A COST AND OPERATIONAL EFFECTIVENESS ANALYSIS OF THE ARMY UTILITY TACTICAL TRANSPORT AIRCRAFT SYSTEM

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ABSTRACT

This paper presents the methods of analysis used by the Training and Doctrine Command Systems Analysis Activity of the U.S. Army to perform a Cost and Operational Effectiveness Analysis (COEA) of the Utility Tactical Transport Aircraft System (UTTAS). First, it discusses the COEA objectives and describes the alternative aircraft systems examined in the study. Second, it gives an overview of the combat scenarios which form the basis for the evaluation. There follows a discussion of the study's analysis methodology. Finally, the paper presents UTTAS COEA results, tabulated as cost-effectiveness ratios which determine alternative preference order.

INTRODUCTION

COEA are performed for Army weapon systems at designated decision-critical milestones in the system's materiel acquisition process. In general, they are comparative analyses which seek to establish a preference order among alternative systems which meet specified operational requirements.

This paper describes the COEA performed for the UTTAS at the "full production" milestone of its materiel acquisition process. It presents the analyses and results used to determine which of several specific utility helicopters is preferred for meeting the Army's operational requirements for utility aircraft in the 1980-1990 timeframe.

COEA OBJECTIVES

The issue addressed by the UTTAS COEA is that of determining which of several alternative helicopter systems can best serve the Army in the "utility" combat role. This issue is not new to Department of the Army decision makers; indeed, the concept of the UTTAS has been around since 1965. Initially it was impelled by the task to find a replacement for the aging UH-1H. However, the present impetus stems from the requirement for an aircraft that can perform a diversity of functions in Army aviation. On the surface this issue appears relatively straight forward. Careful scrutiny, however, reveals that this is far from true. For one reason, the utility mission is at once broad and expansive, ranging from single aircraft administrative missions to massive multiple aircraft troop-lift missions, invariably conducted in the face of hostile forces. And, for another reason, the utility aircraft are the most numerous and widely allocated aviation asset in the Army inventory making it, by sheer numbers alone, potentially the most costly Army aircraft system.

The problem associated with this issue is a particularly challenging one since it must simultaneously address both aspects of the utility question: mission and quantity. Nevertheless, it remains basically a cost-effectiveness comparison of alternative systems. However, it must be a comparison made in an operational environment, for only in this way can the inherent weaknesses and advantages of each alternative aircraft in performing the utility combat role be clearly surfaced.

The objectives of the UTTAS COEA are
(a) to determine the operational effectiveness of the alternative systems when introduced into a combat environment to perform the utility function,
(b) to determine the cost of alternative systems which satisfy the utility function,
(c) to produce, on the basis of meaningful cost and operational effectiveness criteria, a preference ranking of the alternatives,
(d) to recommend, by considering cost and operational effectiveness relationships (as tempered by judgemental considerations) the preferred alternative system which will fulfill the utility aircraft requirement.
These objectives form the basis for the structure and conduct of the UTTASS COEA.

COEA ALTERNATIVES

A partial list of the alternative systems examined in the UTTAS COEA is given in Table 1.

TABLE 1

UTTAS COEA Alternatives (Partial List)

Aircraft	Description
UH-1H	Current Army Utility Helicopter
B-214	Current Iranian Gov't Utility Helicopter
UTTAS	Conceptual Army Utility Helicopter

This list contains the principal COEA alternatives. Only these will be considered in this exposition since the comparative analysis methods of the COEA can be well demonstrated with the partial list. The entire list, however, may be found in THE UTTAS COEA FINAL REPORT (Ref. 1). As a summary, it is noted that the complete list includes aircraft which (a) are currently in the Army inventory, (b) are Navy systems, (c) are foreign systems, (d) are conceptual systems. It also includes two aircraft mixes as alternatives: a UTTAS/UH-1H mix and a B-214/UH-1H mix. In both of these mixes, the UH-1H is included because, being the Army's current utility helicopter, it would be "phased out" of the inventory by any replacement aircraft rather than instantly exchanged. Mixes involving only new acquisition aircraft are categorically excluded as alternatives because such mixes would be contrary to the Army's policy of striving for uniformity in the maintainance and logistic support systems for aircraft.

A comparison of the alternative aircraft with respect to their operational capabilities is given in Table 2. The comparison presented is an engineering (i.e., hardware) comparison. For each aircraft, the entries in this table constitute part of the basic performance data set from which the corresponding operational effectiveness is subsequently calculated. THE UTTAS COEA FINAL REPORT details the performance data for all aircraft.

SCENARIOS

Combat scenarios are the basis for the evaluation of the UTTAS alternatives.

TABLE 2

Aircraft Operational Capabilities

Category	UH-1H	B-214	UTTAS
Performance			
.crs vel (kts)	80	130	147
.max rng (nm)	200	300	370
.vroc (fmp)	450	450	480
.endurance (hr)	2.3	2.1	2.3
.agility	noe	noe	noe
Operations			
.mmh/fh	4.0	2.0	2.8
.pre-flt (min)	30	30	10
.trp ld time			
ingress (sec)	5	5	5
egress (sec)	5	5	5
.medevac			
no. litters	6	6	6
ld time (min)	2	2	2
.lift cap (lbs)			
internal	1800	2600	2640
external	2400	8500	8300
.msn equip			
nav aids	yes	yes	yes
avionics	yes	yes	yes
ase	yes	no	yes
Air Transport			
.deployment			
no. per C5	8	6	6
.handling (hrs)	6.0	6.0	4.5

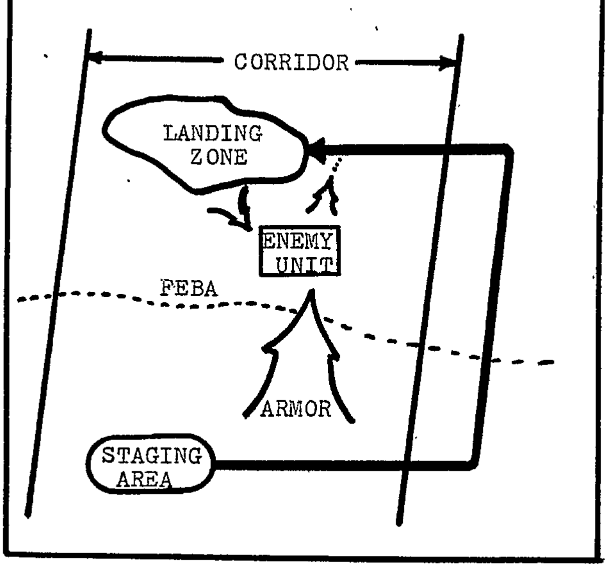
They establish the background operational environment relative to which the effectiveness of the aircraft is determined. As such, they provide a realistic setting in which specified UTTAS mission requirements may be analyzed. In the COEA, they represent a spectrum of conditions, both environmental and tactical, that permit a full examination of the alternatives in the many combat and combat support roles required of utility helicopters.

There are two different scenarios considered in the UTTAS COEA. One scenario is an offensive one and the other is a defensive one. Once again, for ease of exposition, only the offensive scenario will be considered in this paper. A full description of both scenarios, however, may be seen in Ref. 1.

In the offensive scenario (Illustration 1), friendly forces mount an intensive armor attack across the Forward Edge of the Battle Area (FEBA) against established enemy positions with the objective of forcing a withdrawal. Terrain features (not shown) permit withdrawal routes only within the corridor indicated. Complementing the armor attack, a massive air assault operation is conducted into the enemy's rear with the objective of seizing some critical terrain and then linking up with the attacking armor force. This assault is a large airmobile "brigade lift" requiring the insertion of battalion size units into the landing zone. The staging area is the take-off point for this operation. Also required are the resupply and the support of these troops once they are emplaced. Timing, speed, and mobility are the key elements of this scenario.

ILLUSTRATION 1

Offensive Scenario

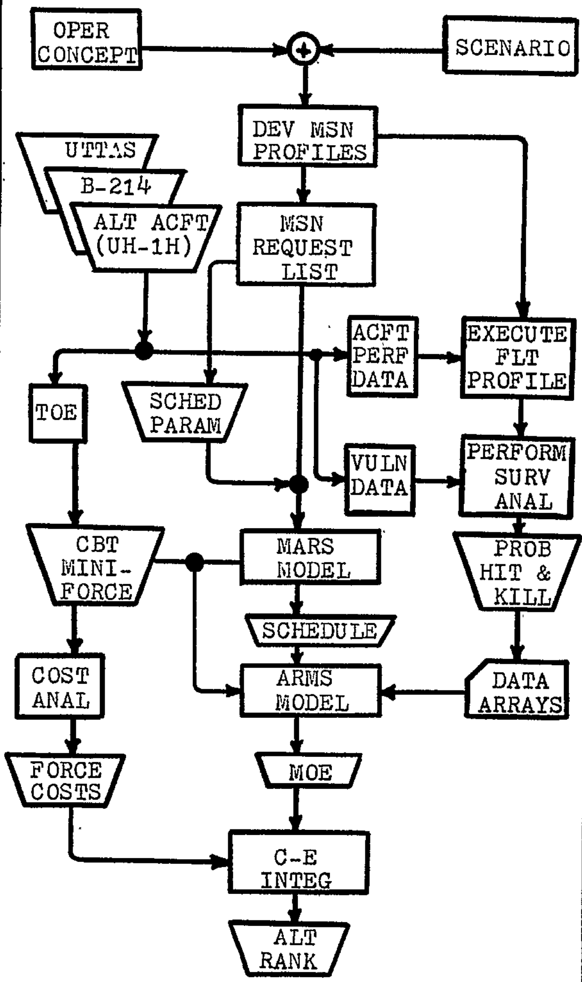


COEA METHODOLOGY

The analysis methodology for conducting the UTTAS COEA is shows in the logic diagram of Illustration 2. The process begins with the definition of the combat scenario as described above and with the specification of the operational concept for utility helicopters in this scenario. From the scenario, tactical operational requirements, as specified by mission profiles, are developed. The mission profiles derive from particular critical events (i.e., combat operations) in the scenario and therefore, determine specific resource requirements for conducting the missions. Additionally, they establish the operational setting and procedure for performing the missions themselves. Finally, in conjunction with mission frequency data, they also serve to specify the overall scenario mission demand (Table 3).

ILLUSTRATION 2

COEA Methodology



For each mission profile developed, a corresponding flight profile is generated. Flight profiles, in contrast to mission profiles, are aircraft dependent and consist of planning and simulating the flight of the aircraft on the mission. For this purpose, performance data is required for all the aircraft considered in the study. The results of the flight profiling operation is an aircraft flight path event history. Using this event data and aircraft vulnerability data, a survivability analysis is performed to define the probability of hit and kill distributions over the entire flight path. These distributions, along with data from the original mission profiles and the generated flight profiles are collected into data arrays and used as inputs to the Aircraft Reliability and Maintainability Simulation (ARMS). This is one of three inputs to the ARMS model.

A second ARMS input is a schedule of missions generated by a resources allocation model (the Mission and Resources Scheduler-MARS) from a "missions requested" list and from scheduling parameters defined by the flight profiles. The mission list used is similar in content to the one a division G-3 staff officer would develop daily. It is derived directly from the mission profiles and the scenarios.

TABLE 3

Scenario Mission Demand

UNIT TYPE	MSN NBR	MISSION TYPE	MSN FREQ
ASLT HEL CO	1	BDE ASLT	1
	2	BDE DIVERT	1
	3	CO INSERT	6
	4	ANTI ARMOR	2
	5	ARTY MOVE	5
	6	INT RESUP	23
	7	AERIAL MINING	15
	8	ECM	24
	9	EXT RESUP	23
AIR CAV SQDN	10	SEC DWN ACFT	9
	11	MAN DIV OP	12
	12	MAN CORPS OP	9
AIR AMBL CO	13	MEDEVAC (LT)	35
	14	MEDEVAC (MED)	41
	15	MEDEVAC (HVY)	24

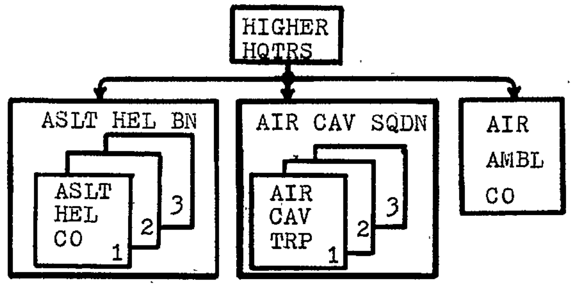
The third and final input to ARMS is the combat force whose operational effectiveness is to be determined. In the COEA, a "mini-force", defined as an aviation force consisting only of those aviation units directly involved in the combat operations, is used for this purpose (Illustration 3). The size and structure of the units in the force are defined by Tables of Organization and Equipment (TOE) for each alternative aircraft. The "components" of the mini-force are defined as the largest tactically independent organizational entities of the force structure. In this case, they are an assault helicopter battalion, an air cavalry squadron, and an air ambulance company.

The ARMS model provides final operational effectiveness results. It is a sustained operations simulation of forces of aircraft functioning in a tactical combat environment. It processes its inputs to quantify the measures of effectiveness (MOE) of the study, namely: (a) number of missions completed; (b) total tonnage delivered; (c) total troops inserted; and (d) total aircraft lost to enemy action.

Complementing the force effectiveness evaluation, a parallel cost analysis is conducted to establish the corresponding "force cost". In the methodology, the costing of the combat force is done with each alternative aircraft successively included in its structure. The cost results

ILLUSTRATION 3

Combat Mini-Force



obtained from this effort are integrated (i.e., combined) with the previously derived effectiveness results to yield cost-effectiveness ratios. These ratios are used to rank the alternatives. The criterion of choice used to establish the alternative preference order is "relative worth".

ANALYSIS AREAS

This section describes the analytical procedures and the corresponding results obtained from the analysis areas of the COEA methodology. Since the exposition can well serve this purpose by considering but one aviation unit type operating in the scenario, only an Assault Helicopter Company (AHC) will be discussed.

Mission Performance

Aircraft mission performance is a measure of how well a given aircraft functions in meeting mission requirements. It is determined by flight profiling the aircraft on each mission in the scenario. In particular, it is quantified by measures of performance (MOP) which depend only on aircraft performance capabilities.

The MOP comparing the COEA alternative aircraft are: (a) short ton (of cargo) moved per aircraft per twelve-hour day, (ST/AC/DAY); (b) short tons moved per aircraft per thousand pounds of fuel (ST/AC/KLBFL); and (c) short tons moved per aircraft per flight hour (ST/AC/FH). These parameters measure the efficiency of the aircraft in their consumption of scarce scenario resources. As such, they serve only to characterize the engineering features inherent to the design of the aircraft. They do not, in themselves, characterize aircraft operational capabilities. Table 4 below gives the mission performance analysis results for an AHC in the offensive scenario. The table gives data for each individual mission type, and at the bottom, it also gives the data for the entire scenario. These latter data are computed by taking mission frequency into account.

TABLE 4

Mission Performance (AHC)

MSN	MSN FREQ	MSN WT (ST)	ALT ACFT	ST/ AC/ DAY	ST/ AC/ KLBFL	TP/ AC/ FLTHR
1	1	223	H B U	4.9 10.9 14.7	.79 .9 1.6	3.1 6.9 9.2
2	1	297	H B U	6.5 15.0 20.0	1.1 1.2 2.1	4.1 9.4 12.6
3	6	24.5	H B U	4.9 9.8 12.7	.8 .8 1.4	3.1 6.1 8.0
4	2	7.5	H B U	4.3 11.5 11.8	.7 .9 1.2	NA
5	5	45	H B U	- 11.4 12.4	- 1.0 1.1	NA
6	23	4.4	H B U	3.8 8.4 11.6	.6 .7 1.2	NA
7	15	5.9	H B U	2.6 3.3 3.7	.5 .4 .4	NA
8	24	7.8	H B U	7.3 9.3 9.3	1.2 .8 1.0	NA
9	23	4.4	H B U	2.2 9.5 9.8	.4 .8 1.0	NA
TOT SCEN ARIO	100	1389	H B U	4.0 8.5 9.7	.7 .7 1.0	3.2 6.6 8.7

Survivability

Survivability is determined on a mission by mission basis for each aircraft. It depends on three factors: enemy weapons characteristics, aircraft vulnerable areas, and engagement geometry.

Enemy weapon characteristics are specified for the threat array (i.e., enemy weapon mix) encountered by the aircraft on each mission. For the scenarios considered in this study the threat array includes the following weapon types: 7.62 mm API, 12.7 mm API, 23 mm HEI, and 57 mm HEI. Also included are the missiles: SA-7, SA-8, and SA-9. For each weapon type, random distributions for the aim bias and for the round-round ballistic dispersion characterize those weapon capabilities which affect the aircraft damage probabilities. For the missiles, infra-red lock-on boundaries provide the requisite capability data for computing the damage probabilities.

Aircraft vulnerable areas specify quantitatively aircraft damage vulnerabilities. Since these areas depend on both aircraft type and on weapon type, they are given for each "aircraft-weapon" pair. They take into account survivability features and equipment designed into the aircraft. They also provide for four levels of aircraft damage: hit, attrition, force landing, and mission abort. In addition, since damage probabilities depend on weapon- to-aircraft aspect angle, the aircraft vulnerable areas are also given for the six cardinal aspect angles: top, bottom, front, rear, right, and left.

Engagement geometry parameters (eg. range, aspect angle, etc.) are calculated from data deriving from the aircraft flight profiles and the weapon locations. They specify the aircraft-weapon geometric relationships obtaining at the time of an engagement and therefore directly influence the damage probabilities.

Survivability results are calculated in two ways: a) as loss ratios and b) as loss rates. The loss ratios are computed by an aircraft survivability model, the Evaluation of Air Defense Engagements (EVADE II). They reflect the results of individual mission combat and exhibit survivability comparisons among the alternatives. Specifically, they are defined as the ratio of aircraft expected attrition. Since the UH-1H is the COEA baseline aircraft, the numerator of this quotient is always the damage probability for the UH-1H. Loss ratios for the offensive scenario are shown in Table 5.

The EVADE II model calculates loss ratios by manipulating the three survivability factors discussed above. Basically, it "flies" the aircraft along the flight path and at each engegement fires the enemy weapons at the aircraft according to a previously defined firing doctrine. It then makes a probability calculation by the use of the "salvo equation" (Ref. 3) on a burst by burst basis. In this way probability distributions are defined over the entire flight path for all levels of aircraft damage. In particular, the EVADE II outputs are the damage distributions: probability of hit, probability of kill, probability of forced landing, and probability of mission abort.

TABLE 5

Mission Loss Ratios

MSN NO	ALT ACFT	TOTAL MSN ACFT	EXP ACFT KILLS	ACFT LOSS RATIOS
1	H	121	60.7	1.0
	B	65	20.1	3.0
	U	52	7.3	8.4
2	H	121	102.7	1.0
	B	65	21.7	4.7
	U	52	18.8	5.4
4	H	13	7.9	1.0
	B	6	3.0	2.6
	U	6	1.3	6.1
6	H	7	4.2	1.0
	B	4	1.5	2.8
	U	3	.4	10.5
8	H	3	3.0	1.0
	B	3	1.5	2.0
	U	3	1.2	2.5
9	H	11	10.1	1.0
	B	3	2.4	4.2
	U	3	.7	14.4

The scenario loss rates are computed by the sustained operations model, ARMS. They represent the expected aircraft losses incurred by the combat mini-force in conducting all the missions required by the scenario. They thereby indicate the comparative combat "staying" power of each alternative force. Loss rates for the AHC are given in Table 6 as totals of aircraft killed and as the percent of the initial aviation force killed.

Operational Effectiveness

Operational effectiveness is a measure of an alternative's capability to meet established mission requirements in a operational environment. It is quantified by the MOE and represents the ability of each alternative to perform a required schedule of missions over the scenario period. In the UTTAS COEA, operational effectiveness is calculated for each individual aviation unit in the mini-force and, by suitable aggregation (see below), for the mini-force itself.

The ARMS model is used to quantify the MOE

TABLE 6

Scenario Loss Rates

MSN NO	MSN LAUNCH FREQ H	B	U	TOTAL ACFT LAUNCHED H	B	U	EXP ACFT KILLED H	B	U
1	1	1	1	23	24	15	6	3	2
4	1	1	1	4	1	3	2	0	1
6	5	10	11	13	29	25	4	2	1
8	5	10	7	11	25	19	11	4	2
9	0	2	3	0	4	7	0	1	0
	Scenario Loss Rates			Total ACFT Killed			23	10	6
				% Force Killed			100	41	40

in the COEA. ARMS simulates the operations of forces of aircraft in a sustained combat and maintainance environment. Essentially, it plays an aviation force, defined through its TOE, against a scenario workload, defined through the mission schedules, and determines the number of missions successfully completed by the force. It takes into account combat and maintainance losses and incorporates within its logic the maintainance support to the force.

The operational effectiveness of each individual unit in the mini-force is determined by playing it through ARMS with its allowance of resources (as specified by the unit TOE) against its prorated share of the scenario mission demand. The results for these unit simulations are given in Table 7 for the MOE, "Number of Missions Completed".

The operational effectiveness of the mini-force is also given in Table 7. However, in this case it is not the direct output of ARMS. Rather, it is the sum of the operational effectiveness (obtained directly from ARMS) for each component of the mini-force. Within the mini-force, summing the components' effectiveness is justified because an aviation unit of given type does not perform missions corresponding to units of another type. (In other words, aviation units are independent with respect to mission function.) Within a force component, on the other hand, the unit independence assumption does not hold since the units in a component are all of the same type. Moreover, it is not even correct to calculate a component's effectiveness multiplicatively (from the number of units in it) since operational effectiveness, in general, is not a linear function of "number of units". In the final analysis, a component's effectiveness must be calculated by playing it as a collective force through ARMS. The results thus obtained constitute that component's contribution to overall mini-force effectiveness. Force component effectiveness is also shown in Table 7. (Effectiveness results for the other study MOE may be seen in Ref. 1.)

TABLE 7

Operational Effectiveness

FORCE TYPE	ALT ACFT	NBR MSN COMP
ASLT HEL CO	H	3 of 100
	B	21 of 100
	U	24 of 100
AIR CAV TRP	H	8 of 30
	B	8 of 30
	U	9 of 30
ASLT HEL BN	H	9 of 100
	B	60 of 100
	U	70 of 100
AIR CAV SQDN	H	22 of 30
	B	22 of 30
	U	24 of 30
AIR AMBL CO	H	71 of 100
	B	86 of 100
	U	94 of 100
MINI-FORCE	H	102 of 230
	B	168 of 230
	U	188 of 230

Cost

There are two methods used for costing the aircraft alternatives: a) the Life Cycle Cost (LCC) method and b) the Force Unit Cost method. The LCC method gives the overall cost of the aircraft fleet given the total number of aircraft purchased (the BUY QUANTITY) and the total number of aircraft pressed into service (the OPERATIONAL QUANTITY). It is based on an underlying life cycle (time period) and takes into account costs in the subcategories of Research and Development (R&D), Investment (INV), and Operating and Support (O&S). The LCC also takes into account time phased delivery schedules since it is neither possible nor desirable to have all aircraft delivered simultaneously. The LCC comparisons for the aircraft, based on a twenty year life cycle, are shown in Table 8. It is stressed that the differences in the BUY QUANTITIES for the alternatives are induced by differences in the aircraft in meeting the utility helicopter requirement. (The requirement is, of course, fixed for all the aircraft.)

TABLE 8

Life Cycle Cost
(Millions of FY77 Dollars)

	UH-1H	B-214	UTTAS
BUY QTY	1587	1609	1107
OPER QTY	1106	1130	914
R&D COST	0.	43.0	111.8
INV COST	1057.9	2354.5	2249.2
O&S COST	8313.1	10050.9	5756.4
LCC	9371.0	12448.4	8117.4

The Force Unit Cost method gives the cost of forces of aviation units (i.e., companies or troops) given specific TOE's for these units. It is derived from the LCC by pro-rating the cost of the aircraft for each unit according to the number of aircraft called for by the TOE. The same subcategories of cost as in the LCC are used in force-costing each individual aviation unit. The total scenario mini-force cost is then determined by summing the separate costs for each unit in the mini-force structure. Force Unit Cost results are shown in Table 9 for the offensive scenario.

TABLE 9

Mini-Force Costs
(Millions of FY77 Dollars)

COST CATEGORY	UH-1H	B-214	UTTAS
R&D	0.	3.2	9.5
INV	78.7	177.1	190.9
O&S	618.1	755.8	488.8
FORCE COST	696.8	936.1	689.2

Cost-Effectiveness Integration

For each COEA alternative, a cost-effectiveness (c-e) measure is established. This measure is defined as a dimensionless ratio accommodating both cost and operational effectiveness for each alternative. As such, it provides the final basis of comparison for establishing the preference order for the COEA alternatives.

The c-e ratio is computed as follows. Let C_α and E_α be the cost and operational effectiveness, respectively, of the COEA alternative, α. (In this study, the parameter α, may take on the "values" UH-1H, B-214, or UTTAS.) Also, let $\bar{\alpha}$ denote the baseline alternative (in this case, the UH-1H). Then the following quantities may be defined for the alternative, α:

$$\text{Relative Effectiveness:} \quad RE_\alpha = \frac{E_\alpha}{E_{\bar{\alpha}}},$$

$$\text{Relative Cost:} \quad RC_\alpha = \frac{C_\alpha}{C_{\bar{\alpha}}}.$$

(Evidently, $RE_{\bar{\alpha}} = RC_{\bar{\alpha}} = 1$.) These ratios provide a direct comparison, on a scale relative to the baseline, of the COEA alternatives with respect to its operational effectiveness and cost. Integration of these two numbers as a quotient yields the ratio

$$\text{Relative Worth:} \quad RW_\alpha = \frac{RE_\alpha}{RC_\alpha}.$$

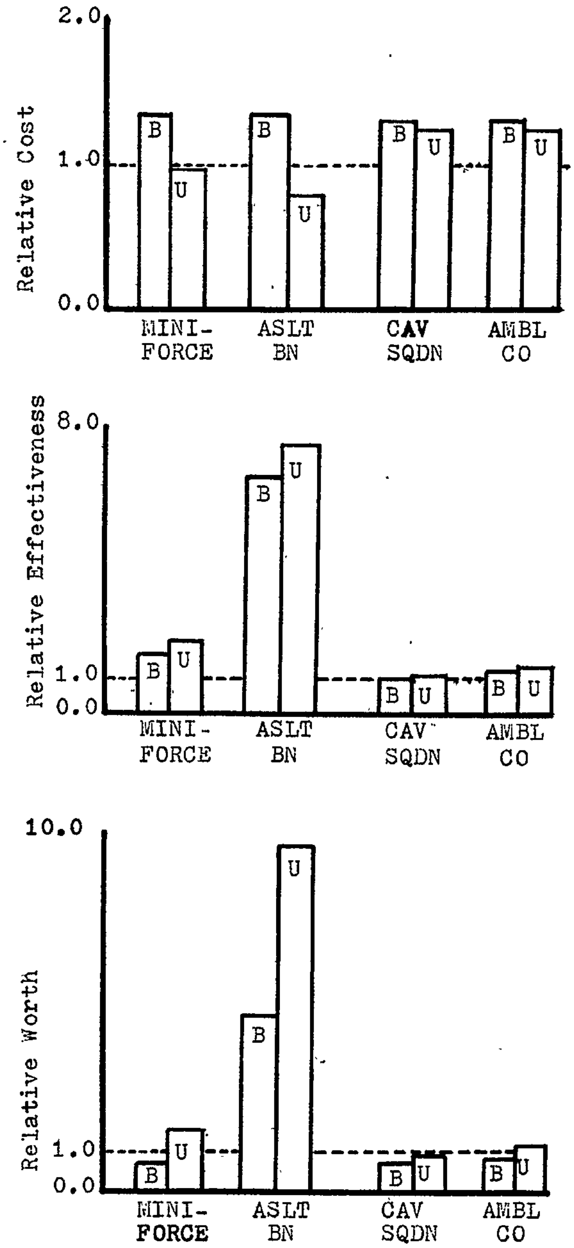
Relative worth clearly takes into account both cost and effectiveness of the alternatives. It provides the ultimate basis of comparison for all the COEA alternatives; it is the "criterion of choice" in the study. In other words, relative worth forms the final basis for defining the preference order among the COEA alternatives.

UTTAS COEA RESULTS

Final UTTAS COEA results are obtained by quantifying the ratios of relative effectiveness, relative cost, and relative worth for all possible combinations of alternatives, MOE, and scenarios. Results for all the combinations may be seen in the UTTAS COEA FINAL REPORT (Ref. 1). Illustration 4, however, shows as representative examples, the results obtained for the offensive scenario for the MOE; "Number of Missions Completed". According to the relative worth comparison the UTTAS aircraft is clearly the preferred alternative. This conclusion, as it turns out, remains true for the other MOE as well and formed the basis for the recommendation, made by the UTTAS COEA Study Group, to initiate full production of the UTTAS.

ILLUSTRATION 4

COEA Alternative Ranking



GLOSSARY

ACFT	-	Aircraft
AMBL	-	Ambulance
ARTY	-	Artillery
ASE	-	Aircraft Survivability Equipment
ASLT	-	Assault
B	-	B-214 COEA Alternative
BDE	-	Brigade
BN	-	Battalion
CAV	-	Cavalry
CO	-	Company
CRS VEL	-	Cruise Velocity
ECM	-	Electronic Counter Measures
EXT RESUP	-	External Resupply
H	-	UH-1H COEA Alternative
LD TIME	-	Load Time
MAX RNG	-	Maximum Range
MAN DIV OP	-	Man Division Observation Post
MEDEVAC	-	Medical Evacuation
MMH/FH	-	Maintainance Man Hours Per Flight Hour
MOE	-	Measure of Effectiveness
MSN	-	Mission
PRE-FLT	-	Pre Flight Inspection
NAV AIDS	-	Navigational Aids
TRP	-	Troops (i.e., soldiers)
SEC DWN ACFT	-	Secure Downed Aircraft
12.7 mm API	-	12.7 Millimeter Armor Piercing Incendiary
2.3 mm HEI	-	23 Millimeter High Explosive Incendiary

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