

Ashley J. Tellis



dogfight!

India's Medium Multi-Role Combat Aircraft Decision

CARNEGIE ENDOWMENT

FOR INTERNATIONAL PEACE

WASHINGTON DC ■ MOSCOW ■ BEIJING ■ BEIRUT ■ BRUSSELS

WASHINGTON DC ■ MOSCOW ■ BEIRUT ■ BRUSSELS ■ BEIJING

dogfight!

India's Medium Multi-Role Combat Aircraft Decision

Ashley J. Tellis

CARNEGIE ENDOWMENT

FOR INTERNATIONAL PEACE

© 2011 Carnegie Endowment for International Peace. All rights reserved.

The Carnegie Endowment does not take institutional positions on public policy issues; the views represented here are the author's own and do not necessarily reflect the views of the Endowment, its staff, or its trustees.

**For electronic copies of this report, visit:
CarnegieEndowment.org/pubs**

Carnegie Endowment for International Peace
1779 Massachusetts Avenue, NW
Washington, DC 20036
Phone: +1 202 483 7600
Fax: +1 202 483 1840
CarnegieEndowment.org

CONTENTS

Acknowledgments	v
Acronyms and Abbreviations	vi
Summary	1
Introduction	3
Conclude The MMRCA Competition Expeditiously	9
Do Not Split the MMRCA Purchase	19
Buy the “Best” Aircraft for the Mission	25
Conclusion	131
Notes	135
About the Author	141
Carnegie Endowment for International Peace	142

ACKNOWLEDGMENTS

The author has incurred many debts in the writing of this report. He is deeply grateful to several individuals in the U.S. and European aviation industry, defense officials in Europe, India, and the United States, officials in the government of India, and officers in the United States Air Force and the Indian Air Force who discussed the six aircraft involved in India's medium multi-role combat aircraft competition. Special thanks are also owed to C. Uday Bhaskar, Dan Blumenthal, Peter Garretson, Gregory Jones, Benjamin Lambeth, M. Matheswaran, and Arun Prakash for their close reading and thoughtful comments on the manuscript. Peter Austin aided the author with all manner of research assistance and spent his Christmas break readying this manuscript for publication—to him especially goes the author's deepest appreciation. Needless to say, the author alone is responsible for the substance and the conclusions of the report.

ACRONYMS AND ABBREVIATIONS

AAA	Anti-aircraft artillery	EW/CGI	Early warning and ground control intercept
AAM	Air-to-air missile	FLIR	Forward looking infrared
AESA	Active Electronically Scanned Array	HAL	Hindustan Aeronautics Limited
AEW	Airborne early warning	HOTAS	Hands on throttle and stick
AI	Air intercept	IADS	Integrated air defense systems
AMCA	Advanced Medium Combat Aircraft	IAF	Indian Air Force
AMRAAM	Advanced Medium Range Air-to-Air Missile	IDECM	Integrated Defensive Electronic Countermeasures
ASMAR	Active Multimode Solid-State Active Radar	IEWS	Integrated Electronic Warfare System
ATFLIR	Advanced Tactical Forward Looking Infrared	IFF	Identification, friend or foe
ATRD	Active towed radar decoy	IIR	Imaging infrared
AWACS	Airborne warning and control system	IJT	Intermediate Jet Trainer
BVR	Beyond-visual-range	IRST	Infrared search and tracking
C³I	Command, control, communications, and intelligence	ISR	Intelligence, surveillance, and reconnaissance
CAESAR	Captor Active Electronically Scanned Array Radar	JDAM	Joint Direct Attack Munition
C-AISR	Counter-airborne intelligence, surveillance and reconnaissance	JSOW	Joint Standoff Weapon
CAP	Combat Air Patrol	LCA	Light Combat Aircraft
CCD-TV	Charge-coupled device television	LPI	Low probability of intercept
CCS	Cabinet Committee on Security	MAWS	Missile approach warning system
DAS	Defensive avionics suite	MMRCA	Medium multi-role combat aircraft
DASS	Defensive Aids Sub-System	MOD	Ministry of Defense
DPB	Defense Procurement Board	NORA	Not Only a Radar
DPP	Defense Procurement Procedure	PAF	Pakistan Air Force
DRFM	Digital radio frequency memory	PESA	Passive Electronically Scanned Array
EADS	European Aeronautic Defence and Space Company	PIRATE	Passive Infra-Red Airborne Tracking Equipment
EOTS	Electro-Optical Targeting System	PLAAF	People's Liberation Army Air Force
ESM	Electronic support measures	R&D	Research and development
EW	Electronic warfare	RCS	Radar cross-section
		RFP	Request for Proposals
		RWR	Radar warning receiver
		SAM	Surface-to-air missile
		SEAD	Suppression of enemy air defenses
		T/R	Transmit/receive
		UAV	Unmanned aerial vehicle
		WVR	Within-visual-range

SUMMARY

The Indian air force (IAF) is entering the final stages of selecting a new medium multi-role combat aircraft (MMRCA). At a cost of about \$10 billion for 126 aircraft, the MMRCA competition is the largest Indian fighter tender in years. Eight countries and six companies eagerly await the outcome of the selection process, which has garnered high-profile attention for its sheer size, its international political implications, and its impact on the viability of key aircraft manufacturers. Furthermore, the winner will obtain a long and lucrative association with a rising power and secure a foothold into other parts of India's rapidly modernizing strategic industries. Once selected, the aircraft will play an essential role in India's military modernization as the country transitions from a regional power to a global giant.

The MMRCA competition comes as challenges to India's national security are increasing in intensity and complexity. Ever since the 1971 war, India's defense strategy has relied on maintaining superior airpower relative to both China and Pakistan. In the event of a regional conflict, Indian air power would serve as the country's critical war-fighting instrument of first resort. Due to delays in its defense procurement process as well as accidents and retirements of older fighter aircraft, however, India's force levels have reached an all-time low of 29 squadrons, and the IAF is not expected to reach the currently authorized force levels of 39.5 squadrons before 2017. This growing and dangerous hole in the IAF's capabilities comes as India's neighbors are aggressively modernizing their own air forces, making India's need to expand its combat aircraft inventories all the more urgent.

In choosing an aircraft, the government of India must employ a speedy decision process that is focused on the right metrics, taking both technical

and political considerations into account. The IAF has already evaluated the six MMRCA competitors against 660 technical benchmarks and has provided its recommendations to the Ministry of Defense. While the IAF has paid special attention to the fighters' sensors and avionics, weapons, aerodynamic effectiveness, and mission performance, India's civilian security managers are certain to emphasize technology transfer as well as costs when making their decision. In fact, the winning aircraft for the IAF ought to be chosen on the triangular criteria of technical merit, relative cost, and optimal fit within the IAF's evolving force architecture.

Political considerations, however, will be key in the selection process. In choosing the winning platform, Indian policymakers will seek to: minimize the country's vulnerability to supply cutoffs in wartime, improve its larger military capacity through a substantial technology infusion, and forge new transformative geopolitical partnerships that promise to accelerate the growth of Indian power globally. While Indian leaders may be tempted to split the purchase among vendors to please more than one country, doing so would needlessly saddle the IAF with multiple airframes in return for meager political gains.

Given the technical and political considerations, New Delhi should conclude the MMRCA competition expeditiously, avoid splitting the purchase between competitors, and buy the "best" aircraft to help India to effectively prepare for possible conflict in Southern Asia. Because of the dramatic transformations in combat aviation technology currently underway, the Indian government should select the least expensive, mature, combat-proven fourth-generation fighter for the IAF as a bridge toward procuring more advanced stealth aircraft in the future.

Under this criterion, the European aircraft are technically superb, but the U.S. entrants prove to be formidable "best buys." If Washington wants an American aircraft to win the game, however, it will need to offer generous terms on the transfer of technology, assure India access to fifth-generation U.S. combat aircraft, and provide strong support for India's strategic ambitions—to counter the perception that the older U.S. designs in the MMRCA race are less combat effective.

In making its decision, India's government must keep the IAF's interests consistently front and center to ensure that its ultimate choice of aircraft is the best one for the service. This will not only help India to strengthen its combat capabilities in the coming years but position it as a rising global power worthy of respect far into the future.

INTRODUCTION

Almost a decade after it began its search for a new multi-role combat aircraft, the IAF is now in the late stages of selecting its preferred fighter from among six different competitors. From summer 2009 to summer 2010, the IAF supervised flight trials of the American Boeing F/A-18E/F Super Hornet and Lockheed Martin F-16IN Super Viper, the French Dassault Aviation Rafale, the Russian RSK MiG's MiG-35, the European Eurofighter Consortium's Typhoon, and the Swedish Saab Gripen NG (Next Generation). Besides the extensive demonstrations conducted in the home countries of these manufacturers, the IAF also directed grueling fly-offs in three different Indian locations—Bangalore, Jaisalmer, and Leh—to test the comparative performance of the aircraft under conditions of extreme humidity, intense heat, and high field elevations, respectively.¹

These field trials constituted just the fourth of the eight stages called for by India's defense procurement procedures for major purchases (see Box 1). However, this step represented the most important *empirical* component of the process: the end-users had the opportunity to inspect at close quarters the aircraft, their key subsystems, and their performance. Accordingly, the conclusion of these fly-offs signified the beginning of the end of this hotly contested competition.

BOX 1. India's Defense Procurement Procedure for Major Acquisitions

1. Formulating Qualitative Service Requirements
2. Solicitation of Offers
3. Technical Evaluations
4. Field Trials
5. Staff Evaluations
6. Technical Oversight Report
7. Commercial Offer Evaluations
8. Contract Signing and Management

As far as the IAF is concerned, the end of stage four of the procurement process could not have come a moment too soon. Demonstrating the urgency, the IAF's Principal Director, Air Staff Requirements, and his team worked feverishly to compile the Flight Evaluation Trials and Staff Evaluation reports, as required by stage five of the acquisition procedure. These reports were handed over to India's Ministry of Defense in early August 2010. At the moment, the ministry's Technical Offset Evaluation Committee is assessing the offset proposals tabled by each original equipment manufacturer as a prelude to creating the short list for the commercial evaluation—stage seven of the process—which will be based on the compliance results from the flight evaluations and the quality of the technical offset proposals.

Given the international attention on this program and the pervasive fears in India about corruption in defense procurement, the IAF has bent backwards to be both scrupulously transparent and extraordinarily neutral throughout this process. Soon after the trials, for example, IAF leaders briefed each of the competitors in detail about how their individual aircraft performed against the IAF's requirements during the fly-offs.

The IAF's reports to the Ministry of Defense were equally comprehensive—and impartial to the point of appearing disinterested. The Air Staff Requirements team compiled detailed data on how each of the contending airplanes complied with the 660 test points stipulated by the service. One

well-connected Indian commentator, in fact, claimed that in its zeal for impartiality, the IAF chose neither to draw any conclusions about these results nor make any recommendations for a finalists' shortlist, leaving the Ministry of Defense to draw the appropriate conclusion on each count.²

This account exaggerates somewhat. The IAF did rank-order the aircraft based on their technical merit, but the reasons for the service's skittishness are not hard to appreciate. The Indian MMRCA competition is big. It is the largest Indian fighter tender in recent years and will likely cost the exchequer something in the vicinity of \$10 billion—and that is only for starters. This outlay is intended to procure 126 combat aircraft: the first eighteen will be delivered in flyaway form by the original equipment manufacturer, with the remaining 108 to be assembled in India through a combination of kits supplied by the foreign seller and indigenous Indian production.

The Indian *Request for Proposals* (RFP) also requires that 60 percent of the aircraft's technology be transferred to India in four phases, with different percentages of technology transfer occurring in each phase. This conveyance is intended to underwrite both the indigenous manufacture of the selected aircraft

and its subsequent maintenance and support, with 50 percent of the foreign exchange component of the purchase costs being defrayed through direct offsets within the Indian aerospace sector.

Given the IAF's weakening force structure—an issue that will be discussed later in this report—it is a distinct possibility that the eventual Indian MMRCA buy will exceed the initial 126 aircraft. The revenue gains to aircraft manufacturers from such an expanded purchase are considerable. In fact, the initial tranche itself is lucrative

enough to warrant strong interest by almost every major international vendor—especially in an era of steady contraction of the mature military markets of the West. Equally pertinent, New Delhi is poised to spend more than \$80 billion

The MMRCA is the largest Indian fighter tender in recent years and will likely cost the exchequer something in the vicinity of \$10 billion—and that is only for starters.

on capital acquisitions in the 2010–2015 timeframe. Thus securing a foothold in this burgeoning market makes the MMRCA prize even more valuable than its putative sticker price. Not only will the winner obtain a long and lucrative association with a rising great power, it will also get a toehold into other parts of India’s rapidly modernizing strategic industries.³

Just as important as these considerations is the fact that the MMRCA competition will heavily affect the viability of several international aircraft programs, especially the Gripen, Typhoon, and Rafale. These three do not enjoy the luxury enjoyed by U.S. aircraft manufacturers—namely, large captive domestic markets. If success in the MMRCA competition or another, smaller international contest does not materialize, it is possible, as one respected aviation analyst concluded, that some of the losers in this competition “might be eliminated from fighter markets where they have competed for decades, facing, at best, a hard and uncertain road back into the business.”⁴

Finally, the combat aviation business, like most defense trade, implicates the interests not simply of important companies but also their governments. In the case of the MMRCA, several states, each important to India in different ways, have sought to intercede on behalf of their own national offerings: France on behalf of the Rafale (where the aircraft finally made it into the MMRCA competition after Dassault’s late efforts to sell India more Mirage 2000s came a cropper in the face of IAF opposition); the United Kingdom and, particularly, Germany canvassing for the Typhoon; Sweden advocating the Gripen; Russia promoting the MiG-35; and, the United States championing its two private entrants, the F-16IN and the F/A-18E/F.

Given the multiple, often conflicting pressures, it is not surprising that the IAF, for its part, has focused mainly on assessing the extent of technical compliance with its 660 benchmarks. Knowing that any IAF decision would inevitably evoke intense interest on the part of major international firms, key

Not only will the winner obtain a long and lucrative association with a rising great power, it will also get a toehold into other parts of India’s rapidly modernizing strategic industries.

foreign governments, and important constituencies in India and abroad—including the government of India itself—IAF leaders have played the MMRCA competition thus far by the book. Having evaluated the competing fighters, identified the extent of their compliance, and appraised them on technical merit, they have left the responsibility for the formal “downselect” of the finalists to the civilian bureaucrats in the Ministry of Defense, who, in any case, are responsible for decisions pertaining to commercial evaluation, offsets, and contract management.

The fact that India’s civilian security managers in the Ministry of Defense and, ultimately, its political leaders who man the Cabinet Committee on Security (CCS), will make the final decision about which aircraft will be procured, underscores one critical reality about the prospective MMRCA countdown. Although the technical qualities of the airplanes, their relative costs, the prospects for technology transfer, and the capacity of the vendors to “leaven” the Indian defense industrial base effectively will all play a role in which candidates are finally shortlisted for contract negotiations, political considerations are

likely to influence which aircraft is eventually selected for the IAF.

Political considerations are likely to influence which aircraft is eventually selected for the IAF.

India’s civilian leaders, both bureaucrats and politicians, are generally not well versed in defense matters. Many of them already appear to believe that at the end of the day most of the competitors in the IAF’s MMRCA fly-off are roughly comparable in capability and, hence, strategic considerations

can dominate technical parameters in aircraft selection without any prejudice to India’s national security. Whether this intuition is correct cannot be conclusively confirmed from the outside, but the IAF’s Field Evaluation Trials and Staff Evaluations should give them the information they need to confirm or disprove their intuitions. Adjudicating these assessments, however, in the context of larger considerations will not be an easy task, but it illustrates why Max Weber once described—appropriately—all political action as being “the strong and slow boring of hard boards.”⁵

This report on India’s MMRCA competition has three broad objectives.

First, it elucidates the kind of combat aircraft that would be necessary for India, given the operational environment that the IAF is likely to confront

over the next few decades. Much of this may be known to air power specialists in India and abroad, but it is generally obscure to policymakers and the larger public.

Second, it illuminates the difficult tradeoffs that India would be confronted with as it chooses among six excellent airplanes on the triangular criteria of technical merit, relative cost, and force structure integrity. The public discussion about the various MMRCA competitors thus far has been dominated by debates about aircraft quality. This is understandable when sophisticated platforms are at issue, but the analysis often does not focus on the right criteria. In any case, this report seeks to broaden the debate by including a discussion of platform quality but integrating it, even if only as a first cut, with questions of cost and force structure in order to highlight the need for Indian decision makers to optimize amid different competing considerations.

Third, it seeks to achieve the foregoing aims by advancing three specific injunctions that policymakers in New Delhi should take to heart as they make their final decision: (1) conclude the MMRCA competition expeditiously; (2) do not split the MMRCA purchase; and, (3) buy the “best” aircraft for the mission. Because of the dramatic transformations in combat aviation technology currently underway, it urges the government of India to select the least expensive, mature, combat-proven fourth-generation fighter for the IAF as a bridge toward procuring more advanced stealth aircraft in the future. As the two American airplanes in the MMRCA fly-off struggle against the perception that their older designs render them unviable competitors—a prejudice not corroborated by the facts—the U.S. government ought to permit the technology transfer package necessary to help its aircraft win the contract.

It is hoped that the analysis offered in this report will contribute to a better understanding of India’s security challenges in the United States, while simultaneously helping Indian security elites and policymakers think through the complexities of an acquisition decision that will leave its mark on the IAF for many years to come.

Policymakers in New Delhi should (1) conclude the MMRCA competition expeditiously; (2) do not split the MMRCA purchase; and, (3) buy the “best” aircraft for the mission.

CONCLUDE THE MMRCA COMPETITION EXPEDITIOUSLY

It is an open secret that although India remains one of the largest arms importers in the world, its defense procurement processes have become seriously dysfunctional in recent years. The problems here are legion and the fact that the Indian armed forces routinely return tens of millions of rupees in unspent procurement funds to the national treasury year after year is a startling indicator of some of the challenges. The failure to spend resources already allocated for procurement does not imply that the uniformed services fail in their duty to identify requirements, solicit bids, conduct trials, and make the appropriate choices. Invariably, these activities are undertaken as specified by the covering regulations, but the process frequently fails to close with a successfully completed contract that yields the needed equipment.

This abortive outcome sometimes results from tenders being withdrawn either because they were poorly drafted or because of errors made in the evaluation process. But ever since the Bofors procurement scandal in the late 1980s, a paralyzing shadow has hung over all Indian arms acquisitions: the specter of “corruption.” The fear of corruption, or even the allegations thereof, which are usually leveled by the losers or other interested bystanders in a competition has had the stultifying effect of either paralyzing the acquisition process or delaying it interminably, or, on rare occasions, even nullifying procurement decisions already announced or on the cusp of being unveiled. Faced with such a charged atmosphere, Indian politicians and civil servants have become exceedingly shy of making rapid procurement decisions for fear of inviting accusations of dishonesty—with the ironic result that concerns about probity have now undermined the preparedness of the Indian military.

Obviously, the sclerosis in defense procurement is not solely the product of an obsession with keeping one's hands clean. There are several other factors responsible for this outcome: the complexity of the acquisition procedure itself, the competition between the domestic defense research establishment and the armed forces, the failure of civilian security managers often to understand both national defense requirements and the utility of specific military technologies, and the chokehold exercised by the Ministry of Finance in important matters pertaining to defense have all contributed collectively to the pathologies of defense acquisition in contemporary India.⁶

Unfortunately for the Indian military—and for the Indian state more generally—defense acquisition problems have resulted in exacerbating its modernization challenges and force structure problems at precisely the time when the national security challenges facing New Delhi have grown more complex, the demands on the Indian armed services are rising, and India's immediate adversaries are actually growing in capability.

The plight of the IAF provides a particularly clear illustration of the problem. Ever since the 1971 war, India's defense strategy has pivoted on maintaining, *inter alia*, superior air power capabilities relative to its immediate neighbors, Pakistan and China. Given India's enormous size and the dispersal of its land forces throughout the country—a product of its historical inheritance, its traditionally reactive military strategy, and the persistence of internal security challenges—the IAF has always been viewed as the nation's premier quick reaction force in the event of a surprise attack.

The basic characteristics of air power—speed, range, mobility, and lethality—permitted India to maintain its heavy land combat formations (as well as its naval forces) at lower levels of routine readiness. Swift and superior air forces, it was expected, would parry the enemy's land or air attacks until the bulk of its other military assets could be either committed from their customary locations or redeployed from their relatively distant peacetime positions deep within the country.⁷ Even today, when India's frontier forces possess far greater combat capability than they ever did historically, the IAF is still viewed as the principal rapid response component of Indian military power—and for very good reason.

At present, when true surprise attacks by Pakistan and China have become improbable—being replaced by the prospect of “limited” conflicts under a nuclear shadow—the role of the IAF has become even more critical. In the majority of plausible combat scenarios, Indian air power will become the critical warfighting instrument of first resort should Indian policymakers feel

compelled to use force either to defend their territory in the face of adversary attacks or to inflict punishment on an antagonist because of a prior provocation.⁸

In such circumstances, Indian air power must be robust enough to achieve simultaneously three objectives: first, it must be able to do whatever is operationally necessary to permit the combat components to successfully carry out their assigned mission; second, it must be able to neutralize whatever the adversary does in response to the initial successes enjoyed by Indian air power,

In the majority of plausible combat scenarios, Indian air power will become the critical warfighting instrument of first resort.

whether that was committed against a competitor's military forces or against other territorial targets; and third, it must be able to effectively support all the other armed services as they prepare for what could evolve into sustained, even if only limited, military operations against the enemy. Implementing such a strategy successfully requires the IAF to maintain significant quantitative and qualitative superiority against Pakistan writ large and sufficient dissuasive

power—flowing from the possession of both technical and operational edge—against China in the likely theaters of operation.

As early as 1959, the IAF assessed that 64 squadrons, including 45 combat aircraft squadrons, were necessary to implement the strategic vision sketched above. The disastrous 1962 war with China only confirmed this requirement a fortiori, but India's economic underperformance from then up to the 1980s made this vision a victim of stark budgetary reality. The initially desired—though still appropriate—force level was thus replaced by a “second-best” requirement of 45 authorized squadrons, of which 39.5 squadrons were to consist of fighter aircraft. India successfully managed to maintain this force level throughout the 1980s, giving the IAF a 2.9:1 advantage in combat aircraft over Pakistan in the early years of that decade.⁹

Since then, however, bloc obsolescence of certain aircraft (primarily early generation MiG-21s), continuing accidents (again largely involving MiG-21s), and premature retirements (of MiG-23MFs and MiG-25s) all combined with the procurement failures discussed above to plunge the IAF's fighter strength

to its current precipitous lows, even as its qualitative capabilities have improved dramatically in some areas.

Various Indian news reports have highlighted the fact that the IAF's current strength has dropped to an all-time low of some 29 combat squadrons (versus the authorized level of 39.5). Even worse, the force seems unlikely to reach its sanctioned strength any time before 2017, even if the MMRCA deal proceeds on schedule. The government of India appears to have conceded this grim reality since by the defense minister's own estimate, the IAF's fighter fleet would not reach a combat strength of 42 squadrons any time before the end of India's 13th Plan in 2022.¹⁰

This current shortfall in IAF end strength has cut deeply into the comprehensive air superiority essential to India's military strategy. The numbers themselves tell a disconcerting story. Despite the lost years of the 1990s, for example, Pakistan has managed to maintain its combat aircraft inventories. And thanks to the new U.S. assistance since 2001—and significant Chinese support that goes back even longer—the Pakistan Air Force (PAF) today

is well on its way toward incorporating significant qualitative improvements. The current PAF force structure consists of some 22 combat squadrons in comparison to the IAF's 29. The IAF's combat force today totals 630 aircraft, which, in comparison to Pakistan's 380-odd fighters, yields a force ratio of 1.6:1, clearly a far cry from the almost 3:1 superiority that the IAF enjoyed in the early 1980s.

The qualitative changes in the PAF—the result of access to new resources and technology brought on in exchange for Islamabad's participation in the global war on terror—make these numbers even more troubling. From the United States, for example, Pakistan is acquiring new F-16C/D Block 50/52 aircraft with more advanced radars, electronic warfare (EW) systems, and air and surface weapons compared to those presently in its inventory. Pakistan is currently slated to acquire up to 36 such new F-16s, but the eventual buy could be close to double that number. If budgetary concerns permit, therefore, the PAF could field a 100-strong contingent of advanced F-16s in the coming decade.

**The current shortfall
in IAF end strength
has cut deeply into
the comprehensive air
superiority essential to
India's military strategy.**

At the same time, the PAF is also scheduled to acquire 10–12 squadrons of new Chinese FC-1/JF-17 aircraft, some in partial replacement for the older F-7s now deployed in the force. The exact numbers of JF-17 aircraft that will enter the PAF inventory eventually have not been settled yet. But it is not unreasonable to expect that the service will finally acquire about 250 airplanes—all equipped with long-range radars and new advanced weaponry—thus making it the core of the PAF’s future fighter capability. These two programs alone—the F-16 and the JF-17—could yield a force of some 350 respectable fourth-generation combat aircraft, each armed with advanced sensors and air-to-air weaponry.¹¹

For the first time in its history, the PAF is also in the process of acquiring beyond-visual-range (BVR) air-to-air missiles (AAMs) for its aircraft. This capability is exemplified by the acquisition of the formidable American AIM-120C Advanced Medium Range Air-to-Air Missile (AMRAAM) for Pakistan’s F-16s. The AMRAAM, which will be complemented by the export version of the remarkable Chinese PL-12 BVR AAM for Pakistan’s new JF-17 airplanes, will allow the PAF to contest the Russian R-77 BVR AAMs that India deploys primarily aboard its MiG-21 BISON and SU-30MKI fighters.¹² New PAF fighters will also be equipped with advanced airborne jamming pods and other defensive technologies.

Enabling the more effective utilization of Pakistan’s improved air defense capabilities are—also a first—its new airborne early warning (AEW) platforms. This component will consist eventually of four Swedish SAAB-2000 aircraft equipped with the Erieye phased array radar. It is almost certain that this contingent will be expanded with four additional Y-8 AEW platforms from China. The PAF’s acquisition of these AEW systems dramatically expands its air surveillance envelope, improves the survivability of its ground-based air defense network, and enables its combat aircraft to operate more effectively in both defensive and offensive missions against India.¹³

At the very least, Pakistan’s new AEW aircraft will accomplish four goals: they will close the gaps currently existing in its early warning and ground control intercept (EW/GCI) radar chain; deny IAF fighters the benefits of strategic and tactical surprise during offensive missions; vector defending PAF aircraft to their initial radar contact more effectively than EW/GCI controllers can, particularly if the Pakistani terrestrial radar net is already degraded by Indian attacks; and provide more effective battle management during PAF offensive operations by being able to identify air and ground threats as they evolve while directing both strikers and escorts appropriately.

From an IAF point of view, the gradual improvements in Pakistani air capabilities are therefore reason for concern, in part because they are occurring

at a time of falling force levels. This does not, however, imply that the IAF is, or will be, unable to successfully prosecute its assigned warfighting missions against Pakistan. The IAF still enjoys significant advantages on this score: it has a larger contingent of high performance aircraft; it operates more BVR-capable platforms than Pakistan; its airplanes deploy better on-board sensors and electronic warfare systems; its pilots are more proficient in advanced air combat tactics, including operations in a BVR environment; and the force possesses superior combat support aircraft, more extensive infrastructure, and a continually improving integrated air defense network.

However, India's historically low (and perhaps still falling) numbers of front-line combat aircraft will increase the risks that always accompany any use of force. The IAF is still likely to prevail in any air combat operations vis-à-vis Pakistan, but in the absence of substantial numerical superiority, its flexibility will be constrained with telling effect at the operational level. While these limitations will be less significant if the scale of conflict assuredly remains limited, they will become critical if what began initially as limited operations were to degenerate into a large-scale war.

In any event, the issue of adverse force ratios becomes particularly problematic for the IAF because India does not have merely Pakistan—a weaker and arguably failing neighbor—to contend with, but more dangerously has to reckon with China as well—an adversary that is not only an emerging global power but a dramatically transforming aerospace threat to boot.

The continuing transformation of the Chinese People's Liberation Army Air Force (PLAAF) poses many serious threats to the IAF, particularly at its current low force levels. To be sure, the PLAAF has traditionally outnumbered the IAF by an order of magnitude. In the early 1990s, for example, when the "old PLAAF" was at its zenith, the Chinese air force inventory was huge, consisting of some 5,000-odd airplanes. From the IAF's perspective, however, even at these force sizes the PLAAF was a dangerous but manageable threat because the backbone of its combat capability consisted of about 3,000 highly obsolete second-generation fighters such as the J-6/MiG-19.

The third-generation fighters in the force at that time, particularly the J-7 E/G and the J-8—the former based on the venerable MiG-21 design and the latter on the failed Russian twin-engine MiG-21 developmental offshoot code-named "FLIPPER" by NATO—were far fewer in number. The J-7 component included roughly 500 aircraft in varying configurations and the J-8s probably never exceeded 100 airplanes in the PLAAF inventory. China also maintained a small bomber component, consisting of indigenous variants of the obsolete Russian Tu-16, which was first introduced in the 1950s; being primarily a

daylight bomber armed with gravity bombs, its survivability in missions against the IAF was highly questionable.¹⁴

The most capable warfighting component of the PLAAF was either as large as or, more likely, smaller than the IAF's combat component for decades after 1971. Furthermore, the PLAAF's poor combat support aircraft inventory, primitive integrated air defense system, and mediocre surface-to-air missile component left the force as a whole a poor challenger to the IAF. What advantaged India even more in this regard was the fact that the PLAAF's best airplanes were deployed not in the southwestern quadrant of the country—against India—but along its northern and eastern borders, where they were designated for contingencies involving Russia and Taiwan and Japan,

respectively. Also, Chinese air bases in the Tibetan region were extremely primitive, the early warning net in this area virtually nonexistent, and the physical infrastructure on the Tibetan plateau simply unable to support any significant air operations against India.

While this balance of air power persisted up until the beginning of the new century, it did not last long after it. Thanks to a concerted modernization effort that began during the 1990s with substantial Russian and Israeli assistance, the PLAAF presently is on its way

to becoming a genuine aerospace power, rather than being merely an air force with high performance aircraft. Achieving this objective has required the service to shed its mass of obsolescent aircraft in order to recapitalize with a smaller number of modern platforms. Accordingly, the PLAAF inventory has contracted dramatically from the 5,000 or so combat aircraft deployed during the 1990s to some 1,700 aircraft today. The large numbers of antiquated J-6s and early series J-7s have been completely retired from the force, with only modernized J-7s and J-8s retained. These 800 or so third-generation survivors have been supplemented by a smaller but rapidly growing core of advanced combat aircraft—over 350-odd fighters currently—the most prominent of which are

India has to reckon with China as well—an adversary that is not only an emerging global power but a dramatically transforming aerospace threat to boot.

the Russian Su-27/30 (in both imported and domestically produced versions) and the indigenous F-10 (which incorporates significant Israeli technology).

Based on current acquisition rates, the PLAAF will probably hover around 1,700 aircraft in 2020, but it will have a higher proportion of advanced systems than it has today. It would not be unreasonable to expect the service at that point to field close to 500 Su-27/30s and 500 F-10s, as well as a small number of fifth-generation stealth fighters at the high end. This component would be supplemented by some 300-odd F-7 and F-8 remnants, along with another 100 or so modern but lightweight fighters such as the FC-1/JF-17 at the low end. Completing the force would be another 250-300 platforms for the ground attack and long-range strike mission.

Such a force structure implies that the PLAAF will possess *more* fourth-generation high-performance combatants a decade from now than the total number of aircraft in the IAF's entire inventory. This unprecedented force ratio would not only be in sharp contrast to that of the past but also, and more perilously, threaten to unhinge the foundations of Indian defense strategy insofar as it relied on the possession of quantitative superiority where advanced combat aircraft were concerned.

What is certain to exacerbate the dangers flowing from this loss of advantage is that evolving PLAAF gains are not manifested by growing numbers alone. Rather, like Pakistan, the Chinese air force is now a BVR-capable force for the first time, deploying the PL-12 AAM (an indigenously improved version of the Russian AA-12 "ADDER"), which is among the most troubling active radar missiles in the world today. Modern Chinese fighters also are equipped with advanced electronic warfare systems—and they are now supported by effective tankers, special mission aircraft, and diverse unmanned aerial vehicles (UAVs) in both combat and supporting roles.

Beyond improvements in fighter aircraft and weaponry, China has invested heavily in upgrading its integrated air defense system to include new sensors,

China is on its way to becoming a genuine aerospace power, rather than being merely an air force with high performance aircraft.

communications systems and data links, and advanced surface-to-air missiles, even as it has expanded its long-range precision strike capabilities through the induction of new ballistic missiles as well as new air-to-surface weapons such as air-launched cruise missiles. The large Chinese investments in intelligence, surveillance and reconnaissance (ISR) systems, space and counterspace capabilities, and cyber warfare have already attracted widespread attention. When conjoined to better training regimes, more advanced air combat tactics, and new doctrinal innovations, they promise to make tomorrow's PLAAF an adversary of the kind the IAF has never faced before.¹⁵

While all of the above improvements are readily apparent throughout the PLAAF, not to mention Chinese naval aviation, they are also steadily becoming manifest in the Lanzhou and Chengdu Military Regions, which border India. These two regions are host to five PLAAF divisions operating some 300 combat aircraft, both fighters and bombers. The quality of this force has steadily increased with the new deployment of fourth-generation systems, such as the Su-27 and the F-10. On the Tibetan plateau in particular, Chinese capabilities, both civilian and military, have undergone progressive upgrades: improved roads, runways, hangars, petroleum, oil and lubricant storage, communications and early-warning equipment, and better defenses.

Although China does not maintain any significant numbers of combat aircraft on the plateau routinely, it is developing the infrastructure and the command and control mechanisms necessary to sustain an injection of additional combat capabilities from more distant parts of the Lanzhou and Chengdu Military Regions (as well as from other outlying regions) toward the Sino-Indian border in times of crisis. This exercise of "strategic air power"¹⁶ against India, however, will have its limits. All Chinese aircraft will continue to be handicapped by the high elevation of the Tibetan plateau, which limits the maximum takeoff weight of any airplane. But, the integration of the new air-to-air refueling capabilities will bequeath the PLAAF some operational workarounds it did not possess before.

The bottom line for India, therefore, remains unchanged: unless India acts to correct the situation, the PLAAF's improvements will place the IAF at a disadvantage. In numerical terms alone, the IAF has to confront two adversaries, Pakistan and China, who routinely maintain close to 700 combat aircraft—equivalent to the IAF's own strength—in the territorial spaces contiguous to the Indian border. Although Indian superiority over Pakistani air power will continue for the foreseeable future, that superiority will contract as Pakistan improves its force capabilities, inter alia, through the induction of new combat aircraft with BVR weaponry.

China poses a greater problem. Not only is the IAF poised to lose forever its traditional numerical superiority where advanced combat aircraft are concerned, this segment of the PLAAF alone is likely to exceed the size of the entire IAF by 2020. When the larger transformation of the Chinese military is taken into account—including the challenges posed by PLA modernization writ large and the burdens imposed by its pursuit of asymmetric strategies vis-à-vis India and others—the situation becomes serious indeed.

A net assessment of the evolving Chinese threat to India cannot be undertaken here, but suffice it to say that, in terms of raw numbers alone, the IAF must plan on confronting by 2020 as many as 1,500 fourth-generation Pakistani and Chinese fighters—not to mention the bombers, cruise missiles, UAVs, ballistic missiles, electronic warfare, computer network attack, and counterspace elements that will also be in service by that date.

Given this stark reality, Indian security managers simply cannot afford to further delay concluding the MMRCA acquisition without exposing the IAF, and the nation at large, to unacceptable risks. As Air Marshal (retired) V. K. Bhatia noted succinctly, “while assurances from various quarters that the MMRCA would be in service by 2014 might appear somewhat unrealistic, it is imperative that the deal is finalized expeditiously.”¹⁷

**Indian security managers
simply cannot afford to
further delay concluding
the MMRCA acquisition
without exposing the IAF,
and the nation at large, to
unacceptable risks.**

DO NOT SPLIT THE MMRCA PURCHASE

While concluding the MMRCA competition speedily is essential to protecting the IAF's strength against further deterioration, avoiding a split in the final buy is vital to protecting the integrity of its force structure. The IAF itself is operating on the assumption that the Indian government will purchase a single aircraft from among the six competitors based on a complex matrix of quality, cost, willingness to transfer technology, and other strategic considerations. The IAF has already given the Indian Ministry of Defense (MOD) the information it needs to draw conclusions about the first issue. The seventh and eighth phases of the procurement process will provide the data necessary to make the appropriate judgments on the second and third issues. And the CCS will have to make its final decision after reflecting on all the data provided and upon taking into account the fourth issue, which lies beyond the competence of the IAF and the civilian bureaucracy in the Indian MOD. The process should, therefore, be sufficient to identify the single best multi-role fighter for the IAF.

The substantial size of the purchase, however, and the fact that its outcome will affect both the survivability of some of the contenders and India's relations with key foreign partners raises the prospect that New Delhi might attempt to satisfy its defense and geopolitical objectives simultaneously by splitting the MMRCA buy and purchasing two different aircraft instead. Such a decision would involve purchasing smaller numbers of each platform—if the current objective of acquiring 126 aircraft remains unchanged—but it would presumably assuage different international allies of importance to India. Alternatively, it could involve a larger total buy of some 200 aircraft, with two different vendors each supplying half the order but based on the same calculus of satisfying multiple foreign countries valued by India.¹⁸

Although the probability of such an outcome obtaining is small, the possibility is all too real. This is because the final procurement decision will be made by civilian decision makers—politicians, not the uniformed end-user—who will attempt to juggle multiple considerations relating to India’s larger strategic interests over and above the precise necessities of defense requirements. The fact that many of them are already inclined to believe that most if not all the contenders are roughly comparable technically only strengthens the prospect that they may settle for a split buy. They might even come to accept that a split would actually improve IAF capabilities, insofar as it would provide not one but two state-of-the-art airframes.

As is to be expected, the IAF will be resolutely opposed to such an outcome. But it is important to recognize that once the service submits its Technical Evaluation Report up the chain, its headquarters ceases to have any substantial say in the subsequent decision making. If other governmental ministries or entities advise the CCS that the necessities of Realpolitik justify consideration of a split buy, there is some—non-trivial—likelihood that a decision along those lines could materialize.

Such a split buy would also not be unprecedented for India. It was implemented in modified form sometime around 2005 in the context of commercial aircraft purchases for India’s government-owned civilian airlines. At the time, both Boeing and Airbus—each strongly supported by the U.S. and European governments, respectively—were fiercely bidding to supply new jets to India’s state-owned carriers, Air India and Indian Airlines.

Just like the MMRCA competition today, the \$10 billion deal was highly lucrative and the political stakes were just as significant. The growing conviction that India represented one of the fastest growing commercial aviation markets in the world meant that both major aircraft producers were eager to secure dominant positions that would enable them to become privileged suppliers over the long term at just the time when the successive governments in India were struggling to cement the growing transformation in U.S.-Indian relations without sacrificing old ties with key European countries, especially France.

The government of India ended up splitting the purchase, but highly asymmetrically. Boeing collected \$8 billion in exchange for providing long-range aircraft to India’s international carrier, Air India, while Airbus walked away in disappointment with a much smaller \$2.2 billion contract for supplying shorter-ranged aircraft to the domestic carrier, Indian Airlines.¹⁹

In this case, however, technical requirements, organizational logic, and political necessities dovetailed perfectly. Air India, which required long-haul

platforms for its transcontinental operations and had long operated Boeing aircraft, found the perfect fit in that company's B777-200 LR, B777-300 ER, and B787 airplanes. Similarly, Indian Airlines, which serviced domestic travel

Pursuing a split buy would involve burdening a single end-user—the IAF in this case—with two different airplanes intended to undertake exactly the same roles and missions.

and operated both Boeing and Airbus platforms previously, was satisfied by the shorter-endurance Airbus A-319s, A-320s, and A-321s acquired through the deal. Since the two airlines then possessed different organizational structures and serviced different kinds of markets, buying different aircraft streams from competing vendors was eminently sensible—even if the buyer itself ultimately was a singular entity, namely the government of India. A “split” buy of this kind, then, had the advantage of being operationally appropriate, even as it enabled

New Delhi to cultivate its emerging partnership with the United States without leaving its old ally, France, entirely in the cold.

The prospective MMRCA competition, however, is very different. For starters, pursuing a split buy would involve burdening a single end-user—the IAF in this case—with two different airplanes intended to undertake exactly the same roles and missions. Combat aircraft are a good example of systems-embedded technologies—that is to say, they require various complementary socio-technical components for their effectiveness. Investing in multiple platforms for a common mission implies increased burdens in regard to supplying the vital ancillaries essential for success: training, logistics, maintenance, and even weapons. A split buy would also pose nightmarish complications where the transfer of technology is concerned. The burdens of license-producing two different platforms simultaneously are considerable and the benefits for improving India's fledgling aerospace industry would be tenuous, even if all the problems imposed on IAF operations and maintenance are disregarded.

To be sure, the IAF, like any other professional service, will develop the organizational capacity to service, maintain, and operate all the aircraft chosen for the MMRCA role, but the increased costs of doing so—in comparison to

purchasing a single aircraft for the mission—implies a wasteful use of air force resources that could be used to better effect in either expanding the size of the force or acquiring new capabilities.

The IAF is already handicapped by an excessive diversity in its inventory. For the air defense mission alone, the IAF today either now operates or will soon acquire at least five different kinds of airplanes: the MiG-21 BISON, the MiG-21FL, the MiG-29, the Mirage 2000H, and the Su-30MKI FLANKER—in addition to the prospective MMRCA. Although the MiG-29s, Mirage 2000s, and Su-30s share ground attack roles as well, their relatively powerful radars, BVR AAMs and onboard electronic warfare capabilities, and current training regimes suggest that the air defense mission still remains one of their key mission taskings.

The number of airplanes by type also varies considerably. Although the IAF is moving toward acquiring substantial numbers of Su-30s as its principal air superiority platform—it will possess just under 300 by 2020—the MiG-29s and the Mirage 2000s are fielded in small contingents of about 50 aircraft each. Furthermore, the MiG-21 BISONS, which are the most capable fraction of the IAF's much larger MiG-21 inventory, will not exceed 125 airplanes on current plans. The IAF expects to retire many of the older MiG-21s during this decade, retaining only the BISON component for as long as possible or until a decision is made about whether to acquire the indigenously produced Light Combat Aircraft (LCA), now christened the Tejas (meaning “radiant” in Sanskrit), in sufficient numbers to fill the low-end portion of the IAF's air defense fighter force.

Recognizing the problems imposed by the diversity of its air defense platforms, the IAF initially wanted to acquire 126 additional Mirage 2000s—a request that mutated into the current MMRCA competition on government insistence—in order to sustain a larger force with fewer types of aircraft.²⁰ That such a goal is utterly sensible can be gleaned from a simple comparison with the United States Air Force. The IAF's total force size today consists of about 630 combat aircraft, of which some 380 platforms of five or six different kinds are operated either exclusively or substantially in the air defense role.

The tactical combat aircraft segment of the U.S. Air Force, in contrast, consists of close to 1,800 airplanes, yet the service operates only three types of fighter aircraft—the F-22A Raptor, F-15C/D/E Eagle, and the F-16C/D Fighting Falcon—for the air defense mission. Before the F-22A entered service, the air defense role belonged to just the latter two, and the F-16 was actually employed more as a multi-role aircraft committed to ground attack missions. Moving the IAF closer toward the U.S. Air Force's force structure for air

defense is thus long overdue, not only to reduce its logistics, maintenance, and training burdens, but also to enhance its operational effectiveness.

The pernicious consequences of a split buy in the MMRCA competition, accordingly, become obvious. Selecting two winners in the competition would saddle the IAF with *seven* different combat platforms for the air defense role. Such

Civilian security managers in New Delhi should use the MMRCA buy, first and foremost, to do well by their air force; satisfying the demands of India's foreign partners should take a back seat on this issue.

an outcome, far from increasing IAF capability, could actually detract from it. For this reason more than any other, civilian security managers in New Delhi should use the MMRCA buy, first and foremost, to do well by their air force; satisfying the demands of India's foreign partners should take a back seat on this issue.

Furthermore, the Indian government should, in concert with the air force, use the opportunities afforded by the MMRCA competition to rationalize the structure of the air defense fighter segment: it should retire aircraft at the low end sooner rather than later and increase the numbers of the surviving platforms to create a

critical mass that bequeaths the IAF with greater combat capabilities overall. Finally, expanding the MMRCA acquisition right away to a total of 200 single-type aircraft—sufficient to equip 10–11 squadrons—should be seriously considered, given the sharply falling force levels of recent years.

BUY THE “BEST” AIRCRAFT FOR THE MISSION

While the government of India obviously should buy the “best” airplane available from among the six contenders currently being examined for the MMRCA component of the air force, identifying which platform precisely fits that bill is by no means easy or self-evident. In part, this is because the IAF seeks a *multi-role* aircraft, meaning one that can fulfill both air-to-air and air-to-ground missions with equal felicity.

The historical record suggests that genuinely successful multi-role aircraft have been the exception, not the norm, because the laws of physics and engineering generally conspire to optimize fighter airframes for one mission or

The historical record suggests that genuinely successful multi-role aircraft have been the exception, not the norm.

the other. The best aircraft for the air-to-air role (or at least for the energetic maneuvering required for close-in aerial combat) are characterized by high thrust-to-weight performance and low wing loading (the ratio of gross weight-to-wing surface area). In contrast, thrust-to-weight performance is less important for aircraft designed for the low-level anti-surface mission, but high wing loading is actually desirable because of its benefits

for airframe stability at the high subsonic speeds usually associated with surface-attack operations.²¹

Aircraft design traditionally has, therefore, been biased in one direction or another and very few airplanes have thus emerged as unambiguous successes in both roles. The existing American F-15E Strike Eagle remains the quintessential multi-role fighter, with the U.S. Air Force's F-16 Fighting Falcon and the U.S. Navy's F/A-18E/F Super Hornet—the latest versions of both currently involved in the IAF's MMRCA competition—in the same league. In contrast, the Russian MiG-23 FLOGGER and the U.S. F-111 were not conspicuous as successful multi-role aircraft: both failed significantly in the air-to-air regime, although they were initially intended to perform both air defense and anti-surface roles concurrently.

The U.S. F-4 Phantom too, despite its legendary status, was not an ideal multi-role aircraft because it owed its aerial successes more to its ability to fire heat-seeking and radar-guided AAMs against less well-equipped adversaries rather than because of any intrinsic aerodynamic advantages. In contrast, the more contemporary Panavia Tornado has been able to perform both air-to-air and air-to-ground missions only because two substantially different airplanes have evolved, one for each role, out of what was originally a common airframe. As Carlo Kopp has explained, the difficulty in producing successful multi-role aircraft is owed to the fact that “fighter airframes are usually exceptionally well suited to one task, reasonably good at a range of other tasks, and marginal for some tasks.”²²

Assessing which of the six contenders in the MMRCA race is best for the IAF, then, requires some judgment about what mission needs the winner is most likely to service. The best clue in this regard is offered by three variables: the character of the IAF as an institution; the most pressing mission likely to be emphasized by India's civilian decision makers in the context of future conflicts; and the force structure of the IAF as a warfighting instrument.

To begin, the IAF is today, and has been throughout its history, primarily a fighter force in terms of both its psychology and its organization. Fighter pilots dominate the institution, play a critical role in defining requirements, and visualize India's future wars as essentially air power-led encounters, where procuring and maintaining air superiority is critical to attaining the political outcomes desired by the state.²³

Furthermore, Indian policymakers, for their part, remain extremely conservative in regard to the use of force. While they will permit the offensive uses of air power when necessary to achieve their goals, they would never authorize such missions at the expense of the primary objectives of protecting Indian air space, cities, key population centers, and critical economic or symbolic assets.

Both these considerations converge to suggest that whatever aircraft is finally selected in the MMRCA competition, its fundamental worth will be assessed first and foremost by its air-to-air performance, with its capacity to undertake precision strike missions being, at least in a relative sense, somewhat secondary

Whatever aircraft is finally selected in the MMRCA competition, its fundamental worth will be assessed first and foremost by its air-to-air performance.

in assessed importance.²⁴ This judgment is only corroborated by the fact that all six aircraft currently in the MMRCA race are world-class performers for the air-to-air mission, though they can obviously prosecute surface attack operations with varying, albeit high, degrees of effectiveness.

The third variable, the structure of the IAF as a fighting force, further reinforces the larger conclusion that air-to-air proficiency will remain the irreducible desideratum by which the MMRCA contest is adjudicated. The IAF already

possesses a dedicated strike component intended for anti-surface operations at both tactical and operational ranges. The IAF's MiG-27 and Jaguar squadrons, currently, are intended exclusively for the air interdiction mission at either the theater or the battlefield level. The Mirage 2000 and the Su-30MKI squadrons also have these same missions as a secondary responsibility, and some of the older MiG-21 squadrons are tasked with performing the close air support role when required. Given this substantial offensive lineup, the aircraft selected for the MMRCA component will no doubt have theater or battlefield air interdiction as an adjuvant responsibility, but it is unlikely to eclipse the IAF's principal mission of protecting Indian air space through the conduct of counterair operations.

Modern technology enables the IAF to meet both these objectives more or less through multipurpose aircraft like the six now under consideration. Advances in aerodynamic design, materials technology, and digital flight control systems, for example, have resulted in the development of new blended wing and fuselage configurations which, by utilizing leading and trailing edge flaps combined with high-thrust turbofan engines, enable fighter aircraft with even nominally high wing loading to exhibit extreme maneuverability. The

F-16C is a great illustration of such a combination. Despite having a higher wing loading than, for example, a MiG-21 or a Mirage 2000, the latest-generation F-16 has instantaneous turn capabilities that exceed the former and almost match the latter, while possessing better slow speed maneuverability—a critical advantage in close-in aerial combat—compared with both.

The dramatic advances in avionics in recent years have further helped to transform what would otherwise be merely superb air combat fighters into more effective multi-role aircraft. The availability of sophisticated radars with integrated air-to-air and air-to-ground modes, mission management computers, automated weapon delivery and navigation systems, and digital map systems, among other technologies, have permitted fighter aircraft to undertake a wider range of tasks than they were originally intended for. In an era of shrinking budgets, and when air forces around the world are seeking to economize on the number of idle platforms in combat, the ongoing transformations in electronics, miniaturization, and automation have made it possible even for single-piloted combat aircraft to execute demanding air-to-ground missions—assuming that their training regimes have prepared them for it—simply because of the miracles of modern technology.

When assessing the current contenders in the MMRCA dogfight, therefore, it is useful to begin by identifying the missions that the IAF expects the successful platform to service. From these missions, then, flow key criteria by which the six airplanes can be judged synoptically. Once this analysis is completed, the final task consists of understanding how the best candidates would fit into the desirable force structure of the IAF over the next two to three decades, a period of time coinciding with the expected lifetime of the MMRCA.

The dramatic advances in avionics in recent years have further helped to transform what would otherwise be merely superb air combat fighters into more effective multi-role aircraft.

UNDERSTANDING THE OPERATIONAL CONTEXT

For the reasons described earlier, the IAF will gravitate toward those aircraft it believes are best suited for the counterair missions necessary to secure Indian air space, assuming they can service the anti-surface requirement satisfactorily as well. The strategic objective of all counterair operations is to acquire and maintain the requisite degree of airspace control in order to protect both the Indian homeland and its forward operating military forces and to apply pressure on the adversary by interdicting its warfighting capabilities and its national assets directly. The degree of air superiority required for these purposes will vary with the adversary, the strategic objectives of the conflict, and operational circumstances. One condition that holds true throughout all these variables is the necessity of using a combination of offensive and defensive counterair operations to achieve and maintain air superiority.²⁵

Offensive counterair operations are measures intended to destroy or degrade an enemy's air capability by attacking it as close as possible to its source. This includes airfield attacks (interdicting adversary aircraft on the ground directly, denying them the use of runways, or destroying operational necessities such as fuel or lubricants); fighter sweeps (seeking out and destroying adversary aircraft in a disputed air space); offensive air escort (missions tasked with protecting friendly strike packages en route to enemy targets); SEAD, or suppression of enemy air defenses (attacks aimed at destroying or neutralizing radars and surface-to-air missile and gun defenses); C-AISR, or counter-airborne intelligence, surveillance and reconnaissance operations (intercepting and destroying an adversary's airborne warning and control systems, or AWACS); and integrated air defense systems (IADS) takedown (suppressing the air defense net or parts thereof by attacking its vulnerable nodes).

Defensive counterair operations, on the other hand, are aimed primarily at nullifying or attenuating the effectiveness of an adversary's air capabilities as they are brought to bear on oneself through either surface-to-air missile (SAM) or anti-aircraft artillery (AAA) systems or through tactical air engagements involving friendly fighter aircraft employed in the following missions: screening (positioning tactical fighters between the threat and friendly forces); CAP, or combat air patrol (positioning aircraft over or near the area or force being defended); defensive air escort (protecting high-value assets involved in airborne early warning, airlift, or air rescue operations); or air intercept (identifying and engaging enemy aircraft engaged in hostile air action). While the broad counterair campaign traditionally employed mainly aircraft supplemented by fixed or mobile land systems such as radars, SAMs, and AAA, all tied together by some battle management network, the modern counterair operation is much

more expansive, utilizing additional instruments such as surface-to-surface missilery, space assets, and electronic and cyber warfare.

In any event, a close scrutiny of the missions subsumed by the terms offensive and defensive counterair indicates that the former includes both air-to-air and air-to-ground taskings, while the latter involves mainly air-to-air operations.²⁶ These are undoubtedly slippery characterizations because the integration of ballistic and cruise missilery, space systems, and electronic and cyber warfare in modern counterair campaigns obliterate the previously neat distinctions between air-to-air and air-to-ground operations.

This is a particularly significant matter in the case of China, though it could apply to Pakistan as well over the longer term. In any event today, China, more than any other power, has invested heavily in attempting to defeat the air power capabilities of its principal adversaries, not just through the conventional air operations of the past but also through the integrated employment of land-based precision strike capabilities. In effect, the PLA and the PLAAF hope to win the air war with future rivals long before the first close-in aerial engagement occurs. By using their land-based ballistic and air-delivered cruise missiles, supported by various space, electronic, and cyber warfare assets, in a massive “knock down the door” operation on the first day of war itself, the Chinese military aims to destroy its adversary’s air bases (including its runways, its parked aircraft, and its petroleum, oil and lubricant and munitions storage sites), its command and control nodes, and its strategic defenses, even before any aircraft ever go head-to-head in aerial combat.

This implies that the precondition for IAF success in any future conflict with China will increasingly not be the quality of its aircraft or the skill of its airmen in the first instance, but rather how well it can protect its combat aviation and the infrastructure that enables its warplanes to operate effectively. The efficacy of the IAF’s rapid runway repair capability, the hardening of its critical infrastructure nodes, the resilience of its command, control, communications, and intelligence (C³I) network, and the effectiveness of its air and missile defenses, will make a fundamental difference to whether the IAF will be able to even generate the sorties required to defeat the sophisticated PLAAF combatants that show up after the initial precision strike salvos have taken their toll.

In such an environment, the IAF will no doubt need superlative aircraft for success. But because the demands of sortie generation take prior precedence, the IAF will have to ensure that its airplanes—and *all* their requisite support capabilities—will actually survive the intense asymmetric counterair campaign that is certain to be directed at the Indian landmass. Having aircraft capable

of short takeoff and recovery will be inordinately valuable in this context, as will other complementary investments such as unmanned combat air vehicles, relocatable sensors, and deeply buried or mobile C³I facilities.

Once IAF fighters survive the initial onslaught—a phase that will decisively blur the traditionally tidy dichotomy between air-to-air and air-to-ground operations—their technical quality, and that of other Indian supporting instruments, becomes critical. Both their air-to-air and their air-to-ground

capabilities become relevant at this point and these will be discussed in the context of prospective combat operations in South Asia.

Since the IAF's preferred aircraft will be one that excels in the air-to-air dimension of the counterair campaign without sacrificing air-to-ground effectiveness, it follows from the mission needs detailed above that the airplane finally selected by the air force must be superior to all others in both offensive and defensive counterair operations.

The airplane finally selected by the air force must be superior to all others in both offensive and defensive counterair operations.

This implies that the prospective MMRCA system must be especially effective in executing the fighter sweep, offensive and defensive air escort, C-AISR, screening, CAP, and air intercept missions in particular.

How the IAF would prosecute such operations, however, is in the midst of a progressive transformation. The fighter sweep and air escort missions traditionally were conducted mainly as preplanned activities, while the screening, CAP, and air intercept missions were more reactive, depending on either the tactical situation on the battlefield or the indicators provided by the extensive terrestrial network of EW/GCI stations located along the periphery of the Indian state. In the past, none of the South Asian states had any AEW or AWACS platforms. Consequently, detecting air intrusions was frequently an erratic exercise and the C-AISR mission was, by definition, also irrelevant. Until recently, most of the regional air forces too possessed only within-visual-range (WVR) AAMs as their most sophisticated air combat weaponry.

As a result of these limitations, the air-to-air campaign in Southern Asia essentially took the form of relatively short-legged aircraft maintaining strip

alerts during times of crisis or war. They scrambled to intercept intruders when these were detected by the EW/GCI network and they finally engaged the attackers after acquiring them either visually or through radar contact through rolling dogfights in which the fighter's short-ranged infrared AAMs and guns could be brought to bear. If the defender maintained periodic combat air patrols, this detection-to-interception sequence varied somewhat, but the terminal phase of the encounter was essentially the same. Fighter sweep and air escort missions, obviously, required prior planning, but the endgame in these engagements was also similar. The aircraft either detected the adversary by means of their onboard radars, or more often than not, they were simply surprised by an enemy's appearance. Following contact, an aerial dogfight ensued, involving either a within-visual-range kill by missile or gun, or disengagement and a return to base. The 1971 air war between India and Pakistan epitomized these kinds of air operations.

With the appearance of new AWACS systems in India, Pakistan, and China, the IAF is steadily preparing for an air-

to-air warfighting regime unlike anything witnessed in the past. This form of warfare will involve a struggle for information dominance, beyond-visual-range air combat at relatively long distances, and the integration of, at least, electronic warfare in tactical engagements designed to degrade the adversary aircraft's sensors and weapons.

Although the IAF has emphasized BVR combat for over a decade now—ever since the first effective semi-active radar AAMs entered its inventory—it is likely to take many more years for the force to fully integrate all its emerging capabilities and to actualize its vision of information dominance in the context of air combat operations.²⁷ Although the IAF's airborne electronic warfare capabilities are highly respectable, its air combat proficiency in the beyond-visual-range regime is still evolving, and it has only just begun to develop tactics that fully exploit the capabilities of its new AWACS platforms.

**With the appearance
of new AWACS systems
in India, Pakistan, and
China, the IAF is steadily
preparing for an
air-to-air warfighting
regime unlike anything
witnessed in the past.**

Since integrating these new AEW capabilities successfully, however, is only a matter of time, understanding the operational demands made by the emerging style of counterair warfare on the MMRCA component—as well as on the IAF's follow-on acquisition programs—yields important insights into how the winner in the current procurement effort will be selected.

Because the future air combat environment in Southern Asia will be defined by the presence of “AWACS symmetry,”²⁸ meaning the availability of airborne early warning platforms in the inventories of all the competitors, the primacy of the C-AISR mission will increase dramatically. This implies that IAF operations at the onset of any major conflict would focus on targeting the adversary's AEW and AWACS assets, either on the ground or in the air, in conjunction with attacks on its land-based integrated air defense system.

In this context, the IAF is also likely to focus on more generic airfield attacks whenever possible, not necessarily for runway suppression but to interdict the combat aircraft that may be lodged in hardened aircraft bunkers, especially at key air bases. The more enemy aircraft are destroyed on the ground in this way—or through complementary ballistic and cruise missile attacks—the weaker the subsequent air threat to India will be.

In any event, attacking high-value AWACS aircraft and other combat aircraft at their bases would require precision strikes, either on key support assets like runways or petroleum, oil, and lubricant storage, or on the individual shelters protecting these high-value assets, or directly on the aircraft themselves (if bedded down in the open). Such missions are what the dedicated strike components of the IAF are most appropriate for. It is not surprising, however, that the MMRCA tender requires all suppliers to demonstrate that their airplanes, too, can carry a wide range of precision direct attack and standoff weaponry capable of executing such missions because it is certain that the multi-role component of the force will also be committed to such tasks. This mission, in fact, will only grow in importance as the dedicated strike platforms are eventually phased out of the IAF over time.

The ideal aircraft for such operations is a stealth attack aircraft such as the U.S. F-117 Nighthawk, a platform capable of interdicting highly defended fixed targets while enjoying high immunity to an enemy's ground defenses and roving interceptors. None of the MMRCA candidates mimics the F-117's very low observability to enemy radar and infrared sensors, so India's multi-role aircraft and its dedicated attack squadrons would have to make do with their direct attack and standoff weaponry. (India would probably use conventionally armed ballistic and cruise missile forces to contribute to these missions as well.)

Pakistan's weak national air defense system and the relatively thin air defenses in the southwestern quadrant of China suggest that the IAF's efforts at destroying high value assets at their bases enjoy a reasonable probability of success, in theory. It is unlikely, however, that the PLAAF would base its AEW platforms anywhere on the Tibetan plateau contiguous to India. Consequently, the IAF's air-to-ground attacks on Chinese air bases in this region, while likely to be successful in targeting combat aircraft, may not suffice to eliminate these critical capabilities.

Since success is not assured in any case—because even the PAF would likely shuttle its AEW aircraft across various air bases or employ deception and denial to mask the true locations of these assets in wartime—the IAF will be faced with the challenge of intercepting those AWACS platforms (as well as other combat aircraft) that survive its air base attacks. Once airborne and operating, AWACS platforms are usually difficult targets to attack because they fly well behind the front, are protected by fighter screens, and are able to detect attacking airplanes well before the latter can pose a direct threat.

To be sure, the AWACS platform, like any other aircraft, is vulnerable to long-range SAM attacks. This threat is potentially serious in the case of Pakistan. Its lack of geographic depth means that its AEW aircraft must operate closer to the Indian border than they otherwise might. For the moment, however, Pakistan considers this a manageable problem because India lacks long-range SAMs in its inventory.

For the foreseeable future, then, the most dangerous Indian threat to both Pakistani and Chinese AWACS will be airborne attack. An all-aspect stealth fighter like the U.S. F-22A enjoys dramatic advantages in the C-AISR mission because its low radar cross-section (RCS) sharply reduces the range at which it can be detected by the opposing AWACS. Moreover, its supercruise capability permits it to close rapidly on the target and fire its beyond-visual-range air-to-air missiles to destroy the AWACS before its escorts can react or the AWACS itself can retrograde to a fallback orbit out of range of the attacker. Since none of the IAF's current aircraft have the stealth characteristics of the F-22A, the force will have to prosecute the C-AISR mission primarily by using its airborne electronic attack (EA) capabilities to degrade the AWACS's detection capabilities, while the high and fast flyers like the SU-30MKI close in to attack the platform with their active radar-guided beyond-visual-range air-to-air missiles.

While the best Indian air superiority platforms have significant EA capabilities, fighter-sized aircraft traditionally have not possessed either the brute power or the waveform agility necessary to effectively jam either the AWACS's main radar or its communications links with the rest of the air defense network.

Ground-based systems or large dedicated airborne EW platforms were usually deployed for such missions, although in recent years helicopter-borne systems and unmanned aerial vehicles have been employed as well. During the 1990s, the IAF modified its old Canberra bomber airframes to conduct the standoff jamming mission, but it is not clear whether these systems have the requisite power and appropriate bandwidth to successfully disrupt Pakistani and Chinese AWACS radars (as opposed to fighter or SAM radars or land-based EW/CGI systems) or even whether these aircraft are operational today.²⁹

For all practical purposes, then, the IAF's C-AISR mission is likely to be prosecuted, at least in the near term, mainly through kinetic attacks on the opposing AWACS's escorts, followed by direct attacks on the AWACS itself. This mission will be eased by the fact that India's own AWACS systems will be able to provide vectoring information for its strikers, while the EA capabilities and the long-range air-to-air missiles aboard the latter increase the probability of successfully neutralizing the adversary AWACS's escorts prior to the terminal attack on the high-value platform itself.

Given the presence of high-performance fighters such as the Su-30MKI and the MiG-29 in the IAF inventory, direct attacks on the adversary's AWACS platforms must be expected at the onset of any major conflict in South Asia. These attacks would take two forms: low-altitude ingress culminating in "pop-up" attacks, which exploit the AEW radar's limitations in the face of ground clutter, or high-speed, high-altitude attacks, which exploit the service ceiling limits of the AEW airframe and/or the restricted elevation coverage of its radar. An MMRCA candidate that possessed high maximum speed, a low radar cross-section, good long-range sensors and more importantly weaponry, and a sophisticated on-board EW system would, therefore, be an ideal platform for the future C-AISR mission in South Asia.

Whether or not Pakistani or Chinese AWACS platforms are destroyed in this way, future air combat operations in and around the subcontinent are unlikely to be dominated by close-in within-visual-range dogfights conducted by fighters that are vectored from strip alert to target by ground-based EW/GCI controllers. Rather, most air combat operations, whether associated with offensive or defensive counterair missions, are likely to be orchestrated by airborne controllers aboard AWACS platforms, who will direct the attacking units and vector the defending interceptors (often doing both simultaneously). The principal constraint on effectiveness in such operations will be the number of AWACS platforms owned and operated by all sides. If the AEW platforms possessed are insufficient to maintain continuous patrol during a conflict, the

reliance on land-based EW/GCI systems will increase, especially when AWACS orbits are unavailable.

Whenever AEW cover is obtainable, however, the air combat component of counterair operations will occur in circumstances where adversary aircraft are detected at long ranges. This will be true so long as the AWACS platforms can survive in what will be a hostile C-AISR environment. In such circumstances, EA conducted either by dedicated ground or airborne jamming platforms (or by the fighters' own organic systems, as relevant) comes into its own as each side seeks to protect the information it has acquired about the other's numbers, location, and disposition, while denying the same data about oneself to the adversary.

Fighter combat in such a milieu consists of each antagonist trying to get the first shot in—at the longest ranges possible—without being detected by the other. The entity that can better protect its own AWACS platforms; whose electronic warfare capabilities can more effectively degrade the opponent's sensors and weapons while preserving the ability of one's own aircraft to operate in a hostile EA environment; whose capabilities for identifying friend from foe (IFF) are superior and can distribute this information securely to its own fighter force; and whose fighters enjoy substantial endurance, have the longest-range on-board active and passive sensors (not simply for detection but also for target tracking and fire control), and can employ longer-ranged weapons compared with the opponent, will carry the day in this battle for the first salvo. After the initial salvos fly, both forces will have to decide whether to press on with their mission or disengage. If the adversary's contingent chooses to disengage, Indian fighters may pursue, using their remaining long-range AAMs, or disengage themselves.

If both sides continue the engagement, however, the stage would be set for the WVR dogfights that the IAF specialized in for most of its existence. Because success in dogfighting demands the greatest skill in airmanship, the self-assured “can-do” attitude characterizing all the IAF's fighter pilots, combined with their traditional lack of BVR AAMs, make getting to—and successfully out of—the “merge” the measure of success in air combat tactics. The problem, however, is that no matter how well structured the transition to the merge may be, once inside the “furball,” coordinated fighter maneuvering becomes difficult for all but the most highly trained aircrews and the opportunities for a rapid and violent demise rise sharply. Up to a point in that exacting environment, those pilots commanding the best situation awareness within the battlespace will be the ones who survive, prevail, and disengage to fight again another day. Sooner or later, however, everyone dies at the same rate in a “furball,” irrespective of

their relative proficiency, because of unobserved shots. Hence, the common fighter-pilot aphorism, “it’s the one you don’t see who will get you.”

For this reason, even advanced air forces tend to avoid combat within visual range if it can be helped, preferring to pick off the adversary whenever possible through long-range BVR shots. Those adversaries that survive the initial salvo are usually dealt with through flow management techniques, where trailing fighters with their unexpended beyond-visual-range air-to-air missiles replace the original first echelon attackers, stage to their optimal missile launch points, and engage the remnants of the enemy formation.

As the IAF develops new tactics to exploit its evolving capabilities in beyond-visual-range combat, it will likely transition to an engagement protocol that dictates engagement in visual-range combat only when necessary or when confronting a less competent adversary. Yet the importance of mastering WVR dogfighting will never go away. This is partly because even the best BVR weapons invariably have less than perfect single shot probabilities of kill, especially in air combat characterized by pervasive EW, and hence what may begin as a long-range engagement could rapidly evolve into a close encounter.

The requirements of positively identifying an adversary before missile launch in some tactical circumstances—especially when AEW cover is absent—may also necessitate IAF fighters closing in on their targets, with visual-range combat becoming the only alternative under such conditions. In any event, it is in these situations that the maneuverability of the IAF’s fighter platforms would become a critical factor in success or failure, along with, of course, other characteristics like the effectiveness of their on-board avionics, short-range AAMs, and defensive countermeasures systems. It is, therefore, not surprising that the IAF will look closely at these qualities when examining the various MMRCA competitors.

While the capacity for air-to-ground operations thus remains a natural adjunct to an aircraft’s air-to-air capabilities where all counterair missions are concerned, the IAF also has important responsibilities in the joint anti-surface campaign where wars with Pakistan and China are concerned. Against both adversaries, the IAF is tasked with undertaking air interdiction, offensive air support, and reconnaissance operations throughout the terrestrial battlespace. While the IAF has traditionally been accused of neglecting the close air support mission in aid of land forces, it has always concentrated on air interdiction missions both at the theater and the battlefield levels, and the MMRCA platform will be certainly employed for this purpose as well.

In previous conflicts with Pakistan and China, India generally eschewed prosecuting a strategic air campaign partly because it lacked the resources for this purpose. The fact that most of these confrontations were less-than-absolute wars only made the need for a strategic air campaign less pressing. With the appearance of nuclear weapons on the subcontinent, the strategic air campaign has become largely irrelevant; if it must be undertaken in extremis, it will be conducted mainly by India's nuclear-tipped missile forces, with air power playing at best a secondary role. The reconnaissance mission too has now steadily migrated to space-based assets and UAVs, although airplanes, given their natural attributes, invariably perform reconnaissance operations even when they are not specifically dedicated for the purpose.

The role of the MMRCA in the land anti-surface campaign, therefore, will revolve mainly around interdiction operations. Depending on the scale of the conflict, it will be employed, along with its other stable mates, to suppress critical rearward targets such as C³I centers, petroleum, oil and lubricant dumps and ammunition storage sites, and critical military infrastructure, such as bridges, rail marshaling yards, and tunnels, all of which make an important difference to the land battle. Again, depending on circumstances, the MMRCA component would also be committed to direct attacks on the adversary's military forces itself, both on the battlefield and in the rear, especially when concentrated or when moving along strategic avenues of approach.

The IAF clearly recognizes that the success of these operations would be greatly enhanced by the ability to attack this wide range of targets with precision munitions, as opposed to dumb bombs, especially at night and in adverse weather. Consequently, it has emphasized that the MMRCA acquisition should yield platforms that possess advanced radars with sophisticated air-to-ground modes as well as other sensors such as forward looking infrared (FLIR) pods, superior EW systems that permit effective and safe penetration to target in the face of the emerging regional SAM threats, weapons delivery systems that ensure a high probability of successful attack on the first pass, and a variety of specialized munitions that would be necessary for executing the various surface-attack operations associated with the air interdiction mission.

While the maritime strike component of the anti-surface mission has not received much public attention, there is little doubt that this assignment will only increase in importance over time. The MMRCA's *Request for Proposals* recognizes this clearly. At the moment, the IAF conducts the maritime strike mission mainly through its Jaguar and Su-30MKI platforms, but all the MMRCA candidates currently under review could easily undertake these operations so long as the relevant weapons were procured. While the IAF has the maritime

strike mission vis-à-vis Pakistan completely under control today, the relevance of these operations vis-à-vis China will only grow in the years to come.

As China begins to increasingly operate in the Indian Ocean, and possibly even obtain access in this part of the world to sustain its growing maritime and naval activities, India will acquire splendid opportunities to hold Beijing's assets at risk. In effect, the emerging presence of Chinese naval and maritime assets around India's oceanic periphery would enable the IAF to respond to China's asymmetric landward counterair campaign with a comparable maritime interdiction stratagem of its own. For this reason, the IAF, along with India's naval forces, will consider carefully how their emerging aviation assets can best be used to checkmate Beijing's growing capabilities through a "horizontal escalation" strategy in case China were to threaten India along their common border.

The operational context in Southern Asia elaborated above suggests that the MMRCA candidate selected by the IAF will have to be an utterly versatile platform that earns the title of "multi-role" precisely because that attribute will be at a premium in future subcontinental conflicts. It must be able to flexibly shift from air combat to ground attack operations during the day, night, or adverse weather because such dexterity will be essential for success in the counterair mission alone. In this context, the ideal aircraft would be one that possesses a low radar cross-section, deploys advanced sensors and self-protection suites, carries a heavy weapons load consisting of both long-range AAMs and diverse precision anti-surface weaponry, and possesses superior agility, endurance, and combat effectiveness. Since the air-to-ground role thus becomes virtually conjoint with the air-to-air requirement where the MMRCA is concerned, the six contenders should be evaluated according to their effectiveness in both missions, although the IAF, being a fighter force, is likely to pay close attention first to the aircraft's aerial combat capabilities.

IDENTIFYING CRITERIA FOR EVALUATING THE MMRCA CONTENDERS

Given the operational context that defines future air engagements in South Asia, the aircraft in the MMRCA competition ought to be judged on the basis of the following seven criteria: sensors and avionics; weapons; aerodynamic effectiveness; mission performance; technology transfer; cost; and political considerations.

Sensors and Avionics. Whether the aircraft’s key role is air-to-air combat or the ground attack mission, the single most important measure of capability remains its sensors and avionics. This is because all modern fighters are essentially platforms for carrying high performance sensors and weapons. Although the latter represent the “pointy end” of the spear, they are largely useless without the former. The centrality of sensors and, more generally, avionics—which refers to the totality of electronic systems on board an aircraft, including the sensors and indicators, communications, navigation and guidance gear, flight management systems, cockpit displays, and the associated electrical systems and computers—in a modern combat aircraft can be gauged from the fact that more than half its total flyaway costs today derive from these components and their embedded software packages. Over time, the costs of the airframe, powerplant, fuel, electrical, and mechanical systems have actually fallen relative to the costs of the avionics aboard, despite all these systems utilizing ever more exotic materials and technologies.³⁰

The single most important subsystem in a fighter aircraft is perhaps its radar.

While the term “sensors and avionics” includes everything from the aircraft’s detection systems to the data buses that transfer their signals to the displays that transform the signals into usable indicators, the single most important subsystem in a fighter aircraft is perhaps its radar. The air intercept (AI) radar in a modern fighter permits it to detect and engage the enemy at long distances during the day, night, or in adverse weather in both the air-to-air and the air-to-ground regimes. For many decades, AI radars were largely mechanically scanned systems. While they were certainly capable of detecting air and surface targets at varying ranges beyond the line of sight, they were limited by their fixed or narrow operating bandwidths, meager radio frequency agility, and susceptibility to counter-detection by an adversary’s electronic support measures (ESM) systems, which are intended to search, detect, identify, and locate radiated electromagnetic energy for purposes of threat avoidance and targeting.

The evolving nature of air combat in Southern Asia has prompted the IAF to require all contestants in the MMRCA competition to demonstrate AI radar systems that possess long-range detection capability against small multiple targets, have a low probability of intercept (LPI), and extreme accuracy at the high relative angular geometries prevalent in aerial dogfighting. The service’s 211-page *Request for Proposals*, in fact, clearly specifies that the winning aircraft’s

radar must be able to detect a five square-meter target (a radar cross-section corresponding with a modern, fully loaded fighter) at a distance of some 130 kilometers, or about 59 miles.

These desiderata have led the force to insist on X-band active electronically scanned array (AESA) radars as a precondition for success in the MMRCAs competition—and rightly so. In a conventional radar, a single high-power transmitter propagates radio waves through an antenna that also receives reflected energy from the target; in a passive electronically scanned array (PESA) radar, the antenna also propagates energy produced by the transmitter, but in electronically shaped form, before receiving the radar return. PESA radars are superior to conventional radars because of their ability to rapidly redirect the main beam from one location to another, thus allowing the system to generate high quality tracks of multiple targets simultaneously. However, they share the same core weakness characterizing all conventional radars—namely, their susceptibility to transmitter failure.

AESA radars overcome this weakness by replacing the single high-powered transmitter with hundreds of individual low-power transmit/receive (T/R) modules whose separate emanations collectively form the propagated radar beam. The synergistic employment of numerous smaller transmitters and the ultra-narrow waveforms associated with each T/R module produce very high effective radiated power through beams that can be directed at multiple points concurrently.

Further, since the transmitters and the receivers are collocated in each individual power module, AESA radars not only have very low system noise in comparison to conventional radars, but their susceptibility to single-point failure is also drastically reduced because the malfunction of any single T/R element has no impact on operational performance. The capacity of AESA radars to degrade gracefully, therefore, yields mean times between failure that are measured not in hours, but in years.

All these benefits come at a cost, however. The T/R module, which consists of gallium arsenide and silicon integrated circuits in a hybrid microcircuit, is extremely expensive. As the Russians have learned, it is also rather difficult to manufacture.

If issues of cost and sourcing can be overcome, there is no doubt that AESA radars bestow incredible operational advantages to warfighters that seek to dominate the aerial BVR battlespace in hostile EW environments. For starters, the high power-aperture product of AESA radars, combined with their low system noise, yields extremely long detection ranges vis-à-vis non-stealthy

adversaries and could, in fact, permit the engagement of even low-observable platforms outside of visual range. This capability will greatly advantage the IAF in the “first detection, first shot” regime relative to any opponents who lack comparable capabilities.

The AESA radar’s waveforms can also be “shaped” through the collation of numerous individual T/R module transmissions. This means that they are inherently LPI signals, resistant to detection by an adversary’s ESM systems. Because they can also be configured to have very low sidelobes, AESA radar transmissions can nullify traditional off-axis standoff noise jamming techniques that concentrate on suppressing these far field components of the beam pattern.

The extensive surveillance capabilities of the AESA radar only magnifies these benefits in that it enables its operator to detect, locate, and track (in azimuth) its conventional opponents and their emissions without betraying the position of the host aircraft, even as it avoids adversary jamming by being able to hop frequencies across its extensive radio frequency spectrum. The ability to shape the AESA radar’s emitted waveform also makes it potentially a valuable weapon for electronic attack directed at either an opponent’s AI radar or its surface air defense network.

Finally, the ability to electronically steer multiple beams in different directions implies that the AESA radar, unlike its conventional competitors, can interleave a variety of air-to-air and air-to-ground functions simultaneously, sometimes even utilizing the same waveform. Thus, for example, the AESA radar can be used to sanitize the air space in support of air combat operations at wide angles of coverage in azimuth and elevation, even as it builds weapons quality track files and supports AAMs in flight, while perhaps developing synthetic aperture high-resolution ground maps—all at the same time. The wide coverage of the AESA-equipped fighter and its multitasking capabilities

**There is no doubt that
AESA radars bestow
incredible operational
advantages to warfighters
that seek to dominate the
aerial BVR battlespace in
hostile EW environments.**

then implies that a single aircraft can provide the same surveillance capacity that once required an entire fighter section equipped with conventional radars.³¹

Using secure links to integrate this capacity with friendly integrated air defense systems and the larger combat force more generally produces revolutionary improvements in situational awareness, flexibility, and responsiveness. Since such gains, moreover, accrue in circumstances where the adversary is essentially unable to detect the AESA radar's own LPI transmissions, the probability of the IAF's fighter force getting off the first lethal missile shots in any aerial engagement increases greatly.

The greatest fighter ace of all time, Erich Hartmann, who scored 352 kills during World War II, always contended that making contact first “was the key to success, and that 80% of the pilots he had shot down never saw him during his attack.”³² The AESA radar, more than any other technology today, helps pilots achieve that crucial advantage identified by Hartmann, which is necessary to win the air war at BVR ranges.

The AESA radar thus remains at the heart of the avionics requirement in the MMRCA competition. However, the IAF has also insisted in its *Request for Proposals* that all contenders integrate a passive infrared search and tracking (IRST) sensor into their airframes—a requirement based on the service's experience operating Russian platforms like the MiG-29 and the Su-30MKI. An IRST sensor, unlike conventional radars, can detect an adversary's presence by sensing its heat sources without simultaneously revealing the host aircraft's own position. Consequently, the IAF has favored these passive systems because they enhance the prospect of successfully executing surprise first-shot attacks.

In an air combat environment characterized by AWACS control, however, IRST systems have reduced utility as *primary* detection sensors because the AEW platform's long-range radar will probably detect the target aircraft well before it enters the effective range of the defender's IRST sensor. Nevertheless, IRST systems provide important operational benefits insofar as they permit their host fighters to silently close in on targets detected by either the AEW or the EW/GCI system and launch their weapons first, utilizing the fire control quality tracks that the IRST sensor can generate at relatively close ranges.

IRST systems come into their own as detection devices, however, when there are no AWACS platforms, when radar detection is compromised by EA, or when air combat engagements are in their terminal phases or within visual range. In all such situations, passive IRST capabilities are very useful, within certain limits. Most IRST systems that operate in the middle-wavelength infrared region have very short detection ranges on the order of a few miles or

at most a few tens of miles. IRST sensors operating in the long-wave infrared region, in contrast, have detection ranges on the order of tens of miles—approaching but still not exceeding the detection ranges of the best AI radars currently in service.

Because all IRST sensors are most effective with respect to intense infrared sources (i.e., hot plumes emanating from jet engines), they work better when the target is moving away rather than toward the defender. Depending on their operating wavelength, their effectiveness can also be attenuated by atmospheric conditions, adverse weather, clutter, flares, and the altitude and angular differentials between the combatants. Within or near visual range, IRST sensors often possess better angular resolution than even radars because of their shorter wavelengths. Consequently, the IAF, following Soviet (and now Russian) doctrine, has tended to utilize the IRST capabilities of its MiG-29s and Su-30MKIs primarily for fire control during close-in air combat operations.

Many modern IRST systems have attempted to compensate for their traditional limitations by incorporating additional technologies such as laser range finders, television imaging systems, and video trackers to provide better capabilities such as search-while-track and the multiple target detection. While these improvements have no doubt made some contemporary IRST sensors highly attractive, they still cannot compete with AESA radars for sanitizing large volumes of air space at great distances.³³

The third and final subsystem of importance to India in the MMRCA competition is the aircraft's defensive avionics suite (DAS). The DAS in a modern combat aircraft generally refers to all those systems that gather information about the threats facing the platform and launch countermeasures to those dangers in the tactical circumstances of combat. From the earliest days of the electronic age, all fighter aircraft have been equipped with some kind of DAS. The most primitive versions consisted simply of a radar warning receiver (RWR), which alerted aircraft to enemy emissions (especially those emanating from fighter or SAM radars), and a set of simple countermeasures, such as chaff or flares, which could be launched when under attack by radar-guided and infrared missiles, respectively.

A contemporary DAS, in contrast, is far more complex and usually consists of an integrated package that includes:

- a radar warning receiver that operates across a wide frequency band and is usually capable of identifying, prioritizing, and locating the most threatening emissions, sometimes with an accuracy that enables a

passive weapons launch against the threatening emitter (if the plane possesses an interferometer capable of precise angular measurement);

- a self-protection jammer, the best kinds of which are digital radio frequency memory (DRFM) systems capable of capturing and retransmitting precise duplicates of the received radio frequency signal to jam, degrade or manipulate the opposing aircraft's (or SAM's) fire control system, thus preventing successful missile attacks;
- a laser detection system and, more importantly, a missile approach warning system (MAWS), which alerts the aircraft that it is either being lased by an adversary's rangefinders or being attacked by radar-guided or infrared missiles approaching along a certain specified bearing; and, finally,
- expendable countermeasures, such as chaff and flares, which can be dispensed automatically when the threat indicators meet certain predefined parameters, as well as more advanced systems like an active towed radar decoy (ATRD), which protects the aircraft by trailing a device that emits a radio frequency jamming waveform in order to attract attacking missiles to itself.

The success of a DAS—which despite its name is essential for offensive missions as well—inevitably derives not simply from the sophistication of its individual subsystems but the degree to which they are integrated with one another and to the aircraft's fire control system as a whole. In modern warplanes, this is done through the onboard databus architecture, with some aircraft possessing dedicated EW databuses—because of the complexity and sophistication of their DAS—which connect to the larger avionics system.

The IAF has made enormous investments in airborne EW in recent years. Utilizing mainly Israeli, Russian, and domestic systems in varying configurations, these capabilities have been greatly responsible for the IAF's remarkable air combat performance, for example, in the Cope India exercises with the United States.³⁴ A critical consideration in the MMRCA acquisition,

consequently, is the need to maintain the IAF's current EW superiority in the regional context. Accordingly, the *Request for Proposals* specifies a requirement for an advanced DAS that includes a wideband RWR, a DRFM jammer, an ATRD, and a MAWS with an infrared detector. The winning airplane, therefore, will be one that brings these new capabilities into the force.

The AI radar, IRST, and DAS, together with the mission management computers, are critical for air-to-ground missions as well. They either alert the aircraft to surrounding threats or help it reach the target. (The AESA radar's ground mapping capabilities are a good example of these advantages.) Anti-surface operations, however, often demand additional sensors, such as FLIR systems, laser rangefinders and designators, low light image intensifiers, and laser obstacle ranging and display systems. With the exception of the laser systems, the rest are essentially passive technologies intended to aid the aircraft in penetrating enemy air space at night or in adverse weather without revealing its location and employing its weapons accurately on target.

In dedicated strike platforms, such as the MiG-27s and Jaguars, many of these systems are permanently integrated into the airframe. In a multi-role fighter, however, such capabilities are added when required through the carriage of a targeting pod, such as Litening or Damocles, whose television and FLIR sensors are usually slaved to a laser tracker to permit target designation during day and night attacks, respectively. The IAF requires all the MMRCA candidates to present advanced targeting pods as part of their sensor offerings in support of the air-to-ground role. Where the American airplanes and the Swedish Gripen are concerned, the quality of the targeting pod offered becomes even more significant because the absence of an organic IRST system on these aircraft can be compensated only by including this capability in a pod system.

On balance, therefore, the sensors and avionics requirements of the MMRCA center on supporting precision engagement in air-to-air and air-to-ground missions in daylight, at night, and in adverse weather conditions. Toward that end, the IAF has demanded a variety of sophisticated and complementary sensors that form the heart of the MMRCA's offensive and defensive electronics suites.

Weapons. An aircraft's weapons are the decisive instruments by which it accomplishes its mission. The success of any aviation weapon depends as much on its own technical characteristics—range, warhead type, guidance package, and propulsion system—as it does on the aircraft's supporting systems—radar, IRST, DAS, and mission management computers. Consequently, the IAF will

assess the weapons offered by the MMRCA competitors by looking at their individual performance as well as their integration with the host platform. In any case, the IAF's goal is to find weapons that protect the service's current regional air superiority over the next thirty years.

Both air-to-air and air-to-ground weapons are pertinent in this context, although the IAF, much like the pre-1990s U.S. Air Force and others, has often been accused of paying more attention to the former at the expense of the latter. To the degree that this is true, the current MMRCA competition, in tandem with other initiatives, is intended to redress that problem while preserving, if not expanding, the IAF's present advantages in air-to-air combat.

In this arena, air-to-air missiles are the coin of the realm and these are typically divided into two groups. The first consists of WVR weapons that are

The IAF's goal is to find weapons that protect the service's current regional air superiority over the next thirty years.

optimized for highly dynamic maneuvering at the expense of range—generally less than 15 miles—and employing infrared guidance to lock on to the heat sources of enemy aircraft. The second consists of BVR weapons that usually rely on radar guidance, either provided by the launching aircraft or by the missile's own onboard seeker, and intended for engagements at ranges beyond sight varying from 20–60 miles.

Parenthetically, it is worth mentioning here that much of the data that is used in popular discussions about air-to-air missile ranges is misleading. Like every other aviation parameter, air-to-air missile ranges are not unique but, rather, dependent on the geometry of the engagement, the speed of the launching aircraft, and the altitude of both shooter and target. Consequently, the operational range of an air-to-air missile will vary dramatically depending on the circumstances of its employment. All numbers pertaining to air-to-air missile range, therefore, should be treated with caution; when offered without qualification, they refer only to pure kinematic capacity and hence must be considered as illustrative, useful mainly for examining relative advantages in the abstract. This is particularly important because some air-to-air missiles cannot be used to the limits of their kinematic capacity because their parent aircraft's fire control system constrains such use. Pure kinematic limits

sometimes also have lesser value if use doctrine permits missile firing only when the probabilities of kill can be maximized or only upon securing positive IFF, both of which often occur at less than maximum limits.

Air-to-air missiles that depend on the aircraft's radar for guidance are called semi-active weapons for the reason that they require the launch platform to track and illuminate their target continuously until missile impact. Such missiles increase the vulnerability of their host aircraft in a dogfight because the launcher enjoys limited freedom to maneuver, given that it must maintain a radar "lock" on the target until the very end of the engagement. Jamming semi-active missiles is also easier. The greater distance from the launch aircraft to the target relative to the supported missile implies that the radar signal has to travel farther, thus increasing its susceptibility to attenuation.

The best BVR weapons today, therefore, are active radar systems: air-to-air missiles possessing organic radars that provide their own illumination with minimal support from the launching platform. These missiles have substantial range advantages over their semi-active counterparts, especially in nose-on engagements, because their onboard radars enable them to seek their targets out independently and, as such, permit launches from much greater distances, since continual illumination by the aircraft's own radar is now unnecessary. Active radar air-to-air missiles, accordingly, bestow great operational advantages because they allow the parent aircraft to release their weapons at longer range and leave the engagement immediately ("launch and leave"), while the missile autonomously tracks and homes in on its target.

Because the quality of air-to-air missiles, along with their supporting aircraft sensors and weapons management systems, makes an enormous difference to the outcomes of air combat—all else being equal—the IAF has sought to procure the best available capabilities that money can buy, given what its opponents possess in their inventories. In the WVR range arena, for example, the IAF deploys the formidable AA-11 AAM on board its MiG-21 BISONs, MiG-29s, and Su-30MKIs, and the effective but less capable Magic-2 AAM on its Mirage 2000 and Jaguar platforms (besides some other older Russian WVR AAMs, such as the AA-8, on other aircraft).

The AA-11 exemplifies the quintessentially lethal WVR weapon because of its extreme agility, robust immunity to infrared countermeasures, short minimum range, and the capacity to engage targets at high off-boresight angles (when slaved to a helmet-mounted sight). This last characteristic is deadly in close range air combat because it minimizes the need for an attacker to achieve a perfect stern conversion relative to the target, relying instead on the capacity of the aircraft's sensors, the helmet-mounted sight, and the weapon's

wide gimbal limits operating in tandem to permit effective interception at high aspect locations such as the attacker's beam.

The IAF's current WVR weapons inventory is thus superior to Pakistan's, although these advantages may reduce somewhat as the U.S. AIM-9L Sidewinder begins to equip all Islamabad's F-16 aircraft. With the exception of the PLAAF's Su-30MKKs, which are also equipped with the AA-11, the IAF enjoys a similar superiority over all other Chinese aircraft, which are equipped with indigenous versions of older Russian air-to-air missiles. The prospective reality that China and Pakistan together will possess more fourth-generation aircraft compared with the IAF's total force—each equipped with effective AAMs of the AIM-9L or PL-8 class—has now forced India to demand even more sophisticated WVR AAMs of its MMRCA competitors.

Because WVR weapons are limited in range by definition, the IAF has focused primarily on demanding better guidance systems—which promise improved tracking and sensitivity, greater immunity to countermeasures, and high off-boresight angles of engagement—and better aerodynamic elements—such as thrust-vector control—which enable a missile to quickly change direction after launch and thus provide greater maneuverability. Consistent with these considerations, the IAF seeks the next generation of WVR AAMs. In contrast to most current systems, which are equipped with cooled infrared sensors of different kinds, the IAF has demanded WVR weapons possessing imaging infrared (IIR) seekers that will bequeath better target detection and tracking over current systems, preserve the all-aspect engagement capability, and permit locking on to targets despite flares and other countermeasures.

Similar considerations apply to BVR AAMs. Until the Chinese development of the PL-12, which is an improved, reverse-engineered, system based on the Russian AA-12, the IAF dominated the BVR air combat arena in Southern Asia through the AA-12 systems carried by its MiG-21 BISONs and Su-30MKIs. Both platforms, along with the MiG-29s, also carry the relatively capable semi-active AA-10 series missiles as well. The Mirage 2000s do not possess any active radar weapons currently, but they do deploy the semi-active Super-530D missile system.

While the semi-active weapons in IAF employ are by no means obsolete and can still be used to great effect, especially when confronting lesser platforms, the trend is clearly toward active radar systems that possess longer effective ranges, better immunity to electronic countermeasures, and greater maneuverability and speed. The use of more effective propellants or increased missile size, the employment of more powerful active radar seekers (possibly combined with dual-mode technologies utilizing both millimeter wave radars

and imaging infrared sensors), advanced digital processing, and either thrust-vector control for increased agility or ramjet power for higher velocity, all promise to make active radar weapons even more lethal in the future.

The IAF's requirements in this context focus less on specific technical parameters and more on overall capability. Beyond the need for an active radar weapon, the service desires a BVR AAM that will allow it to secure first-shot advantages at ranges greater than that available to an adversary. This, in turn, implies that the BVR AAMs offered by the various MMRCA competitors should

possess relatively large launch acceptability regions in azimuth and elevation, the biggest no-escape zone possible, the fewest constraints imposed by the fire control system on employing the weapon out to its kinematic range, and the most effective radar seeker together with the highest immunity to an adversary's electronic countermeasures.

Even as the IAF pays great attention to how the winning MMRCA's weapons would sustain its aerial superiority over the next few decades, it has not lost sight of the need for advanced air-to-ground weapons. For reasons of cost and utility, as well as doctrinal proclivities, the IAF has not focused on close air support weapons but rather on those most effective for battlefield air interdiction operations and deep penetration and strike missions at theater distances. Any aircraft chosen for the MMRCA role would be able to carry the large complement of unguided general-purpose bombs currently in the IAF's inventory because all modern weapons aiming computers can support the effective release of such munitions.

Precision strike systems that can be utilized under all conditions, then, hold the most interest for the IAF because of their disproportionate effectiveness in contemporary warfare. In this connection, the service has sought both direct attack as well as standoff weaponry. The former include both laser-guided bombs and coordinate-seeking weaponry, such as the Joint Direct

**Precision strike systems
that can be utilized
under all conditions
hold the most interest
for the IAF because of
their disproportionate
effectiveness in
contemporary warfare.**

Attack Munition (JDAM), which employs global positioning system signals to reach its targets. The latter includes various long-range systems, such as the Standoff Land Attack Missile and the Storm Shadow, which are employed for highly accurate attacks on deep land targets, as well as shorter-ranged air-to-ground missiles, such as the Maverick and the Joint Standoff Weapon (JSOW), which are designed to engage various tactical targets found during battlefield air interdiction missions, such as armor, vehicles, command posts, and fuel transport systems. Interestingly, the IAF has not solicited any weapons designed specifically for the SEAD mission, which suggests that it intends to use either its strike unmanned aerial vehicles or the AS-17 missile, associated with the SU-30MKI, for this purpose.

Aerodynamic Effectiveness. Given the expected air combat environment in Southern Asia in the future, the IAF has placed great stock on acquiring an airplane that possesses superior aerodynamic performance. For a service that is fundamentally a fighter force, this emphasis should not be surprising.

Aerodynamic effectiveness is, in general, a complex function of a fighter's airframe design, powerplant, and flight control systems. These three elements interact to define the balance between a platform's stability and agility. All else being equal, the former is more relevant for air-to-ground missions, while the latter remains critical for success in the air-to-air arena, especially in WVR combat. Aircraft that are highly agile can be sufficiently stable for most, if not all, kinds of anti-surface operations; the reverse is not necessarily true. Thus, the IAF will lean toward candidates that meet the MMRCAs maneuverability requirements, assuming that their sensors and weapons are acceptable.

In this context, aerodynamic superiority is not a virtue in itself. Rather, it has mainly instrumental utility. The agility of the airframe is relevant only to the degree that it enables the pilot to reach the most advantageous location in time and space for weapons release relative to the adversary.

In the air-to-ground regime, this translates into airframes that are sufficiently steady (meaning those with higher wing loadings) to permit the effective release of various anti-surface weapons, engines that are efficient enough for economical cruising while still being able to generate the necessary dash speeds when required, and flight control systems that can regulate the aircraft's motion effectively depending on the tactical situation.

In the air-to-air regime, aerodynamic effectiveness implies airframes with lower wing loadings that bequeath superior climb rates, higher angles of attack, and tighter turning performance, engines capable of generating the highest thrust

possible and, by implication, the highest speeds necessary in an operational context, and flight control systems capable of managing the aircraft's transitions across various speeds and load factors throughout its operating envelope.

Although there are design trade-offs between these two missions, the IAF has emphasized the air-to-air requirements when evaluating the aerodynamic efficiency of the various MMRCA contenders because of both mission priorities and the reality described earlier: that airframes capable of superlatively performing the air combat mission are likely to be found satisfactory for the air-to-ground requirement as well, so long as the relevant avionics and weapons exist for the purpose. The aerodynamic effectiveness of the six competing aircraft will therefore be judged by the key flight performance characteristics that matter fundamentally in aerial combat such as thrust-to-weight ratios, acceleration capacity, and instantaneous and sustained turn rates.

These variables, in fact, define the maneuverability of a fighter aircraft and ever since the seminal work of Colonel John R. Boyd, USAF, and Thomas P. Christie in the mid-1960s, it has been understood that superior agility remains the foundation of success in all air combat encounters.³⁵ To be sure, sensors, weapons, and training are undoubtedly critical, but if these factors are held constant for purposes of analysis, a fighter's maneuverability, more than any other factor, determines the likelihood of its success in aerial dogfighting. Maneuverability, in this context, is simply the ability of an aircraft to change the direction and/or the magnitude of its velocity vector and Boyd's great contribution to air combat theory consisted of showing how superior maneuverability is intimately related to an aircraft's energy state.

**The agility of the airframe
is relevant only to the
degree that it enables the
pilot to reach the most
advantageous location
in time and space for
weapons release relative
to the adversary.**

As Franklin C. Spinney succinctly summarized Boyd's revolutionary insight,

. . . a fighter's performance at any combination of altitude and airspeed could be expressed as the sum of its potential and kinetic energies and its ability to change these energy states by maneuvering. With this idea as a point of departure, he thought he could describe how well a fighter could perform at any point in its flight envelope. If the hypothesis were true, the next step would be to compare the performance of different fighters and determine which one was superior to the other at each point in the envelope.

Establishing such a global standard of comparison promised two enormous payoffs: First, he could compare the flying characteristics of an existing fighter to those of another, say an American F-4 to a Soviet MiG-17, and thereby identify what tactical regions of the flight envelope were most advantageous or dangerous to the friendly pilot. Second, he could evolve a design for a truly superior fighter by developing a comprehensive tradeoff process that systematically compared the performance of successive, marginally different designs.³⁶

Boyd succeeded on both counts.

Even before he articulated this understanding however, airmen everywhere intuitively understood the importance of energy states. They recognized the importance of attempting to enter an engagement with altitude and airspeed advantages relative to the adversary. Boyd's development of "energy maneuverability" theory, nevertheless, showed how the ability to sustain a better energy state relative to an adversary could increase the chances of inflicting a kill rather than being at the receiving end of one.

Boyd's work thus laid the foundations for developing what would be the only objective methodology for comparing the aerodynamic performance of different aircraft: energy maneuverability diagrams—sometimes colloquially called "doghouse plots"—which map turn rates and turn radii as a function of the airspeeds and load factors for specified aircraft operating at the same altitude, with equal fuel, and carrying comparable weapon loadouts. Consequently, overlaying the energy maneuverability diagrams of two opposing aircraft provides vital operational insight because it indicates where an airplane's advantages (and disadvantages) lie along the flight envelope, thereby enabling

the development of the requisite air combat tactics that exploit a given fighter's aerodynamic characteristics relative to its opponent's.

The only phase in air combat when energy maneuverability is likely to be less significant is when a BVR encounter begins with surprise missile shots unleashed by undetected aircraft. Once the victims are warned that an attack is underway—either by their onboard radars or by their organic DAS or by the loss of some of their cohort to the first inbound missiles—their immediate objective focuses on rapidly updating their situational awareness: developing the three-dimensional picture of the battlespace through the use of active radar as well as ESM systems (and AWACS assistance if available) to understand at least the location of the hostiles relative to the friendly and, ideally, discerning their altitudes, air speeds, and likely angles of attack as well.

Depending on the efficiency of their sensors, this process could take anywhere from minutes to seconds, and even while it is ongoing, the defenders will have to allocate attention and resources to jamming or evading any other missiles that may still be in flight (or attempting to disrupt the attacking aircraft's fire control system supporting the launched missiles). While these immediate responses materialize and as their situational awareness improves, the defenders will begin to rapidly maneuver relative to their attackers, if for no other reason than to degrade the latter's radars, deny them the necessary information about one's own position and, if possible, force them to break lock.

The usual tactic to compel such an outcome is to drag one's own aircraft to the adversary's beam, where its radar is likely to be at its gimbal limits and where the lower closure rates tend to confuse modern pulse-Doppler radars whenever they are operating in a look-down mode. Aircraft agility matters greatly in this situation insofar as it enables one side to stay more easily in the enemy's beam throughout the ensuing rolling engagement, thereby undermining its radar tracking ability and, by implication, further missile attacks.

As the combatants come closer to each other in the transition from BVR to WVR dogfighting, the importance of maneuverability increases dramatically. The aircraft that can make tighter turns at a given altitude than its adversary without applying increased thrust—meaning one that exhibits better sustained turn performance—will acquire substantial positional advantages that enable better gun and missile shots. While it is mathematically true that differences in sustained turn rate as small as one degree per second produce huge positional gains (depending on the size of the arc traversed), most fighter pilots agree that only sustained turn rate advantages greater than two degrees per second denote meaningful aerodynamic superiority, because anything less than that can be overcome by pilot skill and better tactics.

In a swirling dogfight, an aircraft's instantaneous turn rate also matters, but it cannot substitute for weak sustained turning performance. Sustained turn rates represent the optimum value where an aircraft secures the best tradeoff between turning performance (which is a function of lift) and airspeed (which is affected by drag). An aircraft's ability to pull the maximum *G*s possible at low—constant—airspeeds matters greatly here because it produces the smaller turn radius that bequeaths positional advantages over the opponent.

Instantaneous turn rates, in contrast, represent the maximum performance an airplane is capable of when it flies at its highest angle of attack. The induced drag, however, is so great as the aircraft operates along this edge of the envelope that it bleeds airspeed dramatically, hastening toward a stall. The maximum instantaneous turn rate, therefore, lasts literally only for a split second, after which the aircraft must lose either altitude or airspeed.

All combat aviators thus rely on their airplane's sustained turn rate to achieve the positional advantages necessary for success in a dogfight. They conserve their energy to achieve maximum instantaneous turn rates only when they need to defeat incoming missiles or to quickly turn the aircraft's nose out in front of an enemy's flightpath to achieve an opportunistic "snap shot."³⁷

Like so many other parameters in aviation, the sustained and instantaneous turn rates of an aircraft are not unique values but depend on its overall weight, weapons loadings, airspeed, and altitude. Consequently, comparing maximum turn rates—both sustained and instantaneous—requires overlaying one aircraft's energy maneuverability diagram on another's. These diagrams are usually composed when both airplanes are at, or close to, maximum thrust, have equivalent fuel states (usually 50 percent fuel), are armed with comparable weapons, and are flying at identical representative altitudes (usually 5,000 feet for low altitude combat and 15,000 or 20,000 feet for high altitude combat). Only when all these variables are equalized do the aerodynamic performance comparisons of different aircraft produce valid results.

Part of the IAF's evaluation of the MMRCAs competitors' aerodynamic performance will thus involve a close and careful comparative scrutiny of their many energy maneuvering diagrams. The service will compare the flight envelopes of the various aircraft, examine their specific excess power contour lines for various energy states, consider their relative lift as well as their *G* (load factor) and *Q* (total dynamic air pressure) limits, and their corner velocities.³⁸ The sustained and instantaneous turning performance of an aircraft brings together both its airframe (i.e., wing loading) and its powerplant (i.e., engine thrust) characteristics to generate these key indices of maneuverability that exploit an aircraft's thrust-to-weight ratio. Therefore, it is not unreasonable to

conclude that the IAF would prefer those aircraft that can accelerate most quickly and can turn the tightest as well as the fastest, but at the lowest possible loss of airspeed. Obviously, there are many internal trade-offs between these dimensions of performance, so the IAF's choices among the six airplanes will inevitably entail some form of constrained maximization.

Mission Performance. While an aircraft's avionics and sensors, weapons, and aerodynamic effectiveness, taken together, describe its combat potency, its mission performance refers primarily to its operational reach. There are many measures of reach referred to in the aviation literature. An aircraft's maximum range, for example, is the total distance it can fly between takeoff and landing, while its ferry range refers to the maximum range it can fly on a full fuel load—including external tanks—with minimum equipment.

Where fighter aircraft are concerned, the more useful measures are somewhat different. Combat range describes the maximum range an aircraft can fly at combat weight, which pertains to the configuration prepared for warfighting and usually includes the weight of the aircraft, crew, air-to-air weaponry, and 50 or 75 percent internal fuel. The definition of combat weight for air-to-ground missions differs in that it includes the weight of the relevant anti-surface weaponry and possibly full internal fuel, besides any external tanks if used for the mission. Combat radius, a related measure, refers to the maximum distance an airplane can travel, achieve its military objectives, and return to base with a minimal fuel reserve.

Like nominal missile range, the combat radius of a given fighter type is also not a unique number. It varies considerably depending on airframe design, engine thrust and efficiency, combat weight, flight profile, atmospheric conditions, and intensity of operations during the terminal phase of the mission. Consequently, the numbers often bandied about in the popular literature—figures which purport to describe the mission performance of various aircraft—should be treated with caution because the rules used to derive these values are invariably unclear.

Further, because mission performance varies drastically, depending on the configuration and the fuel state of each aircraft, it is not certain that the airplanes being compared have been equalized in some way so as to make a genuine comparison possible. For all these reasons, most of the figures about mission performance available in public writing are unreliable and, if anything, are dangerously biased in the direction of overstatement. Comparing mission performance is a computation-intensive exercise and demands more data,

resources, and skills than are often available to individuals outside of the operational planning cells in various air forces.

In any event, there are two broad ways in which an airplane's mission performance can be assessed, assuming a certain assignment. The first and simplest way is to calculate its flight performance purely in the abstract, concentrating largely on fuel capacity, specific fuel consumption, and flight aerodynamics to the exclusion of real world requirements and constraints. The classical methodology for this purpose is represented by Louis Breguet's famous equation that relates aircraft range to airspeed, lift-to-drag ratio, and specific fuel consumption.³⁹

The second, more complex approach consists of undertaking these calculations but embedding them in the empirical realities of air operations. Such analysis, for example, would include the fuel consumed during start, warm-up, taxi, and takeoff; then, climbing to optimal altitude, cruising to the operational area, descending, loitering and/or engaging in combat; and finally,

egressing from the combat area, climbing back to optimal altitude, cruising toward home, and eventually descending and returning to base with minimal reserves. Computing mission performance accurately in this way is obviously a more involved process, but it is also fundamental for a fighting force that has to make procurement decisions about aircraft that will be used in actual operations.

Such calculations will undoubtedly be undertaken by the IAF as it judges the mission performance of the various MMRCA competitors. There is also, however, a useful shortcut that provides important—but

not comprehensive—information: an aircraft's fuel fraction. The fuel fraction is the weight of an aircraft's fuel divided by its gross takeoff weight (including its fuel), and is usually expressed as a percentage.⁴⁰ Most contemporary jet fighters have fuel fractions of around 30 percent. Obviously, the more fuel an

The real test of mission performance is not so much fuel capacity per se, but whether the aircraft, given its native fuel fraction, can execute its assignments adequately in a specific geographic environment.

aircraft carries, the better its operating radius. Larger fuel fractions also provide other operational advantages, including the ability to exploit “dog legs” or non-direct axes of approach to a target; increased loiter time; greater afterburner use, which allows a fighter to join or disengage from aerial combat at will; and reduced requirements for tanker support.

These advantages notwithstanding, a larger fuel fraction is not always necessarily better, especially in WVR air combat. The Su-30MKI, for example, has a massive internal fuel capacity of more than 20,000 pounds, in contrast to, say, an F-16C’s 7,000 pounds. The former, however, would be an extremely sluggish airplane if it entered a dogfight with its full fuel load. In fact, the turning performance of the Su-30MKI improves dramatically as it transitions from a 75 percent to a 50 percent to a 25 percent fuel capacity and, hence, it is rare for these aircraft to undertake air combat missions with more than 50 percent fuel on board.

The most nimble fighter aircraft, in fact, are designed on the assumption that they would have relatively low fuel levels when entering combat. At low fuel states, they can pull more *Gs* to the benefit of their sustained turn capacity. The real test of mission performance, then, is not so much fuel capacity per se, but whether the aircraft, given its native fuel fraction, can execute its assignments adequately in a specific geographic environment.

For the MMRCA candidates, this translates into certain key requirements with regard to Pakistan and China. Pakistan’s relatively narrow geographic depth mean that the aircraft finally selected in the MMRCA competition must be one that can perform combat air patrol, counterair, and ground attack missions in and around Pakistani air space while operating from forward bases in India, with minimal need for air-to-air refueling. In practice, this implies that the aircraft must be capable of mission radii on the order of 350 miles so as to be able to operate unfettered over eastern and central Pakistan.

The requirements with respect to China, surprisingly, are comparable. Although China possesses great geographic depth, Indian military forces, at least today, are not intended to service any conventional missions beyond frontier defense. Hence, the IAF’s principal task consists of gaining air superiority in the regions contiguous to the Sino-Indian border in order to prevent Chinese air power from threatening India’s cities and its forward deployed forces, while thwarting Chinese land forces threatening the territorial status quo by interdicting their frontline formations and their rearward lines of communication. Executing these missions also requires aircraft with an operating radius of some 350 miles. Any operations beyond this range

will likely be conducted either by the longer-legged Su-30MKIs or India's conventional missile forces.

Ideally, mission performance in the 350-mile range with respect to both Pakistan and China would be serviced by all aircraft entirely on the strength of their internal fuel fraction. Dedicated strike aircraft may in fact be capable of such an achievement, but contemporary multi-role aircraft usually are not. It is simply an unfortunate fact that modern tactical fighters have grown ever shorter legs even as they have improved their combat capabilities. Consequently, it is doubtful whether any of the multi-role aircraft in the MMRCA competition could meet the 350-mile criterion in the air-to-air and air-to-surface regimes on the basis of their internal fuel fractions alone, though all of them could do so when equipped with external tanks and, obviously, when assured of air-to-air refueling.

Technology Transfer. While the MMRCA competition is intended to bequeath the IAF with a superb multi-role fighter that will see service for another thirty years, it is also consciously designed to support India's drive to develop a sophisticated aerospace industry.⁴¹ The dream of being able to design and build a frontline combat aircraft goes back to the years immediately after independence, when ideas about self-reliance, along with the prestige of possessing

an aviation sector, resulted in the formation of what was to become India's largest public aerospace company, Hindustan Aeronautics Limited (HAL). HAL today is a huge enterprise with nineteen production units and nine research and development (R&D) centers in seven locations.

Over the years, through a combination of both internal R&D and licensed production, HAL has chalked up many

achievements. Since its inception, it has manufactured twelve types of indigenous aircraft and fourteen foreign airplanes under license. To date, it is believed to have produced over 3,550 aircraft and 3,600 engines, while overhauling over 8,150 aircraft and 27,300 engines. It exports goods and services to over thirty international customers while remaining at the center

The MMRCA competition is consciously designed to support India's drive to develop a sophisticated aerospace industry.

of India's most ambitious current aviation programs, like the Advanced Light Helicopter, the Tejas, and the Intermediate Jet Trainer (IJT).⁴²

Given its experience with the licensed production of major combat platforms, such as the MiG-21, the MiG-27, the Jaguar, and now the Hawk and the Su-30MKI, HAL will be responsible for manufacturing the airframe and the engine of the aircraft selected from the MMRCA competition. This is not surprising. Among all India's domestic aerospace companies, only HAL possesses end-to-end capabilities in both R&D and manufacturing for defense and civil aviation in India.

HAL's achievements are undoubtedly remarkable, but the company is still struggling to achieve the dream of an indigenously designed and manufactured fighter aircraft capable of competing with the world's best. Ever since it began this quest in the 1950s with the HF-24 Marut (an excellent airframe that failed because India could not manufacture or procure the engine necessary for effective performance), HAL's ambitions have floundered fundamentally on India's larger deficiencies in aerospace design, technology, and manufacturing.

The modern jet fighter represents the acme of cutting-edge innovation, industrial excellence, and quality control. It is also the product of a highly capital-intensive enterprise that incorporates advanced technology in materials, electronics, propulsion, and, ultimately, systems integration. Successful integration remains the sine qua non of the best aircraft designs; it derives from years of experience in development and manufacturing; and this capability actually distinguishes the best in the business from the rest.

There are very few companies worldwide that have the capability to successfully design and build sophisticated combat aircraft, possibly three in the United States, three in Europe, one each in Russia and Japan, and now a small cluster of emerging capabilities in China. While India, too, could be placed on this list simply by virtue of the fact that it has built combat aircraft, one cannot credit it with the capacity to design, manufacture and integrate from scratch all the systems that go into the making of an advanced fighter (as arguably one can in the cases of Japan and China).

**The modern jet fighter
represents the acme of
cutting-edge innovation,
industrial excellence, and
quality control.**

This capability resides in so few aerospace companies because it remains the fruit of massive, long-term investments and is zealously guarded by its cultivators. Protecting this asset is critical to them not only for commercial reasons but also because their major sales ordinarily are to their own governments, which strictly constrain what can be shared abroad for national security reasons. Competitive pressures and strategic inhibitions thus combine to impose significant limits on aviation technology transfer to emerging powers such as India—a fact that can be illustrated by reference to the aerospace production chain.

Building a modern fighter involves a long project cycle that usually spans a decade or more from concept to entry into service. That cycle has seven distinct stages: R&D, engineering design, manufacturing, assembly and integration, testing and certification, user acceptance, and post-delivery service. The R&D and engineering design stages are dominated by the major aerospace companies, which utilize their vast accumulated experience and their huge human capital and financial investment pools to develop new generations of airplanes in response to the requirements laid down by their host nations.

Once the basic designs and prototypes are accepted for serial production—after the relevant selection processes are concluded and the contracts between developer and consumer consummated—the manufacturing stage is shared by the principal producer and a tiered series of subordinate vendors, whose responsibilities range from building complete subsystems to fabricating specific components and parts.

The aerospace majors come into their own principally during the assembly and integration stage when they bring together all the diverse subsystems and components—both those manufactured by themselves and those supplied by the vendors—into a single finished airplane, which is then furnished to the end user after it is tested and certified as meeting the latter's requirements. The military customer thereupon accepts the aircraft and integrates it into the force structure, with the prime contractor or some other vendor subsequently being responsible for the post-delivery service.

The limitations of India's aerospace industry reveal themselves in light of this long and complicated process. They range from insufficient technology to design base limitations, to quality control weaknesses, to skill shortages, to constrained funding, and to limited capabilities in advanced materials. Being thus far unable to master many of the critical elements of the aerospace production chain, India has found itself relegated to licensed manufacturing of foreign airplanes (at least where combat aircraft are concerned), which are sometimes modified or improved by the integration of some domestically produced subsystems or components.⁴³

The Tejas may be the exception to this rule, but its problems are legion and it is still not in serial production after more than twenty-five years of development. Although the indigenous production of the digital fly-by-wire control system has been a great achievement—a success realized after many hiccups, including interruptions caused by U.S. sanctions on India after its 1998 nuclear tests—other components, such as the multi-mode radar, have proven to be more challenging. And to this day, the Tejas’s engine is still imported—the GE F414 powerplant being recently selected—as many of its avionics subsystems and perhaps all of its weapons will be.

Yet India’s aerospace sector has made progress, as is evident from its increasingly ambitious projects such as the multi-role transport aircraft and the fifth-generation fighter aircraft, both of which are slated for co-development with Russia. Success in these endeavors, to be sure, still requires substantial foreign collaboration because, for all improvements in “know-how” accruing from licensed production over the years, Indian aerospace companies such as HAL still lack the “know-why” necessary to make them serious contenders in the major league aviation sweepstakes.

This is because they have been unable to develop many of the key subsystems themselves—especially those that embody the most puissant technology. This has forced them to rely on imports of these critical components, which come as “black boxes” supplied by original equipment manufacturers who are reluctant for both commercial and security reasons to share their most precious secrets. The net result is that Indian aerospace capabilities, while notably improving in some areas, remain severely deficient in many others.

**For all improvements in
“know-how” accruing from
licensed production over
the years, Indian aerospace
companies such as HAL
still lack the “know-why”
necessary to make them
serious contenders in the
major league aviation
sweepstakes.**

If aviation manufacturing is divided into eight key areas—airframes, propulsion, pneumatics, flight control, avionics, fuel, electrical power, and hydraulics—India’s competence today varies considerably. Through a combination of domestic R&D and learning-by-doing in licensed production, India has slowly acquired expertise in pneumatics, fuel systems, electrical power,

The MMRCA contract demands a whopping 50 percent of the deal’s final foreign exchange expenditure to be invested in building up Indian defense capabilities.

and hydraulics. It has gained proficiency in the manufacture of airframes and structures, though it still lags behind in advanced composites and in the development of digital flight control systems. India has yet to master propulsion, especially high-performance jet engines, which are among the most difficult technologies in the world, as well as avionics systems development and integration, which, again, remain among the most recondite capabilities, both at the level of hardware and source code.

Not surprisingly, the IAF and the Indian defense establishment view the MMRCA competition as providing them with a critical opportunity to leaven the country’s aviation capabilities through substantial technology transfers, especially in those arenas where India still lags behind the major powers. This invigoration is expected to occur in two ways: through offsets and through direct knowledge transfers in manufacturing and assembly. The Indian Ministry of Defense has already levied the most demanding offsets requirements for the MMRCA race. Unlike the standard condition, which requires foreign suppliers to plough back 30 percent of the procurement value through either direct purchases of Indian products or direct investment in Indian defense industries or organizations engaged in defense R&D, the MMRCA contract demands a whopping 50 percent of the deal’s final foreign exchange expenditure to be invested in building up Indian defense capabilities.

Whether Indian industry has the capacity to absorb such offsets is entirely unclear, but the high levels stipulated clearly reflect India’s desire to use the MMRCA competition to improve its technological base. This is further reinforced by the existing policy framework’s refusal to permit indirect

offsets or the satisfaction of offset obligations through technology transfer. Consistent with these principles, the IAF has insisted that the winning contender be prepared to share complete manufacturing technology, including new capabilities in the form of 6-axis computer numerically controlled milling machines and large-sized advanced forging and foundry facilities. The IAF has also demanded core design data associated with key technologies, such as engines, radar and EW components, and systems integration more generally—the crown jewels in combat aviation—over and above what are already taxing offset requirements.

Although it is understood that such technology transfers are not easily agreed to in conventional aircraft sales, Indian defense planners are counting on the fact that the eventual size of the MMRCA buy and the likelihood that it will not be repeated internationally any time soon ought to provide serious incentives to the various original equipment manufacturers involved in the competition to transfer technology more generously than usual. Since the future growth and survival of especially the European manufacturers—Dassault, the European Aeronautic Defence and Space Company (EADS), and Saab—will depend greatly on winning this order and developing a long-term product support relationship with India, decision makers in New Delhi expect that a strong technology transfer package by these companies not only offers them the best chance of preserving themselves, their sub-contractors, and their subsidiaries, but it also should stimulate their American competitors to follow suit.

Because it is unlikely that Europe will be able to undertake any manned fighter aircraft development program in the future if one of its three original equipment manufacturers fails to win the MMRCA contract, Indian policymakers have concluded that this acquisition program remains the best opportunity they will have in a long time to dramatically upgrade their aeronautical technology base with foreign assistance.

Although it is widely believed that the U.S. entrants would be the most reluctant to share their technical secrets with India—a perception deriving from the long history of strict American controls on high-technology exports worldwide—it is likely that the European (and perhaps even the Russian) firms in the MMRCA competition would be just as constrained as their American counterparts. This is because U.S. aviation companies have huge domestic markets, unlike their European and Russian peers, and their combat aircraft production runs are much larger than any of their rivals.

The costs accruing from any technology transfer, therefore, are much less significant to their economic viability in contrast to their competitors who stand

to lose their already smaller market shares should any technology diffusion end up further reducing their competitiveness. Moreover, the size of the aerospace R&D and procurement budgets in the United States are even today orders of magnitude greater than in Europe and Russia. Consequently, American companies can afford to be more generous in sharing technology because their velocity of innovation, being so much greater than their rivals', permits them to develop future capabilities much faster than their foreign counterparts, thereby mitigating whatever disadvantages may accrue from any significant transfers of current technology to India.

This advantage, however, could be nullified by the reality that should either Lockheed Martin or Boeing fail to win the MMRCA contract, only their profitability—not their survival—would be at issue. This remains the fundamental difference between the American and the European manufacturers in the Indian contest. Yet even if only profitability is at issue, it cannot be scoffed at because the opportunity to get a foothold into the large and growing Indian defense market promises important long-term advantages that will be difficult to replicate in any other emerging national power.

Consequently, both U.S. companies should bend over backward to offer the most generous technology transfer packages possible to India because this component—along with the lower flyaway costs of their airplanes—could make the fundamental difference to their ability to carry the day in the MMRCA competition. Not only does India prize technology transfer for all the reasons highlighted before, a liberal offer on this count would be essential to neutralize the European claim that their airplanes represent later generations of aviation technology and, by implication, possess greater longevity, which justifies their purchase by India despite what may be their conspicuously higher costs.

Obviously, none of the technology transfers arising out of the MMRCA program will by themselves make India a successful aerospace manufacturing nation. But because the transfer of technology in the current acquisition is viewed by New Delhi as a watershed in terms of leveraging India's huge financial outlay, all the rivals involved are likely to take it seriously. Besides its obvious significance for winning the contract, the importance assigned to acquiring key industrial capabilities also signals India's commitment to becoming an aviation industry major, however distant that goal may appear right now.

Costs. No matter how eager the IAF may be to acquire the most technologically sophisticated airplane in the MMRCA competition, its preferences will always

be constrained by the costs of the various alternatives. This is a simple fact of life. Despite India's impressive recent economic growth, its procurement budgets are still limited relative to all the warfighting capabilities it may wish to acquire. Consequently, a key consideration in the MMRCA selection—certainly for the Indian government, if not the IAF—will be the comparative cost of those airplanes designated as otherwise meeting the service's minimal technical requirements.

Indian acquisition procedures, in fact, stipulate that the cheapest compliant aircraft, identified as “L1,” should be selected for the force. The least expensive aircraft in this context, however, will be that defined by the criteria laid out in the *Request for Proposals* and does not refer simply to either an aircraft's flyaway or acquisition costs. While such a winnowing process would be easy if all the contenders were perfectly commensurate, each airplane in the MMRCA race embodies a different bundle of capabilities. Comparing the costs of the different rivals will, therefore, be a difficult process and, if handled inappropriately, it could produce dangerously suboptimal results.

Given this fact, the Indian government will have to be sensitive not simply to the sticker price of the shortlisted aircraft, but to their true marginal costs—that is, to cost differences insofar as they relate to the true differentials in combat capability, assuming that all the other relevant variables, such as the technology transfer and offset packages, are equal. To the degree that they are not, these differences will also have to be factored into the assessment of marginal costs. In other words, the final cost comparison of the various contending aircraft will be a far more complex matter than a simple price check.

Where prices are concerned, for the first time ever the IAF has instructed the MMRCA contestants to stipulate not just the program acquisition costs of their aircraft but their anticipated life cycle burdens as well. The program acquisition costs of an airplane are the costs of producing the aircraft,

The Indian government will have to be sensitive not simply to the sticker price of the shortlisted aircraft, but to their true marginal costs.

to include any R&D, testing and evaluation outlays that were incurred prior to serial production.

As is obvious, program acquisition costs—like much else in aviation—are not unique numbers but, rather, vary with the size of an aircraft’s production run. Because the fixed costs of production remain constant irrespective of how many airplanes are produced, the larger the production run, the smaller the program acquisition cost of any given unit. American aerospace companies are really advantaged on this count compared with their European counterparts because the large size of the U.S. armed forces, coupled with the substantial export market, results in U.S. fighter aircraft enjoying much larger production runs. This in turn drives down their unit costs considerably, assuming that cost differentials arising from technology variations are not at issue.

While the economics of aircraft production are easy to understand in principle, estimating the actual cost of any given aircraft is an enormously difficult enterprise.⁴⁴ In part, this is because there are different ways of reporting aircraft costs, but the more difficult challenges usually arise from the fact that the price of the inputs often vary depending on the length of the production run, the manner of the reporting required, and the constituent elements that are subsumed under different kinds of reporting labels. Given these challenges, the U.S. Air Force, for example, has a dedicated body, the Air Force Cost Analysis Agency, whose sole responsibility consists of performing independent component cost analyses of major space, aircraft, and information system programs for the U.S. Department of Defense.

The Indian government, at any rate, will consider the differences in the program acquisition costs of the various MMRCA contenders, sometimes referred to as “unit flyway costs.” Because the flyaway costs of an aircraft, however, represent only a small fraction of the total costs of operating the airplane during its active life, the IAF has sought information about all the candidates’ life cycle costs as well. The life cycle costs of an aircraft include its program acquisition costs but, additionally, incorporate the projected expenses associated with fuel, oil, and lubricants, spares, maintenance, system support, and other expenditures that would be incurred to keep the aircraft flying for the duration of its service life. These are the costs in their totality that the IAF will consider when designating the cheapest compliant aircraft as “L1” in the MMRCA competition.

The decision to demand information on life cycle costs as part of the MMRCA bidding process is eminently sensible because experience has demonstrated that the maintenance costs of any combat aircraft over its lifetime easily exceed the costs of its initial procurement. On balance, airframe maintenance, engine

maintenance, line maintenance and component maintenance—not to mention petroleum, oil and lubricants—all together end up being expensive outlays that invariably dwarf the price tag of the original procurement itself. Assessing the MMRCA candidates not simply on what they would cost the IAF today but also on how they would tax the exchequer—and the IAF’s own budget—over their active lives thus remains an important improvement in India’s aviation procurement practices.

Where life cycle costs are concerned, American and European aerospace companies enjoy the greatest advantages over their Russian counterparts because the higher labor costs in the West have induced them to build airplanes that are much more economical to maintain and operate. The more

sophisticated levels of aviation technology present in the United States and Europe have also resulted in the use of equipment with greater mean times between failures, thus further reducing life cycle costs. When American and European fighters are compared among themselves with regard to life cycle costs, U.S. manufacturers generally come out ahead, although some aircraft like the Saab Gripen are exceptional by European standards, where maintenance burdens are concerned.

Russian aircraft, by contrast, have usually been characterized by lower flyaway costs but at the price of considerably higher life cycle burdens. Over their active lives, Russian fighters consequently turn out to be costlier than their Western counterparts, a fact that is frequently obscured by their low sticker prices. If the IAF, therefore, carries through on its commitment to consider the life cycle costs of the MMRCA competitors in its selection process, the Russian MiG-35 platform is likely to be the most disadvantaged, with the French Rafale and its high maintenance demands possibly following behind (all this assuming that their technical capabilities are not at issue).

Recent reporting from India, however, has suggested that the IAF may be renegeing on its pledge to incorporate life cycle costs in its evaluation of the MMRCA bids, despite collecting the necessary information from the various vendors.⁴⁵ If true, an uncharitable explanation might attribute this change of

Russian aircraft have usually been characterized by lower flyaway costs but at the price of considerably higher life cycle burdens.

heart to the pernicious influence of the Russian lobby, which fought tooth and nail against the incorporation of life cycle costs in the original tender. A more charitable account contends that the IAF's supposed soft-pedaling of life cycle costs is based both on its lack of experience with evaluating such data and on the inherent "squishiness" of all such projections.

Thankfully, these reports are false. For starters, India's Defense Procurement Procedure (DPP) does not permit the evaluation criteria laid down in the *Request for Proposals* to be altered after the fact. Doing so would require the entire program to be re-tendered, an outcome that the IAF—and India—simply cannot afford at this point. In point of fact, the IAF has held very firm against all opposition from the defense finance bureaucracy, which was content to settle for flyaway cost comparisons because of their comparative ease of evaluation. The IAF wisely has refused to disregard life cycle costs when reviewing the MMRCA competitors because of the recognition that doing so would turn out to be an expensive misallocation of its scarce resources. Such a blunder would only end up further reducing its combat power at a time when its adversaries will only be growing stronger.

Political Considerations. Although the IAF has been scrupulous in disregarding political considerations when evaluating the six competitors during their field trials, it is unlikely that the government of India—the ultimate decision maker in the MMRCA competition—will overlook political calculations when selecting the final winner. The evaluation process, no doubt, has been designed to minimize unhealthy political interventions. The field evaluation trials, for example, were conducted solely by the IAF, with an eye to assessing the technical characteristics of the various competing aircraft. The staff evaluations that followed will be succeeded by reviews conducted by the Technical Oversight Committee and the Technical Offset Evaluation Committee before any examination of the commercial offers is finally begun.

These precautions notwithstanding, the process still makes room for political judgments in that it allows civilian decision makers to choose from amid a small number of shortlisted aircraft that are deemed to be either equivalent in capability or acceptable in terms of some ranking. As India's Defense Procurement Procedure declares,

In certain acquisition cases, imperatives of strategic partnerships or major diplomatic, political, economic, technological or military benefits deriving from a particular procurement may be the principal factor determining the

choice of a specific platform or equipment on single vendor basis. These considerations may also dictate the selection of particular equipment offered by a vendor not necessarily the lowest bidder (L1). Decisions on all such acquisitions would be taken by the Cabinet Committee on Security (CCS) on the recommendations of the DPB [Defense Procurement Board].⁴⁶

At some point, then, political considerations could intervene, and there is no reason why such issues must be treated invariably as illegitimate a priori. There are, in fact, three types of political factors that are certain to materialize in the Indian government's decision making in the MMRCA competition. And every one of them is not only justifiable, but may actually benefit India in the long run.

For starters, the selection of one aircraft rather than another is certain to be influenced by considerations about minimizing India's vulnerability to supplier cutoffs in times of crisis or war. Although technical performance and cost will dominate the final calculations, the Indian government will also seek to ensure that the vendor (or its host government) will not be able to hold the IAF hostage by threatening to withhold spares, weapons, or support associated with the desired aircraft in the event of a conflict.

The Indian experience of being subject to political sanctions historically makes this a critical consideration in the final MMRCA decision. Acutely aware of the lessons of this experience, Indian policymakers will seek to assure themselves that their freedom to pursue military action will not be constrained by a foreign entity's ability to control access to critical components as a means of influencing its political choices.

Indian policymakers will seek to assure themselves that their freedom to pursue military action will not be constrained by a foreign entity's ability to control access to critical components as a means of influencing its political choices.

While it is often assumed that such problems would arise only with the United States, there is no reason in principle why this should be so. After all, powers like Russia, France, and Great Britain have all sought to shape the decisions of various clients in the past by attempting to control the capabilities that may be made available to them in times of crisis or conflict.

The United States has admittedly used such diplomatic instruments more than most, but there will be fewer incentives for such actions toward India as the bilateral relationship deepens over time. The evolving U.S. policy of assisting India's rise further weakens Washington's motivation to engage in any coercive diplomacy against New Delhi in the future. In fact, the specter of China's rise pushes Washington in exactly the opposite direction—strengthening India's military capabilities rather than diminishing them. In any event, however, the fear that such intimidation may manifest itself will color India's choices in the MMRCA fly-off, even if only on the margins. Consequently, its decision makers will seek to immunize themselves against this threat by negotiating assurances about uninterrupted supply in the event of a crisis.

Further, while narrow technical judgments about aircraft capability may be disproportionately important in selecting the winning MMRCA platform, the political imperative of utilizing this competition to ensure a vaulting improvement in Indian military capacity cannot be overlooked. As one Indian observer has commented, the goal of the MMRCA race ultimately is not simply to procure a capable aircraft but rather to acquire a “truly modern platform that ‘broke the mold’ ... in every possible sense: technology, diplomacy, security cooperation, political opportunity, military interoperability, logistical exchange, and economics.”⁴⁷

Maximizing the benefits across all these issues will require the government of India to think beyond simply the operational virtues of a given fighter. Rather, its choices will have to be, in the final analysis, political, meaning that it takes into account a range of considerations that bear on the larger question of how this contract will elevate India's national capacities writ large. This contest is about more than ferreting out the best combat system.

Finally, the winning MMRCA contender must not only improve India's technological and warfighting competencies, but it must also serve as the instrument for forging new strategic partnerships capable of transforming the global geopolitical landscape. The fundamental purpose of any military instrument is not simply to win wars, but to create the conditions that best protect the national interest. Among the most important mechanisms for this purpose are bilateral ties, and in contemporary international politics the

breadth and depth of the defense trade between different countries serves as important indicators of the quality of their political ties.

This fact should not be shocking. In any competitive environment, defense goods usually represent the acme of a country's technological capability. Consequently, the willingness of a state to share its most potent instruments of power with another invariably reflects the value placed on that partnership. When India chooses its MMRCA platform, therefore, the political signals about desired strategic cooperation conveyed by that selection will eclipse all the technical reasons adduced for the choice.

Mindful of all this, the Indian government will entertain many considerations about how the MMRCA selection will help the country develop its partnership with certain foreign powers. As one perceptive Indian commentary recently noted, Prime Minister Manmohan Singh's foreign policy priority consists of developing "transformational relations with [key] countries around the world: in other words, focus[ing] on [those] countries that can help India overcome the enormous barriers that stand in the way of its ambition to massively grow its economic and political capacities."⁴⁸ Awarding the MMRCA contract in a strategic fashion to cement India's ties with a key foreign partner thus becomes logical. And such actions are eminently justifiable because the ultimate *telos* of any arms acquisition is always the maintenance of a strategic balance that preserves one's own physical security and political autonomy.

When all is said and done, therefore, political considerations will play a critical role, at the level of civilian decision making, in the selection of the winning MMRCA platform. The deciding factors will likely be strategic benefit, technological infusion, aircraft quality, and economic payoffs—probably in that order. And such a rank ordering is entirely legitimate from the perspective

**When India chooses
its MMRCA platform,
the political signals
about desired strategic
cooperation conveyed by
that selection will eclipse
all the technical reasons
adduced for the choice.**

of defense policy so long as the end result does not compromise the IAF's quest for dramatically improved combat capabilities.

ASSESSING THE MMRCA CONTESTANTS

When the six aircraft in the MMRCA competition are viewed at a glance, both their differences and their similarities stand out perceptibly. The variations in aircraft weight, for example, are striking: what started out as the IAF's search for a relatively light, 20-ton, fighter has now resulted in options running across the entire light-to-medium weight spectrum.⁴⁹ At the lighter end, the Gripen and the F-16IN come in with maximum takeoff weights of some 17 and 21 tons, respectively. At the middle of the medium category lie the MiG-35, the Typhoon, and the Rafale, all possessing maximum takeoff weights of about 22–24 tons. And at the heavy end of the medium category lies the F/A-18E/F which, being an extremely sturdy carrier-based aircraft, has a maximum takeoff weight of some 30 tons.

The competitors are also distinguished by differences in the number of engines. The Gripen and the F-16IN are single-engine aircraft, albeit in different dry thrust categories: the former's GE-414 engine produces some 22,000 pounds of thrust, whereas the latter's GE F110 lies in the 30,000-pound category. The remaining competitors are all twin-engine platforms that possess powerplants producing everywhere between 14,000 to 22,000 pounds of dry thrust each.

The six airplanes are also differentiated by airframe design. The Gripen, the Typhoon, and the Rafale are built to a single-tailed combined delta-canard design. The F-16IN also has a single tail, but a blended forebody with cropped delta wings. The MiG-35 and the F/A-18E/F, by contrast, have twin tailfins coupled with relatively large leading-edge extensions and maneuvering flaps.

If the differences between the six airplanes are thus conspicuous, so are some of their similarities as well. To begin with, all the competitors in the MMRCA competition are fundamentally fourth-generation fighters. These aircraft, based on designs developed during the 1970s and 1980s, are marked by an emphasis on enhanced maneuverability, the incorporation of fly-by-wire digital flight control systems, the possession of relatively high thrust-to-weight ratios, and the ability to engage in both BVR and WVR combat utilizing both missiles and guns. All the six aircraft in the MMRCA race—with the exception of the F/A-18E/F Super Hornet—are fully 9G certified airplanes, though their ability to actually pull the full load at any given point in time will depend greatly on variables such as airspeed and combat loads.

Furthermore, while all fourth-generation fighters possess relatively large and efficient low bypass ratio afterburning turbofan engines, none of them are capable of genuinely sustained supercruise flight, even though some aircraft manufacturers in the MMRCA competition have occasionally insinuated to the contrary. The U.S. Air Force defines supercruise as “the ability to cruise at speeds of one and a half times the speed of sound or greater without the use of afterburner for extended periods in combat configuration.”⁵⁰ By this standard, none of the aircraft in the MMRCA race possess supercruise capabilities, although the Typhoon comes closest in this regard.

In any event, the relatively efficient engines and airframe designs of all the platforms in the MMRCA race combine to make them superb air-to-air platforms. Accordingly, they possess decent-to-superlative combined multifunction displays, helmet-mounted sights and head-up displays, and hands-on throttle and stick (HOTAS) controls for ease of pilot response during aerial dogfighting. All the six fighters also possess look down-shoot down capabilities and all can track multiple targets, though the number of simultaneous engagements that can be prosecuted varies by platform. Their capacity to execute the air-to-ground mission, in contrast, derives mainly from the fact that they all carry highly versatile avionics packages, which enable them to switch between missions because their principal sensors and mission computers have multiple combat modes.

Finally, none of the aircraft competing in the MMRCA race are authentically stealthy airframes. All of them incorporate some kind of technology to reduce their radar signatures, mainly by utilizing radar absorbent materials in critical areas of the fuselage or by modifying the leading and trailing edges as well as the engine inlets to reduce radar reflections. None of them, however, were originally shaped from the design stage onwards to achieve the all-aspect diminution in their radar cross-section as is the case with fifth-generation aircraft such as the F-22A Raptor. While their successes in reducing radar reflections thus vary as a function of their size, their design, and their treatment—with the gains being most conspicuous in the case of the F-16 (without its conformal fuel tanks), the Rafale, and possibly the Gripen—no aircraft in the MMRCA competition can claim to possess nose-on radar signatures of less than .01 square-meter, the simple but generally accepted yardstick of a true stealth airframe.⁵¹

Understanding these similarities is important because it establishes that all the six competitors subsist primarily within a common generation of aircraft design. Although three of the airplanes in the MMRCA race—the Gripen, the Typhoon, and the Rafale—were developed in the 1980s, their aerodynamic

performance—as subsequent discussion will indicate—is basically comparable to the F-16, the F/A-18, and the MiG-35, which were designed a decade earlier.

The three “Eurocanards” are sometimes dubbed the “4.5th-generation” because of their later provenance, but this by itself does *not* imply superior combat capabilities. Their key enhancements—AESA radars, digital avionics, integrated sensor and EW suites, high-capacity data links, and advanced weapons—have all migrated to fourth-generation aircraft and in many cases actually developed out of them, sometimes continuing to reside exclusively in these predecessors.

The “Eurocanards,” to be sure, are highly efficient airframes based on an all-moving canard and delta wing combination. They are controlled by advanced digital fly-by-wire flight control systems that are simple and reliable with triple redundancy, in contrast to the more complex, quadruple flight control systems of their fourth-generation predecessors. As a result, they enjoy impressive turn rates, acceleration, and climb performance with much smaller thrust engines. Depending on the aircraft as well as on their airspeed and altitude, they can also have larger flight envelopes compared with their fourth-generation rivals, but these advantages are neither uniform nor unambiguous. Since the “Eurocanards” are, however, mostly early versions of their designs, there is substantial room for future upgrades, in contrast to at least an aircraft like the F-16, which has perhaps peaked, where design improvements are concerned.

Yet for all their technical impressiveness, the flight envelopes of the “Eurocanards” are not consistently superior to their fourth-generation competitors. By several critical measures, such as sustained turn rates, *G* loads, and mission radius, they end up being comparable to their older rivals despite their undoubtedly impressive pitch authority and carefree handling. When sensors and weapons are thrown into the mix, the quality of many a fourth-generation fighter rises considerably. This is particularly true of the American aircraft in the MMCA race and, consequently, the distinction between fourth- and 4.5th-generation aircraft may be less significant, at least as far as effective *warfighting* performance is concerned.

The differentiation between fourth- and 4.5th-generation is useful for purposes of historical accuracy, but the critical attributes that would make a difference to combat outcomes today and in the future—all-aspect stealth, supercruising engines, airframe-embedded sensors, ultra-high angle of attack performance, and internal weapons carriage—cannot be found in either generation. Therefore, great caution should be exercised in concluding that the 4.5th-generation is inherently better, especially given that the aerodynamic

performance and the avionics of many fourth-generation aircraft still remain comparable, if not sometimes superior, to their immediate descendants.⁵²

When the six contestants vying for the IAF's favor are examined more closely, this fact becomes clearer. Indeed, selecting the "best" candidate may prove more difficult than is commonly believed. The discussion that follows will not survey the technical characteristics of the various competitors in any detail, though some key attributes are collated in Table 1.

Publications such as *Jane's All the World's Aircraft*, *Jane's Avionics*, and *Jane's Radar and Electronic Warfare Systems* as well as trade journals such as *Aviation Week & Space Technology*, *Defense Industry Daily*, and *Defense News*, contain additional information. This analysis will only seek to flag key capabilities with regard to the criteria highlighted earlier, mainly in order to clarify the point that the "best" aircraft for the IAF will not be a matter of technical excellence alone.

The MiG-35 Fulcrum is a good place to start this evaluation because it represents the only airplane among the six that is already in service with the IAF in an earlier variant.⁵³ The MiG-35 is the latest and most advanced incarnation of the MiG-29 Fulcrum A, already among the most agile air combat fighters in the IAF inventory today. It shares a high degree of commonality with the MiG-29K, the most sophisticated version currently and one that will be deployed aboard the Indian Navy's aircraft carriers. The MiG-35 on offer to India will be equipped with a new deflected-vector thrust version of the RD-33 engine and advanced avionics.

As IAF pilots often point out, the MiG-29 is a superb fighter. Just like the MiG-21 before it, it was designed primarily for the air defense of point and area targets in relatively close proximity to its host air base. It therefore possessed a short combat radius—in fact, an exceedingly small radius of operation for its class—but made up for this limitation with outstanding acceleration, superb turn performance, substantial energy addition, and advanced air-to-air weaponry, making it arguably the best dogfighting platform in the IAF today.

Also like the MiG-21, however, IAF pilots note that the MiG-29, though a forgiving airplane, has poor handling qualities and terrible cockpit ergonomics. Whether the new engines and digital engine controls on the MiG-35 will liberate it from the angle of attack limitations that handicapped the older platform remains to be seen, but the IAF appears less-than-enthusiastic about the MiG-35 for many reasons, not least of which is its lack of "break the mold" capabilities the service wants for its MMRCA acquisition.

The aircraft's avionics and sensors, which constitute the heart of an advanced combat aircraft, are in part proof of this. Although the MiG-35 displayed a

TABLE 1. Key Characteristics of MMRCA Competitors

	MiG-35	Gripen NG	Rafale	Eurofighter Typhoon	F-16IN Super Viper	F/A-18E/F Super Hornet
Engine	Powerplant 2 x RD-33 Series 3M with OVT	1 x F414G (based on F414-GE-400)	2 x SNECMA M88-2E4	2 x Eurojet EJ200	1 x F110-GE-132	2 x F414-GE-400
	Dry Thrust 2 x 11,085 lb st	14,000 lb st	2 x 10,950 lb st	2 x 13,490 lb st	19,100 lb st	2 x 14,000 lb st
	Wet Thrust 2 x 18,258 lb st	22,050 lb st	2 x 16,400 lb st	2 x 20,250 lb st	32,000 lb st	2 x 22,000 lb st
Airframe	Empty Weight 11,000 kg (24,250 lbs)	8,100 kg (17,857 lbs)	9,850 kg (21,716 lbs)	11,150 kg (24,582 lbs)	10,100 kg (22,267 lbs)	14,552 kg (32,082 lbs)
	Max Takeoff Weight 22,400 kg (49,383 lbs)	16,500 kg (36,376 lbs)	24,500 kg (54,013 lbs)	23,500 kg (51,809 lbs)	21,680 kg (47,796 lbs)	30,209 kg (66,600 lbs)
	Internal Fuel 5,240 kg (11,552 lbs)	2,994 kg (6,600 lbs)	4,750 kg (10,472 lbs)	4,500 kg (9,920 lbs)	4,440 kg (9,788 lbs)	6,354 kg (14,008 lbs)
Avionics	Radar/Status ZhUK-PE Passive Electronically Scanned Array (PESA) (Active)	PS-05/A Slotted Planar Array (Active)	RBE2 PESA (Active)	Mechanically Scanned Planar Array (Active)	AN/APG-80 AESA Radar (Active)	AN/APG-79 AESA Radar (Active)
		ZhUK-AE AESA radar (In Development)	AARBEZ AESA (In Development)	Captoir Active Electronically Scanned Array Radar (CAESAR) (In Development)		
	IRST Internal OLS-UEM	Pod Mounted IR-OTIS	Internal Optronique du Secteur Frontal	Internal Passive Infra-Red Airborne Tracking Equipment (PIRATE)	Based on the Sniper Advanced Targeting Pod	Pod Mounted Advanced Tactical Forward Looking Infrared (ATFLIR)
	DAS ELI/586(v)2	Saab EWS-39	Système de Protection Electronique contre Tous les Rayonnements Adverses (SPECTRA)	Defensive Aids Sub-System (DASS)	New DAS developed exclusively for the MMRCA competition	Integrated Defensive Electronic Countermeasures (IDECM)
Weapons	Maximum Weight 4,500 kg (9,921 lbs)	6,000 kg (13,228 lbs)	9,500 kg (20,944 lbs)	7,500 kg (16,535 lbs)	9,190 kg (20,260 lbs)	8,028 kg (17,700 lbs)
	Representative Air-to-Air Weapons WVR: AA-11 BVR: AA-12	WVR: Python 5, IRIS-T BVR: AIM-120 AMRAAM, Derby	WVR: MICA-IR BVR: MICA-AR, Meteor	WVR: AIM-9L Sidewinder, ASRAAM, IRIS-T BVR: AIM-120 AMRAAM, Meteor	WVR: AIM-9X Sidewinder BVR: AIM-120 AMRAAM	WVR: AIM-9X Sidewinder BVR: AIM-120 AMRAAM
	Representative Air-to-Ground Weapons AS-17, AS-20, KAB-250KR, free-fall bombs	Rb75 Maverick, RBS 15F, KEPD 150 and KEPD 350 SOMs	Apache-AP, SCALP-EG, LGBs	ALARM, Penguin, Harpoon, Brimstone, Taurus, Storm Shadow, LGBs	GBU-31 JDAM, AGM-154 JSOW, AGM-65 Maverick, AGM-88 Harm, Harpoon	GBU-31 JDAM, AGM-154 JSOW, AGM-65 Maverick, AGM-88 Harm, Harpoon

ZhUK-AE AESA radar during its spectacular appearance at Aero India 2007, the fact remains that Russia today lags considerably behind the West in the development of X-band AESA radar technology. As U.S. industry sources accurately point out, these limitations derive partly from the fact that Russia still faces difficulties in manufacturing the monolithic microwave integrated circuits that lie at the heart of the AESA radar's T/R modules. In any event, while the Russian MiG-35 will eventually possess an AESA radar, it is unclear when a mature system will be available and whether it will compare favorably with its Western counterparts.

While Russia is better off where other sensor systems are concerned, these capabilities cannot compensate for the absence of an AESA radar in the large-scale sanitization of air space.

The MiG-35, for example, will be equipped with the OLS-UEM IRST, the OLS-K laser targeting pod, a DAS that incorporates the Italian ELT/568(v)2 self-protection jammer, and a helmet-mounted display. The new medium-wave IRST sensor is certain to be an improvement over older legacy systems, but its physical characteristics will still not compensate for the absence of a good long-range radar. The aircraft's RWR is likely to be respectable as well, but the older MiG-29's radar was not perfectly integrated with its DAS and it is uncertain whether the newer airplane has ironed out these problems.

In any case, the MiG-35 does not bring any new advanced armament to the table, though its ten stations will enable it to carry more weapons than the MiG-29. The aircraft will still be equipped with the superb, high off-boresight WVR AAM, the AA-11. Its new radar will permit the aircraft to support the active radar BVR AAM, the AA-12, and other assorted air-to-ground munitions. In that sense, the MiG-35, just like its predecessors, the MiG-29SM and the MiG-29K, will be a genuinely multi-role combat platform. But all the weapons that it carries are already in the IAF's arsenal. Not only do they not represent the increased potency that the IAF seeks through its MMRCA

The biggest problem characterizing the MiG-35 as a MMRCA entrant is that it is still an airplane in development. It has not yet been purchased by the Russian Air Force.

MiG-35

Advantages	Disadvantages
Good maneuverability	Final configuration not settled
Thrust vectored engines	AESA radar still in development
Generous technology transfer likely	Moderately capable IRST
Low flyaway cost	Weapons offered already in IAF inventory
	Horrendous maintenance requirement
	High life cycle costs
	Modest political benefits

acquisition, some weapons, such as the AA-11, which does not possess an IIR sensor, are not even compliant with the Indian *Request for Proposals*. Moreover, they are also now challenged by many newer systems available in the West and on offer with the MiG-35's competitors.

The biggest problem characterizing the MiG-35 as a MMRCA entrant is that it is still an airplane in development. It has not yet been purchased by the Russian Air Force. Thus, it violates yet another stipulation of the *Request for Proposals*: that the aircraft be in the operational employ of the producer country's air force.

While it is likely to improve somewhat over its predecessor's excellent aerodynamic maneuverability, its sustained turn performance at representative altitudes will place it in the same class as the Eurofighter and the Rafale, all three of which are inferior to the Gripen, the F-16 (without its conformal fuel tanks), and the F/A-18. The MiG-35's maximum instantaneous turn rate is likely to be poorer than all the other competitors save the F-16 when flying with conformal fuel tanks, with bleed rates comparable to other airplanes such as the Eurofighter and the F/A-18. The mission performance of the MiG-35 will have certainly improved over the MiG-29 because of the addition of fuel tanks in its dorsal spine, but it still cannot be described as a long-range counterair fighter.

Given that the MiG-35 remains an evolutionary improvement over the MiG-29, with the same basic airframe, innards, and design philosophy, it is unlikely to dramatically transform the horrendous maintenance requirements associated with this family of airplanes. For all their air combat virtues, every MiG-29 variant has been plagued by low mean times between failures,

resulting in significant weaknesses in system reliability. As a result, the life cycle costs of the MiG-29 have been excessive compared with its peers and that only deepens the IAF's disinclination to treat the MiG-35 as a favored candidate for the MMRCA role.

Since Russia is desperate to secure the MMRCA contract in order to protect its hitherto dominant position as India's principal supplier of combat aircraft and to sustain its domestic aviation industry, it is certain that Moscow will offer New Delhi a more generous technology transfer package for the MiG-35 in comparison to its competitors. A more generous package, however, does not mean it is a generous package all told: although Indian commentators routinely assert that Russia is committed to "complete" technology transfer, these claims are suspect, if the Russian record in regard to past licensed production in India is any indication.

Moscow will undoubtedly share more technology with India than it might with others. While it is likely to allow India to license produce the RD-33 engine, its own economic constraints will prevent it from sharing crown jewels like the aircraft's radar system, its engine know-how, and its avionics. The character of Russia's military-industrial complex may also prevent the RSK MiG from being able to fully satisfy India's demanding offset requirements. There is no evidence, for example, of Russian aviation entities having bought any significant hardware or components from India in the past. All previous Indian aircraft acquisitions from Russia involved direct government-to-government sales, with the Russian original equipment manufacturer simply transferring to HAL the minimum infrastructure required to license produce some number of aircraft indigenously. Today, when the Russian fighter industry is struggling to survive the current dearth of domestic orders amid expanded foreign competition, meeting India's offset demands could prove more burdensome than usual.

**Perhaps the ultimate
detraction from the
MiG-35's allure is that
it provides no particular
political advantages
for India.**

Given extant Russian advantages in aircraft production, however, the MiG-35 is likely to be among the cheaper aircraft on offer, probably coming in somewhere around \$45 million a copy. Against this fact, Russia's abysmal record of delivery performance, its perennial difficulties in providing after-sales support, and the high maintenance and life cycle costs of Russian aircraft, will have to be factored in as well.

Perhaps the ultimate detraction from the MiG-35's allure is that it provides no particular political advantages for India. New Delhi is already a significant buyer of Russian aviation products, Russian-Indian military ties are almost entirely commercial anyway, and the purchase of one more Russian airplane is unlikely to advance India's goal of investing in transformative political relationships in any serious way. Consequently, even if all the technical shortcomings of the MiG-35 are overlooked, the political benefits of this buy for India are minimal.

In contrast to the MiG-35, which fails to evoke the IAF's enthusiasm for all the reasons above, the Swedish Gripen NG at least commands admiration—though translating that into sufficient interest for a purchase still remains a long shot.⁵⁴ The Gripen is the lightest aircraft in the MMRCA competition, with a maximum takeoff weight of about 17 tons. Being “the latest in a long and distinguished line of Saab fighters,” it remains “a remarkable example of squeezing maximum capability and performance into the smallest airframe possible.”⁵⁵

The NG variant currently on offer to India is a new design based on the older JAS-39C, which remains Sweden's principal all-weather, multi-role aircraft (albeit optimized for air defense). The NG is heavier than the original, with larger air intakes, a redesigned undercarriage allowing an increase in internal fuel capacity from 2,300 kilograms to 3,300 kilograms, a new engine offering a 35 percent increase in thrust, and new sensors and avionics that will sustain the aircraft's already remarkable capacity for fully networked operations.

The heart of the Gripen's sensor suite is the mechanically steered PS-05 pulse-Doppler radar (which incorporates a passive mode that can detect other airborne emissions without radiating), a EWS-39 DAS (which provides 360 degrees of coverage), and a Tactical Information Datalink System (which enables secure data sharing between the aircraft, accompanying AEW platforms, and the air defense net as a whole). The Gripen's incredible air defense potential, thus, derives not simply from its superlative aerodynamics but from its cooperative engagement capabilities.

Even when on the ground, the aircraft is fully linked into the prevailing air situation picture and, when airborne, a Gripen pilot can engage his target without betraying his presence, using fire control data provided by another

GRIPEN NG

Advantages	Disadvantages
Light weight*	Final configuration not settled
Excellent sensor fusion and systems integration	AESA radar still in development
Cooperative targeting capability	Sensors, weapons and major subsystems sourced from third-parties
Diverse new advanced weaponry	Availability of most advanced weapons uncertain
Superlative maneuverability	Poor hot and high performance
Low signatures (?)	High flyaway cost
	Minimal political benefits

* Impact of the attribute is ambiguous for the MMRCA race

platform to launch his weapons in complete silence. The high sensor fusion in the Gripen and its ability to share all information seamlessly across the air defense network is what makes this aircraft a formidable weapon in a very light package. Yet, impressive as the Gripen is, it still lacks some key capabilities spelled out in the *Request for Proposals*.

The most consequential deficiency currently is the Gripen's lack of an AESA radar. Saab Microwave Systems is currently developing the NORA ("Not Only a RAдар") AESA system, but the technology is far from ready or mature. Although this program will eventually result in a new AESA radar, the fact that it will be based on the signal processing section of the older PS-05 system leaves some Indian officials queasy. Moreover, the new radar is almost certain to depend heavily on Raytheon T/R modules, since the relatively small Gripen production runs will almost certainly not justify the enormous cost of building these tiles indigenously. Under these circumstances, the attractiveness of the NORA—which will in any case not be ready in operational form for some more years—diminishes considerably, because the IAF would probably be better off purchasing a platform equipped with an entirely Raytheon-produced radar rather than a system that merely incorporates critical American components.

The Gripen NG demonstrated in India, however, had the Vixen 1000E/ES-05 Raven AESA radar, which was first flight tested only in October 2009. The Raven, developed by the Italian firm Selex Galileo, employs a unique "swashplate" design that permits the canted radar to be rotated in

order to increase its coverage in azimuth. This radar is also a candidate for future integration with the Eurofighter Typhoon. While the Raven is likely to be a successful AESA radar when finally operational, it currently remains a developmental system and, hence, embodies a certain measure of technical risk. This characteristic is shared by all the European competitors in the MMRCA race because they sport only emergent AESA radars on their aircraft at present.

The Gripen also lacks an organicIRST sensor, although Saab developed and tested a long-wave infrared system, designated the IR-OTIS, several years ago. Sweden has offered this system in the MMRCA competition, but because it is not in active production, the risks associated with selecting it are not trivial.⁵⁶ The other systems on board the Gripen, such as the DAS and the helmet-mounted display, are of superb quality and very well integrated with the rest of the avionic systems. The DAS will include new DRFM capabilities, a MAWS, and an ARTD. All told, these capabilities will give the Gripen a new effectiveness in EA without in any way compromising the networked defense proficiency for which it is particularly distinguished.

If the aircraft's principal sensors are currently afflicted by uncertainty, the weapons it brings along to the MMRCA race are not. The Gripen has already been certified to carry a remarkably wide range of air-to-air and air-to-ground weaponry, including many new systems prized by the IAF. For the WVR role, for example, Saab can mate the Israeli Python 5 and the multinational IRIS-T, both IIR AAMs that are highly maneuverable, capable of high off-boresight launches, and possessing attractive range. In the BVR regime, the Gripen offers the U.S. AIM-120 AMRAAM, or the active radar version of the Israeli Python 4, the Derby.

None of the Gripen's diverse array of weapons is manufactured in Sweden however. Consequently, the issue of their releasability to India becomes critical. It is entirely possible that some countries would deny Saab the export licenses to offer these weapons if their own aircraft in the MMRCA competition (which also happen to carry the same armaments) are not selected. This reality, of which the IAF is conscious, could reduce the attractiveness of the Gripen, even though its virtues as a combatant command respect and admiration.

There is perhaps no better evidence of the Gripen's combat virtues than its aerodynamic performance. Although the aircraft's top-end speed is limited in comparison to the MiG-35, the Typhoon, and the F-16IN, it remains in the same class as the Rafale and the F/A-18E/F. But more importantly, of all the fighters competing in the MMRCA race, no aircraft has a better sustained turn performance than the Gripen. Its aerodynamically clean design gives it a decisive advantage over the Eurofighter, Rafale, and MiG-35 in any turning fight at

lower altitudes, but much smaller benefits over the F-16IN (without conformal fuel tanks) and the F/A-18E/F. The Gripen's advantages in sustained turning performance diminish at higher altitudes, but it still remains superior to every other aircraft in the MMRCA competition. Its instantaneous turn performance, in contrast, generally falls below that of its competitors (with the exception of the F-16, when equipped with conformal fuel tanks), but its bleed rates are also dramatically smaller, thus permitting it to preserve its energy and get back more rapidly into the fight.

There is perhaps no better evidence of the Gripen's combat virtues than its aerodynamic performance.

This superb aerodynamic capability, moreover, comes in an airframe with carefree handling qualities and the Gripen's cockpit ergonomics are outstanding, enabling its pilot to flexibly prosecute air and ground missions with minimal burdens. Thanks to Sweden's geography and its strategic circumstances, the Gripen also displays excellent short field performance. Its relatively small-thrust engine, while effective for aerodynamic maneuvering, has significant limits, however, when hot and high performance—a critical requirement for the IAF—is concerned. Whatever the virtues of small, highly efficient, engines may be, the diversity of the operating environment in Southern Asia really benefits lightweight aircraft such as the F-16IN with their high-thrust, high-performance engines.

Although the Gripen is unlikely to find itself at an unacceptable disadvantage on most missions that matter within the subcontinent, this is only because its small internal fuel capacity—the smallest among the MMRCA competitors—will be compensated by its economical cruising capability, the ability to carry external tanks, and the availability of in-flight refueling. These remedies, along with its hot and high performance limitations, however, will compromise its basing flexibility in the Indian context and raise important concerns about whether the Gripen, for all its embodied innovation and excellent aerodynamics, remains the best candidate for the MMRCA component of the IAF's force structure.

Sweden's desire to sustain an independent military aviation base should induce Saab to offer both attractive pricing as well as an appealing technology transfer package. If the Gripen were to be priced at about \$50 million per aircraft, it would not only be heavily competitive with the MiG-35 but would

represent a more agile platform with superior multi-role capabilities and, depending on the weapons selected, even greater lethality, at least in air-to-air combat. The Gripen has had a higher price tag in the past, however. During Saab's bid for the Norwegian combat aircraft contract, it came in at a pricey \$82 million per copy. If this is the unit flyaway price offered to India, the Gripen's liabilities would increase considerably.

After all, Saab's ability to transfer technology to India effectively is already suspect. Many, if not most, of the key subsystems (and weapons) associated with the Gripen are sourced from foreign vendors, whose parent governments may not be enthusiastic about sharing their national technologies to support a competitor. Saab might attempt to compensate for these limitations by offering a more attractive offset package to India in other defense areas such as naval warfare, radar and surveillance, and command and control systems. Wherever the Gripen has been sold—there are now four or five Gripen operators internationally—Saab has invariably supported these sales through indirect offsets. Unfortunately, these are not permitted in the MMRCA competition and so Saab would have to come up with a very attractive direct offsets package that, for example, would aid India's capacities in aircraft design or exploit another area of Swedish comparative advantage like sensors, electronics, missiles, or naval systems.

Finally, the political benefits to India from acquiring the Gripen are minimal. While the Indian state is constantly looking to diversify its arms purchases in

**For all the usual liabilities,
an American purchase
would arguably produce
greater political benefits.**

order to avoid becoming hostage to a single country, the fact that Saab does not possess end-to-end capabilities in developing and producing military aircraft means that New Delhi will end up being dependent on a range of second- and third-tier suppliers in more powerful countries like the United States simply to keep its Swedish platforms operational.

Given this fact, there is an argument to be made for India going directly for an American product. For all the usual liabilities, an American purchase would arguably produce greater political benefits. As a distinguished former Indian Foreign Secretary put it, "India should initiate the process by opting for 126 multi-role fighter jets from the United States. Deals of this magnitude should

be struck with an eye on political and strategic gain: in that context the choice between Sweden and [the] United States should be obvious.”⁵⁷

The French Rafale is truly the Phoenix of the MMRCA competition.⁵⁸ The IAF’s original preference centered on purchasing additional Mirage 2000s. The French original equipment manufacturer, Dassault Aviation, had eagerly hoped that the IAF would pursue this option and procure the aircraft through a single vendor process. When the government of India insisted on an open tender competition, however, Dassault demurred and communicated its unwillingness to participate. Throughout this period, the company still clung to the hope that the IAF would simply purchase more Mirage 2000s, even going to the point of advising the service that the Rafale was far too expensive for Indian needs and therefore ought to be substituted by the older airplane.

The subsequent delays in issuing the *Request for Proposals*, however, resulted in the Mirage 2000 eventually exiting the competition, partly because Dassault was unable to keep the production line open indefinitely, but more importantly because the IAF had by now lost interest in acquiring larger numbers of what was perceived to be a dated aircraft. Pressure from the French government, and possibly from India as well, finally induced Dassault to offer the Rafale as a MMRCA candidate. And today, after a long set of twists and turns, the French competitor is now rumored to be among the top choices in the current fly-off.

The Rafale was originally part of the European effort in the early 1980s to develop a common multi-role fighter that would replace an entire generation of aircraft such as the F-4 Phantom, the SPECAT Jaguar, the Super Etendard, and the F-8 Crusader. The objective was to produce an aircraft that would excel in the BVR role in air-to-air combat, while being sufficiently flexible to conduct air-to-ground operations. Because French requirements focused on acquiring an aircraft that would be both land- and carrier-based, Paris eventually broke with its European partners to produce a smaller aircraft, the Rafale, while London, Berlin, Rome, and Madrid collaborated to develop the somewhat larger Eurofighter Typhoon.

The Rafale that competes in the MMRCA competition is the single-seat C version developed for the French Air Force. If selected, it will be built to the F3+ standard, which was developed as a replacement for the Mk2 export version after the aircraft lost out in many foreign acquisition programs. The F3+ standard Rafale is due to be equipped with a multi-mode AESA radar, organicIRST capability, a laser targeting pod, and other sensors that would be fully integrated to provide the aircraft with air-to-air and air-to-ground capabilities.⁵⁹ These sensors support a highly maneuverable delta-wing airframe, which, unfortunately, has not yet realized its full potential because

RAFALE

Advantages	Disadvantages
Highly capable IRST	AESA radar still in development
Excellent sensor fusion and systems integration	Availability of most advanced weapons uncertain
Passive and cooperative targeting capability	High maintenance burdens
Diverse new advanced weaponry	High cost
Good maneuverability	Modest political benefits
Low signatures	

of its underpowered M88-2 engines (which are scheduled to be replaced by the M88 ECO at some point in the future).

Like the Gripen, the Rafale's greatest strength, especially in the air combat arena, is its ability to acquire, process and fuse information from multiple sensors and present it to the pilot in a single tactical display. This frees the pilot from having to operate multiple detection systems individually. The aircraft's fire control system collects the signals from each individual sensor—radar, IRST, and DAS—integrates them into single tracks and displays them in ways that permit rapid response. IAF pilots who have witnessed the Rafale during the MMRCA fly-offs have commented favorably about the aircraft's remarkable cockpit ergonomics and human factors engineering as manifested in its sensors, controls, interfaces, and displays.

That said, however, the Rafale's current sensors and avionics do not yet meet the IAF's specifications in its *Request for Proposals*. The most important lacuna here is the absence of an operational AESA radar, though the current passive electronically scanned RBE2 system—with both multi-mode and multi-target tracking capabilities, is scheduled to be upgraded to an AESA variant in the future. The French government has determinedly pursued AESA technology through the European Active Multimode Solid-State Active Radar (ASMAR) program for many years now, but an AESA radar will probably become part of the Rafale's standard sensor suit only during the middle of this decade.

If the radar is still missing, the rest of the Rafale's sensors are not. The Optronique du Secteur Frontal IRST system, which operates in both the

medium-wave infrared and long-wave infrared spectral region, has true long-range detection capabilities that would shame its Russian counterparts. And the aircraft's *Système de Protection Electronique contre Tous les Rayonnements Adverses* (SPECTRA) DAS permits 360 degree warning coverage, incorporates a DRFM-based self-protection jammer, a laser and missile warning receiver, and various expendables, but not the ARTD specified in the Request for Proposals. All these components, moreover, are fully integrated with the fire control system, and, thanks to the use of secure data links, the Rafale has cooperative engagement targeting capabilities—where one aircraft launches weapons based on the fire quality tracks provided by another aircraft—as well as the capacity to launch weapons based entirely on passive detection.

Although the exported version of the Rafale will not bring all the weapons supported in French employ, it will bring at least two superb but extremely expensive AAMs that India does not currently possess: the MICA-IR, with its IIR seeker, and the MICA-AR, with its active radar sensor. When employed with a helmet-mounted sight, the MICA-IR provides the Rafale with high off-boresight and lock-on after launch capabilities, and while the MICA-AR is not the longest-range BVR active radar missile on the market, it has exceptional maneuverability and electronic counter-countermeasures capability. Although the Rafale will eventually employ the longer-range active radar BVR missile, the Meteor, it is uncertain whether this weapon would be exported to India.

With the Damocles targeting pod, the Rafale will be able to deliver a variety of laser-guided bombs, and it will carry other precision strike weapons such as the Apache-AP and the SCALP-EG as well, though, again, it is not clear whether some of these systems will be exported to India. In the surface strike role, the Rafale has clear advantages: it is designed for high speed, low level attack operations, is capable of terrain following, and has a world-class integrated EW suite that provides both enhanced protection and attack capabilities. Irrespective of what weapons the Rafale carries, the versatility of its avionics system is remarkable. It permits the pilot to shift effortlessly from air-to-air to air-to-ground missions during a single sortie, while offering easy management of information, great situational awareness, and multi-target engagement capability in an airframe characterized by superb handling.

Even with its current underpowered engine, the Rafale's aerodynamic performance is excellent. Its sustained turning performance is comparable to that of the Eurofighter and the MiG-35, but poorer than the F-16 (without conformal fuel tanks) and the F/A-18, not to mention the Gripen. The Rafale maneuvers best at low altitudes and slow speeds, but whether its opponents will oblige it by fighting in this regime remains an open question. Its instantaneous

turn rates, however, are spectacular—in fact, far better than any of the other MMRCA competitors—which makes it a formidable opponent in any tactical situation when a sharp turn of the nose provides a firing advantage.

Dassault will have to sweeten the pot in the MMRCA competition by offering a highly attractive technology transfer package to India.

In such situations, however, the Rafale also bleeds speed dramatically. This could put it at a disadvantage when facing opponents with greater energy reserves. In fact, the Rafale probably has the highest bleed rates of any MMRCA contestant at any altitude. Like the Gripen and the F/A-18, the Rafale has a constrained top-end speed, peaking at about Mach 1.8 at high altitude. Its mission performance in most counterair and ground attack scenarios in the Indian subcontinent will be

adequate, though the Rafale, like its other European counterparts, is certain to require air refueling or external tanks to sustain the desired operational reach.

For all its impressive qualities, the Rafale is a likely to be an extraordinarily expensive aircraft, costing somewhere in the region of \$85 million a copy, second only to the Eurofighter. The continual upgrades that Dassault has proposed to bring the aircraft up to F3+ standards has, therefore, perplexed many industry observers because the smaller French aircraft production runs already raise unit costs considerably above their foreign counterparts. This ends up making the Rafale costly to begin with, which partly explains why it has lost out in every foreign competition thus far. Attempting to compensate for this outcome by incorporating more sophisticated technology ends up making the airplane even more expensive, especially compared with other twin-engine fighters that provide comparable capability at lesser cost. European industry sources also emphasize the Rafale's high maintenance requirements, which are certain to add significantly to its life cycle costs.

Given this fact, Dassault will have to sweeten the pot in the MMRCA competition by offering a highly attractive technology transfer package to India. Whether the company can actually transfer its most precious capabilities, for example, in radar, IRST, sensor fusion, long-range weaponry, and engines, does not require any guesses. India's experience with the Mirage 2000 has shown that, while the French have been very good in providing

spares and support for their aircraft, even aircraft maintenance has yielded little by way of true transfers of either knowledge or expertise. It is also unclear whether Dassault will be able to meet the ambitious offsets requirements in the MMRCA competition, in part because the Indian Mirage 2000 upgrade program—the most obvious candidate for satisfying these considerations—will be concluded long before the winning MMRCA platform is selected. In any event, the incredible costs of the Mirage 2000 upgrade program—believed to now run at more than \$35 million per aircraft—only highlights the traditional weakness of French combat aviation, namely its atrociously high prices that produce a poor cost-to-value ratio.

The purchase of a French aircraft could be quite attractive to India on political grounds because Paris has been one of New Delhi's strongest supporters in the international arena. Moreover, French sales of military technology to India have never been subject to cutoffs or sanctions and, hence, would remain a source of reassurance to New Delhi in politically uncertain times. It is far from clear, however, that this past performance is enough to warrant a reward in the form of a MMRCA purchase, given that other big orders, such as the Scorpene submarine and the European Pressurized Reactors (EPR) have already gone to Paris. Moreover, there are other countries in the queue that have done a great deal for India, particularly the United States, with its civilian nuclear cooperation agreement. Even if all these considerations are disregarded, however, Indian policymakers would still have to make the difficult judgment about whether this incredibly costly purchase would be worth the chance of minimal gains in technology transfer.

Built by a four-country consortium, the Eurofighter Typhoon is the last of the three “Eurocanards” participating in the MMRCA competition.⁶⁰ Like the Rafale, with which it shares a common requirements history, the Typhoon was intended as an all-weather multi-role fighter that by its design, however, is optimized for the air superiority mission. The Typhoon will be built in three tranches, each incorporating additional capabilities. Each tranche will be further sub-divided into batches and blocks of specific configurations, depending on the needs of particular customers. Tranche 1, for example, focused only air-to-air combat requirements; Tranche 2 added basic air-to-ground capabilities, while Tranche 3 is expected to feature the fully mature Typhoon with its complete air-to-air and air-to-ground capabilities deriving from the incorporation of a multi-mode AESA radar, advanced BVR missiles, and possibly thrust-vectoring engines.

Given the IAF's *Request for Proposals*, only the Tranche 3 version of the aircraft will fully meet India's needs. The service has already encountered the

Typhoon in air exercises conducted with the Royal Air Force and has been favorably impressed by its performance. In the aftermath of the MMRCA fly-offs, a variety of stories appeared in the Indian press suggesting that the Typhoon was in fact the IAF's first choice as far as all six competitors were concerned.⁶¹ This conclusion is not implausible. Out of all the aircraft, the Typhoon conformed most closely to the *Request for Proposals*, and in a purely technical sense, it arguably remains the most sophisticated airplane in the mix—at least in its fully mature configuration, which is still gestating.

The Typhoon is undoubtedly an impressive air superiority aircraft. Its intentionally unstable design gives it considerable agility, while its sophisticated flight control system not only provides for carefree handling but also automatically prevents the aircraft from departing into unsafe areas of the envelope where the airplane might stall or spin. The Typhoon's twin EJ200 engines each produce about 13,500 pounds of dry thrust (and more than 20,000 pounds in full afterburner), which bequeath the aircraft with a higher thrust-to-weight ratio at high subsonic speed (at low altitude) than any of its competitors, save the F-16 (without conformal fuel tanks).

This engine output, along with its canard-coupled cropped delta-wing airframe, enables it to achieve superb transonic maneuver as well as excellent supersonic dash performance. In fact, the Eurofighter remains the only aircraft among the MMRCA competitors to have demonstrated some sort of supercruise capability (though this capability falls far short of the sustained supercruise capability of the F-22A and the F-35). It also exhibits striking short takeoff and landing performance.

The Typhoon's integration of sensors and avionics is also remarkable. Like the Rafale, the Eurofighter consortium paid particular attention to the aircraft's Man-Machine Interface, which collects data from all the on-board sensors (and any off-board streams such as the AWACS), presents them as a unified track on the aircraft's main tactical display, and permits the pilot to control most functions through voice inputs (with the exception of weapons launch). The primary sensor of the Typhoon currently is the Captor radar which, although having multi-mode capabilities, is optimized primarily for air-to-air combat. This should not be surprising since the Captor evolved from the British Sea Harrier's Blue Vixen radar; despite being one of the most advanced pulse-Doppler radars of its time, it was designed primarily for air intercept operations.

Judged against the MMRCA requirements, however, the Captor represents the aircraft's biggest weakness because it is not an AESA radar. The Eurofighter consortium has an AESA radar development effort currently underway, but the Captor Active Electronically Scanned Array Radar (CAESAR) system that is

TYPHOON

Advantages	Disadvantages
Highly capable IRST	AESA radar still in development
Excellent sensor fusion and systems integration	Availability of most advanced weapons uncertain
Passive and cooperative targeting capability	High signatures
Diverse new advanced weaponry	Extremely high cost
Good maneuverability	Significant technology transfer constraints
Demonstrated short field performance	Modest political benefits

intended for the future is unlikely to become a standard fit for several years. On this count, the Typhoon shares the same handicap as its other European stable mates, the Rafale and the Gripen (and the MiG-35). While this limitation will be rectified at some point, the Typhoon cannot be considered to be compliant today with at least this one critical element of the MMRCA *Request for Proposals*.

Like the Rafale, the Typhoon “compensates” for the current lack of an operational AESA radar with a superb IRST system—possibly the world’s best—called the Passive Infra-Red Airborne Tracking Equipment (PIRATE). The PIRATE system is capable of detecting targets at distances approaching that of conventional radars. It combines a long-range IRST sensor operating in the long-wave infrared band with a FLIR thermal imager that is capable of passively searching, tracking and designating targets for weapons launch. All system data is seamlessly integrated with the information collected by other sensors to provide the pilot with a unified track for each target.

The Typhoon’s DAS, called the Defensive Aids Sub-System (DASS), also contributes to enhancing the pilot’s overall situational awareness. Incorporating a wideband RWR and ESM system (which provides 360 degree coverage and can locate adversary emitters with angular accuracies of less than a degree), a MAWS, a self-protection jammer, and ARTDs in addition to the usual chaff and flares, the Typhoon’s DAS completes the incredible tactical information suite that provides its pilot with usable, correlated data about the threats facing the aircraft. The principal weakness of this system currently is the lack of a DRFM-based jammer, but the Eurofighter consortium expects to incorporate this capability in the future.

The Typhoon's sensors and avionics showcase how Western aircraft—to include the other European and American competitors in the MMRCA program—gain dramatic advantages over their Russian and Chinese counterparts because they incorporate better sensors and more effectively fuse the information derived from them to ease the pilot's workload amidst the rigors of combat. This capability derives ultimately from the West's superiority in electronics, software, and systems integration. The three "Eurocanards" in the MMRCA competition remain good examples of how fourth-generation European combat aircraft now rank close to, if not on par with, their American peers.

The Typhoon's weapons suite potentially brings new capabilities to the IAF as well. The aircraft can deploy the U.S. AIM-9L Sidewinder, the longer-ranged ASRAAM (which utilizes an IIR seeker originally developed by Hughes but is otherwise a British weapon), and the multinational IRIS-T for the WVR air combat role. For the BVR mission, the Typhoon carries the U.S. AIM-120 AMRAAM, possibly the best all-round active radar missile operational in the

world today. The even longer-ranged MBDA Meteor would supplement the AMRAAM once it becomes operational. It is not certain that the ASRAAM and the Meteor would be available to India, however.

In the air-to-ground role, the Typhoon will carry all modern precision munitions ranging from laser-guided bombs to various kinds of cruise missiles and SEAD weapons. Just like the Rafale and the Gripen, the Typhoon carries a wide variety of munitions manufactured by various countries. However, this could create a problem, in that not all systems capable of being carried by the aircraft would be

available to India because of export restrictions. Unfortunately, this is more frequently the case for the best weapons.

As is to be expected from the foregoing discussion, the Typhoon displays excellent aerodynamic effectiveness. But this judgment must be qualified when

The three "Eurocanards" in the MMRCA competition remain good examples of how fourth-generation European combat aircraft now rank close to, if not on par with, their American peers.

comparing it to its peers not because it is deficient in any particular way but because its competitors are for most part superb dogfighting platforms as well. Where sustained turn rate, for example, is concerned, the Typhoon is superior to the MiG-35 and the Rafale, but yet cannot match the Gripen, which beats it and all other aircraft irrespective of altitude. The Typhoon also turns somewhat slower than the F-16IN (without conformal tanks) and the F/A-18E/F at most representative altitudes. The Typhoon's instantaneous turn performance is far better than the MiG-35 and the Gripen and comparable to the F-16IN (without conformal tanks) and F/A-18E/F at all altitudes, but inferior to the Rafale the closer both aircraft are to sea level. The Typhoon's bleed rates are high, comparable to the Rafale and the F/A-18E/F at all altitudes, but inferior to the Gripen and the F-16IN (even when the latter flies with its conformal fuel tanks).

On balance, then, while the Typhoon is an agile aircraft, it is aerodynamically comparable to the Rafale and the MiG-35, but is not as nimble as the Gripen, with the F-16IN (without its conformal fuel tanks) and the F/A-18E/F falling somewhere in the middle. Pilot quality will, therefore, be critical for success in most air-to-air encounters with these airplanes, though the quality of sensor fusion in the Typhoon will certainly make its occupant's life easier in the stressful circumstances of air combat. The Typhoon has a high top-end speed, putting it in the same league with the MiG-35 and the F-16IN. Lastly, the Typhoon's performance characteristics will certainly permit it to undertake all the theater-level missions to which it may be committed within South Asia, though it will almost certainly require, at the very least, external tanks for the anti-surface mission.

The foregoing advantages of the Typhoon, however, come with two significant liabilities where the MMRCA competition is concerned. The first challenge will be manifested in the arena of technology transfer. Although many European diplomats have blithely asserted that transferring high-end aviation technology to India "will not be a problem," such claims must be taken with a pinch of salt. Because the Typhoon is produced by a four-country consortium, each with different strengths, different political interests and different responsibilities, securing agreement on an extensive technology transfer package to India will be more difficult than the casual commentary sometimes suggests.

This remains true despite the fact that Germany is the lead country responsible for the Eurofighter Consortium's India campaign. If the Typhoon wins the MMRCA competition, it is likely that the aircraft offered to India will be taken from the Luftwaffe's planned acquisition in much the same way that

the 72 aircraft sold to Saudi Arabia came from the Royal Air Force's allotment. Yet getting all four countries involved in the Typhoon's development to agree on a transfer of technology package to India—especially since New Delhi's requirement is far more ambitious than anything the Saudis demanded—will prove to be challenging.

The Eurofighter consortium will have little difficulty agreeing to the co-production of the Typhoon in India. Indeed, it has already done so in Saudi Arabia. However, at a time when Europe is struggling with global competition from the United States, Russia, and now even China, there is cause to doubt that it will agree to share its expertise in sensor fusion, flight control systems, and advanced weaponry. Whether the consortium will be able to satisfy India's direct offsets demands is also unclear. It is easy to imagine the four

Getting all four countries involved in the Typhoon's development to agree on a transfer of technology package to India will prove to be challenging.

nations involved enthusiastically agreeing to indirect offsets, if those were required; reaching a consensus on direct offsets will prove more difficult, particularly in light of the aircraft's high unit flyaway costs.

The second challenge facing the Typhoon is exactly the one just referred to: price. The Typhoon remains the most expensive aircraft in the MMRCA competition, coming in at close to \$125 million a copy. Whether the IAF can actually afford the Typhoon—even if the

aircraft remains its first preference—then becomes a critical question because a purchase of such magnitude could upend the service's budget at a time when critical questions about technology transfer still remain unanswered.

Adding to these disadvantages is the fact that purchasing the Typhoon would produce few obvious political benefits. While New Delhi has good reason to maintain strong relations with the United Kingdom and Germany, the imperatives for deepening a partnership with Italy and Spain—particularly through defense purchases—are less pressing. Given these considerations, the Eurofighter Typhoon may ironically end up being devalued, despite its technical effectiveness, for economic and political reasons that in this case are simply not trivial.

F-16IN

Advantages	Disadvantages
Light weight	Lacks organicIRST
Advanced AESA radar	Diminished maneuverability (with conformal fuel tanks)
Excellent sensor fusion and systems integration	Limited growth prospects
Cooperative targeting	Complications related to deployment in Pakistan
New advanced weaponry	
Remarkable maneuverability (without conformal fuel tanks)	
Low signatures	
Moderate cost	
Generous technology transfer likely	
High political benefits	

The last two candidates are the American fighters, the F-16IN and F/A-18E/F, which have received enormous attention because both aircraft were released for the MMRCA competition as part of the Bush administration's effort to strengthen the rise of Indian power. Both contenders, just like the Rafale and the Eurofighter, also grew out of a common operational requirement: the 1980s U.S. effort to build a superlative lightweight air combat aircraft that incorporated the lessons of the Vietnam War.

Based in considerable part on the work of John Boyd, the original incarnations of the F-16 and the F/A-18 were designed to be relatively simple, low-cost, but incredibly maneuverable fighters with high thrust-to-weight ratios. These attributes were intended to recover the dogfighting advantages that U.S. aircraft last enjoyed during the Korean conflict. The resulting "lightweight fighter program"⁶² ended up with the winning F-16 being selected by the U.S. Air Force as the low-end complement to the F-15 air superiority fighter, while the losing F/A-18 ended up in U.S. Navy service aboard its carriers as the low-end complement to the long-range fleet defense F-14 Tomcat.

The present F-16IN *Super Viper* has come a long way from its original incarnation, the basic F-16A, which first entered service in 1979. From being an uncomplicated, lightweight, daylight fighter intended mainly for WVR

combat with guns and short-range infrared missiles, the F-16 gradually evolved into a heavier multi-role aircraft that today boasts both BVR and WVR air combat capabilities, while simultaneously becoming the principal tactical platform in the U.S. Air Force for air-to-ground missions.

Amazingly, the aircraft's greatest combat attribute, its maneuverability, has remained uncompromised even as it has acquired many more roles. The most recent and capable model is the F-16 Block 60, which was developed for the United Arab Emirates. The F-16IN, the Lockheed Martin entrant for

the MMRCA competition, is based on the Block 60 variant. The F-16 has turned out to be a stupendously successful combat aircraft, as demonstrated by the fact that over 4,400 units have been built since its production was approved in 1976. Although the U.S. Air Force is no longer acquiring F-16s, the aircraft

continues to be built in ever more sophisticated versions for the export market and remains in the active inventories of 23 different countries.

The F-16 is universally acknowledged as one of the best fighters ever built. As one Indian defense analyst, who also happens to be a former IAF pilot, remarked,

The F-16 has been around for nearly 40 years, but it still commands respect among the experts. It is combat proven, has operated in all parts of the world in very demanding conditions, and like the freak, if admirable, design of the venerable MiG-21 and DC-3 Dakota, is destined to be remembered as the best multi-role fighter ever.⁶³

These accolades derive from the F-16's remarkable strengths. Its frameless bubble canopy provides its pilot with a better field of view out of the cockpit than any other aircraft, save possibly the F-15. Its reclined seat (canted back 30 degrees) reduces the effect of *G*-forces on its pilot. Its powerful GE F110-132 engine provides a whopping 32,000 pounds of thrust at sea level, giving the relaxed static stability airframe controlled by a fly-by-wire system incredible maneuverability. Its small size makes it highly difficult to see from nose or tail aspects beyond two to three miles. The "Have Glass" signature reduction program has resulted in an airplane with a remarkably low radar cross-section.

The F-16 is universally acknowledged as one of the best fighters ever built.

And its superb WVR and BVR AAMs, coupled with its advanced sensors and electronic protection capabilities, enables it to dominate the airspace even in the presence of capable adversaries.

The F-16IN, based on the Block 60 version developed for the UAE, has two new features compared to previous incarnations of this legendary fighter.⁶⁴

First, it is equipped with conformal fuel tanks that alter the distinctive profile of the aircraft, boosting its range but, unfortunately, also reducing its aerodynamic performance. The presence of the conformal tanks results in close to a one-third increase in the aircraft's internal fuel capacity, without depriving it of the ability to carry other external tanks as well. Although the conformal tanks do not noticeably add to the aircraft's drag—a tribute to their design—they contribute to its increased weight when loaded with fuel. This weight gain ends up reducing the F-16IN's otherwise superb maneuverability, probably taking it to the bottom of the list of MMRCA competitors whenever it flies in a fully fuelled configuration. The conformal fuel tanks, however, can be easily removed by ground technicians prior to flight. But their presence implies that the F-16IN turns out to be two different airplanes, depending on its configuration: when equipped with conformal fuel tanks, it trades aerodynamic maneuverability for long range, which is ideal when air-to-ground missions are at issue; without its conformal fuel tanks, the aircraft reverts to being the superb dogfighter that originally made its reputation.

Second, the F-16IN is equipped with a true AESA radar, the AN/APG-80 Agile Beam Radar built by Northrop Grumman, which is not present in any other F-16 version in service anywhere else in the world. The presence of the AN/APG-80 AESA radar on the F-16IN makes it (along with the F/A-18E/F) the only aircraft in the MMRCA competition that is truly compliant with the IAF's *Request for Proposals* on this issue today. The AN/APG-80 radar interleaves air-to-air and air-to-surface modes and provides dramatically improved performance over the previous F-16 radar, the AN/APG-68(v)9. Against a one square-meter radar cross-section target in the forward hemisphere, the AN/APG-80 is estimated to have a detection range of some 95 km in both lookup and lookdown modes. This performance vastly exceeds the IAF's own requirements as laid out down in its *Request for Proposals*. The radar can also maintain track files on up to 20 targets, while supporting four simultaneous engagements.

These capabilities, moreover, come though the use of wide operating bandwidths that are highly resistant to disruption and of LPI waveforms that make it extremely difficult for an adversary to even know that the aircraft is present and radiating in the battlespace. The operational AESA radar in the F-16IN, then, bequeaths the IAF with detection capabilities of the kind not

available on any of its other platforms. The radar delivers the “first look-first shoot” advantage that the service seeks in all encounters with its adversaries and when deployed in a fighter force with secure data networks, such as Link 16, will support cooperative targeting. The AN/APG-80 is a phenomenal radar system and its performance parameters will only improve over time as software improvements are applied to the basic system. It is indeed unfortunate that even now few customers will experience its highest capabilities because U.S. technology controls are certain to limit the export of the maximum performance variants of this AESA radar and all others.

Like most other U.S. fighter aircraft, the F-16 did not traditionally have anIRST capability of the kind routinely found on the MiG-29 and the Su-30MKI. For the F-16IN, however, Lockheed Martin has incorporated a FLIR targeting system based on the U.S. Air Force’s Sniper Advanced Targeting Pod. The Sniper is a third-generation FLIR system with a geopointing capability that is ten times more accurate than the U.S. Air Force’s current LANTIRN pod, with thrice its recognition range and twice its resolution. The Sniper is believed to be capable of acquiring targets at altitudes of up to 50,000 feet, versus the 25,000 feet typical of the LANTIRN, and provides laser target designation and ground target position data for coordinate-seeking guided munitions, such as JDAM. The Sniper system incorporates a high-resolution, mid-wave third-generation FLIR, a dual-mode laser and a charge-coupled device television (CCD-TV) along with a laser spot tracker and a laser marker.

Being the best targeting sensor in U.S. Air Force service today, its technology has been incorporated into the F-35’s Electro-Optical Targeting System (EOTS). The Sniper provides the F-16IN with a 24-hour precision strike and navigation capability, allowing the airplane to detect and identify both ground and airborne targets, even at night or in adverse weather, for highly accurate weapons delivery. Although it is unlikely that the F-16IN’s Sniper-based FLIR will have detection ranges comparable to theIRST systems deployed aboard the Rafale or the Typhoon, the presence of a LPI AESA radar on the aircraft makes the requirement for a long-range passive detection system less significant.

Unlike the F-16 Block 60, whose DAS is based on the Falcon Edge Integrated Electronic Warfare System (IEWS), the F-16IN’s defensive systems are composed of newly developed components created to meet the MMRCA’s EW requirements. If the Falcon Edge system is any indication, however, the F-16IN DAS is certain to incorporate both radio frequency and digital technologies. Given the MMRCA’s *Request for Proposals*, the DAS will contain all the defensive subsystems required: a wideband passive RWR, an active DRFM jammer, a MAWS, IFF systems, a ARTD, and chaff/flare dispensers,

all connected by a fiberoptic data bus and controlled by a dedicated electronic warfare management system.

Just like its best European counterparts, the F-16IN has invested heavily in fusing information from the on-board sensors and off-board sources into a common tactical display and simultaneously into the pilot's helmet-mounted sight in an easy to recognize format. The tactical superiority of American pilots in combat is owed greatly to their superior skill and training, but an equal part of the credit goes to the remarkable situational awareness produced by technologies like those in the F-16IN. These systems can correlate data from the radar, infrared and electro-optical sensors, as well as the DAS and the target recognition and IFF systems, to create unified tracks that the pilot can respond to quickly and efficiently.

The F-16IN will also bring a new suite of weapons to the fight. First is the WVR AIM-9X, the extremely agile thrust-vector controlled and helmet-cued IIR AAM with a high off-boresight acquisition and launch envelope, greatly enhanced maneuverability and improved target acquisition ranges in both clear sky and ground clutter. Second is the BVR AIM-120 AMRAAM, whose active radar guidance provides the aircraft with a true "launch and leave" capability, which allows the aircraft to maximize its separation from the threat. The F-16IN will also give the IAF a similar set of new capabilities in the air-to-ground arena with weapons of the kind described earlier in this report.

While the sensors and weapons associated with the F-16IN will provide new increases in IAF combat capability, the aerodynamic effectiveness of the platform will make it a truly formidable rival in the air-to-air arena whenever it flies without its conformal fuel tanks. In this configuration, the F-16IN's sustained turn rate is highly comparable to that of the F/A-18E/F—and both are bettered only by the Gripen. All other aircraft are more or less inferior to these American stalwarts at both low and high altitudes where constant speed turns are concerned. The F-16IN's instantaneous turn rate lags slightly behind that of the Eurofighter and the F/A-18E/F at representative altitudes, but is better than that of the Gripen and the MiG-35, being significantly inferior only to the Rafale at low altitudes. Unlike all its competitors, however, with the exception of the Gripen, the F-16IN has the lowest bleed rates, thus enabling it to recover rapidly from hard turns and re-enter the fight in a relatively superior energy state. When equipped with conformal fuel tanks, the F-16IN's aerodynamic performance drops noticeably across all parameters, save range, suggesting that this configuration is unlikely to be favored in any scenario involving air-to-air combat.

Where mission performance is concerned, the F-16IN will be able to meet all its operational requirements in the South Asian theater without difficulty,

in part thanks to the added reach provided by its conformal tanks. What is perhaps most impressive about the F-16IN, however, is not so much its reach, but its low maintenance demands and its extraordinary reliability. In U.S. Air Force service, the F-16 has demonstrated consistently high readiness and sortie generation rates; in addition, the F-16's ability to operate out of very austere airfields must be chalked up as a significant plus where the IAF, with its vast deployment theater, is concerned. Low maintenance and high reliability translate inevitably into low life cycle costs and it would not be surprising if the F-16IN turned out to be—irrespective of its technical characteristics—the cheapest fighter in the MMRCA competition by this standard.

The F-16IN is expected to be most competitive where technology transfer is concerned because it is a mature aircraft whose domestic production run

The F-16IN will be able to meet all its operational requirements in the South Asian theater without difficulty.

has ended. Although it has been reported that the manufacturer, Lockheed Martin, has offered to transfer the entire F-16 production line to Bangalore, India, if the aircraft is selected in the MMRCA competition, this is unlikely to be the case.⁶⁵ The F-16 continues to have a significant international market and the regional and global maintenance commitments associated with existing F-16 aircraft ensure that Lockheed

Martin will need to maintain substantial production facilities within the United States. In any event, the company's interest in securing a share of the growing Indian defense market and eventually selling India its fifth-generation fighter, the F-35 Lightning, ensures that it would be willing to transfer technology to the maximum degree, while aggressively meeting Indian offset requirements along the way.

As Lockheed Martin positions itself for the long haul, the F-16IN's cost may turn out to be most alluring. The standard F-16C/D Block 50/52, the most up-to-date variant in the U.S. Air Force inventory, cost a meager \$25 million per copy in 1998—a low price that demonstrates the benefits of a long production run over several decades. The highly superior Block 60 version, upon which the F-16IN is based, is far more expensive. The UAE purchased 80 F-16 Block 60s (55 single seaters and 25 dual seaters) for about \$8 billion, of which almost \$3 billion went into R&D, resulting in a unit production cost of

some \$62.5 million.⁶⁶ In the context of a recent debate on the price of the F-35, Lockheed Martin executives indicated that the F-16 Block 60 can be expected to cost something around \$60 million per copy.⁶⁷

Although the MMRCA bid could come in at a somewhat lower price, the F-16IN is highly competitive even at the higher price. While it is more expensive than the MiG-35, it is considerably cheaper than the other European entries, including the Gripen, its weight-class peer. It is also more capable than both the MiG-35 and the Gripen.

The political benefits to India of an F-16IN buy would be unparalleled because of the gains accruing to New Delhi from a stronger partnership with the United States. Such a development would be cheered in Washington and would send important signals to all India's neighbors—especially its adversaries, China and Pakistan.

While the F-16 remains the perfect example of a great fourth-generation fighter that has evolved over time to service new roles—its airframe remaining basically intact while its innards have been transformed in revolutionary ways—the F/A-18—which was developed originally as part of the same lightweight fighter competition—has undergone dramatic structural and internal metamorphoses to make it in reality an entirely new aircraft.

The current F/A-18E/F Super Hornet, Boeing's candidate in the MMRCA competition, shares only the designator, "F/A-18," with its immediate predecessor, the F/A-18C/D.⁶⁸ This designation was maintained largely to keep up the pretense that the new E/F version was merely an "Engineering Change Proposal" of the older aircraft. Such an approach enabled the manufacturer to avoid a costly new demonstration program and fly-off in the United States, even though its principal operator, the U.S. Navy, recognized full well that the Super Hornet was in fact a fundamentally new airplane designed by intention to service both the air-to-air and the air-to-ground regimes interchangeably. Strictly speaking, therefore, the F/A-18E/F should be characterized as a

**The political benefits to
India of an F-16IN buy
would be unparalleled
because of the gains
accruing to New Delhi from
a stronger partnership
with the United States.**

4.5th-generation fighter, since it was redesigned and first built during the 1990s. Because of its well-known ancestor, however, it has usually been considered a fourth-generation airplane.

Nothing could be further from the truth. The F/A-18E/F Super Hornet tracks closely with the F-15 Eagle, the world's finest air superiority platform before the F-22A Raptor, in its size and fuel carrying capacity. At 14,700 pounds, the F/A-18E/F has the largest internal fuel load of any of the MMRCA competitors. Unlike the Eagle however, the Super Hornet is optimized for transonic maneuver, load carrying performance, dominance in both BVR and WVR combat, flexible multi-role operations during a single sortie, and carrier recovery, since it remains the preeminent strike-fighter aboard the large-deck aircraft carriers of the U.S. Navy. In fact, on all the five counts for which it was designed—increased range, payload, bring-back weight, survivability, and growth room—the Super Hornet outshines its predecessor *without* compromising on its superb dogfighting qualities.

That it has been able to do so despite the extra weight associated with carrier-based platforms is truly a tribute to the aircraft's propulsion system and its aerodynamic design. Despite its 30 percent weight gain over the C/D version, the Super Hornet's 25 percent larger wing and the 35 percent increase in thrust from its current twin GE F414 engines, each generating some 22,000 pounds of thrust at sea level, have protected its original agility fundamentally intact. As a Hornet test pilot summarized it,

In the subsonic regime, the E/F performs as good as or better than a C/D in almost every respect. The challenge posed to the contractor was not to compromise the [legacy] Hornet's superb capabilities as a dogfighter. "As good as, or better than ..." was the standard to meet. The result is that the turning performance charts overlay one another. At high angles of attack, the E/F's agility truly shines, with superior roll performance and much more carefree handling. The heritage Hornet was already the stand-out, high angle-of-attack (alpha) machine in the U.S. inventory. The E/F is "hands-down" superior in that environment.⁶⁹

The decision to release the F/A-18 for India's MMRCA competition conveyed the Bush Administration's sincerity about strengthening New Delhi's military capabilities. The Super Hornet was perfect for that purpose because, like the F-16, it was a cutting-edge air combat aircraft that possessed remarkable strike capabilities as well. These attributes are illustrated by the

F/A-18E/F

Advantages	Disadvantages
Best AESA radar in a fourth-generation aircraft	Heavy weight*
Excellent sensor fusion and system integration	Lacks organicIRST
Advanced cooperative targeting and EA capabilities	Weaker energy addition compared to competitors
New advanced weaponry	Constrained technology transfer
Remarkable maneuverability	
Excellent short field performance	
Moderate cost	
High political benefits	

* Impact of the attribute is ambiguous for the MMRCA race

extensive radar cross-section reduction efforts that went into its redesign, its heavy payload carrying capacity, and above all, its avionics and sensors, which no other aircraft save the fifth-generation F-22A and F-35 can match.

The heart of the Super Hornet's avionics systems is its AN/APG-79 AESA radar and the advanced mission computers and displays that integrate data from the radar and the other sensors. The Raytheon AN/APG-79 system is, to put it plainly, the best AESA radar available on any fourth-generation aircraft today. Like other AESA radars, it has the capacity to interleave air-to-air and air-to-ground modes simultaneously, while exploiting all their other virtues such as large operating bandwidths, LPI, and the ability to modify waveforms for purposes of deception and EA. The AN/APG-79's huge power aperture product, however, gives it a phenomenal detection range of the kind that no radars currently available in the MMRCA competition can match. It is rivaled only by its marginally less capable compatriot, the AN/APG-80, which is deployed aboard the F-16IN.

The detection ranges of all U.S. AESA radars are classified, but some fragmentary information appears in the public literature. Jane's Avionics, for example, suggests that the AN/APG-79 can detect a one square-meter radar cross-section target at some 110 km. One Indian commentator, basing his

characterization on IAF sources, places the “radar’s range against tactical-sized targets at roughly 100 to 125 miles [160–200 km] [with even] greater electronic surveillance range.”⁷⁰ Such data are difficult to adjudicate because the detection range of the AN/APG-79, like any radar, varies depending on its search modes and the pulse repetition frequencies employed. The Indian assessment, however, appears largely in the ballpark—and, in fact, may even understate it. This implies that the AN/APG-79 too would abundantly exceed the detection thresholds specified in the IAF’s Request for Proposals in the MMRCA competition. Since the surveillance capability of a fighter aircraft fundamentally determines whether it will be able to enjoy first-look opportunities vis-à-vis an adversary, the Super Hornet’s AN/APG-79 clearly places it at the top of the MMRCA race as far as active sensors are concerned.

The Super Hornet, however, brings to the fight other complementary detection systems as well. The two most significant are based on the Advanced Tactical Forward Looking Infrared (ATFLIR) system and the formidable DAS, formally known as the Integrated Defensive Electronic Countermeasures (IDECM). The ATFLIR is a pod-mounted multi-sensor system that enables high-speed night flying as well as target acquisition and attack capabilities against both air and ground targets. In the absence of a dedicated IRST system, which the F/A-18E/F, like all its American counterparts equipped with high-performance radars, does not possess, the ATFLIR serves to compensate. However, Boeing has indicated that it is willing to integrate an internal IRST system on the Super Hornet should India select it.

The Hornet’s IDECM includes all the components found in modern fighter aircraft: a RWR, a self-protection jammer and an electronic attack system, a countermeasures dispensing set, and an ARTD. A MAWS is planned for integration in the future. What makes the IDECM-based system impressive, however, is the way it automatically detects, prioritizes and responds to threats. Being integrated into the aircraft’s combat system as a whole, it bestows on the pilot a remarkable increase in situational awareness. All threat information in the F/A-18E/F from on-board and off-board sources is fused by the advanced mission computer and displayed in easily accessible form on the multifunction displays and on the Joint Helmet Mounted Cueing System, thus sharply reducing the pilot’s workload and enabling him to concentrate on flying the airplane in a manner that best enables execution of the tactical tasks. From the very beginning, the weapons control system on the Hornet was recognized for being among the best in the world. The accuracy with which even unguided air-to-ground weapons could be delivered simply had no parallel, and the Super Hornet preserves these capabilities as well.

Like the best Western platforms, therefore, the F/A-18E/F emphasizes the superior collection, assessment, and dissemination of information pertaining to an adversary. It does this through its advanced sensors, particularly, but not solely, its superlative AESA radar, and it provides this information to its pilot in convenient form. From the beginning, the sensor suites in the Super Hornet were designed for network-enabled operations. Hence, it should not be surprising that the aircraft supports a variety of cooperative targeting tactics depending on the links and weapons available to other aircraft in the force.

The AN/APG-79, it also ought to be mentioned, is a formidable electronic attack system. The U.S. Navy, for instance, is already experimenting with modulating the radar's waveforms to permit the firing of specialized "algorithms" from the aircraft into any airborne or ground-based antenna of interest.⁷¹ The growth potential of the AN/APG-79, beyond its original mission as an AI radar, therefore bears close watching, and it should be of great interest to India as it attempts to deal with formidable regional challengers such as China.

The F/A-18E/F Super Hornet and its AESA radar will support the same kinds of weapons that the F-16IN will deploy in Indian service: the AIM-9X for WVR combat and the AIM-120 AMRAAM for BVR missions. It will also support the other diverse air-to-ground weapons described earlier. Both American entrants can carry the same kinds of weapons, can carry external stores of about 8,000 kilograms (maximum), and have remarkable delivery accuracies for air-to-ground weaponry, with the F/A-18E/F having an edge on this count.

The aerodynamic effectiveness of the Super Hornet is also remarkable, especially given its greater weight than the other MMRCA entrants. The aircraft was always reputed for its carefree handling qualities and these have only been enhanced further in the E/F variant. When its sustained turn rate is compared with the other aircraft at representative altitudes, the F/A-18 is similar to the F-16 (without conformal fuel tanks) and inferior only to the Gripen. This sustained turning performance confirms its superiority as an excellent dogfighter, just like the F-16 is when it flies without its over-wing tanks. The Super Hornet's instantaneous turn rate ranks among the best in the competition too, behind mainly the Rafale at low altitudes. Like the Rafale and the Eurofighter, however, the F/A-18 has high bleed rates, which implies that its ability to turn sharply comes at a cost of lost speed compared with, say, the F-16 or the Gripen. The F/A-18 is also slower to add energy in comparison with its peers, including the F-16 when configured for air-to-air combat, and its constrained top-end speed makes it similar to rivals such as the Gripen and the Rafale. This could constrain it when its pilot attempts to disengage from higher-powered adversaries in air combat duels.

Both these limitations, consequently, imply that although the F/A-18E/F remains one of the most maneuverable aircraft in the world—and near the very top in the MMRCA competition, where agility is concerned—its comparative advantage ironically lies in BVR combat, where the cumulative advantages bestowed by the AN/APG-79, fused sensors, network-centric targeting, and the AIM-120 AMRAAM would enable it to dominate the lethal look-first, shoot-first regime even in the presence of AWACS platforms in South Asia. This is a quality it shares mainly with the F-16 (when without its conformal tanks) in the current competition. The F/A-18E/F also has remarkable short field takeoff

The F/A-18E/F remains one of the most maneuverable aircraft in the world—and near the very top in the MMRCA competition, where agility is concerned.

and landing performance and its rugged landing gear—designed for carrier operations—enables combat operations even from the most austere air bases.

The transfer of technology package contemplated by Boeing is not known, but it is likely to be limited by the fact that the F/A-18E/F is the principal strike-fighter currently in service with the U.S. Navy and likely to reside in its inventory for at least another twenty-five or thirty years. The transfers necessary to license produce the aircraft

in India will obviously occur, but expecting Boeing to “clearly underwrite the sharing and transfer of manufacturing technology, especially the Super Hornet’s sensor package,”⁷² as many Indians expect, is outlandish. (This is true, incidentally, for all MMRCA competitors, irrespective of what their salesmen and their votaries may occasionally say.)

Given that the F/A-18E/F will remain a critical U.S. Navy strike platform for many years, that it is now being integrated in advanced variants like the E/A-18G Growler, and that it hosts incredibly sophisticated subsystems, the reluctance of the U.S. government to authorize the kind of comprehensive technology transfer that India desires is understandable. On this score, however, it is unclear if the F/A-18’s European rivals will be able to do much better.

Where the F/A-18 will potentially score over its European counterparts is in regards to cost. The unit flyway cost of the airplane ran at some \$60 million in 2010, comparable with an F-16 Block 60. Interestingly, Lockheed Martin has claimed that its fifth-generation F-35 will be produced at comparable costs if

the U.S. government can maintain its purchase levels. For the time being, this declaration is suspect at best. The bottom line on flyaway costs, therefore, is that the F/A-18E/F will be comparable with the F-16IN, and both will be cheaper than any aircraft in the MMRCA competition other than the MiG-35. The F/A-18E/F's operations and maintenance costs, however, will be higher than that of the F-16IN because of its twin engine configuration. But the quality of American technology and U.S. operating requirements ensure that the life cycle costs and the maintainability of both airplanes will be highly competitive with, if not better than, their European competitors. This, in addition to their formidable capabilities makes them deserving of serious consideration.

The political benefits associated with an F/A-18E/F purchase would also be considerable—mimicking those of the F-16IN—but since these have been discussed previously, the point need not be belabored. Having an American airplane in IAF livery would simply be transformative for bilateral defense relations and it would send an important signal about the changing geopolitical dynamics in South Asia.

Where does this synoptic comparison of the MMRCA contenders leave the IAF and India more generally? If it does nothing else, it illustrates the difficult challenges that the service faces in selecting its preferred fighter, in that the contestants are comparable in performance by many measures. Yet Indian decision makers should note a few important differences.

Since none of the MMRCA contenders other than the two offered by the United States possess operational AESA radars currently, how the IAF has managed this lacuna in the competition deserves a brief explanation before any further comparisons of the various aircraft are undertaken. The IAF resolved the difficulties involved by stipulating that even if a development model of the system was demonstrated effectively during the fly-offs, the service would

Having an American airplane in IAF livery would simply be transformative for bilateral defense relations and it would send an important signal about the changing geopolitical dynamics in South Asia.

treat the host aircraft as compliant with its *Request for Proposals* as far as the principal sensor was concerned. So long as there was good assurance that the radar would be operationally integrated into the platform by the time of its final delivery, the IAF circumvented the challenges posed by the fact that all the non-U.S. contenders have only developmental—not operational—AESA radars presently.

While this is no doubt a sensible approach to managing uncertainty—among other things, it enabled more competitors to bring what are otherwise sophisticated airplanes into the race—it also embodies a certain degree of risk, especially given that the radar remains the primary sensor today in any fighter aircraft. The issue of risk is significant because the aviation industry in both Europe and Russia faces serious financial constraints that raise questions about its ability to sustain a vigorous research, development, and production program for AESA radar systems over the longer term. This fact ought to be considered by the IAF and Indian decision makers more generally as they reach their final judgments about the MMRCA.

In any case, of the six aircraft surveyed in the foregoing discussion, the MiG-35 appears to be the weakest contender in the competition. For all the modifications to its airframe and the improvements in combat range and avionics, the MiG-35 still remains a souped-up MiG-29K. It is not yet in service or even in serial production, and it remains only a developmental platform. It may yet turn out to be a great air combat fighter like its predecessor, but it represents an incredible gamble for the IAF right now.

Betting on an aircraft whose final production configuration is not yet settled, whose design does not exhibit any significant reduction in radar cross-section, which lacks a mature AESA radar in the face of Russian difficulties in this arena, and which brings no new weapons to the IAF can hardly be attractive to a service seeking to “break the mold” in its air capabilities. Even if the Russians were to provide a generous technology transfer package (something they have the greatest incentives to do, given the weakness of their contestant), this should not be enough to persuade the IAF to select the MiG-35.

The Swedish Gripen has significant liabilities as well. Make no mistake: the Gripen is an incredible air combat aircraft. It is the most highly maneuverable of the six contenders, provides superb situational awareness, has multi-role versatility, and is lightweight to boot. These virtues have led one of India’s most distinguished air power theorists, Air Commodore (retired) Jasjit Singh to remark that “the choice that comes closest to the ‘medium’ multi-role aircraft that the IAF has been seeking since a decade ago (the Mirage 2000 type) is the Swedish Gripen, which has maximum and empty weights at around 17,000 kg and 7,000 kg, respectively, almost equal to that of the Mirage 2000.”⁷³

In fact, the Gripen is so light, relative to the competition, that the IAF would be better served by purchasing it in place of its own Tejas LCA, which is growing in weight, does not have the combat capabilities anywhere close to the Gripen's, and lacks both the information fusing and the human engineering factors that distinguish the Swedish aircraft. All these virtues admittedly come at a rather high unit price—especially compared with what the Tejas will likely cost the IAF in comparison.

Irrespective of how good a fit the Gripen is for the MMRCA component of the IAF's force architecture—even though it is an excellent fighter—the fact that many of its key sensors, weapons, and systems are imported from third-parties, including the United States, should bear heavily on Indian decision makers. Although it is likely that Washington would release these components for sale

to India—after all, many of the same systems are found aboard the F-16IN and the F/A-18E/F—the strategic benefits to New Delhi of buying a Swedish airplane are not at all obvious.

Moreover, the Gripen NG is still a developmental aircraft. Its final production characteristics have not yet been solidified, and it lacks a mature AESA radar. For the IAF, which is looking to sustain its MMRCA force over the next thirty-odd years, the Gripen cannot look like a great bet largely because Saab continues to remain dependent on foreign vendors for the supply of key components. Equally important, its own longevity as a producer of front-line aircraft is, at a minimum, open to question in a world where small aircraft production runs will increasingly undermine boutique airplane manufacturers. At a time when the coming fifth-generation airplanes built by true aerospace majors promise to become more cost competitive with the relatively expensive 4.5th-generation fighters produced by smaller producers such as Sweden, Saab's future as an independent aircraft manufacturer does not look promising.

That leaves the two “Eurocanards,” the Typhoon and the Rafale, and the two American entrants, the F-16IN and the F/A-18E/F, as the survivors in the pool from which the IAF must make its choice. The foregoing discussion

**The Gripen is so
light, relative to the
competition, that the IAF
would be better served by
purchasing it in place of its
own Tejas LCA.**

should have shown that the distinction between fourth- and 4.5th-generation aircraft is for all practical purposes less significant from the point of view of air warfare. Where sensors are concerned, the U.S. platforms have a decisive advantage because both possess mature AESA radars operational today. Both their European competitors have excellent organicIRST systems, but these cannot yet compensate for the absence of cutting-edge AESA radars with their long-range detection capabilities, LPI waveforms, and EA potential.

Both the Typhoon and the Rafale will operationally deploy the CAESAR and the Active Array RBE2 AESA radars, respectively, at some point during the 2010–2020 timeframe, but even this innovation cannot obscure the fact that the Europeans are over a decade behind the United States in this critical technology. More than any other sensor, the AESA defines combat capability for fighter aircraft today. It should not escape notice that even as the Typhoon and the Rafale are still developing their first-generation AESA radars, the United States has already *fielded* second-generation systems, such as the AN/APG-77 and the AN/APG-81, aboard the F-22A and F-35, respectively.

Where other elements that make a real difference to combat are concerned—sensor fusion, mission computing, automated threat data distribution, and defensive avionics suites—the four European and American rivals are broadly comparable. The Typhoon, perhaps, has an edge here mostly because of its excellent human factors engineering. All four aircraft differ, however, in the area of radar cross-section reductions. The two smaller aircraft, the F-16IN (without its conformal tanks) and the Rafale, appear to have the smallest radar cross-sections nose-on in comparison with the F/A-18E/F and, certainly, the Eurofighter.

Again, this should not be surprising. In all fourth-generation aircraft, there are limits to the radar cross-section reductions that can be achieved through the use of composites and radar-absorbing materials, when the possibility of fundamentally reshaping the aircraft is precluded. In a combat environment dominated by the presence of AWACS, however, the importance of aircraft with the smallest radar cross-section possible cannot be underestimated. That attribute alone gives the F-16IN in its air combat configuration a dramatic advantage, once the relatively high cost of its closest rival, the Rafale, is taken into account.

The weapons that each of the competitors will bring to the IAF's inventory are also broadly similar. All propose to offer IIR AAMs for WVR combat, such as AIM-9X, Python 5, or MICA IR, and all would provide active radar guided weapons, such as AIM-120 AMRAAM, the MICA AR, or the Derby. While other sophisticated weapons such as the ASRAAM and the IRIS-T for the WVR role and the Meteor for the BVR role have been mooted by the Europeans, it is unclear whether these systems will be released to India if their

aircraft are finally selected for the MMRCA role. And some weapons, such as the Meteor, are still in development. When air-to-air and air-to-ground munitions are considered in their entirety, the IAF recognizes that American weapons possess a clear edge, in part because they are combat tested but, more importantly, because they are improved with much greater rapidity than any of their competitors. Their marginal advantages in quality and effectiveness, especially in air-to-ground weaponry, are highly significant. Consequently, the IAF would prefer to acquire U.S. munitions as long as it was afforded access to the best variants and had no reason to fear about reliable access to supply.

Aerodynamic effectiveness is the category in which all four aircraft are commensurate. As dogfighting platforms, the Typhoon, the Rafale, the F-16IN (without its conformal tanks) and the F/A-18E/F all appear to demonstrate comparable agility when their sustained turn performance is compared at representative altitudes. The American aircraft, however, are generally superior, but not by much and certainly not decisively. This, in turn, suggests that for all the advances in airframe design and propulsion incorporated into the Typhoon and the Rafale, the fourth-generation F-16IN (when suitably configured) and F/A-18E/F can still hold their own. This is only corroborated by the fact that whatever their differences, the flight envelopes of the European fighters are neither clearly larger nor consistently superior to their American counterparts, and their angle of attack performance is only comparable, if not inferior, to the high alpha routinely pulled by aircraft such as the F/A-18E/F Super Hornet. When equipped with AESA radars, sophisticated DAS, highly capable BVR missiles such as AMRAAM, and helmet-mounted sights cueing high off-boresight WVR AAMs such as AIM-9X—as both the F-16IN and the F/A-18E/F already are—the American platforms can stand down any of their modern European rivals.

This implies that the common Indian complaint about the older designs of the U.S. offerings, while manifestly true, is also devoid of substantive meaning in the context of air warfare—though obviously not where pure technological progression and growth prospects are concerned. The earlier provenance of their airframes in this case, for example, has had little effect on their aerodynamic performance, which turns out to be just as good as, if not superior to, their European counterparts at varying points of the flight envelope. Their avionics, too, are formidable and the overall situational awareness enjoyed by a pilot in an F-16IN or an F/A-18E/F rivals that of their best European counterparts. When weapons are thrown into the mix, the American contestants become even more compelling. None of these facts should be surprising, given the resources that the United States has sunk over the years into maintaining aerospace dominance globally.

In this context, the reservations often expressed in India about the F-16IN are unfounded. The argument that the IAF should not consider the F-16IN seriously as a MMRCA competitor because it is already in service in Pakistan betrays a lack of understanding not only about the differences between the two airplanes, but also about what produces advantages in air combat. The F-16IN may look like the F-16 Block 50, but their differences are considerable. The AESA radar, the DAS, and the engines are dramatically superior in the F-16IN. And pairing it with the superior BVR combat skills of IAF pilots only increases the distance between the two airframes. There may be good reasons why the IAF

would decide not to purchase the F-16IN; that an inferior version of the aircraft happens to be deployed in Pakistan should not be one of them.

The Eurofighter probably edges to the top of the final four in terms of overall sophistication, but barely.

When these competitors are considered on balance, the Eurofighter probably edges to the top of the final four in terms of overall sophistication, but barely. Despite its present lack of an AESA radar, its sophisticated sensors and avionics will improve with time. Its short takeoff and landing performance and its

supercruise capability (even if it cannot be sustained as in the F-22A) yield operationally relevant benefits. Its weapons bring new capabilities to the IAF (even if the best are not released to India or if those released do not always match the best possessed by the United States). And its swing-role capability enables it to shift effortlessly from aerial combat to anti-surface operations.

Against these advantages, however, must be considered its relatively large radar cross-section, which could prove disadvantageous in many combat situations. Yet it is a relatively young aircraft and so has considerable opportunities for growth—a judgment obviously shared by the six nations that have already ordered the aircraft. The Typhoon, too, comes closest to the static requirements of the MMRCA *Request for Proposals*, or at least appears able to comply with them with fewest changes.

The Rafale comes close to the Typhoon on many counts, but it may not quite measure up across the board. Although it, too, lacks an AESA radar currently, this lacuna will be mitigated over time. Its other sensors and weapons are undoubtedly impressive in any case. Its small radar cross-section, which

Dassault is justifiably proud of, promises critical operational payoffs. And its flexibility in shifting between air and ground roles during a single mission is striking, even though the aircraft otherwise lacks short takeoff capabilities and cannot approach the Typhoon's transient supercruise performance. For all its virtues, however, the Rafale has not found a single foreign order yet, making it the hardest sell psychologically among the four aircraft.

The differences between the European and the American competitors, then, come down to this: the two European aircraft will reach their fullest combat capability only at some point in the future—with more generous opportunities for growth—whereas the two American warplanes are at their peak of maturity now, will continue to evolve further, and at least one, the Super Hornet, offers room for substantial additional growth. Equally important, only the two American competitors have been thoroughly tested and proven in battle in five wars going back to Desert Storm. None of the other contenders can make this claim.

Given that the IAF needs a fighter that will remain in service for another twenty-five to thirty years, it might be tempting for India to wager on the European candidates mainly because of the likelihood that they will mature in the early and middle phases of their lives in IAF service. On this count, however, the Super Hornet has the advantage that it, too, will continue to evolve in active service with the U.S. Navy for at least another twenty-five years. The F-16 will also survive in U.S. Air Force employ till at least 2025 and internationally for much longer.

Still the Europeans arguably have an edge where the maturity of their designs relative to the life cycle of their airplanes is concerned. In purely technological terms—irrespective of its impact on air warfare—all three European fighters are extraordinarily impressive, and their combined canard-wing planforms, digital flight control systems, human factors engineering, enhanced automation and information processing, and progressively better weapons make them quite appealing to IAF planners who have to think about procuring an airplane that will remain relatively effective over a long time horizon.

There is some risk in solving this problem by simply settling for a European combatant today, but this hazard would be acceptable if comparisons and predictions about technology were the only variables.

Unfortunately for India, cost is another significant factor where the four aircraft are concerned. For the MMRCA competition, the only cost differences that matter are the life cycle costs as defined by the *Request for Proposals* and not simply flyaway or unit acquisition prices. Information about life cycle costs of the various aircraft, however, is not publicly available. In all cases, this is proprietary commercial information that has been shared with the IAF, but

BOX 2. Estimated Unit Flyaway Cost	
MiG-35	\$45 million ¹
Gripen NG	\$82.2 million ²
Rafale	\$85.4 million ³
Typhoon	\$123.1 million ⁴
F-16IN	\$60 million ⁵
F/A-18E/F	\$60.3 million ⁶
<ol style="list-style-type: none"> 1. This figure is based on based on the total contract cost of the recent Indian MiG-29K naval purchase divided by the number of planes: "Project 1143," Bharat Rakshak, November 17, 2008, available at http://www.bharat-rakshak.com/NAVY/Ships/Future/193-INS-Vikramaditya.html. 2. This figure is based on based on the Gripen's Norwegian bid reported in Bill Sweetman, "Gripen's Norwegian Blues," Ares, December 9, 2008, available at http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckControler=Blog&plckScript=blogScript&plckElementId=blogDest&plckBlogPage=BlogViewPost&plckPostId=Blog%3a27ec4a53-dcc8-42d0-bd3a-01329aef-79a7Post%3ae7fec93-9d7e-4c42-936a-1627abbac4d2. 3. This figure is based on the flyaway Cost in 2008, converted from Euros, taken from "Projet de loi de finances pour 2009: Défense - Equipement des forces," Senate of France, available at http://translate.google.com/translate?u=http%3A%2F%2Fwww.senat.fr%2Frap%2Fa08-102-5%2Fa08-102-516.html%23toc236&sl=fr&tl=en&hl=en&ie=UTF-8. 4. This figure is based on based on Saudi Arabia's Eurofighter purchase: Emmet Oliver and Massoud A. Derhally, "Saudis Pay 4.43 Billion Pounds for 72 Eurofighters," Bloomberg, September 17, 2007, available at http://www.bloomberg.com/apps/news?pid=newsarchive&sid=a_tmH4i16wBk&refer=europe. 5. This figures is based on Lockheed Martin estimates reported in Graham Warwick, "Lockheed: F-35 Can Compete on Cost," Aviation Week & Space International, June 18, 2010. 6. This figure is based on costs of U.S Navy aircraft in FY2011: "Aircraft Procurement, Navy; vol. 1: Budget Activities 1-4," Department of the Navy Fiscal Year (FY) 2011 Budget Estimates, available at http://www.finance.hq.navy.mil/FMB/11pres/APN_BA1-4_BOOK.pdf. 	

no one else. Consequently, in the discussion that follows, only crude measures of flyaway cost will be utilized mainly to make the point that whatever the technological differences between the various competitors may be, these advantages will have to be qualified at least by their economic burdens. This, in turn, only makes the task of choosing the "best" fighter for the IAF an even trickier proposition.

Accepting these caveats, a comparative survey of the flyaway costs of the various competitors yields the following story. The Typhoon, generically the most capable of the four, also happens to be the costliest at \$125 million. Buying 126 airplanes at this price would run the IAF \$15.75 billion, with a full 200 aircraft buy adding up to \$25 billion. The Rafale is somewhat cheaper at \$85 million; a 126 aircraft contingent would total \$10.7 billion, and 200 aircraft would be \$17 billion. (As noted earlier, the Gripen may be a lightweight fighter, but it is not a cheap aircraft. At about \$82 million a copy, it is almost as expensive as the Rafale and would cost the IAF \$10.3 billion for 126 airplanes and \$16.4 billion for 200.)

If the F-16IN and F/A-18E/F, in contrast, are assumed to cost more or less \$60 million each, the totals for a 126- and 200-aircraft buy are \$7.6 billion and \$12 billion respectively, irrespective of whether the IAF purchases the Super Viper or the Super Hornet for the force. None of these illustrative price tags admittedly take into account life cycle costs, but on this count the two U.S. aircraft have tremendous advantages over all their competitors with the possible exception of the Saab Gripen, which is probably comparable.

In any case, using unit flyaway costs as an illustrative metric for decision raises difficult questions. For example, Indian decision makers will have to assess whether an aircraft like the Eurofighter is actually more than twice as capable as the F-16IN and F/A-18E/F, based simply on the differential in these costs—or, stated

differently, whether the marginal increment in sophistication of the Typhoon is worth twice the price. Similarly, they will have to consider whether the Rafale's current technology and future prospects make it worth the 42 percent more they would pay for either the Super Viper or the Super Hornet. (If the Gripen were admitted for purposes of comparison, it would require the government of India to decide whether this aircraft was some 37 percent—more than a third—more capable than its American counterparts.)

Obviously, none of these prices are precise, but if the rough magnitudes are correct, they do indicate the nature of the challenge facing the IAF and the

Indian decision makers will have to assess whether an aircraft like the Eurofighter is actually more than twice as capable as the F-16IN and F/A-18E/F.

If American manufacturers are to successfully compete with their European rivals in the MMRCA fly-off, they must prepare to fight and win in the arena of technology transfer.

government of India. Given the broad comparisons of aircraft capability adduced in this section—and the competitive, if not superior, warfighting characteristics of the two U.S. contenders on many counts—it would indeed be hard for any Indian national security planner to conclude that the most desirable European fighters in the MMRCA competition were in fact close to, or better than, twice as good as their American counterparts.

If they still choose a European airplane in the face of these burdens, it would ultimately have to be because: they either judge the “Eurocanards” to possess highly desirable growth prospects that make them worth the extra cost; or because they believe that India’s growth rates would allow the IAF to easily amortize the additional burdens over time given the benefits that would be realized; or because the European manufacturers and their governments were able to offer genuinely dramatic transfers in technology that made the added expense of the airplanes worth the cost. Since neither Russia nor Europe can compete with the United States where the value of transformational relations is concerned, their greatest advantage subsists in their ability to offer India more liberal access to advanced technology that, in effect, compensates for the dramatically higher costs of their airplanes.

If American manufacturers are to successfully compete with their European rivals in the MMRCA fly-off—in the face of the widespread Indian perception that their airplanes are older and, hence, are unlikely to make sound purchases for the long-haul—they must prepare to fight and win in the arena of technology transfer. While they do this, however, the U.S. government should continue to assure India about supplier reliability, while reminding New Delhi in word and deed about the benefits that would accrue from a stronger partnership with Washington.

Even as these challenges are navigated both in the United States and in India, the judgment about the price-to-value ratios of the various competing aircraft becomes even more problematic when the relative costs of the rivals are

assessed in the context of how the MMRCA selectee would fit into the IAF's prospective force architecture.

THE MMRCA IN THE IAF'S FORCE ARCHITECTURE

The MMRCA competition has been among the most hotly contested Indian procurement programs in recent times. Accordingly, it has not been without its critics. One scholar, Vipin Narang, for example, decried its “muddled rationale” and questioned whether it was destined to become a “costly adventure.” His anxiety arises from the fact that although the IAF is significantly under strength, the aircraft chosen for the MMRCA component eventually will not be fully integrated into service for “up to 15 years—if not more” after its selection. Assuming (and this is a big assumption) that the government of India will select a winner in 2011 and complete all contractual negotiations by 2012, Narang's assessment visualizes that the last aircraft in the procurement will enter the force only in 2027, when the earliest Su-30MKIs—the most capable aircraft in the current inventory—will be almost twenty-five years old.

As Narang concluded,

This elongated timeline undermines the primary rationale for the MMRCA deal. Since the Tejas and the Su-30MKIs will be operational well before even the first eighteen MMRCAs are delivered, and the Sukhoi PAK-FA fifth generation fighter is likely to be developed around the same time as the indigenously produced MMRCAs, the \$10 billion MMRCA complement could be dated by the time it is incorporated into the IAF's force structure—and certainly by the end of its three-decade life cycle—particularly since an expanded order of Su-30MKIs might provide broadly similar capabilities.⁷⁴

Another well-known Indian analyst, Bharat Karnad, appears to have similar qualms. Commenting on the MMRCA face-off, Karnad argues that “the irony is that India's desire for a new fighter plane is in the context of even the cutting-edge manned aircraft obsolescing so fast as to become expensive museum pieces before they serve out their thirty-year life span with the IAF.”

His fears about the aircraft's progressive desuetude are driven partly by concerns about the time it would take to fully induct the airplane into service. The IAF, complains Karnad, is ignoring alternatives already on the table:

Curiously, the most cost-effective solution—inducting more Sukhoi Su-30MKI aircraft to meet the MMRCA demand—is not even on the table. Already in the Indian air order-of-battle, its development financed in the mid-90s by India, the Su-30, value for money-wise, is the best fighter-bomber in the business. Performance-wise, it can only be bettered by the F-22 Raptor. Dispassionate analyses suggest that it matches or surpasses either of the American aircraft in the race and, in its more advanced configuration, can outperform even the Joint Strike Fighter F-35, a plane Lockheed Martin have promised to replace the F-16 with on a ‘one for one’ basis were India to buy the latter aircraft. Notwithstanding all these factors, the IAF believes the Su-30MKI is ‘simply not good enough!’⁷⁵

Even if one disregards Karnad’s claim that an advanced Su-30 can outperform the F-35 as hyperbole, the sentiments that critics like him and Narang articulate grow out of fears that the position of the MMRCA in the IAF’s force structure is not well articulated; that the costs of the aircraft in the competition are high, especially at the top end; that they may simply not be worth their value given the alternatives; that the technology they embody represents the past and not the future of combat aviation; and that, consequently, the IAF ought to settle for simpler alternatives such as the Su-30MKI, which could be integrated into the service right away. More dramatically, as another thoughtful critic, Ajai Shukla, put it, “Scrap the MMRCA, buy U.S. F-35s.”⁷⁶

These arguments are not frivolous and should be considered by India seriously. But they only indicate how difficult the MMRCA selection will turn out to be because, if the previous discussion about aircraft capabilities has any utility, the choices facing the IAF are likely to be tricky on technical grounds alone. When issues of cost are factored in, the attractiveness of even the newest and arguably most capable aircraft overall diminish considerably. This fact becomes even more prominent when the IAF’s future force structure is examined carefully.

The MMRCA suffers, in the first instance, simply from its location in the spectrum of IAF combat capabilities. The role of the air superiority fighter—the relatively large, high endurance, platforms designed primarily for BVR combat, and secondarily for WVR dogfighting and some strike functions—is easy to understand. In IAF service, this niche is occupied today by the Su-30MKI. In the U.S. Air Force, the F-15 Eagle filled this role before the F-22A replaced it. The importance of the low-end air combat fighter—the relatively smaller, lower endurance, cheaper aircraft optimized primarily for WVR combat but

also able to prosecute BVR missions and strike functions—is also not difficult to appreciate. These aircraft may not represent the acme of endurance or capability, but their low cost justifies treating them as the jack-of-all-trades and permits their acquisition in the larger numbers required to bulk up the force. In the IAF today, this role is played primarily by the MiG-21 BISON and its older, less capable stable mates. In the U.S. Air Force, the F-16 fills this role. In the case of both high-end air superiority fighters and low-end air combat aircraft, the cost-effectiveness of each platform is easier to assess.

The MMRCA component, however, straddles the categories of air superiority and air combat platforms uneasily. It does not have quite the capabilities and the endurance of the high-end air superiority fighter, but it does not have the patently modest price of its low-end air combat counterpart either. Assessing its value and cost-effectiveness, thus, becomes an inherently difficult proposition. The Indian debate about the utility of the MMRCA competition reflects exactly this analytical conundrum.

The logic of the IAF's quest for a MMRCA platform, however, is not at all quixotic. The reason the service sought an additional 126 Mirage 2000-5s originally was to compensate for the retirement of the MiG-23MFs and the assorted lower-end MiG-21s, in effect making an enlarged Mirage 2000 force serve as the MMRCA component of the service as a whole. When the government of India decided that this purchase would be pursued through an open international tender, the IAF revised the *Request for Proposals* accordingly to now solicit bids for an aircraft that would fit the middle ground of responsibilities between the Su-30MKI in the high-end air superiority mission and the MiG-21 BISON (to be replaced by the Tejas LCA eventually) in the low-end air combat role.

The IAF was not particularly enthusiastic about acquiring another Russian platform for this task, again for very sensible reasons. Since the bulk of India's combat aviation already drew upon Russian platforms—Su-30MKIs, MiG-29s, MiG-21s, and MiG-27s—the IAF was hoping to procure a Western aircraft of some sort in order to diversify its arsenal and, very importantly, to serve as a hedge against potential neutralization of any key Russian systems down the line. The fact that India's major adversaries, China and Pakistan, now also deploy principal combatants based on Russian designs, sensors, and weapons—either in their original versions or in indigenously modified form—made the imperative of diversification even more urgent.

This issue is serious because critical Russian technologies in propulsion, radar systems, DAS, and, above all, weapons, have proliferated to China and

Pakistan. While India has generally sought to stay ahead of the curve by acquiring the latest Russian versions from Moscow directly, the advantages accruing from obtaining successive generations of the same basic technology diminish over time, particularly when China is rapidly developing new and advanced variants from a common core technology. Securing a new technology stream thus became essential, and the growing rapprochement with the West after the Cold War only provided the IAF with new opportunities to look beyond its traditional suppliers such as Russia and France.

Understanding how the MMRCA component, accordingly, fits into the IAF requires visualizing the desired snapshot of its force structure in the year 2020, illustrated in Table 2.⁷⁷

TABLE 2. Prospective IAF Force Structure: 2020

Role	Aircraft	Number	Squadrons
Air Superiority	Su-30MKI	280	~15
	MiG-29	50	~3
Air Combat: MMRCA	Mirage 2000	50	~3
	MMRCA Selectee	126/200	~7/11
Air Combat: Light	Tejas	125	~7
Strike	Jaguar	110	~6
Total		741/815	~41/45

These numbers in this table are illustrative and should be treated with caution. They assume that all Indian combat aircraft are organized in standard squadron strengths of sixteen aircraft plus two trainers. Often this is not the case, but it is still useful as a sizing metric. They also assume that the MiG-29, the Mirage 2000, and the Jaguar will be modernized in accordance with current plans in order to remain in service in 2020.

Assuming these things, there are several elements that are significant in the planned force structure indicated in Table 2. First, if all aircraft acquisitions

take place on schedule, the squadron strength of the IAF will grow from its current nadir to a point in line with the expectations articulated recently by India's Chief of Air Staff, Air Chief Marshal Pradeep V. Naik, who stated that "the IAF envisages a combat strength of approximately 40 squadrons by the year 2020."⁷⁸ Meeting this objective successfully, however, would require the IAF to integrate at least the first 126 MMRCA platforms completely by 2020, even if aircraft from the follow-on order come later. This would require the government of India to complete contract negotiations very soon. This would be a welcome surprise, given India's record of delays in past negotiations. In all likelihood, however, these planned IAF targets will not be met. Even if India promptly concludes the commercial phase of the contract, it is simply not clear that HAL would be able to assemble all 108 aircraft scheduled to be domestically produced under license by the end of the decade.

Second, the IAF's intention to resuscitate its force strength to about 40 squadrons by 2020 also hinges on the Tejas LCA being successfully introduced into the force. At the moment, this is questionable. Recent reports indicate that the current version of the LCA still does not meet IAF specifications with respect to "sustained turn rate, speed at low altitude, angle of attack and certain weapon delivery profiles."⁷⁹ Although the service is still committed to acquiring the LCA, it will soon have to make some fundamental decisions about whether the Tejas can actually deliver what the IAF needs in its low-end air combat component to match Pakistan's deployment of aircraft like the JF-17 and China's deployment of late-model F-7s, F-8s, and JF-17s—all of which will carry BVR weapons. Whether the IAF chooses to stay with the LCA or acquire a foreign aircraft for the role, it will again have to procure these aircraft in a hurry if the force structure illustrated above is to be attained because by 2020 the MiG-21 BISONs, which currently make up this component, will already be twenty years old.

Third, many of the higher-end fighter types maintained by the IAF will have seen their best years as well by 2020. Although modernized, the MiG-29s and the Mirage 2000s, will already have been in IAF service for some thirty-five years and will probably be preparing to exit the force at some point thereafter. The Su-30MKIs too will be approaching twenty years of service by 2020; they will certainly have been upgraded in the interim, primarily through

the incorporation of AESA radars, new mission computers, and possibly new weapons, but they will be a little past the halfway point of their service lives. The future of the dedicated strike component of the IAF is unclear. The upgraded Jaguars will probably have a few more years of service beyond 2020, but they will either have to be replaced by similar attack platforms or their roles transferred to the new combatants such as the MMRCA. Part of the uncertainties here derives from the lack of clarity about India's own geopolitical profile in global politics. If the IAF is to become an expeditionary force with new long-range missions, it may require a dedicated strike aircraft like the Su-34, with the Su-30MKIs playing this role in the interim.

The desired IAF force structure in 2020 is, thus, plagued by several imponderables which bear on the selection of the MMRCA platform. If the service is unable to find a satisfactory replacement for the MiG-21 BISON and the Tejas, it makes sense for the IAF to select the cheapest possible MMRCA contender, such as the F-16IN or the F/A-18E/F, and produce it in the largest possible numbers. In effect, this would combine the MMRCA and the LCA segments of the force to yield somewhere between 250–325 aircraft. This would move the IAF toward a two-tiered force structure, with a high-end air superiority component of close to 300 Su-30MKIs and a mid-level segment of a comparable, or perhaps somewhat larger, number (250–325) of only nominally less capable fighters.

This alternative, designated Option I, in Table 3 below, could produce a smaller force of some 35 combat squadrons, if the MMRCA buy is restricted simply to the initial order of 126 aircraft. If India exercises the follow-on purchase option, as would be prudent in order to maintain the desired end-strength, then the IAF would reach the 40 squadrons minimally necessary to ensure Indian security. As the service phases out the MiG-29s and Mirage 2000s, it could enlarge these two tiers by purchasing a larger number of aircraft, either divided between the two categories or concentrated at the lower end, yielding an alternative force structure, represented by Options II and III, respectively, in Table 3. If the IAF eventually eliminates the dedicated strike force, it could merge replacements for the 110 Jaguars now in service into the high- or low-end of the force (or it could divide them between the two) to yield essentially the highest force level in Table 3, namely 815 aircraft in 45 combat squadrons.

TABLE 3. Alternative IAF Force Structures: 2020

Role	Aircraft	Number/ Squadrons Option I	Number/ Squadrons Option II	Number/ Squadrons Option III
Air Superiority	Su-30MKI	280/~15	330/~18	280/~15
Air Combat	MMRCA Selectee	250-325/~14-18	375/~21	425/~24
Strike	Jaguar	110/~6	110/~6	110/~6
Total		640-715/ ~35-40	815/~45	815/~45

All of these alternatives are plausible, however, only if one assumes that the IAF will reject the Tejas for the LCA segment, thereby justifying merging it with the MMRCA component to create a simple high-low mix that would not only vastly increase the IAF’s overall combat capabilities but also radically simplify the logistics, training, and maintenance burdens that have plagued the service for years. What if this assumption turns out to be false? That is, what if the IAF accepts, or is forced to accept, the Tejas in some form as its principal LCA? If this turns out to be the case, then the IAF’s notional force structure in 2020 will closely approximate the one detailed in Table 2, which is where the discussion first began.

If the service’s future architecture resembles Table 2, do the more expensive MMRCA candidates, say the Typhoon or the Rafale, look better? Several voices in the Indian strategic community argue *sotto voce* for exactly this outcome. Noting that the IAF should, or almost certainly will, acquire the Tejas in some form to populate the LCA segment of the force, they argue that India should invest in the most capable MMRCA candidate (and the one with the most room for growth), because a relatively modest performer like the Tejas will be constrained to cover the bottom end. According to this line of thinking, the ideal MMRCA candidate would be one that brings warfighting capabilities that are far superior to the Tejas and close to, if not better than, the Su-30MKI, thus making it the perfect fit between the high and low ends of the Indian combat aviation spectrum. Thus the IAF should consider one of the more expensive “Eurocanards,” the Typhoon, Rafale, or Gripen, because of their combination of combat effectiveness and growth potential.

The chief problem with this reasoning, however, is that there is no simple correlation between relative aircraft cost and combat capability. Even cheaper aircraft in the competition, like the F-16IN Super Viper or the F/A-18E/F Super Hornet, turn out to be remarkable embodiments of high capability because of their sensors, overall integration, and advanced weaponry. And while aircraft such as the Typhoon are indeed superlative platforms—and could probably even be the best platform overall based on the totality of its current and future technical characteristics—the price tag associated with such aircraft raise serious questions about their cost-effectiveness.

In the case of the MMRCA competition, however, the problem is not merely academic or even one related solely to picking the right airplane for the price. Rather, it is embedded deeply in the IAF's future force architecture as becomes obvious when recent Indian decisions to co-produce the Russian fifth-generation fighter, the PAK-FA, are taken into account. The government of India's decision to join the Russian effort in producing a stealth fighter is an eminently sensible one in principle. India's biggest threat, China, already has a fifth-generation fighter development program underway. This effort, designated the XXJ in the West, is expected to produce a stealth platform with advanced aerodynamic performance, supercruise propulsion, internal weapons carriage, and an AESA radar, by about 2020. Given that the future air combat environment in Southern Asia will be quite unkind to conventional fighters facing off against such advanced aircraft, India's efforts to get on to the stealth bandwagon on Russia's coat-tails makes perfect sense.

The Russian PAK-FA program is already at an advanced stage. The basic airframe design has been validated and frozen, the construction of the early prototypes is complete, the AL-31F thrust-vectoring supercruising engine is under development, the AESA radar produced by NIIP Tikhomirov is in active testing, and a vigorous flight-test program has been under way at the Zhukovsky Flight Test Center near Moscow since the aircraft's maiden flight at the factory in Siberia on January 29, 2010.⁸⁰ Given these facts, it is not clear what a Russian "co-development" of the aircraft with India actually means, beyond that New Delhi will financially contribute to the program in exchange for some marginal design changes to accommodate Indian preferences and the responsibility for developing a two-seat version of the same airplane.⁸¹ Since India has little expertise in the functional areas that distinguish a fifth-generation platform from its predecessors—stealth shaping, supercruise propulsion, airframe embedded sensors, and network-centric warfare—its modest technical contributions should be of no concern so long as it can acquire a substantial number of PAK-FA aircraft for its combat fleet. These weaknesses, however, have not prevented it from launching its own fifth-generation stealth fighter program, the Advanced

Medium Combat Aircraft (AMCA), which may in fact both complement and compete with the Russian-Indian cooperative PAK-FA effort.⁸²

Based on current estimates, the IAF expects to induct the first PAK-FA combatants into service sometime in 2018, a development that inadvertently undermines the case for acquiring an expensive MMRCA contestant in the interim.⁸³ If the PAK-FA is now included in the snapshot of the Indian fighter force in circa 2030—on the assumption that the Tejas has been selected for the LCA component previously—the profile detailed in Table 4 obtains.

TABLE 4. Potential IAF Force Structures: 2030

Role	Aircraft	Number/ Squadrons Option I	Number/ Squadrons Option II
Air Superiority	PAK-FA	100/~5.5	200/~11
	Su-30MKI	300/~17	300/~17
Air Combat: MMRCA	MMRCA Selectee	200/~11	200/~11
Air Combat: Light	Tejas	125/~7	125/~7
Strike	F-35	100/~5.5	150/~8
Total		825/~46	975/~54

If the PAK-FA is to compose the highest end of the IAF’s air superiority component by 2030, while another 300 or so upgraded Su-30s still survive in combat service, the case for acquiring a relatively inexpensive MMRCA contestant actually grows even stronger. The role of the MMRCA in this force architecture is to bring the best combat bang for the buck, while the service allocates the bulk of its future acquisition resources for the best fifth-generation platforms.

In practical terms, this would mean—as Option I in Table 4 indicates—inducting at least a hundred stealthy air dominance platforms such as the PAK-FA by 2030 in order to sustain a dissuasive potential vis-à-vis China while simultaneously retaining air superiority over Pakistan. If the IAF, however, is to maintain the theater air supremacy it has enjoyed over the PLAAF since at least 1971, it should concentrate on at least doubling the size of its stealthy

air superiority component to bring its total force strength to some 54 combat squadrons with 975 aircraft.

By this time, the Su-30MKI component will also be reaching the end of its service life and will be in need of replacement. If all goes according to plan, they could be replaced by equivalent numbers of improved PAK-FA fighters in the post-2030 timeframe—seventeen squadrons—in order to permit the IAF to maintain a relatively robust force of some 54 squadrons long after the departure of the Sukhois.

Because the PAK-FA is optimized mainly for air combat, however, the IAF should pursue as a priority acquiring another fifth-generation aircraft,

The role of the MMRCA in this force architecture is to bring the best combat bang for the buck, while the service allocates the bulk of its future acquisition resources for the best fifth-generation platforms.

such as the F-35, which is designed especially for stealthy first-day-of-war missions in the air-to-ground arena. The kind of integrated air defenses that will exist in 2030 even in relatively weaker competitors like Pakistan will put all non-stealthy airframes at significant risk, particularly in the early phases of conflict when the air defense net is largely intact. If limited wars are likely to remain the most important military contingencies confronting the IAF from China and Pakistan in the future, then the need for stealthy air combat and ground attack aircraft will be all the greater, because both surgical

strike missions and contained air warfare will have to be prosecuted successfully even when comprehensive IADS takedown and C-AISR operations have been ruled out.

It is not clear whether the AMCA will be optimized for the air-to-ground role as the F-35 currently is. If so, it could serve as a complement to or a substitute for the F-35 in the role envisaged for the latter in Table 4. The Indian record with respect to indigenous aircraft development and production, however, has thus far been horrendous where producing combat platforms of quality on schedule is concerned. Consequently, it would be unwise for the IAF to gamble on the bet

that India's domestic capabilities would suffice to actually produce something as sophisticated as a fifth-generation stealth platform in time to replace its current strike components or to substitute for a full-fledged acquisition of the F-35.

In all likelihood, if the AMCA program succeeds, it will appear in mature form only during the latter half of the Su-30MKI's service life—from the late 2020s onwards. Even this could be optimistic, unless the MMRCA competition serves to provide the technology access that could be used to develop the AMCA. It should be noted, incidentally, that precisely because this remains the IAF's hope, the service has rejected the idea of abandoning the MMRCA acquisition in favor of acquiring additional Su-30MKIs. Given the risks involved, however, the AMCA should not be conceived as a replacement for the F-35s—which the IAF should seek to acquire as early as possible as a replacement for the Jaguars and the MiG-27s—but as a substitute for the Tejas LCA in the lighter-weight multi-role mission over the longer term.⁸⁴ In this scenario, the Tejas airframes that survive would be relegated to the short range back-up role, before ending their lives primarily as operational conversion or training platforms.

In any event, the IAF today ought to be looking forward toward investing heavily in fifth-generation platforms. It should put the fewest resources possible into the MMRCA acquisition, treating it mainly as a bridge to satisfy the need to maintain the requisite numbers, diversify the force, hedge against uncertainty, and acquire new capabilities beyond what already exist in the inventory. Even if the IAF makes all the investments suggested above, the total force levels embodied by Option II in Table 4 will still be smaller than the 64-squadron force declared to be essential after the 1962 war. But the kinds of aircraft that would populate this inventory would be far more capable and, hence, would warrant a revision of those original requirements *if* the PLAAF and the PAF together do not exceed the current numbers of high-end aircraft that are expected to be in service in both countries around 2030.

Should these levels rise beyond present forecasts, the IAF will have to expand its own force totals accordingly. Option II in Table 4 envisages an end-strength of close to a thousand aircraft with a little over one-third of the force comprising of stealth aircraft. All these numbers may have to be revised depending on how the Chinese and Pakistani air forces evolve in the long term, but any expansion—should it be warranted—ought to be oriented toward increasing the proportion of fifth-generation aircraft in the total force. Given current projections of evolving Chinese and Pakistani air capabilities in 2030, Table 5

actually represents the most prudent force structure that the IAF should possess in the years following: a 60-combat squadron force moving toward deploying fully 80 percent of that capability eventually in the form of stealth aircraft.

TABLE 5. Optimal IAF Force Structure: 2030 and Beyond

Role	Aircraft	Number/Squadrons
Air Superiority	PAK-FA	300/~17
	Su-30MKI Replacement: Improved PAK-FA	300/~17
Air Combat: MMRCA	MMRCA Selectee	200/~11
Air Combat: Light	AMCA	125/~7
Strike	F-35	150/~8
Total		1075/~60

All these considerations converge on justifying a fortiori the least expensive MMRCA platform in the near future, particularly because even the cheapest aircraft in the competition, such as the F-16IN and the F/A-18E/F, embody formidable increases in warfighting capability. If India picks the F-16IN on the defensible grounds of cost-effectiveness, then it will also have acquired a bridge to quickly acquiring a stealthy air-to-ground platform like the F-35. In fact, were the IAF to choose either the F-16IN or the F/A-18E/F as its MMRCA fighter, it should make the option to acquire F-35s subsequently a condition of the deal.

CONCLUSION

The MMRCA bid has been one of the hottest recent aviation procurements not just in India, but internationally, too. Eight countries and six companies eagerly await the outcome of this contest. This has turned into such a sizzling affair not only because of the size of the contract. Indeed, there are bigger procurement battles raging internationally. Rather, this procurement bid has been incandescent because it involves geopolitics, the economic fortunes of major aerospace companies, complex transitions in combat aviation technology, and the evolving character of the IAF itself.

Moreover, the MMRCA fly-off is occurring at just the time when India is gingerly stepping out on to the international stage. The expectation that it will invest even more in military instruments than it has done before drives this particular campaign intensely because getting a foothold in the burgeoning Indian defense market is seen to promise larger long-term payoffs beyond simply the revenues produced through this one transaction.

As the Indian state wades through the welter of competing considerations, it should seek to do best by its air force, first of all. Among other things, this means concluding the MMRCA competition expeditiously because of the toll that further delays would exact on the IAF's steadily falling strength. Identifying the desired platform from among the six competitors is obviously only the first step in the process. Concluding the commercial contracts, including resolving the vexed issues of technology transfer and offsets, have traditionally bedeviled New Delhi in other defense acquisitions.

Bringing the Scorpene submarine contract to a successful close, for example, took the Indian Ministry of Defense almost a decade, and the evidence from

other procurement efforts, such as the Hawk jet trainer or the airborne refueling platforms, provides reason for both fear and dismay. As this report shows, any delays in concluding the MMRCA contract will further undermine the IAF's ability to sustain its minimal fighter strength at a time when both China and Pakistan are pursuing a concerted modernization of their own air forces, and when the dangers of a limited war in Southern Asia make the role of Indian air power even more important than before.

Given these realities, India's civilian decision makers—both bureaucrats and politicians—should move with alacrity to consummate the MMRCA contract, thereby permitting the selected aircraft to populate the IAF's combat inventories as early as possible. In doing so, however, they should resist the temptation to split the aircraft buy in order to satisfy multiple foreign powers who all have keen stakes in the success of their own platforms.

It is to be expected that all the major powers involved in the MMRCA race—the United States, Russia, France, Sweden, and the European quartet, the United Kingdom, Germany, Italy, and Spain—will canvas Indian decision makers to choose their own aircraft. It is

equally reasonable for the government of India to take political considerations into account while making its final decision, but these calculations should not come at the cost of burdening the IAF with more than one aircraft for the MMRCA segment of the force. The IAF already suffers from a larger diversity of aircraft than is wise and, if anything, the MMRCA competition should be the first step in driving down the types of combat aircraft in the IAF inventory over time.

Finally, the Indian state ought to purchase the best aircraft from among the six competitors for the IAF. Obviously, this is easier said than done. All the warplanes in the race are superb by some measure or another. Consequently, a simple aggregation of desired technical characteristics will not produce any universally acceptable result, and the Indian government will be forced to factor the relative costs of the various aircraft into their decision.

The MMRCA fly-off is occurring at just the time when India is gingerly stepping out on to the international stage.

Choosing an aircraft on the basis of a complex triangulation involving assessed capability, relative cost, and fit within the IAF's architecture, then, becomes essential if Indian decision makers are to satisfy the requirement of choosing the "best" aircraft in the MMRCA competition. Because of the radical transformations in combat aviation technology that are occurring today—in particular, the transition to fifth-generation platforms characterized by low observables, supercruising powerplants, sensor embedded airframes, internal weapons carriage, and ultra-high maneuverability—the least expensive, mature, combat-proven fourth-generation fighter turns out to be arguably the best for the IAF.

These criteria end up making the U.S. entrants in the MMRCA race formidable "best buys," even though their European rivals are technically superb machines worthy of admiration and respect—and may even be superior where pure aggregate technology comparisons are concerned. Because the American airplanes, however, have to battle the perception that their older designs are less combat effective, the U.S. government ought to do whatever is required to help them succeed. The most important contributions Washington can make in this regard are to authorize generous technology transfer, open the door to Indian access to fifth-generation U.S. combat aircraft, and provide strong geopolitical support for India's strategic aspirations. The U.S. Department of Defense thus far has only done the minimum necessary to keep the two American fighters in the game. It will need to do more to help one of them win. If the Obama administration can move in this direction—aided, of course, by the government of India's willingness to sign the requisite technology protection agreements—the relatively lower costs and the superb warfighting capabilities of the American competitors could help them win the day.

No matter which way India leans in the MMRCA contest, keeping the IAF's interests consistently front and center will ensure that its ultimate choice will be the right one. A selection process that is transparent, speedy, and focused on the right metrics will not only strengthen the IAF's combat capabilities, but it will also earn the respect of all the competing vendors and their national patrons. Some of them will be disappointed by India's final choice, but those, alas, are the rules of the game.

NOTES

1. Neelam Mathews, "Race is on for India MMRCA," *Aviation Week & Space Technology*, September 21, 2009, available at http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=defense&id=news/MMRCA092109.xml&headline=Race%20is%20on%20for%20India%20MMRCA.
2. These details about the IAF's evaluation process are described in Shiv Aroor, "A Big Fat MMRCA Update," *Livelist*, August 12, 2010, available at <http://livelist.blogspot.com/2010/08/big-fat-mmrca-update.html>.
3. "India's Spending On Defence to Reach about \$80 Billion by 2015," *indiaserver.com*, <http://www.india-server.com/news/indias-spending-on-defence-to-reach-30456.html>.
4. Bill Sweetman, "Fighter Competitions Could Make or Break Contractors," *Aviation Week & Space Technology*, December 5, 2008, available at http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=dti&id=news/DTI-Fighters.xml&headline=Fighter%20Competitions%20Could%20Make%20or%20Break%20Contractors.
5. Max Weber, "Politics as a Vocation," Lecture Before the Freistudentischen Bund of the University of Munich, available at <http://www2.selu.edu/Academics/Faculty/jbell/weber.pdf>.
6. For a useful summary of the contemporary challenges in this regard, see Stephen P. Cohen and Sunil Dasgupta, *Arming Without Aiming* (Washington, D.C.: Brookings Institution Press, 2010).
7. The role of the IAF in traditional Indian grand strategy has been summarized in Ashley J. Tellis, "The Air Balance in the Indian Subcontinent," *Defense and Security Analysis*, vol. 2, no. 4, December, 1986, 263–289.
8. The relevance of air power under conditions of limited war is masterfully articulated in Jasjit Singh, "Dynamics of Limited War," *Strategic Analysis*, vol. 24, no. 7, 2000, 1205–1220.
9. Air Marshal (Retired) V. K. Bhatia, "Walk the Line," *SP's Aviation*, issue 1, 2009, 12–13; Air Marshal (Retired) V.K. Bhatia, "IAF Modernization—Immediate Needs," *SP's Aviation*, issue 8, 2009, available from http://spsaviation.net/story_issue.asp?Article=322; Tellis, op. cit.
10. "India Air Force Targets 42 Squadrons Strength by 2022," *India Defence*, available at <http://www.india-defence.com/reports/4230>.
11. A useful overview of PAF modernization can be found in Shalini Chawla, "Modernization of the Pakistan Air Force," *Air Power Journal*, vol. 3, no. 2, Summer 2008. A summary of recent and upcoming PAF acquisitions can be found in "Procurement, Pakistan," *Jane's Sentinel Security Assessment*, November 25, 2010.
12. Robert Hewson, "Pakistan Joins AMRAAM Club in Biggest-Ever Buy," *Jane's Defense Weekly*, vol. 44, no. 4, January 24, 2007, 14.
13. Leithen Francis, "Pakistan to get Chinese AEW&C aircraft this year," *Flight International*, August 5, 2010, available at <http://www.flightglobal.com/articles/2010/05/07/341584/pakistan-to-get-chinese-aewc-aircraft-this-year.html>.
14. On the transformation of the PLAAF, see Philip C. Saunders and Erik R. Quam, "China's Air Force Modernization," *Joint Force Quarterly*, no. 47, Fall 2007, 28–33, and Kenneth W. Allen, Glenn Krumel, Jonathan D. Pollack, *China's Air Force Enters the 21st Century* (Santa Monica, CA: Rand Corporation, 1995).

15. Mark A. Stokes, *China's Strategic Modernization: Implications for the United States* (Carlisle: Strategic Studies Institute, 1999), and Mark A. Stokes, "The Chinese Joint Aerospace Campaign: Strategy, Doctrine, and Force Modernization," *China's Revolution in Doctrinal Affairs: Emerging Trends in the Operational Art of the Chinese People's Liberation Army* (Alexandria, VA: CNA, 2005).
16. B. Raman, "China Tests its Strategic Air power Capability: Implications for India," *Sri Lanka Guardian*, September 25, 2010, available at <http://www.srilankaguardian.org/2010/09/china-tests-its-strategic-air-power.html>.
17. Air Marshal (Retired) V. K. Bhatia, "In Progress," *SP's Aviation*, issue 7, 2010, 17.
18. Vivek Raghuvanshi, "India Boosts Aircraft Buy, Widens Supplier Options," *Defense News*, November 21, 2005, 34.
19. "India Approves Purchase of 68 Boeing Jets for Eight Billion Dollars," October 13, 2005, orange.mu, available at <http://www.orange.mu/kinews/afp/business/100877/india-approves-purchase-of-68-boeing-jets-for-eight-billion-dollars.html>.
20. Air Marshal (Retired) Ajit Bhavnani, "Fortify the Force," *Force*, vol. 4, no. 7, March 2007, 14–16.
21. Ray Whitford, *Fundamentals of Fighter Design* (Shrewsbury, UK: Airlife Publishing Limited, 2000).
22. Carlo Kopp, "Measures of Fighter Capability," Air Power Australia, <http://www.auseairpower.net/air-superiority-3.html>. Kopp's article is a superb survey of aircraft qualities in the abstract and informs the analysis at various points in this report.
23. For an excellent contemporary study of the IAF, including its worldview, its ethos, and its force structure, see Benjamin S. Lambeth, *India's Transforming Air Posture: An Emerging 21st Century Heavyweight* (Santa Monica, CA: Rand Corporation, 2011), forthcoming.
24. Ajai Shukla, "Buy a Fighter for War, Not Air Shows," *Business Standard*, November 2, 2010, available at <http://www.business-standard.com/india/news/ajai-shukla-buyfighter-for-war-not-air-shows/413413>.
25. For a good overview, see R. A. Mason, *Air Power: An Overview of Roles* (London: Brassey's Defense Publishers, 1987).
26. All the missions subsumed by this range are discussed at length in the Brassey's Air Power series, specifically: M. B. Elsam, *Air Defense* (Washington: Brassey's Defense Publishers, 1989); J. R. Walker, *Air Superiority Operations* (Washington: Brassey's Defense Publishers, 1989); J. R. Walker, *Air to Ground Operations* (Washington: Brassey's Defense Publishers, 1987); and Michael Knight, *Strategic Offensive Air Operations* (Washington: Brassey's Defense Publishers, 1989).
27. A good elaboration of the IAF's vision of information dominance where air power is concerned can be found in Air Commodore (retired) Jasjit Singh, ed., *Aerospace Power and India's Defense* (New Delhi: Knowledge World, 2007).
28. Squadron Leader Ajay Singh, "The Air War With AWACS Symmetry," *Indian Defence Review*, available at <http://www.bharat-rakshak.com/LANCER/idr00008.htm>.
29. "IAF Canberras Phased Out," *Frontier India*, May 11, 2007, available at <http://frontierindia.net/iaf-canberras-phased-out>.
30. Kopp, op. cit.; Whitford, op. cit., 21.

31. An excellent overview of AESA radars can be found in the Office of the Under Secretary of Defense for Acquisition and Technology, *Report of the Defense Science Board Task Force on Future DOD Airborne High-Frequency Radar Needs/Resources*, Washington, D.C., April 2001; Richard S. Deakin, *Battlespace Technologies: Network-Enabled Information Dominance* (Norwood, MA: Artech House, 2010); and Flightglobal/Insight, "Fighter Radars 2010," Special Report, available at http://www.flightglobal.com/airspace/media/reports_pdf/fighter-radars-special-report-2010-52625.aspx.
32. Lt. Col. Jaco Steynberg, "LOOKOUT – DECIDE – ATTACK – BREAK," SAAF News Archive, September 29, 2009, available at http://www.af.mil.za/news/2009/056_2009.htm.
33. Ronald G. Driggers, Paul Cox, and Timothy Edwards, *Introduction to Infrared and Electro-Optical Systems* (Boston: Artech Print on Demand, 1998).
34. Scott Baldauf, "Indian Air Force, in War Games, Gives US a Run," *Christian Science Monitor*, November 28, 2005, available at <http://www.csmonitor.com/2005/1128/p01s04-wosc.html>.
35. This history is documented with remarkable clarity in Robert Coram, *Boyd: The Fighter Pilot who Changed the Art of War* (Boston: Little, Brown and Company, 2002).
36. Franklin C. Spinney, "Genghis John," *Proceedings of the U.S. Naval Institute*, vol. 123, no. 6, July 1997, 42–47.
37. For a superb and thorough overview of air combat maneuvering, see Robert L. Shaw, *Fighter Combat: Tactics and Maneuvering* (Annapolis, MD: Naval Institute Press, 1985).
38. For more on what energy maneuvering diagrams reveal, see Thomas R. Yechout with Steven L. Morris, David E. Bossert, and Wayne F. Hallgren, *Introduction to Aircraft Flight Mechanics: Performance, Static Stability, Dynamic Stability and Classical Feedback Control* (Reston, VA: American Institute of Aeronautics and Astronautics, 2003), 79–144.
39. Ibid.
40. Steven A. Brandt, Randall J. Stiles, John J. Bertin, and Ray Whitford, *Introduction to Aeronautics: A Design Perspective* (Reston, VA: American Institute of Aeronautics and Astronautics, 2004), 345–378.
41. A splendid history of India's aeronautical industry can be found in Jasjit Singh, *Indian Aircraft Industry* (New Delhi: KW Publishers Private Ltd., 2011).
42. "About Us," *Hindustan Aeronautics Limited*, available at <http://www.hal-india.com/aboutus.asp>.
43. An excellent survey of India's aerospace strengths and weaknesses can be found in Confederation of Indian Industry and PriceWaterhouseCoopers, *Changing Dynamics: India's Aerospace Industry*, available at <http://www.pwc.com/gx/en/aerospace-defence/pdf/india-aerospace.pdf>.
44. For more on this issue, see Jan Roskam, *Airplane Design, Part VIII: Airplane Cost Estimation: Design, Development, Manufacturing, and Operating* (Lawrence, KS: DAR Corporation, 2002).
45. Shiv Aroor, op. cit.
46. "Defense Procurement Procedure, Capital Procurement, 2008," Ministry of Defence, Government of India, available at <http://mod.nic.in/dpm/DPP2008.pdf>.
47. Shiv Aroor, "MMRCA BUZZ: MiG-35 Was Never In The Running?" *Livestart*, August 19, 2010, available at <http://livestart.blogspot.com/2010/08/mmrca-buzz-mig-35-was-never-in-running.html>.

48. "Don't Call Them, They'll Call You," *Hindustan Times*, December 7, 2010, available at <http://www.hindustantimes.com/Don-t-call-them-they-ll-call-you/Article1-635181.aspx>.
49. Air Marshal (retired) B. K. Pandey, "Selection of MRCA for the IAF," *Indian Defence Review*, vol. 20, no. 1, January-March 2005, available at <http://www.bharat-rakshak.com/SRR/2005/03/38-selection-of-mrca-for-the-iaf.html>.
50. "F-22 Demonstrates 'Supercruise' for First Time," *Air Force News*, July 21, 1999, available at http://www.fas.org/man/dod-101/sys/ac/docs/n19990721_991378.htm.
51. "Military Aircraft," *McGraw-Hill Yearbook of Science and Technology 1989* (New York: McGraw-Hill Book Company, 1988), 215–217.
52. A useful overview of various fourth- and 4.5th-generation aircraft can be found in Mike Spick, *Brassey's Modern Fighters* (Washington: Brassey's, 2000).
53. This discussion is based on material appearing in Yefim Gordon, *Mikoyan MiG-29* (Hinckley, UK: Midland, 2006); North Atlantic Treaty Organization, *Mikoyan Mig-29 Fulcrum Pilot's Flight Operating Manual* (Los Angeles: Periscope Film, 2007), and Sayan Mazumdar, "The Russian Gymnasts: MiG-29OVT to MiG-35," *Vayu Aerospace and Defence Review*, issue 1, 2009, 121–123.
54. The discussion here is based on material appearing in Gerard Keijsper, *Saab Gripen: Sweden's 21st Century Multi-Role Aircraft* (Hinckley, UK: Aerofax, 2004); David Donald, "JAS 39 Gripen," *International Air Power Review*, vol. 24, 2008, 54–77; and David Donald, "Advanced Gripen," *International Air Power Review*, vol. 25, 2008, 16–19.
55. Donald, 2008, op. cit., 54.
56. Ingmar A. Andersson and Leif Haglund, "SAAB IRST: The System and Flight Trials," *Proceedings of SPIE*, vol. 4820, (2003), 69–83.
57. M. K. Rasgotra, "Reach Out to the U.S. Through Obama," *Mail Today*, October 12, 2010.
58. The discussion here is based on material appearing in Richard Aboulafia, "Dassault Aviation Rafale," *World Military & Civil Aircraft Briefing*, The Teal Group, September 2010; Henri-Pierre Grolleau, "Dassault Rafale: Programme Update," *International Air Power Review*, vol. 22, 2007, 26–35; and Michael A. Taverna, "Three in One," *Aviation Week & Space Technology*, July 19, 2010, 76–80.
59. Pierre Tran, "Thales Touts 'Market-Leading' AESA Radar," *Defense News*, November 10, 2008, available at <http://www.defensenews.com/story.php?i=3811949>.
60. The discussion here is based on material appearing in Jon Lake, "Eurofighter Typhoon," *International Air Power Review*, vol. 20, 2006, 44–75; David Donald, "Eurofighter Typhoon," *International Air Power Review*, vol. 26, 2009, 62–73; and Carlo Kopp, "Eurofighter Typhoon—Demon or Lemon?" *Australian Aviation*, August, 2000, available at <http://www.ausairpower.net/Analysis-Typhoon.html>.
61. "Eurofighter Leading Race for India Deal: Report," *Economic Times*, January 23, 2010, available at <http://economictimes.indiatimes.com/news/politics/nation/Eurofighter-leading-race-for-India-deal-Report/articleshow/5491058.cms>.
62. David C. Aronstein and Albert C. Piccirillo, *The Lightweight Fighter Program: A Successful Approach to Fighter Technology Transition* (Reston, VA: American Institute of Aeronautics and Astronautics, 1997).
63. Ramesh Phadke, "MMRCA: A Difficult Choice for the IAF," *IDS Comment*, Institute for Defence Studies and Analyses, May 19, 2010.

64. The discussion in this section draws on material in "The UAE's F-16 Block 60 Desert Falcon Fleet," *Defense Industry Daily*, January 26, 2010, and Orville Prins, "Super Viper for India," *Force*, vol. 7, no. 9, May 2010, 47–48.
65. "Counting on Experience," *Force*, vol. 7, no. 10, June 2010, 40–41.
66. Captain Gilles Van Nederveen, USAF, "The F-16 Block 60: A High-Tech Aircraft for a Volatile Region," *Aerospace Power Journal*, vol. 14, no. 3, Fall 2000, 96.
67. Graham Warwick, "Lockheed: F-35 Can Compete on Cost," *Aviation Week & Space Technology*, June 18, 2010, available at http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=defense&id=news/asd/2010/06/18/01.xml&headline=Lockheed:%20F-35%20Can%20Compete%20On%20Cost.
68. The discussion in this section is based on material appearing in Bill Sweetman, "Boeing F/A-18E/F Super Hornet," *World Air Power Journal*, vol. 42, Fall 2004, 30–53; Brad Elward, "Boeing F/A-18E/F Super Hornet," *International Air Power Review*, vol. 11, 2004, 36–73; Carlo Kopp, "F/A-18E/F Super Hornet vs. Sukhoi Flanker," *Defense Today*, January/February 2007, available at <http://www.ausairpower.net/DT-SuperBug-vs-Flanker.html>; and Carlo Kopp, "Flying the F/A-18F Super Hornet," *Australian Aviation*, May/June 2001, available at <http://www.ausairpower.net/SuperBug.html>.
69. Commander Rob Niewoehner, "The F/A-18E/F Super Hornet: A Test Pilot Dispels The Myths," available at <http://www.fas.org/man/dod-101/sys/ac/docs/990414-ART-Super-Hornet.htm>.
70. Sayan Mazumdar, "The AESA Radar: Key to the M-MMRCA," *Vayu Aerospace and Defence Review*, issue 5, 2009, 84.
71. David A. Fulghum, "Attack of the Electrons," *Aviation Week & Space Technology*, June 28, 2010, 52–54.
72. Mazumdar, op. cit., 86.
73. Air Commodore (retired) Jasjit Singh, "The Fighter after Next," *Vayu Aerospace and Defence Review*, issue 5, 2010, 47. It is important to note, however, that, despite some press reporting to the contrary, Singh has not endorsed the IAF's purchase of the Gripen for its MMRCA component; he has only stated its benefits in terms of weight, while clearly acknowledging that the F-16IN also is competitive by this yardstick.
74. Vipin Narang, "India's MMRCA Deal: Muddled Rationale, Costly Adventure?" Center of the Advanced Study of India, October 26, 2009, available at <http://casi.ssc.upenn.edu/iit/narang>.
75. Bharat Karnad, "No Good Choices for the Indian Air Forces," Center for the Advanced Study of India, October 12, 2009, available at <http://casi.ssc.upenn.edu/iit/karnad>.
76. Ajai Shukla, "Scrap the MMRCA, buy U.S. F-35s," *Business Standard*, October 19, 2010, available at <http://www.business-standard.com/india/news/ajai-shukla-scrappmmrca-buy-us-f-35s/411923>.
77. An excellent survey of the IAF's evolving force structure, on which this table is based, can be found in Air Marshal (retired) V. K. Bhatia, "Flash Forward," *SP's Aviation*, issue 1, 2009, 20–26.
78. "Interview: Chief of Air Staff, Air Chief Marshal Pradeep V. Naik," *Force*, October 2010, 10.
79. "Indian Light Combat Aircraft Will Miss Some Requirements," *Aviation Week & Space Technology*, November 22, 2010, 34.
80. David A. Fulghum, Maxim Pyadushkin, and Douglas Barrie, "Stealth, Sukhoi Style," *Aviation Week & Space Technology*, February 8, 2010, 30–31, and Carlo Kopp and Peter Goon, "Assessing the Sukhoi PAF-FA," *Air Power Australia Analyses*, February 15, 2010, available at <http://www.ausairpower.net/APA-2010-01.html>.

81. For a particularly trenchant, but on the point, critique, see Admiral (retired) Arun Prakash, "Once More Into the Bear's Embrace: Time to Remember Palmerston," December 28, 2010, available at <http://www.maritimeindia.org/modules.php?name=Content&pa=showpage&pid=189>.
82. "Taking Flight," *Aviation Week & Space Technology*, November 29, 2010, 25.
83. Ashok Nayak, "The India Fifth Generation Fighter is Planned for Induction From 2018," *Force*, vol. 8, no. 2, October 2010, 12–16.
84. Neelam Mathews, "India Develops Requirements for AMCA," *Aviation Week & Space Technology*, April 21, 2010, available at http://www.aviationweek.com/aw/generic/story_generic.jsp?topicName=india&id=news/awx/2010/04/21/awx_04_21_2010_p0-221350.xml.

ABOUT THE AUTHOR

ASHLEY J. TELLIS is a senior associate at the Carnegie Endowment for International Peace, specializing in international security, defense, and Asian strategic issues. While on assignment to the U.S. Department of State as senior adviser to the under secretary of state for political affairs, he was intimately involved in negotiating the civil nuclear agreement with India.

Previously, he was commissioned into the Foreign Service and served as senior adviser to the ambassador at the U.S. Embassy in New Delhi. He also served on the National Security Council staff as special assistant to the president and senior director for strategic planning and Southwest Asia.

CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE

The Carnegie Endowment for International Peace is a private, nonprofit organization dedicated to advancing cooperation between nations and promoting active international engagement by the United States. Founded in 1910, its work is nonpartisan and dedicated to achieving practical results.

As it celebrates its Centennial, the Carnegie Endowment is pioneering the first global think tank, with flourishing offices now in Washington, Moscow, Beijing, Beirut, and Brussels. These five locations include the centers of world governance and the places whose political evolution and international policies will most determine the near-term possibilities for international peace and economic advance.

CARNEGIE ENDOWMENT

FOR INTERNATIONAL PEACE

CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE

1779 Massachusetts Avenue, NW
Washington, D.C. 20036
United States
P +1 202 483 7600 F +1 202 483 1840
CarnegieEndowment.org

CARNEGIE MOSCOW CENTER

Tverskaya, 16/2
125009 Moscow
Russia
P +7 495 935 8904 F +7 495 935 8906
Carnegie.ru

CARNEGIE-TSINGHUA CENTER FOR GLOBAL POLICY

No. 1 East Zhongguancun Street, Building 1
Tsinghua University Science Park
Innovation Tower, Room B1202C
Haidian District, Beijing 100084
China
P +86 10 8215 0178 F +86 10 6270 3536
CarnegieTsinghua.org

CARNEGIE MIDDLE EAST CENTER

Emir Bechir Street, Lazarieh Tower
Bldg. No. 2026 1210, 5th flr.
P.O. Box 11-1061
Downtown Beirut
Lebanon
P +961 1 99 12 91 F +961 1 99 15 91
Carnegie-MEC.org

CARNEGIE EUROPE

Rue du Congrès 15
1000 Brussels
Belgium
P +32 2735 5650 F +32 2736 6222
CarnegieEurope.eu