# Augustine, costs and defense industries

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**Abstract**

Augustine weapons systems are presented as a new class of economic good. Their distinguishing characteristics are identified in the form of advanced technology, inter-generational cost escalation and small quantities. A distinction is made between cost increases between generations of weapons and falling unit costs within a generation of equipment. The impact of Augustine weapons on learning curves is assessed and the article concludes with an evaluation of Augustine systems for the future defense industrial base.

Norman Augustine pioneered work on cost escalation (Augustine, 1987). This article starts by reviewing the evidence on Augustine cost escalation and presents these weapons systems as a new and distinctive class of economic good with clearly defined characteristics. Augustine cost escalation refers to real unit cost increases *between* generations of weapons systems. This article distinguishes between such cost escalation and cost decreases *within* a weapons system reflecting scale and learning economies. Aircraft are presented as a case study of a Decreasing Cost Industry and the impact of Augustine technological change on aircraft industry learning curves is assessed. Finally, consideration is given to the implications of Augustine weapons systems for the future of the defense industrial base.

## Cost escalation

Norman Augustine famously forecast continuously rising unit costs of certain military hardware—rising at an exponential rate with time. For modern high performance fighter aircraft, he forecast unit costs rising by a factor of four every ten years. This rate of growth appeared to be an inherent characteristic of these systems with rising unit costs closely correlated with time rather than with the technical performance features of the aircraft (e.g., speed, weight, etc.). The same trend, but at a lower rate, applies to civil aircraft, helicopters, ships, and tanks—the latter two having a 10 year growth rate (Augustine 1987, p. 140). The results of the predicted rising unit costs led to a second and more famous prediction (Augustine Law XVI), namely, that by the year 2054, the entire U.S. defense budget would purchase just one aircraft. Similar predictions were made for other nations but with earlier dates, e.g., a single aircraft for the United Kingdom by 2052 (Augustine, 1987, p. 144). More widely, there were forecasts of a future comprising a single ship navy, a single tank army, and a Starship Enterprise for the air force (Kirkpatrick and Pugh, 1983).

## Cost escalation: Some evidence

Table 1 presents evidence on the rising real unit prices of U.K. combat aircraft over the period 1940 to 1959. Successive generations of combat aircraft are shown. The table has two notable features. First, the magnitude of the rising unit costs in real terms. Between the World War II propeller-powered Spitfire and the jet-powered Meteor, real unit costs rose nearly five-fold. Similarly, between the Meteor and the next generation Hunter, real unit costs rose by a much smaller 1.2-fold; but between the Hunter and the next generation Lightning, unit costs rose by almost 3-fold.



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Bomber aircraft showed similar cost trends. The Mosquito and Canberra were light bombers and unit costs rose by almost 5-fold from one to the other. From the propeller-powered Lancaster to the jet-powered Vulcan real unit costs rose by a substantial amount, over 13-fold (although this example covers more than 10 years). The context for these cost trends was the original Augustine forecast of unit costs for fighter aircraft rising by a factor of four every ten years.

**Augustine weapons systems represent a new class of economic good, identifiable as having advanced technology, inter-generational cost escalation, and small quantities. These factors mean difficult choices for the United Kingdom and similar states, such as whether to reduce defense capability, import costly equipment, increase collaboration, and/or fund real-term defense budget growth.**

The second notable feature of Table 1 shows falling output for each type of aircraft. Part of this fall reflects the end of the war, but after 1945 the declining output reflects the rising real unit costs of combat aircraft. For example, in 1955, the U.K.'s RAF deployed about 1,000 Hunter fighter aircraft; by 2021, the corresponding number of U.K. RAF fighter aircraft had declined to 160 Typhoons. Hard budget constraints lead to a downward sloping demand curve, meaning that less is bought at a higher price.

Various explanations have been offered for intergenerational cost escalation. These include defense equipment viewed as a tournament good, monopoly pricing by defense industries, optimistic forecasting and changes in operational requirements (Hartley, 2020). Public choice analysis offers a further explanation focusing on the behavior of agents in the military-industrial-political complex. On the demand side of procurement markets, there are procurement officials in defense departments and the armed forces acting as budget maximisers. On the supply side, there are scientists, technologists, and industrialists in the defense industrial base pursuing objectives ranging from maximizing technology (e.g., enjoying shifting the frontiers of technology) to profit maximization. Whilst public choice analysis appears an attractive explanation, it needs much more theoretical modelling and empirical testing.

## Defining Augustine weapons systems

While Augustine's Laws outline the features of certain high technology hardware, this article goes further and proposes Augustine weapons systems as a new class of economic good.[1] The key features of these systems comprise high or advanced technology, rising real unit costs, and small and declining quantities. The classic example of rising real unit costs is military fighter aircraft, with unit costs rising by a factor of four every ten years. This suggests that by 2054, rising unit costs could lead to the purchase of one aircraft, known as Battlestar Galactica or Starship Enterprise. Rising unit costs reflect the greater use of complex electronics, computer software and stealth technology—these industries will become more important in the defense industrial base. New technology leads to "vast new capability vistas" being crammed into each new generation of equipment (Augustine, 1987, p. 140). Critics have used this example to claim that modern weapons systems are laden with technological "bells and whistles" which add much to cost but little to military effectiveness (Franck, 1992). Cost escalation is explained by the "engineering mindset" of decision-makers in the military-industrial–political complex (Hartley, 2017). Public choice analysis views engineering staff and military personnel as budget-maximisers seeking to buy weapons systems which provide them with the greatest satisfaction (rather than the most cost-effective defense equipment). Their mindset values technology for technology's sake, creating cost growth that is unsustainable over time.

Radical frame-breaking technologies open vast new capability vistas, with real options analysis providing a useful way of thinking about Augustine weapons systems. For example, frame-breaking technologies might open new capability options within the weapon system as well as in completely different fields (spin-offs) as with a new fighter aircraft being adapted to perform strike missions and its technologies being used on civil aircraft (e.g., jet engines)

1 Further details are in Brauer, et al, (2021) and Markowski, et al, (2022).



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and in other civil fields (e.g., health and motor cars). As real options, Augustine weapons, can be viewed as the "bundling together" partly-developed technologies, which are "stored" as development options for use when events require an all-out military commitment; otherwise, they are allowed to lapse and are not pursued.

Augustine weapon systems result from an increasing emphasis on smaller volumes of costlier technologically complex weapons—with, for example, one fourth-generation fighter jet costing the same as five first-generation aircraft. In addition, the existence of disruptive technologies is likely to make cost forecasting even more difficult.

## Comedy or reality?

From the outset, Norman Augustine recognized that his book might be classified as comedy or tragedy or even science fiction.[2] His assertions have been viewed as both frivolous and thoughtful insights into the impact of unit cost escalation of complex military equipment on the procurement of successive generations of major weapons systems. The essence of the Augustine crowding-out argument is that the introduction of increasingly sophisticated, complex, and costly warfighting equipment, together with stagnant procurement budgets, results in the acquisition of ever-smaller volumes of equipment. The eventual result is that technology leads to "backdoor" disarmament.

**Table 1: Rising unit prices of U.K. combat aircraft, 1940–1959**

| *Aircraft* | *Date of Contract* | *Unit Prices* | *Aircraft* |
|---|---|---|---|
| *Fighters* | | | |
| Spitfire | June 1940 | 9,700 | 20,351 |
| Meteor | March 1946 | 47,137 | 3,947 |
| Hunter | Jan 1955 | 55,626 | 1,972 |
| Lightning | April 1959 | 160,000 | 337 |
| *Bombers* | | | |
| Mosquito | Aug 1943 | 15,700 | 7,781 |
| Lancaster | June 1943 | 31,700 | 7,377 |
| Canberra | June 1951 | 73,482 | 949 |
| Vulcan | Dec 1954 | 422,991 | 136 |

Notes: U.K. combat aircraft are a sample of fighter and bomber aircraft from World War II, and the subsequent peace to 1959, based on airframe unit costs only. Both fighters and bombers comprise propeller-powered aircraft: Spitfire, Mosquito and Lancaster; and jet powered aircraft: Meteor; Hunter; Lightning; Canberra; Vulcan. Data based on details of the contract for the date shown. Other contracts were available, but their data are not shown in Table 1. Total output comprises output for the United Kingdom and exports.

Source**:** DSTL (2010)

Recent developments have cast doubts on the original Augustine claims, finding that unit prices of military fighter aircraft have *not* increased by a factor of four every ten years, with fifth-generation fighter aircraft costing almost ten times their first-generation predecessors. Unit costs of fighter aircraft will *not* overtake the defense budget, but fighter aircraft will become more expensive over time and quantities will continue to fall. Rising unit costs *are* correlated with aircraft technical performance characteristics reflected in aircraft empty weight and the generation of the aircraft (Johnstone, 2020). It must also be remembered that trends are not causation. This is illustrated the limerick:

2 He presents an amusing anecdote. Long queues of bus passengers were being passed by drivers in half-empty buses. A bus company official responded to the public's objections to this annoying practice by stating that it is impossible for drivers to keep to their timetables if they have to stop for passengers.



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A trend is a trend is a trend
But the question is, will it bend?
Will it alter its course
Through some unforeseen force
And come to a premature end?[3]

Rising costs reflect greater capability. Today's fourth and fifth generation fighter aircraft could easily defeat their first generation equivalents operating at subsonic speeds and without radar or missiles. So, a focus on aircraft costs fails to recognize the *output* implications of new technology weapons systems. Here, there is a major gap in our knowledge since there are no measures of the money value of defense output. Instead, references are made to peace, protection, and security with defense output measures often based on *input* measures.

## Aircraft as a decreasing cost industry

Augustine's focus was on inter-generational cost escalation showing cost increases *between* generations of aircraft. However, there are cost curves *within* each generation of aircraft showing declining unit costs with larger outputs of a given type of aircraft. In other words, whilst cumulative volumes of equipment usually decrease for each new generation of equipment (the Augustine volume effect), there are scale and experience-related efficiencies that lead to lower unit costs as batch size increases and production experience accumulates through learning-by-doing. These intra-generational efficiencies may decline over time as declining equipment volumes (inter-generational effects) restrict opportunities for scale, scope and learning economies with the procurement of new generations of equipment.

**Table 2: Examples of U.K. aircraft as a Decreasing Cost Industry**

| *Aircraft* | *Start Date Index=100* | *Quantity* | *UPC Index at end of contract* | *ULC Index at end of contract* |
|---|---|---|---|---|
| Hurricane Mk1 | Sept 1938 | 1,046 | 57 | 37 |
| Spitfire | Dec 1939 | 10,341 | 74 | 83 |
| Mosquito | Aug 1943 | 3,420 | 66 | 68 |
| Meteor | March 1946 | 2,538 | 24 | 34 |
| Javelin | July 1954 | 200 | 53 | 64 |
| Hunter | Jan 1955 | 585 | 83 | 71 |
| Canberra | June 1951 | 692 | 79 | 59 |

Notes: All are U.K. combat aircraft for periods of war and peace (1938–1955). Hurricane data for Mark 1 version only. Most are fighter aircraft except for Mosquito and Canberra which are light bombers. See also Notes to Table 1. Quantity refers to numbers ordered for a specific contract or from a specific supplier. UPC is unit production cost index based on constant prices. ULC is unit labor cost index in constant prices based on end date for the contract

Source**:** DSTL (2010)

Table 2 presents original evidence of U.K. aircraft as a Decreasing Cost Industry. Decreasing costs apply to both war and peace-time, and to propeller-powered and jet-powered U.K. combat aircraft. Decreasing costs reflected both economies of scale and learning. Falling unit labor costs reflected learning economies and there was evidence of substantial learning for the Hurricane and Meteor aircraft. However, it has to be stressed that unit labor costs are used as a proxy for learning curves: true learning curves are defined with respect to a doubling of cumulative output.[4]

3 Cairncross, (1969, p. 797).
4 The data did not allow curves to be defined with respect to a doubling of cumulative output. Instead, data were only available showing unit labor costs for various quantities which were specified by each contract.


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There was also evidence of major reductions in unit production costs for the Hurricane, Meteor and Javelin aircraft (Hartley, 2022).

## Learning curves

The original Wright model for aircraft industry learning curves was (Wright, 1936):

$$Y = aX^{-b}$$

where Y = average direct man hours
a = man hours at unit number one
X = cumulative output
b = slope of learning curve

Traditionally, labor learning curves for the aircraft industry were estimated at 80%, meaning that direct labor inputs declined by 20% for each doubling of *cumulative* output. For example, the first aircraft produced might require 1,000 man hours; doubling from one to two units would require 800 man hours for unit two; and a further doubling to four units would require 640 man hours for the fourth unit. Learning economies mainly reflected productivity gains from worker repetition and experience. More recent developments have identified "forgetting" curves where knowledge is not retained by workers. Forgetting arises from production breaks, labor turnover, aircraft modifications and new production technology.

Modern examples of learning are available. The learning rate for the U.S. F-15 combat aircraft was 88%; for the U.S. F-18E/F fighter aircraft it was 86%; and for the F-22 Raptor it was 85.4%[5] (Hartley, 2022). The U.S. evidence on learning curves shows the possible impact on learning of Augustine technical progress. Despite the technological differences between the fourth-generation F-18 and the fifth-generation F-22, their learning curves are similar; but for the current generation U.S. F-35 Lightning II combat aircraft, the learning curve was substantially different at 91%.

Modern learning rates differ from the traditional Wright 80% curve. These differences might reflect smaller quantities for new generations of jet fighters and the greater use of automated rather than labor-intensive production methods. Over time, it might be expected that smaller equipment quantities will lead to both scale and experience related (learning) efficiencies becoming weaker, resulting in changes in Wright's traditional scale and experience coefficients. There is tentative support for the possibility that Augustine weapons systems might have affected learning curves and rates, but more data are required to reach a definitive conclusion. Future learning curves will depend on new technology in the production process and the extent to which it offers new opportunities for learning-by-doing. Possible future limitations on the opportunities for achieving scale and learning economies might increase the opportunities for firms to achieve economies of scope.

## Augustine and the future defense industrial base

As a new class of economic goods, Augustine weapons have implications for the future defense industrial base. They are likely to mean a more technology-intensive and a smaller defense industrial base, with fewer opportunities for scale and learning economies but perhaps more opportunities for scope economies. These economic impacts will affect capital and labor inputs for defense industries. Capital inputs will become more R&D intensive and lower

5 There is limited evidence of learning curves for U.K. aircraft. For the 1946 Vampire fighter jet, the median learning rate was 63% (Hartley 2022).

volumes will lead to smaller requirements for production inputs. For labor inputs there will be a shift from production to technology requirements reflected in greater demands for scientific and technical labor.

Augustine weapons systems are likely to lead to a smaller defense industry as measured by numbers of employees and numbers of production plants, but higher unit labor costs and a higher value of unit real sales. Industry structure is also likely to change, with a long-run trend to a smaller number of larger arms companies reflecting more mergers and exits. Some mergers will be international between U.S. and European firms, as firms seek to obtain entry into established defense markets (with prospects for orders).

International mergers, larger firms and increased market concentration will affect industry conduct leading to a decline in competitive tendering with potential adverse effects on industry performance (greater monopoly power). A greater emphasis on arms export markets is likely, with larger arms firms seeking new arms markets. Buying nations might respond to monopoly suppliers by creating international buying consortia. Finally, there will be ownership issues. Privately-owned monopoly suppliers are likely to be subject to greater state regulation; but regulation raises more problems to be solved (e.g., whether to regulate prices, profits, or aspects of conduct).

Augustine weapons systems can lead to battle-field substitution effects. For example, drones are possible substitutes for the increasingly expensive fighter aircraft and could have major economic impacts on the armed forces and defense industries. Their military use means that weapons systems become more capital/technology intensive with less military personnel required for traditional front-line roles (e.g., fewer combat aircraft pilots and personnel for servicing manned equipment). Drones are likely to be acquired in larger quantities and they are accessible to small terrorist groups. However, by the time drones are able to replace modern combat aircraft they might be as costly. A future of Starship Enterprise weapons will lead to Space Forces replacing traditional Air Forces. But the future is uncertain, and no one can predict it accurately: the most likely outcome is that future predictions are likely to be wrong!

## Conclusion

Augustine weapons systems represent a new class of economic good**.** Whilst these goods have some distinctive features, further research work is needed to provide a clear unambiguous definition of their key features. Definitions are needed of *high* technology, *high* unit costs and *small* volumes. In the meantime, Augustine weapons systems are distinguished by cost escalation reflected in continuously rising real unit costs and by higher technology, greater complexity, and smaller volumes—with impacts on the future armed forces and defense industries. All of which means that nations such as the United Kingdom, and similar European states, will face the need for difficult defense choices. Something will have to be sacrificed and the options include abandoning a major defense capability (e.g., no more manned combat aircraft as in New Zealand), importing costly equipment, greater and more efficient international collaboration, or higher real terms defense budgets (Kirkpatrick, 1995).

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