Command of the Skies: An Air Power Dataset

Abstract

We introduce a dataset on air power. Air power is the ability to inflict damage on an adversary through the air, and its successful application depends on achieving command of the skies. To achieve command of the skies, countries invest in a variety of types of military hardware and training, especially fighter aircraft. Our dataset contains information on the number, type and technological characteristics –including weaponry, avionics, speed, maneuverability and stealth characteristics –of each country's fighter and attack aircraft for the period 1973-2013. We also introduce two new air power variables based on this data. The first is Country Air Power (CAP), a country-year measure of air power. The second is Expected Air Superiority (EAS), a dyad-year measure of which actor is likely to achieve air superiority in a military conflict. We illustrate the utility of this dataset by examining the relationship between air power and militarized dispute initiation, the duration and success of coercive bombing campaigns, and coercive behavior more generally. We find that command of the skies significantly affects conflict and coercive behavior.

"For the foreseeable future, the only really effective counter to an aircraft is another aircraft."
- John Warden, 1988

Command of the skies, or air superiority, is a central element of military power, military strategy, and victory in war. Accordingly, all countries or groups contemplating military operations aim for air superiority or to fashion a strategy that neutralizes an adversary's air power advantage. International relations scholars, however, have paid relatively little attention to air superiority. In a recent review of empirical work on air power the phrases 'air superiority' or 'command of the skies' are not mentioned (Martinez Machain, 2017). Instead what little work there is on air power focuses on bombing (e.g. Pape, 1996; Horowitz & Reiter 2001; Allen 2007; Allen & Vincent 2011; Martinez Machain 2015; Allen & Martinez Machain 2017, 2018) and/or drones (e.g. Horowitz et al, 2016). One likely reason for the neglect of air superiority and the focus on bombing campaigns is that there are no datasets on the former but there are on the latter. In this research we present a new dataset on air power and present several applications to show its utility to the international relations research community.

Air power is the ability to inflict damage on an adversary through the air, and its successful application depends on achieving air superiority or command of the skies. Air superiority enhances both offensive and defensive military operations, improves an actor's ability to mass firepower against an adversary and is often a central aspect of combined arms operations. These principles are key to achieving or stopping a battlefield breakthrough as the success of the German blitzkrieg in the early years of World War II shows as well as its failure against the Soviet Union in 1942-43.[1] Similarly without air superiority or command of the skies, neither strategic nor tactical bombing is likely to be effective. One's bombers will simply be shot

[1] For a discussion of air power on the Eastern Front in World War II see Overy (1980, 1995) and Glantz and House (2015).

down. In World War II, German bombing raids that lacked fighter escorts were called 'Stuka parties' by the Royal Air Force (MacIsaac, 2018). It is also instructive to note that air superiority was a necessary prerequisite for every one of the bombing cases in Pape's (1996) classic study. It may be too much to say, no air superiority, no bombing, but it is not too much to say no air superiority, no *effective* bombing. More generally, without command of the sky, a conventional military offensive is likely to be repulsed. With command of the sky, an offensive operation is likely to succeed, ceteris paribus. While early air power theorists focused on bombing, shortly into World War II air superiority became, and has remained, the principle goal of an air force (Mcfarland, 1997; Meilinger, 2016).

How does a country achieve command of the sky? The following factors are important: the number and quality of your fighter aircraft, pilot training, aircraft maintenance and parts, weapons supply, force multipliers such as ground or air-based radar, and surface-to-air missile systems. Each aspect is difficult to measure, some more so than others. In this research, we focus on fighter aircraft. First, fighter aircraft have been and for some time will continue to be the most important element in achieving air superiority. "To achieve air superiority little can be done beyond the elimination of enemy aircraft in the air and the suppression of ground-based systems.[2] …If enemy air forces cannot be attacked on their bases, they must be attacked in the air" (Warden, 1998, 66-67). Given the necessity of destroying enemy forces in the air, having aircraft at least as advanced as your adversary's aircraft may well be a necessary condition for air superiority, while the other components of air superiority are augmenting factors. Second, there is likely a positive correlation between superior aircraft and the other components. For example,

[2] Warden consistently refers to lines of supply for fuel, parts, pilots and new aircraft as the ground-based systems that are necessary to maintain an air force.

if a country can afford superior fighter aircraft, it can most likely afford training, maintenance, and force multipliers. The third reason for focusing on fighter aircraft is practical. It is easier to measure and acquire data on fighter capabilities than it is to measure the other components.

The air power data set we propose will be of wide use to international relations and foreign policy researchers. In this manuscript we illustrate the utility of the data for understanding some aspects of coercive behavior –the duration and success of coercive bombing campaigns, the choice of coercive instruments a country employs in a crisis, and the initiation of militarized interstate disputes. Research on the duration and success of coercive bombing campaigns, for example, will benefit from the inclusion of a variable for air superiority. Similarly, by incorporating air superiority we will be able to attain a better understanding of coercive behavior. For example, whether a country chooses to employ ground troops likely depends on whether it can attain air superiority. Further, research on coercive threats will benefit from the inclusion of air superiority, either as a better proxy for the ability to punish a target or to understand when bombing alone is likely to be chosen.

In addition to these topics, we believe our data will be useful for studying the escalation of militarized conflict, war outcomes, arms races, the diffusion of military technology, military strategy, military force structures, coercive behavior and power projection, and possibly as a component in a new measure of military power to name a few topics.

Our paper proceeds as follows. The next section is the heart of the paper. It describes the data we have collected and how we have organized it. In brief, we present data on each country's fighter aircraft for the period 1973-2013. With this data, we create two new variables, *Country Air Power (CAP)*, measured annually, and *Expected Air Superiority (EAS)*, a dyadic variable measured annually. Following the introduction of these data we examine its validity and illustrate its value by examining the relationship between expected air superiority (EAS) and the duration and success of coercive bombing campaigns, the choice of coercive tools and militarized interstate dispute initiation.

Air Superiority

A country's air force consists of an integrated mixture of people, planes, weapons, bases, and, in some cases radars, satellites, and space-based weapons. Our primary focus will be on a country's aircraft. There are many different types of aircraft in a modern air force, with the most important being fighters, attack aircraft, bombers, transport, refueling and other air support aircraft. We focus on fighter aircraft because these are the most important for attaining air superiority.[3]

Air superiority is the "degree of dominance in the air battle of one force over another which permits the conduct of operations by the former and its related land, sea and air forces at a given time and place without prohibitive interference by the opposing force" (NATO, 2017). In other words, air superiority is command of the airspace over the battlefield. Air superiority does not require that one's adversary be incapable of shooting down your aircraft. If this feat were achieved, then one would have air supremacy. Rather, air superiority means that your adversary cannot engage in "prohibitive interference" of your use of the sky. Air superiority is an inherently relative concept. If one country or one side has it, then the other side does not. In

[3] In this definition of fighter aircraft, we also include strike aircraft. While primarily intended for air-to-ground operations, these aircraft have been used as primary air-to-air combatants by minor powers and in limited situations by major powers. Removing those strike aircraft that might not be used in air-to-air combat from the dataset would require a number of judgement decisions on the part of the authors that we do not believe can be justified. Thus, we include all aircraft capable of air-combat, even if not intended to be air-superiority fighters. However, as discussed below, the technological and flight characteristics of attack aircraft limit their value in air combat. Because of this, they enter our technological typology one to two generations worse than fighter aircraft of a comparable technological era.

some cases, neither side attains air superiority. Air parity is the name for this situation. Military practitioners note that, in modern war, achieving air superiority is a critically important military goal. "Indeed, no nation enjoying air superiority has ever lost a war by the force of enemy arms. A commander who tries to win --or not lose --without air superiority is trying to do what no one has ever done before (Warden, 1998, 129)."

Air superiority is considered critical because it enhances a country's offensive and defensive abilities. Once an enemy's fighter and interceptor aircraft have been destroyed, grounded or otherwise neutralized, friendly air forces are able to carry out airstrikes, close air support and other vital war-fighting tasks with near impunity. One's attack aircraft can bomb the adversary's armor, troops, or other key assets. One's bomber aircraft can attack command and control centers and other critical and valuable targets. But without air superiority, one's close air support units, attack aircraft and helicopters, and bombers will be much less effective as they are much more likely to be shot down. With air superiority, an air force can attack an adversary's forces and protect one's own forces from adversary attack. Without air superiority, an air force can do little else to influence the course of the war but attempt to *gain* air superiority so that it can then carry out other tasks.

Practically speaking, air superiority is a near necessary condition for the effective use of other aspects of air power, particularly bomber aircraft. Previous analyses have found that bombing campaigns are most effective in bringing about the target's compliance with coercive demands when the bombing campaign is very intense in terms of sorties per day (Allen & Vincent 2011), when bombing is selective in terms of targeting (Martinez Machain 2015), and when the target is more militarily vulnerable to airstrikes (Horowitz & Reiter 2001).

Maintaining air superiority throughout the bombing campaign is necessary if the campaign is to possess any of these characteristics.

Sustaining a high number of bombing sorties per day in the face of effective defensive fighter cover will be very costly to the attacker. This nullifies the advantage of bombing over other forms of military coercion –the expected relative low costs of a bombing campaign –and will lead to the rapid degradation of the attacker's bomber force, preventing the attacker from maintaining bombing intensity. Similarly, until the advent of modern guided weaponry, selective bombing required dangerous daylight sorties that exposed the bomber force to not only ground-based fire, but more dangerously, to remaining defensive fighters as well, resulting in significant losses among the bomber force[4] (Correll, 2008b). Even in the modern era of precision stand-off weaponry –ground attack weapons that can be launched from beyond the range of the target's land-based air defenses –defensive fighter cover is the only reasonable option for intercepting attacking strike aircraft before they can reach their weapon's launch distance. Finally, air superiority on behalf of either attacker or defender is one of the primary components of military vulnerability to bombing or lack thereof, as defined by Pape (1996).

To attain air superiority, an actor has to destroy the other side's aircraft, either in the air or on the ground. The primary units responsible for attaining air superiority are a country's fighter aircraft. They accomplish this goal by destroying the other side's aircraft in the air, thereby allowing one's attack aircraft to destroy the enemy's ground based defenses as well as aircraft on the ground. By destroying airfields and aircraft on the ground, bombers and attack

[4] For example, according to the Army Air Forces Statistical Digest, 70% of U.S. bomber losses came due to enemy fighter aircraft while Axis forces enjoyed air superiority over Europe (during 1942). During the period in which allied fighters began to win the air-war (roughly 1943), this figure declined to 37% of bomber losses due to fighter action. By 1945, when allied fighters commanded the skies over Europe, only 17% of U.S. bomber losses came by way of enemy aircraft (Office of Statistical Control, United States Army Air Forces, 1945).

aircraft may contribute to air superiority but they are often not able to reach their targets unless friendly escorting fighters are able to defeat or drive away interceptors that the adversary scrambles to protect its assets. Fighters are often pivotal to the success of bombers. With this in mind we propose measures of air power based on the number and combat effectiveness of a country's air superiority fighters.

Air Superiority Aircraft

Creating a measure of country air power is a challenging task, even when we limit attention to air superiority fighters. At the most basic level, air power is a function of the effectiveness and number of aircraft in one's inventory. Fighter aircraft effectiveness, however, is a multidimensional concept. At a minimum it involves speed, maneuverability, size, radar, weapons, stealth, and training. The challenge of dimensionality is also present with naval power, but in that domain, there is one metric that does much to unify the dimensions (Crisher and Souva, 2014). While there is not a similar single metric with air power, there is a widely embraced notion of different generations of fighters. Tirpak (2009) argues that the aircraft design cycle enforces a generational character on fighter technology growth. New fighters incorporate multiple new technologies leading to major leaps in capability. In what follows, we build on Tirpak's (2009) typology of fighters.[5] We do so in two ways. First, Tirpak limits his focus to American aircraft. We incorporate non-U.S. aircraft into the typology. Second, we present a modified typology that takes into account within-generation variance due to aircraft that possess technological characteristics of more than one generation, such as the F-4 and MiG-23 that are typically thought of as late entries in the 3rd generation of fighters, but that made limited use of

[5] Hallion (1990) is the first that we know of to classify fighters by generation. In 2012, the Royal Australian Air Force also proposed a classification based on generations.

technologies generally associated with the fourth generation of fighters, and therefor generally remained in service decades longer than less advanced members of the generation.

Typology of Fighter Generations

Building upon the Air Force classifications, we have created a basic typology that includes seven distinct generations of fighter aircraft, ranging from the most primitive, "generation 0," to the most advanced active aircraft, "generation 5" (see Table 1). Additionally, in keeping with the common classifications used by the U.S. Air Force, we also include in this typology an intermediate step between fighter generations 4 and 5, which we name generation 4.5. We define each fighter generation according to a number of prominent characteristics that heavily influence the combat effectiveness of an aircraft. These characteristics include the sophistication of the aircraft's avionics equipment, the top speed of the aircraft, the presence and sophistication of an aircraft's radar, the range and sophistication of the weaponry commonly carried, and finally, the level of stealth technology employed. The specific requirements for inclusion in each generation of fighters, according to our classification system, are described in the following paragraphs.[6]

Generation 0 aircraft are powered by piston-driven engines and propellers. They carry no radar, and are armed with only cannon, free-fall bombs or unguided rockets. Generation 0 aircraft are best thought of as representative of the primary level of fighter technology available during the Second World War. In our dataset, generation 0 aircraft include World War-era aircraft that saw postwar service such as the North American P-51D "Mustang" and the Douglas

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[6] Unless noted otherwise, the characteristics of all aircraft mentioned in this paper, along with all aircraft recorded in our dataset, have been derived through cross-referencing three commercially available sources: *The Encyclopedia of Military Aircraft* (Jackson, 2009) and *The Encyclopedia of World Military Aircraft* (Donald and Lake, 2000), and The World Encyclopedia of Fighters and Bombers (Crosby 2011).

A-1D "Skyraider," but also include modern aircraft such as the Pilatus PC-9 that are still commonly employed for counter-insurgency operations around the world.

Generation 1 aircraft are powered by early turbojet engines that were introduced in the mid 1940's. Despite the introduction of jet engines, generation 1 aircraft do not achieve supersonic speeds. In addition, generation 1 aircraft carry no radar and are armed with cannon and unguided weapons. Finally, generation 1 airframes are built along a straight-winged plan that approximates the airframe of earlier piston-driven aircraft that is not conducive to high-speed maneuvering. Examples of the type include 1940's-era jet fighters such as the Lockheed F-80 "Shooting Star" and the British-built de Havilland Vampire. A number of generation 1 aircraft are still in service around the world.

Generations 0 and 1 are differentiated primarily by changes to the speed and maneuverability characteristics of aircraft. Speed and maneuver are key components of the within-visual-range air battles that fighter aircraft of these generations must engage in due to the limited range of their guns. The fighter that can outmaneuver or outrun its opponent can clear the skies of the enemy, thus paving the way for friendly strike aircraft to drop bombs while suffering minimal losses or for ground forces to advance without fear of air attack.

Generation 2 aircraft represent a major advancement in weapons technology over their generation 1 ancestors. While still limited to subsonic speeds, generation 2 airframes are built along a swept-wing design that improves maneuverability as an aircraft's velocity approaches the sound barrier. Additionally, these aircraft are the first to include onboard range-finding radar. They are also the first generation of fighters to commonly carry short-range guided missiles in addition to the cannons and un-guided ordinance carried by previous generations. According to our typology, however, the missiles commonly carried by a generation 2 fighter must be effective only within visual range of the pilot and may be guided only by infrared “heat-seeking” sensors. Prominent fighters of this generation include Korean War era aircraft such as the Mikoyan-Gurevich Mig-15 and the North American F-86 “Sabre,” as well as later ground-attack aircraft such as the Douglas A4 “Skyhawk,” which were commonly designed to emphasize slower speed flight and other characteristics that are not conducive to success in air-to-air combat.

Generation 3 fighters are the first aircraft capable of reaching sustained supersonic speeds during level flight. They are also the first fighters to carry guided missiles that are capable of engaging a target beyond the visual range of the pilot. Finally, generation 3 aircraft incorporate electronics advances such as missile illumination radar that first became available in the 1960’s. However, they lack the ability to reliably engage targets below the horizon. Well known aircraft of this generation include the U.S. “Century Series” fighters such as the Lockheed F-104 “Starfighter,” as well as the Mikoyan-Gurevich MiG-21.

While early generations are marked primarily by advances in the physical flight characteristics of a fighter. Later generations are differentiated largely by advances in the range of weapons and in the ability to detect and track enemy aircraft –called situational awareness. Generations 2 and 3 introduce the first missiles, greatly expanding the range at which one fighter can attack another fighter or bomber. Additionally, advances to radar, especially the development of missile illumination radar and missiles that could be guided by radar to a target well beyond visual range significantly expand a fighter’s ability to detect and destroy enemy aircraft long before they could easily engage friendly strike aircraft or ground forces.

Generation 4 aircraft are differentiated from their generation 3 forebears primarily by advances in avionics and electronics. Like generation 3 fighters, they are supersonic aircraft that make use of guided weapons that are capable of engaging targets beyond visual range. Generation 4 fighters, however, combine these technologies with advanced electronic systems such as fly-by-wire avionics, computer-integrated flight control systems, and variable-sweep wing geometry. In addition, advanced pulse-Doppler radar allows generation 4 aircraft to more easily separate targets from ground interference, giving them the ability to engage targets that are below the horizon as viewed from the aircraft in question –termed "look-down, shoot-down capability." Typical aircraft of generation 4 includes the General Dynamics F-16 and Mcdonnell Douglas F-15 "Eagle," along with the Dassault Mirage 2000 and the Mikoyan MiG-29.[7]

As stated above, we follow the U.S. Air Force convention of including an intermediate generation between generations 4 and 5. Generation 4.5 aircraft include a number of post-Cold War fighters that were introduced into service in the late 1990's and early 2000's, such as the Mcdonnell Douglas F-15E "Strike Eagle," Boeing F/A-18E/F "Super Hornet," Dassault Rafale, and Sukhoi Su-35. These fighters are distinguished by the introduction of active electronically scanned array (AESA) radar, as well as by limited supermaneuvrability provided by advances in fly-by-wire flight controls and airframe geometry, as well as the introduction of advances in high-speed agility through the use of forward-mounted maneuvering canards or chines. Limited sensor fusion and limited stealth or intentionally-reduced radar cross-sections also characterize generation 4.5 aircraft.

Finally, generation 5 is differentiated from the preceding intermediate fighters in that many of the technologies that are characteristic of generation 5 fighters are only partially implemented or have met only limited success in the intermediate fighters. Aircraft that should

[7] Assessing advances in avionics and other fighter components is admittedly challenging for a layperson. We rely largely on the use of key terms in describing an aircraft by our technical sources to make judgements regarding the generational classification of an aircraft's components. A more thorough discussion of these coding rules appears in the appendix.

be included in the fifth generation must be characterized by all-aspect stealth technologies, including internal weapons bays and "active stealth" advances, such as radio waveform-cancelling technology. Generation 5 aircraft also see improvements in maneuverability and the development of "supercruise" capabilities due to the introduction of high-powered, thrust-vectored engines. The only generation 5 aircraft found in our dataset is the Lockheed Martin F-22 "Raptor."

Many aircraft, including those listed above, are well-characterized by this system of classifications. However, military aircraft are intended for a wide range of roles and incorporate advances in technology as they become available. As such, a number of the aircraft included in our dataset possess characteristics that defy easy classification. One such example is the well-known Fairchild Republic A-10 "Thunderbolt II." Because it is intended for use as a close-support aircraft, the A-10 is built on a straight-wing plan and cannot reach supersonic velocities. These are two of the primary characteristics of generation 1 aircraft. However, as it was designed alongside the more advanced fighters of generation 4, the A-10 also incorporates advanced weapons, radar and electronic systems more typical of generation 4 aircraft. In this basic typology, when assigning a generation to aircraft that possess characteristics of multiple generations, such as the A-10, we determine the generation of the aircraft by assigning a generational rating to each major characteristic of the aircraft. The components assessed include weapons, avionics/radar, speed/engine-type, airframe/maneuverability, and stealth/observability. We then assign each component to a generation as defined above in order to generate a numerical rating according to the numbered generation to which the component is assigned. Once these ratings are assigned, we decide the generation of the aircraft by taking an average across all categories, rounding all fractions to the nearest numerical generation. Thus, using this procedure, we assign the Fairchild Republic A-10 to the third generation of aircraft. This process is modified in the construction of our second classification of aircraft generations, discussed below.

We apply these classification criteria to all fighter aircraft owned by all states during years 1973-2013. Data on aircraft type are collected from annual publications of *The Military Balance* for each year in the dataset (Military Balance, 1973-2013). We compare each type of aircraft in the dataset to available reference material and assign each aircraft to a generation based upon its characteristics as discussed above. Reference materials used in this process include *The Encyclopedia of Military Aircraft* (Jackson 2009), *The Encyclopedia of World Military Aircraft* (Donald and Lake 2000), and The World Encyclopedia of Fighters & Bombers (Crosby 2011). This classification system comprises our first measure of fighter capabilities and is best thought of as a direct expansion of the Air Force typology to a number of fighters that are not touched upon in the original article (see Table 1).

When fighter aircraft are designed, they are not intentionally fit into the 7-step generational classification discussed above. Rather, they are designed to take advantage of the best technology as it becomes available. Notably different aspects of aircraft technology frequently progress at different rates. This means that fighters produced late in the general timespan covered by a generation often possess some characteristics of aircraft of later generations, if to a limited degree. For example, as discussed above, the F-4 Phantom and MiG-23 –generation 3 fighters according to the basic typology –possess early pulse-doppler radar with limited look-down shoot-down capability. These technologies, once fully matured, would become a hallmark of generation 4 fighters. Further, where early generation 3 fighters such as the F-100 and MiG-21 carry relatively few weapons due to their underpowered engines (2-4 weapons hardpoints in most cases), generation 4 fighters generally carry hardpoints for 10+ weapons. The afore-mentioned F-4 and MiG-23 split this difference with 8 and 6 hardpoints for mounting missiles (Donald and Lake 2000). To account for these within-generation differences in the quality and lethality of aircraft, we have expanded upon the U.S. Air Force practice of inserting a half-step between generations 4 and 5. In our expanded typology, we also include half-steps between generations 1 and 2, generations 2 and 3, and generations 3 and 4. As with the original 4.5 classification, aircraft that fall into generations 1.5, 2.5, and 3.5 include technological characteristics of both of the bracketing generations. Also, like generation 4.5, in most cases, these half-generations represent cases in which later technological advances were only partially implemented or met with limited success. Inclusion of these half-steps allows us to differentiate, for example, between the North American F-100 "Super Saber," which entered service in 1954 and was retired in 1979 –coded generation "3" –from the McDonnell Douglas F-4 "Phantom II," which entered service in 1960 and remained in combat service with the United States Air Force until 1996 due to the use of more advanced technology in its design –coded generation "3.5" in our secondary classification (see Table 1).[8]

Formally, to create this half-step coding we compare fighter characteristics taken from the data sources mentioned above to the five technological categories that were used to code an aircraft's technological generation in the basic typology. Fighter aircraft that possess characteristics of only one generation across the five categories are coded in accordance with that generation. However, aircraft that possess characteristics of two consecutive generations –e.g.

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[8] Historical evidence also suggests a significant qualitative difference between early aircraft of a generation and their later successors. During the 1973 Yom Kippur war, 130 Israeli F-4's, supported by 330 2nd generation A-4, Mystere and Ouragan fighter-bombers engaged 820 3rd generation MiG-21 and Su-7 fighters of Egypt and Syria. The most common estimates suggest that Israeli fighters shot down roughly 200 Egyptian and Syrian aircraft while losing approximately a dozen of their own in air to air combat. While training and skill played a role, the F-4 Phantom was a superior air-to-air fighter than the MiG-21 and Su-7. (Musella 1985)

generations 3 and 4 in the case of the F-4 fighter discussed above –are coded at the midpoint between those two generations.[9]

Monadic and Dyadic Measures of Air Power

We use the data presented in this paper to construct three country-year measures of air power. The first measure is just a count of a country's combat aircraft, labeled *Total Combat Aircraft*. Combat aircraft include fighters, attack planes, and some combat support planes such as electronic countermeasure aircraft. Combat aircraft does not include transports, tankers, or training aircraft. The primary drawback of this measure is that it treats all aircraft as equal; thus, countries with more aircraft will be treated as having more air power. Yet all fighters are clearly not the same. The next measures we present take into account differences in technology.

We name our technology-based measures *Country Air Power (CAP) 1 and 2.*[10] The first, (*CAP1)*, is constructed using the basic typology of fighter aircraft. The second measure, (*CAP2)*, uses the expanded typology. These measures are a function of the type and quantity of a country's air superiority aircraft. To calculate them, we first place aircraft into their fighter generation and count the number in each. Then we take the natural log of the number of aircraft in each generation, exponentiate it to the number of that generation, and sum across all generations. Specifically, for the basic typology we use the following formula:

Country Air Power1 = ln(Number of Generation 0 Aircraft +1) + ln(Number of Generation 1 Aircraft +1) + ln(Number of Generation 2 Aircraft+1)^2 + ln(Number of

[9] Aircraft that possess characteristics of fighter aircraft 2 or more generations apart, such as the Fairchild Republic A-10, discussed above, are very rare in the dataset and are generally indicative of a highly specialized counter-insurgency or close air support aircraft when they do appear, which are notably less well suited to air-to-air combat than are their contemporary pure fighter aircraft. These aircraft are still coded using the process discussed above in the A-10 example by which we assign a generational score to each component and take a rounded average across these generation scores. Thus, in this second classification, the A-10 remains a generation 3 fighter due to being poorly designed for and ill-suited to air-to-air combat.

[10] Summary statistics for these measures as well as the world-share measure discussed below can be found in Table 6 in the appendix.

Generation 3 Aircraft +1)^3 + ln(Number of Generation 4 Aircraft +1)^4 + ln(Number of Generation 4.5 Aircraft +1)^4.5 + ln(Number of Generation 5 Aircraft +1)^5

We take the natural log of the number of aircraft because not all aircraft are usable for combat. Some aircraft will be under repair. Some will be used as trainers. Some aircraft will simply not be able to fly because there are not enough qualified pilots. Simply put, no air force is able to put all of its airplanes into the sky at once or even within a short window. We weight the aircraft by their fighter generation to account for changes in technology. All fighters are clearly not the same. The challenge is to determine how much better some fighters are than other fighters, net of training and other factors. As we discussed previously the differences across generations are multidimensional. There are differences in speed, maneuverability, stealth, and weapons systems. There is no single metric for quantifying differences in air superiority for one dimension, let alone for multiple dimensions. Faced with a multidimensional aggregation problem, we believe it is best to employ a simple model. Simple models are less ad hoc and, in many domains, better at predicting. These considerations lead us to adopt the fighter generation as an exponential weight. Whether this results in a useful measure depends on assessing its content, face, and context validity.

Content validity assesses whether we are measuring key aspects of the relevant concept. From a material perspective the two key factors affecting air superiority are technology and numbers. The measure we propose incorporates both. Higher generation aircraft are more effective than lower generation aircraft. The F-15, for example, has 104 victories in air-to-air combat against aircraft of lesser generations and zero losses (Correll, 2008a). F-14's in Iranian service during the Iran/Iraq War, are thought to have recorded between 130 and 159 victories against 3rd generation MiG-21, MiG-23 and Mirage F-1 fighter aircraft with 1 recorded loss (Cooper & Bishop 2004). Similarly, during exercises in 2006, the 5th generation F-22 was reported to score between 108 and 144 victories against older 4th generation aircraft, with zero losses (Lopez 2006, Fulghum and Fabey 2007). In brief, the combat record between aircraft of dissimilar generations shows that more advanced aircraft are significantly superior to less advanced aircraft.

Nevertheless, air superiority involves more than just air-to-air combat. First, non-fighter aircraft and surface to air missiles (SAMs) also affect an actor's ability to achieve air superiority. Presently, we do not have information on surface to air missiles, but these can often be neutralized by other combat aircraft. Indeed, hunting and destroying SAMs is the primary job of some aircraft.[11] Second, even if a MiG-29 will never be lucky enough to shoot down an F-22, each Raptor can only expend a limited number of missiles before it has to return to base and reload. Thus, if there is a sufficiently large difference in the number of aircraft in a battle then the side with less advanced aircraft may be able either to prevent the more advanced side from attaining air superiority or attain temporary air superiority itself. In commenting on the Iran-Iraq War, Pollack (2002: 213), for example, writes: "By about 1983, Iraq had won air superiority almost by default. Spare parts shortages had crippled the IRIAF [Iranian Air Force] to the point where it could only generate about 10-15 sorties per day on a sustained basis…" despite Iranian possession of more advanced aircraft. To summarize, from a material perspective command of the sky is a function of technology and numbers, and our CAP measures incorporate both.

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[11] Further, during the time-period covered by our dataset, air-launched standoff weaponry generally out-range surface to air missiles. The AGM-86 air-launched missile, for example, was introduced in the early 1980's and ranges at least 600 miles –double the longest ranged test of a surface to air missile to date, which was conducted in 2018 (Macias 2018, United States Air Force 2010). This gives air forces the ability to destroy or dilute enemy air-defenses without being targeted in return. Even in World War II, the Luftwaffe was a larger threat to Allied bombers than anti-aircraft fire (flak) (Overy, 1980).

Table 2 offers insight on the face validity of the new variables. It lists the five most powerful air forces for each measure at ten-year intervals over the forty-year period in our data, 1973-2013. This table allows us to compare the measures and assess the face validity of each. In 1973 if we focus on total combat aircraft one would view both the U.S.S.R. and China as having more powerful air forces than the United States. This continues to be the case until 1993, well after the end of the Cold War and the breakup of the Soviet Union. The United States, however, has the most powerful air force during this time period based on both the *CAP1* and *CAP2* measures. With a fleet of F-15Cs that have never lost in battle, and a host of specialized combat support aircraft, we suggest that it is not plausible to think of the U.S. as having anything but the most powerful air force in the world during the 1973-2013 time period. Further, while the assessment of the top 5 air forces is similar when measuring air power using *CAP1* and *CAP2* (and thus, both measures have more face validity than total combat aircraft), we believe that *CAP2* is the superior measure of the two because it accounts for technological differences within the relatively coarse fighter generations defined in the basic typology.

To provide an example of the importance of this within-generation technological variance, we turn briefly to the 1973 Yom Kippur War. In 1973, at the outbreak of the Yom Kippur War in which Israel went on to achieve air superiority, *CAP1* shows both Egypt and Syria (co-belligerents against Israel) as having individually more powerful air forces than does Israel. Egypt and Syria are ranked as the 6th and 10th most powerful air forces in the world, respectively, while Israel is ranked 16th. This assessment of the relative air power of the belligerents does not stack up with the reality of Israeli victory in the air in 1973. However, when we account for within-generation technological differences by using *CAP2* as our measure of airpower, we see that the airpower advantage belonged to Israel. In 1973, using CAP2, Israel is shown to possess the superior air force (ranked 5th in the world) when compared with Egypt and Syria (rank 11 and 13, respectively). In the Yom Kippur War, Egypt and Syria relied on relatively numerous but technologically inferior MiG-21's against Israel's relatively scarce but technologically superior F-4 Phantom II's. According to the classic fighter typology used in the construction of *CAP1*, the MiG-21 and F-4 are considered identically effective generation 3 fighters, despite the F-4's incorporation of some technological advances more generally considered to be characteristic of generation 4 aircraft. By accounting for the reality of significant within-generation variance in combat effectiveness, *CAP2* is able to accurately predict that Israel held the advantage in airpower in 1973.

To provide a sense of the country air power data we compare it to the Correlates of War National Material Capabilities data (Singer, Bremer, and Stuckey, 1972). Figure 1 shows the correlation between a country's share of world airpower, measured using CAP2, the COW CINC score, and the six component indicators that comprise CINC. A country's air power score has a .76 correlation with its CINC score. Energy consumption and the number of military personnel a country has are the factors most strongly associated with the CINC score. In contrast, military personnel and population more generally have a relatively weak relationship with air power scores while military expenditures have the strongest correlation. Figures 2a and 2b show CAP2 and CINC for the United States, Soviet Union/Russia, and China for the 1973-2012 period. In Figure 2a we see that the United States has had more airpower than either Russia or China in every year since 1973 and has increased its air power advantage starting in the mid-2000s with the introduction of the F-22. Figure 2b tells a different story about military power. Based on CINC scores Russia was stronger than the U.S. from 1973 through 1987, China surpasses the U.S. in 1995 and has been pulling away since the mid-2000s. Because CAP2 only measures air power we do not view it as a substitute for CINC in all applications. However, in one's goal is to measure air power, then we believe CAP2 is a better indicator than CINC. We also think future research should incorporate air power into a broader measure of military power.

Applications

Air Superiority and the duration of bombing

Allen (2007) examines the duration of bombing campaigns, paying particular attention to how regime type affects the duration and success of bombing. We replicate and extend the original analysis by adding a measure of expected air superiority (EAS) Air superiority is an inherently relational concept. One country can only achieve or fail to achieve air superiority over another country. With the CAP2 variable we can create an indicator for each side's expected air superiority. The variable Expected Air Superiority (EAS) is State A's share of world airpower, based on CAP2, over the sum of State A's and State B's airpower shares. Higher values indicate that State A has more air power than State B and is increasingly likely to achieve air superiority and at a lower cost.

We hypothesize that the expectation of attacker air superiority will alter the expectations of both the attacker and target of the costs that will result from a bombing campaign. Attacker air superiority should lead the target to expect to suffer high costs from bombing while, at the same time, the target will be unable to inflict significant costs on the attacker. In the context of Allen's paper this means that when the attacker possesses air superiority, bombing campaigns should be shorter and end in concessions by the target.

Bombing Duration Hypothesis 1: *Bombing campaigns by an attacker who expects air superiority will end in concession by the adversary more quickly.*

The results of this extension appear in Table 3, Model 1. We see that, as an attacker's air power increases relative to the target, the hazard that a bombing campaign will end in the next period also increases –thus EAS can be interpreted as reducing the length of bombing campaigns generally. Findings for all other covariates are substantively similar to those presented for the 1917-2004 analysis in Allen (2007).

As noted by Allen (2007), the initial study treats bombing campaigns that end because the target has given in to aggressor demands identically to campaigns that end because the attacker has given up on achieving her goals. Thus, we do not know if shorter bombing campaigns lead to more successful coercion. We use a competing risks framework to assess whether expected air superiority leads to more effective bombing coercion. The estimates presented in Table 3 (Models 2 and 3) indicate that EAS has a significant and positive relationship with the successful conclusion of a bombing campaign, but is not significantly related to the hazard that a bombing campaign ends *unsuccessfully* in the next period. This suggests that air superiority on the part of the attacker influences the defender's decision to concede to demands, as coercive success requires the defender's compliance. Air superiority, however, takes a negative but statistically insignificant coefficient in the failure model. As Allen notes, a bombing campaign ends in failure when an attacker chooses to relent prior to achieving her goals. As such, we conclude that the expectation of air superiority effects the target's decision to back down, but does not appear to influence the attacker's decision to end a bombing campaign short of achieving its goals. Since air superiority effects the attacker primarily through reducing the costs of bombing, it is likely that an attacker's decision to back down after initiating a bombing campaign is driven by factors other than the direct cost of continuing to bomb. To summarize, we find that air superiority affects the duration of bombing campaigns and how quickly a target concedes.

Air Superiority and Crisis Behavior

In an innovative study, Allen and Martinez-Machain (2018) examine the relationship between regime type, wealth, and the choice of air power as a coercive tool. They find that (1) democracies are no more likely than autocracies to employ air power as a coercive tool in a crisis, relative to other coercive tools; (2) states with greater wealth are more likely to employ air power than ground troops or nonviolent methods as a coercive tool in a crisis; (3) states that are militarily stronger compared to the coercive target are more likely to employ air power than ground troops or joint forces as a coercive tool in a crisis; and (4) that relative to ground troops or joint forces, air power is less likely to be used when issue salience is high.

We contend that expected air superiority reduces the bombing country's expected costs. In turn this increases the expected net benefits of aerial bombing relative to solving disputes through negotiation. Thus, we expect that countries expecting air superiority are more likely to respond to an international crisis by waging a bombing campaign rather than negotiate. Further, air forces are used in conjunction with the deployment of ground troops in many cases. Air superiority over the zone of ground combat provides protection to one's ground forces from enemy air-attack and allows one's own ground support and bomber aircraft to attack the enemy with relative impunity. Thus, the expectation of air superiority over a potential target is also likely to increase the expected benefit of deploying ground forces relative to negotiation. Specifically, we test the following hypotheses:

Choice of Coercion Instrument Hypothesis 1 (CCI-H1): *States that expect air superiority over a target are more likely to employ air power than negotiation during a crisis.*

Choice of Coercion Instrument Hypothesis 2 (CCI-H2): *States that expect air superiority over a target are more likely to employ ground forces or a combined-arms intervention than negotiation during a crisis.*

Table 4 Model 1 presents the results of the extension. We see that as a crisis actor's expectation of air superiority over a rival increases, the actor is more likely to engage in a bombing campaign rather than relying on negotiation to resolve the crisis. This is consistent with CCI-H1. Additionally, the estimates are largely consistent with CCI-H2. An increased expectation of air superiority over a target appears to increase the likelihood that ground forces are also used against that target during a crisis. Interestingly, we find that the expectation of air superiority has no effect on the propensity to choose only bombing over bombing along with the deployment of ground forces. This suggests that, while a state that possesses air superiority over its rival gains the ability to resolve a crisis through the use of force rather than being forced to negotiate, the decision between using airstrikes alone to resolve a crisis or airstrikes as part of a ground deployment will be driven primarily by political concerns and operational objectives.

Aerial Arms Races

To the best of our knowledge there is no quantitative research on aerial arms races. In this section, we present evidence for an aerial arms race between the United States and Soviet Union throughout the Cold War and especially in the 1980s as well as India and Pakistan in the late 1980s.

The essence of an arms race is a significant increase in armaments by two competitors. Quantitative research on arms races typically analyzes changes in military expenditures or personnel.[12] Diehl and Crescenzi (1998), however, argue that research on arms races should focus on weapons stocks and not expenditures. We follow their suggestion and examine changes in *Country Air Power (CAP 2)* between rivals. How much of a change in air power is necessary for analysts to claim that an arms race is present? Diehl (1983) contends that there is substantial arming when a country increases its military personnel or expenditures by at least eight percent for at least three years. Since we are examining changes in weapons and weapons inventories are sticky, we focus on a three-year moving average. We stay with Diehl's eight percent or more criteria for three years. To determine if the arming is directed at a specific adversary, and is not driven primarily by domestic politics, we focus on Thompson rivals (Gibler et al, 2005).

Based on these criteria we identify several likely aerial arms races. Further, detailed examination of the dataset allows us to characterize the nature of an arms race. It appears that the U.S. and Soviet Union had an aerial arms race between 1980 and 1988. This competition appears to have largely taken the form of a race in fighter *technology*. After the United States introduces the F-15C in 1979, the Soviet Union introduces the MiG-31 and MiG-29 in 1982 and 1983. Then in 1984 the U.S. rolls out the F-16C while the Soviets introduce the SU-27. The United States caps off this race with the introduction of the first Generation 4.5 fighter, the F-15E Strike Eagle. We also show a high level of competitive arming between India and Pakistan from 1986-1989 that is characterized primarily by increasing fighter *inventories* rather than technological advancement. In this period, India increases its inventory of the new fourth generation Mirage 2000 fighters, from 7 in 1985 to 24 in 1986 to 40 in 1987 and 1988 and 52 in

[12] Some research examines naval arms races (Bolks and Stoll, 2000; Crisher and Souva, 2014).

1989. India also acquires approximately 40 fourth generation MiG-29s in 1987 and increases its inventory of older generation 3 fighters by 28% (130 aircraft). At the same time Pakistan increases its number of F-16s (a fourth-generation fighter), from 6 in 1984 to 30 in 1986 and 39 in 1987 while also increasing its inventory of generation 3 aircraft by 14% and generation 2 aircraft by 45% (105 fighters across gens 2 and 3). It is interesting to note that neither of these would qualify as arms races if we only examined changes in military expenditures or personnel. This suggests that an examination of buildups in weapons and technological advances may lead to different answers on the occurrence of and effects of arms races.

Expected Air Superiority (EAS) and MID initiation

We add the continuous EAS variable discussed above to a common model of dyadic militarized interstate dispute (MID) initiation (Maoz et al 2018; Palmer et al 2015).[13] We expect that one country is more likely to attack another when it expects to have air superiority. Our justification for this expectation draws on Mettler and Reiter's (2012: 858-9) arguments for why states armed with ballistic missiles are more likely to attack others, as well as the aforementioned work by Allen (2007) and Allen and Martinez-Machain (2018). First, an air power advantage generally gives one an offensive advantage because you can bypass an adversary's defenses. Second, an air power advantage reduces one's expected casualties.

Figure 3 shows the marginal effect of EAS on dyadic MID initiation for seven samples. In each case we find that the greater the potential initiator's advantage in air power, the more likely it is to initiate a MID. This positive and statistically significant relationship holds for all

[13] Control variables include State A's regime type, State B's regime type, regime type interaction, rivalry, contiguity, capital-to-capital distance, alliance portfolio similarity, peace years, peace years squared and cubed. Full descriptions of the variables are in the online appendix.

dyads, democratic initiators, non-democratic initiators, contiguous dyads, non-contiguous dyads, rivals, and non-rivals (full results are in the Appendix). In light of these relationships, we think that future research on coercion, deterrence, and the causes of war will benefit greatly from using the air power data we present here.

Conclusion

Air power is one of the primary tools countries use to coerce others, but until now we lacked a dataset on each country's air power. The air power dataset presented here focuses on air superiority and air superiority fighters. Air superiority or command of the skies is the first and primary goal of a country's air force (Meilinger 2016). Having command of the skies greatly magnifies the offensive and defensive capabilities of a country. While multiple factors affect whether a country can achieve air superiority, more often than not the most important feature is a country's fighter jets. Accordingly, we present measures of air power based on fighter technology and numbers. An analysis of the content, face, and context validity of our preferred measure, CAP2, indicates that it has substantial validity.

In terms of content CAP2 is a function of the quantity of a country's combat aircraft as well as their quality. Drawing on extant air power research, we conceive of quality in terms of fighter generations and classify aircraft accordingly. For CAP2 we add intrageneration distinctions based on the avionics, speed, stealth, maneuverability, and other characteristics. To incorporate the non-linear technological differences between aircraft, and accurately express differences between aircraft, we employ an exponential weighting function. Country air power rankings serve as our primary means for assessing the surface validity of our measure. Our CAP2 measure indicates that the United States has had the world's most powerful air force every year between 1973 and 2013, an observation with which we believe all air power experts would agree. It also shows that Israel has more air power than its principal rivals, Syria, Iran, and Iraq.

We assess the context validity of our measure through several applications. Building on work by Allen (2007) and Allen & Martinez-Machain, we examine whether Expected Air Superiority (EAS) affects coercive behavior. We find that it does. Specifically, EAS decreases the duration of bombing campaigns and increases the probability that the coercer achieves her goals. We also demonstrate that EAS increases the probability that a country will choose to engage in bombing over negotiation. In another application, we show that countries with an air power advantage are more likely to initiate militarized interstate disputes than countries without an air power advantage. This relationship obtains in a number of subgroups, contiguous and non-contiguous, rivals and non-rivals. These findings lend support to a dyadic-level offense-defense theory. Finally, we note that one may use this data to identify arms races. We find evidence of an aerial arms race between the U.S. and Soviet Union in the 1980s and Pakistan and India in the mid-to-late 1980s. Neither of these would have been identified based on the extant Correlates of War capabilities data.

In conclusion, the air power data presented here will be valuable for those who want to examine the aforementioned topics in more depth as well as the diffusion of military technology, military force structures, military strategy, and many other substantive research questions.

Table 1: Expanded Fighter Generation Typology

Generation	**Examples Appearing in Dataset** (Non-exhaustive)
Generation 0	A-1 Skyraider, AT-6 Texan II, AU-23 Peacemaker, F-51D Mustang, IA-58 Pucara, OV-10 Bronco, EMB-312 Tucano
Generation 1	F-80 Shooting Star, F-84 Thunderjet, L-39 Albatross, de Havilland Venom, de Havilland Vampire, MB-326 Impala/Xavante, Gloster Meteor
Generation 1.5	A-37 Dragonfly, J-5, L-59 Albatross, CM-170 Magister
Generation 2	A-4 Skyhawk, Dassault/Dornier Alpha Jet, English Electric Lightning, F-86 Sabre, Hawker Hunter, S-32 Lansen, F-5A/B Freedom Fighter, MiG-17
Generation 2.5	MiG-19, SAAB J-35Oe, F-5E/F Tiger II, F-7 Airguard
Generation 3	F-100 Super Sabre, F-104 Starfighter, Saab 37 Viggen, Dassault Mirage F1, MiG-21, Sukhoi Su-15, Mirage V, IAI Dagger/Nesher
Generation 3.5	F-4 Phantom II, J-8 Finback, MiG-23
Generation 4	F-14A/B Tomcat, F-15A/B Eagle, F-16A/B Fighting Falcon, F-18A/B Hornet, MiG-29, MiG-31, Su-27, Dassault Mirage 2000, J-10B, Su-30, Su-33
Generation 4.5	F/A-18 E/F Super Hornet, F-15E Strike Eagle, Eurofighter Typhoon, Su-35, JAS-39 E/F
Generation 5	F-22A Raptor

Sources: *The Encyclopedia of Military Aircraft* (Jackson, 2009), *The Encyclopedia of World Military Aircraft* (Donald and Lake, 2000), and *The World Encyclopedia of Fighters and Bombers* (Crosby 2011).
Note: In the basic typology, generations 1.5, 2.5 and 3.5 collapse back into the preceding generation.

Table 2: Top 5 Countries for Three Measures of Airpower

Top 5 Countries by Airpower (Selected Years)			
Year	Total Combat Aircraft	*CAP1*	*CAP2*
1973	USSR China United States India Poland	United States USSR Poland India France	United States USSR United Kingdom West Germany Israel
1983	USSR China United States Poland India	United States USSR Israel Egypt Belgium	United States USSR Israel West Germany Egypt
1993	Russia China United States Ukraine North Korea	United States Russia Ukraine United Kingdom Israel	United States Russia Ukraine Israel Germany
2003	United States China Russia India North Korea	United States Russia Saudi Arabia Israel Taiwan	United States Russia Saudi Arabia Israel China
2013	United States China Russia India North Korea	United States Russia China Japan Saudi Arabia	United States Russia China Japan Saudi Arabia

* CAP1 and CAP2 are based on the following formula:

CAP = (ln(number of aircraft in generation$_i$ + 1)^Generation$_i$) summed across all generations

Table 3: Air Superiority and Bombing Campaign Duration, 1973-2004: Extension of Allen (2007)

	Model 1: Air Superiority Coefficient (se)	Model 2: Success Model Coefficient (se)	Model 3: Failure Model Coefficient (se)
EAS	3.50*	10.28***	-1.75
	(1.50)	(1.04)	(3.05)
Democratic Attacker	0.16	-2.26+	3.89**
	(0.68)	(1.12)	(1.63)
Democratic Defender	5.05**	-[1]	2.60
	(1.73)	(-)	(3.78)
Denial Vulnerability	1.59**	2.72***	0.37
	(0.50)	(0.61)	(0.60)
Punish Vulnerability	-0.81**	-0.98**	-0.54
	(0.31)	(0.38)	(0.64)
Other Forces Used	-2.02***	-[1]	-3.41**
	(0.47)	(-)	(86)
Major Power Attacker	-1.68*	-2.49**	-0.97
	(0.71)	(0.87)	(0.86)
Attacker's Demand	0.65	-0.26	2.76**
	(0.60)	(1.00)	(1.07)
Log Likelihood	-39.64	-9.21	-21.096
N	23	23	23

Clustered Standard Errors; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

1: *Democratic Defender* and *Other Forces Used* are perfectly collinear with the success outcome during 1973-2004.

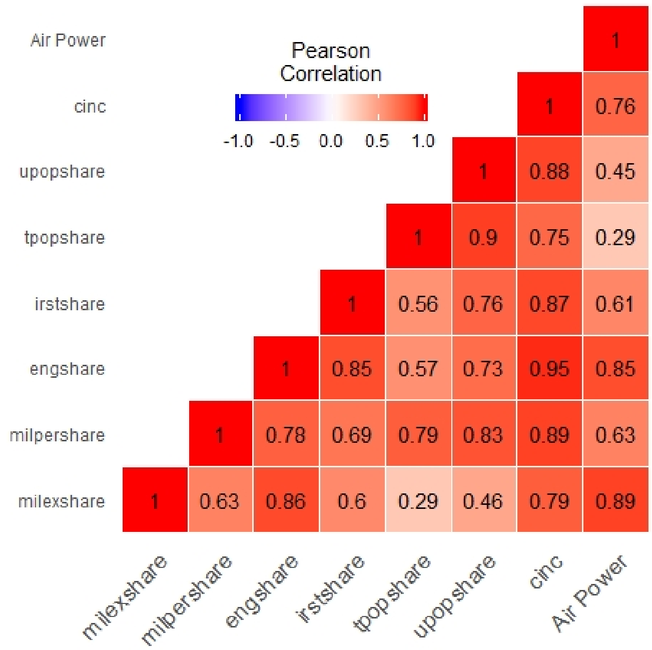
Allen (2007) data with inclusion of air superiority variable.

Table 4: Air Superiority and International Crisis Response, 1973-2006: Extension of Allen & Martinez-Machain (2018)

Model 1	Bombing V. Nonviolent (se)	Ground V. Nonviolent (se)	Ground V. Bombing (se)
EAS	1.24**	1.26**	0.01
	(0.49)	(0.48)	(0.61)
Power Differential	-<0.001	-0.01**	-0.01**
	(0.003)	(0.003)	(0.003)
Polity	0.05*	-0.007	-0.05*
	(0.02)	(0.23)	(0.03)
Joint Democracy	-0.68	-10.56***	-9.87***
	(0.46)	(0.36)	(0.42)
Ln(Energy)	-0.07	-0.25**	-0.2*
	(0.06)	(0.09)	(0.09)
Crisis Location	0.01	0.18	0.17
	(0.15)	(0.19)	(0.17)
Issue Salience	0.12+	0.34**	0.22+
	(0.07)	(0.11)	(0.12)
Number of Actors	0.01	0.01***	0.09***
	(0.02)	(0.02)	(0.02)
Protracted Crisis	0.43	1.1**	0.66
	(0.35)	(0.36)	(0.43)
Intercept	-1.93***	-2.13**	-0.19
	(0.47)	(0.74)	(0.75)
Log Pseudolikelihood	-251.28		
N	377		

Clustered Standard Errors; + p<0.10, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Allen & Martinez Machain (2018) data with inclusion of air superiority variable.

Figure 1: Air Power and Correlates of War Capabilities Correlation Matrix
1973-2012



Air Power = CAP2share
COW components from National Material Capabilities version 5 (Singer, Bremer, Stuckey (1972))

Figure 2b: World Share of COW CINC Scores for USA, Russia, and China
1973-2012

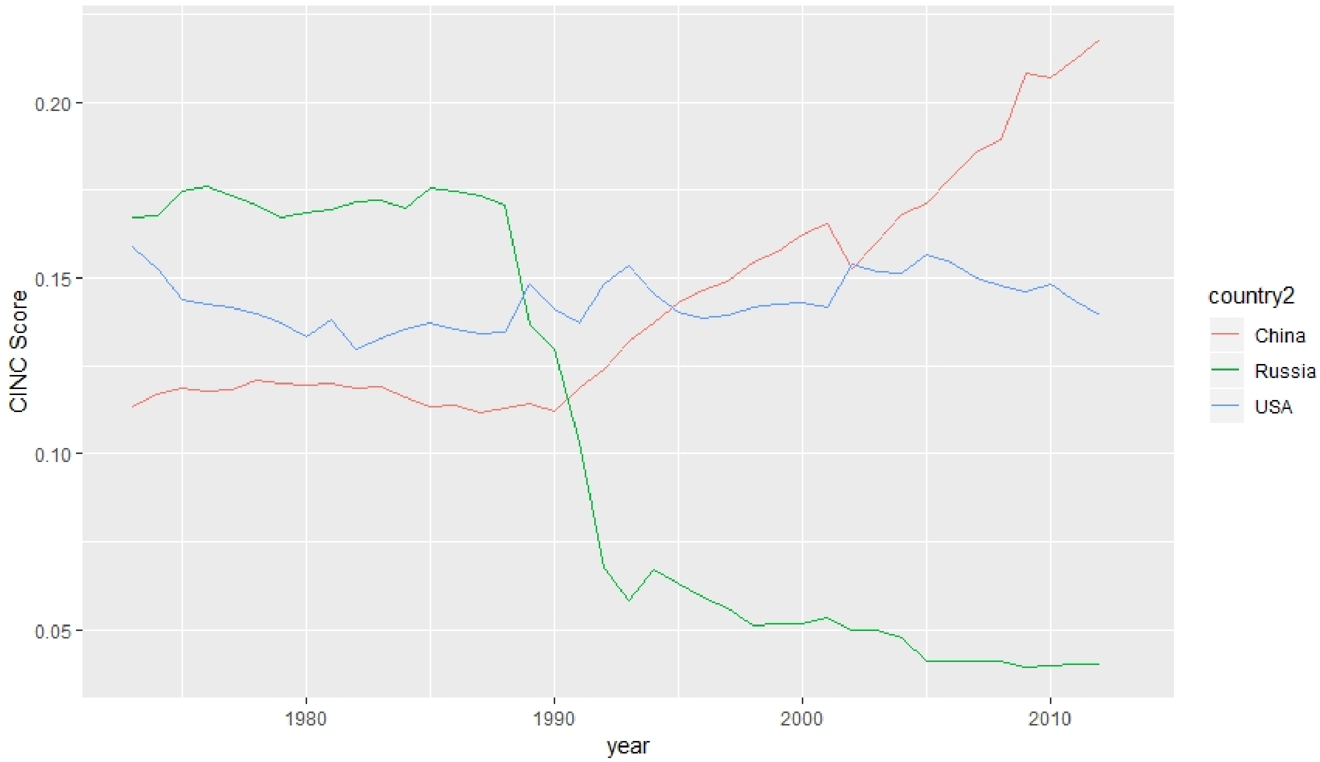


Figure 2a: World Share of Air Power for USA, Russia, and China
1973-2013

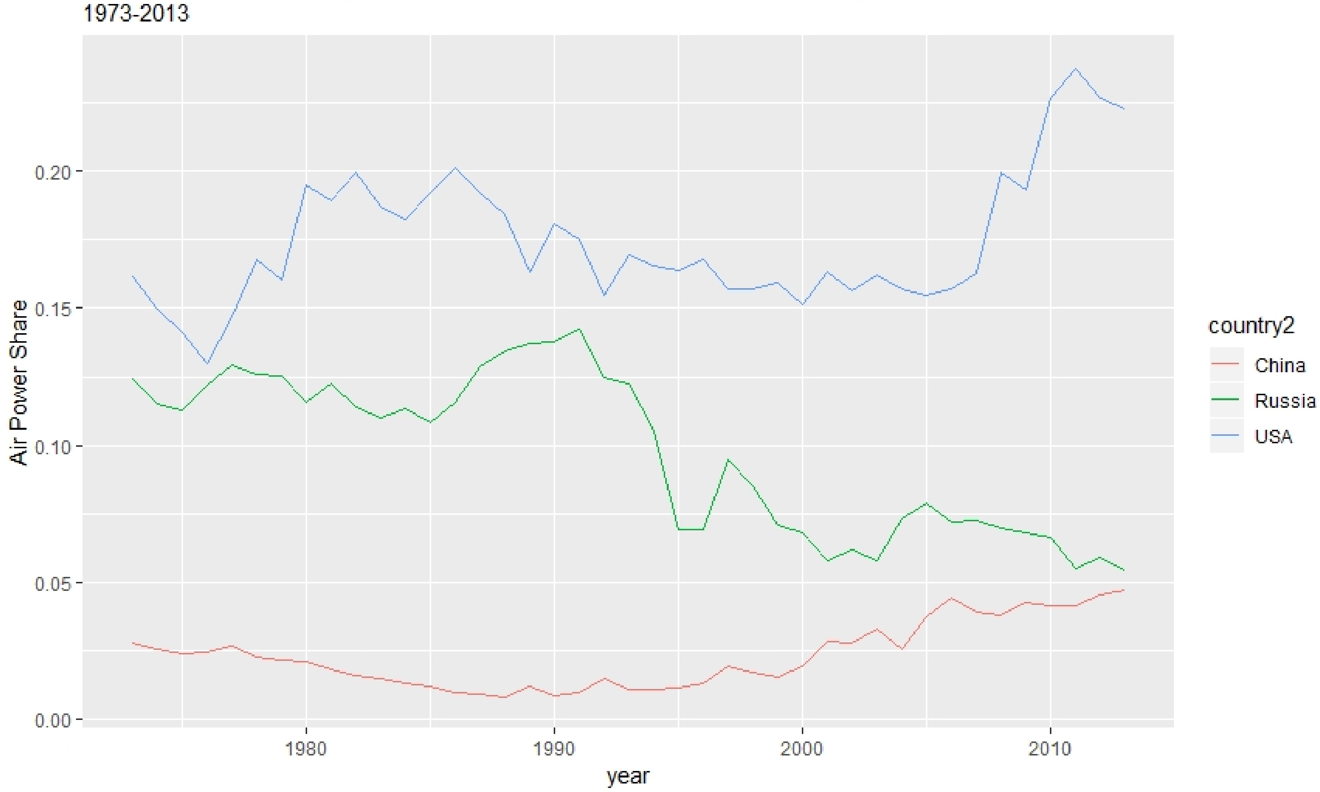
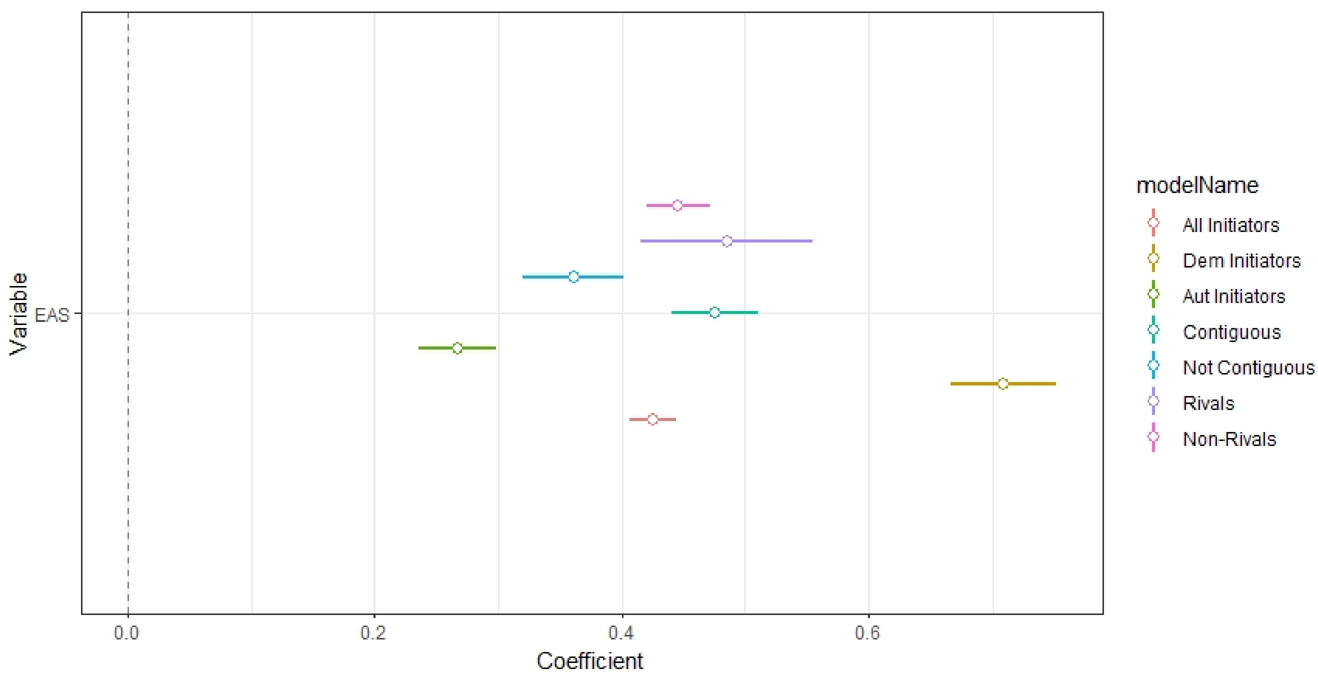


Table 6: Summary Statistics for 4 Measures of Air Power

Measure	Mean	S.D.	Minimum	Maximum	Observations
Combat Aircraft Raw Numbers	144.76	530.52	0	7487	7,183
Country Air Power 1 (CAP1) Raw Score	150.97	511.03	0	10946.54	7,183
Country Air Power 2 (CAP2) Raw Score	165.59	539.42	0	10946.54	7,183
Country Air Power 2 (CAP2) World Share	0.0057	0.017	0	0.239	7,183

Figure 3: Marginal Effect of Expected Air Superiority (EAS) on MID Initiation

1973-2008



95% CIs and clustered standard errors
EAS = State A's air power/(Sum of State A and State B's air power)
Controls include Initiator Democracy, Target Democracy, Joint Democracy, Rivalry, Contiguity, Distance, Portfolio Similarity, Peace Years

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Appendix A

Table A1: Variables and Data Sources for Dyadic MID Initiation Models

Variable	Measurement	Data Source
Expected Air Superiority (EAS)	**State A's CAP2 share/(State A + State B's CAP2 share)**	**Author**
Rival	**=1 if Thompson and Dreyer rivalry**	**Thompson and Dreyer (2011)**
Dem Initiator	**=1 if State A's polity2 >= 6**	**Marshall, Jaggers, and Gurr (2010)**
Dem Target	**=1 if State B's polity2 >= 6**	**Marshall, Jaggers, and Gurr (2010)**
Joint Democracy	**=1 if both Initiator and Target polity2 >= 6**	**Marshall, Jaggers, and Gurr (2010)**
Distance	**Capital to Capital, Cshapes**	**Weidman et al (2010)**
Contiguity	**=1 if < 400 miles of water separation; COW version 3.2**	**Stinnet et al (2002)**
Portfolio Similarity	**Unweighted S; COW alliances version 4.1; generated from Eugene**	**Signorino and Ritter (1999); Bennett and Stam (2000); Gibler (2009)**
Peace Years, Squared, and Cubed	**Time since last dyadic MID, squared, and cubed**	**Carter and Signorino (2010)**
MID Initiation	**MID version 4.2; Dyadic MID version 3.0**	**Palmer et al (2015); Maoz et al (2018)**

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Table A2: Air Power Models 1-3

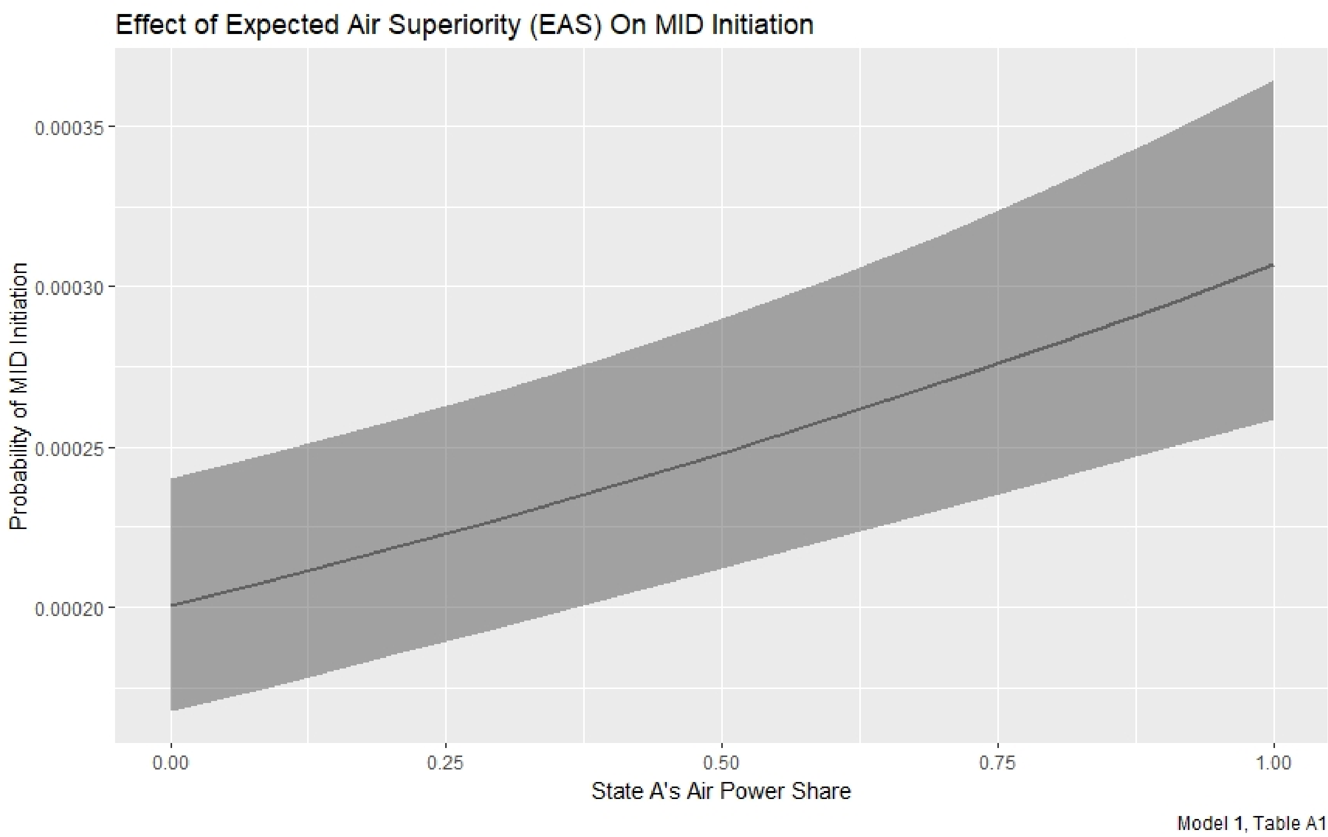
	Dependent variable:		
	Dyadic MID Initiation		
	All Initiators	Dem Initiators	Aut Initiators
EAS	0.426***	0.709***	0.267***
	(0.081)	(0.135)	(0.103)
Rival	1.542***	1.381***	1.558***
	(0.079)	(0.153)	(0.093)
Dem Initiator	0.484***		
	(0.083)		
Dem Target	0.542***	−0.476***	0.593***
	(0.082)	(0.107)	(0.084)
Distance	−0.0003***	−0.0003***	−0.0002***
	(0.00002)	(0.00003)	(0.00003)
Contiguous	2.495***	2.065***	2.862***
	(0.100)	(0.145)	(0.142)
Portfolio Similarity	−0.275***	−0.271**	−0.261**
	(0.083)	(0.124)	(0.112)
Peace Years	−0.133***	−0.142***	−0.130***
	(0.006)	(0.009)	(0.008)
Peace Years Sq	0.002***	0.002***	0.002***
	(0.0001)	(0.0002)	(0.0002)
Peace Years Cubed	−0.00001***	−0.00001***	−0.00001***
	(0.00000)	(0.00000)	(0.00000)
Joint Democracy	−1.070***		
	(0.131)		
Constant	−5.267***	−4.620***	−5.529***
	(0.142)	(0.198)	(0.196)
Observations	766,313	317,040	449,273
Log Likelihood	−6,060.301	−2,469.153	−3,570.018
Akaike Inf. Crit.	12,144.600	4,958.306	7,160.037

Note: *p<0.1; **p<0.05; ***p<0.01
Two-tail significance levels; Clustered standard errors

Table A3: Air Power Models 4-7

	Dependent variable:			
	Dyadic MID Initiation			
	Contiguous	Not Contiguous	Rivals	Not Rivals
EAS	0.476***	0.361***	0.485**	0.446***
	(0.108)	(0.125)	(0.193)	(0.090)
Rival	1.354***	3.878***		
	(0.081)	(0.233)		
Dem Initiator	0.178	1.017***	−0.166	0.688***
	(0.112)	(0.144)	(0.174)	(0.098)
Dem Target	0.501***	0.781***	0.439***	0.599***
	(0.100)	(0.152)	(0.155)	(0.098)
Distance	−0.00001	−0.0003***	0.0001	−0.0003***
	(0.0001)	(0.00003)	(0.0001)	(0.00003)
Contiguous			0.885***	2.559***
			(0.283)	(0.104)
Portfolio Similarity	−0.201*	−0.073	−0.013	−0.293***
	(0.105)	(0.150)	(0.173)	(0.097)
Peace Years	−0.129***	−0.125***	−0.109***	−0.139***
	(0.008)	(0.009)	(0.013)	(0.007)
Peace Years Sq	0.002***	0.002***	0.002***	0.002***
	(0.0002)	(0.0002)	(0.0003)	(0.0001)
Peace Years Cubed	−0.00001***	−0.00001***	−0.00001***	−0.00001***
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Joint Democracy	−0.858***	−1.268***	−0.407	−1.289***
	(0.173)	(0.212)	(0.287)	(0.150)
Constant	−2.713***	−5.895***	−2.457***	−5.288***
	(0.141)	(0.221)	(0.363)	(0.158)
Observations	28,488	737,825	3,408	762,905
Log Likelihood	−2,990.870	−2,987.661	−1,105.389	−4,901.749
Akaike Inf. Crit.	6,003.740	5,997.321	2,232.779	9,825.499

Note: *p<0.1; **p<0.05; ***p<0.01
Two-tail significance levels; Clustered standard errors


Effect of Expected Air Superiority (EAS) On MID Initiation
Probability of MID Initiation
0.00035
0.00030
0.00025
0.00020
0.00
0.25
0.50
0.75
1.00
State A's Air Power Share
Model 1, Table A1

Appendix B

Country Air Power Dataset Codebook

Variables and Coding:

Country-Year Data:

For each type of fighter or attack aircraft owned by a country during the years 1973-2013, we record the designation, technological generation, number of squadrons and number of aircraft in inventory. This results in 4 variables per fighter type. The largest number of different fighter/attack aircraft in service with a state for a given year is 32, thus the dataset includes 32 separate groupings of the four variables listed below.

Fighter/Attack Type(X): Name or alphanumeric designation (e.g. "F-15C/D", "Dassault Rafael") of a class of aircraft owned by the listed state in the listed year.

Fighter/Attack Type(X) Generation: This column includes the numerical technology generation to which each type of aircraft has been assigned.

Assignment to a technological generation is based upon the characteristics of a fighter in five separate areas –weapons, speed, avionics, stealth, and airframe/maneuverability. Tirpak (2009) –our source for the description of fighter generations –notes that a step-like or generational nature is forced upon the progress of fighter technology by the aircraft design cycle. Once built, a new fighter will generally be upgraded many times as new technologies become available. Despite this, new technologies are eventually developed that cannot be incorporated into the existing aircraft. For example, adding delta wings to a straight-winged airframe would likely result in an unflyable aircraft. Similarly, more advanced radar systems make greater demands on an aircraft in terms of electrical power and heat dissipation, meaning that powerful new radar units often cannot be incorporated into older airframes. Once a number of such incompatible technologies have been developed so as to make the benefit of designing a new clean-sheet fighter outweigh the cost, a new fighter is designed to incorporate these technologies that will possess radically more advanced capabilities than its predecessor. We take advantage of this enforced generational nature of fighter technology advancement in developing a measure of technology.

Assignment of a generational "score" for a given fighter in each of the five catagories listed above is based on the use of certain key words or inclusion of key descriptive characteristics by our technical sources in describing the aircraft. A summary of key words and the generations they are associated with appears below for each category. In cases where a definition for a given category overlaps (e.g. both Gen 0 and Gen 1 fighters use guns and unguided weapons), the generation score for that category was determined by the highest generation the aircraft falls into across the other categories. For example, the "weapons" score for a subsonic, jet-driven aircraft that uses only guns and unguided weapons would be "1", as the remaining technological characteristics of the aircraft place it among the early jet-fighters of Generation 1 rather than among the late propeller-driven fighters of World War II (Gen 0). In our "basic" typology, used to construct *CAP1*, described below, in cases where an aircraft possesses characteristics of more than one generation, assignment to a classification is based upon an average, rounded in the direction of the score assigned to the aircraft's weapons. For the "expanded" typology used to construct *CAP2*, these aircraft are instead coded at the mid-point between the neighboring generations to which its components belong.

	Weapons	Speed/Engine	Avionics/Radar	Stealth/Visibility	Airframe/Maneuver
Gen 0	Unguided Weapons	Piston-driven	None*	None	Strait-Wing airframe
Gen 1	Unguided Weapons	Jet-powered + Low subsonic	None*	None	Strait-wing airframe
Gen 2	Infrared-Seeking Missiles	Jet-powered + High subsonic	Basic radar, Range-finding radar	None	Swept-wing airframe
Gen 3	Beyond visual range missiles/ Radar-guided missiles.	Supersonic	Air-to-air radar, missile-illumination radar.	None	Swept-Wings
Gen 4	Beyond visual range missiles/ Radar-guided missiles.	Supersonic	Pulse-doppler radar, look-down-shoot-down capability	None	Fly-by-wire, computer-integrated flight controls, variable wing geometry
Gen 4.5	Beyond visual range missiles/ Radar-guided missiles.	Supersonic	AESA/Active Electronically Scanned Array Radar, Integrated Communications (i.e. Link-16 system), limited sensor fusion	Reduced radar cross section	Limited supermaneuvrability, planned favorable post-stall flight characteristics
Gen 5	Beyond visual range missiles/ Radar-guided missiles.	Supercruise	Full sensor fusion, Integrated modular avionics,	All-aspect stealth	Internal weapons bays, multi-axis thrust vectoring

* Some limited and experimental use of terrain mapping and search radar did occur

Fighter/Attack Type(X) Squadrons: This is the number of squadrons of the type of aircraft in question that are in the country's inventory in the given year.

Fighter/Attack Type(X) Number: This is the number of aircraft of the listed type in the country's inventory in the given year.

CAP1: This is a measure of country air power using the basic technological typology without half-steps between generations 1-2, 2-3, and 3-4. This value is calculated as the sum of the natural log of the number of fighters of each type owned by a country in a given year, each raised to the power of that fighter's generational rating.

CAP2: CAP2 is a measure of country air power that uses the expanded generational typology that includes half-steps between all generations after generation 1. Like CAP1, it is calculated as the sum of the natural log of the number of fighters of each type owned by a country in a given year, each raised to the power of that fighter's generational rating.

Total Combat: This is sum, by year, of all *Fighter/Attack Type(X) Number* values. It is a total count of all fighter/attack aircraft owned by a country in a given year.

We also provide a second dataset that includes the component-level technology coding for each fighter and attack aircraft included in the dataset.

This second dataset includes the following variables:

Aircraft Name/ Designation: This variable lists the generic name or designation for each fighter/attack aircraft. For example, F-15 variants A-D are listed under the designation "F-15."

Variants and Alternate Designations Included: Most aircraft are built in a number of variants and are frequently assigned different designations in the service of different countries. This variable includes information on all variants of a given fighter appearing the dataset (F-15's A, B, C and D, for example) as well as information on any alternate designations of the fighter that might be used by different countries. For example, the F-15E is called the Ra'am in some Israel country-year observations.

Combined Generation: This variable contains the combined generation score for each fighter/attack aircraft, and should be identical to the generational coding appearing in the CAP dataset listed above.

Weapons: This variable contains the generational coding of weaponry for each aircraft.

Speed/Engine: This variable contains the generational coding of the speed and engine type for each *aircraft.*

Avionics/Radar: This variable contains the generational coding of avionics and radar for each aircraft.

Stealth/Visibility: This variable contains the generational coding of visibility characteristics for each *aircraft.*

Airframe and Maneuverability: This variable contains the generational coding of the airframe and maneuverability characteristic for each aircraft.

Source: This variable includes the name of the primary data sources used in coding the component variables for each fighter/attack aircraft.