SYSTEM DYNAMICS AND CONVENTIONAL APPROACHES FOR MANAGING TECHNOLOGICAL SUBSTITUTION IN NATIONAL SECURITY PLANNING

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A system dynamics model is developed to detail essential combat aircraft survivability parameters and their causal relationships for the Joint Technical Coordinating Group for Aircraft Survivability of the Department of Defense. The model is comprised of five submodels: (1) Economy Submodel, (2) Budget Submodel, (3) Procurement Submodel, (4) Attrition Submodel, and (5) Survivability Submodel. The model is illustrated using aircraft carrier oriented combat scenarios which include fleet defense, counterair, interdiction. and close surface support missions for the carrier-based aircraft. Tradeoff analyses are performed to determine the allocations between procurement; operations and maintenance; and research, development, test and evaluation that will generate values of aircraft inventory, availability and survivability that optimize life cycle costs and kill-to-loss ratios.

BACKGROUND

This year the Virginia Polytechnic Institute and State University was awarded a research grant to develop and implement a survivability management model for use by advanced program planners. The purpose of the model is to detail the essential survivability management parameters and their causal relationships throughout the life cycle of aircraft systems, and demonstrate the feasibility of obtaining a desired level of functional capability through a given approach and the connection between current needs and future returns. Specific objectives include the forecasting of macro-behavior, predicting consequences of proposed actions and failure to act, and the conducting of sensitivity analyses to establish research and data gathering priorities, as well as providing aids to communication among those concerned with survivability issues and in their understanding.

Aircraft combat survivability is defined by the United States Department of Defense as "the capability of an aircraft to avoid or withstand a man-made hostile environment without sustaining an impairment of its ability to accomplish its designated mission". From this definition, the broad scope of the concept of survivability is evident leading the JTCG to update its response to its charter requirements to include the promotion of survivability as a design discipline and the coordination of research and development results among the military services and industry, as well as within the services.

2. OVERVIEW OF THE MODEL

The survivability problem in this research has been defined as consisting of two decisionmaking orientations: the hierarchical and the chronological. Regarding the former, three policy levels of defense economics and national security planning are identified: (1) the quantity of resources available to the nation in general and to the defense establishment in particular; (2) the allocation of these resources within the Department of Defense both by service -- Army, Navy, Air Force and Marines -- and function -- personnel, construction, procurement, operations and maintenance, and research, development, test and evaluation; and (3) the allocation of RDT and E resources within the Joint Technical Coordinating Group for Aircraft Survivability within the DOD. Referring to the "chronological orientation" there are the identification of decision nodes throughout the combat aircraft systems life cycles -- from mission requirements to research to conceptual design to development to preliminary design to acquisition to modification to retirement, in the case of peacetime, and to attrition, in the case of wartime.

The model is comprised of five submodels:
(1) Economy Submodel, (2) Budget Submodel,
(3) Procurement Submodel, (4) Attrition Submodel, and (5) Survivability Submodel. In this paper these will be represented visually in the form of causal diagrams, consistent with the system dynamics methodology. Model parameters are clearly identified and the interactions

between the parameters displayed using arrows (solid or dashed) and signs (plus or minus) Since arrows denote the direction of causality, the two basic types of parameters--constants and variables -- are easily distinguished. A parameter with only arrows emanating from it is a constant. Three types of variables used in system dynamics are also apparent. Level or state variables appear at the heads of solid arrows. Rate or change variables appear at the tails of solid arrows. Other variables are auxiliary variables. The signs on solid arrows tell whether the rate adds to or subtracts from the level variable. Signs on the dashed lines tell whether the parameters at each end of the arrow vary directly or inversely.

THE DEFENSE ECONOMY

The Economy Submodel is depicted in Fig. E-1. It is comprised of four subsystems: Aerospace Industry, Defense Industry (other than Aerospace), Air Transportation Industry, and Non-Defense Industry (other than Air Transportation). The Economy Submodel generates the annual "Gross National Product" and "Federal Government Budget" of the U.S. It is used to project the quantity of national resources available, now and in the future. Another important function of the Economy Submodel is to account for the critical need of a national research and development policy to sustain a healthy economic and military preparedness. Basically, the model uses the parameters, "Fraction X-Industry Product to Research" and "Fraction Government Budget to X-Industry Research", to accomplish this.

4. DEFENSE MANAGEMENT

In the previous section, organized around the Economy Submodel, we considered the highest hierarchy of defense economics—the quantity of national resources available. In this section, organized around the Budget Submodel, the questions of the proportion of these resources allocated to national security and the efficiency with which these resources are so used-are addressed. The Budget Submodel is made up of three subsystems: (1) the Procurement Subsystem, (2) the Operations and Maintenance Subsystem and (3) the Research, Development, Test and Evaluation Subsystem. The Procurement Subsystem of the Defense Budget Submodel is shown in Fig. DB-1A. Problems within the scope of these three subsystems consist in choosing efficiently, or economically, among the alternative methods of achieving military tasks, objectives, or missions. These alternative methods may be different strategies, different tactics, various forces, or different weapons.

PROCUREMENT

The Procurement Submodel is comprised of three subsystems: (1) Army Combat Aircraft, (2) Air Force Combat Aircraft, and (3) Navy Combat Aircraft. The portion of the Procurement Submodel dealing with the third subsystem-Navy Combat Aircraft-- is shown in Fig. P-1. Basically the inventory of each of the eight Navy

aircraft shown is increased by acquisition of new aircraft or modification of an older version of the same type aircraft. Older version inventories are reduced by retirement and modification to improved versions. Both the acquisition and modifications rates depend directly on the acquisition and modification budgets and inversely with acquisition and modification costs. The acquisition and modification budgets are determined from the outputs of the Budget Submodel.

6. ATTRITION

The Attrition Submodel acts on the inventory of "Combat Aircraft" in the event of war. The number of combat aircraft increased by the outputs of the Procurement Submodel over years of peacetime are reduced in wartime through the "Attrition Rate for Combat Aircraft", which depends on the number of "Combat Aircraft", the "Sortic Rate for Combat Aircraft", "Mission Survivability for Combat Aircraft", and the "Availability of Combat Aircraft". The Attrition Submodel is made up of ten subsystems: (1) U.S. Army Aircraft, (2) U.S. Air Force Aircraft, (3) U.S. Navy Aircraft, (4) Soviet Aircraft, (5) U.S. Air-to-Air Weapons, (6) U.S. Air-to-Surface Weapons, (7) U.S. Surface-to-Air Weapons, (8) Soviet Air-to-Air Weapons, (9) Soviet Surface-to-Air Weapons, and (10) Soviet Air-to-Surface Weapons. Fig. A-1A depicts the U.S. Navy Aircraft Subsystem and the Soviet Surface-to-Air threats it would likely face (Subsystems 3 and 9 as identified in the previous sentence).

7. SURVIVABILITY SUBMODEL

The Survivability Submodel is comprised of four subsystems: (1) Detection Susceptibility, (2) Hit Susceptibility, (3) Vulnerability and (4) Availability. The Survivability Submodel outputs are the "Mission Survivability for Combat Aircraft" and the "Availability of Combat Aircraft". The former is the product of the "Susceptibility of Combat Aircraft" and "Vulnerability of Combat Aircraft", both of which depend on the magnitude of the "Aircraft Survivability RDT&E Budget" outputed from the Budget Submodel. Reductions in the "Susceptibility of Combat Aircraft" and "Vulnerability of Combat Aircraft" affect the "Acquisition Cost of Combat Aircraft" and "Modification Cost of Combat Aircraft" used in the Procurement Submodel.

8. APPLICATION TO NAVAL AIR POWER

The concepts of tactical air power, in general, and aircraft survivability, in particular are both contingent on, and shapers of, the objectives of contemporary U.S. doctrine and what sorts of aircraft are needed for these purposes. Unlike the strategic forces, U.S. tactical forces are charged with carrying out a variety of activities aimed for the most part at defeating the enemy on the battlefield. Because the logic of technological substitution decisions with respect to specific weapon systems is based on the priority given various missions, it seems appropriate to mention the principal

tactical mission areas: (1) counterair or air superiority, (2) interdiction, (3) close ground support, (4) reconnaissance and electronic warfare, and (5) tactical airlift. In the case of naval air power, these manifest themselves slightly differently; however, this example has been chosen for the sake of relative simplicity in illustrating the model.

U.S. naval air power is carrier-oriented in contrast to Soviet naval air power which, at least for the present, is still principally land-based. Probably the single most distinguishing characteristic of U.S. tactical air structure is the extent of reliance on aircraft carriers. The U.S. Navy currently operates 14 aircraft carriers (one of which is always in overhaul) consisting of 12 ships of post-World War II construction including four nuclear powered carriers. Current plans call for no increase in this number through the century, although by the year 2000, half of the 14 are expected to be nuclear powered. The rest of the world has a combined total of only nine (including four Soviet carriers), most of which are less than half the size of the typical U.S. aircraft carrier. Based on their size and design, carriers such as those possessed by the U.S.S.R. would be used for operating V/STOL aircraft against surface ships rather than projecting air power ashore--the primary role of U.S. carriers.

U.S. Naval Aviation operates more aircraft than any other country except the U.S.S.R. and China. A typical carrier air wing consists of 24 Fighter Aircraft (F-4 or F-14), 36 Attack Aircraft (A-4, A-6 or A-7), 4 Tactical Electronic Warfare Aircraft (EA-6B's), 4 Airborne Early Warning Aircraft (E-2's), 16 Antisubmarine Aircraft (S-3 and SH-3), and about 9 miscellaneous types such as reconnaissance, photographic, communications, patrol, mine countermeasures and logistic support aircraft. Since it is the Fighters and Attack Aircraft that take the war ashore, these are singled out for inclusion in the model and for discussion in this paper. Referring to Fig. P-1, computer plots for the generation of inventories of five naval fighter/attack aircraft types are shown—the A-6, A-4, F-14, F-18 and AV-8.

9. MISSION SCENARIOS

The relative mix of carrier-based fighters and attack aircraft, and how U.S. tactical air resources should be distributed between the two, centers on the survivability of the carrier. For example, the second largest tactical air program for the 1970's, the F-14, has been justified by the Navy primarily on the ground that it will improve the chances of carrier survival against a sophisticated air attack. To act as an equalizer against the American advantage of the aircraft carrier, the Russians developed Mach 2 attack-bombers capable of launching cruise air-to-surface missiles with a long-range stand-off capability. Since these missiles have a range of over 200 miles, the carrier's radar may not be able to pick up the launching bomber placing the protection of the carrier from this threat clearly on the fleet defense role of the aircraft carrier's fighters.

However, the ability to counter the bomber threat is not enough. Once the cruise missiles have been launched, an effective method of dealing with these anti-ship missiles must exist. A number of the F-14's high technology features allow it to engage up to six targets in rapid sequence and at very long ranges, making it possible for this fighter to defeat both the bomber and the missile.

In addition to the fleet defense or interceptor mission of carrier-based fighters, like all fighters they must meet the counterair mission challenge. The obvious threat in a tactical situation is the enemy's fighter. Control of the air as a dominant factor in successful warfare is no longer questioned. The Russians have learned this historical lesson and have been pursuing the development of first class fighters like the MIG-21 and MIG-23. These are two current threat aircraft that modern U.S. carrier-based fighters such as the F-14 and F-18 are designed to counter so as to fulfill their air superiority mission.

Tactical airpower can be divided into two groups: planes that fight other airplanes as discussed above and those that attack surface targets. Each group can be further divided into components according to range and weight (or size). The mission in which planes fly across the front line of battle or, in case of carrier-based aircraft, penetrate inland to attack targets such as bases, airfields, roads, pipelines, depots, etc., at long range is called interdiction. In contrast to the long distance typical of interdiction, close air support aircraft attack nearby surface targets including enemy ships. For example, the A-4 was developed in the 1950's as a lightweight, daylight only nuclear strike aircraft for use in large numbers from aircraft carriers. In contrast, the A-6 is an all-weather and night attack aircraft developed for conventional surface attack. Then there is the AV-8B to be flown in the light attack role by carrier-based marine squadrons in support of landings. In short, U.S. carrier-based attack aircraft fulfill the same functions as Soviet land-based naval strike-bombers described in this section.

In Fig. CS-13 a causal diagram for the portion of the JTCG/AS Model used to generate carrier-based mission scenarios is shown. The submodel shown consists of three components: (1) an attrition component (approximately the top half of the diagram); (2) a peacetime-buildup component (essentially the bottom 40% of the diagram below the parameter KLR, Kill to Loss Ratio; and (3) a trade-off component (across the middle of the page). The two principal generic types of U.S. carrier-based aircraft, fighters and attack aircraft, are designated \$F and \$A. Their Soviet counterparts are XF and XA. Using this submodel, survivability, availability, and inventory tradeoffs can be performed for navy combat aircraft as will be explained in the next section.

10. TRADE-OFF ANALYSIS

One of the great ironies of the civil efficiency/military effectivenesses mismatch

is the contradictory ways in which new technology is viewed in different environments. Applied in industry it is referred to as progress; employed in the military it is called "gold plating". American defense planners have long assumed, properly, that U.S. weaponry must be technologically superior to the Soviet Union's. Spending on technology makes sense in our military, just as in the private sector, because it is typically a substitute for people, and in our society people is a more valuable resource than capital. Some economy-minded defense reformers have failed to see the weapons-evolution phenomenon for what it really is—the same technological substitution trend that is taking place across society.

Waging war is no different in principle from any resource transformation process, and improvements should be pursued just as vigorously as for farming, mining, manufacturing and construction. If anything, automation within the military makes even more sense than in other sectors where human labor is consumed only figuratively.

The ultimate technological assessment for combat aircraft is the level of attrition, or loss of mission capability under combat conditions. attrition is higher than expected and mission objectives cannot be fulfilled due to misguided peacetime preparations, it is too late to do anything about it after war starts. The measures of mission effectiveness are varied so that any system can be evaluated with respect to its mission objectives. The two measures used in this trade-off analysis are "Life Cycle Cost per Surviving Aircraft" and "Kill-to-Loss Ratio". Basically, the problem can be stated as follow: allocate a given "Program Cost of Combat Aircraft" between procurement, operations and maintenance (O&M), and research, development, test and evaluation (RDT&E) so as to obtain the combination of aircraft inventory, aircraft availability, and aircraft survivability that will optimize the measure of effectiveness selected.

Table 1 presents a summary of how a tradeoff analysis would be performed for a special
case of the model shown in Fig. CS-13 in which,
instead of two distinct aircraft \$F and \$A,
a multi-mission aircraft designated \$F/A
is utilized. Such an aircraft actually
exists in the form of the F/A-18 since
McDonnell Douglas has developed the attack
version of the F-18. Moreover, for the
past decade the Navy has studied the possibility of a multi-mission VTOL referred to
as the VFMX.

11. MODELING TECHNOLOGICAL DEVELOPMENT

The technological development process, as applied to combat aircraft, can be thought of as a series of prototype problems that tend to emerge throughout the life cycle of the aircraft system. Basically these can be reduced to the acquisition, distribution, allocation, utilization and scheduling of resources. A number of techniques of operations research, management science, and systems analysis have evolved which lend themselves to modeling

the individual prototype problems such as input-output analysis, inventory theory, queueing theory, linear programming, PERT, etc. A few of these (see figure) have been utilized in this research in conjunction with system dynamics, and will be discussed briefly.

The input-output method depicts the structure of an economy in terms of the flows among its producing and consuming sectors. Such transfers are displayed in an "input-output table" for an economy. In the figure the U.S. economy has been depicted in terms of two sectors, Basic (for Defense Industry) and Non-Basic (for Non-Defense Industry) so as to facilitate showing the relationship between input-output and system dynamics modeling. In the model four sectors are used as shown in Fig. E-1. The input-output framework provides a point-of-departure in determining the impact of a defense buildup on the whole economy and the impact of investment in R&D by industry and/or government on military strength.

Military decisions may be classified by kind as well as by level. It is useful to distinguish: operations decisions (strategy and tactics), procurement or force composition decisions, and research and development decisions. The basic difference among these kinds of decisions, from the point of view of analysis, is the time at which the decision affects the capability of the military forces concerned. An operations decision can affect capability almost immediately. A decision to procure something. on the other hand, cannot affect capability until the thing procured has been produced and fitted into operational forces. Finally, decisions to develop something based on researching it tend to affect capabilities at an even later date--after the system has been developed, procured and fitted into operational forces. Inventory theory (see figure) provides the conceptual device for trading-off force size and force availability through the allocation of financial resources between procurement and operations and maintenance.

The basic mission trade-off model depicted in Fig. CS-13 has two end products. The first is the determination of the force composition of aircraft to accomplish the set of mission objectives in the combat scenario. The second is to accomplish these objectives as minimum cost. The latter is addressed in Table 1 using a single multi-mission aircraft. Suppose, however, we return to the more conventional situation in which two types of carrier-based aircraft are used, \$F and \$A. The numbers of each required to do their respective jobs are plotted in the figure, "Linear Programming" as constraints on the graph. The third constraint is the aircraft carrier capacity (for accommodating these two types of aircraft). The solution space determined by these three constraints is shown on the graph. If the objective function is total program costs of the two, one can easily superimpose these on the graph to determine the optimum number of each type of aircraft.

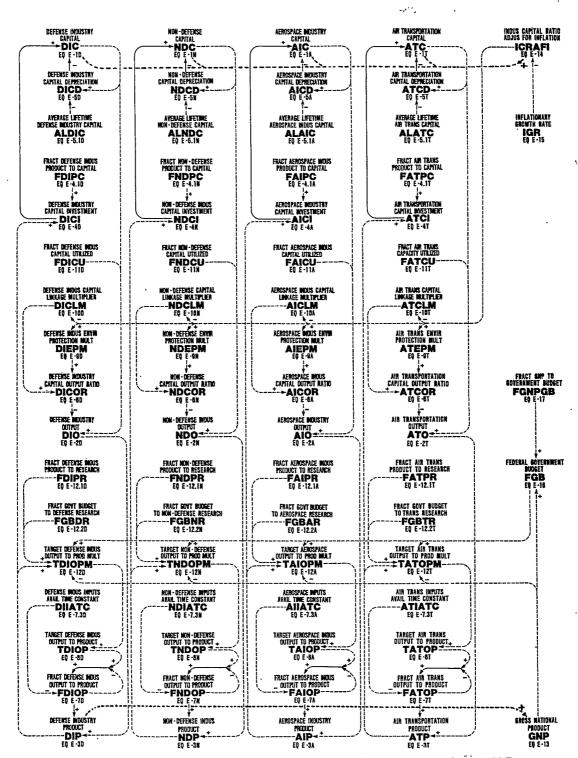


FIG E-1 ECONOMY SUBMODEL

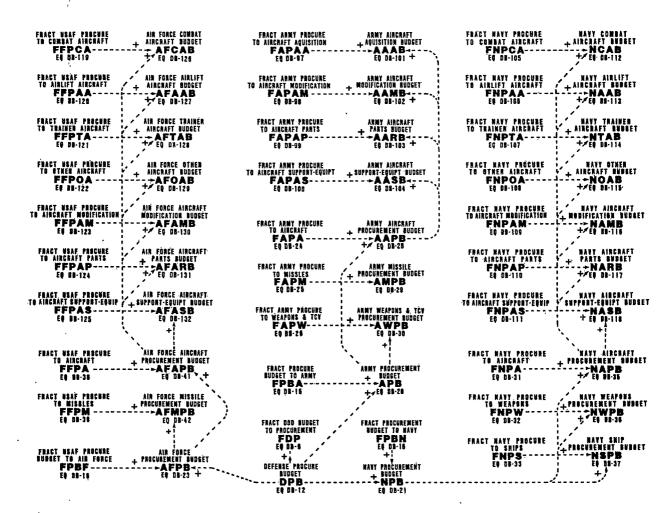


FIG DB-1A DEFENSE BUDGET SUBMODEL

TABLE 1

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FDOM	FDP	FNRCA	AV\$F	\$F	MS\$F	FC\$FOM	FC\$FP	FC\$FRD	PC\$F	UPC\$F	AC\$F	LGC\$F	KLR
25 35 35 35 35 35 35 35 35 35 35 35 35 35	350 355 355 355 355 355 355 355 355 355	.05 .05 .10 .10 .25 .25 .50	.2957 .4140 .5398 .3726 .5108 .6152 .5029 .6063 .7456 .5679	1014 8694 8094 690 5753 5938 471 404	.900 .900 .950 .950 .950 .980 .980 .980	.3584 .4376 .5195 .3512 .4286 .53313 .4039 .4789 .3685	.6211 .5416 .4593 .6086 .5305 .4498 .5741 .4999 .4234 .5244	.020 .021 .021 .040 .041 .045 .096 .098 .173	76.55B 75.24B 73.94B 78.11B 76.81B 75.50B 82.82B 81.51B 80.21B 90.66B 89.35B	75.47M 86.55M 102.10M 97.04M 111.30M 131.30M 139.60M 160.30M 189.30M 192.20M 221.00M	53.81M 53.81M 53.81M 67.80M 67.80M 92.02M 92.02M 92.02M 915.70M	103.4M 117.9M 145.8M 134.1M 154.4M 159.0M 209.1M 260.6M 353.3M 357.0M	2.368 2.786 2.956 2.885 3.348 3.278 3.267 3.281 3.2946 2.981
.35	.25	.50	8116	337	990	.4362	. 3857	. 178	88.05B	261.30M	115.7M	941.0M	2.604

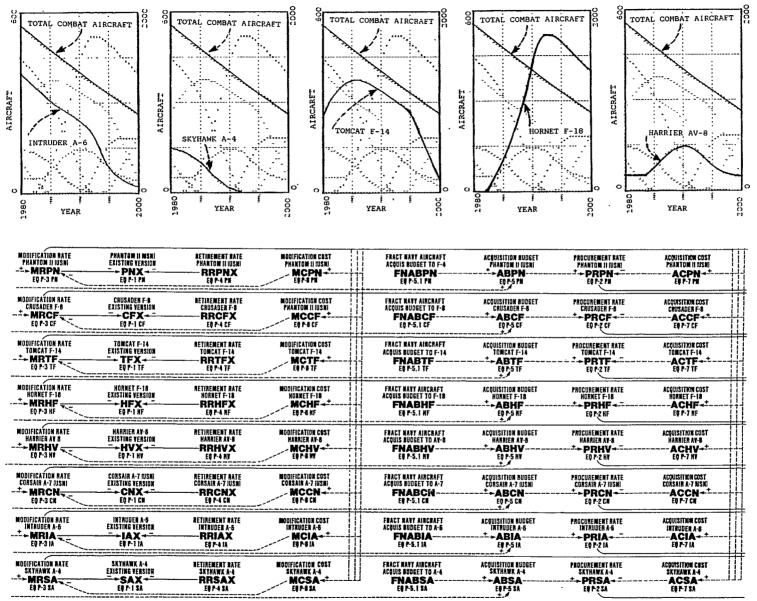
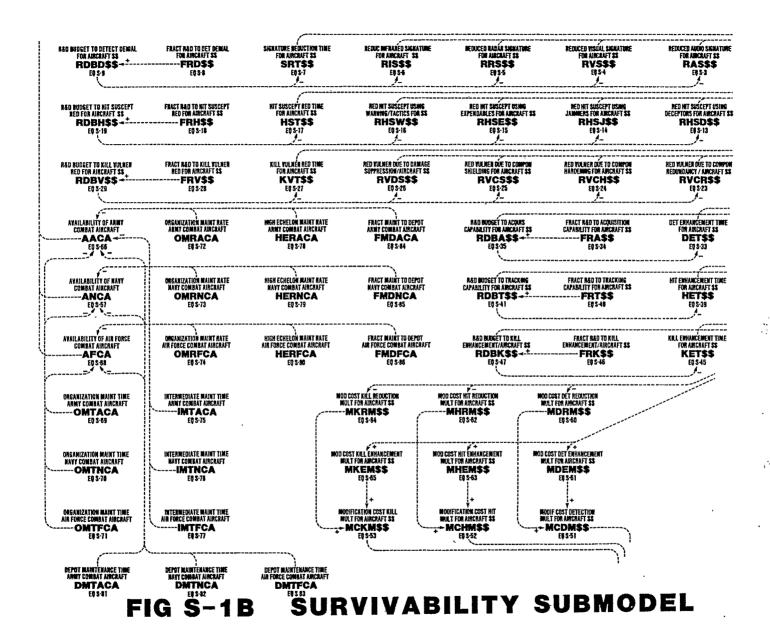


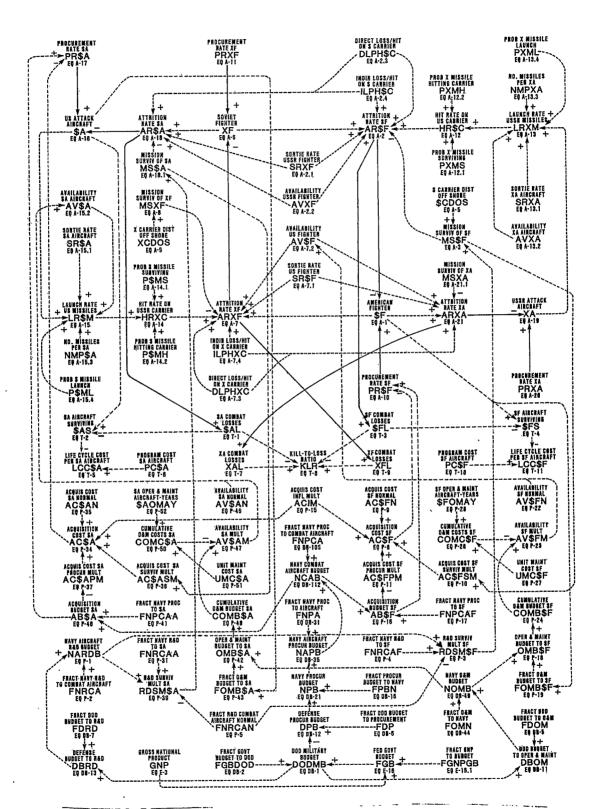
FIG P-1 PROCUREMENT SUBMODEL

	COMMAT AIRCRAFT NATION II F-4 (USN)	ATTRITION RATE PHANTOM II F-4(USH)	SORTIE RATE Pharton II F-4 (USH)	FRACT REMAINING Phanton N F-4 (USN)	MISSON SURWAL PHANTON N F-4 (USH) MSPN	SURY OF AND VS SURFACE THREA SPNF	T PLATFORMS
	PN-	ARPN-	SRPN-*-	FRPN	DASM	3FRF	
us	COMBAT AIRCHAFT CRUSADER F-8	ATTRITION RATE CHUSADER F-8	SONTHE NATE Crusader F-8	FRACT REMAINING CRUSADER F-8.	MISSION SURVIVAL Chusaden F-8	SUMY OF MEA VS. SUMFACE THIEA	T PLATFORMS
	CF -	ARCF→ [™] EQ A-2 CF	EQA3DF	FRCF	MSCF EQA-605	SCFR	TF-
U.S.	COMBAT AIRCRAFT TOMCAT F-14	ATTRITION RATE TOMCAT F-14	SORTIE RATE TUNCAT F-14	FRACT-REMAINING TOMCAT F-14	MESSION SLEVINAL Torreat F-14	SUM OF MICE YS SUMFACE THREAT	PLATFORMS .
	TF→==	ARTF-*	SRTF	FRTF	MSTF EQ A-5 TF	STFR	TF+
ns.	COMBAT ARCRAFT HORNET F-18	ATTRITION RATE HORNET F-18	SORTIE RATE Hornet F-18	FRACT REMAINING HORNET F-18	MISSION SURVIVAL Hornet F:18	SURV OF AIRC	
	HF ₩A-1HF	ARHF-	EQ A-3HF	FRHF Đ∱4₩	MSHF BASH	SHFF	tTF+
U.S.	COMBAT AIRCRAFT HARRIEL AV-8	ATTRITION RATE B-VA REMAN	SORTIE RATE Karrier av-8	FRACT REMAINING HARRIER AV-8	MSSION SURVIVAL 8-Va Remaah	SURY OF AIRC YS SURFACE THRE	RAFT HY
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11.5	COMBAT AİRCHAFT	ATTRITION BATE	SORTHE RATE	FRACT REMAINING	MISSION SURVIVAL	SURY OF AIR YS SURFACE THREA	CRAFT CN
,	CN- EQ A-I CH	CORSAIR A-7(USH) ARCN EQ A-2 CH	CORSAR A-7 (USH)SRCN EQ A-3 CH	CORSAIR A-7 (USIN) FRCN EQ.A-4 CN	CORSAIN A-7 (USIN) MSCN EQ A-5 CH	SCNI	TF
U.S	COMBAT ARCRAFT	ATTRITION RATE	SORTHE RATE	FRACT REMAINING	MISSION SURVIVAL	SURY OF AM	CRAFT IA
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YS LÁNDT SSSI	NAEATS LTF	VS SA-7	BY SA-7 K\$\$ SA 7 EQ\$ A 955UA TO A 355SA KILL PROB ON AIRCRAFT \$3 BY 2SU K\$\$ZSU	BY SA-7 HSSSA 7 EQS A-349KT TO A-349SA HIT PROBON AIRCRAFT \$3 BY ZSU H\$\$ZSU	BY SA-7 D\$\$\$A7 EQS A-34-3UH TO A-34-35A OET PROB OF \$S BY ZSU D\$\$ZSU	AIRCRAFT 31 MS A 7\$\$ EQS A33 TUH TO A 337 SA NO. SHOTS FINED FROM 2SU AT AIRCRAFT 31 NZSU\$\$	ERAIL SA-7
YS LÁNDT SSSI	NAEATS LTF	#\$ 54.7 \$\$\$\$A7 EQRA 4310H [10 A3315A SURY OF AHRCHAFT \$\$ \$\$ 25U \$\$\$\$ZSU \$\$\$\$ZSU \$\$\$\$A320H TO A3325A SURY OF AHRCHAFT \$\$ \$\$\$5A2 EQRA 43330H TO A3335A SURY OF AHRCHAFT \$\$ \$\$\$\$A6 EQRA 4330H TO A3345A EQRA 4340H TO A3345A	BY S.A-7 K\$\$\$A7 EGS A-950M TO A-9555A KILL PROB ON AIRCRAFT \$3 BY 25U K\$\$Z\$U EGS A-9560M TO A-9565A KILL PROB ON AIRCRAFT \$5 OY SA-2 K\$\$5A2	BY SA-7 H\$\$\$A 7 E95 A-3 90H TO A-3 95A HIT PROB ON AIRCRAFT \$3 BY 25U H\$\$Z\$U E95 A-350UH TO A-3505A HIT PROB ON AIRCRAFT \$5 BY 5A-2 H\$\$SA-2	OF SA-7 D\$\$\$A7 ED\$\$\$A7 ED\$A3430H TO A3435A OET PROB OF \$\$ EQ\$A3440H TO A3445A OET PROB OF \$\$ EY \$A2 D\$\$\$A2 D\$\$\$A2 D\$\$\$A2 D\$\$\$A2	AIRCRAFT 33 NS.A.7\$\$ = 1 EQS.A33714 TO A3375A NO. SHOTS FIRED FROM 2SU AT AIRCRAFT 35 NZSU\$\$ = 1 EQS.A33814 TO A3385A NO. SA-2 FIRED AT AIRCRAFT 35 NS.A.2\$	GRAIL SA-7
YS LÁNDT SSSI	NAEATS LTF	#\$ 54.7 \$\$\$\$A7 EQRA 4310H [10 A3315A SURY OF AHERRAFT \$\$ \$\$ 25 USY \$\$\$\$2\$U \$\$\$\$2\$U \$\$\$\$2\$U \$\$\$\$4.3320H 10 A3325A SURY OF AHERRAFT \$\$ \$\$\$5\$A2 EQSA 2333H 10 A3325A SURY OF AHERRAFT \$\$ \$\$\$\$5\$A6 EQSA 2334H 10 A3325A SURY OF AHERRAFT \$\$ \$\$\$\$A6 EQSA 2334H 10 A3325A SURY OF AHERRAFT \$\$ \$\$\$\$\$A6 EQSA 2334H 10 A3325A EQSA 2334H 10 A3325A EQSA 2344H 10 A3325A EQSA 2344H 10 A3325A EQSA 2344H 10 A3325A	BY SA-7 K\$\$\$A7 EVS-ASSOINT TO A 3555A KILL PROB ON AIRCRAFT \$\$ BY ZSU K\$\$Z\$U EQS A-35GUN TO A-3565A KILL PROB ON AIRCRAFT \$\$ BY SA-2 EQS A-35 TIM TO A-3575A KILL PROB ON AIRCRAFT \$\$ BY SA-5 K\$\$\$A2 K\$\$\$A5 KILL PROB ON AIRCRAFT \$\$ BY SA-6 K\$\$SA6	BY SA-7 H\$\$\$A 7 EQS A-3 GON AIRCRAFT \$3 BY 2 SU H\$\$Z SU H\$\$Z SU EQS A-3 SOUN TO A-3 SOSA HIT PROB ON AIRCRAFT \$2 BY SA-2 EQS A-3 SOUN TO A-3 SOSA HIT PROB ON AIRCRAFT \$3 BY SA-5 H\$\$SA 2 EQS A-3 SOUN TO A-3 SOSA HIT PROB ON AIRCRAFT \$3 BY SA-6 H\$\$\$A 6	87 SA-7 D\$\$\$A7 EQS A343M TO A3435A OET PROB OF \$5 87 7 25U D\$\$ZSU EQS A344W TO A3445A OET PROB OF \$5 BY SA-2 EQS A345W TO A3455A D\$\$PROB OF \$5 BY SA-5 D\$\$A-5 D\$\$A-5 D\$\$A-6 D\$\$A-6 D\$\$A-6 D\$\$A-6	ARGART 33 NO. SHOTS FIRED FROM 25U AT ARICRAFT 35 NZSUSS 1 EQS A338M TO A3385A NO. SA-G FIRED AT ARICRAFT 35 NSA-Z SASS NSA-Z SASS NO. SA-G FIRED AT ARICRAFT 35 NO. SA-G FIRED AT ARICRAF	ERAIL SA-7
YS LÁNDT SSSI	NAEATS LTF	#\$ 54.7 \$\$\$\$A7 EQS A3310H 10 A3315A SURY OF AIRCRAFT \$\$ \$\$\$ZSU \$\$\$\$ZSU \$\$\$\$ZSU \$\$\$\$SA2 \$\$\$\$\$A320H 10 A325A SURY OF AIRCRAFT \$\$ \$\$\$\$\$A2 \$\$\$\$\$A330H 10 A335A SURY OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$\$A6 EQS A330H 10 A335A SURY OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$A35 SURY OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$A35H 10 A335A SURY OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$\$A5 SURY OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$A35H 10 A335A SURY OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$A55A6 EQS A355H 10 A355A	BY S.A-7 K\$\$\$A7 EYS ASSOCIATIO A 3555A KILL PROB ON AIRCRAFT \$\$ BY ZSU K\$\$Z\$U EQS A 3560H TO A 3555A KILL PROB ON AIRCRAFT \$\$ BY S.A-2 EQS A 3570H TO A 3575A KILL PROB ON AIRCRAFT \$\$ BY S.A-5 K\$\$\$A6 EIS A 3560H TO A 3585A KILL PROB ON AIRCRAFT \$\$ BY S.A-5 K\$\$\$A6 EIS A 3560H TO A 3595A KILL PROB ON AIRCRAFT \$\$ BY S.A-5 K\$\$\$A9 EQS A 3500H TO A 3595A	BY SA-7 H\$\$\$A 7 EQS A-3 490H TO A-3 495A HIT PROB ON AIRCRAFT \$3 BY ZSU H\$\$ZSU EQS A-3 500H TO A-3 505A HIT PROB ON AIRCRAFT \$3 BY SA-2 EQS A-35 10H TO A-35 15A HIT PROB ON AIRCRAFT \$3 H\$\$SA-6 EQS A-35 10H TO A-35 25A HIT PROB ON AIRCRAFT \$3 H\$\$SA-6 EQS A-35 2H TO A-35 25A HIT PROB ON AIRCRAFT \$5 BY SA-6 H\$\$SA-6 EQS A-35 2H TO A-35 25A HIT PROB ON AIRCRAFT \$5 BY SA-6 H\$\$SA-8	07 SA-7 D\$\$\$A7 EQS A3430H TO A3435A OET PROB OF \$5 BY ZSU D\$\$ZSU EQS A3440H TO A3445A OET PROB OF \$5 BY SA-2 EQS A3450H TO A3455A OET PROB OF \$5 BY SA-8 D\$\$SA-8 EQS A3450H TO A3455A DET PROB OF \$5 BY SA-8 EQS A3450H TO A3455A	ARCART 33 NS.A7\$\$ = 1 EQS.A33TM TO A33TSA NO. SHOTS FINED FROM 2SU AT ARCART 33 NZSUS\$ = 1 EQS.A338M TO A33TSA NO. SA-2 FIRED AT ARCART 33 NS.A2\$\$ = 1 NS.A3\$\$ = 1 NS	ERAIL SA-7
YS LAND T SASSIE EYS A SOUND A SAN TO FAM YS SHIPBORN YS SHIPBORN YS SHIPBORN YS SHIPBORN THE SAN THE	UREATSTFTO A 330SA	#\$ 54.7 \$\$\$A7 EQA A316H, DA A315A SURV OF AIRCRAFT \$\$ \$\$ \$\$ \$\$ZSU S\$\$\$ZSU S\$\$ \$\$ZSU SURV OF AIRCRAFT \$\$ \$\$ \$\$5\$A0 SURV OF AIRCRAFT \$\$ \$\$\$\$A30H, TO A325A SURV OF AIRCRAFT \$\$ \$\$\$\$A5 S\$\$\$A6 EQA A334H, TO A335A SURV OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$A50H, TO A335A SURV OF AIRCRAFT \$\$ \$\$\$\$A6 S\$\$\$A6 EQA A354H, TO A335A SURV OF AIRCRAFT \$\$ \$\$\$\$A6 \$\$\$\$A50H, TO A355A SURV OF AIRCRAFT \$\$ \$\$\$\$A6 S\$\$\$A6	BY SA-7 K\$\$\$A7 ECS A-950M TO A-9555A KILL PROB ON AIRCRAFT \$3 BY 25U K\$\$Z\$U ECS A-956M TO A-9565A KILL PROB ON AIRCRAFT \$5 DY SA-2 ECS A-957M TO A-9575A KILL PROB ON AIRCRAFT \$5 BY SA-6 K\$\$\$A6 ECS A-950M TO A-9585A KILL PROB ON AIRCRAFT \$5 BY SA-6 K\$\$\$A6 ECS A-950M TO A-9585A KILL PROB ON AIRCRAFT \$5 BY SA-6 K\$\$\$A8 ECS A-950M TO A-9585A KILL PROB ON AIRCRAFT \$5 BY SA-6 K\$\$\$A8 ECS A-950M TO A-9585A	BY SA-7 H\$\$ \$ A 7 EQS A-3 90H TO A -3 49 SA HIT PROB ON AIRCRAFT 33 BY ZSU HS \$ ZSU EQS A-3 500H TO A -3 50 SA HIT PROB ON AIRCRAFT 33 BY SA-2 EQS A-3 500H TO A-3 50 SA HIT PROB ON AIRCRAFT 34 BY SA-6 EQS A-3 5 10H TO A-3 50 SA HIT PROB ON AIRCRAFT 35 BY SA-6 EQS A-3 5 20H TO A-3 50 SA EQS A-3 5 3 0H TO A-3 50 SA HIT PROB ON AIRCRAFT 35 BY SA-8 EQS A-3 5 3 0H TO A-3 50 SA HIT PROB ON AIRCRAFT 35 H\$\$ \$ A 8 EQS A-3 5 3 0H TO A-3 50 SA HIT PROB ON AIRCRAFT 35 H\$\$ \$ SA-8 EY SA-9 H\$\$ \$ SA-9 H\$\$	87 SA-7 D\$\$\$A7 ED\$ A3430H TO A3435A OET PROB OF \$\$ EY 750 D\$\$Z\$U EQ\$ A3440H TO A345A OET PROB OF \$\$ EY 5A-6 D\$\$SA2 EO\$ A3450H TO A3455A OET PROB OF \$\$ BY SA-6 EY S	ARGART 33 NSA 7\$\$ = EQS A 33TM TO A 33TSA NO. SHOTS FIRED FROM 25U AT ARICHAFT 33 NZ SUS\$ = EQS A 33TM TO A 33TSA NO. SA 2 FIRED AT ARICAGAT 33 NSA 2\$\$ = EQS A 33TM TO A 33TSA NO. SA 2 FIRED AT ARICAGAT 34 NO. SA 5 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 340M TO A 340SA NO. SA 5 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 340M TO A 340SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 341M TO A 341SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 341M TO A 341SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 341M TO A 341SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 341M TO A 341SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 6\$\$ = EQS A 341M TO A 341SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 9\$\$ = EQS A 341M TO A 341SA NO. SA 9 FIRED AT ARICAGAT 35 NSA 9\$\$ = EQS A 350M TO A 345SA NO. SA 9 FIRED AT ARICAGAT 35 EQS A 350M TO A 345SA NO. SA 9 FIRED AT ARICAGAT 35 EQS A 350M TO A 345SA NO. SA 9 FIRED AT ARICAGAT 35 EQS A 350M TO A 345SA NO. SA 9 FIRED AT ARICAGAT 35 EQS A 350M TO A 345SA NO. SA 9 FIRED AT ARICAGAT 35 EQS A 350M TO A 345SA	GRAIL SA-7
\$\$.400 T \$\$\$\$! EYS A 3300M + 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	UREATSTFTO A 330SA	## S \$ A 7 EQS A 30 (M) TO A 30 (SA SURY OF AIRCRAFT \$ S ## S \$ S S S SURY OF AIRCRAFT \$ S ## S \$ S S A 2 EQS A 30 (M) TO A 30 (SA SURY OF AIRCRAFT \$ S ## S \$ S A 2 SURY OF AIRCRAFT \$ S ## S \$ S A 8 SURY OF AIRCRAFT \$ S ## S \$ S A 8 EQS A 30 (M) TO A 30 (SA SURY OF AIRCRAFT \$ S ## S \$ S A 8 EQS A 30 (M) TO A 30 (SA SURY OF AIRCRAFT \$ S ## S \$ S A 8 EQS A 30 (M) TO A 30 (SA SURY OF AIRCRAFT \$ S ## S \$ S A 9 EQS A 30 (M) TO A 30 (SA SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S SURY OF AIRCRAFT \$ S ## S \$ S A 4 SURY OF AIRCRAFT \$ S ## S S A 4 SURY OF AIRCRAFT \$ S SURY OF AIRC	BY SA-7 K\$\$\$A7 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$3 BY ZSU K\$\$ZSU ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-2 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-5 K\$\$\$A6 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-6 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-6 K\$\$\$A6 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-9 K\$\$\$A9 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-9 K\$\$\$A9 ECS A-55CM TO A-55SSA KILL PROB ON AIRCRAFT \$5 BY SA-9 K\$\$\$A9 ECS A-55CM TO A-55SSA	BY SA-7 HS SSA 7 EQS A-3 DOIN TO A-3495A HIT PROB ON AIRCRAFT \$3 BY 2 SU HS \$Z SU EQS A-350UH TO A-3505A HIT PROB ON AIRCRAFT \$3 BY 5-7 HS \$SA 2 EQS A-351UH TO A-3515A HIT PROB ON AIRCRAFT \$3 BY SA-5 HS \$SA 6 EQS A-352UH TO A-3525A HIT PROB ON AIRCRAFT \$3 BY SA-8 HS \$SA 8 EQS A-353UH TO A-3535A HIT PROB ON AIRCRAFT \$3 BY SA-9 HS \$SA 9 EQS A-353UH TO A-3545A HIT PROB ON AIRCRAFT \$3 BY SA-9 HS \$SA 9 EQS A-354UH TO A-3545A HIT PROB ON AIRCRAFT \$3 BY SA-9 HS \$SA 9 EQS A-354UH TO A-3545A HIT PROB ON AIRCRAFT \$3 BY SA-9 HS \$SA 9 HS	## SA-7 D\$\$\$A7 ED\$\$\$A7 ED\$ A343M TO A3435A OET PROB OF \$\$ ## Y 750 D\$\$Z\$U EQ\$ A3440M TO A3445A OET PROB OF \$\$ ## SA-2 ED\$ A345M TO A3455A OET PROB OF \$\$ ## SA-6 EQ\$ A345M TO A3455A DET PROB OF \$\$ ## SA-6 EQ\$ A347M TO A3455A DET PROB OF \$\$ ## SA-6 EQ\$ A347M TO A3455A DET PROB OF \$\$ ## SA-6 D\$\$\$A6 EQ\$ A347M TO A3455A DET PROB OF \$\$ ## SA-9 D\$\$\$A9 D\$\$A9 D\$	ARGART 33 NSA 7\$\$ = EQS A 33TUH TO A 33TSA NO. SHOTS FINED FROM ZSU AT ARCRAFT 33 NZ SUBS = EQS A 33BUH TO A 33SSA NO. SA 2 FINED AT ARCRAFT 33 NSA 6 FINED AT ARCRAFT 33 NSA 6 STS	GRAIL SA-7
YS LAND T S\$\$\$! EYS A 3300M +	UREATSTFTO A 330SA	## S \$ A 7 *** S\$ \$ \$ A 7 *** E C \$ A 33 10 H	BY SA-7 K\$\$\$A7 EX\$A50M TO A 3555M KILL PROB ON AIRCRAFT \$\$ BY ZSU K\$\$Z\$U EQS A-356WITO A 3565A KILL PROB ON AIRCRAFT \$\$ BY SA-2 EQS A-357WITO A-3575A KILL PROB ON AIRCRAFT \$\$ BY SA-5 KILL PROB ON AIRCRAFT \$\$ BY SA-6 EQS A-359WITO A-3595A KILL PROB ON AIRCRAFT \$\$ BY SA-6 EQS A-359WITO A-3595A KILL PROB ON AIRCRAFT \$\$ BY SA-6 K\$\$\$A8 EQS A-359WITO A-3595A KILL PROB ON AIRCRAFT \$\$ BY SA-6 K\$\$\$A9 K\$\$\$A9 K\$\$\$A9 K\$\$\$A1 EQS A-34WITO A-3495A KILL PROB ON AIRCRAFT \$\$ BY SA-1 K\$\$NA1 EQS A-34WITO A-345A KILL PROB ON AIRCRAFT \$\$ BY SA-1 K\$\$NA1 EQS A-34WITO A-345A	BY SA-7 HIS SSA 7 EQS A-3 GON AIRCRAFT SS BY 2 SU HIS PROB ON AIRCRAFT SS EQS A-3 SOUN TO A-3 SOSA HIT PROB ON AIRCRAFT SS BY SA-2 EQS A-3 SOUN TO A-3 SOSA HIT PROB ON AIRCRAFT SS BY SA-5 HIS PROB ON AIRCRAFT SS BY SA-8 HIT PROB ON AIRCRAFT SS BY SA-1 EXSA A1 EXSA A3 TURN TO A-37 ISA HIT PROB ON AIRCRAFT SS BY WA-1 EXSA A3 TURN TO A-37 ISA HIT PROB ON AIRCRAFT SS BY WA-3	## SA-7 D\$\$\$A7 ED\$ A340H TO A3435A OET PROB OF \$\$ EY 750 D\$\$Z\$U EQ\$ A3440H TO A3455A OET PROB OF \$\$ EY 5A-2 D\$\$SA2 ED\$ A3460H TO A3455A DET PROB OF \$\$ BY 5A-5 D\$\$SA6 EQ\$ A3460H TO A3465A DET PROB OF \$\$ EY 5A-5 D\$\$SA6 EQ\$ A3460H TO A3465A OET PROB OF \$\$ EY 5A-5 D\$\$SA9 EQ\$ A3460H TO A3465A OET PROB OF \$\$ EY 5A-5 D\$\$SA9 EQ\$ A3460H TO A3465A OET PROB OF \$\$ EY 5A-5 D\$\$SA9 D\$\$SA9 EQ\$ A3460H TO A3465A	ARCART 33 NS.A7\$\$	GRAIL SA-7 GRAIL EQA-377A USSR ANTI-AIRGRAFT VERICLE 25U-23-4/57-2 EQA-376A USSR SURF-TO-AIR MISSILE EQUIPME EQ A-376A USSR SURF-TO-AIR MISSILE SCHO SA-8 GRECHO EQ A-360A USSR SURF-TO-AIR MISSILE SCHO SA-8 EQ A-361A USSR SURF-TO-AIR MISSILE SCHO SA-8 EQ A-361A USSR SURF-TO-AIR MISSILE SCHO SA-8 EQ A-361A USSR SHIP-TO-AIR MISSILE SURT-YO-AIR MISSILE SURT-YO-AIR MISSILE SURT-YO-AIR MISSILE SURT-YO-AIR MISSILE GOA EQ A-361A USSR SHIP-TO-AIR MISSILE GOA EQ A-361A USSR SHIP-TO-AIR MISSILE GOBLET 3-43 GOBLET A-36 GBLT

FIG A-1A ATTRITION SUBMODEL



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SURVIVABILITY, AVAILABILITY, INVENTORY TRADE OFFS FOR NAVY COMBAT AIRCRAFT

INPUT-OUTPUT EQUATION

 $\begin{bmatrix} BO \\ NO \end{bmatrix} - \begin{bmatrix} FBB & FBN \\ FNB & FNN \end{bmatrix} \cdot \begin{bmatrix} BO \\ NO \end{bmatrix} = \begin{bmatrix} BP \\ NP \end{bmatrix}$

WHERE FBB=BB/BO FBN=BN/NO FNB=NB/BO FNN=NN/NO

BC-BASIC SECTOR CAPITAL BCI-BASIC SECT CAP INVESTMENT BP-BASIC SECTOR PRODUCT FBPC-FRACT BASIC PROD TO CAPITAL BCD-BASIC SECT CAP DEPRECIATION LBC-LIFETIME BASIC SECT CAPITAL BO-BASIC SECTOR OUTPUT BCOR-BASIC SECT CAP OUTPUT RATIO BCORN-BASIC CAP OUTPUT RATIO NORM BCORM-BASIC CAP OUTPUT RATIO MULT BI-BASIC INPUTS FBB-FRACT BASIC INPUT FROM BASIC FNB-FRACT BAS INPUT FROM NON-BAS BV-BASIC VALUE-ADDED BU-BASIC USAGE BB-BASIC INPUT FROM BASIC BN-BASIC INPUT FROM NON-BASIC NC-NON BASIC SECTOR CAPITAL NCI-NON BASIC SECT CAP INVESTMENT NP-NON BASIC SECTOR PRODUCT FNPC-FRACT NON BASIC PROD TO CAP NCD-NON BASIC CAP DEPRECIATION LNC-LIFETIME NON BASIC SECT CAPITAL NO-NON BASIC SECTOR OUTPUT NCOR-NON BAS SECT CAP OUTPUT RATIO NCORN-NON BAS CAP OUTPUT RAT NORM NCORM-NON BAS CAP OUTPUT RAT MULT NI-NON BASIC INPUTS FNN-FRAC NON BAS INPUT FROM NON BAS FBN-FRACT NON BAS INPUT FROM BASIC NV-NON BASIC VALUE-ADDED NU-NON BASIC USAGE NN-NON BASIC INPUT FRON NON BASIC

NB-NON BASIC INPUT FROM BASIC

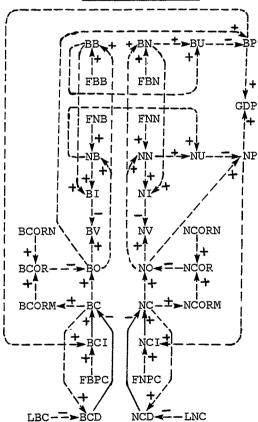
INPUT-OUTPUT TABLE

B N

B BB BN BU BP BO N NB NN NU NP NO

> BI NI BV NV BO NO

CAUSAL DIAGRAM



INPUT-OUTPUT ANALYSIS

