until November 2005.²⁹ Colonel General Alexander Zelin, commander in chief of the Russian Air Force, estimates that PAK FA fighters will be delivered to operational units in 2015.³⁰ In preparation, Russian pilots are already receiving training in piloting fifth-generation fighters.³¹

23. Adam J. Hebert, "The 2018 Bomber and Its Friends," *Air Force*, October 2006, at <http://www.airforce-magazine.com/MagazineArchive/Pages/2006/October%202006/10062018.aspx> (September 28, 2010).

24. Rebecca Grant, "Return of the Bomber: The Future of Long-Range Strike," *Air Force Association Special Report*, February 2007, p. 28, at <http://www.afa.org/mitchell/reports/0207bombers.pdf> (November 15, 2010).

25. RIA Novosti, "Russia, India to Develop Joint 5G-Fighter by 2016," March 2, 2010, at http://en.rian.ru/military_news/20100302/158065429.html (September 23, 2010), and RIA Novosti, "Rusia y la India planean desarrollar un caza de quinta generaci3n para 2016," March 2, 2010, at <http://sp.rian.ru/news/20100302/125310373.html> (September 23, 2010).

26. Pandit, "Russia Conducts First Test of Fifth-Generation Sukhoi."

27. RIA Novosti, "Russia's 5th Generation Jet Fighter to Start Tests in April," March 1, 2010, at <http://en.rian.ru/russia/20100301/158054167.html> (September 23, 2010).

28. RIA Novosti, "New Russian Fighter to Make 2,000 Flights Before Production Starts," March 1, 2010, at <http://en.rian.ru/russia/20100301/158056158.html> (September 23, 2010).

29. Paul Jackson, ed., *Jane's All the World's Aircraft 2006-2007*, 97th ed. (Coulsdon, U.K.: Jane's Information Group, 2006), p. 798.

30. RIA Novosti, "Russian 5th-Generation Fighter Deliveries Delayed Until 2015," February 9, 2010, at <http://en.rian.ru/russia/20100209/157824658.html> (September 23, 2010).

As one expert recently noted: “In this modern era of stealth combat, there are two types of fighters: stealth fighters and targets.”³² Similarly, the commander in chief of the Russian navy stated that “it would be impossible to win contemporary and future wars without air and space supremacy. Whoever understands this is on the right path.”³³ Mikhail Pogosyan says that “the most important thing is stealth to enemy radar, which allows the aircraft to approach enemy positions without being noticed.”³⁴

One risk is that Russia or potential PAK FA customers around the world could use the sophisticated aircraft to conduct sneak attacks against U.S. forces or allies. Russian doctrine still considers the U.S. its “principal adversary,” even though successive U.S. Administrations have announced that Russia is no longer our enemy.³⁵

Viewing the U.S. and NATO as potential opponents in a future war, Russia has designed the PAK FA to compete with the F-22 and to devastate formations of F-35 stealth fighters.³⁶ It takes more than technology to make an advanced fighter classified as fifth-generation, including pilot skill and training, aircraft, and tactics. It remains to be seen whether Russia will develop advanced operational

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concepts and fighter doctrine to employ the PAK FA. If this occurs, it is possible that the twin-engine F-22, which was devised as an air superiority fighter, would perhaps be the only credible match for the PAK FA. Even if the F-22 proves superior, PAK FAs may still pose a formidable threat. F-35s, which were partly designed to serve as force multipliers for the F-22, may be vulnerable to PAK FA attack. Although the U.S. plans to build more than 2,000 F-35s, the numerical advantage of the F-35 fleet could potentially be offset by the PAK FA’s larger weapon capacity, especially if it proves technologically superior.

In addition, the PAK FA could pose a threat to the F/A-18E/F Super Hornet and F-35C Lightning II squadrons operating from America’s aircraft carriers. The Russian navy plans to deploy 15–20 naval PAK FAs on its aircraft carrier after it is modernized, perhaps by 2020.³⁷ Russia may also seek to reduce the numerical advantage of the overall U.S. fighter fleet by building large numbers of a lighter version of the PAK FA, a possible equivalent to the F-35.³⁸

31. Yefim Gordon and Dmitriy Komissarov, *OKB Sukhoi: A History of the Design Bureau and Its Aircraft* (Hersham, U.K.: Midland Publishing, 2010), p. 542.
32. A&E Home Video, *Dogfights of the Future*.
33. RIA Novosti, “Comandante de la Marina rusa dice que la principal ventaja en la guerra es la supremacía aérea y espacial,” February 26, 2010, at <http://www.sp.rian.ru/news/20100226/125266454.html> (October 27, 2010).
34. RIA Novosti, “Rusia iniciará entre 2010 y 2011 la creación del motor de segunda etapa para el avión de quinta generación,” June 17, 2010, at <http://sp.rian.ru/Defensa/20100617/126740994.html> (October 27, 2010).
35. Ariel Cohen, “Dangerous Trajectories: Obama’s Approach to Arms Control Misreads Russian Nuclear Strategy,” Heritage Foundation *Backgrounder* No. 2338, November 9, 2009, at <http://www.heritage.org/Research/Reports/2009/11/Dangerous-Trajectories-Obamas-Approach-to-Arms-Control-Misreads-Russian-Nuclear-Strategy>.
36. RIA Novosti, “Russia’s Future Fighter Conquers the Skies,” January 29, 2010, at http://en.rian.ru/military_news/20100129/157712091.html (September 24, 2010); Press Trust of India, “Indo-Russian 5th Generation Fighter to Take-Off by 2012,” *The Times of India*, October 30, 2007, at http://timesofindia.indiatimes.com/World/Europe/Indo-Russian_5th_generation_fighter_to_take-off_by_2012/articleshow/2503005.cms (September 24, 2010); and Ariel Cohen, “Swords and Shields: Russia Bets on PAK FA,” Heritage Foundation *Commentary*, January 21, 2009, at <http://www.heritage.org/Research/Commentary/2009/01/Swords-and-Shields-Russia-bets-on-PAK-FA>.
37. Ilya Kramnik, “Moscow Set to Upgrade Admiral Kuznetsov Aircraft Carrier,” RIA Novosti, April 6, 2010, at <http://en.rian.ru/analysis/20100406/158454665.html> (September 24, 2010).
38. ARMS-TASS, “Lëgkii istrebitel’ 5-go pokoleniia budet sozdan na baze tekhnologii tiazhelogo perspektivnogo istrebitelia” (The light fifth-generation fighter will be created on the basis of the technology of the heavy prospective fighter), April 16, 2008, at <http://arms-tass.su/?page=article&aid=53759&cid=25> (September 24, 2010).

In a dogfight, U.S. Air Force models predict that small formations of F-22 fighters would prevail over far larger numbers of fourth-generation enemy fighters because the F-22's superior stealth would give it a substantial advantage.³⁹ However, how the F-22 would fare against the PAK FA is unclear. The PAK

How the F-22 would fare against the PAK FA is unclear. The PAK FAs may ultimately match the F-22s in capability and possibly outnumber them.

FAs may ultimately match the F-22s in capability and possibly outnumber them. It is also unclear how mixed formations of F-22s and more numerous F-35s would fare against PAK FA formations or against combinations of PAK FAs and lighter variants. The Department of Defense needs to develop a comprehensive understanding of the capabilities of the various Russian platforms to accurately gauge the threat to U.S. planes and to develop appropriate responses.

The PAK FA Compared to U.S. Fighters

According to information in the public domain, the PAK FA could be superior to the F-35, equal or nearly equal to the F-22, and superior to fourth-generation fighters. This section compares these fighters across a range of capabilities and discusses nascent and unfolding security implications.

Stealth. The PAK FA will likely incorporate several advanced stealth features. According to the Sukhoi firm, the fighter's "use of composite materi-

als and advanced technologies, improved aerodynamics, and reduced engine heat signature minimizes its radio-frequency, optical and infrared visibility."⁴⁰ Like the F-22, the PAK FA was designed according to the principle of planform alignment,⁴¹ which means that surfaces and edges—such as the leading edges and horizontal control surfaces of the wings and the vertical sides of the engines' air intakes—are aligned to share the same angles. The pilot's canopy is also angled to deflect incoming radar waves away from the radar source.⁴²

An additional stealth feature that could be incorporated is curved S-ducts to mask the engine compressor blades from radar.⁴³ The T-50 prototype tested earlier this year was not fitted with stealthy engine nozzles, but the operational version of the PAK FA will likely have stealthy thrust-vector-control nozzles, like those on the F-22. A stealthy engine nozzle has been fitted on one of Russia's Su-27 test aircraft.⁴⁴

The PAK FA is expected to be built with radar-absorbing material.⁴⁵ About 30 percent of the aircraft fuselage will be made of composite materials.⁴⁶ It could also be fitted with a "stealthogenic" system, an advanced technology reportedly developed by Soviet scientists. This stealthogenic technology is a form of anti-radar cloaking device using "wisps of plasma formed by pencils of electromagnetic rays from special generators installed on the aircraft; the plasma absorbs radio waves, reducing the aircraft's radar cross section (RCS) approxi-

39. A&E Home Video, *Dogfights of the Future*.

40. RIA Novosti, "Russia Draws Back Veil of Secrecy with Peek at Future Fighter," January 29, 2010, at <http://en.rian.ru/russia/20100129/157715872.html> (September 24, 2010), and Ilya Kramnik, "Russia Successfully Tests Sukhoi T-50 Stealth Fighter Jet," RIA Novosti, January 29, 2010, at <http://www.en.rian.ru/analysis/20100129/157716197.html> (September 24, 2010).

41. A&E Home Video, *Dogfights of the Future*. See also David A. Fulghum, Maxim Pyadushkin, and Douglas Barrie, "Stealth, Sukhoi-Style," *Aviation Week & Space Technology*, February 8, 2010, p. 30.

42. A&E Home Video, *Dogfights of the Future*.

43. Yefim Gordon, *Sukhoi S-37 and Mikoyan MFI: Russian Fifth-Generation Fighter Technology Demonstrators* (Hinckley, U.K.: Midland Publishing, 2001), pp. 73, 82, and 33, and Maxim Pyadushkin and Douglas Barrie, "The Fifth Element," *Aviation Week & Space Technology*, July 19, 2010, p. 82.

44. Yefim Gordon, *Sukhoi Su-27* (Hinckley, U.K.: Midland Publishing, 2007), p. 102. For a picture of the Russian stealthy two-dimensional thrust vector control nozzle, see Yandex, "PAK FA fotografia," at <http://img696.yfrog.com/img696/7397/5427.jpg> (October 22, 2010).

45. Gordon, *Sukhoi S-37 and Mikoyan MFI*, pp. 33–34.

46. Pyadushkin and Barrie, "The Fifth Element," p. 82.

mately 100 times,⁴⁷ making it almost invisible to radar. The U.S. Air Force is reportedly interested in using a similar, cold plasma cloaking device “as the next generation of stealth technology” for its fighter aircraft.⁴⁸

The Indian version of the PAK FA is said to have a radar cross section of 0.5 square meter, the equivalent of a missile’s RCS. By comparison, older tactical jets have RCSs between 5 and 100 square meters. For example, the fourth-generation Su-30MKI has a RCS of approximately 20 square meters.⁴⁹

Russia is likely to reserve the more advanced stealth capabilities for its own aircraft. The stealthogenic cloaking device under development could reduce the PAK FA’s radar cross section even further, making it potentially as stealthy as the F-22, which has the RCS of a small bird or a bumblebee at between 0.001 and 0.01 square meter.⁵⁰ The stealthogenic system may even enable the fighter to carry a full load of missiles, bombs, and/or drop tanks externally and still remain stealthy. It is possible Russia may have already tested the technology successfully; if so, one could reasonably assume Russia would then be readying it for deployment on the operational version of the PAK FA.

The F-35 normally carries two beyond-visual-range AMRAAM⁵¹ missiles and two JDAM-guided⁵² bombs in its two internal weapon bays. It

could carry two additional AMRAAMs or AIM-9X Sidewinders under its wings, but this would make it less stealthy.⁵³ Based on the current capabilities of Russian airborne fire-control radars, the PAK FA’s active electronically scanned array (AESA) radar can simultaneously detect, track, and target six to eight F-35s with impaired stealth, offsetting the advantage of the additional weapons.⁵⁴

The PAK FA and F-22 differ from the F-35 in that both can carry two short-range air-to-air missiles in internal side compartments, which significantly reduces their RCS and enables them to maintain their stealth outlines, even when carrying additional weapons. The F-35’s engine nozzle may give it a stealth disadvantage versus the PAK FA. This means a PAK FA flying high above an F-35 could potentially detect and track the F-35’s nozzle. In a battle against an F-35 formation, the PAK FA’s stealth and radar would likely be significant force multipliers.

Radar. Although the T-50 prototype probably used a modified Irbis-E radar (the passive electronically scanned array technology used on the Su-35 fighter),⁵⁵ the Russians are developing more advanced radar systems for the PAK FA. Approximately 30 companies are developing the PAK FA’s integrated avionics suite.⁵⁶

Ultimately, the PAK FA is expected to have an AESA radar system with 1,500 individual transmit-

47. Gordon, *Sukhoi S-37 and Mikoyan MFI*, pp. 21–22.

48. A&E Home Video, *That’s Impossible: Death Rays & Energy Weapons*, DVD, 2009.

49. Shukla, “India, Russia Close to PACT on Next Generation Fighter.”

50. GlobalSecurity.org, “F-22 Raptor Stealth,” modified January 21, 2008, at <http://www.globalsecurity.org/military/systems/aircraft/f-22-stealth.htm> (September 24, 2010); Tony Halpin, “Russia Unveils Its First Stealth Fighter Jet—The Sukhoi T-50,” *The Times* (London), January 30, 2010, at <http://www.timesonline.co.uk/tol/news/world/europe/article7007913.ece> (September 24, 2010); and Jeff Scott, “Radar Cross Section,” Aerospaceweb.org, March 21, 2004, at <http://www.aerospaceweb.org/question/electronics/q0168.shtml> (September 24, 2010).

51. Advanced Medium-Range Air-to-Air Missile.

52. Joint Direct Attack Munition.

53. Bill Sweetman, “All-Seeing Eye,” *Defense Technology International*, October 2008, at http://www.es.northropgrumman.com/solutions/f35targeting/assets/dti_eodas.pdf (June 10, 2009), and A&E Home Video, *Dogfights of the Future*.

54. Yefim Gordon, *Russian Air Power: Current Organization and Aircraft of all Russian Air Forces* (Hinckley, U.K.: Midland Publishing, 2009), p. 325; Gordon, *Sukhoi Su-27*, p. 175; and Edward Downs, ed., *Jane’s Avionics 2006-2007*, 25th ed. (Coulsdon, Surrey: Jane’s Information Group, 2006), pp. 668 and 672–673.

55. Gareth Jennings, “Russian PAK-FA Fifth-Generation Fighter Makes Maiden Flight,” *Jane’s Defence Weekly*, February 3, 2010, p. 5.

56. Gordon and Komissarov, *OKB Sukhoi*, p. 541.

ter/receiver (T/R) modules. A prototype is being tested, and development should be completed in mid-2010.⁵⁷ In comparison, the F-22's AESA radar system has about 2,000 T/R modules.⁵⁸

In addition to AESA radar, the PAK FA will have a side-looking radar and a rear-facing radar.⁵⁹ The sting fairing in the tail, located between the engine's exhaust nozzles, may harbor a small fire-control radar⁶⁰ for detecting airborne targets and attacking missiles and to provide fire-control solutions for its air-to-air missiles. With AESA radars in the nose and tail, the PAK FA could cover 120 degrees of both the plane's front hemisphere and its rear hemisphere.⁶¹ In addition, the aircraft will have an L-band AESA radar in conformal arrays on the wings' leading edges. According to some reports, L-band arrays can detect stealth aircraft the size of the F-35.⁶²

The PAK FA's design may also allow placement of additional AESA conformal arrays on the fighter's surfaces that could provide radar coverage of its starboard and port sides,⁶³ allowing all-round radar surveillance. Perhaps with this in mind V. K. Naik,

the Indian Air Force Chief of Staff, said that the FGFA's "highly advanced avionics... [would be] giving 360-deg. situational awareness."⁶⁴ In addition, the PAK FA's AESA radar will have electronic countermeasures that can jam enemy radar. The F-35 has a similar system. Like the F-35's radar, the PAK FA's radar can use radio waves to burn the electronic systems of enemy radar, the command-and-control computer of a surface-to-air missile (SAM) battery,⁶⁵ and perhaps even the flight computer of an enemy fighter. The L-band AESA radars on the aircraft's wings could potentially track, locate, and jam the Joint Tactical Information Distribution System (JTIDS), Multifunctional Information Distribution System (MIDS), and Link-16 communications links and emitters.⁶⁶

The PAK FA's optoelectronic system may incorporate a LADAR (laser radar) to identify targets, including other stealth fighters, by providing an image of a contact in three dimensions.⁶⁷ The PAK FA may also incorporate a more advanced, fifth-generation version of the infrared search and track/

57. "Russia's Fifth Generation Jet Tested Successfully," Pravda, January 29, 2010, at http://english.pravda.ru/russia/economics/29-01-2010/111923-fifth_generation-0 (September 24, 2010); Douglas Barrie and Alexey Komarov, "Fighter Order Rekindles Russian Air Force," *Aviation Week & Space Technology*, August 26, 2009, at http://www.aviationweek.com/aw_generic/story_channel.jsp?channel=defense&id=news/RUSSAF082609.xml (September 24, 2010); and Fulghum *et al.*, "Stealth, Sukhoi-Style," p. 31.
58. Downs, *Jane's Avionics 2006–2007*, p. 697.
59. Gordon and Komissarov, *OKB Sukhoi*, p. 541.
60. There were plans to install a small radar in the rear of the S-37/Su-47 fifth-generation fighter technology demonstrator to warn of airborne contacts appearing behind the aircraft. See Gordon, *Sukhoi S-37 and Mikoyan MFI*, p. 83; Paul Jackson, *Jane's All the World's Aircraft 2004–2005*, 95th ed. (Coulsdon, U.K.: Jane's Information Group, 2004), p. 446; Downs, *Jane's Avionics 2006–2007*, pp. 676–677.
61. Fulghum and Barrie, "Sukhoi T-50 Prototype Demonstrated for Putin."
62. Pyadushkin and Barrie, "The Fifth Element," p. 82; Carlo Kopp, "Assessing the Tikhomirov NIIP L-Band Active Electronically Steered Array," *Air Power Australia Analyses*, September 14, 2009, at <http://www.ausairpower.net/APA-2009-06.html> (September 24, 2010); Chris Mills, "F-35 Joint Strike Fighter vs Russia's New Airborne Counter-Stealth Radars," *Air Power Australia NOTAM No. 48*, September 14, 2009, at <http://www.ausairpower.net/APA-NOTAM-140909-1.html> (September 24, 2010); Carlo Kopp, "Russian/PLA Low Band Surveillance Radars (Counter Low Observable Technology Radars)," *Air Power Australia Technical Report*, updated February 2010, at <http://www.ausairpower.net/APA-Rus-Low-Band-Radars.html> (September 24, 2010); Norman Friedman, *The Naval Institute Guide to World Naval Weapon Systems*, 5th ed. (Annapolis, Md.: U.S. Naval Institute Press, 2006), p. 263; and Martin Streetly, *Jane's Radar and Electronic Warfare Systems 2004–2005*, 16th ed. (Coulsdon, U.K.: Jane's Information Group, 2004), p. 121.
63. Barrie and Komarov, "Fighter Order Rekindles Russian Air Force," and Gordon and Komissarov, *OKB Sukhoi*, p. 541.
64. Neelam Mathews, "Russia Submits Draft of FGFA Contract to India," *Aviation Week*, October 8, 2010.
65. Gordon and Komissarov, *OKB Sukhoi*, p. 541; Keijsper, *Joint Strike Fighter*, p. 249; and A&E Home Video, *Dogfights of the Future*.
66. Kopp, "Assessing the Tikhomirov NIIP L-Band Active Electronically Steered Array."

laser rangefinder (IRST/LR) optoelectronic system that was used in earlier Russian fighter aircraft. The T-50 prototype has already been fitted with a newer version. The system has a sensor in the cockpit and uses infrared and television channels for day and night operations; a laser rangefinder for accurate targeting; and a “look down/shoot down” capability for detecting, tracking, and engaging targets over land, sea, and air. The system can detect approaching fighters at 40 kilometers (km) and departing enemy fighters at 100 km.⁶⁸

According to some reports, a Russian-made IRST/LR may have already proven effective in downing U.S. stealth aircraft. Although the U.S. Air Force officially determined that the F-117A stealth fighter downed during the Kosovo crisis of 1999 was shot

According to some reports, a Russian-made IRST/LR may have already proven effective in downing U.S. stealth aircraft.

down by a Russian-made surface-to-air missile launched by the Serbs, some military analysts believe that it was shot down by a Russian-made MiG-29 operated by the Yugoslav air force. According to that account, the Serbian MiG-29 fired its infrared-guided missiles at the F-117A and destroyed it with the first missile launched. Some accounts say that the Serb pilot used the MiG-29's IRST/LR system to stealthily detect, track, and engage the F-117A,⁶⁹ even though the U.S. plane was designed to mask its engines' exhaust infrared signature. According to sources interviewed by *Jane's*

Defense Weekly, the Serbs may have intercepted the F-117A using the fighter's mission flight plan, which was allegedly stolen by a spy working for Russian military intelligence who had infiltrated NATO.⁷⁰

The F-22 does not have a built-in IRST/LR system, but such a system could be added. The F-35's electro-optical sensor system (EOSS), which includes the optronic distributed aperture system (DAS) and the electro-optical targeting system (EOTS), will give the fighter 360 degrees of infrared coverage for searching and tracking enemy surface and air targets. Using DAS, the F-35 could fire a short-range air-to-air missile at an enemy fighter in a lock-on mode and then escape from the fight.⁷¹ Ultimately, it is unclear exactly how the PAK FA's radar systems will compare in power and sensitivity with the radar systems in the F-22 and the F-35.

Range. The PAK FA's combat range will be roughly equivalent to the F-22's range, but possibly greater than the ranges of some F-35 variants. According to Russian sources, the PAK FA will have a maximum range of 5,500 km.⁷² Realistically, this is probably its maximum range with at least one air refueling. Similarly, the Russian fourth-generation Su-30MK multirole fighter reportedly has a top combat range of 5,200 km with one in-flight refueling. With internal fuel tanks, the PAK FA—like the Su-30M—will likely have a range of about 3,000 km.⁷³ By comparison, the F-22 has a reported combat range of more than 2,963 km with two external fuel tanks.⁷⁴ According to Russian sources, the PAK FA will be capable of repeated air refueling for extended operations.⁷⁵

67. See Michael J. Gething, ed., *Jane's Electro-Optic Systems 2006–2007*, 12th ed. (Coulsdon, U.K.: Jane's Information Group, 2006), p. 13.

68. Gordon, *Sukhoi Su-27*, pp. 175 and 428–429.

69. Yefim Gordon, *Mikoyan MiG-29* (Hinckley, U.K.: Midland Publishing, 2006), p. 273.

70. See Lajos F. Szászdi, *Russian Civil–Military Relations and the Origins of the Second Chechen War* (Lanham, Md.: University Press of America, 2008), p. 242.

71. The F-35 was not designed for super maneuverability in a dogfight. It lacks engine thrust vectoring control and has a higher wing loading. Sweetman, “All-Seeing Eye,” and Downs, *Jane's Avionics 2006–2007*, p. 616.

72. RIA Novosti, “Russia's Fifth-Generation Fighter T-50 (PAK FA),” January 29, 2010, at http://en.rian.ru/military_news/20100129/157717728.html (September 24, 2010); RIA Novosti, “Russia's Future Fighter Conquers the Skies,” RIA Novosti, “VVS predstavili predlozheniia po dorabotke ustrebitelia piatogo pokoleniia,” February 12, 2010, at http://www.rian.ru/defense_safety/20100212/208837122.html (September 24, 2010).

73. Jackson, *Jane's All the World's Aircraft 2006–2007*, p. 501.

In contrast, the U.S. Air Force's F-35A and the U.S. Navy's carrier-based F-35C will have a range of about 2,222 km with internal fuel tanks, but the U.S. Marine Corps's F-35B will have a range of about 1,667 km.⁷⁶

Weapons. With a maximum length of about 22 meters and a wingspan of 14.8 meters, the PAK FA will be similar in size to the Russian Su-27 Flanker fighter.⁷⁷ Both aircraft are larger than the F-22, which has an overall length of 18.9 meters and a wingspan of around 13.6 meters.⁷⁸ Because of its larger size, the PAK FA will be able to carry more fuel, more missiles, and heavier bombs internally.⁷⁹ It will also be able to carry numerous kinds of weapons, enabling it to simultaneously attack multiple surface and air targets in all weather conditions⁸⁰—hence, its classification as a multirole fighter.

The PAK FA could carry a deadly mix of weapons.⁸¹ Russia's Vypel State Machine-Building Design Bureau is reportedly developing very long-range beyond-visual-range (BVR) missiles and

short-range air-to-air missiles designed to fit inside the PAK FA's weapon bays.⁸² Development of the new R-77M BVR missile is due to be completed in 2010. The PAK FA could carry eight of these missiles in its two main weapon compartments.⁸³ Like the F-35,⁸⁴ the PAK FA may also be able to carry an additional BVR missile attached to the inner side of

Because of its larger size, the PAK FA will be able to carry more fuel, more missiles, and heavier bombs internally.

each weapon compartment door, enabling it to carry four R-77M missiles while reserving internal space for two bombs or two very long range air-to-air missiles. Another weapon under development for the PAK FA is the ramjet-powered R-77M-PD,⁸⁵ which has a reported range of 160 km, twice that of the R-77M.⁸⁶ The PAK FA could carry four of them internally.

74. Lockheed Martin, "F-22 Raptor: Specifications," at <http://www.lockheedmartin.com/products/f22/f-22-specifications.html> (September 24, 2010).

75. RIA Novosti, "Russia's Fifth-Generation Fighter T-50 (PAK FA)."

76. Lockheed Martin, "F-35 Lightning II Program Update and Fast Facts," August 11, 2010, at <http://www.lockheedmartin.com/data/assets/aeronautics/products/f35/F-35FastFacts.pdf> (September 24, 2010), and Jackson, *Jane's All the World's Aircraft 2006–2007*, p. 809.

77. RIA Novosti, "Russia's Future Fighter Conquers the Skies."

78. Lockheed Martin, "F-22 Raptor."

79. RIA Novosti, "Russia's Fifth-Generation Fighter T-50 (PAK FA)."

80. BBC News, "Russia Unveils Its First Stealth Fighter Jet," January 29, 2010, at <http://news.bbc.co.uk/2/hi/8486812.stm> (September 24, 2010); Sukhoi Company, "Sukhoi Company Launches Flight Tests of PAK FA Advanced Tactical Frontline Fighter," January 29, 2010, at <http://sukhoi.org/eng/news/company/?id=3143> (September 24, 2010); "Different FGFA Fighter Versions for India, Russia," *India Today*, September 29, 2008, at <http://indiatoday.intoday.in/site/StoryPrint?sid=16398&secid=4> (September 24, 2010); and "Russia's Fifth Generation Jet Tested Successfully," *Pravda*, January 29, 2010, at <http://english.pravda.ru/russia/economics/29-01-2010/111923-fifth-generation-0> (September 24, 2010).

81. Gordon and Komissarov, *OKB Sukhoi*, p. 541; Gordon, *Russian Air Power*, pp. 335–336; and RIA Novosti, "The T-50 Fifth-Generation Fighter."

82. Gordon and Komissarov, *OKB Sukhoi*, p. 541, and Robert Hewson, ed., *Jane's Air-Launched Weapons*, No. 45 (Coulsdon, U.K.: Jane's Information Group, 2005), p. 75.

83. RIA Novosti, "Russia's Fifth-Generation Fighter T-50 (PAK FA)"; RIA Novosti, "VVS predstavili predlozheniia po dorabotke ustrebitelia piatogo pokoleniia"; RIA Novosti, "Caza de quinta generaci3n realiza con 3xito segundo vuelo," February 12, 2010, at <http://sp.rian.ru/news/20100212/125083946.html> (September 24, 2010); and "Russia's Fifth Generation Jet Tested Successfully," *Pravda*. See also Gordon, *Sukhoi S-37 and Mikoyan MFI*, p. 83.

84. See pictures in Keijsper, *Joint Strike Fighter*, pp. 219–220.

85. Gordon, *Russian Air Power*, pp. 335–336.

86. Hewson, *Jane's Air-Launched Weapons*, p. 65.

The original R-37 air-to-air missile (maximum range of 300 km) was designed to shoot down valuable air targets, such as airborne warning and control system (AWACS) aircraft, Joint Surveillance Target Attack Radar System (J-STARS) aircraft, air tankers, reconnaissance planes, electronic warfare aircraft, transport aircraft, Airborne Laser aircraft, and bombers. Improved versions of the R-37 missile are under development, including the R-37M very long-range air-to-air missile (range of 300 km to 400 km) and the Izdelie 810 (range of 375 km to 450 km). They will also be able to engage targets at extremely high altitudes. Both of these next-generation missiles will have active and passive radar guidance systems designed to seek enemy radar and electronic countermeasures emissions. In passive mode, an R-77M missile could conceivably target an F-35 at up to 240 km if the F-35 is using its AESA radar in a jamming operation.⁸⁷

In addition to the larger weapons compartments, the PAK FA has two smaller compartments located in the rear, which could each carry one short-range air-to-air missile.⁸⁸ This design feature was borrowed from the F-22, which has two smaller side compartments, which could each hold one AIM-9M or AIM-9X.⁸⁹

The PAK FA's smaller compartments could accommodate several types of short-range air-to-air missiles. One possibility is an improved Vympel R-73M short-range air-to-air missile with a high off-boresight capability, which enables it to turn 160 degrees to engage enemy targets in the plane's rear hemisphere using infrared guided-missile technol-

ogy. It could lock on before or after launch, and the rear AESA radar could provide the necessary targeting information. This new missile, the Izdelie 760 or R-74, may have a range of around 40 km. It is due to enter production this year. Alternatively, the PAK FA could carry the Vympel K-30, a new compact short-range air-to-air missile, or the K-MD short-range air-to-air missile, a new weapon for close combat and for shooting down enemy missiles, which could be developed by 2013.⁹⁰

In its larger weapon compartments, the PAK FA could accommodate two precision-guided 1,500 kilogram (kg) bombs,⁹¹ such as the new KAB-1500LG family of laser-guided bombs. The PAK FA could also carry two satellite-guided KAB-500S-E bombs, which weigh 500 kg, or new versions that could weigh 1,500 kg. These bombs are dubbed "Russia's JDAM" after the highly effective U.S. bomb guidance package.⁹²

The U.S. Phantom Ray unmanned combat air vehicle (UCAV), which has been proposed as the basis for a future bomber, could carry two 1,000 kg JDAM bombs, or a payload of up to 2,000 kg, on a long-range strike mission of 3,704 km.⁹³ The stealthy UCAV can also carry eight Small Diameter Bombs and refuel in the air independently and repeatedly to enable it to conduct global strike operations.⁹⁴ The PAK FA, by contrast, could have an internal bomb payload exceeding 3,000 kg. In addition, the PAK FA might be able to carry two subsonic Kh-35E anti-ship missiles (range of 130 km) internally.⁹⁵ The PAK FA may also be able to carry two Kh-35UE GLONASS satellite-guided

87. Yefim Gordon, *Soviet/Russian Aircraft Weapons Since World War Two* (Hinckley, U.K.: Midland Publishing, 2004), p. 70; Hewson, *Jane's Air-Launched Weapons*, pp. 64 and 75–76; Gordon and Komissarov, *OKB Sukhoi*, pp. 541–542; and Gordon, *Russian Air Power*, pp. 335–336.

88. Fulghum *et al.*, "Stealth, Sukhoi-Style," p. 30.

89. See Jay Miller, *Lockheed Martin F/A-22 Raptor: Stealth Fighter* (Hinckley, U.K.: Aerofax, 2005), pp. 98–99.

90. Hewson, *Jane's Air-Launched Weapons*, pp. 24 and 28–30; Gordon and Komissarov, *OKB Sukhoi*, p. 541; Gordon, *Russian Air Power*, pp. 334–335; Fulghum *et al.*, "Stealth, Sukhoi-Style," p. 31.

91. RIA Novosti, "Russia's Fifth-Generation Fighter T-50 (PAK FA)"; "VVS predstavili predlozheniia po dorabotke ustrebitelia piatogo pokoleniia," *Pravda*; and RIA Novosti, "Caza de quinta generaci3n realiza con 3xito segundo vuelo."

92. Carlo Kopp, "Soviet/Russian Guided Bombs," *Air Power Australia Technical Report*, August 2009, at <http://www.ausairpower.net/APA-Rus-GBU.html> (March 11, 2010), and Hewson, *Jane's Air-Launched Weapons*, pp. 395–397.

93. Caitlin Harrington, "Boeing offers Phantom Ray bomber," *Jane's Defence Weekly*, March 10, 2010, p. 10.

94. *Ibid.*

missiles, which can strike land targets at a range of 260 km.⁹⁶

The PAK FA may also have up to eight external hardpoints to which additional missiles and bombs could be mounted.⁹⁷ The Indian FGFA and the PAK FA may be armed externally with “BrahMos super-sonic missiles,”⁹⁸ which were jointly developed by Russia and India, or the 3M55 Oniks anti-ship missile, which has a maximum speed of Mach 2.6 at altitude and a range of at least 300 km.⁹⁹

Speed. The PAK FA and F-22 are expected to have roughly equivalent top speeds and altitudes, but the F-35 is potentially less capable in both areas. The F-22 has demonstrated supercruise speeds above Mach 1.5 and is designed for sustained supersonic operation without using afterburners. Reportedly, it has a maximum supercruise speed of Mach 1.82 at 30,000 feet (9,000 meters) altitude.¹⁰⁰ Russian sources claim that the PAK FA is slightly faster (Mach 1.83) at 30,000 feet.¹⁰¹ High supercruise speeds enable these aircraft to control wide expanses of territory. The F-35 will not have supercruise capability.

Using afterburners, the F-22 has a maximum speed of about Mach 2.5,¹⁰² likely faster than the PAK FA. Although the Russian air force initially established the PAK FA's maximum speed at Mach 2.5, it revised its operational requirement down-

The PAK FA and F-22 are expected to have roughly equivalent top speeds and altitudes, but the F-35 is potentially less capable in both areas.

ward to Mach 2 in December 2004.¹⁰³ Nevertheless, the PAK FA will probably be able to reach Mach 2.45 with afterburners. The T-50 and F-22 will likely have the same service ceiling of about 20,000 meters.¹⁰⁴ By contrast, the F-35's maximum speed at altitude is about Mach 1.6 or more than Mach 1.8 with afterburners, and its maximum altitude is estimated to be 15,000 meters.¹⁰⁵

Maneuverability. The F-22's engine nozzles have thrust vector control for superior maneuverability, which can be essential in close air combat and for successfully evading attacking missiles. The PAK FA will incorporate the same capability.¹⁰⁶ However, the F-35 is not planned to be fitted with thrust vector control technology.

Both F-22 and F-35 fighters will likely have shorter takeoff distances than the PAK FA. In air interception mode, the F-22 may be able to take off from an airstrip of only 274 meters.¹⁰⁷ On land, the Marine Corps vertical/short take-off and landing (V/STOL) F-35B is capable of taking off in just

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95. Hewson, *Jane's Air-Launched Weapons*, pp. 172–174; Carlo Kopp, “Soviet/Russian Cruise Missiles,” *Air Power Australia Technical Report*, August 2009, at <http://www.ousairpower.net/APA-Rus-Cruise-Missiles.html#mozTocId501956> (September 24, 2010).
96. Carlo Kopp, “Soviet/Russian Cruise Missiles,” and Hewson, *Jane's Air-Launched Weapons*, pp. 172–173.
97. “Russia's Fifth Generation Jet Tested Successfully,” and Fulghum *et al.*, “Stealth, Sukhoi-Style,” p. 30.
98. RIA Novosti, “Russia, India to Develop Joint 5G-Fighter by 2016.”
99. Hewson, *Jane's Air-Launched Weapons*, pp. 168–169, and Kopp, “Soviet/Russian Cruise Missiles.” See also RIA Novosti, “La Marina rusa se dotará de la fragata ‘Almirante Gorshkov’ en 2011,” February 26, 2010, at <http://sp.rian.ru/news/20100226/125262287.html> (September 24, 2010).
100. Miller, *Lockheed Martin F/A-22 Raptor*, p. 102.
101. RIA Novosti, “Russia's Fifth-Generation Fighter T-50 (PAK FA).”
102. Lockheed Martin, “F-22 Raptor,” and RIA Novosti, “The T-50 Fifth-Generation Fighter.”
103. Gordon and Komissarov, *OKB Sukhoi*, p. 542.
104. RIA Novosti, “The T-50 Fifth-Generation Fighter,” and Miller, *Lockheed Martin F/A-22 Raptor*, p. 102.
105. Lockheed Martin, “F-35 Lightning II Program Update and Fast Facts”; Jackson, *Jane's All the World's Aircraft 2006–2007*, p. 809; and GlobalSecurity.org, “F-35 Joint Strike Fighter (JSF) Lightning II,” at <http://www.globalsecurity.org/military/systems/aircraft/f-35-specs.htm> (September 24, 2010).
106. RIA Novosti, “Russia Draws Back Veil of Secrecy with Peek at Future Fighter.”
107. Jamie Hunter, ed., *Jane's Aircraft Upgrades 2006–2007*, 14th ed. (Coulson, U.K.: Jane's Information Group, 2006), p. 184.

167 meters.¹⁰⁸ By contrast, the PAK FA requires an airstrip of 300 meters to 400 meters.¹⁰⁹ The F-22 also has a slightly higher maximum takeoff weight of 38 tons,¹¹⁰ compared to the PAK FA's reported 37 tons.¹¹¹

Engine. The PAK FA will be fitted with a new "engine of the second stage," which is set to begin development in 2010 or 2011.¹¹² The engines are being developed by the United Engine Building Corporation in cooperation with NPO Saturn and Salyut, Russia's two largest producers of aircraft engines. The engine in the T-50 prototype is the NPO Saturn 117M, an improved, modernized version of the 117S engine in Russia's Su-35 fourth-generation-plus aircraft, which already incorporates fifth-generation technologies, including a full-authority digital engine control system and three dimensional thrust vectoring control nozzles.¹¹³ The first operational PAK FAs would use the 117M engines. Later PAK FAs would use the new second-stage engine when it enters into service.¹¹⁴

According to Russian sources, the new PAK FA engine could provide 17,500 kg of thrust.¹¹⁵ Realistically, the engine may only achieve a lower thrust. It is still being developed, and Pogosyan stresses

that the engine will not be ready before 2015 and could take up to 12 additional years to develop fully.¹¹⁶

Communications. One feature of fifth-generation fighters is the ability to communicate vast amounts of tactical information in real time within a formation of fighters. The F-22 has an advanced communications, navigation, and identification system called the TRW AN/ASQ-220.¹¹⁷ It has multifunction antennas distributed in conformal arrays along the leading edges of the wings and vertical control surfaces, which enable radar track warning, missile launch detection, threat identification, and communication of this information between aircraft.¹¹⁸

It is unclear whether the PAK FA will have a comparable system, but it will likely have communication equipment that allows real-time data exchange within flight groups and with ground-based control systems.¹¹⁹ For example, the Indian FGFA will reportedly have a "very high degree of network centrality" and "multi-spectral reconnaissance and surveillance systems."¹²⁰ Like the F-22 and the F-35, the PAK FA and the Indian FGFA will presumably have sensor data fusion, which will organize the

108. GlobalSecurity.org, "F-35 Joint Strike Fighter (JSF) Lightning II."

109. RIA Novosti, "Russia's Fifth-Generation Fighter T-50 (PAK FA)."

110. Lockheed Martin, "F-22 Raptor."

111. RIA Novosti, "The T-50 Fifth-Generation Fighter."

112. RIA Novosti, "Rusia iniciará entre 2010 y 2011 la creación del motor de segunda etapa para el avión de quinta generación."

113. Pyadushkin and Barrie, "The Fifth Element," p. 82; Gordon, *Russian Air Power*, pp. 324 and 329; RIA Novosti, "Russia's Fifth-Generation Fighter T-50 (PAK FA)"; Gordon, *Sukhoi Su-27*, p. 175; and RIA Novosti, "Russia Draws Back Veil of Secrecy with Peek at Future Fighter."

114. Sweetman, "PAK FA Will Be Operational In 2015," and Pyadushkin and Barrie, "The Fifth Element," p. 82.

115. "Russia to Test Stealthy Fifth Generation Sukhoi T-50 Fighter Jet," *Pravda*, January 28, 2010, at http://english.pravda.ru/russia/economics/28-01-2010/111914-fifth_generation-0 (September 24, 2010).

116. ARMS-TASS, "Integratorom dvigatelia 2-go etapa dlia istrebitelia 5-go pokoleniia budet 'Obsiedinennaia dvigatelestroitel'naia korporatsiia,'" March 2, 2010, at <http://arms-tass.su/?page=article&aid=81615&cid=25> (September 24, 2010).

117. Jackson, *Jane's All the World's Aircraft 2006-2007*, p. 800.

118. Miller, *Lockheed Martin F/A-22 Raptor*, p. 88.

119. Sukhoi Company, "Sukhoi Company Launches Flight Tests of PAK FA Advanced Tactical Frontline Fighter." See also "Different FGFA Fighter Versions for India, Russia," and RIA Novosti, "Rusia desvela el futuro de su aviación de combate con el primer vuelo de su caza de quinta generación," January 29, 2010, at <http://sp.rian.ru/news/20100129/124894765.html> (September 24, 2010).

120. Pandit, "Russia Conducts First Test of Fifth-Generation Sukhoi."

information into a unified tactical picture and feed it to the pilot in easily usable form.¹²¹

The PAK FA may possibly be one step ahead of the F-22 and F-35 in computer processing functions. The PAK FA's computer will not only process data from various sensors and sources and provide it to the pilot, but also function as a battle management system. Instead of the system serving as the

The PAK FA may possibly be one step ahead of the F-22 and F-35 in computer processing functions.

pilot's pocket combat information center, it could serve as a combat direction center by analyzing the information and offering the pilot combat decisions from which to choose. The head of Avionika, Russia's leading avionics manufacturer, described the PAK FA as having "advanced avionics that act as an electronic pilot." Avionika representatives claim that "[t]he fighter itself analyses the situation and offers options to the pilot," which "greatly reduces the mental load on the pilot and allows him to focus on tactical tasks."¹²²

Whereas the F-22's sensor fusion technology is touted as allowing the pilot to spend "less time monitoring basic systems and more time making combat decisions,"¹²³ the PAK FA's battle management system could allow Russian pilots to spend less time making combat decisions if these were already made by the fighter's artificial intelli-

gence.¹²⁴ In this case, the pilot would then simply choose the best tactical decision offered by the plane's "electronic pilot" and press a button, which could give the pilot a decisive time advantage in combat. General Nikolai Makarov, chief of the General Staff of the Russian Armed Forces, describes the PAK FA's computer system as so powerful that it practically has "human intelligence."¹²⁵ The PAK FA's electronic pilot can also fly the plane autonomously in many situations, in much the same way that a UCAV is controlled. In other situations, the human pilot could use his discretion to fly the fighter manually, particularly to perform evasive maneuvers.

The T-50's instrument panel is dominated by two large color multifunction displays, similar to the Su-35's instrument panel. The screen arrangement may have been influenced by the cockpit design of the F-35 with two large multifunction displays integrated to form one large display. It is widely thought to be a simpler, easier-to-read arrangement than the four-multifunction-display design in the F-22 cockpit. The T-50's displays are surrounded by control buttons, in contrast to the F-35's touch screen technology. Touch screen technology may be incorporated into later versions of the PAK FA, depending on how the systems perform in testing.¹²⁶

Like the F-22, the T-50 currently has a heads-up display (HUD), a transparent display that presents data without requiring a pilot to look away from the view through the windshield.¹²⁷ In future versions of the PAK FA, pilots may have helmet-mounted

121. Shukla, "India, Russia Close to PACT on Next Generation Fighter."

122. Izvestia, cited in RIA Novosti, "What the Russian Papers Say," February 12, 2010, at <http://en.rian.ru/papers/20100212/157858932.html> (September 24, 2010).

123. A&E Home Video, *Dogfights of the Future*.

124. Sukhoi Company, "Sukhoi Company Launches Flight Tests of PAK FA Advanced Tactical Frontline Fighter," and Evgeniya Chaykovskaya, "New Russian Jet Fighter to Threaten Raptor?" *The Moscow News*, January 29, 2010, at <http://www.mn.ru/news/20100129/55406919.html> (September 24, 2010).

125. ARMS-TASS, "Rossiiskii samolet 5-go pokolenia budet obladat' ogromnim 'intellektom' i prevoskhodit' inostrannii mashini—nachal'nik Genshtaba VS RF," February 11, 2010, at <http://arms-tass.su/?page=article&aid=80998&cid=24> (September 24, 2010).

126. Cockpit photo, in Stels' Machine, "Perspektivni aviatsionni kompleks frontovoi aviatsii," at <http://www.paralay.com/pakfasu/556.jpg> (September 24, 2010); Gordon, *Russian Air Power*, p. 322; Keijsper, *Joint Strike Fighter*, pp. 170–171; Sweetman, "Lockheed Martin F-22 Raptor," in *International Air Power Review*, Vol. 5 (Summer 2002), p. 57; and Miller, *Lockheed Martin F/A-22 Raptor*, p. 85.

127. Cockpit photo, in Stels' Machine, "Perspektivni aviatsionni kompleks frontovoi aviatsii."

displays (HMD), like those planned for the F-35 and upgraded F-22.¹²⁸ HMDs are similar to HUDs, but project the information onto the pilot's visor, allowing the pilot to obtain situational awareness and cue weapons systems based on the direction the pilot's head is facing.

Implications for U.S. Defense Policy and Force Structure

If the PAK FA proves to be as deadly as Russian officials claim, the Pentagon will need to revise its assessment of U.S. air superiority requirements. New requirements could expose larger fighter shortfalls in the Air Force and Navy than are currently predicted—not just numerically, but also in terms of vital air superiority capabilities. If a new, comprehensive assessment leads the U.S. Air Force to revise its fighter requirements upward in numbers and/or capabilities, the Air Force, Department of Defense, and Congress should explore ways to modernize and strengthen the U.S. tactical fighter force. Specifically, Congress should:

- **Fund F-22 tooling to preserve future options.** Given the uncertain long-term threat environment and the possible proliferation of PAK FA fighters to countries that are hostile to the U.S. and its allies, purchasing additional F-22s may be in the national interest, both to augment U.S. fighter forces and to enable loyal allies to defend themselves against the PAK FA threat. The best way to preserve that option would have been to sustain domestic production in the U.S. Regrettably, with the F-22 production line shut down, resuming production may prove prohibitively expensive. Nonetheless, to hedge against this threat, the U.S. Air Force has decided to “retain tooling for the F-22” so that it can repair and modernize existing F-22s and possibly manufacture new Raptors in the future.¹²⁹ Congress
- **Allow Japan and Israel to acquire export variant F-22s.** Another helpful hedge against uncertainty would be for Congress to allow loyal allies, such as Japan and Israel, to purchase an allied variant of the F-22 from the U.S. This would preserve the U.S. capability to procure additional F-22s and improve their capabilities if needed. In June 2010, Boeing announced that it would share F-18 technologies with Japan and allow Japan to develop a new derivative of the F/A-18 Super Hornet itself.¹³⁰ Similar arrangements should be made for the development of F-22 technologies. The U.S. could encourage Lockheed Martin and Boeing to allow Japan and Israel access to some F-22 technologies so that they can develop them further in pursuit of F-22 allied variants. Israel Aerospace Industries is in negotiations to manufacture the wings for its future F-35.¹³¹ If the PAK FA is exported to countries in the Middle East and proves as effective as Russia and India have been claiming, the F-22 would be the best aircraft to guarantee the Israeli Air Force's air superiority in the region.
- **Invest in pilot training.** The short-sighted decision to cancel F-22 production has constrained the U.S. ability to improve the technological and numerical advantages of its fighters, but the U.S. military still maintains a significant skills overmatch. America's pilots are the best trained in the world. Maintaining this advantage could prove decisive on the battlefield. However, wartime demands and financial strains from current operations in Iraq, Afghanistan, and elsewhere have undermined pilot training to some degree. The range and intensity of training courses have suffered as scarce resources have been diverted toward developing capabilities for ongoing oper-

128. Keijsper, *Joint Strike Fighter*, pp. 172–173 and 176, and A&E Home Video, *Dogfights of the Future*.

129. Stephen Trimble, “Lockheed to Preserve Tooling for Future Use,” *Flight International*, July 30, 2010, at <http://www.flightglobal.com/articles/2010/07/30/345519/lockheed-to-preserve-f-22-tooling-for-future-use.html> (October 19, 2010).

130. Leithen Francis, “Boeing Willing to Let Japan Develop New Derivative of the F/A-18,” *Flightglobal*, June 9, 2010, at <http://www.flightglobal.com/articles/2010/06/09/343016/boeing-willing-to-let-japan-develop-new-derivative-of.html> (September 24, 2010).

131. Yaakov Katz, “Israel Mutes Concerns Ahead of Arms Sale Signing,” *Jane's Defence Weekly*, September 22, 2010, p. 18.

ations. Congress should renew its efforts to fully fund aviation training to help to sustain American dominance of the skies.

- **Fully fund the F-35 Joint Strike Fighter and develop additional force multipliers.** Investing in additional force multipliers is another way to maximize the impact of limited numbers of F-22s. Congress should provide adequate funding and oversight to ensure that the F-35 program succeeds. Congress should fully fund the President's fiscal year 2011 budget request for 42 F-35s. Congress should then ask the Defense Department to explore an additional cost-effective option to build stealth unmanned combat aerial vehicles. These could operate from land bases and aircraft carriers, conducting intelligence, reconnaissance, and surveillance missions as well as strike operations with the F-35. In a tactical scenario, F-22s and F-35s could engage enemy fighters in air combat, while other formations of F-35s and UCAVs attack SAM and radar sites, command and control centers, and air bases, overwhelming the adversary's defenses with sheer numbers.
- **Build an alternate engine for the Joint Strike Fighter.** If Congress fails to fund the alternate engine this year, even though the program is more than 80 percent complete, the success of the F-35 will depend on only one type of engine. In 2035, the F-35 will constitute 90 percent of all U.S. fighters. Thus, because the F-35 is a single-engine plane, a problem with the engine could ground all F-35s until the problem is identified and fixed, unless an alternative engine is available. Such a scenario constitutes an unacceptably high risk. Further, in 2009, Congress passed an acquisition reform law that requires competition for all major subsystems, including fighter engines. This engine program would also help to ensure that the U.S. maintains engine competition for future fighter programs including potential sixth-generation aircraft.
- **Strengthen economic and military-to-military cooperation with India.** India's involvement in the PAK FA program could be potentially helpful. A large fighter fleet in the hands of the world's largest democracy and a key American partner could counterbalance China's growing air power capabilities and other powers in the region. Given the historical rivalry between India and China, New Delhi will likely seek to convince Moscow to restrict exports of advanced weapons technology, such as the PAK FA fighter, to China. Indeed, India may make its participation in the project contingent on such restrictions. India is increasingly relying on U.S. weapons technology and equipment to fulfill its military modernization requirements, while still maintaining a strong defense relationship with Russia, its long-standing friend. The U.S. should continue to strengthen economic and security cooperation with India. The U.S. Air Force and Indian Air Force should continue to conduct joint wargaming exercises, such as Red Flag in 2008.¹³² Just as Lockheed Martin reportedly offered the F-35C to the Indian Navy to deploy on its future aircraft carriers,¹³³ the Administration should encourage the Indian Air Force to acquire the Joint Strike Fighter, allowing it to operate alongside the FGFA.
- **Continue to modernize the U.S. Air Force.** The Air Force and Congress should adopt a longer view and begin to research and develop a sixth-generation fighter. For the first time since the beginning of military aviation, the U.S. military does not have a manned aircraft program under development. Boeing has already revealed its design concept for a sixth-generation fighter, featuring a stealth and tailless aircraft with supercruise capability that would replace the Navy's F/A-18E/F in 2025 and the F-22 in 2027–2028.¹³⁴ As the U.S. military margins of technological superiority decline across the board, select competitors and potential future challeng-

132. See IndiaServer, "US Air Force Wants IAF Regularly in Red Flag Exercise," at <http://www.india-server.com/news/us-air-force-wants-iaf-regularly-in-red-3170.html> (September 24, 2010).

133. RIA Novosti, "EEUU presentará el caza F-35 en el concurso convocado por la India," June 29, 2010, at <http://sp.rian.ru/international/20100629/126917366.html> (September 24, 2010).

ers are embarking on their own military modernizations. Rather than cede ground, the U.S. should begin developing new fighter aircraft and air defenses that are so effective that they discourage rivals from developing or even investing in stealth fighter aircraft. The greater the U.S. air power advantage, the riskier and costlier other countries' air power investments will be.

- **Deploy networked anti-stealth surveillance against emerging stealthy air threats.** In cooperation with Israel, the U.S. should produce and deploy a new generation of CAEW¹³⁵ with "track before detect" technology for both Air Force and Navy aviation to detect stealth aircraft and low-observable flying craft.¹³⁶ In addition, the U.S. should deploy electronic intelligence (ELINT) aircraft with an airborne detection system similar to the Czech Tamara, which can reportedly detect stealth aircraft using the signals from its avionics. Surveillance satellites equipped with radar may also be able to detect and track stealth fighters because the upper surface of their stealth designs might not be as stealthy against radar waves from space. ELINT satellites might also detect the signals from the avionics of stealth fighters flying in formation. Stealth fighters can also be detected with low-frequency metric-band radars by using computers to identify low-observable targets in a cluttered environment.¹³⁷

Ladar (laser radar) in combination with radar could help to detect, track, and identify air targets, including stealth aircraft.¹³⁸

Conclusion

The decision by the Obama Administration and Congress to permanently close the F-22 production line has exposed the U.S. and its allies to increased security risks in the future. This was entirely predictable. In a rapidly changing threat environment in which rising powers and potential rivals are expanding their global presence, developing advanced weapons systems, and becoming more assertive, the U.S. needs to preserve a wide range of core defense capabilities to ensure that the U.S. military will remain dominant and can hedge against all possible contingencies. Instead, the U.S. has reduced its aerospace manufacturing to one fifth-generation fighter production line, while China and Russia are operating 12 fighter and bomber lines between them today.

Although the F-22 cancellation decision took a valuable defense option off the table, Congress can still salvage other possibilities for the future. Congress and the Pentagon should focus on widening the U.S. lead in the areas where the nation retains a competitive advantage, such as piloting skills, research and development, and innovation. Defense and military leaders should work with friends and

134. Caitlin Harrington, "Boeing Unveils Concepts for Sixth-Generation Fighter," *Jane's Defence Weekly*, May 19, 2010, p. 5.

135. Conformal Airborne Early Warning.

136. The Israeli operational CAEW system uses a dual frequency L-band and S-band radar system combined with powerful signal processors to detect, track, and identify the weak signals that may be generated by stealth aircraft and unmanned aerial vehicles. See Martin Streetly, ed., *Jane's Electronic Mission Aircraft*, No. 21 (Coulsdon, U.K.: Jane's Information Group, 2008), pp. 29–30.

137. Carlo Kopp, "Russian/PLA Low Band Surveillance Radars (Counter Low Observable Technology Radars)," *Air Power Australia Technical Report*, updated February 2010, at <http://www.ousairpower.net/APA-Rus-Low-Band-Radars.html> (April 2, 2009); Balajti Istvan, "Multi-Radar Tracking of VHF Radar Plots," *Zrinyi Miklos Nemzetvedelmi Egyetem*, at <http://www.zmne.hu/tanszekek/ehc/konferencia/may/balajti.htm> (April 3, 2009); and P. Lacomme, "Airborne Metric Frequency Surveillance Radar," *Radar '97 Conference Publication No. 449*, October 14–16, 1997, pp. 70–74.

138. Christopher Bolkcom and John Pike, *Attack Aircraft Proliferation: Issues For Concern*, Federation of American Scientists Space Policy Project, updated June 15, 1996, chap. 6, at <http://www.fas.org/spp/aircraft/part06.htm> (May 10, 2009); J. Gavan, "Ladar/Radar Dual Mode Operation System for Enhancing Tracking Range and Accuracy," *International Journal of Infrared and Millimeter Waves*, Vol. 15, No. 1 (January 1994), pp. 145–149 and 152–153; M. Haridim, H. Matzner, Y. Ben-Ezra, and J. Gavan, "Cooperative Targets Detection and Tracking Range Maximization Using Multimode LADAR/RADAR and Transponders," *Progress in Electromagnetic Research*, No. 44 (2004), pp. 217–219 and 226–227; and Alex Lovett and Chyau Shen, "Radiant Outlaw Technology for Non-Cooperative Identification," presented at the TECOM Test Technology Symposium '97, March 19, 1997, at <http://www.fas.org/irp/program/collect/docs/radiant-outlaw97.htm> (May 9, 2009).

allies to reinforce collective defense and to ensure that the world's freedom-loving democracies maintain their ability to secure the skies.

—*Mackenzie Eaglen* is Research Fellow for National Security and *Lajos F. Szaszdi, Ph.D.*, is a former Researcher in the Douglas and Sarah Allison

Center for Foreign Policy Studies, a division of the Kathryn and Shelby Cullom Davis Institute for International Studies, at The Heritage Foundation. Julia Bertelsmann, a former Heritage Research Assistant, assisted in writing this report.