Concentration and Asymmetry in Air Combat: Lessons for the Defensive Employment of Air Power

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Have air power theorists learned the right lessons from history? We argue that, in the employment of air power to deny air supremacy or defend surface targets, they have not. The classic hypothesized dynamic of air combat is Lanchester's 'Square Law', under which numbers are disproportionately important. Using data from various air campaigns, we demonstrate that air combat does not obey a tactical Square Law. Rather it consistently displays a very different, hitherto-unobserved property: it is asymmetric between attack and defence. Air power theory's stress on the offensive, combined with a principle of concentration (often framed as 'mass'), obscures this asymmetry. We consider historical air campaigns to show that in air defence, especially when outnumbered, concentration does not equate with mass, instead requiring dispersal and parsimony. This resonates with the British experience: in the Battle of Britain, in the Falklands and in lessons for the future optimal employment of British fighter aircraft.

Introduction

I.

A mathematical model of war is a dangerous thing, as military analysts know. No attempt to predict the outcome of a conflict as a function of the order of battle can possibly survive the fog of war. And yet such models persist, and become ever more complex, ever higher-dimensional. The danger is that one of their principal virtues, the stimulation of careful thought about the quantifiable aspects of combat, becomes lost in the 'black box'.[1] When the UK Ministry of Defence announces that its procurement software has 'millions of variables and constraints', alarm bells should ring.[2]

The discipline of operational research (OR) has flourished for nearly a century, ample time to furnish a historical perspective.[3] The oldest and simplest mathematical models of war are the coupled differential equations of Lanchester.[4] These are very much in the spirit of their age, for they were derived independently in the USA and Russia (although not published there at the time), and their essential conclusions were also reached in France.[5]

Lanchester's aim was to understand the implications of the new conditions of warfare then developing, in which long-range weapons, both aimed and unaimed, enabled force concentration to take new forms. In particular, his 'square law' implies that, in the use of targeted long-range firepower, concentration is disproportionately effective. As we shall see, the irony is that Lanchester's work, and the subsequent formulation of the principles of war by Fuller, who precisely understood Lanchester's point, became distorted through a perspective, a distortion of Jomini and Clausewitz,[6] in which 'mass' became predominant and was conflated with concentration. Indeed, when the US Army adopted Fuller's principles of war in 1921 the term 'concentration' was replaced with 'mass,' a change which has promoted much confusion in doctrinal thinking.

Lanchester believed that the equations of his 'square law' should describe air combat,[7] and it is a striking coincidence that it was his country which, less than thirty years later in the Battle of Britain, had to fight the first great purely aerial battle of attrition. Further, the central controversy of the battle, that of 'Big Wings' whether, all else equal, it was better to concentrate fighters before engagement – was precisely a Lanchestrian question. During the inter-war period, the fighting force which had to answer this question, the Royal Air Force, was conceived, developed its principles and doctrine, and invented its traditions. Its development, and its first great task, the Battle of Britain, were the subject of recent work by two of the present authors,[8] and form a natural beginning from which to approach two questions:

(1) Does air combat obey Lanchester's 'square law' of concentration of aimed firepower?
(2) How should fighter forces, especially in defensive roles and when outnumbered, be employed?

As we shall see, the answer to the first question is 'No'. A meta-analysis, using data from the Battle of Britain, the US-Japanese Pacific air war and the Korean War, leads to a clear overall picture: air combat is not square-law. There is no tactical advantage in terms of concentration to be gained by massing aircraft. Rather the historical data, including engagement-level data from Vietnam, indicate that the opposite can be true for one force, and that attrition scaling in air combat may typically be asymmetric. Cases in which an outnumbered defence achieves its aims, as in the Battle of Britain or the Falklands War, or over Vietnam, thus indicate a nuanced situation, in which asymmetry is the most salient feature. Conversely, the defeat of a numerically inferior force defending the attacker's surface objectives, such as that of the Luftwaffe in the US daylight offensive of 1944-5, does not necessarily demonstrate a tactical advantage in battle for the larger, attacking force: the critical issue might well be the availability of resources for a sustained attritional struggle. In 1940 the outnumbered RAF enjoyed constant and growing reinforcement – in 1944-5 the Jagdwaffe did not. The resources of its enemy grew, the USAAF mounting 559,617 effective combat sorties in the European Theatre in 1944 compared to 50,163 in 1943,[10] while its own diminished at an increasing rate for reasons not exclusively connected with the battle in the air. The Lanchestrian concept of concentration, as refined by Fuller,[11] remains valid at an operational or strategic level, but requires a more subtle treatment than it has typically received.

The latter conclusion changes radically the approach needed to answer the second question. Air power theory has not been strong in conceptualizing the asymmetry between attacker and defender. Principles of air war have typically stressed offence,[12] but the tactics by which an outnumbered defending force can best frustrate an offensive have rarely been discussed, let alone elevated into theory.[13] Asymmetry was first incorporated into Lanchester's models in the 1960s,[14] but the implications for air power have been considered very little. The conditions which lead to asymmetry are those in which the defender can conceal all or part of his force from the attacker's weapons and thus shift the odds in his favour, very dramatically if the defender can still bring all his weapons to bear on the enemy. In such circumstances it is pointless to speak in terms of attrition or loss ratios as the defender has merely to frustrate rather than annihilate the enemy. It is possible, however, to discuss the Lanchestrian concept of concentration as Fuller understood it: as the economical and effective use of firepower.

This paper is structured as follows, in approximate historical order. In section II, based on the authors' previous historical work, we discuss Lanchester models and the Battle of Britain,[15] reviewing the development of ideas which culminated in the 'Big Wing' controversy. In section III we discuss the US experience during the Second World War and over Vietnam. In section IV we answer our first question, by examining attrition data from the Second World War, Korea and Vietnam,[16] and arrive at the conclusions noted above: air combat is not square-law, but it is asymmetric. In section V we explore further our second question, drawing parallels between the Battle of Britain and the use of air power in the 1982 Falklands campaign. Section VI examines the Gulf War of 1991 and lessons for the future, particularly with regard to unmanned aerial vehicles. As we note in a concluding section, the importance of this work lies in the

possibility of unhappy historical experiences being repeated in the absence of a conscious understanding of the influence of false conceptions of 'concentration' on real air warfare.

II.

To anyone steeped in the natural sciences or engineering, Lanchester's ideas are naturally framed as a question about scaling: How do two antagonists' losses scale with their own and their opponents' numbers? From the answer one can deduce for each force an *exponent*, the power of that force's number of engaged units which, when multiplied by their individual effectiveness, yields the force's fighting strength. This in turn allows us to deduce for each force the value of numbers and their concentration relative to individual prowess. Concentration adds to the fighting power of the individual to the extent by which the exponent exceeds one. When the two exponents differ – that is, when a battle is asymmetric – they have a second implication, with the ratio of the two forces' individual fighting effectiveness being multiplied by the ratio of the exponents, giving the side with the lower exponent a 'defender's advantage',[17] classically associated with guerrilla warfare.[18]

Lanchester contrasted two scenarios, in both of which the battle is symmetric, and the two forces' exponents the same. In the first, his 'linear law', the exponent is one, and there is no particular value in concentration. This occurs in 'ancient' warfare, of roughly equal numbers engaging hand-to-hand along a battle line. It also applies to long-range fire when that fire cannot be aimed accurately ('firing into the brown'). This is in stark contrast to his 'square law', where the exponent is two, and which follows from combat in which each force causes losses in simple proportion to its numbers, which Lanchester believed would result from accurate long-range aimed fire.[19]

Lanchester was a keen self-publicist, visiting the western front, corresponding with important figures such as Trenchard and Henderson, and distributing copies of his book widely to Royal Flying Corps officers.[20] His direct influence on the shaping of the RAF was great.[21] Lanchester's ideas were developed by J. F. C. Fuller, whose 1916 principles of war formed the basis of most post-war doctrine, and were taken up wholesale by the RAF via the Army's Field Service Regulations.[22] Fuller's was a subtle understanding of the square law: above all, he appreciated that 'whilst formerly the application of the principle of concentration aimed at massing numbers of men, it should now aim at accentuating weapon-power'.[23] The implications of this distinction for air defence were profound but as yet unappreciated.

When aircraft were new, operational tactics had to be developed for them *ab initio*, first in the combat conditions of the Second World War, and then at greater leisure during the inter war period. Discussion of the development of RAF fighter doctrine tends to be masked by the large literature on use of the bomber, but it is quite possible to trace its development through the inter-war period in the lectures of the RAF Staff College, and this has been done elsewhere by the present authors.[24] It is striking, indeed, how little real intellectual development and exploration there was: the College was deliberately closed to external scholarly influence and

seems rather to have functioned as a vehicle for entrenching an RAF doctrinal culture than as an open-minded and responsive developer of tactics appropriate for rapidly-changing technology.[25] The result was that ambiguity and inconsistency developed in doctrine over time in the absence of rigorous debate and the testing of concepts. Indeed, it has been argued that in most major powers before the Second World War, 'air doctrine, being drawn closely into the general battle doctrine of the army leadership, was still over-influenced by Clausewitzian thinking from which it was slowly disentangled as the war progressed'.[26]

The picture that had emerged on the eve of the Battle of Britain was confused. At squadron level, formation attacks remained paramount as they were assumed to be the best means of concentrating firepower on formations of bombers at a time when the capability of single aircraft to down raiders was not trusted. At operational level, even in 1939 there remained great uncertainty about what bomber formations should be attacked, and whether attacks should be concentrated. The main antagonists – at group level, Park and Leigh-Mallory – could both consider on the basis of their staff college education that their views represented effective concentration. Leigh-Mallory's 'Big Wings' were clearly consistent with the principle of mass.[27] But, as Fuller had emphasized, concentration of aimed weapons – in this case, the fighters themselves – in Lanchestrian terms was a matter of ensuring that all fighter sorties found targets while not becoming targets themselves in the air or on the ground at their stations. As has been pointed out, Park's tactics achieved this, often with very large numbers of planes in the air, but without necessarily achieving local numerical superiority.[28]

Nor was this necessary: Overy argues that in the Second World War, 'air activity was continuous. Air battles in the conventional sense in which armies and navies fought battles could not be fought because air forces apparently defeated could be reconstituted in days by new production, repair or re-siting.'[29] Obsession with mass was therefore inappropriate to the air battle, particularly as 'although superiority could be gained at one moment or in one place it was often to prove during the war that this was at the expense of superiority somewhere else.'[30] The concept of massing aircraft for a decisive encounter could thus be considered illusory. 11 Group units, particularly the Poles, demonstrated that slashing attacks by one or two squadrons on large bomber formations exploited a target-rich environment and degraded the enemy's cohesion while being themselves hard for escorting Luftwaffe fighters to fix and engage successfully.

Before interception there was also less reward for German fighters in bouncing a climbing squadron than a similarly disadvantaged Wing. Indeed, Wings tended to move away from the enemy initially to formate in peace before joining the battle, which limited their involvement and placed units on the ground, the bombers' targets, in danger. The large unwieldy formation was also easier for the enemy fighters to see and parry with their famously fluid tactics when it did arrive. Thus the employment of the Big Wing, which seemed quintessentially offensive to its proponents, seemed rather less aggressive to the enemy and 'suited the Luftwaffe better' than the early, constant and wearing attacks of Park's squadrons.[31]

Another way of framing the situation is as a contrast between offensive and defensive tactics.[32] While Fuller and Lanchester understood that firepower concentration was neutral on this point, the Jominian perspective adopted by the allies' inter-war doctrine emphasized offensive through mass, to which Leigh-Mallory's mind was very receptive, but which did not allow for evolution of Lanchestrian defensive tactics. Indeed, one can perhaps better frame Dowding and Park's parsimonious approach, limiting commitment of the total force and rotating units through the battle area, in very old-fashioned terms, as a reverse-slope defence in which the Luftwaffe was unable to hit the RAF accurately, and north of the Thames not at all.[33] Furthermore, destruction of German bomber formations was not entirely necessary, as disruption resulting in failure to destroy fighters on those stations they could reach achieved a Lanchestrian effect. This was a benefit opposite to the tardy Big Wings' tendency to cause losses by exposing airfields to attack. Thus Dowding and Park's employment of Fighter Command engineered for it a defender's advantage, unanticipated in the pre-war formulations of Lanchester's equations, which never incorporated asymmetry between the forces.[34]

The confusion remained in the famous Air Ministry meeting of October 1940 which led to the removal of Park and Dowding, where it reached its acme in the phrase 'it was generally agreed that ... the more we could outnumber the enemy, the more we should shoot down'.[35] This is clearly the case, but is not what was needed to win even the attritional battle, which was rather to maximize the number of enemy casualties for each of one's own casualties. Mathematically, the crux of the argument is arrived at when one recasts Lanchester's equations as a statement about the casualty exchange ratio (the ratio of the two forces' losses). If this is proportional to the force ratio, the square law follows. If it is approximately constant, the linear law follows. And only in the former case is there any value in mere massing of sorties, all other things being equal.[36]

III.

If Fighter Command in 1940 had won a great victory it did not fully understand as an institution, the same might be said of the USAAF's elimination of the Luftwaffe air defence of Germany in 1944-5. This victory is usually perceived in the context of a transformation achieved by the introduction of genuinely long range fighter aircraft in 1944-5, escorting in great strength US bombers which themselves degraded the German air defence, particularly by attacking its fuel supply. This situation is contrasted with the bloody reverses of 1942-3 when daylight bomber formations proved unable to defend themselves effectively after their escort had turned for home.

However, it is not necessarily the case that massed Mustangs swept the sky of opposition by themselves. In the first six months of 1944, for example, the Luftwaffe destroyed 2,216 enemy aircraft by day over Germany, losing 2,010 itself.[37] These numbers do not speak for the tactical extermination of the outnumbered Luftflotte Reich, especially as allied figures included only aircraft which failed to return from enemy territory and excluded those damaged aircraft which crashed closer to home. Moreover most allied aircrew who survived the loss of their aircraft would become prisoners.

The Jagdwaffe, however, was fighting more numerous enemies on many fronts and faced sharp degradation in 1944 from many causes. Not least of these was Hitler's near complete lack of interest in air defence. His concept of concentration was very much based on mass and the offensive, and he therefore 'refused to sanction the diversion of resources to a defence in depth like that practiced by the RAF in 1940'.[38] He compounded this error with a 'failure to understand how the system of air reserves operated, and insisted that reserves should be used for concentrated operations with the largest numbers that could be mobilised at any one time'.

Even without the malign influence of the Fuhrer, the Luftwaffe faced a hopeless situation in the medium term. The enduring stress caused by having to meet RAF bombing by night as well as US incursions by day, often with the same aircraft and pilots, and the attrition faced on retreating battlefields on the Eastern and Mediterranean fronts was greatly added to by the successful allied invasion of France, which the Luftwaffe was utterly unable to resist. It met 12,837 aircraft with 300 and these, 'along with the German reinforcements were shot out of the skies in ten hours'.[39]

The success of the Normandy landings and the subsequent collapse of the German position in France brought the massive tactical air power of the western allies within reach of Germany, removing a key defender's advantage which had prevailed before June 1944. It also tore a hole in the German radar screen. The Luftwaffe was thus overwhelmed on many fronts and wasted away, unable to pilot and fuel the many aircraft Speer was delivering from factories. Thus, in addition to their own efforts the vast USAAF formations which flew over Germany in 1944-5 were powerfully assisted by a concatenation of other forces. It would be a heroic assumption that massed fighter escort by itself would have turned the tide against an undiminished air defence by day.

The danger, therefore, is to confuse a massive material advantage in the context of total war with the tactical realities of air combat; and, as the Allies waged industrial war so consciously and effectively, this was a tempting mode of thought. Certainly, the victorious experience of 1944-5 reinforced the US emphasis on mass as an interpretation of concentration and enhanced confidence in the pre-war conception that offensive use of air power over the enemy homeland was the key to victory. The formation of Strategic Air Command and its leadership by LeMay embodied this interpretation of the Second World War experience which was left untouched and untested by the Korean War, in which the severe losses experienced by the escorted B-29 force were ascribed to their relative technological backwardness rather than any doctrinal failings. In the non-nuclear context, however, the next thorough test of US doctrine would come in the sustained struggle over North Vietnam, where conditions more closely resembled the Battle of Britain than the fight over Germany.

The American experience over North Vietnam gave full play to the subtleties of asymmetry and placed great strain on the US conception of concentration in air warfare.[40] The USAF and

USN faced a fully integrated air defence and one which could not be degraded by a downward spiral of material resources available to face many tasks as the Luftwaffe had been. The NVAF had only one goal, to resist US incursions on its territory, and it enjoyed secure lines of supply to a superpower through a committed neighbour.[41] Thus without escalating the war to include North Vietnam's allies, or separating the communist states diplomatically as Nixon and Kissinger attempted with temporary success late in the war, US air power faced a daunting task in achieving national goals.

Indeed, the aims of policy were unclear beyond preventing the fall of the South Vietnamese domino. In this context the offensive use of US air power would involve a bomber offensive intended to produce a collapse of the political will to continue the war in Hanoi. USAF and USN pilots thus found themselves in a position more closely resembling the Luftwaffe after 7 September 1940 in the Battle of Britain than the USAAF over Germany later in the Second World War, in that the air arm was used optimistically in pursuit of an ill-defined political effect intended to produce victory.[42]

The stage was thus set for a protracted battle of attrition in which it was revealed that mass was not synonymous with concentration. Though the US deployed its air assets continuously on a colossal scale, the failure of bombing to produce a strategic as opposed to a political result placed an enormous strain on the larger force.[43] Facing a fully integrated air defence the USAF and USN were constantly exposed to loss from ground fire of all types and a small but agile fighter force which inflicted steady losses but which did not itself suffer sufficient attrition to reduce its core strength over time.[44] American aircraft proved less suited to the struggle than obsolescent Soviet types such as the MIG 17 and MIG 19 which were nevertheless well-adapted for the air defence role, particularly against American types such as the F105, which was designed for the nuclear battlefield and was notably deficient in air-to-air combat.[45] The NVAF thus achieved concentration in that it maximised the effectiveness of its weapon power, whereas the US emphasis on fruitless bombing did not. The combat situation thus produced a political outcome opposite to that which was intended, matching that of the wider war in which the US public were not willing to countenance continued losses and expenditure without a clearly identifiable victory.

IV.

A pivotal figure in US air power theory since Vietnam is John Warden, the architect of the 1991 air war against Iraq and the last great doyen of the massed air campaign. Warden's first significant opportunity to advocate such views came when he took command of the Bitburg F15 wing in 1986, at a time when 'the established view [was] that NATO would necessarily be on the defensive in the first few days of a European war', and tactics assumed two- and four-fighter formations. Warden was an outspoken advocate of Big Wing tactics. 'He was convinced that the practice of pitting small numbers of highly capable fighters like the F15 against very large numbers of enemy [aircraft] was a recipe for disaster.' Instead he 'told his pilots that they should assume that a combat wing formation consisted of 56 aircraft'.[46]

Warden's *The Air Campaign* was published in 1988, just before he returned to the Pentagon. In it he nowhere discusses Lanchester's equations explicitly, but the work is suffused with belief in numerical superiority.[47] Warden's views are expressed very precisely, as the belief that 'Loss rates vary disproportionately with the ratio of forces involved … as the force ratios go against one side, that side will have greater loss rates than the changed ratio would suggest'.[48] This is an even stronger statement of the value of concentration than the square law which itself is still being used as a justification for views on air power policy.[49]

Since Warden claimed to have based his views on historical and statistical evidence,[50] it is worth going over this in some detail. Despite the many hundreds of papers on Lanchester theory that were written in the second half of the 20th Century, there is none that does so for air combat, nor indeed any theoretical treatment of concentration and asymmetry.[51]

Before looking at the statistical evidence, it is important to understand the effects of data aggregation. For most of the possible scaling regimes of losses with numbers, there are density effects, so that the generalized Lanchester equations only apply to individual engagements. To the extent to which the data aggregates these, it has two effects. First, it increases the apparent randomness, reducing goodness of fit, and making it harder to distinguish between linear and square laws. Secondly, it biases the results, pushing the overall scaling power of each side's loss rate towards one.[52] In a symmetric battle this bias is neutral in its effect on the single overall exponent. In an asymmetric battle, aggregation has a neutral effect on the average of the exponents, but alters the difference between them. Typically it reduces the apparent asymmetry between the two forces. Thus any observed difference between the two forces' exponents is probably underestimated: the true asymmetry will be greater than is apparent from the data.

In the Battle of Britain the best that we can do is to aggregate each day's sortie and loss numbers. When we do so, we find that the best estimates of RAF and Luftwaffe exponents are 0.8 and 1.3 respectively. Thus the RAF certainly had a defender's advantage, and (since its exponent is less than one), certainly did not benefit from mere mass. For the Luftwaffe there is modest evidence of an advantage in concentration (since 1.3>1) but little for a full square-law effect. A robust conclusion is that, while the battle overall was approximately linear- rather than square-law, it was certainly asymmetric, since the RAF defender's advantage, evident in the difference of 0.5 between the exponents, will have been reduced from its true value by the biasing effects of aggregation.[53]

Similar data for the US-Japanese Pacific Air War of 1942-45 mixes small engagements and aggregates of these. With exponents of 1.3 and 0.9 respectively for US and Japanese forces, once again we see an approximately linear-law battle with a strong (and probably understated) asymmetry between US attack and Japanese defence.[54]

The simplest way, both mathematically and intuitively, to seek evidence for a symmetric square law is to ask how the casualty exchange ratio (CER) depends on the force ratio (FR). The square

law holds if the CER is proportional to the FR, while the linear law holds if the CER is constant and independent of the FR. For the Battle of Britain, with the true data, there is almost no such dependence: the proportion of variance described by the best-fitting power of the force ratio is always less than 0.05. Results are similar for the Pacific air war.[55]

Warden bases his claim for such dependence of the CER on the FR, noted above, on a 1970 study of two data sets: monthly data from the Korean War, and a study of twelve campaigns of the Second World War.[56] The Korean data do not support any such conclusion.[57] It is only in the Second World War campaigns that there is any evidence for the square law, and this data set suffers severely from two problems: first, extreme aggregation of data, and, secondly, what Helmbold famously called 'the constant fallacy', in which the data points differ in both numbers and effectiveness of individual sorties, so that the data are not controlled for the latter and it is impossible to disentangle the two.[58] Thus the only evidence here for the square law is in the worst, most aggregated and inappropriate data.

The very best data we have is for Vietnam. Here, for the first time, we have details of numbers and losses on both sides in individual encounters, from January 1965 to July 1967.[59] Thus this is the case in which we can most clearly discriminate the effects of numbers in small engagements. Because the numbers are small (mostly single figures on each side, and including many zeros), rather than seek scaling laws and exponents we instead performed the simplest possible analysis, linear regression of the two sides' losses against their numbers. Effectively, we are limiting ourselves to the simple question 'Are losses proportional to numbers or are they not?' While the proportions of variance explained are small (because the numbers of aircraft engaged are small and thus the randomness great), the results are nevertheless stark. US losses are *not* significantly dependent on either their own or enemy numbers. However, North Vietnamese Air Force (NVAF) losses against F4s (fighters) are significantly proportional to both their own and enemy numbers, while those against F105s (fighter-bombers) are mildly proportional only to their own, NVAF numbers.[60]

From the US point of view, Warden is thus proved partly correct: F4s, at least, should sortie in large (up to squadron-size) numbers, not for their own safety but in order to shoot down enemy aircraft. But the campaign is asymmetric, and such a conclusion would be diametrically wrong for the NVAF, for whom the correct approach is to be parsimonious, sortieing in small numbers and avoiding large encounters. For the NVAF, losses are proportional to the total number of aircraft in an engagement, yet only slightly (if at all) dependent on the extent to which they are outnumbered.[61]

To summarize: if one had begun with the null hypothesis that air combat is a simple, symmetric, linear-law battle – a set of duels – one would reach the conclusion that there is no evidence to reject the linear law in favour of the square law.[62] However, in the cases for which we have the best data we observe a distinct asymmetry, between the attacker, for whom 'mass' may be an effective principle, and the defender, for whom it certainly is not. Thus the early

Lanchestrian view of attrition in air combat – that it is square law and symmetric – is precisely wrong. The answer to our first question is 'No, air combat is not square-law – but it *is* asymmetric'.

V.

So there is no principle of mass in defensive air warfare. Rather, and in answer to our second question, there is no evidence that one can do better than the pragmatic approach, as practised to good effect by British forces from the Battle of Britain to the Falklands campaign,[63] of getting the best available aircraft and honing the tactics which will utilize them, typically in small numbers, to their best possible relative advantage.

Indeed the Falklands War is possibly the most appropriate post-Second World War conflict for examination of Lanchestrian ideas.[64] Involving a discrete conflict with clear objectives for both sides and a limited number of aircraft, conditions similar to the Battle of Britain were recreated for the aerial battle. Nigel 'Sharkey' Ward's memoir of the conflict, as commander of *Invincible*'s 801 Squadron FAA, is (in every sense) combative, yet is quite unconscious in its echoes of the 1940 battle: Ward's thinking developed from his experience of air combat training and was not informed by any doctrinal influence stressing Park's tactics in 11 Group. Particularly striking is his contention that his own clear concept of the necessary role of carrier aircraft was not understood by a leadership group (on HMS *Hermes*, 'Flag,') whose conceptions now seem to owe more to the 'Big Wing' idea which emerged institutionally triumphant from the Second World War.[65]

Much commentary at the time emphasized that the British Sea Harrier force was decisively outnumbered (in the region of 10 to 1), and a number of pilots and Task Force personnel shared this fear. Ward, steeped in fighter tactics, argued that the essence of the battle he would fight could not be reduced to a 'numbers game' in this way, and that the disparity between the outnumbered British carrier aircraft and the entirety of the enemy air force was not a decisive issue. The objective was rather to impose the British agenda, frustrate the enemy's objectives completely and maintain the Sea Harrier force in being during the process. As with 11 Group's experience in 1940, Ward's training had exposed the difficulty for a large formation of attacking aircraft in dealing with a relative handful of opponents. He notes that by maintaining Combat Air Patrols (CAPs) of two aircraft he could impose his will on the enemy: 'The key to disrupting or dissuading a large number of aircraft from attacking was to get in amongst them with a small number of easily controlled fighters. One pair let loose against 10 or 15 bogeys could easily keep track of each other, whereas the opposition would have great difficulty in sorting out friend from foe. I had experienced this on several occasions in the past during exercises.'[66]

This analysis resonates with the experience of Park: to try to assemble a mass of aircraft in the hope of achieving a decisive attritional result was effectively to chase an illusion.[67] In terms of concentration the unit of mass could be as small as the individual aircraft, or pair of aircraft, and the aim was not to destroy the maximum number of enemy aircraft but to defeat their mission. The correctness of this analysis was demonstrated during the only solely air-to-air phase of the

campaign, on 1st May 1982, when the Argentinian air arm made its only attempt to gain air superiority while attacking the Royal Navy's carriers, effectively the British base. Although the number of attackers destroyed was small, their enterprise was utterly defeated and enemy groupings turned for home after the initial clash, convinced of the tactical futility of continuing their attacks against an air base and its defences which could simply move out of range and pick them off at will.[68]

After the British landing at San Carlos Water, the difficulty for the Sea Harrier force was increased, as it became necessary to defend a fixed position within range of enemy air attack which offered numerous hidden avenues of approach. Ward nevertheless believed that a low level CAP mounted by the entire Sea Harrier force, operating as the outer layer of a defence in depth, could defeat the enemy mission. A recent analysis of Argentine air operations in the conflict reveals that the mere fact of detection by a two-aircraft Harrier CAP was often enough to cause the enemy to jettison their ordnance, including scarce drop tanks, and retire without engagement.[69] Thus, while the British possessed too few aircraft to seal the beachhead, they could reduce the numbers getting through to a total insufficient to halt the landing. In this context, any kills were a bonus which enhanced the Harriers' deterrent effect. In fact Ward claims that: 'Without the jump-jets' extraordinary deterrence factor and its combat results in defence of San Carlos, the amphibious landings would probably have realised unsupportable casualties.'[70]

Ward, however, contends that these results were obtained by 'three pairs' of CAP patrols and that effectively only half the Sea Harrier Force, his own 801 Squadron FAA, performed this essential function. 800 Squadron on *Hermes* pursued what for Ward was the 'arguably misguided' policy of high level interception. It is not, therefore, surprising that Flag did not (according to Ward) understand the dynamics of the situation if the views of both mirrored conflicting interpretations of the Battle of Britain.[71] In 1940, the Big Wing took valuable time to climb and form up away from the threat and then came in to deliver a massed attack, but only after the bombing aircraft had hit their targets and were returning to base. Ward effectively contends that the decision by Flag to have *Hermes*' aircraft perform CAP at high altitude had the same effect, in that they had to descend to engage, by which time and 'critically, [they] were only able to engage enemy attack aircraft after the latter had been through their target (San Carlos) and when they, the CAP, were directed down onto the tails of the escaping Argentine aircraft'. The effective absence of 800 Squadron at key moments, Ward contends, thus resulted directly in avoidable losses of British ships as raiders infiltrated through the gaps they left. Thus: 'More CAPS at low level would have increased the deterrence factor and kept more attackers away.'[72]

However, an argument could be made that if the detection of a CAP was sufficient reason to abort a raid, then the higher, more easily detectable, CAP might have served a deterrent purpose inadvertently. Actual Argentine losses to Harriers often occurred at low level when, absorbed with their mission, raiders failed to see their attackers until missiles had been fired upon them.[73] From the British point of view a raid undramatically thwarted had a value as did

a raid destroyed. There is an echo here of the later stages of the Battle of Britain, when the sight of an approaching Big Wing had a moral effect on German aircrew, whatever its operational shortcomings.

The experience of British forces in the Falklands conflict in achieving victory in the air with dangerously limited resources is instructive. However, in the US this idiosyncratic war was rather dissonant with established doctrine, and successive Air War College theses failed to conceptualize the asymmetry of the situation. The Argentines, it seemed, failed for lack of mass, not for lack of material capability and advantage.[74]

VI.

The Falklands War was overshadowed by the far larger Gulf War of 1990-91. Many perceived this as the truly decisive modern event in the development of air warfare, the 'apotheosis of twentieth century air power'.[75] Warden, its architect, conceived the campaign as *Instant Thunder*, in conscious distinction to the perceived error of Vietnam's more gradual Operation *Rolling Thunder*.[76] The destruction of the air defence system of a 'well-endowed opponent'[77] in a matter of hours, or indeed within the first hour, was seen to have produced a decisive shift in the capability of offensive air power, and to have overcome the difficulties faced by the USAF in Vietnam. Indeed, 'the coalition's loss rate to Iraqi surface defences by the end of *Desert Storm* was only one aircraft per 1800 combat sorties, 14 times lower than the US loss rate to enemy defences in Operation *Linebacker II* against Hanoi during the Vietnam War a generation earlier.'[78] The orchestration of allied air forces delivering multiple simultaneous attacks, and thus presumably achieving concentration, was contrasted with 'the halting conduct of Operation *Rolling Thunder* against North Vietnam from 1965-8'.[79] The use of precision guided munitions delivered by stealth aircraft, and the successful application of drone-inspired SEAD techniques perfected by the Israeli Air force against Syrian air defences in the 1982 Lebanon conflict, lifted the shadow of Vietnam from the USAF as effectively as the Gulf War did from so many other areas of American consciousness, and made possible the defeat of the enemy through '*functional* effects, rather than through a more classic drawdown by way of attrition'.[80]

There are caveats, however. The extent to which Iraqi air defence was 'well-endowed' is questionable. It was certainly lavishly equipped for the size of the state it defended, Iraq possessing a population in 1990 slightly larger than the Netherlands'. However, it was devoid of allies and in terms of the forces ranged against it, consisting of a massive international coalition wrapped round NATO's Cold War core, hopelessly outmatched. Nor did it make any special attempt to prepare its air defences, choosing instead to hide and evacuate, rather than disperse, its aircraft and save the bulk of them for more manageable future conflicts while simply waiting for the blow to fall on the remainder. Even though the Coalition air campaign was carried out with notable efficiency, the outcome was never in doubt.

Iraq's position was analogous to the Luftwaffe in 1944-5, and US experience in the Gulf War was also more closely fitted to that conflict than to Vietnam. For although the Gulf War revealed

advances in offensive air power it had nothing to say about advances in defensive technique and it would be dangerous to say that Iraq's defeat proved that there had been none. The totality of historical experience in the areas of concentration, asymmetry and air defence should rather be seen as relevant to the near future. Indeed, in the conditions now faced by western powers, of financial stringency and rising new challengers, there is a far greater emphasis than previously displayed on the optimal use of resources. The age of the overwhelming coalition seems to be over.

Surprisingly, economy is seen to be embodied in the form of new technologies and in speculation about an unmanned future in which robotic aircraft will become the principal units of air combat.[81] For developing countries, who 'always find themselves at a disadvantage when it comes to bridging the gap between technology and force levels,' the Unmanned Combat Aerial Vehicle (UCAV) 'could provide lower operational costs and increase sortie rates'.[82] At the other end of the scale but with similar difficulties the British MOD is particularly interested in unmanned technology, after deep cuts have been made to air assets in recent years, including pilots in training.[83] However, while the promised environment of unmanned scientific and technical purity is closer than before, it is nearly 60 years since the Sandys Report promised the near-immediate elimination of manned interceptors in the RAF and thus caution is advisable. Nevertheless, an environment in which manned, remotely piloted and robotic aircraft are integrated is now with us; and this relationship will only become more deeply enmeshed and sophisticated as time passes and the balance shifts in favour of unmanned aircraft.[84]

It is surprising, therefore, that the possibilities of the UCAV as part of an integrated air defence have not been studied more intensively, particularly in support of an outnumbered force.[85] There are many possible reasons for this. Air power theory stresses the offensive, while recent commentary has concentrated on counterinsurgency and the use of drones for surveillance and targeted strikes on insurgents, and on the ethical and political problems raised by their use in these ways. It is also argued that unmanned aircraft are unsuited for air defence on the grounds of inferior performance relative to manned fighters, though there are no restrictions on the severity of high–*g* manoeuvres of the type encountered with manned aircraft. They also lack the sensor suite and data transfer capacity required for a remote pilot to engage in air combat, while fully autonomous robot aircraft are some distance from this capability and face difficulties in separating friend from foe.

However, unmanned aircraft of various types will only improve in these areas relative to manned aircraft over time, and the existing level of technology provides a potentially powerful air defence capability utilising aircraft with varying degrees of sophistication. The historical experience of air defence is that disruption of enemy attacks combined with sustained rather than spectacular attrition offers the best hope of victory.[86] In this context the UCAV's long endurance and low unit cost relative to manned aircraft may matter rather more than agility. A UCAV can, for example, remain on CAP for an extended period, locate an incoming enemy

force and fire missiles at it, causing sufficient disruption to defeat its mission. As importantly, UCAVs can add to the effectiveness of airborne early warning, creating a three dimensional multi- aspect coverage which would make the operation of stealth aircraft much more difficult, as well as obviating their use for precision strikes on ground based command nodes in the air defence system.[87]

There is a possible danger in attempting to replicate the performance of manned aircraft in remotely piloted or robotic vehicles, in that the complexity and thus the cost of such a vehicle may rise to a level close to that of a manned aircraft.[88] In the context of an integrated air defence based on Lanchestrian principles there is perhaps a point at which diminishing returns might be encountered in developing UCAVs such as the American X-47 or the British Taranis. Between the Battle of Britain and Vietnam, technology moved the balance of forces in the direction of the defence, in that AAA and SAM technology improved so rapidly that a genuinely integrated air defence became possible. The principle of economy achieved by Park and the Luftwaffe, before it was overwhelmed, was manifested much more effectively by the North Vietnamese in countering the most powerful air arm in history with very limited resources. The advantage apparently regained by the offensive during the Gulf War was effectively another example of the application of overwhelming force, in which the systemic mathematical advantage of the defence did not come close to offsetting the material advantage of the attacking force.

Unmanned technology, along with other advances in detection and communications, should make possible deeper and broader integration in air defence and present an attacking force with an ever greater range of difficulties to be countered at ever greater expense. There should also be growing implications for the idea that 'cheaper' nuclear deterrents are possible and a still more defined appreciation of the immutable truth that has existed since the 1950s, that ballistic missiles remain the only unstoppable form of air attack. Indeed, the recently announced development of the SR72 hypersonic strike aircraft is an acknowledgement of this fact, in recognising that aircraft can only defeat an integrated air defence if they assume some of the qualities of the ballistic missile. If it really is the case that 'Speed is the next aviation advancement to counter emerging threats in the next several decades'[89] then the inability of stealth to overcome air defence in the same time frame is tacitly admitted.

VII.

Air power in war, according to Phillip Meilinger, is both a strategic force and, primarily, an offensive weapon.[90] But, as we have seen, air power is not symmetric, and the organization of air defence to deny air power theorists' propositions may require subtly different principles, which clearly separate offensive-mindedness from conceptions of concentration. Further, the British experience in the Falklands War suggests that celebration of mass, born before the Second World War and cemented in doctrine during it, has had a remarkably long shelf-life considering the lack of evidence in its favour. In the context of defensive aerial warfare, it seems, there is no advantage in mere concentration of numbers of aircraft in single engagements.

What of the cultural lessons? As we have seen, to have acted on square-law principles of mass and offensive would have been the wrong tactics for the Battle of Britain, a conclusion reinforced by the evidence from Leigh-Mallory's 1941 fighter sweeps over France. We would argue further that neither the formalization of the principles of war nor the mathematization of the effects of firepower concentration aided RAF inter-war development of fighter tactics. They led to clarity neither of thought nor in the resulting doctrine, rather serving to reinforce the RAF's developing identity and invented tradition, so that, in the immense organizational and technical achievement that was Fighter Command in 1940, tactics were the weakest point. Of course the RAF, unlike the Luftwaffe, had not had the opportunity to learn from experience in the Spanish Civil War. But principles and models, if they are to have any worth, should give a military force a higher level of thinking, enabling it to adapt rapidly to changing technology and campaign scenarios.

The development of scholarship in the post war period has tended to repeat the confused development of the interwar period. The organisational victory of the Big Wing in the UK and a similar tendency to celebrate mass in the US might be said to spring from the same Lanchestrian root, propagated by interwar development in British and US staff colleges. In US doctrine, use of words such as 'mass' and 'focus' continues to suggest that concentration must have a spatial centre, a 'decisive place', and militates against a more subtle understanding of the role of dispersal and concealment in defensive tactics.[91] It has to be considered a failure of OR that it did not conduct the contemporary meta-analysis of the mid-20th Century wars which would have shown that air combat does not obey the square law. At the level of fine tactical detail, aerial clashes did not provide promising material for analysis until the Falklands War of 1982 pitched air arms against each other over water. Here, doctrinal problems were again evident, with clashes between different conceptions of fighter tactics echoing the 1940 experience.[92]

More recent clashes have also tended to obscure the fallacy of mass, as hopelessly outmatched air forces such as that of Iraq have been overwhelmed by combined western air forces.[93] Future operations may not be so one sided, however. It is not impossible to imagine circumstances in which a much-attenuated British air arm might have to fight alone, or even that US air power might be faced by multiple simultaneous threats and be forced to engage at a numerical disadvantage in a particular theatre. In a defensive air battle the lessons of history might have to be relearned yet again, and tactics and technology adapted.

Ultimately, the equation of concentration with mass has hindered understanding of the principles of attrition in air war. The lesson reiterated in the conflicts of 1940, 1965-7 and 1982 is that effective defensive concentration does not depend on mass, and that the effective unit of concentration can be as small as the individual aircraft if it can exert a deterrent effect on multiple opponents. More broadly, the development of tactics and strategy for a future air war requires a clear and detailed understanding of the evolution of the principles of war, from their inception to the present day, as a historical process. Such a study suggests, at the very

least, that grave difficulties have resulted from the metaphor of mass, the doctrinal emphasis on the offensive, the assumption of symmetry between forces, and the incorporation of these in air power theory.

Notes

[1] This view of mathematical modelling of war is expounded in T. W. Lucas and J. E. McGunnigle, 'When is model complexity too much? Illustrating the benefits of simple models with Hughes' salvo equations', *Naval Research Logistics* **50** (2003) 197-217.
[2] L. Hoehl and T. Scales, 'Using linear programming to support high level defence procurement decisions', proceedings of *Mathematics in Defence*, QinetiQ, Farnborough, November 2009.
[3] The standard work is M. Kirby, *Operational Research in War and Peace: The British Experience from the 1930s to 1970* (London, 2003).
[4] F. W. Lanchester, articles in *Engineering* 1913-14, reprinted in *Aircraft in Warfare: the Dawn of the Fourth Arm* (London, 1916).
[5] J. V. Chase, 'A Mathematical Investigation of the Effect of Superiority of Force in Combats Upon the Sea', unpublished secret paper, 1902 (reprinted in Appendix C of Fiske, Fighting Machine, below); B. A. Fiske, 'American Naval Policy', USNI Prize Essay, Proceedings of the United States Naval Institute **31** (1905) 1-80 and 'The Navy as a Fighting Machine' (New York, 1916 and Annapolis, 1988); Lt A. Baudry (French Navy), *The Naval Battle: studies of tactical factors* (London, 1914); M. Osipov, 'The influence of the numerical strength of engaged forces on their casualties' (1915), trans. R. Helmbold and A. S. Rahm, *Naval Research Logistics* **42** (1995) 435-490.
[6] See for example J. J. Schneider and L. L. Izzo, 'Clausewitz's elusive center of gravity', US Army War College *Parameters*, September 1987, pp. 46-57.
[7] An explicit statement of this during the Second World War is in his Letter to the Editor, *Engineering* **154** (1942) 174.
[8] I. R. Johnson and N. J. MacKay, 'Lanchester models and the Battle of Britain', *Naval Research Logistics* **58** (2011) 210-222; Niall MacKay and Christopher Price, 'Safety in Numbers: Ideas of concentration in Royal Air Force fighter defence from Lanchester to the Battle of Britain', History **96** (2011) 304-325.
[9] N. J. MacKay, 'Is air combat Lanchestrian?', *Phalanx: the Bulletin of Military Operations Research* **44** no.4 (2011) 12-14.
[10] USAAF Statistical Digest, Table 119: Airborne and Effective Combat Sorties flown in the European Theatre of Operations, August 1942-May 1945.
[11] J. F. C. Fuller, *The Foundations of the Science of War* (London, 1926).
[12] Recent examples are Phillip S. Meilinger, *Ten Propositions Regarding Air Power* (Washington, DC, 1995) and J. A. Warden III, *The Air Campaign: planning for combat* (Washington, 1989). But the criticism applies throughout the history of airpower theory: '[Trenchard's] emphasis on the importance of offensive action has remained a constant theme in the history of air power thinking.' Group Captain Peter W. Gray, 'Air Power: Strategic Lessons from an Idiosyncratic Operation', in S. Badsey, R. Havers and M. Grove (eds), *The Falklands Conflict: twenty years on* (London, 2005).
[13] US air power defensive doctrine is to 'detect, identify, intercept, and destroy' enemy air forces.

The conception is thus of attrition in the air, rather than of preventing the aerial enemy from achieving its surface objectives. *Basic Aerospace Doctrine of the United States Air Force*, Air Force Manual 1-1, vol. I (Washington, 1992), p. 6. This is later nuanced as 'defeating the enemy's defensive plan and … inflicting unacceptable losses' (p. 11), but the possibility of tension between these two goals is not explored.

[14] S. J. Deitchman, 'A Lanchester model of guerrilla warfare', *Operations Research* **10** (1962) 818-827.

[15] I. R. Johnson and N. J. MacKay, 'Lanchester models and the Battle of Britain', *Naval Research Logistics* **58** (2011) 210-222; Niall MacKay and Christopher Price, 'Safety in Numbers: Ideas of concentration in Royal Air Force fighter defence from Lanchester to the Battle of Britain', History **96** (2011) 304-325.

[16] Full details in MacKay, 'Is air combat Lanchestrian?'.

[17] See Johnson and MacKay.

[18] See Deitchman.

[19] An elementary mathematical introduction is given by one of the authors in N. MacKay, 'Lanchester combat models', *Mathematics Today* **42** (2006) 170-173. By framing the question as 'Is there a scaling law for attrition?', we are stepping back from Lanchester's association of his square law with aimed long-range fire. In air combat the natural unit is the sortie, and the question becomes whether a sortie tends to cause a kill (leading to the square law), a loss (leading to the 'logarithmic law'), or some mix of the two, summarized by the exponent.

[20] Lanchester archive 514.16-514.99, Coventry University.

[21] See for example R. Higham, *The Military Intellectuals in Britain 1918-1939* (New Brunswick, 1966), John Buckley, *Air Power in the Age of Total War* (Bloomington, 1999), J. E. ('Johnny') Johnson, *Full Circle: The Story of Air Fighting* (London, 1964).

[22] N. Parton, 'The development of early RAF doctrine', *Journal of Military History* **72** (2008) 1155-1177.

[23] Fuller, *Foundations*, p. 271.

[24] MacKay and Price.

[25] This has been commented on elsewhere regarding RAF bomber doctrine: see T. D. Biddle, *Rhetoric and Reality in Air Warfare: The Evolution of British and American Ideas About Strategic Bombing, 1914-1945* (Princeton, 2002).

[26] R. Overy, *The Air War 1939-45* (London, 1980), p. 9.

[27] Indeed Leigh Mallory's views on fighter tactics were set out at length in 1928 and changed very little thereafter. T. Leigh-Mallory, 'The maintenance of air superiority in a land campaign', *RAF Quarterly* **2** (1931) 245-252.

[28] Peter Townsend, *Duel of Eagles* (London, 1970). Park's approach would have been in flat contradiction to US air power doctrine, where the principle of concentration is that 'Aerospace power is at its most effective when it is focused in purpose and not needlessly dispersed'. Again the possibility of tension, here between unity of purpose and unity of place, is not discussed. *Basic Aerospace Doctrine of the USAF*, p. 8.

[29] Overy, *The Air War*, p. 9.

[30] Overy, *The Air War*.

[31] D. Wood and D. Dempster, *The Narrow Margin* (London, 1961), p. 272.
[32] Wood and Dempster, *Narrow Margin*, p. 273.
[33] Indeed one can find an echo of the two contrasting conceptions of concentration, mass versus firepower, in the Napoleonic column and the British line.
[34] Recall that, in the generalized Lanchester approach we described at the beginning of section II, the defender's advantage is realized in differing values of the two forces' exponents. The force with the lower exponent benefits from cover and concealment, and, bound up with this, gains less from mere concentration of numbers. See MacKay and Johnson, and the appendix to MacKay and Price. Readers steeped in the operational research literature should note that this is very different from Helmbold's 'advantage parameter,' which is not a fixed parameter of the dynamics at all but rather a variable, related to cumulative losses. See *The Advantage Parameter*, Tactical Analysis Division, US Army Concepts Analysis Agency, July 1997. CAA-MR-97-3.
[35] The minutes are reproduced in Dilip Sarkar, *Bader's Duxford Fighters: The Big Wing Controversy* (Worcester, 1997) and in Douglas Bader's 1969 notes on the controversy, RAF Museum London MF10073.
[36] Of course one of Park's central points was that all else was typically not equal: he simply did not have the time to form wings or Big Wings. Rather `It [is] better to have even one strong squadron of our fighters over the enemy than a wing of three climbing up below them' (K. Park, memo of 1st October to 11 Group, reproduced in Sarkar, *Bader's Duxford Fighters*).
[37] A. Price, *Battle Over the Reich: The Strategic Bomber Offensive Over Germany*, Vol.2, (Hersham, 2005) p. 219.
[38] Overy, *The Air War*, p. 78.
[39] Overy, *The Air War*, p. 77.
[40] Since its inception in 1947, the USAF had endorsed concentration as a fundamental principle of war. It was an article of faith within the new service that the US Army Air Forces had achieved this objective to decisive effect during their Second World War campaigns over Germany and Japan. This experience reinforced the USAF's interpretation of concentration as 'mass', and enhanced the service's confidence in the classical conception of air power as primarily an offensive weapon capable of independently achieving decisive results. Robert F. Futrell, *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force*, Vol. II, *1961-1984*, (Maxwell AFB, Al, 1989), p. 6; James L. Cate, 'Development of United States Air Doctrine, 1917-1941', Eugene M. Emme (ed.), *The Impact of Air Power, National Security and World Politics* (Princeton, 1959), pp.187-190; David P. Handel, 'The Evolution of United States Air Force Basic Doctrine', unpublished research study (Maxwell AFB, Al, 1978), pp. 37-40 & 52-53, & Earl H. Tilford, *Setup: What the Air Force Did in Vietnam and Why* (Maxwell AFB, Al, 1991), pp. 1-40. See also: Kurt A. Chichowski, *Doctrine Matures through a Storm: An analysis of the New Air Force Manual 1-1*, thesis, School of Advanced Airpower Studies (Maxwell AFB, Al, June 1993).
The validity of the principle of concentration-as-mass remains accepted within the USAF as a generally-applicable truth. The *Warrior Knowledge Handbook* (2014), provided to USAF ROTC students still contains the 'principles' of war, including 'concentration', here entitled 'mass' and defined as 'concentrate combat power at the decisive time and place'. LLLAB6.
[41] According to a JCS report of 25 April 1968, as long as North Vietnam continued to receive

equipment from its external Communist supporters it would be able to continue to operate an effective air defence system, and it was impossible to eliminate the MiG threat while the NVAF continued to employ Chinese air bases near the North Vietnamese border that were off-limits to US air strikes. Herman S. Wolk, *USAF Plans and Policies, R & D for Southeast Asia, 1968*, (Office of Air Force History, July 1970) & Thomas C. Hone, 'Southeast Asia', in Benjamin F. Cooling, (ed.), *Case Studies in the Achievement of Air Superiority*, (Washington, D.C, 1994), p. 541.

[42] The USAF was confident that an intense bombing campaign over North Vietnam would force Hanoi to abandon its support for the insurgency in the South. At the outset, however, the shape of the US air campaign over North Vietnam was not one of the USAF's own choosing, but one thrust upon it by the civilian executive: the pressure was to be gradually increased on North Vietnam so that it would be encouraged to accept a negotiated solution that would guarantee the independence of South Vietnam. Gradual coercion, however, involved gradual escalation, and it has been argued that the final shape of the American ROLLING THUNDER campaign between 1965 and 1968 may not have been so very different from that originally envisioned by the USAF. Robert A. Pape Jr, 'Coercive Air Power in the Vietnam War', *International Security*, **15**:2 (Fall 1990), pp. 118 & 123-124.

[43] US and South Vietnamese aircraft flew about 350,000 attack sorties over North Vietnam throughout the war, delivering approximately 800,000 tons of bombs, but neither Washington nor the US military ever fully appreciated the full extent of Hanoi's commitment to the objective of national reunification. Nor, when one considers the circumstances of the war in South Vietnam between 1965 and 1968, was the interdiction of the line-of communications between North Vietnam and the South ever likely to yield a significant or permanent diminution of the NLF strength in the South. The less-constrained LINEBACKER campaigns of 1972 were more effective in impeding the North Vietnamese offensive of that year and forcing Hanoi into negotiations that would permit US withdrawal, but these were lesser objectives than those for which the USA had originally gone to war in Vietnam – indeed, by the light of those original objectives the USA had already lost the war by 1972. The point here is that 'mass', in terms of 'massive' bombing, did not constitute concentration at the decisive point, because it was not applied to a facet of North Vietnam's society or war effort that could significantly influence the outcome of the war. Wayne Thompson, *To Hanoi and Back: The United States Air Force and North Vietnam, 1966-1973* (Washington, DC, 2000), p. 301 & Pape, 'Coercive Air Power', pp. 144-146.

[44] According to US figures USAF and USN combat losses over North Vietnam during ROLLING THUNDER totalled 526 aircraft, with 54 aircraft lost to SAMs, 430 aircraft lost to anti-aircraft artillery, and 42 aircraft shot down in air-to-air combat. John Schlight, *A War too Long: The USAF in Southeast Asia, 1961-1975* (Washington, DC, 1996), p. 53. During the entire course of the air war over North Vietnam the USA lost 67 aircraft in air-to-air combat while the VNAF lost 137 aircraft to US fighters, a kill ratio of approximately two to one in the US favour. Throughout most of the war the VNAF maintained an interceptor force of 60 to 75 aircraft. Rebecca Grant, 'The Crucible of Vietnam', *Air Force Magazine* **96** no.2 (2013) 74-78.

[45] The Communist aircraft were designed from the outset as short-range interceptors. The MiG-19s and 21s outclassed the American F-105 by a considerable margin and could hold

their own against F-8s and F-4s. Although obsolete and with an inferior performance to the American aircraft in a vertical fight, the MiG-17 still proved a dangerous adversary in horizontal engagements below 500 knots. Marshall L. Michel III, *Clashes: Air Combat Over North Vietnam, 1965-1972* (Annapolis, Md, 1997), pp. 75-76, 79-84 & 86.

[46] J. A. Olsen, *John Warden and the Renaissance of American Air Power* (Dulles: Potomac, 2007), p50-96. Olsen notes that Warden's 'insistence on huge modern fighter force formations in Europe was unprecedented'. His emphasis on mass, 'for better or for worse ... bears a strong resemblance to that of Jomini', but 'they [both] ignored those cases in which military experience did not conform to the predictions based on their formulas'. Exploring the parallels further, Olsen goes so far as to say 'Warden provided an equivalent [of Jomini] for air warfare'.

[47] John A. Warden III, *The Air Campaign: planning for combat* (Washington, DC, 1989).

[48] Warden, *The Air Campaign*, p.61.

[49] E. S. Gons, *Access Challenges and Implications for Air Power in the Western Pacific*, Pardee RAND PhD thesis, May 2010, p. 99; Maj R. E. Gilbert, *Strategic implications of US fighter force reductions: air-to-air combat modelling using Lanchester equations* Air University thesis (Maxwell AFB, Al, 2011).

[50] Warden's justification for Big Wing tactics rested, according to Olsen, on precisely the dependence of the casualty ratio on the force ratio which we shall expose as being unfounded. Further, 'Warden's knowledge of the controversy over the Battle of Britain and of the actions of Dowding and Leigh-Mallory enabled him to refute most of the arguments' against Big Wings, apparently, although no evidence is given that this was refutation rather than disputation. Olsen, *John Warden*, p. 89.

[51] See, for example, S. Wrigge, A. Fransen and L. Wigg, 'The Lanchester Theory of Combat and Some Related Subjects. A Bibliography 1900-1993', FOA report D-95-00153-1 (Stockholm, 1995).

[52] See Johnson and MacKay. At its root this is due to (what is known to mathematicians as) Jensen's inequality.

[53] For details of each force's scaling of losses with own and opposing numbers, leading to this result, see Johnson and MacKay. However, if the same analysis is performed using RAF *claims* for Luftwaffe losses, rather than *actual* losses, the situation is reversed, and the RAF and Luftwaffe exponents become 1.5 and 0.8. The reason is disproportionate overclaiming on days of heavy fighting: the RAF claimed 'kills' not merely in proportion to their sorties, but nearly as their square.

[54] B. Matthews, *Fitting Generalize Lanchester Models to the Pacific Air War*, University of York BSc dissertation, May 2008. In fact the campaign splits into two clear phases, before and after the mid-1943 lull. In the earlier phase, with only 10 data points, it is the Imperial Japanese Navy which is on the defensive; in the later phase (46 points), this is clearly reversed.

[55] MacKay, 'Is air combat Lanchestrian?'

[56] *The Relationship Between Sortie Ratios and Loss Rates for Air-to-Air Battle Engagements During World War II and Korea*, Saber Measures (Charlie) (Washington, DC, 1970), document call no.M-U 42210-75.

[57] MacKay, 'Is air combat Lanchestrian?'

[58] R. L. Helmbold, 'The Constant Fallacy', Eur. J. Op. Res. **75** (1994) 647-658.

[59] J S Attinelio, *Air-to-Air Encounters in South-East Asia*, October 1967. Weapons Systems Evaluation Group report 116 / Defense Technical Information Center report R-123.
We extracted data for 157 encounters between F105s and NVAF aircraft, typically a mix of MiG-17, 19 and 21s, and for 82 F4 encounters, from the tables on Vol.I p. 17-18, Vol.II p. 17-19 and Vol.III p. 15-20.
[60] Against F4s, NVAF losses are significantly dependent on both their own (at p=0.01) and opposing (p=0.02) numbers, accounting for 0.23 of the variance. Against F105s, NVAF losses are slightly dependent on own numbers at p=0.05, although the variance explained is small. No other relationships are significant at better than p=0.3.
[61] If we make the independent variables the sum and difference of US and NVAF aircraft, we find that NVAF losses against F4s are highly significantly dependent on the sum (p=0.0004), but only mildly so on the difference (p=0.2) . Against F105s the significance of the sum declines to p=0.17, and of the difference to 0.76.
[62] For a recent perspective see Wayne P. Hughes, 'Prediction', keynote address to the Military Applications Society 2012 conference, Monterey. Hughes has long held the view that air combat is primarily a set of duels (private communication).
[63] For an account of the Falklands air campaign see Nigel 'Sharkey' Ward, *Sea Harrier over the Falklands: a maverick at war* (Annapolis, 1992), balanced by S. Woodward and P. Robinson, *One Hundred Days: the memoirs of the Falklands Battle Group Commander* (Annapolis, 1997). As we shall see, Ward's preferred tactics of forward interception can be seen as directly paralleling those of Park in both the Battle of Britain and the defence of Malta.
[64] This view is put most trenchantly by Philip Grove: 'The Falklands Conflict, which is increasingly overlooked by airpower students and writers, is … a vital paradigm in the use and misuse of air assets … in many ways it was a war of the future.' Philip D. Grove, 'Falklands Conflict 1982 – The Air War: A New Appraisal', in Badsey, Havers and Grove, *The Falklands Conflict*.
[65] In the preface to the Second edition of his memoir, Admiral Woodward notes that Ward's use of the term 'Flag' to refer to the Task Force leadership group on Hermes was, 'A very loose term' referring at different times to different people, and that he was unaware of any controversy between the aerial commanders on Invincible and Hermes. *One Hundred Days*, p. xxxv. Ward acknowledges this qualification in the second edition of his own book.
[66] Ward, *Sea Harrier over the Falklands*, p. 100.
[67] The parallel with the Battle of Britain is noted in Air Commodore R. A. Mason, '"Hay for the Hobby Horses": reflections on the air war in the South Atlantic 1982', *RUSI Journal* **127** no 4 (1982) 34-41.
[68] M. Middlebrook, *The Falklands War*, (London, 2012), Ch. 7.
[69] S. Rivas, 'Wings of the Malvinas: The Argentine Air War over the Falklands, (Manchester, 2012), pp. 181, 183, 189, 255.
[70] Ward, *Sea Harrier over the Falklands*, p. 234. This point is made in Gray, 'Air Power': 'the reliance on total superiority is misleading. [Dunkirk and the Falklands] highlight what can be done – or undone – in situations of air parity.'
[71] Similar criticisms of the command culture are made in Alastair Finlan, *The Royal Navy in the Falklands and the Gulf War: Culture and Strategy* (London, 2004). Finlan stresses the anachronism

of relying on visual searches instead of the Sea Harriers' radar (p. 167), the failure to devolve decisions on air combat tactics to lower-ranking experts, and (in a perfect echo of the Park / Leigh-Mallory dispute) the tendency to engage Argentinian aircraft 'after bomb runs on ships rather than before' (p. 90).

[72] *Ward, Sea Harrier over the Falklands*, p.234. Interestingly, Admiral Woodward acknowledges that Ward's views were 'largely correct' in that the snr command group on Hermes apparently did not trust their aircraft and particularly the efficiency of its 'Blue Fox' Radar. Woodward argues that with hindsight Ward was uniquely qualified to judge the capabilities of this new, untried and in practice devastatingly effective weapons system, and his implication seems to be that it was regrettable that Ward's views were not heeded. Woodward, *One Hundred Days*, 2nd Ed. ,p. xxxv.

[73] Rivas, *Wings of the Malvinas*, pp. 179, 255.

[74] Lt Col J. E. Marr, *War in the Falklands: Perspectives on British Strategy and Use of Air Power* Air War College thesis (Maxwell AFB, Al, 1988) notes 'the failure of the Argentines to exercise the principle of mass' and that 'the defensive air campaign was singularly successful'. Lt Col C. B. Hezsely, *Argentine air power in the Falklands war* (Air War College thesis (Maxwell AFB, Al, 1988) , writes that 'the Argentines may have underestimated the havoc that the 17 Sea Harriers caused [sic]' and concludes that 'The Argentine air campaign proved that air power alone is not enough!'. Perhaps the most incisive judgment comes much later, in Lt Cdr J. L. Huber, *The Falklands Air War: lessons revisited*, Naval War College paper (Monterey, 1995): 'Why waste airplanes and pilots attempting to shoot down Harriers one at a time when they could neutralize most or all of them by hitting a carrier?' Huber's conclusion that 'defensive air superiority schemes are only suitable when facing opponents possessing significantly weaker air power' apparently went unnoticed.

[75] Air Vice-Marshal R. A. Mason Ret. 'The Air War in the Gulf', *Survival* **33** no. 3 (1991) 225. Quoted in Benjamin S. Lambeth, 'Air Power, Space Power and Geography', *Journal of Strategic Studies* **22** nos 2-3 (1999) 64.

[76] Olsen, *John Warden*, p. 22 and Ch. 8.

[77] Lambeth, 'Air Power', p. 70.

[78] Lambeth, 'Air Power', p. 66.

[79] Lambeth, 'Air Power'

[80] Lambeth, 'Air Power', p. 70.

[81] 'The development of UAVs and UACVs thrived when the need for them was apparent, but when there was no need, they were forsaken'. Lt Col R. M. Clark, *Uninhabited Combat Aerial Vehicles*, CADRE paper no. 8 (Maxwell AFB, Al, 2000), p. 42. New technologies, especially of command and control, are likely to make this a thing of the past.

[82] G. N. Gosh, Application of Unmanned Aerial Combat vehicles in future Battles of the Subcontinent', *Strategic Analysis*, **25** no.4 (2001) 600-601.

[83] MOD Joint Doctrine Note 2/11, *The UK Approach to Unmanned Aircraft Systems*, p. 103.

[84] *Securing Britain in an age of Uncertainty: The Strategic Defence and Security Review* (London, 2010), p. 5.

[85] As with the development of inter-war doctrine, the emphasis has mostly been on offensive

rather than defensive air power. See, for example, Maj D. Larm, *Expendable Remotely Piloted Vehicles for Strategic Offensive Airpower Roles*, Air University thesis, 1996; J. M. Sullivan, 'Evolution or Revolution? Rise of UAVs', *IEEE Technology and Society* **25** no. 3, (2006) 94-101; Maj D. Berkland, 'Douhet, Trenchard, Mitchell, and the Future of Airpower', *Defense and Security Analysis* **27** no.4 (2011) 389-393; L.-M. Clouet 'Drones as Future Air Power Assets: The Dawn of Aviation 2.0?', in E. Fels *et al*. eds, *Power in the 21st Century* (Berlin: Springer, 2012).

[86] The potential revolutionary effect of UCAVs as a 'disruptive technology' is noted – albeit not in the context of air defence – in D. Hastings-Dunn, 'Drones: disembodied aerial warfare and the unarticulated threat', *International Affairs* **89** no. 5 (2013) 1237-1246.

[87] The diverse advantages of small UAV carriers for UK forces, including the possibilities for fighter UCAVs, is noted in I. Shields and J. Spencer, 'An Unmanned Future for Naval Aviation', *RUSI Journal*, **156** no. 6 (2011) 48-54.

[88] The *UK Approach to Unmanned Aircraft Systems*, p. 104.

[89] Lockheed Martin's Hypersonic Program Manager, quoted in *Combat Aircraft Monthly*, **15** no. 1 (January, 2014).

[90] Meilinger, *Ten Propositions*.

[91] The US understanding of what happened in the Battle of Britain remains ambiguous. For example, in Air Force Doctrine Document 1 (AFDD1, September 1997), we find that 'Even highly successful defensive air campaigns such as the Second World War Battle of Britain were based upon selective offensive engagements rather than fragmenting into small patrols everywhere.' Park's tactics were certainly offensive (and the Dowding system had removed the need for standing patrols), but they did not achieve this through massed numbers. AFDD1's position on 'mass' in this context remains unclear.

[92] For a wide-ranging analysis of the command culture in the Falklands, see Finlan, *The Royal Navy in the Falklands*.

[93] T. A. Keaney and E. A. Cohen, *Gulf War Air Power Survey Summary Report* (Washington, DC, 1993).