FREEMAN AIR & SPACE INSTITUTE

KING'S College LONDON

ISSN 2754-0510

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Dr Daniel Salisbury

Paper 14

Published: February 2023

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About the Author

Dr Daniel Salisbury is a Senior Research Fellow at the Centre for Science and Security Studies (CSSS) within the Department of War Studies. He is currently undertaking a three-year research project on arms embargoes as part of a Leverhulme Trust Early Career Fellowship. Daniel is also an Associate Fellow at the Royal United Services Institute (RUSI) and a Fellow of the Royal Historical Society. He previously held positions at Harvard University's Belfer Center for Science and International Affairs, the Stimson Center, the James Martin Center for Nonproliferation Studies, CSSS and the International Institute for Strategic Studies. Daniel is the author of *Secrecy, Public Relations, and the British Nuclear Debate: How the UK Government Learned to Talk about the Bomb, 1970–1983* (Routledge Cold War History series, 2020). He is also the author and co-author of over 20 journal articles and book chapters, and the co-editor of two books on Open Source Intelligence (OSINT) and UN Security Council resolution 1540. Daniel's research interests include nuclear and intelligence history, nuclear and conventional arms proliferation, countering illicit networks, and preventing nuclear terrorism.

Abstract

This paper considers how the Russian Aerospace Forces (VKS) might be impacted by the arms embargo and technology-based sanctions imposed by the West in response to Russia's war in Ukraine. The paper outlines the effects of embargoes on air forces and considers historic embargo cases and their effects on air power. These cases are used to illustrate a typology of how embargoed air forces respond to restrictions through both dependency and self-sufficiency strategies. This includes, looking for new aircraft suppliers, scouring black markets for spare parts, cannibalising older and damaged air frames, and building up a domestic defence industrial capability to maintain existing aircraft and manufacture new types. It argues that Russia is most likely to be impacted by the embargo on dual-use technologies that are prevalent across its military systems, including in cruise missiles and unmanned aerial vehicles (UAVs), as well as manufacturing technologies used in aircraft production and maintenance. Shortages of these components and technologies will likely have an impact on Russia's ability to replace lost aircraft, maintain existing systems, and replenish stocks of weaponry. The greatest impact may be felt on Russia's ability to develop next-generation weapons systems. The willingness of China to supply Russia with technology in the medium-to-long term is likely to be crucial in shaping the VKS's future relevance.

Introduction

Russia's 2022 illegal invasion and Ukraine's formidable defence has seen the degradation of the Russian Aerospace Forces (VKS). This is through the loss of around 60 combat jets and 60 helicopters (as of January 2023), but also the various arms embargoes and export restrictions put in place against the country.[1] Arms embargoes are a sub-section of the sanctions toolset that is used by sender states in pursuit of a range of policy objectives, but primarily to signal, constrain, and coerce. Arms embargoes fulfil all three of these objectives. However, through their ability to 'constrain', embargoes can have a tangible impact on the target country's assets and means of power projection – in this case the armed forces, the air force, and air power.

The effects of economic sanctions put in place against Russia have seen some discussion, while less analysis has considered the impact of the arms embargo.[2] There are persistent challenges in understanding the impact of technology embargoes due to the secrecy surrounding the defence industrial complex, and the technological contents of weapons systems. It has been challenging to get a picture of what technologies are inside Russia's aircraft, sub-systems, munitions, and manufacturing complex. Much analysis surrounding the embargo has focused on the Western-origin components in Russian weapons systems, drawing on data from wreckage, damaged, and captured systems removed from the Ukrainian battlefields. This has provided unprecedented insights into Russia's dependency on foreign suppliers. Fewer insights have thus far been gained into Russia's aircraft.

This paper seeks to consider the current and future impacts of the arms embargo on the VKS. To do so, it draws on publicly available information, as well as significant insight from historical cases. Russia is far from the first state – and one with a large and developed air force – to face an arms embargo. The paper considers the context of the Russian embargo and how embargoes impact air power. It provides a framework for considering possible responses by air forces to an embargo, encompassing both dependency and self-sufficiency strategies. It then draws on insights from historical cases to consider the different coping strategies and tactics outlined. It concludes by considering the Russian case: Which strategies are likely being used by Russia today? What are the challenges the country is facing in maintaining an operational air force during the Ukraine conflict? And what might the future hold for Russian air power, as the embargo inevitably remains in place for the foreseeable future?

The paper argues that Russia will be most impacted by the embargo on dual-use technologies that have been found to be prevalent across its military systems, including in cruise missiles and UAVs, as well as manufacturing technologies used in aircraft production and maintenance. Shortages of these components and technologies will likely have an impact on Russia's ability to replace lost aircraft, maintain existing systems, and replenish stocks of weaponry in the medium-term. The greatest impact will be felt on Russia's ability to develop its next-generation aircraft projects. The willingness of China to supply Russia with technology in the medium-to-long term – with both weapons systems and dual-use goods and technologies – will be a crucial factor in shaping the VKS's future relevance.

Russia, the VKS and Arms Embargo

Russia has long been proficient in the production of military aircraft – including fighters, bombers, transport, and utility aircraft. It is one of a handful of states that have successfully designed and manufactured combat jets. Recent revelations from the war in Ukraine have shown the prevalence of Western technologies inside Russian military equipment. Much of the imported technology constitutes electronic components, with one report by the thinktank RUSI identifying 450 unique foreign-manufactured components across 27 weapons systems.[3] These included missiles, UAVs, air defence, SIGINT, and communications systems. Many of these components are 'dual-use' technologies – having both military and civil applications. Because of their wide-ranging civilian uses, these technologies have been subject to less stringent controls, are more readily available, and more easily accessible on the international market.

Russia's illegal invasion of Ukraine has seen heightened efforts by Western states to curtail the transfer of technology to the country; but the invasion far from marked the start of such efforts. During the Cold War through the Coordinating Committee for Multilateral Export Controls (CoCoM), NATO member states and Japan sought to prevent the transfer of technologies that could aid the military programmes of the Soviet Union and other communist states. Facing these restrictions, the Soviet Union developed a vast effort to procure – often illegally – controlled technologies using intelligence-run illicit procurement networks, front companies in third countries, and industrial espionage.

Traditionally, Russia's military aircraft and related systems have benefitted from Western technologies – although recent studies suggest direct replication efforts played less of a role than popularly perceived.[4] During the late Cold War, a 1985 US intelligence report noted 'a massive, well organised campaign by the Soviet Union to acquire Western technology illegally and legally for its weapons and military equipment projects'.[5] Among the 'hundreds' of examples of Soviet technology that benefitted from Western technology and products, the report listed: fighter aircraft, ground attack aircraft, and transport aircraft.

Over the past decade, a range of restrictive measures have been imposed to prevent Russia from benefitting from imported technologies. Notably, the EU imposed an arms embargo following Russia's illegal seizure of Crimea in 2014.[6] Since then, US export controls against Russia have been tightened iteratively. In February 2022, following the start of the invasion, the UK extended the restrictions on the transfer of dual-use goods to Russia to a full embargo, amidst wide-ranging sanctions put in place by the US and its partners.[7]

Prefacing these more dramatic steps to curtail the flow of technology, export licensing systems in Western economies have weeded out some of the direct procurement attempts originating from Russian arms companies. Many states have military and WMD end-use controls in their export controls that allow for the denial of licenses for exports of goods, regardless of their control status, to Russian and other military and WMD-related end-users. But many Russian procurement attempts through third countries, or using other means of deception, will have been successful. To be discussed are several cases that illustrate the shocking willingness possessed by some Western companies to sell to Russian customers, with this activity occurring until just a couple of years ago.

Whether the war in Ukraine reaches a conclusion in the coming months, or endures for many years, it is likely that arms and dual-use technology embargoes put in place by a range of states on Russia will remain in place. Concerns for further aggression by Russian President Vladimir Putin or a future Russian leadership will endure within NATO for many years. The embargo will remain as a means of containing the Russian threat, delaying military development and production, and raising the costs of imported technology. The embargo will continue to be used to constrain and contain Russian air power. Given that the embargoes will endure, their effects on Russia's air power and understanding VKS responses to the measures is of longer-term interest.

Arms Embargoes and Air Power

Before state and air force responses to arms embargoes are considered, it is necessary to survey the broader effects of embargoes on air power. Embargoes can put some of the greatest pressures on air forces outside of wartime conditions; at the same time, the types of impacts they have can be caused by conflict or other circumstances. The effects of the embargoes are largely technological – but also have knock-on effects on training, preparedness, willingness, and capability to exercise air power. The following are all possible effects of embargoes on air power, ranging from hardware to more organisational impacts:

Quantitative erosion. Embargoes reduce operational aircraft numbers by allowing aircraft and systems to degrade over time, and complicating engineering solutions without access to foreign-sourced spare parts and expertise. States may also lose access to aircraft that have been sent overseas for maintenance when the embargo is put in place.[8]

Qualitative erosion. Aircraft operated by embargoed states will become outdated – and possibly museum pieces – over time. North Korea today, for example, operates a historic fleet featuring Soviet designed aircraft as old as the MiG-15, MiG-17, MiG-19, and MiG-21 (first entered service between 1949 and 1959).[9] Similarly, the US Defense Intelligence Agency (DIA) notes that the US aircraft acquired by the Iranian air force in the 1960s and 1970s 'still constitute the most-capable platforms in the IRIAF today'.[10]

Pursuit of alternatives. States that are unable to purchase or develop advanced aircraft often pursue less conventional technologies and means to project power – for example, through a ballistic or cruise missile programme or developing UAVs.

Safety compromised. A lack of spares and the use of ageing aircraft has implications for safety and may see organisations alter their approach to risk. For example, a veteran Iranian pilot recently made the connection between sanctions and recent safety issues in Iran's air force.[11]

Limited training. The US DIA notes that North Korea limits its pilot flying hours to 15-25 annually because of fuel shortages and difficulties in keeping aircraft operational.[12] Limits to flying hours and training impact combat readiness and effectiveness.

Risk aversion. Air forces with limited options to procure spares and new aircraft, and facing challenges in maintaining existing fleets, often take decisions to use air assets and air power in a risk averse manner.[13]

Low morale. Air forces that lack access to modern technologies are forced to restrict their training programmes and experience a greater number of related safety issues. This can have a negative impact on morale of personnel.

The above effects, and how organisations respond to them, are closely entwined with attitudes to and, appetite for, risk. The risk appetite of an air force is shaped by a range of factors, including organisational culture and the main threats it is maintained by the state to counter. Attitudes to risk and losses can also change drastically in a conflict situation where losses are taken as a given, the organisation is expected to be under pressure, and the stakes are high. Indeed, being under embargo can go some way towards creating wartime conditions for an air force in peace time. There are also clearly cases – for example, contemporary Russia – where air forces have navigated wartime and embargo pressures concurrently, whether related or unrelated to each other.[14]

The effects of arms embargoes discussed above can also be caused by other factors – and could potentially be compounded by the implementation of an embargo. These can be a result of political and economic shocks, financial pressures, or other events that could impact supply chains – such as pandemics. Take for example the Iraqi Air Force of the early 2020s: while not under sanctions, a mixture of evacuation of contractors due to the security situation, lack of spare parts, and corruption has seen the force of F-16s and other Western aircraft degrade in a way that may resemble an air force under embargo.[15] An embargo can compound an already bad situation, where poor equipment, training, and organisational culture are already present. Alternatively, the effects of an embargo can be mitigated if an air force has a strong organisational culture, engineering capability, and entrepreneurial personnel.

How Air Forces Respond: A Loose Framework

While the data on the impacts of the embargo on the VKS and the organisation's response to the restrictions is currently limited, some insights can be gained from examining historical embargo cases. Several states have maintained or developed air forces under embargo in some form since the 1920s to the present day.[16] The below framework (Figure 1) seeks to encompass how states and their air forces can respond to these restrictive measures. The different coping strategies and tactics are explored in more depth below, drawing on historical examples from the Cold War and beyond.

The framework includes coping tactics that are associated with broader dependency or self-sufficiency strategies. The precise dividing line between the two types of strategy is blurred, since even states that produce aircraft or spares domestically are likely to rely on imports of components and other constituent parts. States pursue multiple coping tactics – and sometimes both strategies – in their response to an embargo. The framework is illustrative in nature, rather than practical or predictive. Figure 1 defines the tactics, associating them with dependency or self-sufficiency strategies. It also outlines the embargoed states' required technological capacity to implement these tactics, and whether they are pursued before or during the embargo period.

Dependency strategies assume some continuing dependence on outside supply. This would either be a result of a deliberate choice, or more likely, necessity due to low technological capability. The tactics relating to continued dependency are ordered from less to more technologically complex – and from those involving less to more technological risk. All air forces stockpile parts to a degree. However, the stockpiling tactic assumes foresight of a potential embargo and intention to minimise the effects, or otherwise lucky decision-making before an embargo is implemented. Bringing in external expertise can help to reduce risks. Looking to black markets for spare parts is inherently risky – as the quality of spares is far from guaranteed. Procuring new aircraft could also be riskier since it would involve mastering the maintenance of a new type of airframe and related systems.

Self-sufficiency strategies – involving the development or use of domestic capability to counter the embargo – require a higher level of technological capacity. Tactics focusing on developing advanced capability domestically include developing the ability to maintain aircraft by domestically manufacturing spares, replicating, or attempting to replicate existing designs (perhaps through obtaining a manufacturing licensing agreement), updating or overhauling existing airframes, and innovating by developing new aircraft. These, like the dependent coping strategies, are listed in order of greater technological complexity, required technological capability, and increasing technological risk.

Timeframe	Technological Capability of State	Coping Strategy and Tactics		Explanation
Before embargo	Basic		Stockpile	Stockpile spares prior to the embargo
During embargo	↕	Dependency: Continued dependency on foreign design, development, manufacturing, and supply	Cannibalise	Cannibalise older and damaged airframes
			Procure	Look for new suppliers for spare parts
				Bring in expertise by enticing foreign technicians
				Scour black or grey markets for spares
				Look for new suppliers for aircraft
		Self-sufficiency? Development of enhanced capabilities domestically	Maintain	Develop (or use) the capability to produce spares domestically
			Replicate	Develop (or use) the capability to replicate existing designs
	Sophisticated		Innovate	Develop (or use) the capability to design and produce new aircraft

Figure 1: How do Air Forces Respond to Embargoes?

Case	Dates	Embargo(es)	Technical capability
Rhodesia	1966 – 1980	UN arms embargo	Low
South Africa	1966 – 1994	UN voluntary (1966–) and mandatory embargoes (1977–1994)	Medium
Iran	1979 – present	US arms embargo 1979 – present; UN embargo 2010–2020; other unilateral restrictions	Medium
Iraq	1990 – 2004	UN arms embargo	Medium
China	1950s – present	Cold War Western export controls (CoCoM from 1949–1994; CHINCOM 1952–1957); sporadic export controls since the 1990s	High
Russia	1920s – present		High

Figure 2: Summary of Illustrative Cases

Responses falling under the self-sufficiency strategy and tactics would be more applicable to the modern Russian case, with the country long having the capability to manufacture combat aircraft and an air force largely composed of Russian manufactured aircraft. This will make Russia far less vulnerable to an embargo than some of the cases that mainly pursued a dependency strategy discussed below. However, as will be explored, Russia is also likely to be pursuing dependency strategies and tactics such as cannibalization and seeking technology from the international market to sustain its aircraft production lines.

To illustrate the framework, several historical cases are discussed (see summary in figure 2) in the following section. These cases are diverse in several ways: in terms of technology, the Rhodesian de Havilland Vampires and Hawker Hunters are incomparable to the technological complexity of the aircraft that South Africa, Iran, and Iraq operated in the 1980s – let alone those that Russia and China are seeking to manufacture and operate today. Russia and China are capable of manufacturing combat aircraft, unlike Iran and Rhodesia who were largely dependent on a single supplier (the US and the UK respectively) when the embargo came into place.[17] Furthermore, states' capability requirements vary drastically – from Rhodesia's air support for an internal counterinsurgency campaign, to South Africa and Iran's regional security concerns, to Russia and China's high-technology competition with the US and allies.

The embargoes that these states faced were also different. Some, such as South Africa, Iraq, and Iran (2010-2020) faced universal UN sanctions that were legally binding on all states. Others were subject to multilateral embargoes implemented by a range of states through collaborative mechanisms such as CoCoM. Others have just faced sporadic and *ad hoc* Western export controls. What all the cases have in common, however, is that no single embargo has ever been fully implemented and 'watertight'. Technology – to different degrees – is always able to seep through the gaps.

Air Force Coping Strategies: A Historical Survey

Cases from the Cold War and beyond are used to illustrate the coping strategies and tactics outlined in the framework.

Strategies Emphasising Dependency

Air forces that are dependent on external suppliers suffer the most under embargoes, with issues in maintaining operational aircraft – often increasingly historic fleets – and avoiding risk to prevent further depletion. Strategies emphasising continued dependency involve the embargoed air force scraping together the parts and expertise to keep these air frames operational and seeking new aircraft when possible.

Stockpile. Before the embargo, states may either instinctively stockpile spares, envisaging an embargo in response to their future actions, or fortuitously over-order. The Islamic Republic of Iran Air Force (IRIAF) inherited large stockpiles of spare parts procured during the 1970s as part of the deals to purchase F-4, F-5, and F-14 aircraft under the Shah.[18] US government sources suggest that the limited organisational capacity and challenges of technological absorption meant that Iran faced huge difficulties in keeping track of spares. As an unnamed US official allegedly noted in 1989, fortuitously for Iran, 'The Iranians are constantly finding warehouses filled with spare parts needed for American equipment'.[19]

Cannibalise. When spare parts start to run out, air forces will cannibalise from existing airframes, removing working parts from aircraft that have the most technological problems. Like stockpiling, this is not a strategy only used by states under embargo. Indeed, cannibalised airframes – sometimes referred to jokingly as the 'squadron Christmas tree' – are a common feature at many airfields around the world. Some states also retain older airframes in 'boneyards' for cannibalization purposes, as well as storage for future contingencies. Air forces may also cannibalise when facing supply chain issues, or when systems start to age with airframes and systems starting to degrade, and it is economically unviable to manufacture new spare parts.

As the IRIAF struggled to find the necessary spares, the organisation started to cannibalise. A May 1980 CIA report noted 'Because of a severe shortage of spare parts and inadequate maintenance, the Air Force has been forced to cannibalize many of the F-14s'.[20] An assessment in 1984 noted that of 150 non-operational fighter aircraft: 'Most of these aircraft have been cannibalized and are strewn around Iranian airfields... the Iranians have nearly exhausted the spare parts available on cannibalized aircraft'.[21] Cannibalisation clearly becomes more extensive and a more crucial tactic when maintaining an air force under embargo.

Procure – External expertise. Dependent air forces under embargo also become more heavily reliant on engineering ingenuity and creativity to keep their aircraft airworthy. In Rhodesia, 'the Canberras were kept flying mainly by the ingenuity of the Rhodesian engineers'.[22] Where expertise was not available domestically, states sought it elsewhere. Rhodesia allegedly relied heavily on companies and expertise in South Africa, their sanctioned neighbour, for more taxing maintenance work.[23] South Africa similarly relied on international expertise – with 10% of the 6,100 personnel workforce of its largest aerospace company, Atlas Aircraft Corporation, allegedly being foreigners in the late 1980s.[24] As discussed below, the country also relied on Israeli expertise in some of its upgrade efforts.

Other states have looked to bring in engineers from outside of the country. Iran, for example, allegedly brought in 120 foreign engineers from the Philippines, South Korea, Taiwan and 'at least one West European country' – all states with experience operating F-4 and/or F-5 aircraft.[25] Iran also needed to replace the expertise provided by the 800 American Grumman engineers based in Iran in the late 1970s that had departed around the revolution, and the US-based engineers that maintained the most sensitive parts of the F-14 – a labour intensive aircraft requiring 50 hours of maintenance for each hour flown.[26] Allegedly, Iran later brought in Soviet, North Korean, and Pakistani engineers to maintain the Iraqi aircraft transferred by Saddam Hussein for 'safekeeping' on the eve of the Gulf War.[27]

Procure – Spares from state suppliers. Air forces will also procure spare parts from witting suppliers – states that are open to an approach, unconcerned about the embargo, or willing to supply in an exchange. Embargoes – and their implementers – work to reduce the pool of these types of suppliers. In the case of Iran, a request lodged by Iran with the US for further spare parts in 1981 was turned down.[28] However, Iran allegedly did manage to procure some spares for the F-4 aircraft from the Israeli government.[29] This account was later confirmed when a F-4 was landed in Saudi Arabia by a defecting pilot. Subsequent analysis of the airframe showed that the Iranian aircraft included components originating from Israel, among those that had likely been illicitly procured from other NATO member states.[30]

South Africa had to find new suppliers as the number of states willing to supply in the face of UN embargoes decreased. The UK stopped supplying spares in 1963, so South Africa turned to France, who continued to honour contracts for spare parts even after deciding to stop supplying aircraft when the mandatory UN embargo came in during the late 1970s.[31] A more recent case suggests that states willingly supplying aerospace technologies to embargoed states may not be a thing of the past. In 2013, a North Korean ship was stopped in Panama carrying a cargo which included MiG-21 engines and fuselages from Cuba. This was the latest of a string of incidents where North Korea had sought to get hold of retired MiG-21 aircraft and spares from other states – including allegedly through a visit to Russia by the North Korean air force chief.[32]

Procure – Spares from black or grey markets. States under embargo frequently turn to black or grey markets to procure spare parts and technologies for their military programmes – including to maintain aircraft.[33] This is slightly different to the procurement from states, involving deception of, or reliance on unscrupulous private suppliers to breach the embargo. Procurement often takes place through third country hubs and complex supply chains, where the identity of the embargoed end-user is obscured.[34] This helps to alleviate supplier concern and makes illicit shipments more difficult for export controllers or intelligence agencies to identify.

A 1984 CIA report highlights Iran's use of illicit procurement to obtain spare parts. It noted, 'Iran has been able to secure some avionics and electronic equipment but usually at inflated prices and through circuitous channels... Many parts are ordered simply by contacting companies listed in the Swiss defense publication *Interavia*'.[35] During the 1980s, Iran's main external source of F-14 spares was – ironically – the US Navy. A smuggling network was uncovered in 1985 that had tapped straight into the Navy's supply network. The network stole F-14 parts from 1981, with insiders on three aircraft carriers overordering around $25 million of parts to transfer to Iran.[36]

In the African context, Rhodesia relied on black market spares in the 1960s and 1970s – particularly seeking engines for its Hawker Hunters.[37] There is also evidence that South Africa turned to the black market. In 1987, the US government indicted five individuals – including two based in Florida – for shipping aircraft parts to Iran and South Africa. The network had sent 79 shipments worth $2.4 million to the South African Air Force over the previous seven years – mostly parts for their C-130 Hercules aircraft.[38]

Procure – Aircraft. Embargoed air forces will seek to procure complete aircraft from the relatively limited number of states capable of construction of combat aircraft. While embargoes will limit the options open to states, they often do not close down options completely, especially when embargoes are laxly implemented or not legally binding on all states, such as those put in place by the UN Security Council. South Africa, for example, was able to procure Mirage IIIs from France during the period of the voluntary UN embargo.[39] Other unique circumstances have provided aircraft of questionable condition. For example, the Iraqi aircraft moved to Iran on Saddam Hussein's instruction on the eve of the Gulf War.[40]

Other states successfully managed to procure numerous aircraft illicitly. Rhodesia, for example, procured a wide range of light aircraft and helicopters throughout the late 1960s and 1970s. In the 1970s, illicit procurement saw the Rhodesian air force expand massively.[41] The procurements allegedly included as many as 20 Cessna-Reims FTB-337, 14 Britten-Norman Islanders, 11 Agusta-Bell 205A helicopters, 22 SIAI-Marchetti SF.260W Warriors and even several Rockwell OV-10 'Bronco' aircraft.[42] These were procured by circuitous routes through third countries, either flown or transferred disassembled in crates.

Dual-use and/or second-hand aircraft markets provide good opportunities for embargoed states. With aircraft able to easily move around, historically, they have been notoriously difficult for states to track. Many of the aircraft acquired by Rhodesia were civilian light aircraft that could be used in counterinsurgency operations. Rhodesia largely had air superiority during the conflict, and therefore did not need highly capable aircraft that would have been required in other contexts.

Strategies Emphasising Self-Sufficiency

Several states have pursued self-sufficiency strategies and tactics, either spurred on by, or in the face of arms embargoes. These states are either more technologically capable or aspire to be.

Maintain (indigenous parts). Embargoed states frequently attempt to manufacture their own spare parts. The complexity of such an effort increases with the technological complexity of the aircraft operated. The South Africans were able to manufacture spare parts for many of their aircraft under embargo. By 1979, they were allegedly self-sufficient in producing all spares for their French manufactured helicopter fleet.[43] By the late 1980s, the country claimed it had developed the ability to produce jet engines, but still needed to import titanium for this purpose.[44] States capable of producing parts indigenously will still likely rely on imported sub-components, materials, or manufacturing equipment. This is true in the contemporary Russian case.

Throughout the four decades under various embargoes, there has been significant debate about Iran's ability to manufacture spare parts domestically. The IRIAF Chief noted in the mid-1990s that the organisation had 'reached self-sufficiency in all fields, including pilot training, missiles, radar, air defense, maintenance and repair, manufacture of parts and basic repair of facilities'.[45] US experts disagreed with these assessments.[46] Nevertheless, Iran's current ability to keep a range of systems airworthy certainly suggests some level of self-sufficiency.

Replicate (new air frames – foreign designs) and modify. Embargoed states with limited technological capacity often attempt to replicate foreign-designed systems – either with or without consent. Licensing production of aircraft in a sanctioned country has long been used by aircraft producing states as a means of avoiding backlash for breach of arms embargoes. South Africa's entry into aerospace manufacturing from the 1960s was through the construction of counterinsurgency and light aircraft using Italian and US technology, and the indigenous assembly of French Mirage I jet aircraft.[47] Industrial espionage has also provided payoffs for some states cut off from Western technologies.

Overhauling existing systems indigenously, or with some external support, has also been a tactic of embargoed states without the capability to design and build new systems. In the 1980s, South Africa redesigned and overhauled the Dassault Mirage III aircraft provided by France in the 1960s and 1970s to create the Cheetah, while benefitting from Israeli technology and support. There is some disagreement over the division of labour between South Africa and Israel, and the location where the upgrade work took place.[48] Iran has also taken steps to overhaul some of its F-5 aircraft to create its HESA Kowsar system.

Innovate (new designs). Only a small number of countries can design and produce new types of combat aircraft. This has been done by highly technologically capable states that have faced restrictions. For example, Russia and China have developed domestic capabilities to build jet aircraft since the 1940s and 1970s respectively. They faced various sanctions, embargoes, and restrictions on access to Western technology during this period. They have nevertheless been able to rely on imported materials and components when necessary. The exponential increase in the complexity of weapons systems – and modern combat jets representing one of the most complex modern weapon types – has called into question the ability of China to compete with US and Western technological advances in aircraft production.[49]

Embargoed states have claimed to have produced indigenous aircraft designs, often to feed into narratives of self-sufficiency and techno-nationalism. For example, counter to much analysis that suggests the Cheetah was a French Mirage III upgraded with Israeli support, the South African Defence Minister claimed the aircraft was 'our very own fighter' and the country was 'entering a new era of self-sufficiency'.[50] Similarly, the HESA Kowsar was declared by Iran to be '100-percent indigenously made'.[51]

As with states manufacturing spare parts, or overhauling systems, states that can design and develop new aircraft are unlikely to produce all the technology domestically. Supply chains in the modern defence and aerospace are dispersed and transnational in nature. The F-35 programme led by prime contractor Lockheed Martin – one of the most technologically capable companies in the most developed economy on earth – benefits from a transnational supply chain spread across several states. In short, a truly 'indigenous' aircraft programme does not exist. The challenging nature of developing and manufacturing new systems, particularly those that can compete with the most advanced capabilities such as those fielded by the US and NATO militaries, is already hugely challenging for states, let alone those cut off from dual-use technologies in the international market.

The Russian Wartime Air Force Under Embargo: 2022 – ?

The above framework provides insights as to how states and their air forces have historically responded to sanctions. What does this mean for the Russian case? Russia has long had the capability to design combat aircraft, and a significant military industrial base to maintain its systems domestically. It has built up these capabilities throughout the Cold War, whilst under the CoCoM embargo that prevented the transfer of certain goods and dual-use technologies at different points. In this regard, Russia pursues the self-sufficiency strategies outlined above. The Russian case, therefore, is unlike most of the examined cases, which primarily due to necessity, had to pursue dependency strategies.

However, Russia will also pursue some of the dependency strategies due to a combination of wartime pressures, the embargo, and the Russian aircraft industry's continued dependence on foreign-sourced components for some aircraft and weapons systems. This includes illicit procurement from the international market. There is also some evidence of cannibalisation, largely in the Russian civil aviation sector. However, it is also likely to be occurring at a heightened level in the VKS due to the wartime pressure and the routine nature of the practice in peacetime. Import substitution efforts have also been attempted over the past decades in direct response to the embargoes, and to move more of Russia's aircraft production capability towards self-sufficiency and reduce dependency.

Wartime Pressures

The challenging wartime situation in which the VKS finds itself is compounded by the embargo – but also stems largely from the pressures of the conflict itself. The VKS has lost over 60 fast jet aircraft as of January 2023, out of a force of around 350 deployed for operations in Ukraine.[52] It has also lost over 60 helicopters, including at least 40 attack helicopters.[53] Beyond lost air frames, it is highly likely that stocks of weaponry, munitions, and spare parts are running low. The military industrial base is also under great pressure to manufacture replacement parts and replace lost aircraft.

The VKS is clearly under stress, as several accidents involving Su-25, Su-30, and Su-34s outside of combat situations in recent months suggest. As Justin Bronk and others have noted, 'Each one may be individually explained by bird strikes, pilot error or technical failures. However, collectively they suggest that eight months of war have taken a toll in terms of accumulated airframe and aircrew fatigue'.[54] The VKS has also lost 25 examples of the Ka-52 attack helicopter – the greatest of any one helicopter. As Bronk and his colleagues note, 'Multiple Ka-52 airframes have also been recovered after being shot down in a condition that suggests poor maintenance and crew training are problems'.[55]

The conflict situation – and increasingly, Russian military failures – puts the VKS under pressure to deliver while operating far above pre-war assumptions. On aircraft, the periodic maintenance checks undertaken in peacetime likely collapsed in the early weeks of the war for the operational force. Small technical issues that would be resolved through routine maintenance are likely to be going unsolved, with aircraft being given permission to fly on a sortie-by-sortie basis. This is in some sense a 'slippery slope'. As more failures are accepted, the eventual maintenance burden grows, unless the air frame is run into the ground and cannibalised.

Coping with Dependency

The main pressure on the VKS currently stems from the conflict rather than the embargo. Nevertheless, the embargo compounds the challenges and will have the greatest impact in the longer-term. Certain aircraft operated by the VKS will likely have a greater dependency on Western components for maintenance or production. Some models of Russian aircraft have allegedly benefitted from French technology that was transferred because of contracts drawn prior to the 2014 EU arms embargo and delivered after it came into place. This has allegedly included navigation systems, cockpit display screens, viewfinders installed in Su-30s, and navigation systems and helmets for use in MiG-29.[56] French companies also allegedly transferred electro-optical infrared systems for Ka-52 helicopters.[57]

Other aircraft communications systems are also apparently highly dependent on Western technology. For example, the Ilyushin-76 transport plane included a communications suite that contained 80 foreign-origin parts that could not be replaced with those manufactured in Russia, according to a Russian report obtained by Ukrainian intelligence.[58] A similar report from 2017 on proposed helicopter mounted radio-jamming equipment showed that only 242 of the 921 required foreign components could be replicated by Russian manufacturers.[59]

Evidence of Russian dependency on Western components obtained from wreckage recovered off the battlefield is slimmer when it comes to aircraft. Fewer aircraft have been shot down or crashed than pieces of ground equipment have been abandoned, and there is also less aircraft wreckage than missile debris available for analysis.[60] Also, the types of aircraft that Russia has lost the most frequently, have tended to be less advanced models (such as the Su-25 – the single fixed-wing aircraft type that the VKS has lost in the greatest numbers). Therefore, they are likely more dependent on Russian domestically produced components. However, wreckage of a Su-24M targeting system analysed in December 2022 was found to be rich in Western microchips.[61] Also, UK-based NGO, Conflict Armament Research, has found that non-Russian components were used in part of the on-board computer systems used in the Ka-52 attack helicopter.[62]

To maintain foreign-manufactured systems, and VKS aircraft more broadly, as well as manufacture new airframes, there is evidence that Russian procurement agents are looking to the international market for components. An unsealed US indictment from September 2022 alleges that in 2019, Russian nationals working through a German-based company approached US businesses for assistance in procuring technology. This included 'tactical air navigation interrogators', 'multi-mode receivers' and 'radiation-hardened, military-grade two-terminal temperature transducers' allegedly for use in Sukhoi fighter jets, with a Malaysian 'shell entity' listed in paperwork as an end-user.[63] While this specific procurement attempt was not successful, the network did procure over $250,000 of unspecified goods between 2018 and 2020, some of which were allegedly recovered from the battlefields of Ukraine.

While systems are likely being cannibalised at a higher rate than in peacetime to meet wartime needs, evidence in the military realm is difficult to come by. The immediate impacts have been clearer in Russian civil aviation where near to 80% of Aeroflot's fleet is composed of US-manufactured Boeing and European-manufactured Airbus aircraft. Reporting suggests that Russia started to cannibalise jetliners for spare parts over the summer of 2022, following government guidance to keep two-thirds of the fleet operational by the end of 2025.[64] Indeed, a senior Russian transport official noted in July 2022 that Russia had three to four years for import substitution in the aviation sector.[65] Russia is planning a licensing system for the cannibalisation of civil aircraft spares, which may be introduced in 2023.[66]

The degree to which supply-chains – both domestic and illicit overseas – are under stress likely relates to the amount of notice that VKS and defence industry planners were given before the 'special military operation' commenced. Reporting has emphasised the lack of notice given to other elements of the Russian military in advance of the invasion.[67] This stress has likely put pressure on the Russian procurement apparatus to certify a broader range of components for use by Russian defence companies. The certification process for defence electronics is undertaken by the All-Russian Research Institute of Radio Electronics, including components for manufacturing, repairs, upgrades, and experiments.[68] Furthermore, holographic stickers of the Federal Security Service (FSB) sword and shield logo have been found on some components.[69]

Enhancing Self-Sufficiency and the Future of Russian Air Power

The Russian government and industry have heightened import substitution efforts for military aircraft – particularly for electronic components – given their dependence on foreign-sourced technology and the arms embargo since 2014. These efforts have sought to move more of Russia's aerospace supply chain from dependency towards self-sufficiency. Putin made a key speech on speeding up import substitution in the military domain in a July 2014 meeting with industrialists close to Moscow. He noted:

'The questions which we are discussing are – without a doubt – key questions for Russia's military and economic security, our technological and manufacturing independence, [and our] technological sovereignty. Our objective [is to] protect ourselves from the risks of non-fulfilment of contracts by our foreign partners, this includes risks of a political character'.[70]

The following year, a state commission on import substitution was established, with a sub-commission focusing on military sectors.[71] This substitution effort responded in part to access to Ukrainian and Western technology being cut off because of the 2014 seizure of Crimea and invasion of Eastern Ukraine.[72]

In 2018, Deputy Prime Minister Yury Borisov noted that supply problems because of losing access to Ukraine's industry had been overcome – citing examples related to helicopter engines and ship gear boxes.[73] In 2019, Putin noted five years of import substitution had enabled Russia to advance self-sufficiency in several areas, with the production of 350 weapon systems relying solely on Russian technology. Meanwhile, Defence Minister Sergei Shoigu noted that Russia would continue to develop technologically independent weapons systems regardless of Western sanctions.[74] The Russian impetus for import substitution has increased, given the response to its heightened aggression in Ukraine in 2022. In September 2022, at a meeting with Russian defence industry, Putin stated: 'Within the military industry, we need to conduct a full [100%] import substitution and not lower the quality of Russian technical production [products]'.[75]

While Russian sources – particularly those citing Russian officials – suggest great success in import substitution, such efforts appear to have provided limited returns, particularly at the high-end. Russia continues to struggle with domestic production of screens and displays, optics, and high-end chips for its aircraft and related weapons systems. The VKS systems and projects that will be most affected by Western sanctions are those that are most advanced – whether more advanced in-service aircraft, such as the Su-35, or newer systems still under development. These systems are more likely to include foreign-sourced components and utilise foreign-sourced manufacturing technology such as high-specification computer numerically controlled machine tools.[76] Challenges in procurement will compound already existing problems in newer projects, such as the next-generation Su-57 multirole jet fighter, and the Su-70 stealthy heavy unmanned combat aerial vehicle (UCAV).[77]

Russia's ability to replace airframes lost is limited. For example, in 2017, prior to the 2022 full-scale invasion, the Komsomolsk factory planned to 'deliver' ten Su-35S in a year.[78] But there is no evidence of Russia's aircraft factories grinding to a halt, as was allegedly seen in other parts of the Russian defence industrial complex early in the war.[79] Three new Su-35S aircraft were delivered as recently as September 2022.[80] Russia's slow rate of production means that losses have exceeded the defence industry's ability to replace them. However, the slow production rate also means that a minimal stockpiling of the relevant foreign-sourced components would take a while for Russian industry to burn through before any halts in production. There is also potentially time for Russia's procurement networks to undertake targeted procurement efforts to keep production going.

The above analysis – and the VKS's struggles through the conflict in Ukraine and the related embargoes – leads to bigger questions surrounding the future of Russian air power, particularly because the embargoes will likely have the greatest impacts on the more advanced Su-57 and Su-70 programmes. Whether the war in Ukraine ends in the short-term, or continues for years, the arms embargo and sanctions are likely here to stay as the US, NATO, and allies seek to prevent Russian rearmament and future aggression. How far will the war and the embargo set back Russian air power in the longer-term when it inevitably impacts higher-end plans?

A key factor will be the medium-term decisions of China, which amid warnings from the Biden administration about breaching sanctions, has not yet openly supplied weapons to Russia.[81] Some transfers of dual-use technologies with potential military applications by Chinese companies have been detected.[82] When the war in Ukraine ends, with Russia under Western embargoes for the foreseeable future, would China potentially provide technology of use to the VKS? China can produce some of the technologies that Russia has struggled with domestically, such as chips, displays, radars, targeting pods, and Precision Guided Munitions.

Russia has sought to strengthen its relationship with China in recent months, due to its increasingly isolated diplomatic position since the February 2022 invasion. It has also sought military technologies from other willing suppliers such as Iran and North Korea.[83] In the medium-term, China could have an interest in occupying US and Western military power in Europe to counter the continuing threat posed by Russia. Any transfers of military technology between China and Russia – and concerns over shortfalls in the new US export controls on the provision of semiconductor technology to China – could incentivise the development of a new broader US-led multilateral export control arrangement to prevent further technology leakage to Russia and China.

Conclusion

This paper has considered the impact of the arms embargo and technology-based sanctions on Russia and the VKS during and after the war in Ukraine. It has outlined the effects of arms embargoes on air forces and presented a novel typology of how they respond to restrictions using both dependency and self-sufficiency strategies and tactics. These included: approaching new suppliers for spare parts and new aircraft, scouring black markets for spare parts, cannibalising older and damaged air frames, and building up an indigenous defence industrial capability. The paper has used a variety of historic cases from the Cold War and beyond to illustrate these strategies and tactics.

Building on this historical analysis, this paper has considered the contemporary Russian case. It examined how the VKS is likely to navigate and respond to the challenges of the various arms embargoes and export controls placed on Russia since its 2022 illegal invasion of Ukraine. It argued that the pressures that the VKS is currently facing due to the embargo are likely minimal relative to the stress of operating far above pre-war assumptions during the war in Ukraine.

Russia – unlike many of the historic cases considered – has long been proficient in the design and manufacture of jet aircraft. However, there is evidence that the Russian defence industry is still dependent on foreign sources for defence electronics and manufacturing technologies. Russia has clearly resorted to illicit procurement networks to acquire these technologies – essentially using similar means and *modus operandi* that the Soviet Union used throughout the Cold War.

The embargoes and export controls currently in place will likely influence Russia's ability to replace its lost aircraft and manufacture weapons in the medium-term. However, any stockpiles of components may take some time for Russian industry to exhaust, especially given the slow pace of production of new aircraft. This may provide time for targeted illicit procurement efforts to alleviate some of the strain on supply chains. However, the perpetual uncertainty surrounding the ability of these illicit supply-chains to deliver will undoubtedly cause problems in the longer term.

Beyond replacing lost systems and used weapons stocks, the embargo will have a greater effect on the higher-end next-generation projects such as the Su-57 and Su-70 programmes, which are already progressing at a slow pace and facing many issues. This will limit the prospects for Russia and the VKS to come anywhere close to being able to compete with the US and NATO militaries in the future and will likely – along with the effects of the war – have a huge impact on the future of Russian air power.

More broadly, examination of the historical cases – as well as the contemporary Russian one – in this paper has provided some lessons regarding the opportunities and challenges for using arms embargoes to counter air power. Arms embargoes are more difficult for states and their air forces to contend with when their technological capacity is low. They are also more likely to have an effect when the systems that states are seeking to develop, manufacture, or maintain are more technologically complex. Greater levels of sophistication mean fewer opportunities to cannibalise, procure, and even copy or innovate.

The picture, and prospects for countering the flow of technology, however, are not entirely positive. The historic cases discussed highlight the creative and entrepreneurial ways that air forces have responded to embargoes. They also show that embargoes – whether heavily or lightly implemented and enforced – almost always allow technology to leak through. Greater efforts to implement export control will undoubtedly have some effects on stemming the flow of technology, but no embargo has ever been watertight.

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The Freeman Air and Space Institute is an inter-disciplinary initiative of the School of Security Studies, King's College London. The Freeman Institute is dedicated to generating original knowledge and understanding of air and space issues. The Freeman Institute seeks to inform scholarly, policy and doctrinal debates in a rapidly evolving strategic environment characterised by transformative technological change which is increasing the complexity of the air and space domains.

The Freeman Institute places a priority on identifying, developing and cultivating air and space thinkers in academic and practical contexts, as well as informing, equipping and stimulating relevant air and space education provision at King's and beyond.

The Institute is named after Air Chief Marshal Sir Wilfrid Freeman (1888–1953), who was crucially influential in British air capability development in the late 1930s and during the Second World War, making an important contribution to the Allied victory. He played a central role in the development of successful aircraft including the Spitfire, Lancaster and Mosquito, and in planning the wartime aircraft economy – the largest state-sponsored industrial venture in British history.

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