Air Superiority and Battlefield Victory

Richard Saunders

Florida State University

and

Mark Souva

Florida State University

Abstract

Air superiority enhances military firepower and maneuverability and is critical to battlefield success. We offer the first quantitative test of the relationship between air superiority and battlefield outcomes. To conduct the test, we create a data set of which side, if any, achieved air superiority in the decisive battle of conventional wars between 1932 and 2003. We find that air superiority significantly improves a country's probability of winning the decisive battle as well as the overall war. Further, we find that air superiority is a better predictor of winning a war than other well-known factors such as adoption of the modern system, regime type, civil-military relations, and a general measure of military power.

Introduction

Why are some militaries more likely to win in battle than others? Some of the most common answers to this question are material resources (Desch, 2002), regime type (Reiter and Stam, 2002), adoption of the modern system (Biddle, 2004; Grauer and Horowitz, 2012), civil-military relations (Narang and Talmadge, 2018; Brooks, 2006), and military strategy (Bennett and Stam, 1996). We argue that a specific aspect of military power is critical to victory in modern conventional battles, air superiority. While air power theorists like Trenchard, Mitchell, and Seversky have long maintained "that command of the air is of first priority to any military success in war (Smith, quoted in Westenhoff 1990)," recent research places much greater emphasis on other factors, particularly adoption of the modern ground forces system (Biddle, 2004). We agree that the modern system is an important military innovation, but air superiority is generally more critical to battlefield victory. We evaluate the air power theorists' hypothesis and conduct the first quantitative test of the relationship between air superiority and battlefield victory.

Battlefield victory is primarily a function of combat power. While a number of factors affect combat power, we demonstrate that air superiority is an especially important one. Air superiority increases the maneuverability and concentration of one's forces. This increases the success of battlefield breakthrough and reduces the odds of breakthrough by the other side. To test the relationship between air superiority and battlefield victory, we create a new variable that identifies which side, if any, achieved air superiority in the decisive battle of conventional wars between 1932 and 2003. We find that air superiority is a better predictor of victory than other well-known factors such as adoption of the modern system, regime type, civil-military relations, and general measures of military power.

This research improves our understanding of military effectiveness. The most effective militaries are those that control the skies. From a force structure perspective, our research suggests that investments in air power as well as anti-air defenses are vital for countries that may enter into conventional wars. In addition, our research suggests that some factors associated with military effectiveness matter most because they affect a country's ability to attain air superiority. Democracy, wealth, and civil-military relations, for example, likely affect a country's willingness and ability to invest in air superiority aircraft and training.

This research also fills a gap in research on air power. In international relations, most air power research examines the effects of bombing. Pape (1996) argues that strategic bombing is not an effective coercive strategy, a conclusion supported by Horowitz and Reiter (2001, 160). Kocher et al. (2011) find that U.S. bombing during the Vietnam War often harmed civilians more than combatants, leading to increased support for the Viet Cong. Allen and Martinez Machain (2018) note that states seem to rely on air power when they do not want to experience significant casualties; the use of air power thus signals low resolve. Similarly, Post (2019) finds that coercion attempts that employ air power are more likely to fail than other coercion strategies.

Recently, Saunders and Souva (2019) created measures of country air power and expected air superiority (EAS) for the period 1973-2013. Those measure differ from the one we present here in important ways. EAS is based on the number and technological sophistication of a country's aircraft. EAS does not account for the skill of pilots, availability of parts and fuel, ground based air-defenses, effectiveness and availability of radar and electronic warfare equipment, and other variables that influence who actually attains air superiority in a given battle. The measure we present is a qualitative holistic assessment of which side actually achieved air superiority in major battles and wars. By incorporating factors besides the number and type of fighters, the measure we present here more accurately describes which side actually achieved air superiority in major battles and wars. In the appendix we more fully discuss the relationship between these two measures including cases where they disagree.

Air Superiority

Air superiority is control of the sky over the battlefield. It means an actor's air and ground forces can act "without prohibitive interference" by the other side's aircraft or air defenses (NATO, 2018). Prohibitive interference is present when an adversary can shoot down a significant portion of one's aircraft, thereby disrupting aerial surveillance and air-to-ground attacks. Adversary resistance is not prohibitive when one's fighter and attack aircraft can effectively carry out their mission. If one side has air superiority the other side does not, but it is possible for neither side to attain air superiority. Such a situation is defined as air parity.

Air superiority is the first principle of air power (Meilinger and Sachs, 1995) because it allows other aircraft and military units to do their job more effectively. For example, in World War II, unescorted bombers attacking German factories suffered extreme losses from enemy fighters (Overy, 2014, 150). Similarly, strike-fighters must jettison their bomb-loads, abandoning their mission if they hope to defend themselves when attacked by air superiority fighters. Reconnaissance, electronic warfare or transport aircraft can do little but hope to flee in the face of fighter opposition. None of these aircraft can do their jobs well if air superiority has not first been established. Similarly, ground forces are less effective when the adversary has air superiority. To protect themselves from air attack, ground forces have to devote more effort to concealment and dispersion. This can limit the damage of air strikes, but it degrades maneuverability, force concentration, and effectiveness.

Air superiority increases combat power –the amount of force one can apply at a particular place and time

(Staff, 2017). The actor with a combat power advantage is likely to win the engagement. Air superiority facilitates combat power by enhancing combined arms operations and the maneuverability and firepower of one's forces. Combined arms operations use two or more weapons systems in such a way that it is difficult for an adversary to defend itself from both. Combined arms operations do not require air power, but it is often a component. For example, "Targets which cannot be effectively suppressed by artillery are engaged by close air support (Corps, 1997, 95)." The U.S. Marine Corps Warfighting Manual also explains how air attack, which is only effective when air superiority has been obtained, contributes to battlefield breakthrough: "in order to avoid our deep air support, he must stay off the roads, which means he can only move slowly. If he moves slowly, he cannot reinforce in time to prevent our breakthrough (Corps, 1997, 95)." Without air superiority, one's ground forces move slower and lose firepower by not being able to employ attack aircraft.

To summarize, air superiority has offensive and defensive implications. Offensively, air superiority allows an actor to employ attack, surveillance, bomber, and other aircraft without significant losses. Air superiority also facilitates air/ground combined arms operations. Defensively, an actor with air superiority does not have to fear that the adversary will attack their ground troops from the air and can more easily shift resources to stop enemy advances or quickly maneuver ground forces to capitalize on a weak point in the enemy battle line. More generally, air superiority facilitates the concentration of forces on a particular area, increasing the probability of a battlefield breakthrough or stopping an adversary's attempted breakthrough. If one side has air superiority, it is more likely to have a combat power advantage and is more likely to win the battle.

These considerations lead to our central hypothesis: In conventional battles, a side that achieves air superiority is more likely to win than a side that fails to achieve air superiority.

Research Design

To test our hypothesis, we build on the work of Grauer and Horowitz (2012). The primary difference between their research design and other prominent research on military effectiveness such as Reiter and Stam (2002) is that Grauer and Horowitz focus on decisive battles in conventional wars. In the next section we explain how this reduces endogeneity concerns. We analyze battles between 1932 and 2003 using a series of logistic regressions. The unit of analysis is the country-decisive-battle-participant.[1] Airplanes were used sparingly prior to 1932 and 2003 is the end of the Grauer and Horowitz data. The dependent variable, *Win*, is a binary indicator of which side won the decisive battle.[2]. There is only one draw in their data. For that case they

[1] Following Grauer and Horowitz, we disaggregate multilateral wars. Our primary analysis has 45 wars and 99 participants. With no disaggregation, there are 28 unique wars (Reiter et al., 2016)

[2] The outcome of a war is mostly a function of the outcomes of major battles. In sensitivity tests, we examine the outcome of the war. None of the substantive results change. To ensure World War II does not drive the results, we estimate models for 1946-2003. There are no major changes. (see Appendix)

code both sides as losing. We employ all their codings. Our contribution is to add to their data an expert coded indicator of which side, if any, attained air superiority during the decisive battles of these wars.

The variable *Air Superiority* equals one if a country had air superiority over its opponent(s) in the decisive operation, zero otherwise. *Air Parity* equals one if neither achieved air superiority, zero otherwise. To identify which side, if any, had air superiority we consulted over 80 sources. In the appendix we list our sources and provide a brief narrative of the air-campaign in each war. We code air superiority in accord with the NATO definition of the concept: "That 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, 2018). Air superiority obtains if an actor can effectively employ air assets and prevent the adversary from effectively employing its air assets over the battlefield. To achieve air superiority, an actor aims to destroy or deter the other side's air force either with its aircraft or land-based air defenses. Air superiority does not require one air force to be eliminated from the battlefield entirely. Instead, we look for evidence that one actor prevents its enemy from engaging in significant air-strikes, air transport, or close air support (CAS) operations during the decisive operation while maintaining the ability to engage in these activities itself. If neither side is able to use aircraft effectively in the battle, we code it as parity. If both sides in the battle were able to use their air forces effectively in support of their ground forces, we also code this as parity. [3]

We measure air superiority at the time of the decisive battle for two reasons. First, by Grauer and Horowitz's definition, the decisive battle represents a point in time in which the outcome of the war is in doubt. By measuring air superiority at this point rather than over the war in total, we reduce the possibility that our measurement of air superiority is endogenous –simply crowning the ultimate war winner as having won in the air as well. Second, in some wars the side with air superiority changes over time. The decisive battle is a single point at which holding air superiority can significantly influence the outcome of the war.

We also include the following control variables: Modern System Adoption, Democracy, Autocracy, Anocracy, National Power, Troops Engaged, Opponent Troops Engaged, and Past Coups. We take each of these variables from the Grauer and Horowitz replication data. See the Appendix for a full discussion of these controls.

[3] Two coders were responsible for examining the available historical documents and making an expert judgment on the question of air superiority. The online appendix contains narrative summaries as well as citations for the primary sources that were consulted. Intercoder agreement is 90.5% with a Krippendorff's Alpha reliability statistic of 0.8535 and P$>|t|$0.000 where 0.80 and above is commonly considered highly reliable (Krippendorff, 2004). Table 1 in the appendix reports alternate measures of reliability. In each case, the test statistic suggests high intercoder reliability.

Empirical Results

Table 1 shows a cross-tabulation between air superiority and victory in battle. The relationship is striking. Countries that achieve air superiority win almost twice the amount one would expect by chance. Approximately 79% of all decisive battle winners have air superiority. Only two times has a country with air superiority lost the decisive battle. [4]

Next, we estimate a series of multivariate logit models. Once we control for potential confounders, is air superiority still related to victory in battle? It is (see Figure 1), and quite strongly so. Model 1 reproduces the main findings from Grauer and Horowitz (2012) in our shorter time frame. Adoption of the modern system, democracy, and national capabilities (CINC) increase the probability of winning. Model 2 adds Air Superiority and Air Parity.[5] Achieving air superiority in the decisive battle is positively and strongly correlated with victory ($p < 0.001$). The effect of modern system remains statistically significant but democracy and national capabilities are no longer significant. The air superiority model also fits the data much better (Model 1 AIC=101.7; Model 2 AIC=65.7).

Air superiority has a large effect on battle outcomes (see Figure 3), larger than any other variable in the model (see Figure 2). The predicted probability of victory for an air inferiority institutionalized autocracy is only 0.03, when holding other covariates at their mean or median values. An autocracy with air superiority has a predicted probability of victory of 0.83![6] By comparison, when there is no air superiority an autocracy that has adopted no elements of the modern system wins with probability 0.02. When the modern system has been fully adopted, the probability of victory increases to 0.14. The effect of air superiority is similar for democracies. We conclude that air superiority is not only an important determinant of victory in modern war, but that, contrary to Biddle's expectation (Biddle, 2004, 52-77), air superiority has a larger effect on victory than adopting the modern ground-forces system.[7]

Air superiority explains war outcomes better than a general measure of military power. In Model 1, in which air superiority is absent, the COW CINC measure of power shows a statistically significant and positive relationship with victory in war. When we include air superiority in the model, the coefficient associated with CINC declines in magnitude and becomes statistically indistinguishable from zero.[8] At least

[4] These countries are Italy, which lost to Greece, and Cambodia, which lost to Vietnam. Alternative codings for both cases are reasonable. Britain provided air support to Greece during the Greco-Italian war, nullifying the Italian advantage. Similarly, Cambodian superiority over Vietnam was a product of U.S. air activities against the Viet Cong, which were not coordinated with Cambodian forces.

[5] Air superiority and modern system adoption correlate at .5.

[6] In this sample, 16 of the 18 institutionalized autocracies with air superiority prevail in battle.

[7] We also estimate models with an alternative coding of air superiority for cases in which our coders disagree. The effects are largely unchanged in these models.

[8] AIC for a model with CINC but not air superiority is 103.6. The AIC for a model with air superiority but not CINC is 65.2. The air superiority model fits the data significantly better.

on the modern battlefield, air superiority and not power in general is the key to victory.[9]

Adding air superiority to the model of battle outcomes renders democracy not significant (Model 2). Table 2 sheds light on this finding. Democracies are much more likely than other regimes to attain air superiority. This may indicate that the observed democratic war-fighting advantage stems from advantages in aircraft technology or doctrines and force structures that emphasize air superiority. It seems likely that regime type, wealth, and civil-military relations influence a country's force structure and strategy (Caverley, 2010; Brooks, 2006). Still our data indicates that the relationship between regime type, wealth, and air superiority is only probabilistic. Non-democracies, such as Nazi Germany, can achieve air superiority and when they do they are more likely to win. Future research should examine the relationship between air power, regime type, wealth, strategy, and military outcomes more thoroughly.

Illustrative Examples of the Importance of Air Superiority

One useful way to understand the effect of air superiority on victory is to ask who would have won if the other side would have achieved air superiority. Would the British have defeated Argentina if Argentina controlled the skies in the Falklands/Malvinas War? Would Israel have defeated its adversaries if it did not achieve air superiority in 1967 or 1973? The 1973 Arab-Israeli War underscores the importance of air superiority. Initially, the war went poorly for Israel. After the Six-Day War, Egypt and Syria invested heavily in ground based air defense networks that covered much of the Sinai and Golan Heights (Gribling, 1988; Pollack, 2004, 4). While Arab forces remained under this air-defense umbrella, they scored major breakthroughs in both the Sinai and the Southern portion of the Golan Heights. Arab air defenses negated Israel's air power and contributed to the ineffectiveness of Israel's counterattacks on both fronts (Pollack, 2004, 115,500). Herzog (1975, 391) notes that Israeli air power had little effect due to enemy defenses. Without control of the skies, more than half of the 170 Israeli tanks committed to the initial counter-attack in the Sinai were lost for no gain. On the Northern front, the situation was even more dire for Israel with Syrian units running unchecked behind the lines on the first day of fighting (Gribling, 1988, 9). One observer notes when discussing the collapse of Israel's 188th Armored Brigade in the Golan Heights, "The missiles and dense anti-aircraft fire wreaked havoc. ...an Isreali battalion commander asked for air support at first light. As the sun rose, four (Israeli) Skyhawks penetrated to bomb the Syrians, but as they approached their targets the tell tale smoke trails of SAMS were seen. All four planes exploded in the air in full view of the hard pressed troops of the battalion"(Herzog, 1975, 286) While the Arab forces maintained an effective

[9] In the online appendix, we also present evidence that winning air superiority in a given battle significantly increases the performance of a side's ground forces in terms of loss-exchange ratios, even when controlling for CINC and modern system adoption. A side that wins air superiority in the decisive battle of a war suffers approximately 1.5 fewer casualties per casualty inflicted upon the other side.

air defense, Israeli forces were hard pressed to check the Arab advance, and suffered extreme losses in their attempted counter-attacks. However, by the end of the first week the situation had changed. The Syrian front was stabilized when Israeli aircraft swept through Lebanese airspace to bomb Damascus. This forced Syria to thin its air defense network over the Golan and contributed to ammunition shortages for the Syrian air defense units, allowing Israeli aircraft to provide support to their battered ground forces (Pollack 2004, 500; Gribling 1988, 11). A similar turn of events occurred in the Sinai when Egyptian leader Anwar Sadat insisted, against the advice of his generals, that the Egyptian 2nd and 3rd armies strike Eastward to relieve pressure on the Syrian forces (Pollack, 2004, 118). This attack took Egyptian troops out from under the cover of their air defense umbrella, resulting in a crushing Egyptian defeat as Isreaeli fighters could finally be brought to bare against Egyptian ground forces(Herzog, 1975, 314). Following this defeat, the tide soon turned in Israel's favor.[10]

Recent scholarship also underscores the critical importance of air superiority in the Battle for Moscow. The German attack on the Soviet Union in 1941 stalled outside Moscow in part due to Soviet air superiority. Describing a failed German offensive on November 28, General Veiel wrote: "Throughout the whole day continuous bombing attacks on all parts of the div[ision]. Absolute Russian air superiority despite Luftwaffe activity. At the spearheads there were no German fighters observed" (Stahel, 2015, 244). As a result, the Wermacht forces were unable to maneuver without suffering losses from the air. This made it impossible for German commanders to concentrate their forces for a breakthrough. The day after Veiel's message was received by high command "Fritz Todt, the minister for armaments and munitions, bluntly informed Hitler: 'This war can no longer be won by military means.'" The historian Stahel explains why: "Evidence for which was nowhere better seen than in the east; and above all in the skies over Russia (Stahel, 2015, 246)." Germany had lost air superiority, dooming its chances of prevailing.

Conclusion

Air power theorists maintain that air superiority is critical to battlefield victory. We conduct the first quantitative test of air superiority and battlefield outcomes and find that air superiority is strongly associated with victory. We contend that this is because air superiority enhances the maneuverability and firepower of one's forces. We also find that air superiority has a larger substantive effect than other factors associated with victory in war. Air superiority may also explain why democracies generally prevail in war. Democracies generally achieve air superiority over their adversaries. However, when autocracies do achieve air superiority, they prevail about 84% of the time.

[10]See (Pollack, 2004) and (Rabinovich, 2007) for a fuller discussion.

Among the implications of our research is that more attention needs to be given to the effects of advanced technology on military effectiveness. Future research should more fully examine the causes of air superiority as well as the interaction of strategy and air power. For policymakers, this research suggests that air superiority should not be neglected at the expense of other missions.

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Table 1: Air Superiority and Decisive Battle Outcomes, 1932-2003

	Loss	Win
No Air Superiority	49 (30.4)	10 (28.6)
Air Superiority	2 (20.6)	38 (19.4)

Cell entries are observed frequency followed by expected frequency in parentheses. Chi-square: 58.0, $p<.001$. Air Parity is coded as no air superiority for each side. Unit of analysis: battle-country-participant.

Table 2: Air Superiority and Regime Type, 1932-2003

	No Air Superiority	Air Superiority
Autocracy	31 (29.2)	18 (19.8)
Anocracy	17 (10.7)	1 (7.3)
Democracy	11 (19.1)	21 (12.9)

Cell entries are observed frequency followed by expected frequency in parentheses. Chi-square: 17.8, $p<.001$. Air Parity is coded as no air superiority for each side. Autocracy is defined as a polity2 score from -10 to -6; Anocracy equals polity2 score from -5 to 5; Democracy equals polity2 score from 6 to 10. Unit of analysis: battle-country-participant.

Figure 1: Air Superiority and Decisive Battle Outcome: Logistic Regression Estimates, Models 1-2

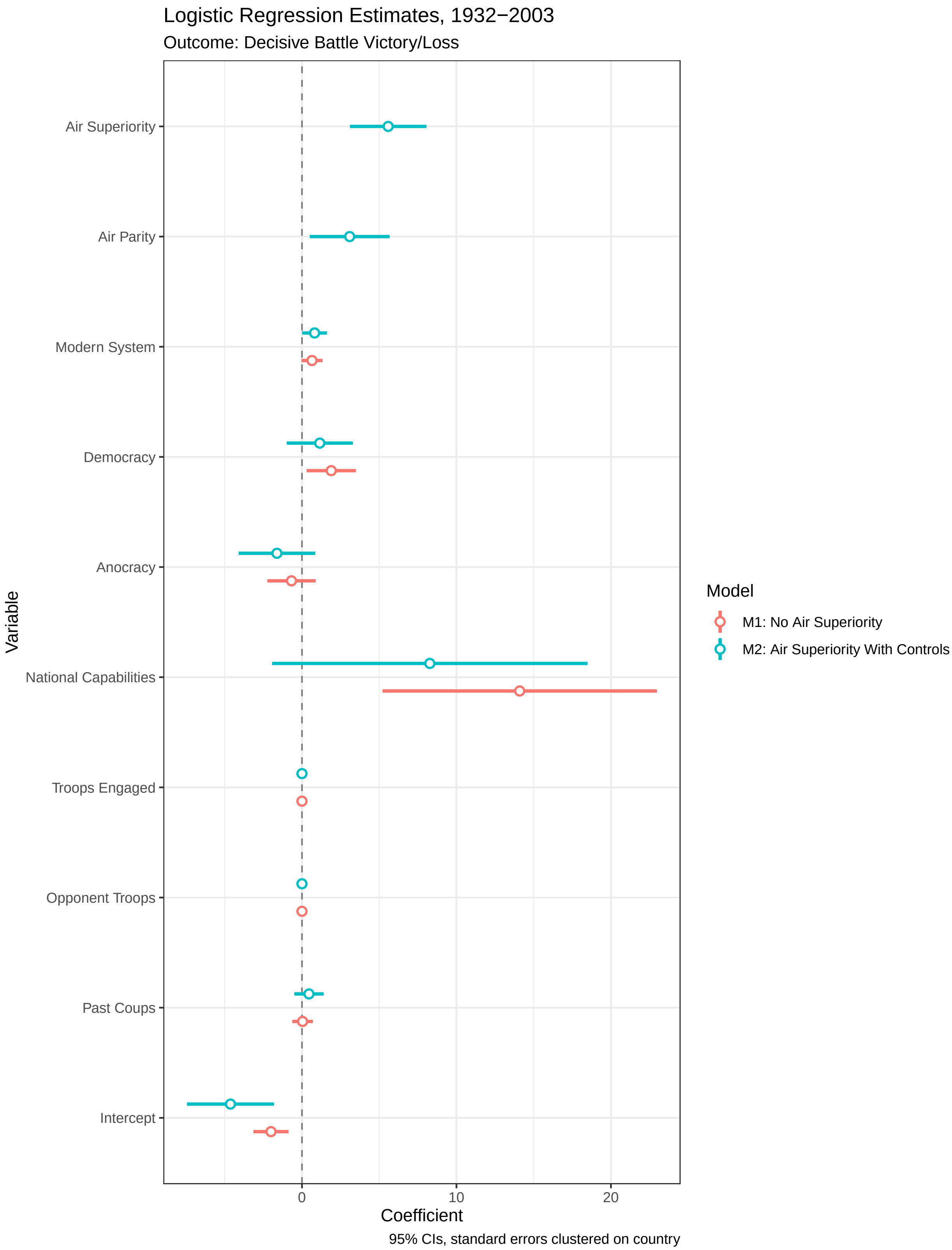

Figure 2: Change in Predicted Probability of Victory, Selected Covariates

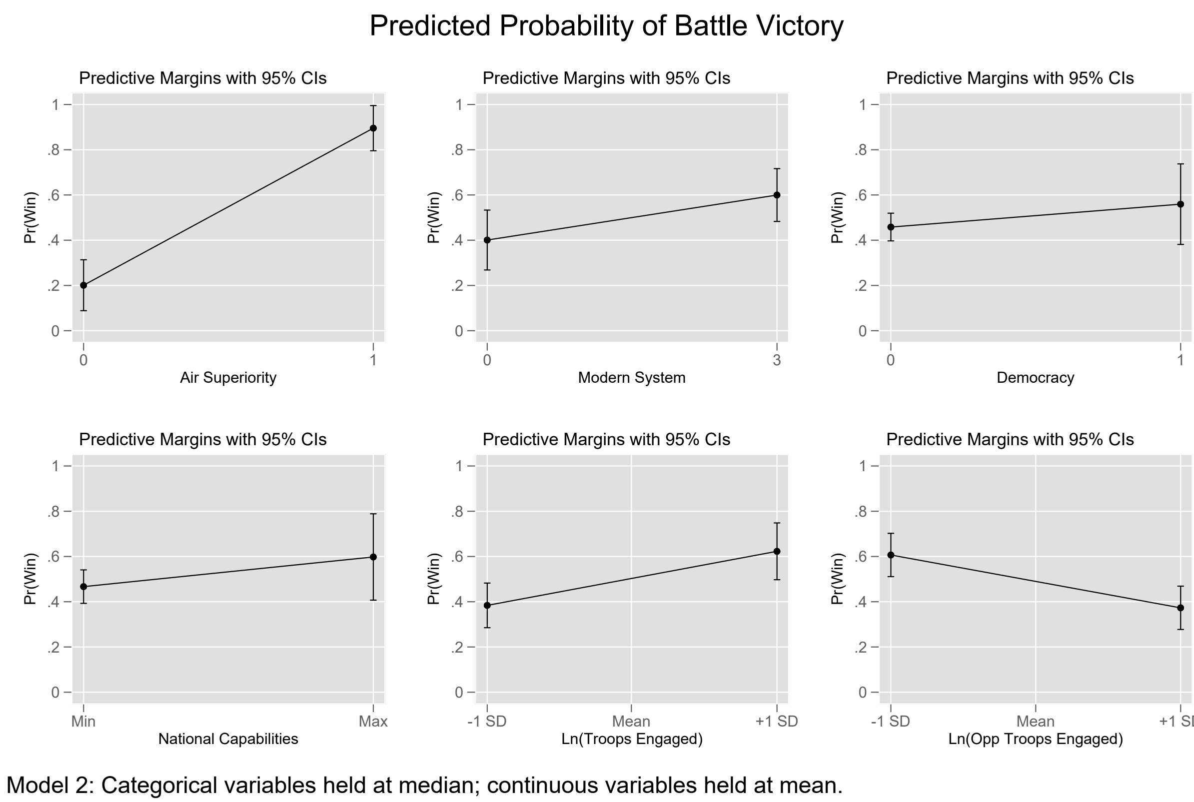

Figure 2 displays the predicted probability (with 95% confidence intervals) of battlefield victory. Quantities of interest displayed are 1: Air inferiority to superiority; 2: No modern system adoption to full modern system adoption; 3: Autocracy to Democracy; 4: Minimum CINC score to maximum; 5-6: 1 standard deviation below the mean to one standard deviation above in terms of troops employed by the side examined as well as the opponent. The estimates are based on Model 2 with other variables held at their mean or median values.

Figure 3: Substantive Effect of Air Superiority on Decisive Battle Victory, 1932-2003

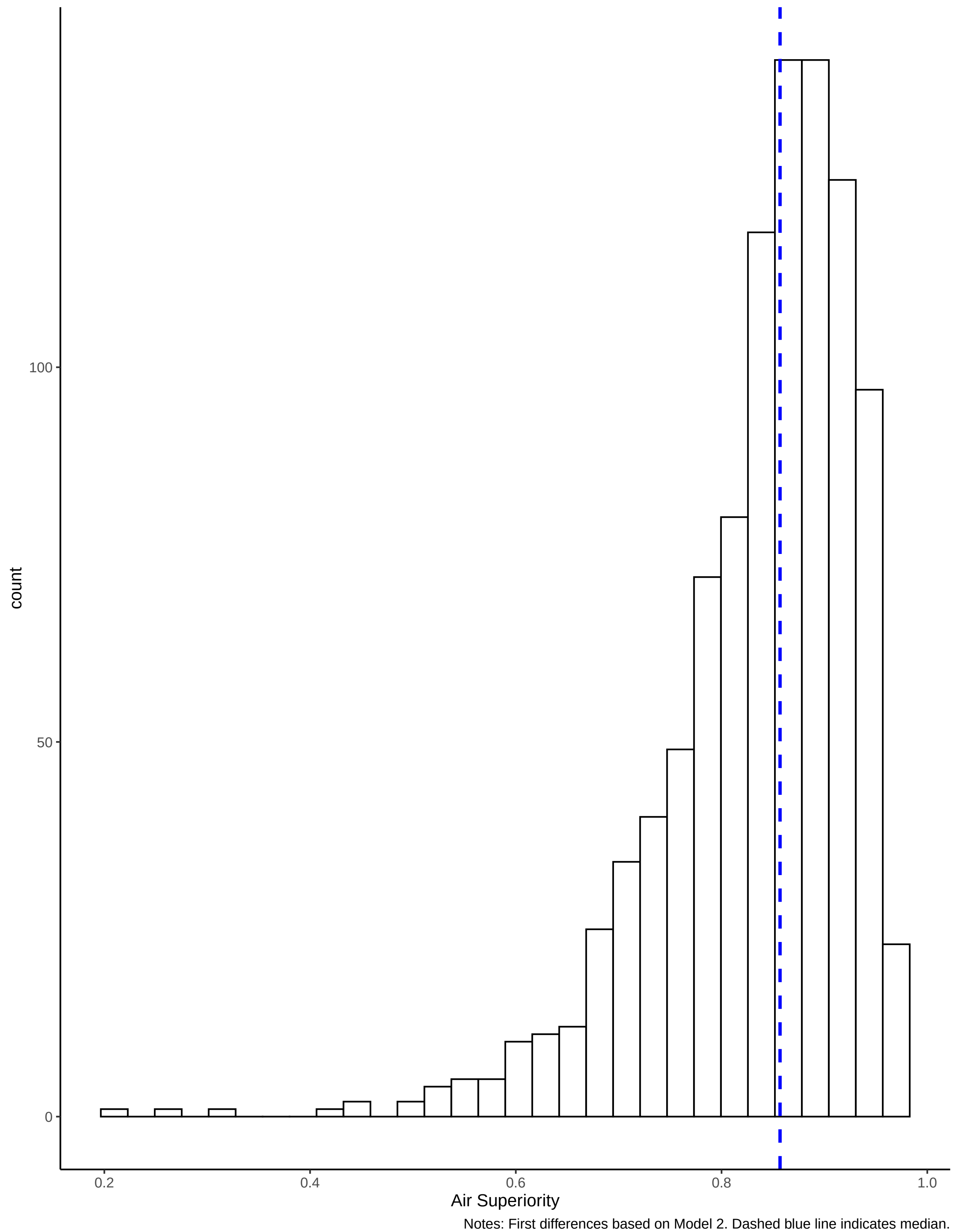

Figure 3 displays the distribution of the first difference of the predicted probability of victory –moving from no air superiority to air superiority –across 1000 draws from a multivariate normal distribution based on the variance covariance matrix of Model 2. Calculated using Zelig 5.1.6.1(Choirat et al., 2016)

Appendix A

- Appendix Table 3: Summary Statistics

Table 3: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Outcome	99	0.48	0.50	0	1
Air Superiority	99	0.40	0.49	0	1
Air Parity	99	0.23	0.42	0	1
Modern System	99	1.52	1.22	0	3
Democracy	99	0.32	0.47	0	1
Anocracy	99	0.18	0.39	0	1
CINC	99	0.06	0.08	0.0001	0.28
Troops Engaged	99	161,003.90	337,222.50	100	2,300,000
Opponent Troops Engaged	99	164,353.50	326,813.10	100	2,300,000
Past Coups	99	0.28	0.70	0	4

- Appendix Table 4: Correlation Matrix

Table 4: Correlation Matrix

	win	Airsup	Parity	M-Sys	Democ	Anoc	CINC	Troops	Op Troops	Coup
win	1									
Air Superiority	0.77	1								
Air Parity	-0.15	-0.45	1							
Modern System	0.51	0.52	-0.33	1						
Democracy	0.41	0.36	-0.07	0.31	1					
Anocracy	-0.35	-0.33	0.36	-0.37	-0.33	1				
CINC Score	0.45	0.46	-0.19	0.46	0.14	-0.26	1			
Troops Engaged	0.05	0.1	-0.21	0.1	-0.05	-0.15	0.24	1		
Opptroops Engaged	0	0.07	-0.22	0.13	0.06	-0.12	0.21	0.82	1	
Past Coups	-0.19	-0.22	0.05	-0.11	-0.28	0.18	-0.24	-0.09	-0.14	1

- Appendix Table 5: Logistic Regression Estimates, Models 1-4,

Table 5: Models 1-4: Logistic Regression Estimates, 1932-2003

	DV: Decisive Battle Outcome			
	Model 1	Model 2	Model 3	Model 4
	(Base)	(Air Sup)	(Chng Dem Ref)	(1946-2003)
Air Superiority		5.58^{***}	5.46^{***}	5.83^{***}
		(1.27)	(1.24)	(1.96)
Air Parity		3.09^{***}	2.54^{**}	2.43
		(1.18)	(1.05)	(1.58)
Modern System	0.65^{**}	0.82^{**}	0.82^{**}	0.78
	(0.28)	(0.41)	(0.39)	(0.58)
Democracy	1.90^{***}	1.15	1.57^{*}	1.02
	(0.69)	(1.00)	(0.94)	(1.25)
Anocracy	−0.68	−1.62		−1.99
	(0.89)	(1.34)		(1.87)
CINC	14.09^{***}	8.28	9.68	13.96
	(5.23)	(7.25)	(7.26)	(14.57)
Troops Engaged	0.000002	0.000003	0.000004	−0.000002
	(0.000002)	(0.000003)	(0.000003)	(0.00001)
Opponent Troops Engaged	-0.000003^{*}	−0.00001	−0.00001	−0.000003
	(0.000002)	(0.000004)	(0.000004)	(0.00001)
Past Coups	0.04	0.45	0.25	−0.40
	(0.42)	(0.53)	(0.50)	(1.03)
CONSTANT	-2.01^{***}	-4.63^{***}	-4.68^{***}	-3.93^{**}
	(0.62)	(1.27)	(1.21)	(1.64)
Observations	99	99	99	63
Log likelihood	−42.86	−22.88	−23.71	−14.49
Akaike information criterion	101.73	65.76	65.42	48.98

Notes: $^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$
Two-tail significance levels
Cell entries are coefficients, with standard errors in parentheses.
Standard errors clustered on country.

- Appendix Table 6: Logistic Regression Estimates, Models 5-6

Table 6: Logistic Regression Estimates of Air Superiority on IWD War Outcome, 1932-2003

	DV: IWD War Outcome	
	IWD Wars and Subwars Model 5	IWD Wars Model 6
Air Superiority	4.50***	20.47
	(1.30)	(2,215.17)
Air Parity	3.20***	19.04
	(1.20)	(2,215.17)
Modern System	0.02	−0.10
	(0.31)	(0.38)
Democracy	2.03***	2.31***
	(0.73)	(0.82)
CINC	−8.47*	−9.19*
	(4.48)	(4.73)
Troops Engaged	0.000000	0.000000
	(0.000002)	(0.000002)
Opponent Troops Engaged	−0.000001	0.000000
	(0.000002)	(0.000004)
Past Coups	0.29	0.87
	(0.86)	(1.11)
CONSTANT	−4.03***	−19.79
	(1.19)	(2,215.17)
Observations	87	73
Log likelihood	−34.04	−27.01
Akaike information criterion	86.08	72.02
Notes:	***p < .01; **p < .05; *p < .1 Two-tail significance levels Cell entries are coefficients, with standard errors in parentheses. Standard errors clustered on country.	

Table 7: Logistic Regression Estimates, 1932-2003

	DV: Decisive Battle Outcome Air Superiority Alternate Coding
Air Superiority Alternate Coding	4.51^{***}
	(1.05)
Air Parity Alternate Coding	2.33^{**}
	(0.96)
Modern System	0.78^{**}
	(0.36)
Democracy	1.55^{*}
	(0.92)
Anocracy	−1.29
	(1.24)
CINC	8.33
	(7.04)
Troops Engaged	0.000004
	(0.000002)
Opponent Troops Engaged	-0.000005^{*}
	(0.000003)
Past Coups	0.44
	(0.49)
CONSTANT	-4.18^{***}
	(1.06)
Observations	99
Log likelihood	−27.82
Akaike information criterion	75.64
Notes:	***p < .01; **p < .05; *p < .1 Two-tail significance levels; Standard Errors Clustered on Country Cell entries are coefficients with standard errors in parentheses.

Table 8: Logistic Regression Estimates, 1932-2003

	DV: Decisive Battle Outcome Terrain Robustness
Air Superiority	6.18***
	(1.66)
Air Parity	2.88**
	(1.25)
Modern System	0.73*
	(0.44)
Democracy	1.16
	(1.08)
Anocracy	−1.46
	(1.46)
CINC	7.92
	(8.04)
Troops Engaged	0.00001
	(0.00001)
Opponent Troops Engaged	−0.00001
	(0.00001)
Past Coups	0.44
	(0.54)
Terrain	0.79
	(2.00)
CONSTANT	−5.03**
	(2.1)
Observations	92
Log likelihood	−19.22
Akaike information criterion	60.43
Notes:	***p < .01; **p < .05; *p < .1 Two-tail significance levels; Standard Errors Clustered on Country Cell entries are coefficients with standard errors in parentheses.

Table 9: Air Superiority and Loss-Exchange Ratios

	Air Superiority b/se	Modern System b/se	Combined b/se
Air Superiority	-1.500*		-1.556+
	(0.540)		(0.772)
Modern System		-0.030	0.217
		(0.975)	(1.096)
Polity2	0.129	0.063	0.127
	(0.104)	(0.125)	(0.108)
National Capabilities	19.271+	13.289	18.366*
	(9.897)	(9.530)	(7.823)
Civil-Military Relations	1.358	1.408	1.423
	(1.325)	(1.464)	(1.386)
Constant	1.296	0.948	1.075
	(1.613)	(1.944)	(1.825)
Observations	31	31	31

Notes: *p < .05; +p<.1
Two-tail significance levels; Standard errors clustered on country

All covariates in this analysis are measured as discussed for the main models. We draw information on loss exchange rates from two data sources. For every decisive battle that appears in the Biddle & Long (2004) replication data, we use their LER figures. For battles that don't appear in Biddle & Long, we fill in using the LERD dataset by McNabb Cochran & Long (2017).

Discussion of Covariates

Modern System: Modern system's adoption ranges from "0" (no modern system adoption) to "3" (full modern system adoption). Modern System is based on the extent to which each combatant's forces employ cover and concealment, dispersion of forces, small-unit independent maneuver, use of combined arms, force concentration at the point of attack, defensive depth, and the ratio of operational reserves to frontline forces(Grauer and Horowitz, 2012).

Democracy, Anocracy and Autocracy: The variable Democracy equals one if a country scores seventeen or higher on the Polity IV democracy-autocracy index, zero otherwise. Anocracy equals one if a country scores between six and sixteen inclusive on this index, zero otherwise. Autocracy is the reference category in our models. Data come from the Polity IV project (**?**).

National Capability: National Capability is a country's score on the Correlates of War Composite Indicator of National Capabilities (CINC) (**?**).

Civil-Military Relations: We measure Civil-Military Relations in the same way that Grauer and Horowitz do. We use their measure of the number of military coups in a country in the last 5 year period (Grauer and Horowitz, 2012).

Troops Engaged: Troops Engaged and Opponent Troops Engaged measure (Grauer and Horowitz, 2012).the number of troops engaged in battle for each side of the conflict. Both measures of troop strength are devised by (Grauer and Horowitz, 2012).

Logged GDP Per Capita: Finally, we also include a control for logged GDP per capita that is drawn from the Grauer and Horowitz (2012) replication data (Grauer and Horowitz, 2012).

Comparison with Saunders and Souva Expected Air Power Measure

The measure presented in Saunders and Souva (2019) is not a direct measure of air superiority. Saunders and Souva create a measure that takes into account the number of fighters in a state's air force inventory as well as the technological quality of those fighters. This is a useful measure in that it can be used in comparisons between states regardless of whether they actually engage in conflict or not, making it useful for assessing questions about conflict onset and potential selection into conflict. However, this measure is limited because it is only an indirect measure of air superiority. Much more goes into achieving air superiority than simply fighter aircraft. A perfect predictive measure of air superiority must also account for the training and skill of the pilots, availability of spare parts and fuel, the effectiveness of ground based air-defenses, the effectiveness and availability of radar and electronic warfare equipment, distance of the combat zone from each side's airfields and a number of other factors that are important in determining victory in the air. A purely quantitative measure of air superiority has great difficulty in capturing how all of these factors interrelate to determine air superiority. Thus, the Saunders and Souva EAS measure is necessarily only an approximation of actual air combat outcomes. Qualitative expert-coding procedures can and do provide a much more precise measure of actual achieved air superiority. Thus, when exploring questions related to conflict outcomes we argue that our more precise measure of achieved air superiority is superior to the Saunders and Souva measure of expected air superiority. We provide summary statistic below to further explain why that is the case.

Table 10: Cross tabulation of Saunders and Souva Expected Air Superiority (EAS) with Expert Coded Air Superiority.

	Inferiority	Parity	Superiority	Total
EAS = 0	10 (5)	7 (6.8)	2 (7.2)	19
EAS =1	0 (1.3)	1 (1.8)	4 (1.9)	5
EAS =2	1 (4.7)	7 (6.4)	10 (6.9)	18
Total	11	15	16	42

Observed value over (Expected) value
Pearson chi2 = 17.2471 Pr = 0.002

A cross tabulation of EAS and air superiority provides interesting insight into the difference between the two measures. A Chi^2 value of 17.3 and p-value of 0.002 show that we may reject the null hypothesis that these two measures are independent of one another. EAS and achieved air superiority are clearly measuring aspects of the same concept. However, note that while EAS predicts well in terms of combatants that go on to achieve either air inferiority or air superiority, EAS has a much more difficult time predicting an actual outcome of air parity –about equal to what we would expect from random chance.

An interesting illustration of why EAS has difficulty predicting cases of parity occurs during the Nagorno-Karabakh War between Armenia and Azerbaijan (1992-1994). EAS predicts that Azerbaijan should have held air superiority during the war, however, our qualitative coding reveals that Azerbaijani forces were unable to benefit from their numerical superiority in the air. Armenia had virtually no air force at all during this war, owning only 2 poorly maintained Su-25 fighter bombers. In contrast, Azerbaijan owned four squadrons (46 aircraft) composed of MiG-21 and MiG-25 air superiority fighters along with a contingent of Su-24 close air support aircraft. Further, Azerbaijan had hired well trained Russian and Ukrainian mercenary pilots to fly these aircraft. As the EAS measure suggests, on paper Azerbaijan should have easily dominated the skies with its fighters and should have been able to employ its ground attack aircraft to maximum effect. However, while lacking in aircraft, Armenia had invested heavily in a sophisticated surface to air missile network. This air defense system was ultimately responsible for shooting down over half of the Azerbaijani air force and prevented the remainder from playing any significant role in the fighting. This example is illustrative of the cases where air parity attains while EAS yet predicts clear air superiority or inferiority. Ground based air defenses, concealment, distance from airfields, and many other factors that are important in air combat can do little to *win* air superiority for the inferior side, but they can do a great deal to neutralize a more powerful country's advantages, leading to cases of air parity where a measure relying only on aircraft inventories would predict air superiority for the numerically and technologically superior side.

Table 11: Correlation of EAS With Air Superiority.

	EAS	Air Superiority
EAS	1.00	
Air Superiority	0.7424	1.00

Further, in predicting inferiority/superiority, EAS correlates with actual achieved inferiority/superiority at 0.74 in our data. This is a strong positive correlation, but demonstrates that EAS is far from the perfect measure of air-combat outcomes. Where the research design of a study allows a more accurate measure to be used, such as the measure we introduce in this article that is designed for studying combat outcomes, researchers should elect to use the more accurate measure over the approximation.

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