2002-3622

VALUE MODELING FOR TECHNOLOGY EVALUATION

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Abstract

A value model was developed to support the VAATE program to evaluate propulsion system technologies and provide an objective for parametric studies that would identify optimal engine cycles. The value model determines a score for a prospective engine design based on ten propulsion system properties that describe the design.

Introduction

The US Air Force VAATE program (Versatile Affordable Advanced Turbine Engine), administered by the Propulsion Directorate of the Air Force Research Laboratory, seeks to identify the key enabling technologies for future military aircraft engines, emphasizing performance, affordability and dual military and commercial use.

At Allison Advanced Development Company (AADC), a wholly owned subsidiary of Rolls-Royce, a value model was developed to evaluate potential technologies and compare thermodynamic cycles in support of the VAATE program.

What is a Value Model?

The value model is essentially a scoring system (Figure 1). A propulsion system design is described by ten properties which fall into four categories: performance, size, supportability and acquisition. Performance and size properties are fed into an aircraft model which determines how these impact the performance and survivability of the overall weapon system. Such a transformation is not necessary for supportability and acquisition properties—their impact on weapon system supportability and acquisition is more direct.

The resulting properties describing the weapon system and the propulsion system go into the value model. The value model outputs a single scalar: the relative surplus value of the propulsion system. Surplus value is a score for the design. A higher score indicates a better design.

The VAATE program is unique among technology research programs for recognizing the need for such a scoring metric to evaluate technologies. VAATE provided the Cost-Capability Index [Stricker, 2000] which creates a capability over cost ratio from thrust, weight, SFC, development cost, production cost, and maintenance cost. The Cost-Capability Index is itself an expansion of the thrust to weight ratio used as a metric in the earlier IHPTET program.

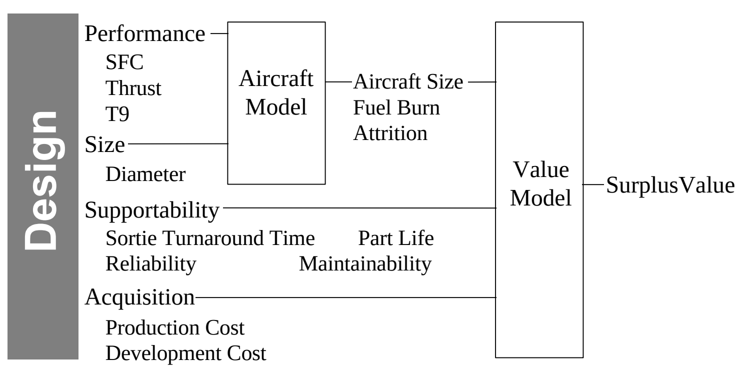

Figure 1: What is a Value Model?

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The value model improves upon the Cost-Capability Index by inputting four more properties, by using economic logic to interrelate the performance variables, and by using a difference metric, Surplus Value, instead of a ratio.

One way to think of the model is in terms of a high dimensional property space, where every property is an orthogonal coordinate axis of the space. Each design is described by a point in the space. The value model is a potential function on the space. It maps every point in the property space to a unique scalar value, much as an electric field assigns to each point in geometric space a unique voltage (electrical potential), or a flow field assigns to each point a unique pressure. The mapping forms a value surface over the space. Technologies that move the design up the value surface are good, even if they detract from some properties. For example, a new turbine blade coating may increase cost and weight, but may decrease fuel consumption and increase life. If the net effect of these changes is movement up the value surface, the technology is an overall improvement.

Using the Value Model

The value model has several applications. First, it can be used to perform **system trade studies**. If their are four options in a trade study, for example, the properties of the propulsion system are determined for each option. Then the value model assigns a score to each option. The option with the highest score is the preferred approach.

Second, the value model can be used to **evaluate technologies**. For each technology, the propulsion system designs are evaluated with and without the technology. The difference between the scores, with and without, is the value of the technology (Figure 2). Since the output of the model is denominated in dollars of value per engine, the score can be used as a basis for determining the value of the technology in dollars. When considered together with the cost and risk of developing the technology, the value can inform the decision as to which technologies warrant investment and which do not.

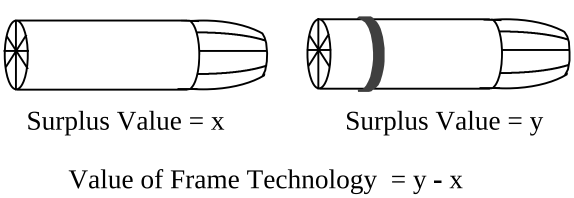

Figure 2: Technology evaluation example

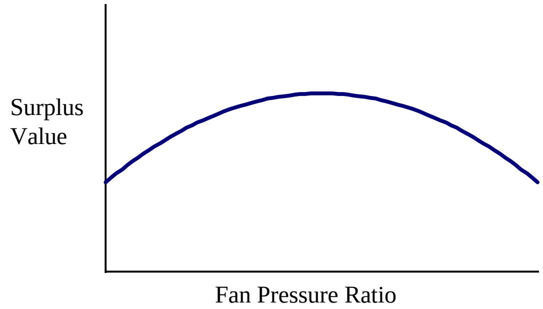

Figure 3: Hypothetical parametric cycle study

Third, the value model can be used for **parametric studies**. A series of engine designs can be considered over a range of cycle parameters such as pressure ratios and cycle temperature limits. Value can be plotted in the parametric space (Figure 3, a hypothetical example). A peak in the value surface identifies the coordinates to which the parameters should be set to create the best design. The thermodynamic cycle studies performed at AADC are examples of this application.

Fourth, the value model is an essential tool for **distributed optimal design**, which can dramatically improve the affordability of complex aerospace systems. [Collopy, 2001].

Fifth, the value model is necessary to conduct **value-based acquisition** [Lippitz et. al., 2000], a strategy for acquisition of weapon systems yields more capable systems for lower cost than current practices, including price-based acquisition. Combined with distributed optimal design, value-based acquisition can reduce the cost of a program like the Joint Strike Fighter by $50 billion [Collopy, 1999].

Structure of the Value Model

To date, four value models have been used at AADC for VAATE studies: three for unmanned military aircraft and one for a commercial product that would share the engine core. One value model specifically considers an Uninhabited Combat Air Vehicle used as a strike platform. The mission of the weapon system is central, since the value model represents the way the propulsion system is used in service.

Where a performance model bases its calculations on physical laws, the value model bases its logic and

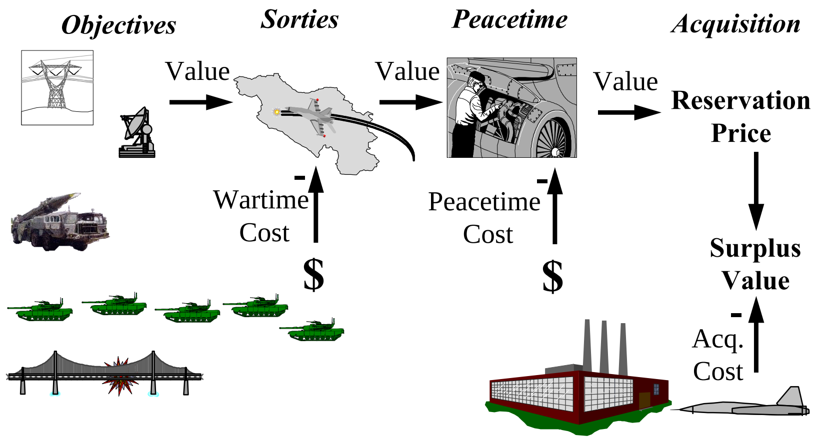

Figure 4: Value Model methodology

computations on the laws of economics. In Figure 4, the ultimate measure of the weapon system is its surplus value. Surplus value is the value of the military objectives the weapon system achieves, less the cost of operating the system in wartime, less the cost of maintaining system readiness in peacetime, less the cost of acquiring the system. Essentially surplus value is the benefits of the weapon system minus all the costs.

The Surplus Value Metric

Surplus value is a difference, not a ratio. The classic measure of affordability is capability divided by cost, such as "cost per kill" [Chew, 1998, p. 11 and Stricker, 2000, p. 1]. While the ratio may give similar results to surplus value when evaluating whole systems, it fails to provide correct evaluations of individual technologies. For example, consider a hypothetical surveillance system that costs $1,000 million but provides $5,000 million of value. A technology is added to the system that increases cost 2% but increases value by 1%. This technology decreases the value over cost ratio, or capability over cost. By the traditional affordability measure, it is a bad thing. However, it adds $50 million in value for only $20 million in cost, so it is clearly an improvement. The surplus value of the technology is $50 - $20 = +$30 million.

Outline of Methodology

The value model performs the calculation of surplus value in six steps:

1. Determine the impact of the propulsion system properties on the weapon system platform
2. Evaluate the average sortie.
3. Evaluate the performance of a system in a campaign.
4. Extend the evaluation to wartime and peacetime use over the life of the weapon system.
5. Determine the economically optimal fleet size.
6. Estimate the surplus value for the fleet, and deduce the surplus value per unit.

Impact on the Platform

In this step, the value model determines the effect of the engine on weapon system size and performance. The determination is based on the assumption that the engine and aircraft can be separately scaled in size to the optimum match to a fixed mission. This is called rubber engine / rubber aircraft sizing. Implicit in the aircraft scaling procedure is the assumption that wing loading (takeoff gross weight divided by wing area) is constant. The engine is scaled to a ratio of takeoff thrust to weight.

Critical to development of the platform-impact module of the value model is the availability of sufficient vehicle scaling information to isolate the growth of aircraft empty weight and the impact of engine characteristics relative to a system baseline. These are typically obtained using a vehicle-mission performance simulation like those traditionally used in preliminary design. For the purpose of value modeling, such a simulation is in effect reduced to a few simple relationships.

Three engine properties are used to determine the impact of the engine on aircraft size and consequent engine value: thrust rating (Fn), weight of the engine (Wt_{eng}), and cruise SFC.

The propulsion weight fraction is obtained as follows:

$$\text{PropFrac} = \frac{\text{Aircraft Thrust to Weight Ratio}}{\dfrac{\text{Fn}}{\text{Wt}_{\text{eng}}}} \quad (1)$$

Next, the relationship between empty weight and takeoff gross weight is determined by fitting a curve to data from conventional aircraft sizing models:

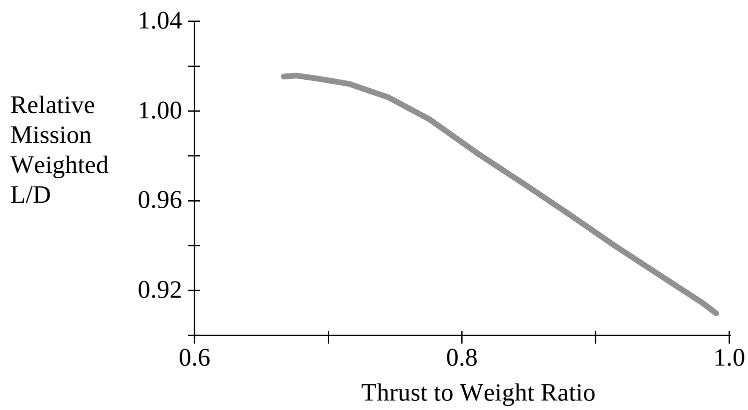

Figure 5: Relationship of L/D to Aircraft T/W

$$\frac{Wt_{ac}}{TOGW} = D \cdot TOGW^{C} \qquad (2)$$

TOGW is Takeoff Gross Weight, Wt_{ac} is TOGW minus fuel and propulsion weight, and C and D are coefficients determined in the curve fit.

Takeoff gross weight is then obtained by inverting the relationship:

$$TOGW = \left(\frac{1 - FuelFrac - PropFrac}{D} \right)^{\frac{1}{C}} \qquad (3)$$

FuelFrac is the fuel weight fraction of TOGW, which is obtained from a baseline mission with the nominal engine and airframe. The fuel fraction is adjusted based on the variation of mission-weighted lift over drag to aircraft thrust to weight ratio. This trend for the UCAV is illustrated in Figure 5.

Figure 6 shows the overall accuracy of value model trends (solid lines) when compared to results obtained from the vehicle simulation for UCAV (dashed lines).

The fuel fraction times the TOGW is the fuel burn for the nominal mission. The propulsion fraction times the TOGW is the propulsion system weight. Aircraft production cost, AC, is a base cost plus a linear cost factor times the change of Wt_{ac} from nominal. Design payload weight is treated as a constant. All the change is in wing and structure. Engine production cost, PS, is determined in a similar way from the difference in the scaled propulsion system weight (PropFrac times TOGW) and the baseline propulsion system weight.

Evaluate the Average Sortie

The value model assesses the average sortie by four measures:

- Sortie Cycle Time—the time from takeoff on one sortie until takeoff on the next sortie

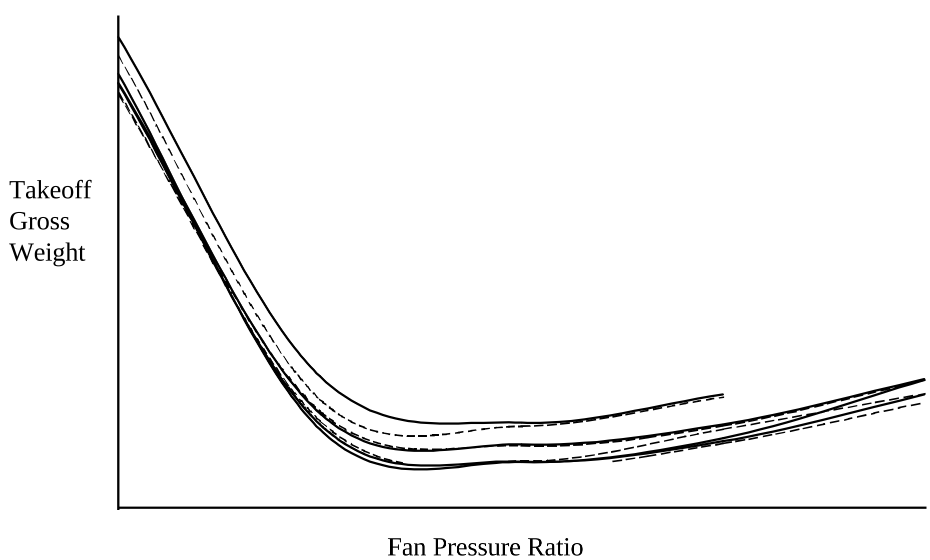

Figure 6: Comparison of value model trends with trends from a full performance simulation

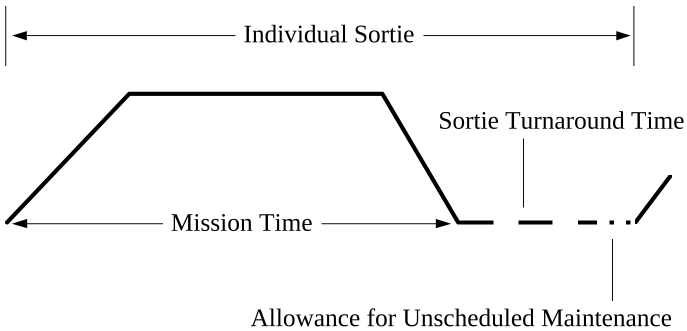

Figure 7: Sortie cycle time

- Fuel Cost
- Maintenance Cost
- Attrition—the probability that the aircraft will be lost to enemy fire

Sortie Cycle Time

Sortie cycle time is the sum of mission time, sortie turnaround time and an allowance for unscheduled maintenance (Figure 7). Mission time, takeoff to touchdown, is given. (The model does not evaluate speed.) Sortie turnaround time is an input property, insofar as it is impacted by the engine features such as advanced health monitoring and diagnostics. The allowance for unscheduled maintenance is, precisely, the expectation of unscheduled maintenance time required per sortie. This is estimated as the probability of a failure requiring unscheduled maintenance times the average amount of time required to service a failure, which is maintainability times mission time over reliability.

Fuel Cost

Fuel burn is the fuel fraction determined for the platform times the takeoff gross weight. Fuel cost is determined by multiplying the fuel burn by fuel price.

Maintenance Cost

The ratio of mission time to engine life determines the fraction of engine life consumed in each sortie. Multiplying this fraction by the engine manufacturing cost gives the hardware component of maintenance cost. This is adjusted for opportunistic maintenance, the phenomenon that parts are generally replaced during an overhaul before their life is completely consumed.

Attrition

Attrition is the probability that the aircraft will be shot down on a single sortie. This probability is influenced by fan face area (loss to radar guided weapons) and infrared emissivity of the exhaust (loss to infrared sensor guided weapons). Fan face area is proportional to fan diameter squared. Emissivity is proportional to exhaust flow, which varies with fan diameter squared, and exhaust temperature, in absolute degrees, to the fourth power. The following formula results:

$$p = k_1 \cdot \phi^2 + k_2 \cdot \phi^2 \cdot T9^4 + k_3 \qquad (4)$$

ϕ is Fan Diameter, T9 is exhaust gas absolute static temperature, and the k's are coefficients determined by survivability analysis, and p is Attrition.

No special stealth technologies are considered, although the model framework could accommodate such features.

Performance in a Campaign

The campaign analysis centers around utilization, that is, how many sorties an aircraft can perform in a campaign. The average duration of a campaign is a fixed parameter. The number of sorties per campaign is determined by two parameters, sortie cycle time and attrition. First the ideal number of sorties is determined (the number of sorties that would be achieved if there were no attrition). The ideal number of sorties is campaign duration divided by the sortie cycle time (Figure 8).

The impact of attrition is illustrated by the probability tree in Figure 9. Each sortie is represented by a node in the tree. The upper branch from the node leads to the event that the aircraft is lost during the sortie. The lower branch leads to the event that the sortie is completed safely. p is Attrition, the probability of an

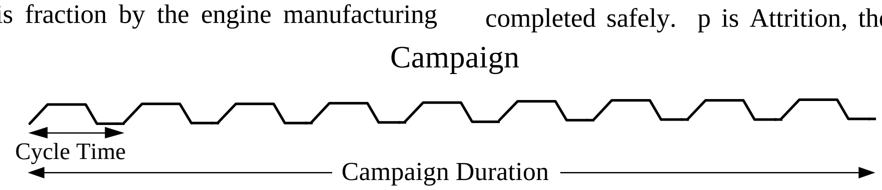

Figure 8: Ideal sorties per campaign

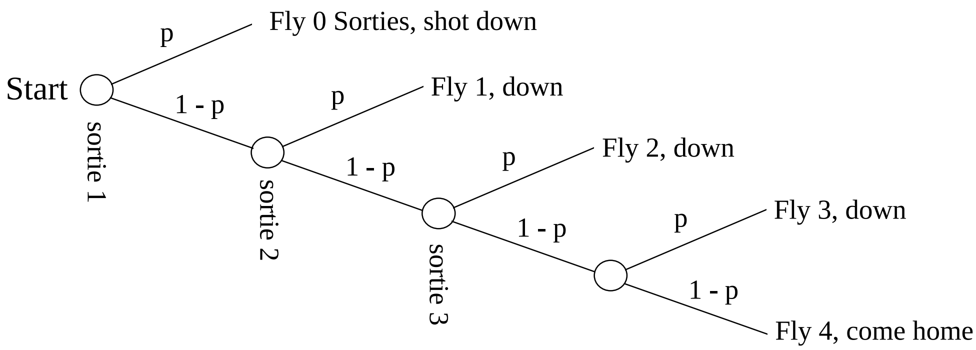

Figure 9: Probability tree for attrition in a campaign

aircraft loss. The probability that an aircraft will be survive a sortie is 1-p. The probability that an aircraft will survive all n sorties in a campaign is

$$q = (1-p)^n \tag{5}$$

the product of all the lower branches in the tree.

Attrition impacts the expected number of sorties per aircraft during a campaign. Figure 10 shows that, even though most aircraft may complete the ideal number of sorties in a campaign, some aircraft are lost, so they complete fewer sorties. The expected number of sorties per aircraft during the campaign is calculated by the formula for probabilistic expectations: the probability of one sortie times one sortie plus the probability of two sorties times two sorties, and so on:

$$\begin{aligned} E[\text{sorties}] &= p \cdot 0 + p \cdot (1-p) \cdot 1 + p \cdot (1-p)^2 \cdot 2 + \cdots \\ &\quad \cdots p \cdot (1-p)^{n-1} \cdot (n-1) + (1-p)^n \cdot n \\ &= \sum_{1}^{n-1} \left[p \cdot i \cdot (1-p)^i + n \right] \cdot (1-p)^n \qquad (6) \\ &= \frac{1-p}{p} \cdot \left[1 - (1-p)^n \right] \\ &= \frac{1-p}{p} \cdot (1-q) \text{ sorties} \end{aligned}$$

Wartime and Peacetime Cost

Wartime cost is collected by summing together all the campaigns in the lifetime of the weapon system. Peacetime cost is calculated by determining the cost between campaigns then summing the same way the campaigns are summed.

Effective number of campaigns

The model takes as an assumption the mean time interval between campaigns (m years) and computes value as if campaigns were regularly spaced at this interval for the indefinite future. When all the campaigns over the lifetime of the weapon system are combined, two issues arise:

1. Costs from different years cannot be added together because $1 paid in the near term is more painful than $1 paid in the long term.

2. A particular aircraft is less likely to participate in later campaigns due to attrition.

Both these issues are modeled with the same mathematical form: the cost or value from the next campaign is a certain fraction of the corresponding cost or value from the current campaign. The first issue is modeled with cashflow discounting. The impact of time on value is captured in a cashflow discount factor, r, defined as follows:

> *The ratio of the value of a dollar received today to a dollar received one year from today is 1+r.*

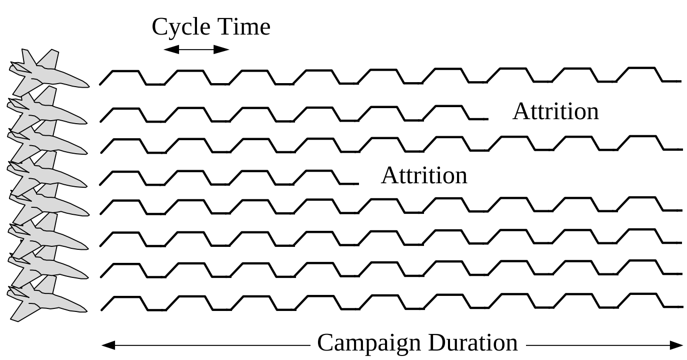

Figure 10: Expected sorties per campaign

The same ratio is assumed to apply to any benefit or cost compared across a one year interval. Consequently, if there are m years between campaigns, a dollar of cost incurred in the next campaign is equivalent to $(1+r)^{-m}$ times a dollar incurred in this campaign.

Attrition reduces the number of aircraft and therefore the number of sorties the fleet can fly in the next campaign. All values and cost shrink accordingly. If q is the probability that a particular aircraft will survive a campaign (equation 5), then q is also the ratio of the fleet size entering the next campaign to the fleet size entering this campaign. Therefore the ratio of the value of the next campaign to the value of the current campaign, considering both effects, is $q(1+r)^{-m}$. This is illustrated in Figure 11. The white bars show the effect of cashflow discounting on the value of successive campaigns, with a discount rate r of 7% and an interval of 5 years between campaigns. The shaded bars combine this with the impact of a 50% probability of surviving a campaign (q = 0.5).

If x is the cost of fuel in the first campaign, the relative cost of fuel in the second campaign is $q(1+r)^{-m}x$. The sum cost across all campaigns, assuming the aircraft can be maintained to last forever[#], is

$$Cp \cdot x = x + q(1+r)^{m} x + \left[q(1+r)^{m}\right]^{2} x + \cdots$$

$$= x\sum_{0}^{\infty}\left[q \cdot (1+r)^{m}\right]^{i} = \frac{x}{1 - q \cdot (1-r)^{m}} \qquad (7)$$

$$Cp = \frac{1}{1 - q \cdot (1-r)^{m}}$$

Cp can be thought of as an *effective number of campaigns*. The cost and value of all campaigns forever, properly discounted and accounting for attrition, are the same as the cost and value of Cp campaigns with no discounting and no attrition.

Wartime Cost

In the campaign analysis, the expected number of sorties per aircraft was determined. Multiplying this by Cp gives s, the mean equivalent lifetime sorties per aircraft. Like Cp, this is equivalent in the sense that, if

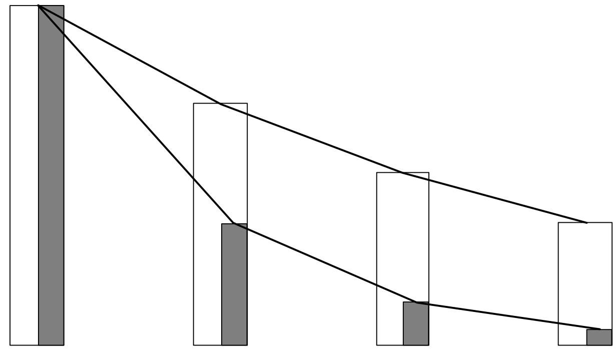

Figure 11: Summing over campaigns.

s sorties occurred at once at the beginning of the aircraft's life, the value and cost would equal the properly discounted and attrition adjusted value and cost of the sorties as they actually occur.

The evaluation of the average sortie determines the fuel and maintenance cost per sortie. Multiplying these costs by s, the equivalent lifetime sorties, gives the engine-driven wartime operation and support costs over the system life, essentially forever.

Peacetime Cost

Peacetime cost is based on annual requirements for training exercises, in hours. Fuel consumption per hour is estimated by dividing the nominal mission fuel by the nominal mission time. The other cost that is tracked is part life consumption per hour, which is the reciprocal of the design life, corrected for opportunistic replacements as in the wartime sortie. Fuel cost per hour is fuel consumption times nominal price, and hourly maintenance cost is part life consumption times engine production cost. Multiplied by peacetime annual flying hours, these give the annual peacetime operation and support costs. Costs are totaled for the interval between campaigns, applying the appropriate cashflow discounting, and this total is multiplied by the equivalent lifetime campaigns, Cp, to provide the total peacetime cost.

Wartime cost and peacetime cost are then summed to give total discounted lifetime operation and support cost, OS.

Fleet Size

A unique aspect of the value model is that it determines the number of aircraft in the fleet based on the average sortie cost. A design with a low sortie cost, SC, is an efficient weapon system and will be procured in greater

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[#] With a reasonable discount rate and any amount of attrition, the difference between a finite life of several decades and an infinite horizon is inconsequential. See Figure 11.

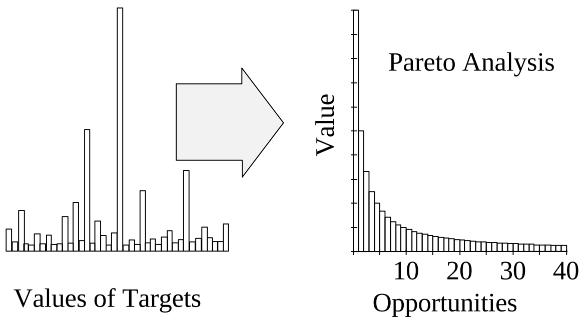

Figure 12: Pareto analysis of target value

quantities than a design with a high sortie cost. This fits with experience: The B-2 is more expensive than originally planned, and this has caused it to be procured in smaller numbers. Arguments for expanding the B-2 fleet are based on economic efficiency, claiming its ability to destroy more targets in fewer B-2 sorties with fewer support sorties.

Target demand curve

The reason for the positive relation between value and fleet size is basic economics, but may be novel to the CONOPS (concepts of operations) community.

In any campaign there are a variety of potential strike targets. Destruction of some of these are very valuable to the attacker, such as the only bridge on the enemy's main supply route. Many are less valuable. The left side of figure 12 illustrates the relative value of a set of target opportunities. When the opportunities are sorted in descending value, the right side of figure 12 is obtained. This sorting is called a *Pareto Analysis* after Italian economist Vilfredo Pareto. Pareto said that when such a sorting is done on any of a wide variety of classes of things of value, the shape of the resulting plot will be a hyperbola. We know this statement as Pareto's law, or the 80-20 rule: 80% of the value will be found in the first 20% of the items. The 80-20 relationship characterizes a hyperbola.

A curve drawn through the points on the right side of figure 12 is a hyperbolic plot of value versus quantity, which is similar in many ways to an economic demand curve [Pindyck and Rubinfeld, 1992, p. 42]. The more valuable targets will be assigned to strike sorties and the less valuable will be ignored or will be dealt with by other forces. The dividing line is roughly where the value of the target equals the cost of the destroying the target (figure 13).

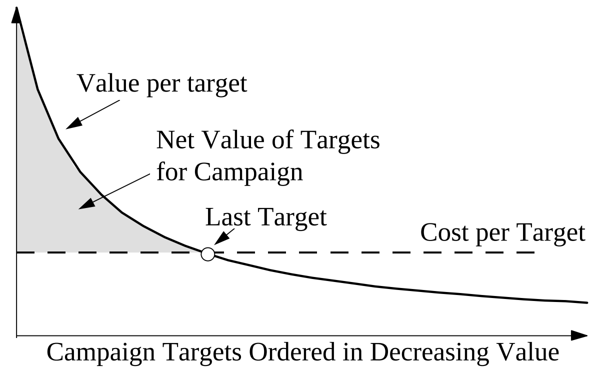

Figure 13: Target demand curve

Targets to the left of the intersection of the cost and demand curves are attacked because the value of the target exceeds the cost of destroying it. Targets to the right are not worth attacking given the cost of the strike sortie. Even though value equals cost at the point of intersection, value substantially exceeds cost on the far left. The shaded area is the total value of all targets selected minus the total cost of destroying them, which is the basis of Surplus Value (SV), the metric produced by the value model. Actual SV is the change in this area from a baseline rather than the total area, since the total is generally so large as to be unwieldy.

When cost changes, the number of targets change. Figure 14 shows a reduction in cost per target and the consequent increase in the number of targets allocated. When the cost line moves down, the point of intersection between cost and demand moves to the right, increasing the number of targets to the left of the intersection. More targets will require more aircraft, so the fleet size increases proportionately.

Average sortie cost

In the model, sorties are counted rather than targets.

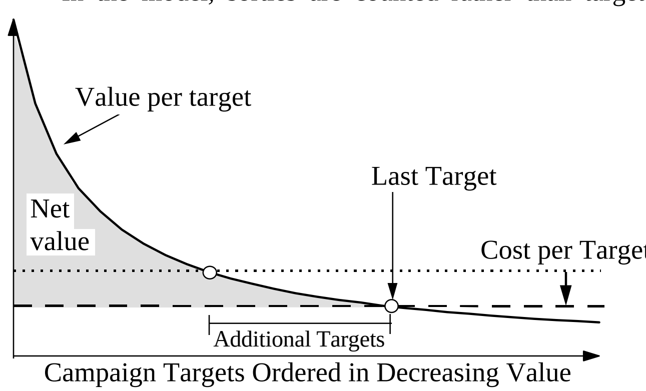

Figure 14: Lower cost increases fleet size

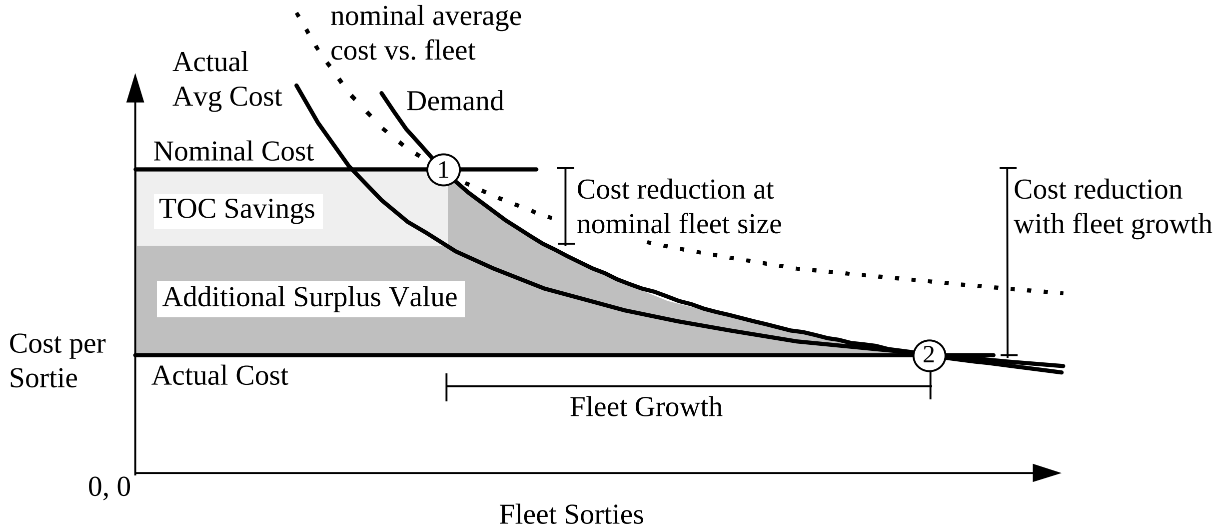

Figure 15: Fleet sizing

The value of a sortie is then the value of the average number of targets destroyed per sortie. The general form of demand and cost curves still follow figure 14. The VAATE model uses sorties because the propulsion system properties have little to do with strike lethality or number of weapons in the bay—targets per sortie are independent of engine properties.

Recall that wartime and peacetime costs are quantified as OS. Aircraft and propulsion system production costs are AC and PS, and are determined by the impact of the engine on the platform TOGW. These costs are anchor points for learning curves. The average production costs, with learning, also depend on the fleet size. Development cost of the engine is input to the model and development cost of the weapon system is a fixed parameter. Thus the life cycle cost of a fleet is

$$LCC_{fl} = \left(OS + f\left(PS, AC, fl\right)\right) \cdot fl + Dev \qquad (8)$$

where fl is the number of aircraft in the fleet, f is a learning curve, and Dev is the sum of weapon system and propulsion development costs. Dividing fleet LCC by the number of aircraft in the fleet and the equivalent number of sorties per aircraft gives the average cost per sortie:

$$SC = \frac{OS + f(PS, AC, fl)}{s} + \frac{Dev}{fl \cdot s} \qquad (9)$$

Note that the level of the average cost curve decreases as fleet size increases. The learning curve decreases with increasing fl and the development cost term has fl in the denominator. Thus if, for example, OS is reduced, then SC is reduced, which moves the sortie value-cost intersection to the right, increasing the fleet size and further reducing average cost. The full situation is illustrated in figure 15.

Point 1 is the original equilibrium point because 1 is where the dotted line, original SC as a function of fleet size, intersects the demand curve. Thus, when the fleet is sized to deliver the sorties that are the abscissa of 1, the value of all the sorties are greater than their cost. The average cost of sorties when the fleet is sized at point 1 is the horizontal line that intersects the cost versus fleet size curve at 1.

Now, consider what happens when cost is reduced. Whether development, production, operation or support cost is reduced, the cost versus fleet curve moves downward. The intersection with the demand curve moves to point 2. Now the average cost is the horizontal line passing through point 2. Fleet size has more than doubled with a cost curve reduction of 25% at the original fleet size. This is fairly typical and explains the extreme shrinkage of the B-2 fleet brought on by cost growth. The simple shrinkage that would correspond to figure 14 is amplified as the development cost is spread over fewer and fewer units and the production cost backs up the learning curve.

Surplus Value

The change in fleet surplus value resulting from cost reduction is the shaded area in figure 15. Notice that the entire shaded area is roughly four times the small shaded rectangle that represents the cost reduction which a traditional study would credit, without considering the impact of engine properties on sorties per aircraft or fleet size. The *entire* surplus value is actually the region between the horizontal actual cost line and the demand curve. However, the surplus value attributed to the change in cost is the shaded region.

Since cost is measured in average cost per sortie, increasing the number of sorties per aircraft also reduces the cost versus fleet function (note s in the denominator of equation 9). Decreasing the sortie turnaround time, increasing engine reliability or increasing platform survivability will increase sorties per aircraft and produce savings as illustrated in figure 15. Traditional life cycle cost or total ownership cost studies find none of these savings, although part of the savings are identified by affordability studies using capability over cost ratios.

The surplus value generated by the model is surplus value per engine. The area of the shaded region in figure 15 is divided by the nominal fleet size to calculate the per-engine value. Because the nominal fleet size is held constant, per-engine surplus value is directly proportional to fleet surplus value. The per-engine number is used because it is more easily grasped by the user, being roughly dollar to dollar with engine manufacturing cost.

Results

The UCAV value model was developed in late 2000 and has been used on three weapon systems. In the course of eighteen months of use, the model has been improved and integrated into the preliminary design analysis tool set used on the VAATE program.

The value model has been used to locate optimal cycles for weapon systems. In comparison with the VAATE Cost-Capability Index [Stricker, 2000], the value model finds a different balance among SFC, thrust and weight, and is strongly influenced of observability drivers in cycle selection.

Conclusions

For the VAATE program at the Allison Advanced Development Company, a value model has been developed to assess technologies and perform cycle parametric studies. The value model provides an objective numerical evaluation methodology which is a major improvement over multi-objective approaches used in the past because of the clear indications of which technologies are superior, the balanced consideration of performance and cost, and the more accurate attribution of value to the technologies.

Notation

ϕ	Fan Diameter
AC	Aircraft Production Cost (less engines)
C	Wing to TOGW weight curve fit coef
Cp	Equivalent number of campaigns
D	Wing to TOGW weight curve fit coef
Dev	Engine & weapon sys. development cost
fl	Fleet size
Fn	Takeoff thrust rating
FuelFrac	Ratio of max fuel capacity to TOGW
k_1, k_2, k_3	Coefficients of Attrition formula
L/D	Aerodynamic lift to drag ratio
LCC_{fl}	Life cycle cost for the fleet
m	Mean years between campaigns
n	Ideal number of sorties per campaign
OS	Operation and support cost, total
p	Attrition: probability of loss per sortie
PropFrac	Ratio of propulsion sys weight to TOGW
PS	Propulsion system production cost
q	Probability aircraft will survive campaign
r	Cashflow discount rate
s	Equivalent sorties for whole aircraft life
SFC	Specific fuel consumption
SV	Surplus value
T9	Exhaust static absolute temperature
T/W	Thrust to weight ratio, engine or aircraft
TOGW	Maximum takeoff gross weight
Wt_{eng}	Unscaled propulsion system weight
Wt_{ac}	TOGW less fuel and propulsion weight
x	Cost of fuel in one campaign

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