CONSIDERATIONS IN THE DEVELOPMENT OF A SURVIVABILITY/LETHALITY TRADEOFF SUBMODEL FOR ADVANCED TACTICAL AIRCRAFT CONCEPTUAL DESIGN

by

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(ABSTRACT)

System dynamics is based on principles borrowed from engineering -- especially feedback concepts. It makes possible a representation of decision policies and information flow. The systems approach is a mixture of scientific approaches to conceptualizing problems and solving them through research, design and analysis. In system dynamics, differential equations are represented in the form of difference equations. There is no limit to the number that can be employed to represent the complex details of any system. The models developed here help in determining the superiority or inferiority of the Advanced Tactical Aircraft (ATA) over the baseline aircraft. The advanced tactical aircraft is a proposed replacement aircraft that can undertake any of the three missions - air superiority, fleet defense and attack/interdiction. The baseline aircraft for air superiority and fleet defense is the Tomcat Fighter, F-14 and for attack/interdiction it is Intruder, A-6. Several measures of effectiveness are presented to evaluate the superiority or inferiority of the replacement aircraft over the baseline aircraft.

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1.0 CHAPTER 1 - INTRODUCTION

1.1 INFRASTRUCTURE AND CIVIL ENGINEERING

Where the people go, public works follow -- and vice versa. A ready supply of fresh, clean water must be available along with a sanitary sewer system to handle the wastes. A transportation network of highways, bridges, airports and railroads make cities accessible to each other, while streets and public transit systems allow movement within the cities. Public works, however, are not limited to urban areas; they stretch far beyond to include rural highways, dams, power plants, irrigation systems, electric utility lines and others. This underlying foundation of public capital facilities, the basic framework which permits a nation to function is "infrastructure."

The American Society of Civil Engineers has commented on the infrastructure problem and the role of the civil engineer as follows:

> It is civil engineers, who design, build, and maintain the nation's infrastructure, the civil engineer has a responsibility to make known both the problems with the nations's infrastructure and possible solutions to them.

Engineers should focus on the technical aspects of infrastructure needs. In addition to the acknowledged great financial need, there is an equally important need to review design standards and performance levels. These standards and levels need to be changed, where necessary, to conform to severe financial constraints. In many cases, engineers simply do not have the luxury of the higher budgets of the past.

Civil engineers have an important role in accurately assessing the nation's true infrastructure needs. A realistic assessment by professionals is necessary if the proper decisions are to be made to allocate resources to correct deficiencies.

Engineers must also tackle the problem of delay and inefficiency to gain productivity and cost savings.

Engineers must make the point that proper maintenance is vital to extend service lives of public capital investments. They must point out the false economies involved in reduction of maintenance budgets.

At the national level these two get the attention. But one of our greatest strengths is our economic system. Our economy depends, among other things, on a healthy infrastructure.

Civil engineers must take a more active role in the debate on budget problems at all levels of government. There is a very real danger that public works' needs will "fall between the cracks" while the battle rages over social and defense needs.

Civil engineers must take the lead in advocating the reallocation of city, county, state and federal resources in favor of infrastructure renewal and maintenance.

Civil engineers must recognize and make known the fact that infrastructure needs vary across the nation. Some cities, which had witnessed large scale decline in their infrastructure, have been able to rally support in recent years for expanded programs to reverse the trends. On the other hand, cities have reduced infrastructure renewal programs to zero in the face of inefficient or misdirected programs and citizen campaigns to reduce taxes.

Civil engineers must develop and apply innovative techniques to renew and rehabilitate infrastructure that are cost effective and minimally disruptive.

Civil engineers must also develop new techniques for future public works projects that build on the lessons learned in our older cities so that the same problems will not continue to occur.

The civil engineering profession must apply its unique capabilities to the infrastructure problem if the nation is to prosper and grow.

Today's engineers will leave a legacy to future generations. The kind of a legacy depends on how well the profession protects the huge investment in urban public works infrastructure made by previous generations. How well the countries of the world work in the future depends upon the ability of civil engineers to help reverse the decline in the public works infrastructure -- starting now" [1].

While virtually every economist, planner, engineer, politician and manager would agree that the world's countries can be ranked as to the socio-eco-political power according to their infrastructure, there would probably be little agreement as to what should be included in "infrastructure." For civil engineers the list includes the following facilities: irrigation; waterways; flood control and drainage; sewers and wastewater treatment; community water supply; solid wastes; roads, streets and highways; urban mass transit; airways and airports; public buildings; parks and recreation; energy; and military installations [2].

Whereas the engineer and social scientist would tend to rank military facilities low on the priorities of infrastructure requirements, the politician and economist continue to give this category more respect.

Perhaps the difference can be attributed to the fact that politicians and economist tend to view the world as it is; engineers and social scientists look at it as it ought to be. Most of the countries in the world spend more on their military than on any other category of infrastructure. Even those that abhor this development might be inclined to agree that if this money is to be spent in this way, it ought to be spent wisely.

1.2 THE SOVIET MILITARY THREAT

It can probably be said that as we enter the mid-1980's, the goals of most countries in the world are to enhance socio-economic stability and lessen the risks of war. For pursuing these goals, it is necessary to assess the threat posed by the growing size and capabilities of the Soviet Unions's Armed Forces. Recent key development in the continuing upgrade of USSR's Armed Forces include [3].

- Modernization of the fourth-generation SS-18 and SS-19 ICBMs nears an end, while the USSR proceeds with the testing of the fifth-generation SS-X-24 and SS-X-25 ICBMs. There are no security requirements for the development of so large a quantity of strategic nuclear offensive weapons.
- The 25,000-ton TYPHOON-Class strategic ballistic missile submarine, which in 1983 was conducting tests firings of its SS-N-20 missiles, is now fully operational. And now, another new SLBM, the SS-NX-23, is being tested.

- The Soviet Union has three long-range, land-attack nuclear-armed cruise missiles nearly deployed-the sea-launched SS-NX-21, the aircraft-launched AS-X-15 and the ground-launched SSC-X-4&el.and it is pressing ahead with the development of more advanced strategic cruise missiles.
- The Soviets now have three manned strategic bombers in development or production. In addition to the new BLACKJACK long-range strategic bomber and the BACKFIRE bomber, the USSR has reopened production lines for the BEAR bomber and is producing a new BEAR H variant assessed to be the initial carrier for the AS-X-15 cruise missile.
- The soviets have continued to field additional mobile SS-20 launchers, each with a three-warhead missile and reload. In 1981, Soviet Military Power reported 250 launchers; in 1983, the total had risen to 330 launchers and now the total is 378 launchers. Construction of new SS-20 missiles with 729 warheads and an equal number for refire are already in place opposite NATO.
- New MiG-29/FULCRUM twin-engine fighter interceptors are now being introduced into Soviet air forces, greatly increasing offensive air capabilities. Additionally, the Su-27/FLANKER is nearing deployment.
- Fast-paced development continues in the Soviet space shuttle program, which will further increase the flexibility and capability of the USSR's essentially military manned and unmanned space systems.
- The USSR continues a great investment in strategic and tactical defenses-with across-the-board upgrading of Soviet air, sea, land and missile defense forces.

This Soviet build-up is made possible by a national policy that has consistently made military materiel production its highest infrastructure priority. Underlying Soviet military power is a vast and complex industrial, mobilization and logistics support system designed to focus the resources of the Soviet State on the capability to wage war. Moreover, the emphasis that Soviet leadership places on the utilization of science and technology for military purposes, together with exploitation of Western technology, has erased the qualitative edge that West once had to balance the Soviet lead in numbers of weapons and men.

1.3 SHIFTING EMPHASIS IN NATIONAL SECURITY PLANNING

The timeliness of this research arises from the growing national concern over the state of security of the United States stimulated by evidence of increasing Soviet military strength and willingness to use it to advance an expansive foreign policy throughout the world. The situation is made more ominous by concurrent evidence of America's apparent impotence in dealing with events inimical to American foreign policy. Fortunately, the U.S. government is giving indications of intentions to redress the shifting balance in relative strength by a substantial program to rebuild and improve its military forces despite a poor economic situation that tends to raise powerful arguments against any such undertakings. Surely this matter will remain a national issue indefinitely requiring a clear understanding of what the nation's security entails and how it can be assured against the most probable and the most dangerous threats that may arise [4].

Security planners are faced with the difficulty of distributing available financial and human resources wisely to meet the competitive needs of several threats at the same time. Since the advent of nuclear weapons, the problem has centered on the needs of the strategic forces versus those of conventional forces. The dilemma posed is whether to emphasize the most destructive but least probable threat or most probable threat with a variable damage potential. In the past, the advocates of the former have prevailed under an implicit policy of "deterrence by assured destruction," i.e., the capability, after absorbing a counterforce strike, to impose "unacceptable damage" on the enemy's population and industry. Now, due to technological developments, the growth in importance of economic interdependencies in international relations, the increasing sentiment in Western Europe and the U.S. for a nuclear freeze, and because of Soviet doctrine, policy and action, it appears that assured destruction is rapidly becoming infeasible and therefore not a viable option [5].

As a result of the strategic balance of terror, the importance of air power within the U.S. conventional forces has risen dramatically. While more will be spent on tactical air forces in the current budget than on all components of the strategic nuclear forces or on the combined surface forces, because of the continuing sharp increase in aircraft costs, the tactical air forces are receiving fewer aircraft and modernizing more slowly than at any time since the 1960's. Tactical aviation appears in danger of pricing itself out of business as it tries to overcome increasingly effective defenses. Potential aircraft fleet combat attrition rates due to sophisticated overlaping air defenses, modern surface-to-air missiles and anti-aircraft systems can cause a much more rapid reduction in tactical aircraft force size than were suffered in World War II, Korea, and Viet Nam. The cumulative effect of projected attrition and obsolescence rates reveals the life cycle cost considerations at stake and demonstrates the impetus for development of concepts for improved aircraft survivability, the thrust of this research [6].

1.4 EVOLUTION OF WAR AT SEA

"The United States is a naval power with an army; the Soviet Union is a land power with a navy" [7]. This fundamental difference in outlook is crucial to an understanding of the nature of sea power as it is seen through Soviet and Western eyes.

At the end of World War II the United States enjoyed overwhelming and unquestioned naval supremacy. Today it has begun to realize that a differently constituted and growing Soviet sea power is challenging America's assumption about its Navy's control of the seas. This is not the first time the U.S. Navy has been in serious trouble, but in that earlier time there was no major threat to the country and its use of the seas, as is perceived from the USSR today. The need to maintain links to other parts of the world was much less critical. The Navy was needed more for protection of commerce than for the security and perhaps the very life of the nation.

Today's U.S. naval force composition can be evaluated fully only in contrast to the naval forces of the USSR, the only other major naval power in the world today. Although the United States has pioneered the use of nuclear-powered attack and strategic-missile submarines, our general purpose naval forces are built mainly around seaborne air power. The large aircraft carrier is the main capital ship. There is a large variety of aircraft for tasks ranging from reconnaissance and early warning to air defense, attack of land targets and ships, and antisubmarine warfare. Other combat ships are designed mainly to protect the carrier from submarine and air attack.

The Soviet Union, like Germany in World War II, is an essentially land-locked power facing naval powers; and just as Germany did at that time, the USSR has stressed submarines and land-based aviation for maritime operations. Its surface fleet has grown slowly from a large number of small combat craft, with modern cruisers, destroyers, and frigates being added at a modest pace. Although its intended uses have not yet become fully apparent, the addition in 1976 of the Kiev, an intermediate-sized carrier with vertical-takeoff aircraft and antisubmarine helicopters, signalled an expanded interest in extending surface-based sea power. Additional striking power of a very different kind is added by the slowly growing force of modern Backfire supersonic bombers being added to the older Badger and Blinder bombers of Soviet Naval Aviation. The "glue" that holds these naval forces together and integrates their operations is a system of long-range reconnaissance and surveillance aircraft and satellite surveillance systems. There are also advanced communications for the tactical coordination of strike forces, rapid exchange of targeting information among air, surface and submarine forces, and coordination of simultaneous strikes against surface naval targets in more than one ocean. These various capabilities have been demonstrated in worldwide maneuvers and exercises.

Thus, we have reached the situation where, although both the American and the Soviet navies have all of the elements of sea power in some degree, the United States seems to have stressed the large, concentrated, easy-to-find surface fleet, while the Soviet Union has concentrated mainly on building a hard-to-find submarine fleet supported by land-based air power as a means of defeating American sea power [8].

1.5 NAVAL AIR POWER

Besides the 458 ships assigned to the Navy, there are 4,663 aircraft assigned to the Navy and Marine Corps. Approximately 1,000 are aboard large aircraft carriers. Another few hundred, mostly helicopters, are aboard smaller ships, including amphibious assault ships. Land-based aircraft include 24 squadrons of nine P-3s each [9].

The offensive power of the US carrier lies in its three attack squadrons. Two of these are 12-plane squadrons equipped with the lightweight A-7 Corsair; the third is a 10-plane squadron of all-weather A-6 Intruders, supported by a detachment of four A-6 tanker. Both the A-7 and the A-6 could be expected to make strikes upto 500nm (926 km) from their parent ship. They might be accompanied on some missions by EA-6 electronic counter-measures (ECM) aircraft whose mission is to jam enemy radar transmissions to reduce the effectiveness of their missile defenses. In the absence of assistance from other sources, enemy surface forces would be detected by one of the four E-2 Hawkeye early warning aircraft which are fitted with a very capable search radar inside a revolving radome. The Hawkeye would also provide warning of air attack, to counter which the carrier has two 12-plane squadrons of fighter aircraft. Some of the older U.S. carriers still operate the F-4 Phantom as their interceptor. The newer ships however, are equipped with the much more capable F-14 Tomcat. Fitted with a relatively jam-proof radar capable of handling up to 24 targets, the Tomcat can launch six Phoenix missiles simultaneously in a fire-and-forget mode with a good chance of success against aircraft 60 to 100nm (111 to 185 km.) away. An important addition to the carrier air wings during the seventies has been a squadron of 10 S-3 Viking ASW aircraft, which give the carrier a long-range capability against Soviet submarines. Able to undertake lengthy patrols, these aircraft could be expected to respond quickly to data from passive area detection systems. The Vikings would then attempt to localize the position of the submarine using sonobuoys and its own sophisticated data processing equipment, and attack with homing torpedoes or depth bombs. At closer ranges a defensive ASW patrol would be mounted by SH-3 Sea King helicopters, of which a squadron of six is carried [10].

Clearly the U.S. carriers would be a prime target for the Soviet Navy in the event of hostilities and, with little sea based aircraft of their base, the Soviets have developed a variety of measures to deal with the threat they pose. A large force of naval land-based bombers armed with stand-off missiles has been built up in each of the four fleet areas. The new long-range Backfire is now being deployed in significant numbers. The carriers would be located by an Ocean Surveillance System combining intelligence satellites and long-range reconnaissance aircraft.

The early Soviet naval strategy was to defend against seaborne invasion. This led to the development of a large coastal force covered by strong shore-based airpower. Subsequently, nuclear strikes by western carrier-based forces became the greatest threat and led to a reliance on long-range shore-based aviation and heavy investment in attack submarines and larger surface ships armed with cruise missiles. The USSR pioneered the development and use of naval cruise missiles, probably because these weapons offered a quick and cheap solution to the problem of acquiring effective antiship firepower. It was probably fairly easy for the Soviet Union to make this innovation because they did not have large current investments in gun-armed ships. The Soviet navy has already deployed six classes of naval cruise missiles, on everything from fast patrol boats to submarines and their newer guided missile destroyers and cruisers, and, of course, the air-launched cruise missiles carried by their land-based strike-attack aircraft.

In the light of their high degree of exposure, the weakness of the U.S. Navy is the small number of large aircraft carriers it possesses. At the end of the war in the Pacific, the American Navy had 129 carriers: ten years ago, it still had 24 carriers-15 attack carriers and 9 ASW carriers. As a consequence of the ever increasing size and weight of ever-more-effective types of aircraft, of attempts to carry the largest possible number of them, and of the fact that modern aircraft require much longer runways, the size of the carriers has increased considerably. In the process, the combat potential of each carrier increased, but the number of them in service fell off. By the end of the Carter administration the fleet of American attack carriers had dwindled to 12 ships, four with nuclear propulsion. The Reagan administration is committed to halting this trend to the extent that a 15 nuclear carrier fleet is projected for the mid-1990's. Still, in view of possible carrier losses, many feel that there are too many eggs in one basket: the elimination of only one carrier meaning the destruction of 7 percent of American carrier and naval air strength [11].

1.6 CARRIER AIRCRAFT OF THE FUTURE

A strong tactical naval air capability on the high seas will continue to be indispensable for the maintenance of mastery of the sea in the face of Soviet ambitions. The importance of this weapon will grow rather than diminish. Some believe that this problem can be solved only by building smaller carriers of which one can afford to have a large number. But smaller carriers necessitate smaller aircraft. In both East and West it is, if one subscribes to this point of view, common knowledge that the problem has to be tackled from the aircraft side, and that the trend towards ever larger and heavier, costly, multi-purpose, high-performance aircraft must not be continued [12].

There are various ways to achieve this objective if one agrees with this point of view. The most radical one would be to switch over to aircraft for which the size of the carrier platform is irrelevant, that is to say, to aircraft that take off vertically, be they fixed-wing VTOL aircraft or helicopters. Compared to current high-performance aircraft, VTOL craft so far developed are slow and do not have sufficient operational radius or payload capacity. However, it is expected that they will finally attain supersonic speed. For the helicopter, too, an increase of speed up to 700 km. an hour appears realistic possibility. Yet, although helicopters, besides their ASW capability, lend themselves to an array of other duties (reconnaissance, electronic countermeasures, missile defense), they can never fully replace fixed-wing aircraft.

Another possibility would be the construction of much cheaper, lightweight, single-purpose aircraft that could be developed into short takeoff and landing craft by means of special takeoff aids, e.g., thrust-augmented wings (STOL). Such "compact" naval aircraft could take advantage of the development of very advanced structural materials of high tensile strength and light weight, as have been successfully tested for use in aircraft construction by the U.S. Air Force.

Whatever such new developments might bring, it will be some time before V/STOL craft can match the performance of present high-speed aircraft. It would be possible to settle for aircraft of a lower rate of performance for combat over the oceans if both sides renounced high performance aircraft. In attacking ship targets, and aircraft using standoff weapons can remain outside the range of surface to air missiles and aerial combat. Accordingly, it will be superior sensoring equipment, as well as the range and precision of air-to-air missiles, rather than the speed and handling of aircraft, that will be of the essence. Operational radius and a payload factors that allows for a satisfactory sensoring capability and reasonable armament will, however, be indispensable for new types of carrier-borne aircraft. It is still uncertain whether V/STOL will be able to qualify in this respect.

Even if these requirements were met, such new developments would not be entirely devoid of problems. If carrier-borne aircraft lagged behind land-based aircraft, then the threat, already considerable, to aircraft carriers within the range of enemy land-based naval aviation would increase. Since the overall strategic situation at sea would require such operations primarily for U.S. aircraft carriers, the scaling-down of sea based aircraft would put the United States at a disadvantage. For operations in such areas, the United States would have to rely upon high-performance aircraft and, hence, upon its large aircraft carriers.

Although the trend towards new types of carrier-borne aircraft has barely become visible, and although the final outcome cannot be foreseen, both the Soviet Navy and the U.S. Navy have to some extent acted in anticipation of the future. The Soviets have built an aircraft carrier of 30,000-40,000 tons, the Kiev, which has no catapult or arresting gear and is obviously designed for V/STOL craft and antisubmarine helicopters. Since a second ship of the same type is under construction, it is assumed that the Soviets plan on a series. The tactical value of these ships will largely depend on the performance of their V/STOL aircraft. At present, this is not known. A surprise is not to be excluded, since the Soviets are credited with a lead in V/STOL technology.

The Americans have started building a series of small aircraft carriers. These 14,000-ton "sea control ships" will have 14 helicopters and 3 V/STOL aircraft. As they are only sparingly provided with sensors and weapons, they will probably not be able to operate, or to operate by themselves, in sea areas where the enemy might attack. The missions to be assigned to this type of ship are to serve merely as escort vessels for the protection of convoys, as their name indicates; participation in the defense of aircraft carriers would necessitate a high speed, which they lack. Sea control ships will, therefore, not be able to replace attack carriers. If the United States is considering building other new smaller carriers, they will have to think in terms of a ship more or less equivalent to the Kiev in size.

Making smaller carriers would solve only some of the carrier problems. Inferiority in speed to the nuclear submarine would continue to be a handicap. That is also true of carrier surface escort ships. Given traditional hull configurations, a considerable increase in the speed of surface ships is out of the question. The limit that cannot be exceeded at reasonable expenditure is 35 knots. Neither gas turbines nor nuclear propulsion change this state of affairs. Since the future does not seem to have in store a major change in the relationship between the carrier and the submarine, one may well ask whether there are any prospects for better protection of the carrier.

No substantial change is to be expected as regards screening destroyers. New destroyer types, as the Americans are now building them, will be quieter than their predecessors and will be equipped with more sophisticated electronics, including automation and long-range sonar that will be less affected by the ship's own speed. They are, nevertheless, bound to lose their role as autonomous ASW systems whose principal instrument is sonar. Their future cooperative role in ASW will consist of carrying helicopters and providing long-range AS weapons to be fired at submarines detected and localized by helicopter.

Thus, defending against fast nuclear submarines is not a task that can be entrusted to destroyers, even modern ones. Interest, therefore, is increasingly directed towards interception of submarine missiles, which, of course, includes interception of antiship missiles fired by bomber aircraft or surface ships. There is a joint defensive effort by carriers, destroyers, helicopters specially assigned for the purpose, and such carrier-borne fighter planes as protect the task force. Interception weapons include such long-range, air-to-air missiles as, for instance, the Phoenix, and short-range missiles to be fired from ships and helicopters [12].

1.7 THE ADVANCED TACTICAL AIRCRAFT (ATA)

A basic truth of modern air warfare is, to survive in an era of high speeds and superaccurate weapons, a pilot needs all the help he can get from his airplane. And a new generation of American jets -- the F-14 Tomcat and the F-15 Eagle -- gave it to them, proving so fast and agile that earlier fighters seemed rudimentary by comparison. The genesis of these superplanes of the 1970's and 1980's went back nearly 20 years to the F-111. The U.S. Department of Defense wanted an all-purpose plane to outduel any jet, deliver bombs reliably, and be able to takeoff from an aircraft carrier, which would be the frontline fighter for both the Navy and Air Force. The result -- five years and a billion dollars later was the General Dynamics F-111, a 50-ton monster that was promptly dubbed "the Aardvark." From the start, it had problems. It was too unwieldly for dogfighting and far too big and heavy for the Navy's carriers.

Gradually, the new planes mechanical troubles were eliminated and the F-111 became a reasonably effective all-weather attack aircraft. Nevertheless, the Navy and the Air Force still needed a new fighter. So, using the research that had gone into creating the F-111, American aircraft manufacturers set to work. By the early 1970's, they had produced the two most formidable tactical jets in the world -- the F-14 for the Navy and the F-15 for the Air Force -- aircraft that would have to be the mainstay American fighters into the 1990's. Now the Navy and the Air Force are planning their aircraft for the 21st century -- referred to as the Advanced Tactical Aircraft (ATA) and Advanced Tactical Fighter (ATF) -- respectively [13].

In contemplating this new generation of tactical aircraft, the lessons of the F-14 and F-15 must be kept in mind. At $6.5 million , their cost was bearable when these planes were introduced in 1970. But the price rocketed upward and they soon became too expensive for the Navy to equip all its carriers and the Air Force all its fighter wings with them. The lower cost, lightweight, multi-purpose F-16 (for the Air Force) and F/A-18 for the Navy were conceived to fill in. The F-16, utilizing one Pratt and Whitney F-100 Jet engine, in contrast to the two on the larger F-15, is an extraordinary aircraft. But, it is no F-15 [14].

In 1971 the Navy became concerned at the cost of the F-14, which had caused both rate of procurement and total number to be restricted to the extent that the Navy could not afford the number of Tomcats that it deemed necessary. Furthermore, the aging F-4 Phantoms and A-7 Corsairs would need to be replaced in the not too distant future, and various alternative solutions were examined, including a cheaper F-14, a navalized F-15 and improved F-4's. A group called Fighter Study IV discussed and rejected these alternatives, formulating instead the requirements of a new Naval Air Combat Fighter with a secondary attack capability, known as VFAX (fighter/attack experimental aircraft) and to be armed with both the short range Sidewinder and the medium range Sparrow. It was anticipated that this would be a totally new design, but Congress decreed that the USN should study derivatives of the Air Force Air Combat Fighter Contenders. The general reasoning was that basic commitments demanded more fighters than the numbers of F-14's and F-15's that could be purchased with the funds available, so a nucleus of expensive high-technology fighters was to be supported by austere and much cheaper ones. This became known as the hi/lo mix, in which the fighter force was to have adequate numerical strength containing a significant level of high technology [15].

The prototype for the future F/A-18 as the Navy's new fighter attack airplane was decided upon in 1975. Now, as the F/A-18 is under production, it is often cited as another example of "gold-plating" -- loading weapon systems with the latest in sophisticated technology with embarrassingly small improvements in fighting capabilities. The Navy wants 1,366 of the new aircraft at a total cost of $41 billion, or $30 million each, triple the $9.9 million cost originally expected and also triple the cost of the latest version of the A-7, the principal aircraft it is to replace. Navy test pilots warn that the flashy Hornet burned fuel so fast in test flights that its combat radius is now calculated at only 390 miles, about half the range of the A-7. Some experts now believe that the very concept of such a multipurpose plane is wrong. They point out that in Viet Nam war, Navy pilots who specialized in either dogfighters or bombing missions outperformed Air Force pilots who tried to do both. Now consideration is being given to cutting back the Navy's order to 900 Hornets -- but that would drive the cost of the individual aircraft still higher [16].

1.8 NEXT GENERATION TACTICAL AIRCRAFT

Intended to enter service in the mid-'90 s are the Advanced Tactical Fighter (ATF) and the Advanced Tactical Aircraft (ATA). The ATF and the ATA will be the primary Air Force and Navy Tactical aircraft into the 21st century. To accomplish their respective missions, these aircraft must be capable of defeating emerging and postulated threats of ever more technological sophistication. The need to carry the air battle deep into hostile airspace necessitates improvements not only in lethality but also in survivability and autonomy in a high-threat environment. This translates to maneuverability, range, landing performance, lethality, and supportability. Technological developments required in association with these two new systems include advanced structures and materials, integrated flight/propulsion controls and advanced engines [17].

Composites allow tailoring structural strength and stiffness to individual applications. Aeroelastic tailoring should allow designing a supersonic thin wing not only to satisfy rigorous strength and stiffness requirements, but also to produce a lightweight solution to demanding flutter and divergence problems. Use of variable-camber leading and trailing edges should optimize lift and reduce drag. By taking full advantage of advanced nonlinear transonic/supersonic aerodynamic design, through optimum use of this wing twist, compromises to transonic maneuvering performance due to the requirement for improved supersonic persistence (higher supersonic L/D ratios) can be minimized. Advanced flight control systems will enable operation at greatly reduced static stability, thus reducing trim drag and improving handling qualities.

Integrated flight/propulsion controls might use two-dimensional thrust-vectoring and thrust-reversing engine nozzles. Thrust vectoring could augment lift as well as reduce drag to improve both cruise and maneuvering performance. Maximum turning performance (turn rate) could be increased by as much as 25% in some portions of the flight envelope. The thrust-reversing mode might reduce landing distance anywhere from 50-75%, especially on wet or icy runways. Operations from short segments of battle-damaged runways would become feasible, the number of alternate or dispersal bases in the case of the ATF that could be available greatly expanded, and the enemy's problem in attempting to close allied airbases vastly complicated.

Historically, advancements in engine thrust-to-weight ratio have driven fighter performance. Recent studies show that the propulsion system will be a major contributor to life-cycle cost of the system. Engine development, acquisition, operating and support, and fuel costs could account for over 30% of the total life-cycle cost of the proposed aircraft. As everyone knows, developing an advanced engine will prove complex, lengthy, and expensive. The engine develops internal operating temperatures ranging up to 3,600 F, pressures to 600 psia, and powerful g-forces. The aerodynamic, thermodynamic, and structural problems necessitate an iterative process of empirically based design, extensive testing, and redesign and retesting. From exploratory development to operational use can take 15 years. Yet the potential performance payoff for applying new technology in these engines will be well worth the time, cost, and risk involved. Supersonic persistence (perhaps even at dry thrust) and improved supersonic maneuverability will almost certainly characterize an Advanced Tactical Fighter. Each has an important impact on propulsion-system requirements, technologies, and design. Together they may dictate some variable-cycle engine features. At the very least, high nonaugmented specific thrust will be necessary. These points favor turbojets as opposed to the turbofans of more moderate bypass ratio used in today's fighters. Besides improving takeoff and landing performance and meeting supersonic persistency requirements, the engine must have high thrust-to-weight ratio to support the needed supersonic maneuverability, reduced fuel consumption, good operability, durability, reliability, and maintainability, and-most important-affordability. It is clear that a propulsion system designed to meet the difficult and diverse challenges of the requirements will have to make extensive use of advanced technology.

The ATF and ATA must be able to fly offensive missions. This leads to a requirement for high survivability operating against dense, highly lethal, and well-integrated air-defense systems. This operating environment leads to a high possibility that engagements by different types of threats could occur from various aspect angles, perhaps simultaneously. This implies the need for a combination of superior performance, reduced signatures, and advanced electronic countermeasures.

Perhaps the most dramatic combat gains will be made in the area of beyond-visual-range (BVR) engagement of enemy fighters. BVR engagement will probably require "fusion" of all source sensor inputs and data from both direct (onboard) and indirect (external) sources. Given the wealth of sensor data anticipated, only information essential to battle management should be presented to the pilot, and that unambiguously. All aspect missile and gun attacks will then require but a minimum of time for maneuvering to obtain proper firing position. Both the desired high survivability and lethality postulate integrating avionics and weapons. An integrated avionics suite needs to be built around a common architecture and common signal and data-processors to support all avionics and flight-control functions. This integrated suite will also likely include multifunction sensors, active-element arrays, shared apertures and antennas, integrated inertial-reference assemblies, and advanced controls and displays [17].

The emphasis on supportability in these programs presents challenges and opportunities. Supportability will be weighed coequally with operational performance, cost, and risk in assessing mission effectiveness (the primary evaluation criterion). Emphasis on supportability this early in a weapon-system program proves difficulty because detailed designs, operating concepts, and support concepts are not set.

The system-level work bears on system reliability, sortie generation, mobility, maintenance, and direct support of personnel, and operations and support cost. System reliability drives spares and maintenance requirements and, together with cost and operational risk, defines the maintenance concept.

Operation and support costs, a principal factor in life-cycle cost and affordability, may prove to be the major design challenge. High reliability, decreased dependence on support equipment, and especially reduced dependence on direct-support personnel can lower operation and support costs. The challenge will be to achieve these characteristics at reasonable acquisition costs!

The ATF, as a single mission, pure, air-superiority or fighter aircraft, is simpler than the multimission ATA which could be called upon to perform air-superiority, fleet defense and interdiction missions. Now well into the concept exploration stage, the Air Force has issued contracts to seven major airframe companies (Boeing, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Northrop, and Rockwell). Each will recommend an ATF solution. These solutions are being subjected to intense analysis by the Air Force. This will be followed by the Air Force recommending an ATF concept that will form the basis for a follow-on competitive demonstration/validation phase to start in 1986, and will culminate in selection of a prime contractor at the start of ATF full-scale development later in the decade. Contractors have been asked to analyze their preferred ATF designs in each of several scenarios. They have been given the opportunity to propose changes in current operating or support concepts that would enable special features of their designs to be exploited.

Similarly, ATF contractors have been asked to analyze new technologies and design approaches. For instance, weapons can be carried in many ways. Racks or pylons to attach weapons externally offer obvious maintenance advantages, but can degrade aircraft performance. Sustained supersonic operation may drive designs toward other concepts, such as conformal or blended weapons carriage, but they may present supportability problems. The established munition-loading techniques, for instance, may not be adequate for ATF. Other, comparable complexities can be foreseen for packaging of avionics, integrated diagnostics, methods to repair battle damage, new structural materials, and support equipment integrated into airframe design [17]. Comparative analysis requires analysts to specify a baseline case built from currently fielded subsystems and to present detailed engineering estimates of system performance, supportability, and cost. This forces analysts away from the parametric trend extrapolation that has been invaluable up to now but fails to give implementation details needed for the crucial ATF and ATA programmatic decisions to be made over the next year. Comparative analysis will force the designers and supportability analysts to cooperate in establishing values and engineering rationale.

It would seem that all that the Navy has to do is follow the Air Force's lead in conceptualizing its ATA. The problem is that while the comparative analysis approach of the Air Force for the ATF looks great, there is no methodology available for evaluating these comparative designs so as to determine which is best. The Navy has faced-up to this and is in the process of developing such a methodology.

1.9 PURPOSE AND OBJECTIVES OF THIS RESEARCH

The Navy is presently in the process of evaluating methodologies which assess different design concepts for the Advanced Tactical Aircraft

(ATA). The main purpose of the assessments will be to measure the implications of advanced technologies on the combat capability of the ATA, of which combat survivability is key element. One can see that beyond the known technological state-of-the-art, it must be possible to estimate the impacts of risks concerning future possible technological advances on the timely development of weapon systems and there relationship to combat readiness. In addition, economic and budgetary considerations, coupled with operational policies, are important in the planning of future force capabilities. The Air Force, in assessing the Advanced Tactical Fighter (ATF) has similar requirements. Therefore, needed is an evaluation tool that is comprehensive and flexible enough to address the many inter-disciplinary and trans-disciplinary issues involved in this effort. Such a tool, is possible by using the work performed by Professors Drew and Tran of the Virginia Polytechnic Institute and State University under Project DI-3-10 of the JTCG/AS (Joint Technical Coordinating Group for Aircraft Survivability of the Department of Defense) [18].

In the words of the Asst. Director of Mission and Effectiveness Analysis Division of the Naval Air Systems Command the proposed task in justified on two major points [19]:

> First, based on the review of the present status of Project DI-3-10, the developed model and its methodology have the capability and flexibility to account for both inter-disciplinary and trans-disciplinary considerations. This is important by virtue of the fact that the results of other already-developed-and-tested studies can be incorporated. In addition, since the methodology lends itself to defining problems in terms of variables and their causal relationships, a simple and concise means of inter-disciplinary communication is inherent. Just as "a forest is made up by many trees," the ability to properly incorporate the expertise from many different disciplines is essential to the evaluation of concepts for the ATA. Since we are addressing crucial and expensive weapon systems, our ability to formulate and understand the right problem

> is more important than that of finding the right solutions to the wrong problem. The second point is our urgent need to provide preliminary specifications to industry for Requests for Proposals (RFPs) on advanced-design concepts for the ATA. A basic tenet of the survivability discipline is that survivability considerations must be incorporated at the earliest time in the development cycle in order to optimize cost-benefits. This is also true of other disciplines. That time is now for the ATA/ATF and the existing established methodologies are not tractable for concept formulation. Furthermore, the co-operative effort on sharing technology with the Advanced Tactical Fighter (ATF) of the Air Force will be more fruitful if we can gain appropriate insights into the future characters of these aircraft and the direct impact of emerging technologies by a common methodical approach. Due to the urgent time requirements of this phase of concept development, the proposed immediate task will not be a means to an end. The simple model to be developed for this task will require successive refinements for more detailed assessments as these advanced aircraft proceed through the DSARC process. That is, as feedback from industry is received and as the government continues to conduct additional reviews through the development cycle of the ATA/ATF.

A two year research project has been drawn-up whereby Virginia Tech will develop a methodology for conceptual design evaluation for the ATA. The immediate task is to develop a first-cut model which will contain all the presently perceived, essential operational parameters (e.g., speed, altitude, ECM, avionics, etc.) of the aircraft. The output of this model will be used as input to a modified version of SURMAN (acronym for SURvivability MANagement model developed by VPI under JTCG/AS Project DI-3-10) for evaluation purposes. In the early phase of this task, all parties of concern will be invited to provide inputs so that their concepts can be synthesized into the model.

The first-cut model will be subjected to accepted facts relating to an existing aircraft for a proof-of-concept validation. The result of the validation will be used to decide if the second phase of the model development should be initiated. The second phase is an extension of the first-cut model and must be accomplished in accordance with the milestones set forth for the ATA/ATF. The product will be a dynamic tool which can be used to aid in the decision making process at various points of the aircraft's development.

The proposed task to develop the "first-cut" model started in the latter part of June, 1985 and will last for three (3) months with an approximate effort of five (5) man months. This amendment to DI-3-10 will result in a commensurate modification to the existing project presently scheduled for the end of December, 1985. The remaining effort for the ATA/ATF beyond the first-cut model will require approximately two-man years to complete and be dependent upon the ATA/ATF milestone scheduling.

The specific objective of this Thesis is to develop a "first-cut" survivability/lethality/cost tradeoff submodel that will help fulfill the requirements of the overall "first-cut" ATA Conceptual Design Model described above. In the next chapter a review of the concepts of tradeoff analysis and the system dynamics methodology used to develop the Survivability/Lethality/Cost tradeoff submodel will be presented. In Chapter 3, single mission tradeoff components will be developed and in Chapter 4 the composite tradeoff submodel will be presented. Chapter 5 is the summary and conclusions of this research.

2.0 CHAPTER 2 - SYSTEM DYNAMICS APPROACH TO TRADEOFF ANALYSIS

2.1 INTRODUCTION

As a result of previous studies, the Navy will begin soon to solicit industry views on a new tactical aircraft. The objective of this solicitation will be to elicit state-of-the-art Advanced Tactical Aircraft (ATA) alternatives for the purposes of making comparative assessments on performance, capability, and cost. It is desired that cost/capability trade-offs be examined. Analyses will be of sufficient depth to assess whether alternative design concepts will be capable of defeating the circa 2000 threats, as well as to project the costs to develop and produce a new tactical aircraft to meet the all weather medium attack requirements.

As experiences have shown, one of the key areas of concern of such an effort is the issue of aircraft survivability and how survivability can be brought to bear upon the overall force capabilities. In order to successfully study this issue, we need inputs from many fields of expertise and be able to synthesize these inputs. A way to achieve this is outlined in this research. It can be instrumental in accomplishing a new approach to combat aircraft conceptual design.

2.2 AIRCRAFT COMBAT SURVIVABILITY

One of the elements of design which significantly contribute to the effectiveness and availability of military aircraft weapons systems is the extent to which combat survivability are embodied in the earliest acquisition phases and subsequently regarded throughout the development and operational phases of their respective system life cycles. The steadily mounting costs of these systems and the necessity of realizing high force readiness and operational effectiveness require that utmost attention be given to combat survivability.

As the result of high damage and aircraft loss rates in Southeast Asia, the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) was established in the 1970's [20]. The JTCG/AS is chartered to coordinate the non nuclear survivability Research and Development effort within the three Services of the Department of Defense.

"Survivability" -- the capability of a weapon system to continue to carry out its designated missions in a combat threat environment -- is a function of both "susceptibility" (the combination of factors that determine the probability of hit by a given threat) and "vulnerability" (the extent of degradation of the system after having been subjected to combat threat) [21]. From these definitions, the broad scope of the concept of survivability is evident, leading the JTCG/AS to update its response to its charter requirements to include: (1) the promotion of survivability as a design discipline, and (2) the coordination of research and development results among the Services and industry, as well as within the Services.

The Joint Technical Coordinating Group on Aircraft Survivability was formed as a tri-service organization to bring together expertise in each of the Services to plan and execute a program to reduce the vulnerability of current fleet aircraft, and to develop design criteria and improved technology to increase the survivability of future aircraft. Specifically, the purpose of the JTCG/AS is to: (1) provide a mechanism to coordinate the individual Service programs to increase the combat survivability of aeronautical systems in a nonnuclear threat environment; (2) provide for the implementation of efforts to complement the Services' survivability and vulnerability programs; (3) assume a liaison role with the Services to ensure that all survivability research and development data and systems criteria are made available to the developers of new aircraft.

The JTCG/AS must provide technical data and inputs for survivability improvements to cognizant aircraft program managers in the Navy and Army, as well as system program directors and system managers in the Air Force. Continuing JTCG/AS assistance to those offices is provided for both the design and production of new aircraft, or retrofiting of existing aircraft. Furthermore, to support the overall JTCG/AS objectives, the responsibilities of the JTCG/AS include the following: (1) coordinate research and advanced development efforts contributing to the reduction of vulnerability for aeronautical systems in a nonnuclear threat environment; (2) plan and propose joint critical technology programs contributing to the improvement of survivability in aeronautical systems; and (3) conduct studies to assess enhanced survivability design features in a combat environment.

2.3 "SURMAN" - A COOPERATIVE RESEARCH EFFORT

To plan and coordinate our national security effort effectively, defense strategists and policy makers must bring together a variety of mental models, translate them into a common language, and determine simultaneously all their important implications. While it is possible for experts to understand portions of the combat survivability development system, synthesizing these so as to account for all the interactions without a formal technique is impossible. Therefore, a formal model -- one whose assumptions are stated explicitly -- is required. Ultimately a formal model should be expressed mathematically for three reasons: (1) mathematics is precise and interdisciplinary, (2) equations can be manipulated in response to changing inputs, and (3) the mathematical notation permits processing by a computer.

The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) has undertaken the development of a tool for efficiently allocating its resources among candidate research and development projects aimed at improving the combat survivability of aeronautical systems. The objective of the model is to aid the JTCG/AS Central Office staff in their interactions with the JTCG/AS Subgroups, Committees, and Principal Members, as well as with other DOD organizations and industry.

The model is referred to as "SURMAN" for survivability management. The model details the essential survivability management parameters and their causal relationships throughout the life cycles of the weapon systems which are within the charter of the JTCG/AS. Other aspects to be included in the model are forecasting macrobehavior; predicting the consequences of proposed actions or inactions; conducting sensitivity analysis to establish research and data gathering priorities; and providing aids to communication among those concerned with survivability issues.

SURMAN was developed using the system dynamics methodology, a field that was begun at the Massachusetts Institute of Technology's Sloan School of Management. The project is now in its third and final phase which requires implementation of the model. In the problem definition stage of the project, the survivability problem was defined as consisting of two decision-making orientations: the hierarchical and the chronological [3]. 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&E resources within the Joint Technical Coordinating Group for Aircraft Survivability within the DOD. Refering 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 [22].

In response to these two-dimensional considerations, two complementary approaches were formulated: (1) the "Top Down" Approach, and (2) the "Bottom-Up" Approach. The "Top Down" Approach consists of five submodels:

(1) Economy Submodel, (2) Budget Submodel, (3) Procurement Submodel, (4) Attrition Submodel, and (5) Survivability Submodel. Whereas the "Top-Down" Approach starts at the top of the hierarchy, the "Bottom-Up" Approach starts with the Subgroups in the JTCG/AS and works up the hierarchy. A block diagram representation of the top-down organization of the model is shown in Figure 1 The bottom-up aspects of the model deal with survivability/vulnerability assessment and feed into the "survivability tradeoffs" block of Figure 1.

When the control parameters in each submodel are traded-off using the combined model, those areas that are in critical need for improvement are identified. Then the proper actions can be taken to make those improvements that would lead to greater national security. For example, the spendings in research & development can be traded-off with spendings in procurement, operations & maintenance, construction, etc. among the services and among activities in each service to find the best combination of force size, survivability, and availability of military combat aircraft. The model also provides the opportunity for trading-off the aircraft survivability enhancement techniques and selecting those techniques that have higher benefits and lower penalties.

The model can perform survivability tradeoff analysis for seven generic vulnerability reduction techniques (shielding, redundancy, active damage suppression, passive damage suppression, component isolation, component elimination, and material hardening) and six susceptibility reduction techniques (signatures, countermeasures, tactics, performance, and threat suppression), applied to over a hundred generic components in eighteen subsystems, in response to five primary weapon effects (ballistic impact or penetration of nonexplosive projectiles, ballistic impact or penetration of fragments from externally detonated missile warheads, external blast effects, internal blast effects, and high energy lasser effects) and five secondary weapon effects (internal fires and explosions, hydraulic ram effects, and liberation of corrosive materials, high temperature gases, and high toxic gases), inflicted by four types of small arms weapons, seven types of antiaircraft artillery, two types of airborne cannon, four types of airborne rockets, six types of airborne missiles, nine types of land-based surface-to-air missiles, and four types of sea-based surface-to-air missiles.

The model generates scenarios based on technological threat projections as well as technological modifications of aircraft for survivability enhancement. Aircraft threat forecasting is a form of technological forecasting that supports aircraft survivability planning and management. It should yield an output that would include adversary platforms, acquisition systems associated with these platforms, and countermeasure systems. The approach utilized to develop this portion of the model is based on normative projections of antiaircraft missile technology that seek to identify likely technological paths that the Soviets may follow in near-, mid-, and long-term development of future systems. The analytical framework associated with making these projections begins with their operational mission requirements assumed to include: improving standoff capability, increasing missile response time, increasing speed, improving reliability, reducing vulnerability, enhancing target discrimination, and increasing accuracy [23].

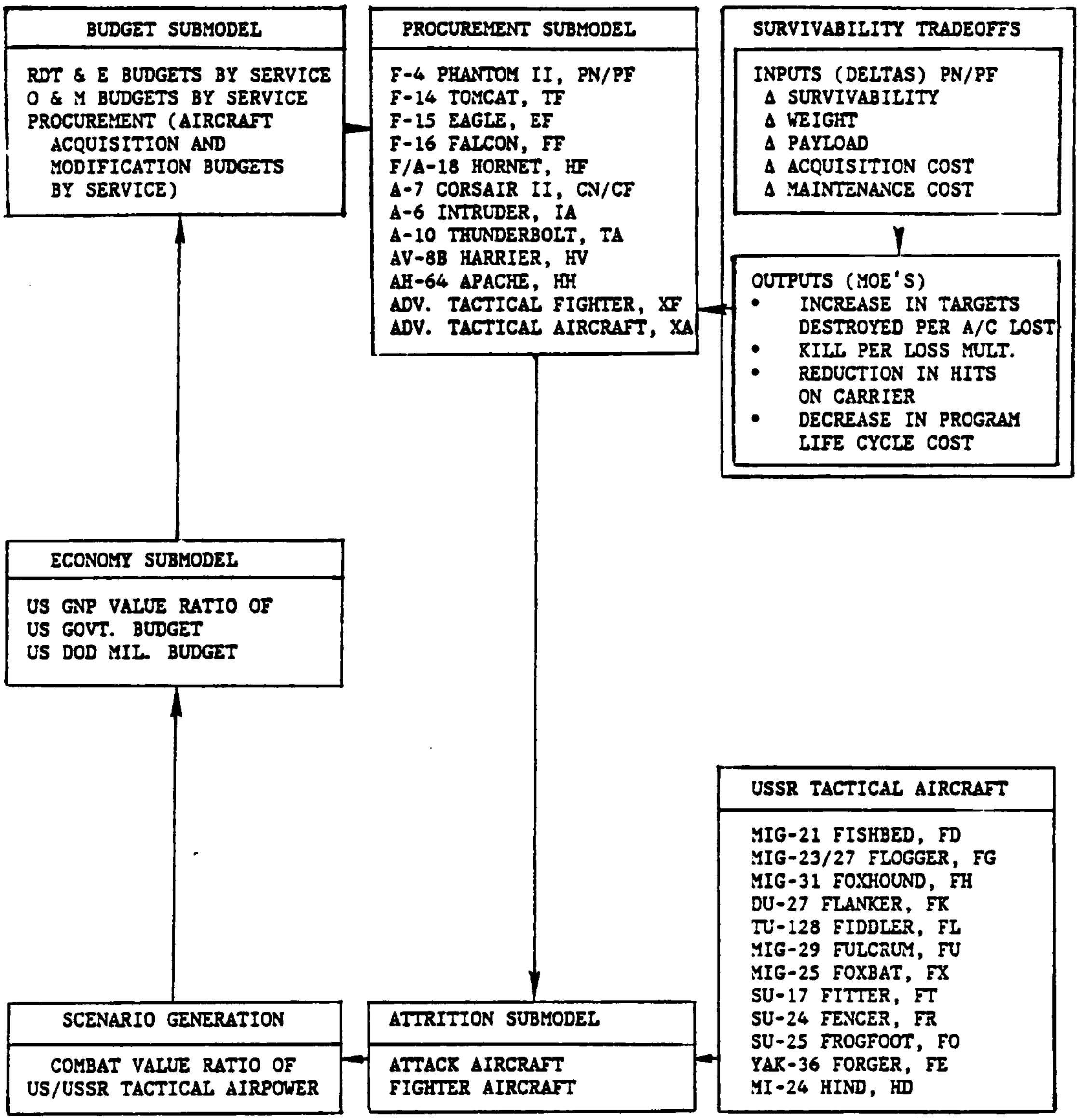

Figure 1. SURMAN TOP-DOWN APPROACH INTERRELATIONSHIPS

2.4 SYSTEM EFFECTIVENESS CONSIDERATIONS

The justification for selection and incorporation of a survivability feature into an aircraft system must be proven by an evaluation of its contribution to the effectiveness of the total system. This effectiveness must also be evaluated in terms of its impact upon the total life-cycle cost of the system. Currently, there is no single life-cycle cost assessment method established or endorsed for triservice use by the JTCG/AS or other service agencies. The state-of-the-art seems to present in military handbooks, standards and specifications the most significant trade-off factors that must be considered for aircraft survivability enhancement and emphasis on the importance of their impact on the systems life-cycle cost, and then establish through negotiation between the contracting agency and the contractor the specific method to be used on any given aircraft system. This is considered to be one of the most important factors in the ability of the government and industry S/V Engineering Community to ensure that adequate and effective survivability of each aircraft weapon system is achieved. This process is essential to provide the aircraft systems design management (both government and industry) with the information necessary to enable the proper decisions on incorporation of specific design features to be made. It is an iterative process that is continued throughout the design and development program as shown in Figure 2.

The basic tradeoff factors for the survivability enhancement features are related to the effect each has on the overall system effectiveness and lifetime cycle costs, including combat and noncombat operations. They include the following areas: probability of survival, vulnerability, safety, maintenance, reliability, logistics, performance, cost, weight, and operational effectiveness (see Figure 3). A few of these are discussed in more detail [23].

Maintenance. Addition of survivability design features as a modification to an existing aircraft generally results in an increase of maintenance man-hours, (scheduled and unscheduled) for the total system. For new designs, the penalties can be minimized and, in some cases, may result in benefits. Each design feature must be judged on its own merits, such as the man-hours malfunctioning or time-inspection per piece of equipment. Concentration and integration of a number of components in a subsystem, to minimize its vulnerability to weapon effects, may also require less maintenance effort and time to troubleshoot and repair. The above factors are evaluated for changes in: maintenance man-hours per flight hour, downtime per flight hour, and mean task times.

Reliability. System reliability values can be affected by survivability enhancement features. The addition of redundant subsystem circuits may impose higher reliability requirements upon individual components within each of the redundant systems in order to attain the overall system reliability allocations. The above factors are evaluated for changes in: component reliability, component redundancies, and mission success reliability.

Logistics. The operation of military aircraft requires logistic support in order to perform their designated missions. The major items that can be affected by survivability enhancement features include fuel consumed, spares required, and payload (munitions) expended to achieve a given level of combat effectiveness. The addition of weight to a design, for survivability improvements, requires more fuel to be used to achieve a given level of performance. Increase in system complexity will affect the number of aircraft for specific missions over a given time period. These factors are evaluated to determine the changes affected in terms of dollar costs.

Performance. Aircraft performance penalties are generally expressed in terms of mission range (or radius) loss or reduction in payload. For major subsystem additions in the case of advanced aircraft designs, the penalties may be expressed in terms of aircraft growth, with performance factors running constant. Similarly performance factors are measured for changes to those accountability items that influence cost or effectiveness such as mission range, payload capability, turnaround time, radar cross-section signature, infrared (IR) signature, etc.

Operational effectiveness. The capability of an aircraft to perform its designated missions is a measure of its operational effectiveness. The parameters involved in this area are:

a. Combat missions accomplished.
b. Number of targets killed.
c. Number of aircraft available for flight.
d. Number of training missions accomplished.
e. Utilization rate (number of hours flown per month).

Cost. The cost of an aircraft system is the one factor to which all trade-off study values must be ultimately related. It provides a basis upon which design management can decide what combinations of survivability enhancement features will be the most effective for a specific design configuration and hostile threat spectrum. Cost factors that may be influenced by survivability features are:

1. Development costs (RDT&E).
    a. Aircraft design
    b. Tests
    c. Research
2. Acquisition costs
    a. Production Aircraft
    b. Spares
    c. RDT&E
    d. PEMA (Planning Engineering Maintenance Ability)
3. Life cycle costs.
    a. Peacetime operations/logistics
    b. Wartime operations/logistics
    c. Peacetime attrition
    d. Wartime attrition
    e. Acquisition costs.

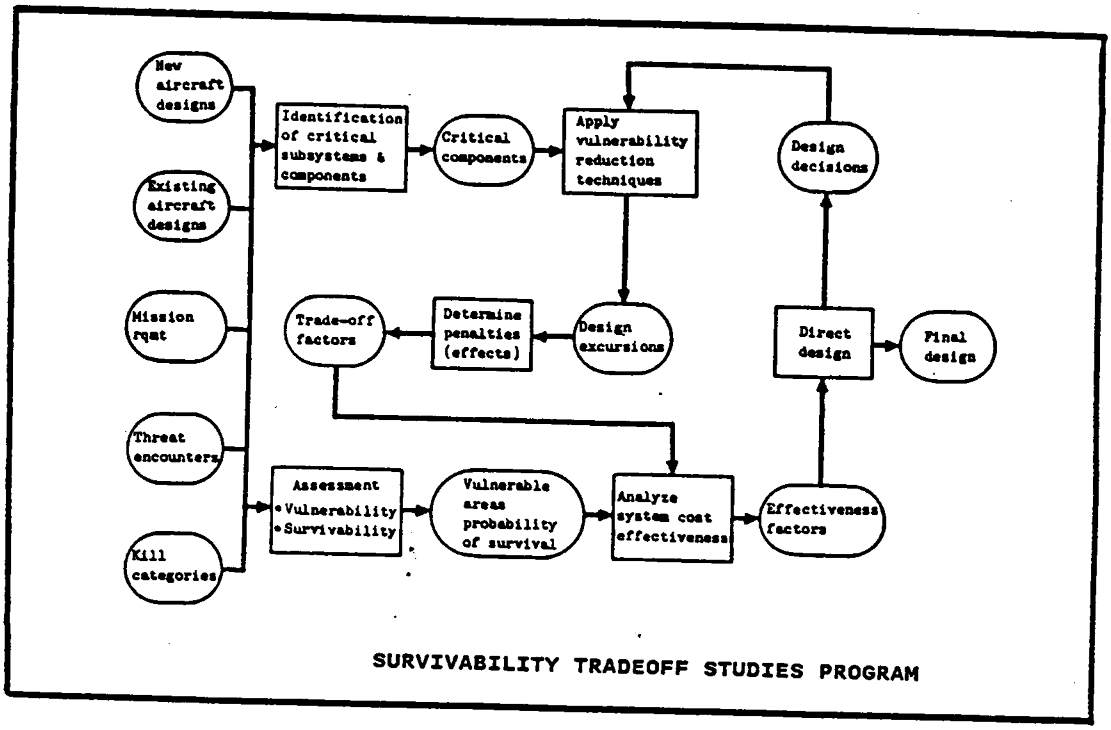

Figure 2. SURVIVABILITY TRADEOFF STUDIES PROGRAM

Survivability Enhancement Techniques	Trade off factors															
	Installed weight	Flyaway cost	RDT&E cost	Installed volume	Total system survivability	Total system vulnerability	Maintenance	Human factors	Safety	Reliability	Logistics	Secondary power	Electrical power	Total system cost impact	Total system weight impact	Life-cycle cost impact
Minimized detection																
RCS																
Infrared (IR)																
Visual																
Aural																
Active mission countermeasures																
Performance																
ECM/threat detection																
Decoys/chaff/aerosols																
Tactics																
Protection methods																
Redundancy/separation																
Damage tolerance																
Delayed failure																
Leakage suppression/control																
Fail safe response																
Masking/armor/geometry																

SURVIVABILITY ENHANCEMENT TECHNIQUES AND TRADEOFF FACTORS SUMMARY MATRIX

Figure 3. SURVIVABILITY ENHANCEMENT TECHNIQUES AND TRADEOFF FACTORS

2.5 TRADEOFF STUDY APPROACH

In the previous section we reviewed briefly some of the factors considered in survivability enhancement trade-off analysis--the process of examining and quantifying both the survival benefits and the penalties associated with alternative survivability enhancement techniques of aircraft and subsystems so as to obtain insights necessary to select the optimal configuration or utilization for defined roles. The procedures used to perform these trade-offs should integrate penalties such as increased weight, reduced payload, reduced performance, increased cost, etc., with benefits measured in terms of increased probability of survival, reduced force requirements, reduced attrition cost, etc.

In this section we begin by considering measures of effectiveness -- parameters used to define the benefits and penalties associated with aircraft design or usage alternatives -- and merit rating systems -- methodologies including concepts, techniques, and procedures, for quantifying, combining and interpreting figures-of-merit. Measures of effectiveness have been arbitrarily classified as effectiveness figures-of-merit (weight, attrition, exchange ratio, and combat sortie life), cost figures-of-merit (flyway cost impact, attrition effects, support requirements, program effects, and force impact) [21].

Portions of the submodels lend themselves to analytical techniques which together with the system dynamics simulation, the basis of the research approach, offer considerable insights into system behavior and trade-offs. For example, the organization of the Defense Budget Submodel reflects the breakdown of the DOD Military Budget into service and activity categories described above. All the parameters are expressed in equation form in the model. Viewed as a multi-variable optimization problem, the task is to find the fraction of the total budget that should be allocated to the scores of subcategories so as to maximize military effectiveness, subject to the constraints that all the fractional allocations add up to unity. An additional aspect of the defense budget problem is the trade-offs between R&D, procurements, and operations and maintenance and their interactions within the concept of "availability."

A popular surrogate for military effectiveness is civil efficiency. In recognition of the need for considering the entire subject of factors affecting defense costs, life-cycle cost analyses has emerged as a preferred survivability evaluation methodology. It is predicated on the basic understanding of the weapon system life cycle commencing with the need and extending through planning, budget, research, design, procurement, fabrication, evaluation, and retirement. The ultimate output is a system that not only meets performance requirements, but does so in a cost-effective manner. The problem is that true cost effectiveness is impossible to measure since there are many factors that influence the operation and support of an individual weapon system that cannot be realistically quantified because of the system interaction effects resulting from other complementary weapon systems.

In trying to compare life cycle costs for a given system designed to various levels of survivability or between different systems designed to fulfill the same wartime mission, there are other problems. All the cost elements are peacetime costs, including development, purchases and operation of potential wartime military effectiveness in an orderly peacetime way, without stress, over a fixed period of time. Although incompatible, they must be accepted because we do not know how long a war will last, nor when in the system life cycle it will take place, for cost-accounting purposes. In practice, the life-cycle cost is taken as the system acquisition cost plus the cost of operating some number of units of the systems for the system's planned lifetime. The operating costs include the costs of crews, training where it is particular to the system (as distinct from force training, which is not charged to any particular system), maintenance and repair, and such consumables as fuel.

Program cost per aircraft, a simpler figure-of-merit to calculate and apply, is the total amount that will be spent on a program over some specific time divided by the number of units acquired. It coincides with the lifecycle cost per aircraft only if the specified period of time (e.g., fifteen years) begins at the same time as system development. However, program cost and life-cycle cost can be very different from each other. For example, if we are comparing the cost-effectiveness of existing F-4 fighters with that of new F-16s, we might find that, when the effects of inflation are discounted, the life-cycle costs of the two systems differ by about 50 percent. If we were to compare them on the basis of program costs over the period 1978 to 1993, however, we might find that because the F-4s had already been purchased before 1978 while the F-16s were still in the development stage at that time, the program cost of the F-16 would be two or three times as high as the F-4. Obviously, the kind of costs used will affect the outcome of any cost-effectiveness comparison [22].

The tradeoff study approach now utilized by the Navy is depicted on the left side of Figure 4. It is based on the results of the baseline survivability assessment. Available technology is reviewed for reduction of susceptibility and vulnerability and development of alternative design concepts. The feasibility of each design alternative is investigated with respect to application to the aircraft or missile and availability of required technology. The payoffs and penalties of each are determined. The payoffs are calculated by iterations through applicable phases of the survivability evaluation process. Penalties considered are some of the characteristics mentioned previously -- cost, weight, performance, reliability, etc. After study, the concepts are ranked (see right side of Figure 4) and recommendations are presented to the procuring agency. In Figure 5, the payoff axis (the ordinate) is expressed as vulnerable area, a measure of vulnerability, and the penalty axis (the abscissa) is expressed as weight [25].

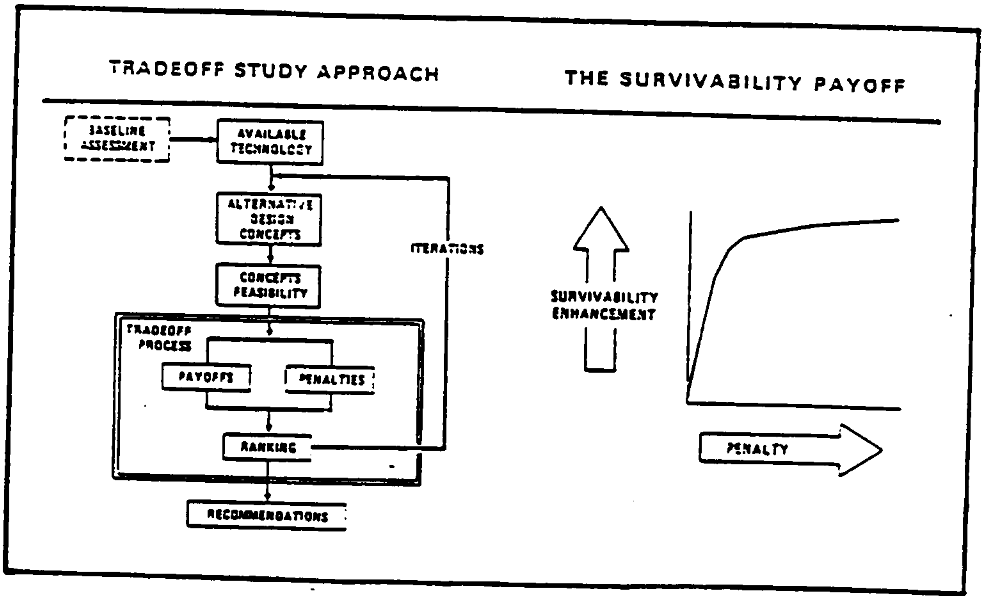

Figure 4. TRADEOFF STUDY APPROACH AND THE SURVIVABILITY PAYOFF

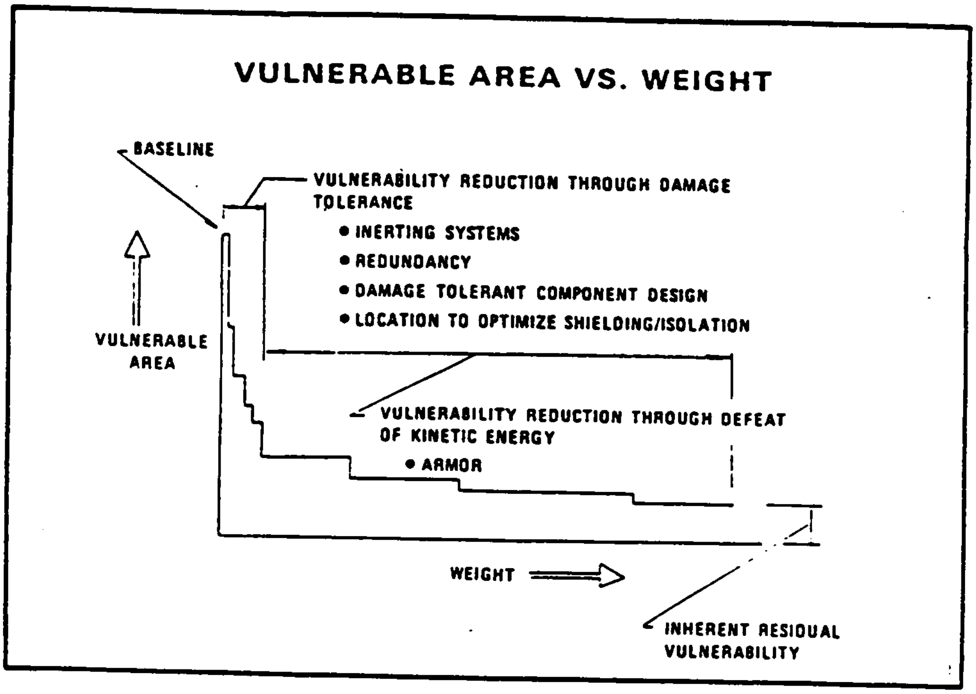

Figure 5. VULNERABLE AREA VS. WEIGHT

2.6 APPLICATION TO CARRIER AIRCRAFT

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 Aviation operates more aircraft than any other country except the U.S.S.R. and China. A typical carrier air wing consists of 36 Attack Aircraft (A-6's and A-7's), 24 Fighter Aircraft (F-14's and F-4'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 (EA-6B's etc.). A typical combat situation for a carrier task-force is depicted in Figure 6.

Since it is Fighters and Attack Aircraft that take the war ashore, these are singled out for inclusion in illustrating the application of the JTCG/AS Model. The key step in the survivability assessment process is the determination of the survivability of an aircraft as it performs its missions in the threat environment. In a mission survivability analysis, results from one airborne target versus one threat weapon evaluations are combined with threat densities, deployment, and data from mission-threat analysis. The results are relative attrition rates, gross measures of the effectiveness of the system in its mission, and the cost associated with accomplishing mission objectives.

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 to the light attack role by carrier-based marine squadrons in support of landings [22].

2.7 MATHEMATICS OF SURVIVABILITY - ATTRITION RELATIONSHIPS

When an aircraft penetrates a specified threat scenario, its survivable probability can be estimated from susceptibility and vulnerability considerations. Specifically, the probability of the aircraft surviving a single encounter with the i th type of weapon system is

$$P_S/E_i = 1-P_H{*}P_{K/H} \tag{2.1}$$

Where P_H is the probability of the aircraft being hit and $P_{K/H}$ is the probability of aircraft kill given it is hit. P_H, sometimes called the "threat system effectiveness" is the product of several probabilities

$$P_H = (P_{LOS})(P_D)(P_L)(P_G)(P_{DET}) \tag{2.2}$$

where P_{LOS} = probability of line-of-sight to the target, P_D = probability of detection, given line-of-sight, P_L = probability of launch or firing, given detection, P_G = probability of successful guidance, given launch, and P_{DET} = probability of warhead detonation.

Now the probability of not being killed in n shots can be expressed in terms of the probability of single shot kill P_{SSK} and the number of shots fired in the encounter n

$$P_{K/H}(0) = \sum_{x=0}^{0} \frac{n}{x\ (n-x)} (P_{SSK})^x(1-P_{SSK})^{n-x} = (1-P_{SSK})^n \tag{2.3}$$

$$= [(1-P_{SSK})^{-1/P_{SSK}}]^{-n\ P_{SSK}}$$

$$= e^{-n\ P_{SSK}} \tag{2.4}$$

$$= 1-n\ P_{SSK}+\ \ldots \tag{2.5}$$

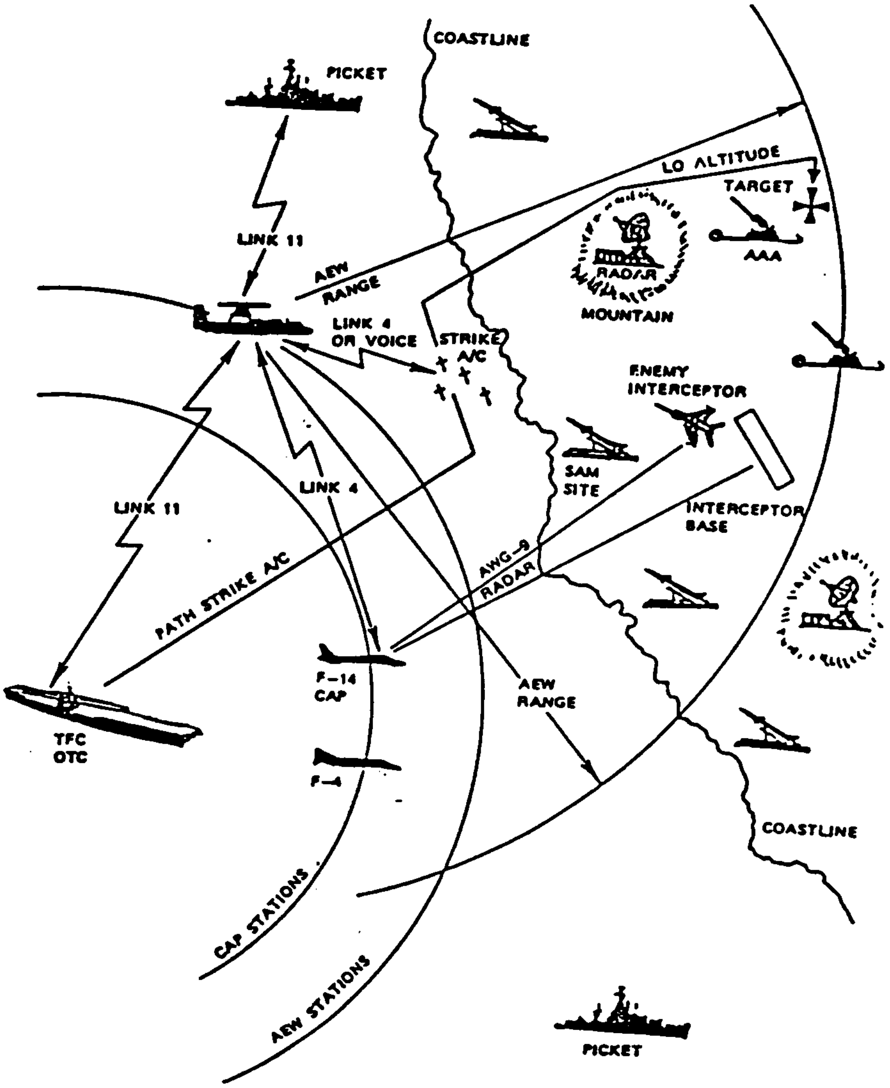

Figure 6. TYPICAL COMBAT SITUATION FOR CARRIER TASK-FORCE

Substituting (2.5) into (2.1)

$$P_{S/E_i} = 1-(P_H)[1-P_{K/H}(0)] \tag{2.6}$$

$$= 1-(P_H)(n\ P_{SSK}) \tag{2.7}$$

A basic measure of effectiveness for an aggressor force is the cumulative number of sorties flown CS after n scheduled sorties which is given by the sum of terms of a geometric series [26]

$$CS = (1-P^n{}_{S/E_i})/(1-P_{S/E_i}) \tag{2.8}$$

Taking the limit as n approaches infinity, the expected number of sorties scheduled by an aircraft with encounter survivability P_{S/E_i} in its lifetime is

$$E(n) = (1-P_{S/E_i})^{-1} \tag{2.9}$$

The number of targets destroyed per aircraft lost, TDPL, can be expressed as

$$TDPL = E(n)*TDPS \tag{2.10}$$

where TDPS is the number of targets destroyed per sortie.

Time t can be brought into the picture by letting

$$n = SR*t$$

where SR is the sortie rate. Substituting (2.11) into (2.8)

$$CS = (1-P_{S/E_i}{}^{SR*t})/(1-P_{S/E_i}) \tag{2.12}$$

The cumulative sorties flown by a force of N aircraft CS_N is obtained by multiplying (2.12) by N,

$$CS_N = CS*N \tag{2.13}$$

and the cumulative targets destroyed by a force of N aircraft T_N is obtained by multiplying (2.13) by the target kill potential TDPS,

$$T_N = (TDPS)(N)(CS_N) \tag{2.14}$$

The fraction of force remaining after n sorties, common and useful parameters, is defined as

$$FFR = P_{S/E_i}{}^{n} = [(1-P_K)^{-1/P_K}]^{-n\ P_k} \qquad (2.15)$$

$$= e^{-n\ P_K} = e^{-(1-P_{S/E_i})*(SR)*(t)} \qquad (2.16)$$

Recognizing that FFR = $\$_t/\$_0$ where $\$_t$ is the number of aircraft at time t and $\$_0$ is the initial value for this variable,

$$d\$_t/dt = -(1-P_{S/E_i})(SR)(\$_t) \qquad (2.17)$$

Expressed as an integral equation, (2.17) becomes

$$\$_t = \$_{t-1} - \int_{t-1}^{t} AR\$_t\ dt \qquad (2.18)$$

where $AR\$_t$, the aircraft attrition rate, is given by

$$AR\$_t = \$_t*SR*(1-P_{S/E_i}) \qquad (2.19)$$

2.8 SYSTEM DYNAMICS FORMULATION

The idea that the dispassionate and yet clear mind of the scientist can aid in problem solving is by no means new. Plato had it many years ago when he formalized his thoughts on the model for a city-state in his treatise, The Republic. The basic tenet of the Systems Age is that a "systems approach" can be used to advantage on any definable system. The systems approach is the modus operandi for dealing with complex systems. It is holistic in scope, creative in manner and rational in execution. Thus, it is based on looking at a total activity, project, design or system rather than considering the efficiency of the component tasks independently. It is innovative in that rather than seeking modifications of older solutions to similar problems, new problem definitions are sought, new alternative solutions generated, and new measures of evaluation are employed if necessary.

The systems approach is an amalgam of scientific approaches to conceptualizing problems and solving them through research, design (or synthesis), and analysis. In order to interpret the systems approach in these terms, it is instructive to consider the "black box" concept of a system. The system design task is to find the system which will produce a specified output from a given input. The other two activities -- research and analysis, can be described in a similar manner. The objective of science in this context is the discovery of the laws affecting the transformation from input to output for the phenomenon being studied. The task of systems analysis is to determine the output for a given input or to find the input which will achieve a certain output. The systems approach strives to be logical, consistent, objective and quantitative in analyzing systems and solving problems. It recognizes the need to make compromises and tradeoffs among the system factors. It facilitates the selection of the best approach from the many alternatives. Through the process of model building and scenario analysis it makes possible the prediction of future system performance [27].

An important aspect of the systems approach is model building. Models are intellectual tools that helps us distinguish what is possible from what is impossible and then, from the realm of the possible, to distinguish the better from the worse. Basically, a model is anything that illuminates and clarifies the interrelations of subsystems and components, of actions and reactions, and causes and effects. Models range from subjective mental models to explicit mathematical models. In between is the verbal model which reflects the implicit ideas of a mental model explicitly.

Mathematical models use mathematical notation expressed in equation form to describe a system. Often (as is the case in system dynamics) these mathematical equations have graphical analogs (called "causal diagrams" in the system dynamics methodology to be described in this section). Three characteristics of mathematical models that render them especially useful are: (1) they are precise, (2) they are concise, and (3) they are manipulatable. Unfortunately, these highly desirable qualities are not generally appreciated by high-level decision-makers who do not understand the symbology or rules of manipulation. In the case of system dynamics, this communication gap between model builders and model users through the use of three complementary forms of modeling -- verbal, graphical and mathematical. When the mathematical model is so complex that it cannot be solved analytically, the solution may be obtained through a technique called simulation using a digital computer. Such a mathematical model is then referred to as a computer simulation model. System dynamics models are of this class [28].

An important concept in the systems approach is that of systems state. The state of a system refers to the value or the nature of system attributes at a particular moment in time. Most commonly, states of a system are studied for a chronological succession of instances (which may be seconds, minutes, hours, days, weeks, months or years) throughout some desired period of time. This leads to the construction of a history of some state variable of the system.

A system is said to be stable when its measured performance varies within an acceptable range despite changes to its components and associated attributes. A system may also display erratic or unsatisfactory behavior when its performance falls outside the range of acceptance. This instability may often be anticipated and corrected by "feedback." Feedback may occur on two levels: (1) through automatic adjustments to a system, and (2) through feedback of data to a human monitor who interprets these data and makes the necessary adjustments. When the feedback provides information for and causes changes in the direction of system stability, it is called negative feedback. Negative feedback helps a system adopt to the unexpected and undesirable changes in system components, their attributes, and their relationships. Another type of system feedback is positive; it tends to be maladaptive because it tends to contribute to greater system instability. These concepts of feedback theory and simulation modeling provide the foundations of the systems methodology, called system dynamics [29].

System dynamics is based on principles borrowed from engineering -- especially feedback concepts. It makes possible a representation of decision policies and information flow. The major concepts of this methodology can be organized and sequenced as follows: All systems that change through time can be represented by varying levels and rates. A level represents an accumulation within a system. This could be people, dollars, pollution, natural resources and almost anything tangible or intangible. It is analogous to a storage device or facility. It also provides an indicator of the condition or state of a system. A rate is a flow from one area to another of what has been accumulated. Rates of flow cause, and control, changes to levels. A rate of flow need not be constant -- it can vary. These flows symbolize activities within the systems. Decision rules control system activities -- that is rates of flow. Decision rules are called policies by Forrester. A policy describes how available information is used to generate decisions. It defines what a decision maker does (or should do) when he receives specific kinds of information [30].

A policy determines how goals are set, what information sources are used for making decisions, and the nature of the response to available information about present and past conditions of the system and to various personal and political pressures. The environment, once determined, is considered constant during a particular set of time periods being simulated. According to Forrester [30], feedback loops are the basic building blocks of a system. A simple feedback loop is a closed path connecting a decision point (decision rules which control rate of flow), a system level and the environment. Available information is the basis for a current decision that causes action to be taken. The action, in turn, alters the level of some system variables. It should be kept in mind that there are often delays or distortions (noise) appearing around a feedback loop.

There are two types of feedback. The "goal seeking" or negative feedback has a goal or desired value for a level. If the level departs from this value the rate of flow is modified to bring the level back to its desired value much like a thermostat. Conversely, positive feedback loops contribute to either persistent growth or continuous decline of levels -- frequently past what is desired. A system dynamics model consists of multiple positive and negative feedback loops linked together.

In difference equation terminology, any level variable L_i is expressed as functions of rate variables R_j and the previous value of the level,

$$L_i(t+dt) = L_i(t) + (dt) \sum_{i=1}^{n} R_j(t) \qquad i=1,2,\ldots,m; \tag{2.20}$$

with the R_j's assumed to be constant over the interval from t to t+dt. The rate variables are of the form

$R_j(t) = F[L_i(t), E_k(t), A_{ij}(t), A_{kj}(t)]$

where E_k are the set of exogenous inputs that affect R_j directly and A_{ij} and A_{kj} are the impacts of auxiliary variables in the causal streams from the ith level variable and kth exogenous input, respectively. Since the exogenous inputs are known time functions or constants, if the initial values of the level variables are known, all other variables can be computed from them for that time. Then the new values of the level variables for the next point in time can be found from Eq. 2.20 [31].

Because of the inability of any computer language to handle subscripts, DYNAMO uses a postscript notation in which .K stands for the present time t, .J stands for past time t-dt, and .L stands for future time t+dt. As in all computer programming, upper case letters are used and DT is called the solution interval, the time between successive computations in the simulation. Since rate variables are assumed to be constant over DT, the double postscript is used, .JK for rates on the right side of an equation and .KL for rates on the left side [32].

Thus the integral equation of (2.18) is easily expressed as a system dynamics difference equation as follows

$$\$.K = \$.J - (DT)(AR\$.JK) \tag{2.22}$$

Equation 2.19 becomes a "rate equation" in system dynamics nomenclature and is written

$$AR\$.KL = \$.K*SR*(1-PSE) \tag{2.23}$$

Depicted in Figure 7 in the causal diagram corresponding to the mathematical model comprised of eqs 2.22 and 2.23. Obviously the modeling technique is easily extended to include hundreds of variables and constants, each appearing on the diagram and then defined by

All the relevant parameter classes employed in the system dynamics methodology -- level variables, rate variables, auxiliary variables, supplementary variables and constants are easily identifiable in this form of causal diagram. For example, a level variable is always at the head of a solid arrow and a rate variable is always at the tail of a solid arrow. The sign on the solid arrow tells us if the rate variable adds to or subtracts from the level variable. Whereas solid arrows denote physical flows, dashed arrows in the causal diagram define information flows from level variables to rate variables. Any intermediate variable on the path from a level variable or exogenous input to a rate variable is called an auxiliary variable. The signs on dashed arrows have the following interpretation: If + it means that an increase in the parameter at the tail of the arrow will cause an increase in the variable at the head of the arrow; if - it means that an increase in the parameter at the tail of the arrow will cause a decrease in the parameter at the head of the arrow. Exogenous inputs are easily identified on a causal diagram since they have no arrows leading to them, but have one or more dashed arrows emanating from them. Supplementary variables, in contrast, do not form part of the system itself, but merely indicate its performance, and therefore are always identifiable as being at the head of a dashed arrow, and having no arrows emanating from them. In summarizing the causal diagramming convention:

1. the arrows describe the direction of causality between pairs of variables;
2. the lines (solid or dashed) denote (physical or information) flows; and
3. the signs tell us the nature of the relationship between a dependent-independent variable pair (direct or inverse).

The causal diagram step in system dynamics fulfills two functions. Firstly, it facilitates writing the system equations. Secondly, in the case of comprehensive models such as will be developed in the next chapter the causal diagram serves as a kind of communication gestalt. "Gestalt" is German word meaning the way a physical entity, experience, or phenomenon is put together or has been made, referring to the pattern or shape of it. Through graphics it is possible to portray a gestalt-like statement about a complex problem identifying its structure, elements, and interactions. The significance of the causal diagramming tool in the modeling paradigm is that it takes one out of a communication cul-de-sac, providing a common vocabulary and structure of reasoning between individuals, professions, specialists, administrators, and cultures. To extend an analogy: the narrative of a verbal description functions like the readings of a long, detailed Victorian novel, whereas the causal diagram functions like a film based on the novel. Certainly much detail is left out, but the "movie" communicates a whole or gestalt perspective that is hopelessly lost in the details of the "novel." A picture is worth a thousand words. appearing on the left hand side of an equation.

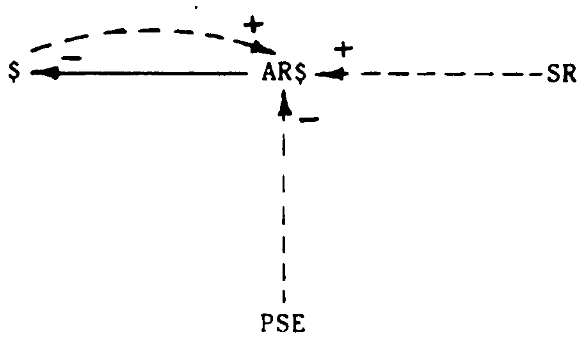

Figure 7. A SIMPLE CAUSAL DIAGRAM

3.0 CHAPTER 3 - DEVELOPMENT OF MISSION COMPONENTS

3.1 INTRODUCTION

A prominent feature of modern Government is the extent to which the executive branch has institutionalized quantitative methodology (cost-effectiveness analysis, computer modeling, etc.) as an aspect of budgeting and decision making. Proponents term this "Systems Management," and view it as a salutary extension of the "objective" tools of science and mathematics. This argument has substantial merit, but it obscures the fact that quantitative methodology has considerable potential in both scientific (or "objective") and "subjective" applications. The difference, whether an application is based on scientific fact or "quantified judgement," has obvious importance in the context of decision making.

From a scientific point of view, the present "understanding of war" -- insofar as the effectiveness of conventional military forces is concerned -- is in a relatively primitive state. Basic research aimed at understanding the fundamentals of combat is needed, but quantitative or numerical techniques have not been systematically applied to achieve these discoveries.

What is the effectiveness of a weapon system?

How can its effectiveness be measured?

How can this be linked to the broader objective of determining the most effective mix of ground and tactical air forces that can be bought and maintained for, say, $30 billion per year?

Defense decisions -- whether based on military judgements or sophisticated economic techniques -- are critically dependent on the knowledge of what a military force can reasonably be expected to do. That knowledge is essential, not only to permit realistic force comparisons, but also for gauging the individual contributions of new weapons and tactical concepts.

The quantitative method offers the opportunity to bring together the "best" of science and considered judgement. That it has aided Defense decision making is without question. But, its full potential has not been achieved. To do so, Defense decisionmakers must act on the premises that:

- Quantitative decision making is beneficial only when it embodies, rather than replaces, expert judgement and "objective" fact.
- Analysis may give the appearance of scientific work but may not have been subjected to the normal evaluative standards of science.
- The theory and supporting data may not equal the quality of the analytic tool.
- The assumptions and limitations of the analysis must be made a part of the study report.

Throughout the Department of Defense there are a number of computer models to assist in the analysis of issues related to the planning, programming, and budgeting of U.S. conventional forces [34]. This chapter and chapter 4 present the development of a survivability/lethality tradeoff component to be used in a conceptual design evaluation model for the Advanced Tactical Aircraft. Throughout this project, the research team is emphasizing the need for ensuring that the models derived are:

- <u>Transparent</u> so that a decisionmaker can understand and use the model as an extension of his/her own judgement. Implying that
  - Assumptions are clearly described and held to manageable proportions, and
  - The deductive process leading to the model's assertions is clear (transparent).
- <u>Appraised</u> so that a decision maker can be assured that
  - The model is mathematically correct,
  - The part of the model that is science matches the real world, and
  - The model uses empirically valid data.
- <u>Consistent</u> so that communication is facilitated throughout the decision making hierarchy. Implying that
  - Problems are analyzed in the same context, and
  - Differing viewpoints can be discussed on the basis of specific assumptions.

In the next section, we begin by discussing the diverse assumptions employed in the system dynamics modeling of attrition -- the principal combat process which drives casualty levels and resupply/reinforcement requirements.

3.2 AIRCRAFT COMBAT ATTRITION MODELING

Mathematical representations of combat attrition have long fascinated analysts and practitioners. In this section three general models, with relevance to the aircraft combat attrition phenomenon are described. They are identified as: Case 1 - the independent attrition model; and Case 2 - the Lanchester linear law model; Case 3 - the Lanchester square law model.

3.2.1 CASE 1 - THE INDEPENDENT ATTRITION MODEL

Figure 8 is the causal diagram representation of an extension of the simple attrition model of Figure 7, in which the input parameters, "availability", "mission survivability" and "payload", and the measure of effectiveness, "target destroyed per aircraft lost," are incorporated. Figure 9 contains the system dynamics equations corresponding to the causal diagram in Figure 8. The analytical treatment of this model is described as follows:

The first order differential equations corresponding to the level equations for \$ and X are

$$d\$/dt = -AR\$\$_t = -M*\$_t \tag{3.1}$$

$$dX/dt = -ARXX_t = -N*X_t \tag{3.2}$$

$$\text{where } M = SR\$*A\$*(1-MS\$) \tag{3.3}$$

$$N = SRX*AX*(1-MSX) \tag{3.4}$$

The second order representation of the model is obtained by differentiating (3.1)

$$d^2\$/dt^2 = -M(d\$/dt) = M^2*\$_t \tag{3.5}$$

which has the general solution

$$\$_t = C_1e^{\omega t} + C_2e^{-\omega t} \tag{3.6}$$

The constants C1, C2 and ω are easily found yielding

$$\$_t = \$_0e^{-Mt} \tag{3.7}$$

In similar fashion, we determine the progress of the other side to be

$$X_t = X_0e^{-Nt} \tag{3.8}$$

The measures of effectiveness can be determined as shown for the \$ side:

$$TDP\$L_t = CPDT\$_t/CL\$_t \tag{3.9}$$

where $CPDT\$_t$ and $CL\$_t$, as integral equations, are reduced to

$$CPDT\$_t = (\$_0*P\$)(1-e^{-Mt})/(1-MS\$) \tag{3.10}$$

and $$CL\$_t = \$_0(1-e^{-Mt}) \tag{3.11}$$

giving by substituting (3.10) and (3.11) in (3.9)

$$TDP\$L = (P\$/(1-MS\$))*TDPUP\$ \tag{3.12}$$

Likewise, one finds that

$$TDPXL = (PX/(1-MSX))*TDPUPX \tag{3.13}$$

This is called the "independent" attrition model because the number of aircraft lost by each side is independent of the number of aircraft on the other side. Therefore it is mostly applicable to aircraft types that tend not to engage enemy aircraft, but rather fly attack/interdiction and close air support missions.

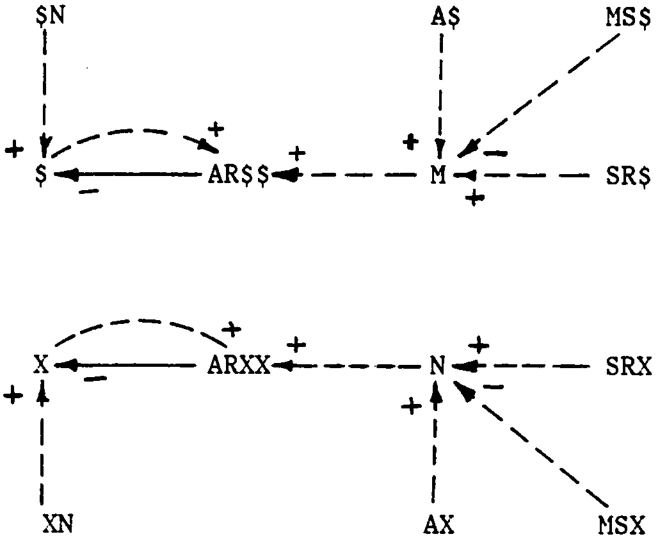

Figure 8. CAUSAL DIAGRAM FOR INDEPENDENT ATTRITION MODEL

```
NOTE *****************************************************************************
NOTE ***************      INDEPENDENT ATTRITION MODEL      *******************
NOTE *****************************************************************************
L    $.K=MAX($.J-(DT)(AR$$.JK),0)
N    $=$N
NOTE $ - U.S. AIRCRAFT (AIRCRAFT)
C    $N=480
NOTE $N - U.S. AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    AR$$.KL=M*$.K
NOTE AR$$ - ATTRITION RATE OF U.S. AIRCRAFT (AIRCRAFT/DAY)
N    M=SR$*A$*(1-MS$)
NOTE M - ATTRITION CONSTANT FOR U.S. AIRCRAFT (FRACT/DAY)
C    SR$=4
NOTE SR$ - SORTIE RATE OF U.S. AIRCRAFT (NUMBER/DAY)
C    A$=0.5
NOTE A$ - AVAILABILITY OF U.S. AIRCRAFT (PROB.)
N    MS$=0.98
NOTE MS$ - MISSION SURVIVABILITY OF U.S. AIRCRAFT (PROB.)
L    X.K=MAX(X.J-(DT)(ARXX.JK),0)
N    X=XN
NOTE X - U.S.S.R. AIRCRAFT (AIRCRAFT)
C    XN=720
NOTE XN - U.S.S.R. AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    ARXX.KL=N*X.K
NOTE ARXX - ATTRITION RATE OF U.S.S.R. AIRCRAFT (AIRCRAFT/DAY)
N    N=SRX*AX*(1-MSX)
NOTE N - ATTRITION CONSTANT FOR U.S.S.R. AIRCRAFT (FRACT/DAY)
C    SRX=4
NOTE SRX - SORTIE RATE OF U.S.S.R. AIRCRAFT (NUMBER/DAY)
C    AX=0.5
NOTE AX - AVAILABILITY OF U.S.S.R. AIRCRAFT (PROB.)
C    MSX=0.96
NOTE MSX - MISSION SURVIVABILITY OF U.S.S.R. AIRCRAFT (PROB.)
NOTE *****************************************************************************
NOTE ********************      CONTROL STATEMENTS      **************************
NOTE *****************************************************************************
SPEC DT=0.05,LENGTH=30,PRTPER=2,PLTPER=2
PRINT $,X
PLOT  $,X
RUN
QUIT
```

Figure 9. DYNAMO EQUATIONS FOR INDEPENDENT ATTRITION MODEL

3.2.2 THE LANCHESTER - TYPE APPROACH

Lanchester's theory of combat is another approach to attrition modeling. This theory, when first introduced by Frederick W. Lanchester in 1914, was an attempt to describe the effects of concentration in warfare by means of a set of differential equations. The equations have come to be known as [35]:

- Lanchester's linear law, representing combat where there is no concentration of force (area fire; shooters do not know when a target is killed); and
- Lanchester's square law, representing the effect of concentration (aimed fire; shooters know when a target is killed, and concentrate fire on the survivors).

3.2.3 CASE 2 THE LANCHESTER LINEAR LAW MODEL.

Figure 10 is the causal diagram and Figure 11 the system dynamics equation representation of Case 2. This model differs from Case 1 in that the interaction between the aircraft force and enemy threat is accounted for. The first order differential equations corresponding to the level equations for \$ and X are

$$d\$/dt = -AR\$\$_t = -R*\$_t*X_t \qquad (3.13)$$

$$dX/dt = -S*\$_t*X_t = -ARXX_t \qquad (3.14)$$

$$\text{where } R = SR\$*A\$*(1-MS\$)*U \qquad (3.15)$$

$$S = SRX*AX*(1-MSX)*V \qquad (3.16)$$

and U and V are constants. Dividing (3.13) by (3.14) so as to eliminate time given

$$d\$/dX = R/S \tag{3.17}$$

$$\text{or } S\, d\$ = R\, dX \tag{3.18}$$

Integrating,

$$S\$_t = RX + K \tag{3.19}$$

Using boundary conditions at t=0 to evaluate the constant of integration,

$$K = S\$_0 - RX_0 \tag{3.20}$$

Substituting (3.20) in (3.19)

$$X_t = X_0 - (\$_0-\$_t)S/R \tag{3.21}$$

Separating variables,

$$\frac{d\$}{\$_t(C+\$_t)} = -S\, dt$$

$$\text{where } C = (RX_0-S\$_0)/S \tag{3.23}$$

Converting the left-hand side of (3.22) to partial fractions,

$$\frac{1}{C}\left(\frac{d\$}{\$_t} - \frac{d\$}{C+\$t}\right) = -S\, dt \tag{3.24}$$

The solution to (3.24) is

$$\$_t = \frac{C{*}\$_0}{(C+\$_0){*}e^{(C{*}S{*}t)} - \$_0} \tag{3.25}$$

3.2.4 CASE 3 - THE LANCHESTER SQUARE LAW MODEL

Figure 12 is the causal diagram and Figure 13 is the corresponding system dynamics set of equations for Case 3. The first order differential equations corresponding to the level equation for \$ and X are

$$d\$/dt = -AR\$\$_t = -B*X_t \quad (3.26)$$

$$dX/dt = -ARXX_t = -C*\$_t \quad (3.27)$$

$$\text{where } B = SRX*AX*(1-MS\$) \quad (3.28)$$

$$C = SR\$*A\$*(1-MSX) \quad (3.29)$$

The second order representation of the model is obtained by differentiating either (3.26) or (3.27) with respect to time to get the same general solution as (3.6). Evaluation of constants leads to solutions expressed in terms of hyperbolic functions:

$$\$_t = \$_0 \cosh (\sqrt{BC})\, t - X_0 (\sqrt{B/C}) \sinh (\sqrt{BC})\, t \quad (3.30)$$

$$X_t = X_0 \cosh (\sqrt{BC})\, t - \$_0 (\sqrt{C/B}) \sinh (\sqrt{BC})\, t \quad (3.31)$$

A popular measure of effectiveness for combat situations is the exchange ratio. The kill-loss ratio KLR is the cumulative kills CK divided by the cumulative losses CL

$$KLR_t = CK_t/CL_t \quad (3.32)$$

$$\text{where } CK_t = \int ARX\, dt \quad (3.33)$$

$$\text{and } CL_t = \int AR\$\, dt \quad (3.34)$$

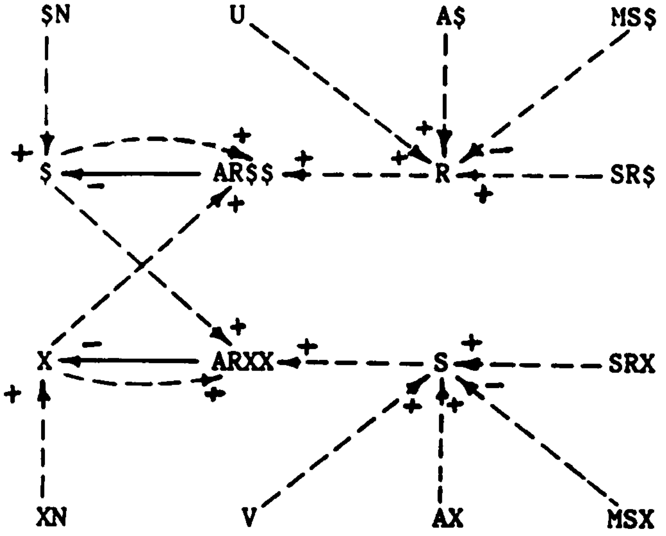

Figure 10. CAUSAL DIAGRAM FOR THE LANCHESTER LINEAR LAW MODEL

```
NOTE *******************************************************
NOTE ************ LANCHESTER LINEAR LAW MODEL **************
NOTE *******************************************************
L    $.K=MAX($.J-(DT)(AR$$.JK),0)
N    $=$N
NOTE $ - U.S. AIRCRAFT (AIRCRAFT)
C    $N=480
NOTE $N - U.S. AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    AR$$.KL=R*$.K*X.K
NOTE AR$$ - ATTRITION RATE OF U.S. AIRCRAFT (AIRCRAFT/DAY)
N    R=U*SR$*A$*(1-MS$)
NOTE R - ATTRITION CONSTANT FOR U.S. AIRCRAFT (FRACT/DAY)
C    SR$=4
NOTE SR$ - SORTIE RATE OF U.S. AIRCRAFT (NUMBER/DAY)
C    A$=0.5
NOTE A$ - AVAILABILITY OF U.S. AIRCRAFT (PROB.)
N    MS$=0.98
NOTE MS$ - MISSION SURVIVABILITY OF U.S. AIRCRAFT (PROB.)
C    U=0.008
NOTE U - EFFECTIVENESS CONSTANT
L    X.K=MAX(X.J-(DT)(ARXX.JK),0)
N    X=XN
NOTE X - U.S.S.R. AIRCRAFT (AIRCRAFT)
C    XN=720
NOTE XN - U.S.S.R. AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    ARXX.KL=S*X.K*$.K
NOTE ARXX - ATTRITION RATE OF U.S.S.R. AIRCRAFT (AIRCRAFT/DAY)
N    S=V*SRX*AX*(1-MSX)
NOTE S - ATTRITION CONSTANT FOR U.S.S.R. AIRCRAFT (FRACT/DAY)
C    SRX=4
NOTE SRX - SORTIE RATE OF U.S.S.R. AIRCRAFT (NUMBER/DAY)
C    AX=0.5
NOTE AX - AVAILABILITY OF U.S.S.R. AIRCRAFT (PROB.)
C    MSX=0.96
NOTE MSX - MISSION SURVIVABILITY OF U.S.S.R. AIRCRAFT (PROB.)
C    V=0.010
NOTE V - EFFECTIVENESS CONSTANT
NOTE *******************************************************
NOTE **************** CONTROL STATEMENTS  ******************
NOTE *******************************************************
SPEC DT=0.05,LENGTH=30,PRTPER=2,PLTPER=2
PRINT $,X,S,R
PLOT  $,X
RUN
QUIT
```

Figure 11. SYSTEM DYNAMICS EQUATIONS FOR THE LANCHESTER'S LINEAR LAW MODEL

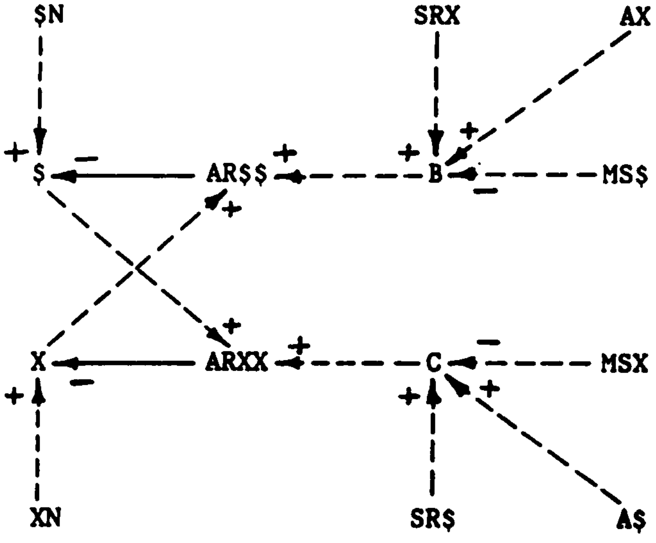

Figure 12. CAUSAL DIAGRAM FOR CASE 3

```
NOTE *******************************************************
NOTE ************ LANCHESTER SQUARE LAW MODEL **************
NOTE *******************************************************
L    $.K=MAX($.J-(DT)(AR$$.JK),0)
N    $=$N
NOTE $ - U.S. AIRCRAFT (AIRCRAFT)
C    $N=480
NOTE $N - U.S. AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    AR$$.KL=B*X.K
NOTE AR$$ - ATTRITION RATE OF U.S. AIRCRAFT (AIRCRAFT/DAY)
N    B=SRX*AX*(1-MS$)
NOTE B - ATTRITION CONSTANT FOR U.S. AIRCRAFT (FRACT/DAY)
C    SRX=4
NOTE SRX - SORTIE RATE OF U.S.S.R. AIRCRAFT (NUMBER/DAY)
C    AX=0.5
NOTE AX - AVAILABILITY OF U.S.S.R. AIRCRAFT (PROB.)
N    MS$=0.98
NOTE MS$ - MISSION SURVIVABILITY OF U.S. AIRCRAFT (PROB.)
L    X.K=MAX(X.J-(DT)(ARXX.JK),0)
N    X=XN
NOTE X - U.S.S.R. AIRCRAFT (AIRCRAFT)
C    XN=720
NOTE XN - U.S.S.R. AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    ARXX.KL=C*$.K
NOTE ARXX - ATTRITION RATE OF U.S.S.R. AIRCRAFT (AIRCRAFT/DAY)
N    C=SR$*A$*(1-MSX)
NOTE C - ATTRITION CONSTANT FOR U.S.S.R. AIRCRAFT (FRACT/DAY)
C    SR$=4
NOTE SR$ - SORTIE RATE OF U.S. AIRCRAFT (NUMBER/DAY)
C    A$=0.5
NOTE A$ - AVAILABILITY OF U.S. AIRCRAFT (PROB.)
C    MSX=0.96
NOTE MSX - MISSION SURVIVABILITY OF U.S.S.R. AIRCRAFT (PROB.)
NOTE *******************************************************
NOTE ***************** CONTROL STATEMENTS  *******************
NOTE *******************************************************
SPEC DT=0.05,LENGTH=30,PRTPER=2,PLTPER=2
PRINT $,X,B,C
PLOT  $,X
RUN
QUIT
```

Figure 13. SYSTEM DYNAMICS EQUATIONS FOR THE LANCHESTER'S SQUARE LAW MODEL

3.2.5 CHOICE OF ATTRITION MODEL

The choice of attrition model profoundly affects the results of cost-effectiveness analyses, in general, and therefore survivability/lethality tradeoff analyses, in particular. One would expect, then, that the models would agree on the basic form of attrition model for a given combat situation. This, unfortunately, is not the case. In reference 36, for example, surface-to-air missiles attrite attack by a linear law equation; while in [37], the analysts use an exponential approximation of the square law for the same process. Moreover, throughout the reams of air combat survivability literature (inspite of the fact that attrition governs survivability understanding and decision making), there is a paucity of reference to attrition and where it is treated, such as in [6], the form of attrition model, though never even identified, can be deduced to be a naive form of what we refer to as the independent model in Case 1.

Variation of the basic Lanchester equations have been used to analyze the outcomes of specific battles. In 1954, J.H. Engle [38] published a well known study which attempted to verify the application of Lanchester's basic equation to the casualty data of the Japanese and American sides during the battle of Iwo Jima. The model he considered was

$$d\$/dt = P(t) - bX \qquad (3.35)$$

$$dX/dt = -c\$ \qquad (3.36)$$

Where P(t) denotes resupply to the American side. The Japanese began with a fixed force and did not introduce extra forces as the combat continued. On the other hand, American forces landed 54,000 troops on the first day; none on the second; 6,000 on the third; none on the fourth and fifth; 13,000 on the sixth; and none thereafter. The initial number of Japanese troops was determined by a body count at battle completion, which occurred 36 days after its commencement. It was found to be 21,500. Engle was able to show that, given values of 0.0544 and 0.0106, the Lanchester equation produced results that fit the data extremely closely.

Springall [39] considered the following model:

$$d\$/dt = -R\$X - BX \tag{3.37}$$

$$dX/dt = -S\$X - C\$ \tag{3.38}$$

where R, B, S and C are the attrition coefficients. This model has the unusual feature of replacement of forces in the fields from reserves, which at least for some conflict applications, adds one further dimension of realism. Both sides deploy only a constant fraction of their initial strengths actually in the field, the remainder being held in reserve and used to replace casualties. This phase continues until only one side can replace and finally there may follow a phase which is in classical Lanchester equation with no replacement possible.

The emphasis on the deterministic approach has persisted to the present day. The explanation seems to reside in the difficulty involved in solving the equations associated with a stochastic formulation, and the complexity of the solutions in the rare cases where the equations have been solved. Because of the fact that force sizes are often very large and it was believed that a deterministic approach provides an adequate approximation to the stochastic results. In the light of recent work, this has been found to be substantially correct, at least for non-time dependent results. A stochastic analysis nevertheless has to be carried out in order to permit this conclusion [39].

Isbell and Marlow [40] have formulated the stochastic equivalent of the following deterministic model:

$$d\$/dt = -BX - M\$ \tag{3.39}$$

$$dX/dt = -C\$ - NX \tag{3.40}$$

but were unable to solve it except for the case
where $B + N = M + C$

Helmer [41], Snow [42] and Weiss [43] have considered various cases involving heterogeneous forces, that is to say, each side is composed of different types of unit. The results are so complicated that there seems little hope that the stochastic equivalent of their work will be developed in the immediate future.

If one wishes to consider a lengthy set of engagements including operational losses inflicted by surface threats, we may extend the basic model to the more complex one [43]:

$$d\$/dt = A - BX - M\$ \tag{3.41}$$

$$dX/dt = P - C\$ - NX \tag{3.42}$$

in which M and N are the operational air-ground attrition coefficients and A and P are combat aircraft production rate [43].

So one has a right, indeed an obligation to ask "what is correct"? It is believed that the answer to this is not known. Quantitative techniques, including, especially, rigorous field experimentation have not been systematically applied to achieve these discoveries. Actually, this is an underlying purpose of this research. In fulfilling this objective, recall that all the above models are intended to serve as an extension of the decisionmaker's judgement -- but how can they? All of the assumptions of a model must be made explicit. If they are not, this is defect. We feel that this shortcoming can be overcome using system dynamics in developing the "first-cut" survivability/lethality tradeoff model for the conceptual design of the ATA. In the final model, which picks up where this research leaves off, the products of this effort will be extended to include combat between heterogeneous forces and such operational factors as: target acquisition considerations, range-dependent weapon-system capabilities, suppression and other temporal variations in fire effectiveness, countermeasures, the effects of logistics constraints, the effect of crew ratio on sortie rate, the effect of multimission aircraft on crew training and on availability, the effect of tactics on attrition, and the effect of managed attrition on outcome. In the remainder of this chapter, single mission tradeoff components for the "first-cut" survivability/lethality tradeoff model will be developed employing the basic structure of Lanchester's square law since it is most applicable for the missions the ATA will be expected to fly.

3.3 DESCRIPTION OF THE AIR SUPERIORITY COMPONENT

This mission is undertaken by a fighter aircraft. The rate of decrease of Advanced Tactical Aircraft (ATA) depends directly on the rate of attrition of ATA when in confrontation with Soviet fighter -- referred to as XF. The attrition rate of ATA against XF is equal to the product of XF aircraft and the Effectiveness of XF Aircraft Against ATA (EXFATA). Effectiveness of XF Aircraft Against ATA is directly proportional to

Sortie Rate of XF (SRXF) and Availability of (AXF), and is inversely proportional to the Survivability of ATA Against XF Aircraft (SATAXF) (or is directly proportional to the Probability Kill of ATA Against XF - PKXATF).

The Initial Value of the Soviet Fighter Aircraft (XFN) is directly proportional to the Initial Value of F-14s (TFN) and the Effectiveness of F-14 Against XF (ETFXF) and is inversely proportional to the Effectiveness of XF Against F-14 (EXFTF). The idea is to find the initial value of XF when the effectiveness exchange ratio of XF against F-14 is equal to one.

The initial value of F-14 increases with the increase in initial value of ATA (ATAN) and Fraction of Sorties to Air Superiority (FSAS) and decreases with increase in Delta Acquisition Cost (DATF) and Fraction Sorties of F-14 to Air Superiority Role (FSTFAS).

The rate of decrease of XF aircraft is directly proportional to the Attrition Rate of XF Against ATA (AXFATA). AXFATA is the product of ATA and its Effectiveness Against XF (EATAXF). EATAXF is the product of Sortie Rate of ATA (SRATA), Fraction Sorties to Air Superiority (FSAS), Availability of ATA replacing F-14 (AATATF) and Probability Kill of XF by ATA (PKXFAT).

The Effectiveness of XF Against F-14 (EXFTF) increases with increase in Sortie Rate of XF (SRXF) and the Availability of XF (AXF) and decreases with an increase in the value of Survivability of F-14 against XF (STFXF). The Effectiveness of F-14 Against XF (ETFXF) increases with an increase in its Sortie Rate (SRTF), its Availability (ATF), Fraction Sorties of

F-14 allocated to Air Superiority Role (FSTFAS) and Probability Kill of XF by F-14.

The probability kill of XF by F-14 (PKXFTF) increases with an increase in Number of Air-to-Air Missiles on the F-14 in Air Superiority Role (NMTFAS) and increases with Probability Kill of XF by ATA (PKXFAT). PKXFAT is directly proportional to the Probability kill of XF by F-14 (PKXFTF) and is inversely proportional to Delta Lethality of ATA Against XF Aircraft (DLF).

Survivabilities are defined similar to kill probabilities. Survivability is equal to one minus the corresponding probability of kill. Delta Lethality of ATA versus XF aircraft (DLF) is defined as the product of Delta Ordnance (DOTF), Number of Air-to-Air Missiles on F-14 in Air Superiority Role (NMTFAS) and Probability Kill of XF by Air-to-Air missiles (PKXFAA).

The inputs to this model are divided into two classes -- the relative parameters and the absolute parameters. The parameters for all the three models are shown in Table 3.1. The relative parameters in this model are Delta Survivability of ATA with respect to Baseline Aircraft (DSTF), Delta Lethality of ATA with respect to Baseline Aircraft (DLTF), Delta Acquisition of ATA with respect to Baseline Aircraft (DATF), and Delta Maintenance Cost of ATA with respect to Baseline Aircraft (DMTF). The absolute parameters are Survivability of F-14 against XF (STFXF), Survivability of F-14 Against Air-to-Air Missile (STFAAM), Probability Kill of XF by F-14 Aircraft (PKXFTF) and Probability Kill of XF by Air-to-Air Missile (PKXFAA).

Figure 14 shows the causal diagram for baseline air superiority aircraft and Figure 15 shows the causal diagram for replacement air superiority aircraft. All the parameters have not been included in these two causal diagrams. The variables in both cases are almost the same. In Figure 15 ATA replaces the F-14 in Figure 14. Delta survivability comes into the picture in Figure 15. Figure 16 is the dynamo model for the air superiority mission.

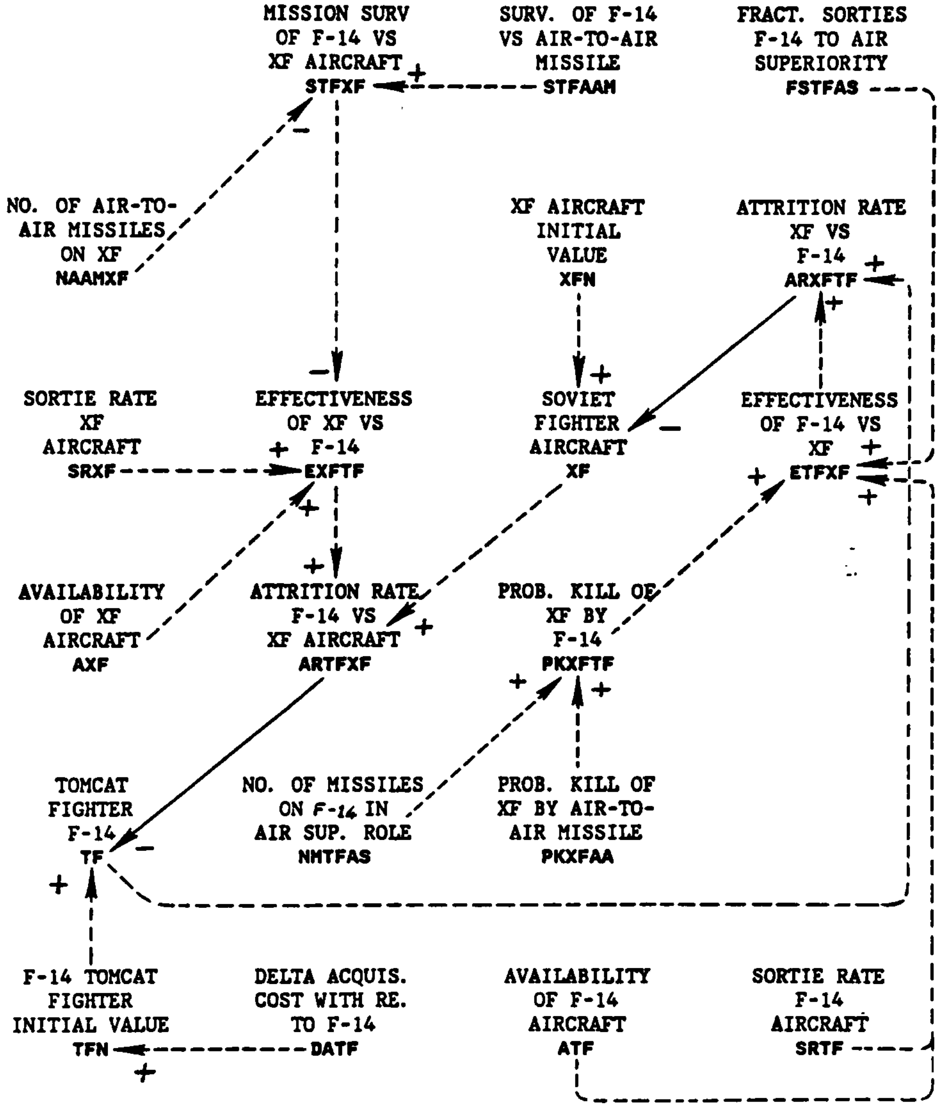

Figure 14. CAUSAL DIAGRAM FOR BASELINE AIR SUPERIORITY AIRCRAFT

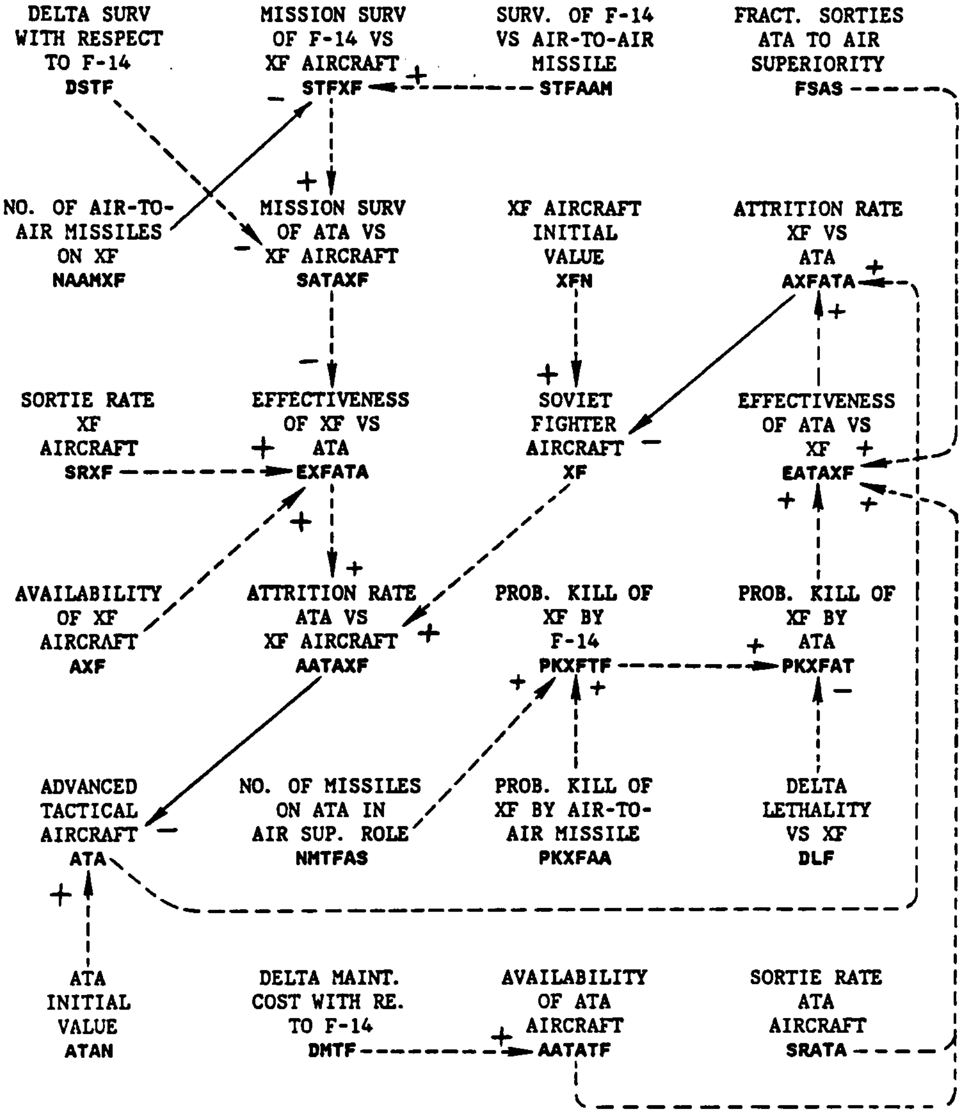

Figure 15. CAUSAL DIAGRAM FOR REPLACEMENT AIR SUPERIORITY AIRCRAFT

```
* ATA CONCEPT EVALUATION
NOTE ********************************************************************
NOTE SURVIVABILITY/LETHALITY TRADEOFF ANALYSIS (AIR SUPERIORITY MISSION)
NOTE ********************************************************************
L    ATA.K=MAX(0,ATA.J-(DT)(AATAXF.JK))
N    ATA=ATAN
NOTE ATA - ADVANCED TACTICAL AIRCRAFT (AIRCRAFT)
N    ATAN=1200
NOTE ATAN - ADVANCED TACTICAL AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    AATAXF.KL=CLIP(XF.K*EXFATA.K,0,XF.K,0)
NOTE AATAXF - ATTRITION RATE ATA VS XF (AIRCRAFT/DAY)
A    EXFATA.K=SRXF*AXF*(1-SATAXF)
NOTE EXFATA - EFFECTIVENESS OF XF VS ATA (FRACT/DAY)
C    SRXF=4
NOTE SRXF - SORTIE RATE XF (NUMBER/DAY)
C    AXF=0.5
NOTE AXF - AVAILABILITY OF XF (PROB)
L    XF.K=MAX(0,XF.J-(DT)(AXFATA.JK))
N    XF=XFN
NOTE XF - SOVIET FIGHTER AIRCRAFT XF (AIRCRAFT)
N    XFN=1548
NOTE XFN=TFN*SQRT(ETFXF/EXFTF)
NOTE XFN - SOVIET FIGHTER AIRCRAFT XF INITIAL VALUE (AIRCRAFT)
N    EXFTF=SRXF*AXF*(1-STFXF)
NOTE EXFTF - EFFECTIVENESS OF XF VS F-14 (FRACT/DAY)
N    ETFXF=SRTF*FSTFAS*ATF*PKXFTF
NOTE ETFXF - EFFECTIVENESS OF F-14 VS XF (FRACT/DAY)
C    SRTF=4
NOTE SRTF - SORTIE RATE F-14 (NUMBER/DAY)
C    ATF=0.5
NOTE ATF - AVAILABILITY OF F-14 (PROB)
C    FSAS=0.2
NOTE FSAS - FRACTION OF SORTIES TO AIR SUPERIORITY (DIM)
N    PKXFTF=1-EXP(-NMTFAS*PKXFAA)
NOTE PKXFTF - PROB KILL XF BY F-14 (PROB)
C    NMTFAS=6
NOTE NMTFAS - NO OF AIR-TO-AIR MISSILES ON TF IN AIR
X               SUPERIORITY ROLE (DIM)
R    AXFATA.KL=CLIP(ATA.K*EATAXF.K,0,ATA.K,0)
NOTE AXFATA - ATTRITION RATE XF VS ATA (AIRCRAFT/DAY)
A    EATAXF.K=SRATA*FSAS*AATATF*PKXFAT
NOTE EATAXF - EFFECTIVENESS OF ATA VS XF (FRACT/DAY)
N    SRATA=SRTF
NOTE SRATA - SORTIE RATE OF ATA (NUMBER/DAY)
N    AATATF=ATF/(1-DMTF)
NOTE AATATF - AVAILABILITY OF ATA REPLACING F-14 (PROB)
N    PKXFAT=PKXFTF*(1-DLF)
NOTE PKXFAT - PROB KILL OF XF BY ATA (PROB)
N    DLF=DOTF*NMTFAS*PKXFAA
NOTE DLF - DELTA LETHALITY VS XF AIRCRAFT (DIM)
N    SATAXF=STFXF*(1-DSTF)
```

```
NOTE SATAXF - SURV OF ATA VS XF (PROB)
N    STFXF=EXP(-NAAMXF*(1-STFAAM))
NOTE STFXF - SURV OF F-14 VS XF (PROB)
C    NAAMXF=4
NOTE NAAMXF - NO OF AIR-TO-AIR MISSILES ON XF (DIM)
N    TFN=ATAN*(1-DATF)*FSAS/FSTFAS
NOTE TFN - F-14 TOMCAT FIGHTER INITIAL VALUE (AIRCRAFT)
C    FSTFAS=0.5
NOTE FSTFAS - FRACT SORTIES F-14 TO AIR SUPERIORITY ROLE (DIM)
C    PKXFAA=0.03
NOTE PKXFAA-PROB KILL OF XF AIRCRAFT BY AIR-TO-AIR MISSILE ON F-14 (PROB)
NOTE *********************************************************************************
NOTE ********** INPUTS FROM  SURVIVABILITY/LETHALITY ASSESSMENT **********
NOTE *********************************************************************************
C    DOTF=0
NOTE DOTF - DELTA ORDNANCE (OTF-OATA)/OTF (DIM)
C    DSTF=0
NOTE DSTF - DELTA SURVIVABILITY (STF-SATA)/STF (DIM)
C    DMTF=0
NOTE DMTF - DELTA MAINTENANCE COST (MCTF-MCATA)/MCTF (DIM)
C    DATF=0
NOTE DATF - DELTA ACQUISITION COST (ACTF-ACATA)/ACTF (DIM)
C    STFAAM=0.9950
NOTE STFAAM - SURV OF F-14 VS SOVIET AIR-TO-AIR MISSILE (PROB)
NOTE *********************************************************************************
NOTE ******************* MOE FOR AIR SUPERIORITY MISSION **********************
NOTE *********************************************************************************
A    CVATAS.K=(ATAN/XFN)*SQRT(EATAXF.K/EXFATA.K)
NOTE CVATAS - COMBAT VALUE RATIO OF ATA IN AIR SUPERIORITY ROLE (DIM)
A    CVTFS.K=(TFN/XFN)*SQRT(ETFXF/EXFTF)
NOTE CVTFS - COMBAT VALUE RATIO OF TF IN AIR SUPERIORITY ROLE (DIM)
A    KLATAS.K=(ATAN*EATAXF.K)/(XFN*EXFATA.K)
NOTE KLATAS - KILL LOSS RATIO OF ATA IN
X             AIR SUPERIORITY MISSION (XF/ATA)
A    KLRTFS.K=(TFN*ETFXF)/(XFN*EXFTF)
NOTE KLRTFS - KILL LOSS RATIO OF TF IN
X             AIR SUPERIORITY MISSION (XF/TF) (DIM)
A    EXATAS.K=KLATAS.K/(XFN/ATAN)
NOTE EXATAS - EFFECTIVE EXCHANGE RATIO FOR ATA
X             OVER XF IN AIR SUPERIORITY (DIM)
A    IXRTFS.K=EXATAS.K/EXRTFS.K
NOTE IXRTFS - INC IN EXCHANGE RATIO FOR ATA OVER
X             F-14 IN AIR SUPERIORITY (DIM)
A    EXRTFS.K=KLRTFS.K/(XFN/TFN)
NOTE EXRTFS - EFFECTIVE EXCHANGE RATIO FOR F-14
X             OVER XF IN AIR SUPERIORITY (DIM)
A    FFRATA.K=ATA.K/ATAN
NOTE FFRATA - FRACT FORCE REMAINING ATA (DIM)
A    FFRXF.K=XF.K/XFN
NOTE FFRXF - FRACT FORCE REMAINING XF (DIM)
NOTE *********************************************************************************
```

```
NOTE ********************     CONTROL STATEMENTS     ******************
NOTE ************************************************************************
SPEC DT=0.05/LENGTH=100/PRTPER=50/PLTPER=2
PRINT ATA,XF,TFN
PRINT XFN,CVATAS,CVTFS,KLATAS
PRINT KLRTFS,IXRTFS,FFRATA,FFRXF
PRINT EXRTFS,EXATAS
PLOT  ATA=A,XF=X
PLOT  FFRATA=A,FFRXF=X(0,1)
RUN   RERUN
C     DATF=-.5812
RUN
QUIT
```

Figure 16. DYNAMO MODEL FOR AIR SUPERIORITY MISSION

Table 1 (Part 1 of 2). INPUTS FROM SURVIVABILITY/LETHALITY ASSESSMENT

MISSION	AIR SUPERIORITY	FLEET DEFENSE	ATTACK/ INTERDICTION
BASELINE AIRCRAFT	TF TOMCAT FIGHTER F-14	TF TOMCAT FIGHTER F-14	INTRUDER ATTACK IA A-6
RELATIVE ARAMETERS			
DELTA SURVIVABILITY OF ATA WITH RESPECT TO BASELINE AIRCRAFT	DSTF	DSTF	DSIA
DELTA LETHALITY OF ATA WITH RESPECT TO BASELINE AIRCRAFT	DLTF	DLTF	DLIA
DELTA ACQUISITION COST WITH RESPECT TO BASELINE AIRCRAFT	DATF	DATF	DAIA
DELTA MAINTENANCE COST WITH RESPECT TO BASELINE AIRCRAFT	DMTF	DMTF	DMIA
ABSOLUTE ARAMETERS			
MISSION SURVIVABILITY OF BASELINE AIRCRAFT	STFXF	DLPH & ILPH	SIART
ENCOUNTER SURVIVABILITY OF BASELINE AIRCRAFT	STFAAM		SIASAM
THREAT PLATFORM PROB. OF KILL	PKXFTF PKXFAA	PKXAAA	PKRTAS PKXAAI

Table 1 (Part 2 of 2). INPUTS FROM SURVIVABILITY/LETHALITY ASSESSMENT

MISSION	AIR SUPERIORITY	FLEET DEFENSE	ATTACK/ INTERDICTION
THREAT PROPAGATOR PROB. OF KILL		PKCMPM PKCMTF	

3.4 ANALYSIS OF AIR SUPERIORITY MISSION COMPONENT

The equations in this analysis are in the form of continuous subscript notation. The basic equations are obtained by referring to the model given in dynamo equation form in Figure 16.

The level equation for ATA can be written as

$$dATA_t/dt = -AATAXF_t = -EXFATA_t*XF_t = -B*XF_t \qquad (3.43)$$

and the level equation for XF can be written as follows:

$$dXF_t/dt = -AXFATA_t = -EATAXF_t*ATA_t = -C*ATA_t \qquad (3.44)$$

where,

$$B = SRXF*AXF*(1-SATAXF) = 4*0.5*(1-0.9802) = 0.0396 \qquad (3.45)$$

$$C = SRATA*FSAS*AATATF*PKXFAT = 4*0.2*0.5*0.16473 = 0.0659 \qquad (3.46)$$

From equations (3.43) and (3.44) equations for ATA and XF at any time t is given by

$$ATA_t = ATAN*Cosh(\surd B*C)t-XFN*(\surd B/C)*Sinh(\surd B*C)t \qquad (3.47)$$

$$XF_t = XFN*Cosh(\surd B*C)t-XFN*(\surd C/B)*Sinh(\surd B*C)t \qquad (3.48)$$

Since all the values of the parameters to the right are known one can find the value of ATA and XF at any given time t. An analytical solution is very helpful in model building. It helps in decision making.

The effectiveness of F-16 against XF aircraft is given by

$$ETFXF = SRTF*FSTFAS*ATF*PKXFTF = 4*0.5*0.5*0.16473 = 0.16473 \qquad (3.49)$$

The effectiveness of XF against F-14 aircraft is given by

$$EXFTF = SRXF*AXF*(1-STFXF) = 4*0.5*(1-0.9802) = 0.0396 \qquad (3.50)$$

INITIAL VALUE OF XFN

DELTA SURVIVABILITY

DSIA = (SIART-SATART)/SIART
WHERE
SIART = EXP(-NSAMRT*(1-SIASAM))
SIASAM = SURV OF A-6
IN SAM ENCOUNTER
NSAMRT = NO. OF SAMS ON PLATFORM
SATART = SURV OF ATA
VS SURFACE THREAT
SIART = SURV OF A-6
VS SURFACE THREAT

DELTA ACQUISITION COST

DAIA = (ACIA-ACATA)/ACIA
WHERE AC = ACQUISITION
RELATIONSHIP TO
INITIAL VALUE INVEN.
SINCE FOR AN ACQUISITION BUDGET, AB
AB = ATAN*ACATA = IAN*ACIA
IAN = ATAN*ACATA/ACIA
= ATAN*(1-DAIA)

DELTA MAINTENANCE COST

DMIA = (MCIA-MCATA)/MCIA
WHERE MC = MAINTENANCE COST
RELATIONSHIP TO
AIRCRAFT AVAILABILITY
SINCE FOR A MAINTENANCE BUDGET, MB
MB = AATAIA*MCATA = AIA*MCIA
AATAIA = AIA/(1-DMIA)

DELTA LETHALITY

DLTF = (PKCMTF-PKCMAT)/PKCMTF
WHERE
PKCMTF = 1-EXP(-NPMCM*PKCMPM)
RELATIONSHIP TO ORDNANCE (DOTF)
DLTF = 1-(PKCMAT/PKCMPM)
= 1-EXP((-NPMATA+NPMTF)*PKCMPM)
= (NPMTF-NPMATA)*PKCMPM
BUT DLTF~DOTF*NPMTF*PKCMPM
~DOTF*PKCMTF
RELATIONSHIP TO AIRCRAFT WEIGHT

$$OAT=\frac{\begin{array}{c}(WTF+OTF+FTF-WAT)*(2*WTF+OTF)-2*WAT\\ FTF\end{array}}{\begin{array}{c}1+2*WTF+OTF\\ FTF\end{array}}$$

WHERE
WTF = EMPTY WEIGHT OF F-14
OTF = ORDNANCE WEIGHT OF F-14
FTF = FUEL WEIGHT OF F-14
WAT = EMPTY WEIGHT OF ATA
OAT = ORDNANCE WEIGHT OF ATA
DOTF = DELTA ORDNANCE (F-14 & ATA)
DLTF = DELTA LETHALITY (F-14 & ATA)
PKCMPM = PROB. KILL OF CRUISE
MISSILE BY PHOENIX
MISSILE ON F-14 OR ATA

Figure 17. ANALYSIS OF DELTAS

XFN is calculated so as to make Effective Exchange Ratio Versus F-14 (EXRTFS) equal to 1

$$EXRTFS = KLTFS/(XFN/TFN) = 1 \tag{3.51}$$

$$XFN = TFN*(TFN*ETFXF)/(XFN*EXFTF) \tag{3.52}$$

The initial value of F-16 is given by

$$TFN = ATAN*(1-DATF)*FSAS/FSTFAS = 1200*(1-0)*0.2/0.5 = 480 \tag{3.53}$$

Substituting values of the variables on the right hand side of Equation 3.52

$$XFN = TFN*(\sqrt{ETFXF/EXFTF}) = 480*(\sqrt{0.16473/0.0396}) \doteq 979 \tag{3.54}$$

COMBAT VALUE RATIOS (when DATF=0)

$$\begin{aligned} CVATAS &= (ATAN/XFN)*(\sqrt{EATAXF/EXFATA}) \\ &= (1200/979)*(\sqrt{0.0659/0.0396}) \\ &= 1.5812 \end{aligned} \tag{3.55}$$

$$\begin{aligned} CVTFS &= (TFN/XFN)*(\sqrt{ETFXF/EXFTF}) \\ &= (480/979)*(\sqrt{0.16473/0.0396}) \\ &= 1.0000 \end{aligned} \tag{3.56}$$

The combat value ratio of ATA in the air superiority role is 1.58 times higher than that of the baseline aircraft, the F-14.

EQUILIBRIUM ANALYSIS

At equilibrium the attrition rates of the baseline and replacement aircraft should be the same. Consequently, the Fraction Force Remaining of ATA (FFRATA) and Fraction Force Remaining of XA (FFRXA) will be the same. Therefore

$$FFRATA = FFRXA$$

i.e. $ATA_t/ATAN = XF_t/XFN$

$$(ATAN*Cosh(\sqrt{B*C})t - XFN*(\sqrt{B/C})*Sinh(\sqrt{B*C})t)/ATAN$$

$$= (XFN*Cosh(\sqrt{B*C})t - ATAN*(\sqrt{C/B})*Sinh(\sqrt{B*C})t)/XFN \tag{3.57}$$

Simplifying the above equation we have

$$XFN^2*(\sqrt{B/C}) = ATAN^2*(\sqrt{C/B}) \tag{3.58}$$

Substituting the values we have

$$XFN = 979*(1-DATF) = 1548 \tag{3.59}$$

$$1-DATF = 1.5812$$

$$DATF = -0.5812$$

The Delta Acquisition Cost has to be equal to -0.5812 for the system to go into equilibrium.

3.5 OUTPUTS OF THE AIR SUPERIORITY MISSION COMPONENT

The outputs of the survivability/lethality tradeoff model are shown in Table 3.2. Table 3.3 shows the comparison of outputs for Scenario 1 and Scenario 2. The outputs obtained show that the combat value ratio of the ATA is 1.58 times more than the combat value ratio of the F-14 aircraft, indicating the potential superiority of the multimission ATA. The effective exchange ratio of replacement aircraft is much higher than the effectiveness exchange ratio of the baseline aircraft, also.

The Time to Defeat the Threat for Baseline Aircraft (TDTTFS) can be obtained from computer outputs. The time required to reduce the threat to zero is equal to TDTTFS. Similarly, it could be calculated for the replacement aircraft, i.e. TDATAS. Figure 18 shows the computer output. The output is given for both Scenario 1 and Scenario 2. The only change in Scenario 2 from Scenario 1 is in the variable, Delta Acquisition Cost

(DATF). Figure 19 shows the graph for Fraction Force Remaining ATA (FFRATA) and Fraction Force Remaining XF (FFRXF) for the case when Delta Acquisition of ATA with respect to Baseline Aircraft (DATF) is equal to -0.5811.

Figure 20 shows the relationship between the Fraction Force Remaining for the ATA (FFRATA), the Fraction Force Remaining for the threat (FFRXF, FFRXA and FFRRT), the Combat Value Ratio for ATA (CVRATA) and the Decreased Program Life Cycle Cost (DPLCC). The y-intercept can either be obtained from computer output or from the equation:

$$Y = \mathrm{Cosh}(\mathrm{Coth}^{-1}\mathrm{COMVR}) - \mathrm{Sinh}(\mathrm{Coth}^{-1}\mathrm{COMVR})/\mathrm{COMVR} \quad \text{when x-intercept} = 0$$

This equation also represents the Decreased Program Life Cycle Cost in percent, as is shown in the figure.

```
   TIME=     .00    ATA=   1200.     XF=   979.0    TFN=   480.0
    XFN=   979.0 CVATAS=   1.581  CVTFS=   1.000 KLATAS=   2.039
 KLRTFS=   2.039 IXRTFS=   2.500 FFRATA=   1.000  FFRXF=   1.000
 EXRTFS=   1.000 EXATAS=   2.500
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   25.00    ATA=    929.     XF=      .0    TFN=   480.0
    XFN=   979.0 CVATAS=   1.581  CVTFS=   1.000 KLATAS=   2.039
 KLRTFS=   2.039 IXRTFS=   2.500 FFRATA=    .774  FFRXF=    .000
 EXRTFS=   1.000 EXATAS=   2.500
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   49.99    ATA=    929.     XF=      .0    TFN=   480.0
    XFN=   979.0 CVATAS=   1.581  CVTFS=   1.000 KLATAS=   2.039
 KLRTFS=   2.039 IXRTFS=   2.500 FFRATA=    .774  FFRXF=    .000
 EXRTFS=   1.000 EXATAS=   2.500
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   74.99    ATA=    929.     XF=      .0    TFN=   480.0
    XFN=   979.0 CVATAS=   1.581  CVTFS=   1.000 KLATAS=   2.039
 KLRTFS=   2.039 IXRTFS=   2.500 FFRATA=    .774  FFRXF=    .000
 EXRTFS=   1.000 EXATAS=   2.500
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
            DATF
 PRESENT  -.5812
ORIGINAL      0.
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=     .00    ATA=   1200.     XF=   1548.    TFN=   759.0
    XFN=   1548. CVATAS=   1.000  CVTFS=   1.000 KLATAS=   1.290
 KLRTFS=   2.039 IXRTFS=   .9999 FFRATA=   1.000  FFRXF=   1.000
 EXRTFS=   1.000 EXATAS=   .9999
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   25.00    ATA=    334.     XF=    431.    TFN=   759.0
    XFN=   1548. CVATAS=   1.000  CVTFS=   1.000 KLATAS=   1.290
 KLRTFS=   2.039 IXRTFS=   .9999 FFRATA=    .278  FFRXF=    .278
 EXRTFS=   1.000 EXATAS=   .9999
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   49.99    ATA=     93.     XF=    120.    TFN=   759.0
    XFN=   1548. CVATAS=   1.000  CVTFS=   1.000 KLATAS=   1.290
 KLRTFS=   2.039 IXRTFS=   .9999 FFRATA=    .077  FFRXF=    .078
 EXRTFS=   1.000 EXATAS=   .9999
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   74.99    ATA=     25.     XF=     35.    TFN=   759.0
    XFN=   1548. CVATAS=   1.000  CVTFS=   1.000 KLATAS=   1.290
 KLRTFS=   2.039 IXRTFS=   .9999 FFRATA=    .021  FFRXF=    .023
 EXRTFS=   1.000 EXATAS=   .9999
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 18. COMPUTER OUTPUT FOR AIR SUPERIORITY MISSION

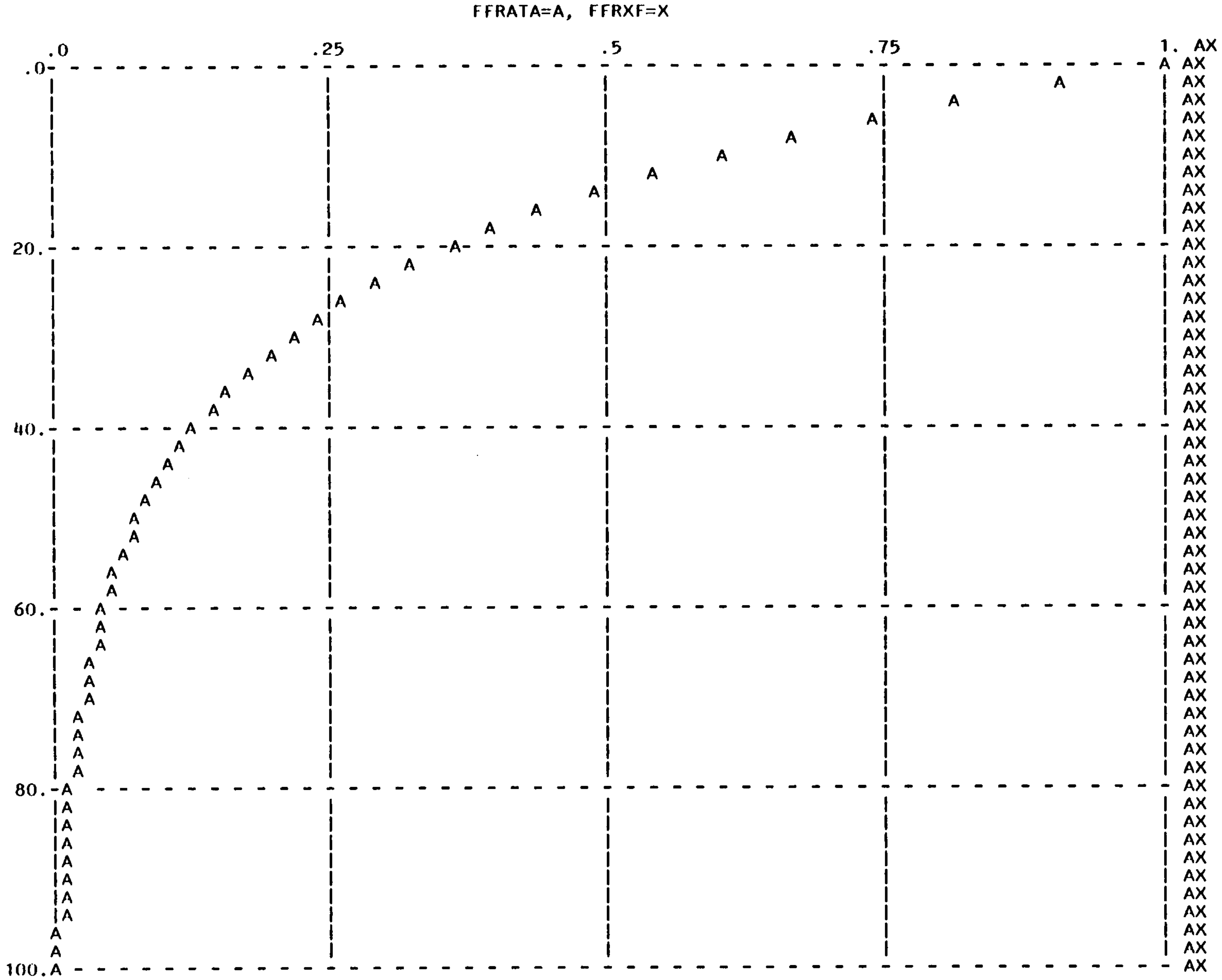

Figure 14. PLOT OF FFRATA AND FFRXF FOR EQUILIBRIUM CASE

Table 2 (Part 1 of 3). OUTPUTS OF SURVIVABILITY/LETHALITY TRADEOFF MODEL

MEASURES OF EFFECTIVENESS	AIR SUPERIORITY MISSION	FLEET DEFENSE MISSION	ATTACK/INTERDICTION MISSION	
			THREAT SUPPRESSION	AIRFIELD INTERDICTION
FRACTION FORCE REMAINING ATA	FFRATA			
FRACTION FORCE REMAINING THREAT	FFRXF	FFRXA	FFRRT	FFRXX
COMBAT VALUE RATIO BASELINE A/C	CVTFS	CVTFD	CVIATS	CVIAAI
COMBAT VALUE RATIO ATA	CVATAS	CVATAD	CVATAT	CVATAI
KILL-LOSS RATIO BASELINE A/C	KLRTFS	KLRTFD	KLRIAT	KLRIAI
KILL-LOSS RATIO ATA	KLATAS	KLATAD	KLATAT	KLATAI
EFFECTIVE EXCHANGE RATIO BASELINE A/C	EXRTFS	EXRTFD	EXRIAT	EXRIAI
EFFECTIVE EXCHANGE RATIO ATA	EXATAS	EXATAD	EXATAT	EXATAI
INC. EXCHANGE RATIO OVER BASELINE A/C	IXRTFS	IXRTFD	IXRIAT	IXRIAI
DECREASED PROGRAM LIFE-CYCLE COST	DPLCCS	DPLCCD	DPLCCT	DPLCCI

Table 2 (Part 2 of 3). OUTPUTS OF SURVIVABILITY/LETHALITY TRADEOFF MODEL

MEASURES OF EFFECTIVENESS	AIR SUPERIORITY MISSION	FLEET DEFENSE MISSION	ATTACK/INTERDICTION MISSION	
			THREAT SUPPRESSION	AIRFIELD INTERDICTION
CUM HITS ON CARRIER DEFENDED BY F-14	-	CHCTF	-	-
CUM HITS ON CARRIER DEFENDED BY ATA	-	CHCATA	-	-
DECREASED CRUISE MISSILE HITS ON CARRIER	-	DCMHC	-	-
TIME TO DEFEAT THREAT FOR BASELINE A/C	TDTTFS	-	TDTIAT	-
TIME TO DEFEAT THREAT FOR ATA	TDATAS	-	TDATAT	-
ORDNANCE TO TARGET PER BASELINE LOST	-	-	-	OTPIAL
ORDNANCE TO TARGET PER ATA LOST	-	-	-	OTATAL
INC TARGETS DESTROYED PER A/C LOST	-	-	-	ITDPAL

Table 2 (Part 3 of 3). OUTPUTS OF SURVIVABILITY/LETHALITY TRADEOFF MODEL

MEASURES OF EFFECTIVENESS	AIR SUPERIORITY MISSION	FLEET DEFENSE MISSION	ATTACK/INTERDICTION MISSION	
			THREAT SUPPRESSION	AIRFIELD INTERDICTION
COST ELASTICITY TARGETS DES PER LOSS	-	-	-	CETDPL

Table 3. COMPARISON OF OUTPUTS (AIR SUPERIORITY)

		SCENARIO 1	SCENARIO 2
1	CVATAS	1.58	1.00
2.	CVTFS	1.00	1.00
3.	KLATAS	2.04	1.29
4.	KLRTFS	2.04	2.04
5.	EXATAS	2.50	1.00
6.	EXRTFS	1.00	1.00
7.	IXRTFS	2.50	1.00

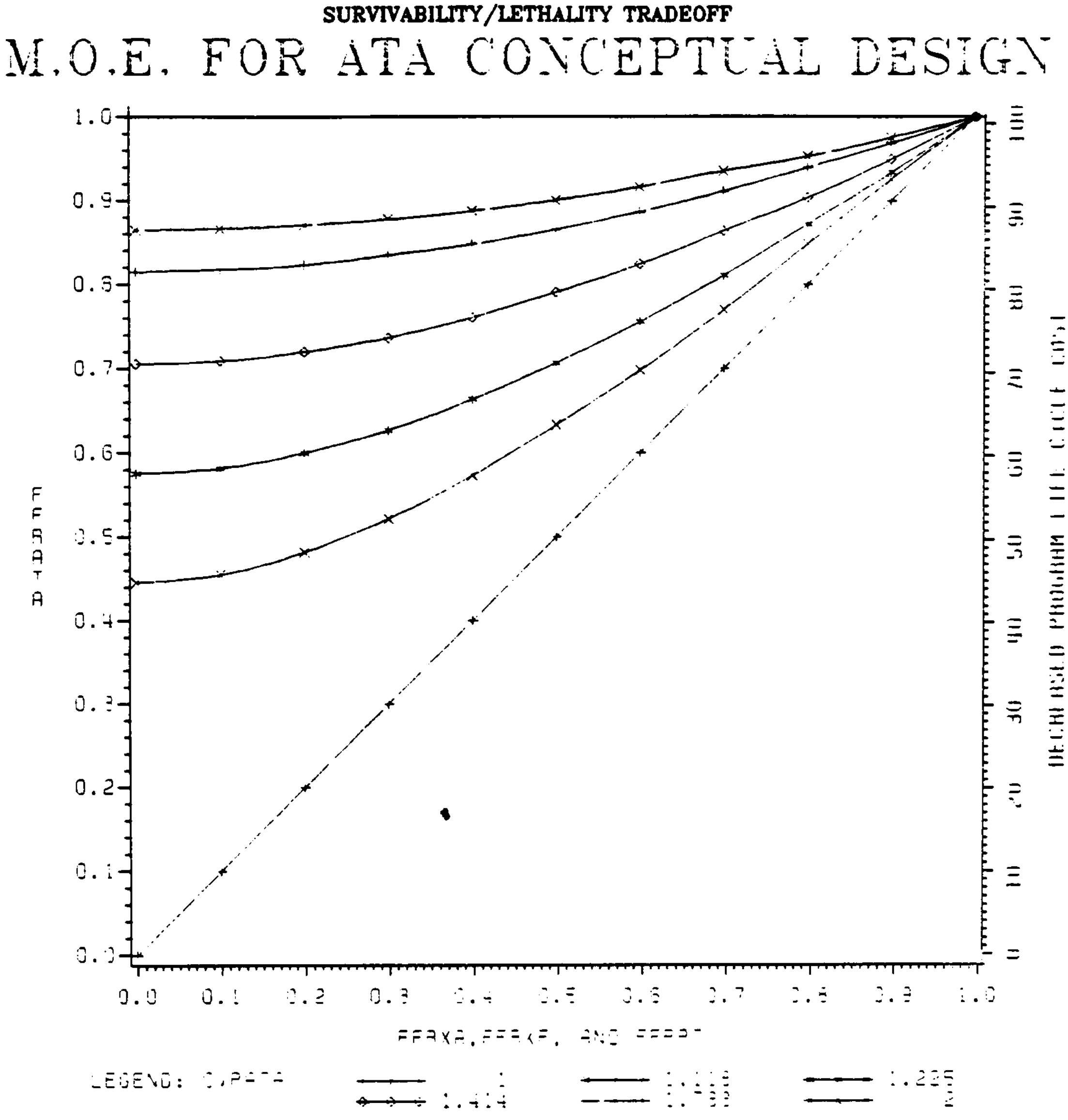

Figure 20. SURVIVABILITY/LETHALITY TRADEOFF M.O.E. FOR ATA CONCEPTUAL DESIGN

3.6 DESCRIPTION OF THE FLEET DEFENSE MISSION COMPONENT

Figure 21 shows the causal diagram for baseline aircraft and Figure 22 represents the causal diagram for replacement case. The F-14 in Figure 21 is replaced by ATA in Figure 22.

The fleet defense mission is undertaken to protect aircraft carrier from the threat posed by the enemy's attack aircraft. Thus the basic aim in this mission is to detect and destroy enemy attack aircraft and protect the fleet. Twenty percent of the sorties of the ATA are assigned to this mission in this model.

The initial value of ATA is determined on the basis that the number of aircraft carriers is 15 with each aircraft carrier requiring about 60 aircraft with the attrition replacement constant as 1.333. The product gives the initial number of ATA, as 1200.

The ATA decreases in number due to Attrition Caused by Carrier Damage (AATACD). AATACD is equal to the sum of Indirect Loss Per Hit (ILPH) plus Direct Loss Per Hit (DLPH), multiplied by Hit Rate of Cruise Missiles on Carrier (HRCMC). HRCMC is equal to the product of Launch Rate of Cruise Missiles From XA's (LRCMXA), Probability of Cruise Missile Hitting Carrier (PCMHC) and one minus Probability Kill of Cruise Missile by ATA.

The Launch Rate for Cruise Missiles From XA's (LRCMXA) is equal to the product of Sortie Rate of XA (SRXA), Availability of XA (AXA), Number of Attack Aircraft XA (XA), Number of Cruise Missiles Per XA (NCMPXA) and one minus Probability Kill of XA by ATA (PKXAAT). Launch rate of cruise missiles from XA increases with Sortie Rate of XA

(SRXA), Availability of XA (AXA), Number of Attack Aircraft XA (XA) and Number of Cruise Missiles per XA, but decreases with increase in Probability Kill of XA Aircraft by ATA (PKXAAT). The rate of decrease of XA aircraft by ATA is directly proportional to, the Attrition Rate of XA because of ATA (AXAATA). The initial value of XA (XAN) is calculated so as to make Effectiveness Exchange Ratio of XA against F-14 (EXRTFD) equal to one.

The Probability Kill of XA by ATA (PKXAAT) increases with an increase in Probability Kill of XA by the Baseline Aircraft (PKXATF) and decreases with increase in Delta Lethality Against XA Aircraft (DLA). DLA is equal to the product of Delta Ordnance (DOTF), Number of Air-to-Air missiles on F-14 (NAAMTF) and Probability Kill of XA by Air-to-Air missiles on F-14 (PKXAAA).

The inputs for this model are divided into relative parameters and the absolute parameters. Relative parameters show the relationship of a parameter for replacement aircraft in relation to the baseline aircraft. The relative parameters in this model are Delta Survivability of ATA with Respect to Baseline Aircraft (DSTF), Delta Lethality of ATA with Respect to Baseline Aircraft (DLTF), Delta Acquisition Cost of ATA with Respect to Baseline Aircraft (DATF) and Delta Maintenance Cost of ATA with Respect to Baseline Aircraft (DMTF).

The absolute parameters of the baseline and replacement aircraft as the name indicates, are not expressed in relation to one another. The absolute parameters in this model are Direct Loss Per Hit (DLPH), Indirect Loss Per Hit (ILPH), Probability Kill of XA by Air-to-Air missile (PKXAAA), Probability Kill of Cruise Missile by Phoenix Missile (PKCMPM) and Probability Kill of Cruise Missile by F-14 (PKCMTF). Figure 23 gives the dynamo model for the fleet defense mission.

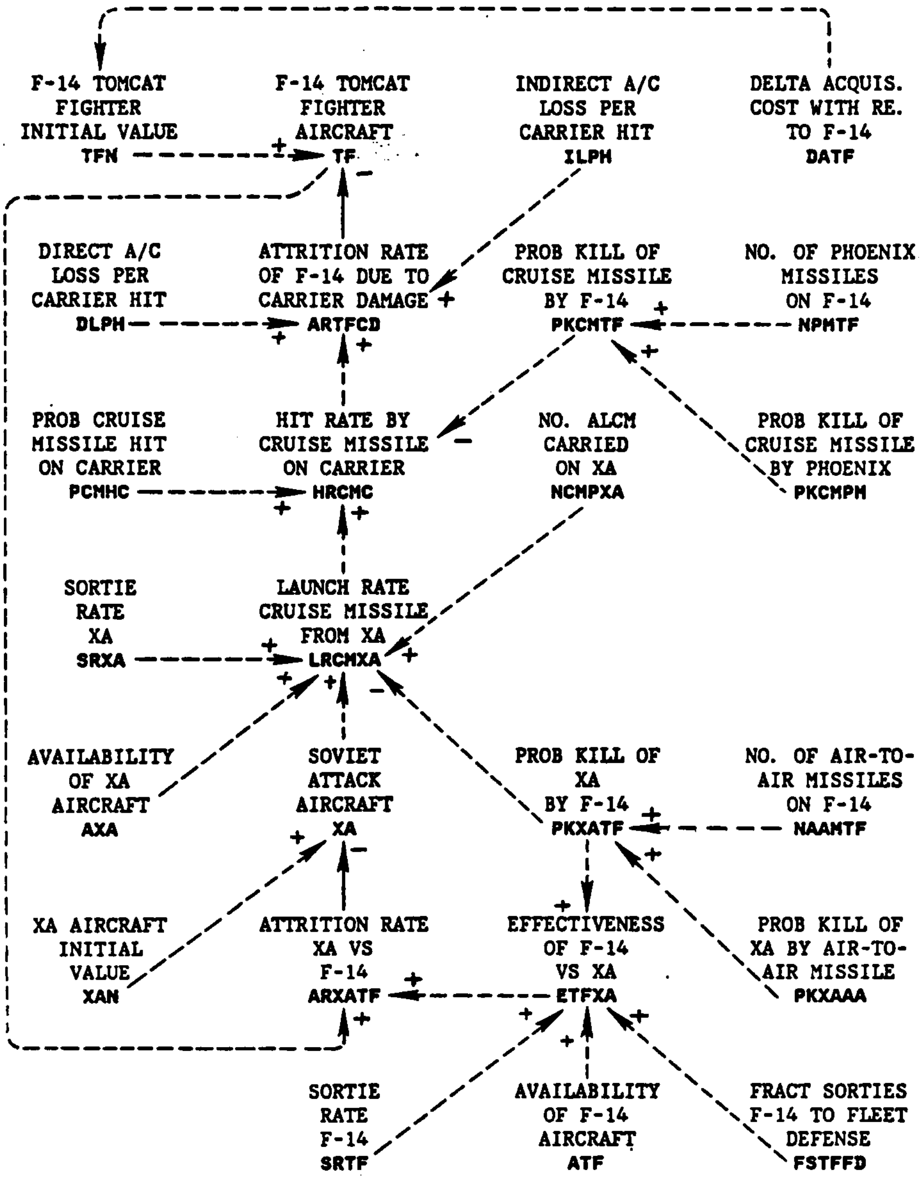

Figure 21. CAUSAL DIAGRAM FOR BASELINE FLEET DEFENSE AIRCRAFT

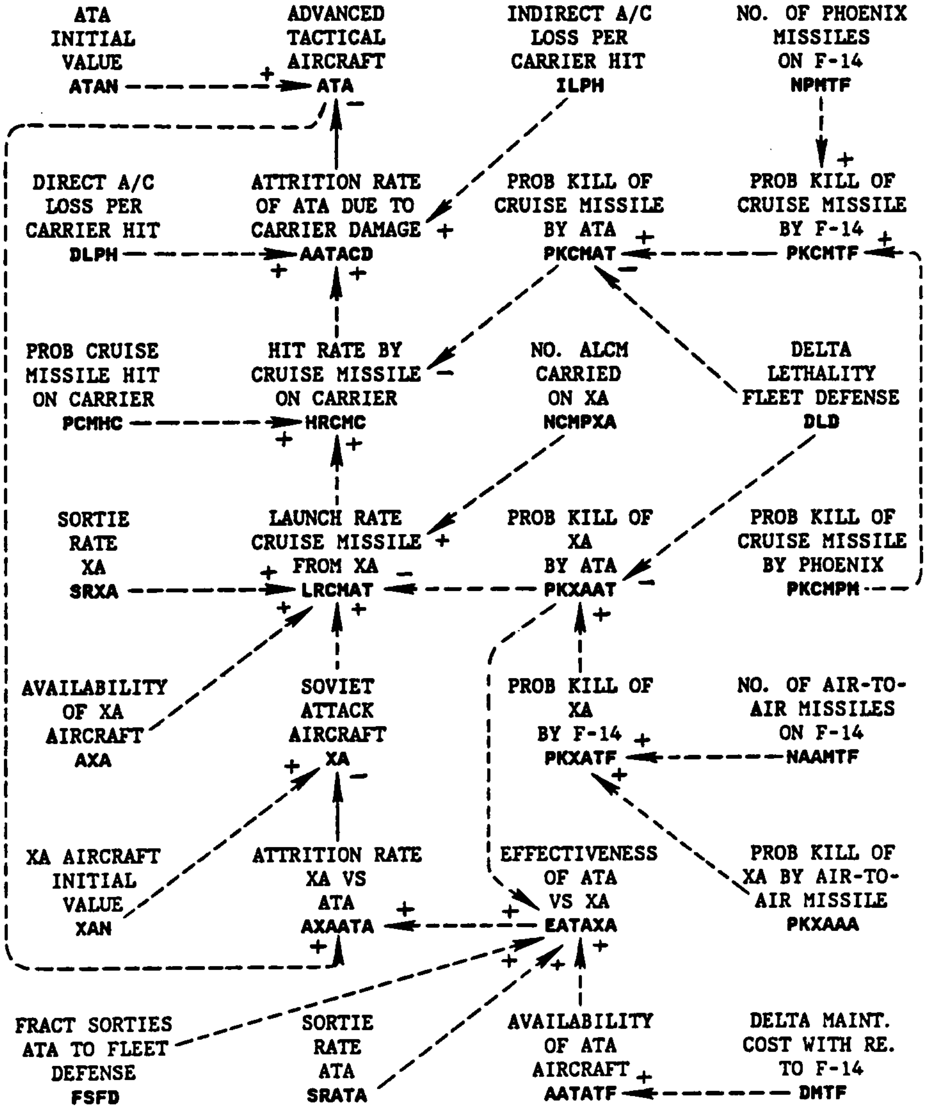

Figure 22. CAUSAL DIAGRAM FOR REPLACEMENT FLEET DEFENSE AIRCRAFT

```
* ATA CONCEPT EVALUATION
NOTE ************************************************************************
NOTE  SURVIVABILITY/LETHALITY TRADEOFF ANALYSIS (FLEET DEFENSE MISSION)
NOTE ************************************************************************
L     ATA.K=MAX(0,ATA.J-(DT)(AATACD.JK))
N     ATA=ATAN
NOTE ATA - ADVANCED TACTICAL AIRCRAFT (AIRCRAFT)
N     ATAN=NAC*ATAPC*ARC
NOTE ATAN - ADVANCED TACTICAL AIRCRAFT INITIAL VALUE (AIRCRAFT)
C     NAC=15
NOTE NAC - NO OF AIRCRAFT CARRIERS (SHIPS)
C     ATAPC=60
NOTE ATAPC - NO OF ATA PER CARRIER (AIRCRAFT/SHIP)
C     ARC=1.333
NOTE ARC - ATTRITION REPLACEMENT CONSTANT (DIM)
R     AATACD.KL=CLIP(HRCMC.K*(DLPH+ILPH),0,XA.K,0)
NOTE AATACD - ATTRITION RATE ATA DUE TO CARRIER DAMAGE (ATA/DAY)
C     DLPH=3
NOTE DLPH - DIRECT LOSS PER HIT (ATA/CM)
C     ILPH=1
NOTE ILPH - INDIRECT LOSS PER HIT (ATA/CM)
A     HRCMC.K=LRCMXA.K*(1-PKCMAT)*PCMHC
NOTE HRCMC - HIT RATE OF CRUISE MISSILES ON CARRIER (CM/DAY)
C     PCMHC=0.01
NOTE PCMHC - PROB OF CRUISE MISSILE HITTING CARRIER (PROB)
N     PKCMAT=PKCMTF*(1-DLM)
NOTE PKCMAT - PROB KILL OF XA CRUISE MISSILE BY ATA (PROB)
N     PKCMTF=1-EXP(-NPMTF*PKCMPM)
NOTE PKCMTF - PROB KILL OF XA CRUISE MISSILE BY F-14 (PROB)
N     DLM=DOTF*NPMTF*PKCMPM
NOTE DLM - DELTA LETHALITY VS CRUISE MISSILE (DIM)
C     NPMTF=6
NOTE NPMTF - NO OF PHOENIX MISSILES ON F-14 FLEET DEFENSE MISSION (DIM)
A     LRCMXA.K=SRXA*AXA*XA.K*NCMPXA*(1-PKXAAT)
NOTE LRCMXA - LAUNCH RATE CRUISE MISSILES FROM XA'S (CM/DAY)
C     NCMPXA=2
NOTE NCMPXA - NO CRUISE MISSILES PER XA (CM/XA)
C     SRXA=4
NOTE SRXA - SORTIE RATE XA (NUMBER/DAY)
C     AXA=0.5
NOTE AXA - AVAILABILITY OF XA (PROB)
N     PKXAAT=PKXATF*(1-DLA)
NOTE PKXAAT - PROB KILL OF XA BY ATA (PROB)
N     PKXATF=1-EXP(-NAAMTF*PKXAAA)
NOTE PKXATF - PROB KILL OF XA BY F-14 (PROB)
C     NAAMTF=2
NOTE NAAMTF - NO OF AIR-TO-AIR MISSILES ON F-14 (DIM)
N     DLA=DOTF*NAAMTF*PKXAAA
NOTE DLA - DELTA LETHALITY VS XA AIRCRAFT (DIM)
L     XA.K=MAX(0,XA.J-(DT)(AXAATA.JK))
N     XA=XAN
```

```
NOTE XA - SOVIET ATTACK AIRCRAFT XA (AIRCRAFT)
N    XAN=TFN*SQRT(ETFXA/EXATF)
NOTE XAN - SOVIET ATTACK AIRCRAFT XA INITIAL VALUE (AIRCRAFT)
N    ETFXA=SRTF*FSTFFD*ATF*PKXATF
NOTE ETFXA - EFFECTIVENESS OF F-14 VS XA (FRACT/DAY)
N    EXATF=(DLPH+ILPH)*PCMHC*(1-PKCMTF)*SRXA*AXA*(1-PKXATF)*NCMPXA
NOTE EXATF - EFFECTIVENESS OF XA VS F-14 (FRACT/DAY)
N    TFN=ATAN*(1-DATF)*FSFD/FSTFFD
NOTE TFN - F-14 TOMCAT FIGHTER INITIAL VALUE (AIRCRAFT)
C    FSTFFD=0.5
NOTE FSTFFD - FRACT SORTIES F-14 TO FLEET DEFENSE (DIM)
R    AXAATA.KL=CLIP(ATA.K*EATAXA.K,0,ATA.K,0)
NOTE AXAATA - ATTRITION RATE XA VS ATA (XA/DAY)
A    EATAXA.K=SRATA*FSFD*AATATF*PKXAAT
NOTE EATAXA - EFFECTIVENESS OF ATA VS XA (FRACT/DAY)
N    SRATA=SRTF
NOTE SRATA - SORTIE RATE ATA (NUMBER/DAY)
C    SRTF=4
NOTE SRTF - SORTIE RATE F-14 (NUMBER/DAY)
N    AATATF=ATF/(1-DMTF)
NOTE AATATF - AVAILABILITY OF ATA REPLACING F-14 (PROB)
C    ATF=0.5
NOTE ATF - AVAILABILITY OF F-14 (PROB)
C    FSFD=0.2
NOTE FSFD - FRACTION OF SORTIES TO FLEET DEFENSE (DIM)
C    PKCMPM=0.5
NOTE PKCMPM - PROB KILL OF XA CRUISE MISSILE BY AIM-54 C PHOENIX
X                  MISSILE (PROB)
C    PKXAAA=0.05268
NOTE PKXAAA - PROB KILL OF XA A/C BY AIR-TO-AIR MISSILE ON F-14 (PROB)
NOTE *******************************************************************
NOTE ********* INPUTS FROM  SURVIVABILITY/LETHALITY ASSESSMENT *********
NOTE *******************************************************************
C    DOTF=0
NOTE DOTF - DELTA ORDNANCE (OTF-OATA)/OTF (DIM)
C    DMTF=0
NOTE DMTF - DELTA MAINTENANCE COST (MCTF-MCATA)/MCTF (DIM)
C    DATF=-0.58114
NOTE DATF - DELTA ACQUISITION COST (ACTF-ACATA)/ACTF (DIM)
NOTE *******************************************************************
NOTE **************** MOE FOR FLEET DEFENSE MISSION ********************
NOTE *******************************************************************
A    DCMHC.K=(CHCATA.K-CHCTF.K)/CHCTF.K
NOTE DCMHC - DECREASE IN CRUISE MISSILE HITS ON CARRIER NORMALIZED (DIM)
L    CHCATA.K=CHCATA.J+(DT)(HRCATA.JK)
N    CHCATA=0
NOTE CHCATA - CUM HITS ON CARRIER VS ATA (HITS)
L    CHCTF.K=CHCTF.J+(DT)(HRCTF.JK)
N    CHCTF=0
NOTE CHCTF - CUM HITS ON CARRIER VS F-14 (HITS)
C    O=0.00000001
```

```
NOTE 0 - ZERO
R    HRCATA.KL=HRCMC.K
NOTE HRCATA - HIT RATE ON CARRIER DEFENDED BY ATA (HITS/DAY)
R    HRCTF.KL=(1-PKCMTF)*PCMHC*SRXA*AXA*XA.K*NCMPXA*(1-PKXATF)
NOTE HRCTF - HIT RATE ON CARRIER DEFENDED BY TF (HITS/DAY)
A    EXAATA.K=(DLPH+ILPH)*PCMHC*(1-PKCMAT)*SRXA*AXA*(1-PKXAAT)*NCMPXA
NOTE EXAATA - EFFECTIVENESS OF XA VS ATA (FRACT/DAY)
A    CVATAD.K=(ATAN/XAN)*SQRT(EATAXA.K/EXAATA.K)
NOTE CVATAD - COMBAT VALUE RATIO OF ATA IN FLEET DEFENSE (DIM)
A    KLATAD.K=(ATAN*EATAXA.K)/(XAN*EXAATA.K)
NOTE KLATAD - KILL LOSS RATIO ATA IN FLEET DEFENSE MISSION (DIM)
A    CVTFD.K=(TFN/XAN)*SQRT(ETFXA/EXATF)
NOTE CVTFD - COMBAT VALUE RATIO OF TF IN FLEET DEFENSE (DIM)
A    KLRTFD.K=(TFN*ETFXA)/(XAN*EXATF)
NOTE KLRTFD - KILL LOSS RATIO TF IN FLEET DEFENSE MISSION (XA/TF) (DIM)
A    EXRTFD.K=KLRTFD.K/(XAN/TFN)
NOTE EXRTFD - EFFECTIVE EXCHANGE RATIO FOR F-14 OVER XA IN
X                FLEET DEFENSE (XA/TF)
A    EXATAD.K=KLATAD.K/(XAN/ATAN)
NOTE EXATAD - EFF EXCH RATIO FOR ATA OVER F-14 IN FL DEF MISSN (XA/ATA)
A    IXRTFD.K=EXATAD.K/EXRTFD.K
NOTE IXRTFD - INC IN EXCH RATIO FOR ATA OVER F-14 IN FLEET DEFENSE (DIM)
A    FFRATA.K=ATA.K/ATAN
NOTE FFRATA - FRACT FORCE REMAINING ATA (DIM)
A    FFRXA.K=XA.K/XAN
NOTE FFRXA - FRACT FORCE REMAINING XA (DIM)
NOTE ****************************************************************************************
NOTE ****************************       CONTROL STATEMENTS        *************************
NOTE ****************************************************************************************
SPEC DT=0.05/LENGTH=1000/PLTPER=20/PRTPER=200
PRINT ATA,XA,DCMHC
PRINT CHCATA,CHCTF,HRCTF,EXAATA
PRINT CVATAD,KLATAD,CVTFD,KLRTFD
PRINT EXRTFD,EXATAD,IXRTFD,EATAXA
PRINT FFRATA,FFRXA,HRCATA,HRCMC
PLOT  ATA=A,XA=X(0,1200)
PLOT  FFRATA=A,FFRXA=X(0,1)
RUN   RERUN
C     DATF=-0.58114
RUN
QUIT
```

Figure 23. DYNAMO MODEL FOR FLEET DEFENSE MISSION

```
   TIME=       .0     ATA=    1200.       XA=    1792.  DCMHC=  -1.000
 CHCATA=      .00  CHCTF=       .00   HRCTF=    3.212 EXAATA=  7.169A
 CVATAD=    1.581 KLATAD=     3.735   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     2.500 IXRTFD=     2.500 EATAXA=  40.00A
 FFRATA=    1.000  FFRXA=     1.000 HRCATA=     3.212  HRCMC=   3.212
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=     50.0     ATA=     929.       XA=       0.  DCMHC=    .000
 CHCATA=    67.67  CHCTF=     67.67   HRCTF=     .000 EXAATA=  7.169A
 CVATAD=    1.581 KLATAD=     3.735   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     2.500 IXRTFD=     2.500 EATAXA=  40.00A
 FFRATA=     .774  FFRXA=      .000 HRCATA=      .000  HRCMC=    .000
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=    100.0     ATA=     929.       XA=       0.  DCMHC=    .000
 CHCATA=    67.67  CHCTF=     67.67   HRCTF=     .000 EXAATA=  7.169A
 CVATAD=    1.581 KLATAD=     3.735   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     2.500 IXRTFD=     2.500 EATAXA=  40.00A
 FFRATA=     .774  FFRXA=      .000 HRCATA=      .000  HRCMC=    .000
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=    150.0     ATA=     929.       XA=       0.  DCMHC=    .000
 CHCATA=    67.67  CHCTF=     67.67   HRCTF=     .000 EXAATA=  7.169A
 CVATAD=    1.581 KLATAD=     3.735   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     2.500 IXRTFD=     2.500 EATAXA=  40.00A
 FFRATA=     .774  FFRXA=      .000 HRCATA=      .000  HRCMC=    .000
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=    200.0     ATA=     929.       XA=       0.  DCMHC=    .000
 CHCATA=    67.67  CHCTF=     67.67   HRCTF=     .000 EXAATA=  7.169A
 CVATAD=    1.581 KLATAD=     3.735   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     2.500 IXRTFD=     2.500 EATAXA=  40.00A
 FFRATA=     .774  FFRXA=      .000 HRCATA=      .000  HRCMC=    .000
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
             DATF
 PRESENT   -.5811
ORIGINAL       0.
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=       .0     ATA=    1200.       XA=    2834.  DCMHC=  -1.000
 CHCATA=       .0  CHCTF=        .0   HRCTF=    5.079 EXAATA=  7.169A
 CVATAD=    1.000 KLATAD=     2.362   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     1.000 IXRTFD=     1.000 EATAXA=  40.00A
 FFRATA=    1.000  FFRXA=     1.000 HRCATA=     5.079  HRCMC=   5.079
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=     50.0     ATA=     514.       XA=    1215.  DCMHC=    .000
 CHCATA=    171.3  CHCTF=     171.3   HRCTF=    2.177 EXAATA=  7.169A
 CVATAD=    1.000 KLATAD=     2.362   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     1.000 IXRTFD=     1.000 EATAXA=  40.00A
 FFRATA=     .429  FFRXA=      .429 HRCATA=     2.177  HRCMC=   2.177
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=    100.0     ATA=     220.       XA=     521.  DCMHC=    .000
 CHCATA=    244.8  CHCTF=     244.8   HRCTF=     .934 EXAATA=  7.169A
 CVATAD=    1.000 KLATAD=     2.362   CVTFD=    1.000 KLRTFD=   3.735
 EXRTFD=    1.000 EXATAD=     1.000 IXRTFD=     1.000 EATAXA=  40.00A
 FFRATA=     .184  FFRXA=      .184 HRCATA=      .934  HRCMC=    .934
```

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=   150.0    ATA=      94.       XA=     224.  DCMHC=    .000
CHCATA=   276.2  CHCTF=    276.2   HRCTF=     .401 EXAATA=  7.169A
CVATAD=   1.000 KLATAD=    2.362   CVTFD=    1.000 KLRTFD=   3.735
EXRTFD=   1.000 EXATAD=    1.000 IXRTFD=    1.000 EATAXA=  40.00A
FFRATA=    .078  FFRXA=     .079 HRCATA=     .401  HRCMC=    .401
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=   200.0    ATA=      40.       XA=      97.  DCMHC=    .000
CHCATA=   289.7  CHCTF=    289.7   HRCTF=     .175 EXAATA=  7.169A
CVATAD=   1.000 KLATAD=    2.362   CVTFD=    1.000 KLRTFD=   3.735
EXRTFD=   1.000 EXATAD=    1.000 IXRTFD=    1.000 EATAXA=  40.00A
FFRATA=    .033  FFRXA=     .034 HRCATA=     .175  HRCMC=    .175
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 24. COMPUTER OUTPUT FOR FLEET DEFENSE MISSION

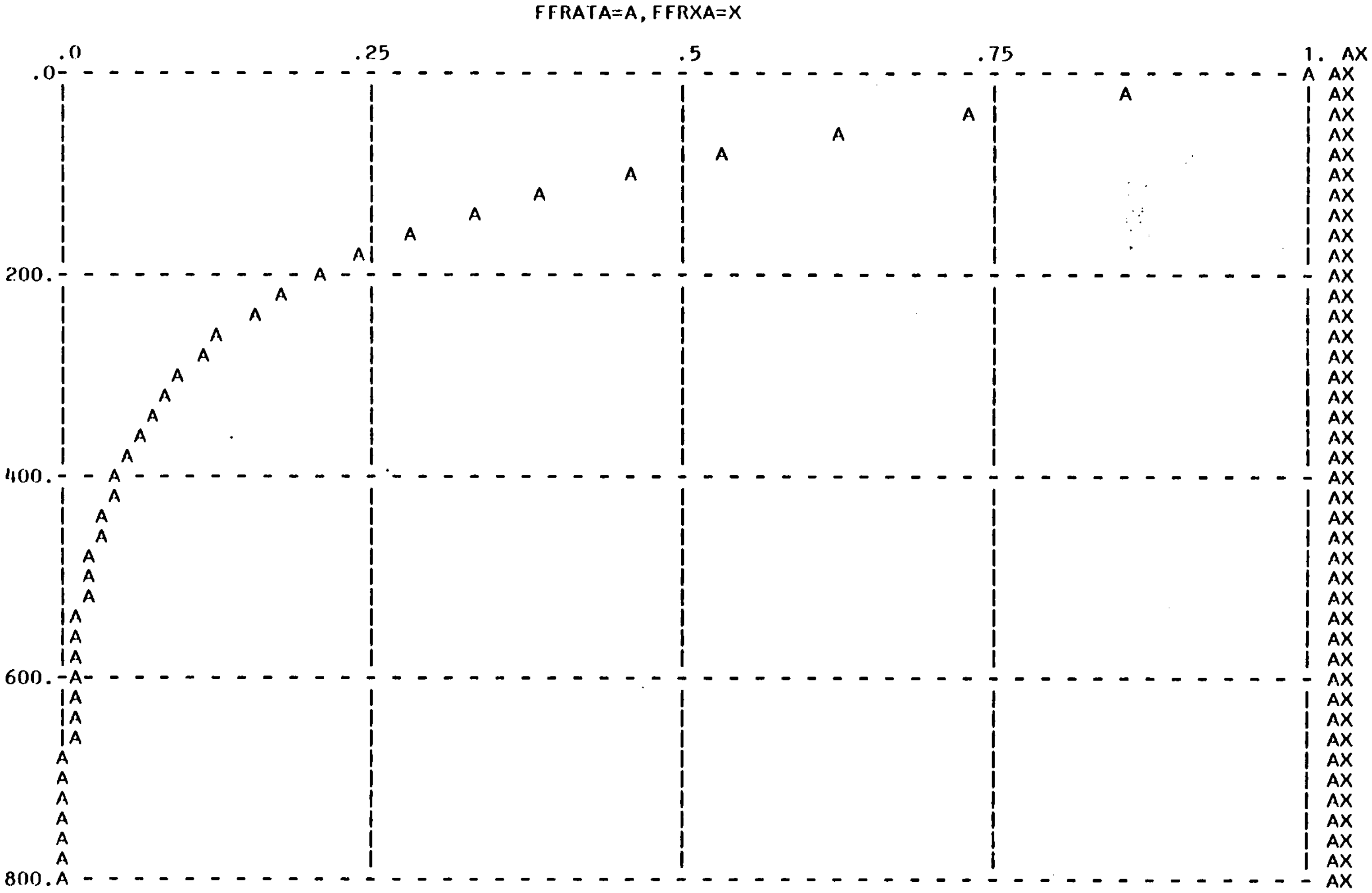

Figure 25. PLOT OF FFRATA AND FFRXA FOR EQUILIBRIUM CASE

3.7 ANALYSIS OF THE FLEET DEFENSE MISSION COMPONENT

This section consists of an analytical solution to calculate level variables at any value of time, the equilibrium solution, and the calculation of the initial value of XA.

The initial value of XAN is that particular value which makes the Effective Exchange Ratio Versus F-14 (EXRTFD) equal to one. Equating EXRTFD to one we get

EXRTFD = KLRTFD/(XAN/TFN) = 1 (3.60)

From the above equation

XAN = TFN*KLRTFD = TFN*(TFN*ETFXA)/(XAN*EXATF) (3.61)

Taking XAN to the left hand side and further simplifying Equation 3.59 we get

XAN = TFN*SQRT(ETFXA/EXATF) (3.62)

The initial value of F-14 (TFN) is given by the equation

TFN = ATAN*(1-DATF)*FSFD/FSTFFD

= 1200*(1-0)*0.2/0.5

= 480 (3.63)

Effectiveness of F-14 against XA is given by

ETFXA = SRTF*FSTFFD*ATF*PKXATF

= 4*0.5*0.5*0.10

= 0.10 (3.64)

Probability Kill of XA by F-14 is calculated from the equation

$PKXATF = 1-e^{(-NAAMTF*PKXAAA)}$

$= 1-e^{(-2*.05268)}$

$= 0.1000$

Effectiveness of XA Against F-14 (EXATF) is given by

$EXATF = (DLPH+ILPH)*PCMHC*(1-PKCMTF)*SRXA*AXA*(1-PKXATF)*NCMPXA$ (3.65)

$= 0.007169$

Substituting values of variables in the right hand side of Equation 3.62 above we have

$XAN = 480*SQRT(0.10/0.007169)$

$= 1793$ (3.66)

SOLUTION FOR LEVEL VARIABLES

In this part of the analysis the general solution for level variables is arrived at. The equations in this analysis are in the form of continuous subscript notation. The basic equations are obtained by referring to the model given in dynamo equation form in Figure 23.

The level equation for ATA can be written as

$dATA_t/dt = -AATACD_t = -B*XA_t$ (3.67)

The level equation for XA can be written as

$dXA_t/dt = -AXAATA_t = -EATAXA_t*ATA_t = -C*ATA_t$ (3.68)

where

$B = (DLPH+ILPH)*PCMHC*(1-PKCMAT)*SRXA*AXA*NCMPXA*(1-PKXAAT)$

$= 4*0.01*(1-0.9502)*4*0.5*2*(1-0.10)$

$= 7.169E-03$ (3.69)

$C = SRATA*FSFD*AATATF*PKXAAT$

$= 4*0.2*0.5*0.10$

$= 0.040$ (3.70)

From equations (3.65) and (3.66) the equations for ATA and XA can be written as follows:

$$ATA_t = ATAN*Cosh(\sqrt{B*C})t - XAN*(\sqrt{B/C})*Sinh(\sqrt{B*C})t \quad (3.71)$$

$$XA_t = XAN*Cosh(\sqrt{B*C})t - ATAN*(\sqrt{C/B})*Sinh(\sqrt{B*C})t \quad (3.72)$$

From the equations the level variables ATA and XA can be found at any time t since all the values to the right hand side are known.

EQUILIBRIUM ANALYSIS

This part of the analysis is for Scenario 2. Scenario 2 represents the equilibrium case, i.e. the attrition for both the level variables is to be balanced. Since the attrition rates are balanced the Fraction Force Remaining of the ATA (FFRATA) is equal to the Fraction Force Remaining of the XA (FFRXA).

Equating FFRATA and FFRXA

$$FFRATA = FFRXA \quad (3.73)$$

Substituting the values for FFRATA and FFRXA we get

$$ATA_t/ATAN = XA_t/XAN \quad (3.74)$$

From equations (3.69), (3.70) and (3.72) we have

$$(ATAN*Cosh(\sqrt{B*C})t - XAN*(\sqrt{B/C})*Sinh(\sqrt{B*C})t)/ATAN$$

$$= (XAN*Cosh(\sqrt{B*C})t - ATAN*(\sqrt{C/B})*Sinh(\sqrt{B*C})t)/XAN \quad (3.75)$$

Simplifying the above equation we have

$$XAN^2*(\sqrt{B/C}) = ATAN^2*(\sqrt{C/B}) \quad (3.76)$$

Substituting the values we have

$$XAN = 768*(1-DATF) = 1208 \quad (3.77)$$

1-DATF = 1.5730

DATF = -0.5730

The Delta Acquisition Cost has to be equal to -0.5730 for the system to go into equilibrium.

3.8 OUTPUTS OF THE FLEET DEFENSE MISSION COMPONENT

The outputs obtained from this model are presented in Table 3.3. The outputs obtained show that the combat value ratio of ATA is 1.58 times more than the combat value ratio of F-14 aircraft, indicating the potential superiority of the ATA. The effective exchange ratio of replacement aircraft much higher than the effectiveness exchange ratio of the baseline aircraft. The increase in exchange ratio over the baseline aircraft. These parameters depend on the input parameters.

Figure 20 shows the relationship between the Fraction Force Remaining for the ATA (FFRATA), the Fraction Force Remaining for the XF (FFRXF), the Combat Value Ratio for ATA (CVRATA) and the Decreased Program Life Cycle Cost (DPLCC). Figure 24 shows the computer output for the fleet defense mission. Figure 25 gives the plot for FFRATA and FFRXA for the equilibrium case.

The Time to Defeat the Threat for Baseline Aircraft (TDTTFS) can be obtained from computer outputs. The time required to make the threat reach zero is the value required. Similarly, it could be calculated for replacement aircraft, i.e. TDATAS.

Table 4. OUTPUTS OF FLEET DEFENSE SUBMODEL

		SCENARIO 1 (DATF=0)	SCENARIO 2 (DATF=-0.58)
1	DCMHC	0 (t=50 days)	0 (t=50 days)
2.	CHCATA	67.67 (t=50 days)	171.30 (t=50 days)
3.	CHCTF	67.67 (t=50 days)	171.30 (t=50 days)
4.	HRCATA	0 (t=50 days)	2.177 (t=50 days)
5.	HRCTF	0 (t=50 days)	2.177 (t=50 days)
6.	EXAATA	7.169E-03	7.169E-03
7.	CVATAD	1.581	1.000
8.	KLATAD	3.375	2.362
9.	CVTFD	1.000	1.000
10.	KLRTFD	3.735	3.735
11.	EXRTFD	1.000	1.000
12.	EXATAD	2.500	1.000
13.	IXRTFD	2.500	1.000

3.9 DESCRIPTION OF THE ATTACK/INTERDICTION MISSION COMPONENT

Attack/Interdiction is the third type of mission to be discussed here. The baseline aircraft for this type of mission is the Intruder A-6 and the replacement aircraft is the ATA. This mission leads the offensive part of the war game. The aircraft in this mission attack the surface threats and also attack aircraft at bases. This mission could be against enemy infrastructure also. Maximum percentage of sorties is assigned to this type of mission, due to its importance. Figure 26 shows the causal diagram for the baseline attack/interdiction aircraft. Figure 27 shows the causal diagram for the replacement attack/interdiction aircraft.

The rate of decrease of ATA is directly proportional to the Attrition Rate of ATA Against Surface Threat (AATART). The initial number of ATA aircraft is the same in all types of missions, only the fraction sorties assigned differ in each case.

Attrition Rate of ATA Against Surface Threat (AATART) is directly proportional to the number of Surface Threat Platforms (RT) and to the Effectiveness of Surface Threat Against ATA (ERTATA). ERTATA is equal to the product of Sortie Rate of ATA (SRATA), Availability of ATA Replacing A-6 (AATAIA), Fraction of Sorties of ATA to Attack Interdiction (FSAI) and one minus Survivability of ATA Against Surface Threat (SATART).

Availability of ATA Replacing A-6 (AATAIA) is directly proportional to Availability of A-6 (AIA) and is inversely proportional to one minus Delta Maintenance Cost (DMIA). Survivability of ATA Against

Surface Threat (SATART) increases with increase in Survivability of A-6 Against Surface Threat (SIART) and also increases with decrease in Delta Survivability of A-6 (DSIA).

The decrease of Surface Threats (RT) is directly proportional to Attrition Rate of Surface Threats Against ATA (ARTATA) which in turn is equal to the product of number of ATA and Effectiveness of ATA Against Surface Threats (EATART). EATART increases with increase in Sortie Rate of ATA (SRATA), Availability of ATA Replacing A-6 (AATAIA), Fraction Sorties to Attack/Interdiction (FSAI), Probability Kill of Surface Threat by ATA (PKRTAT) and Fraction Ordnance Against Surface Threat (FORT).

Probability Kill of Surface Threat by ATA (PKRTAT) increases with increase in Probability Kill of Surface Threat by A-6 (PKRTIA) and also increases with decrease in Delta Lethality Versus Surface Threat (DLR). Delta Lethality Versus Surface Threat (DLR) is the product of Delta Ordnance (DOIA), Effective Number of Air-to-Surface missiles on A-6 (NASMIA) and Probability Kill of Surface Threat by Air-to-Surface Missile (PKRTAS). Probability Kill of Surface Threat by by A-6 (PKRTIA) increases with increase in Effective Number of Air-to-Surface Missiles on A-6 (NASMIA) and also increases with increase in probability Kill of Surface Threat by Air-to-Surface missiles (PKRTAS).

Effectiveness of A-6 for Destroying the Surface Aircraft (EATASA) is equal to the product of Sortie Rate of A-6 (SRIA), Availability of A-6 (AIA), Fraction Sorties of A-6 to Attack/Interdiction (FSIAAI), Probability Kill of Surface XA by A-6

(PKXAIA) and Fracton Ordnance Against Air Defense (FOAD). Fraction of Ordnance to Airfield Destruction (FOAD) is equal to one minus the Fraction Ordnance Against Surface Threats (FORT).

Effectiveness of Surface Threat Versus A-6 in Airfield Interdiction (ERTAAI) can be said to be equal to the product of Effectiveness of Surface Threat Versus A-6 (ERTIA) and Fraction Ordnance to Airfield Destruction (FOAD).

The rate of decrease of XA is directly proportional to Attrition Rate of XA due to Airfield Destruction (ARXAAD). ARXAAD is equal to the product of number of ATA and Effectiveness of ATA for Destroying Surface Aircraft (EATASA). In this model the baseline and replacement aircraft fight against the surface threat and aircraft at bases. Hence XA can be destroyed by ATA but not the vice versa. Figure 28 shows the dynamo model for the attack/interdiction mission.

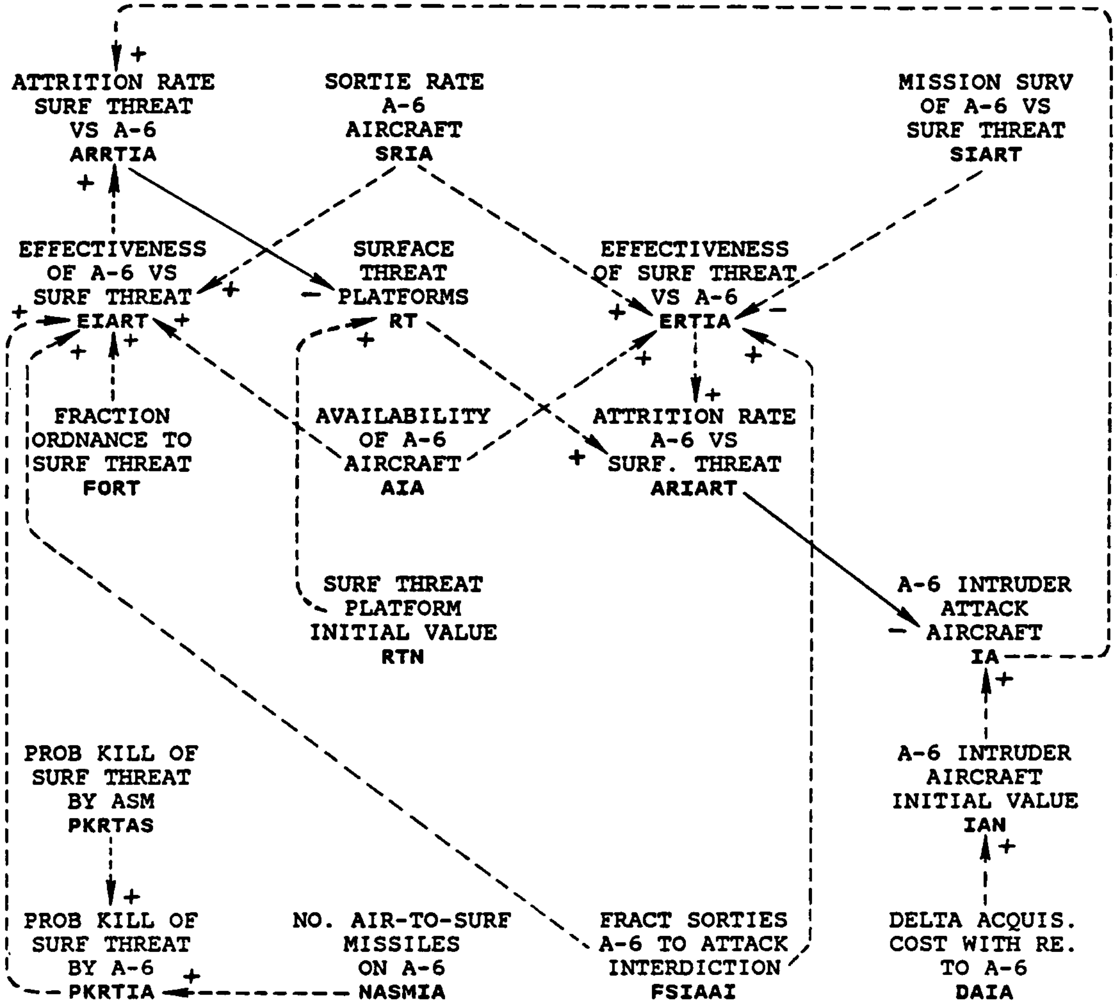

Figure 26. CAUSAL DIAGRAM FOR BASELINE ATTACK/INTERDICTION AIRCRAFT

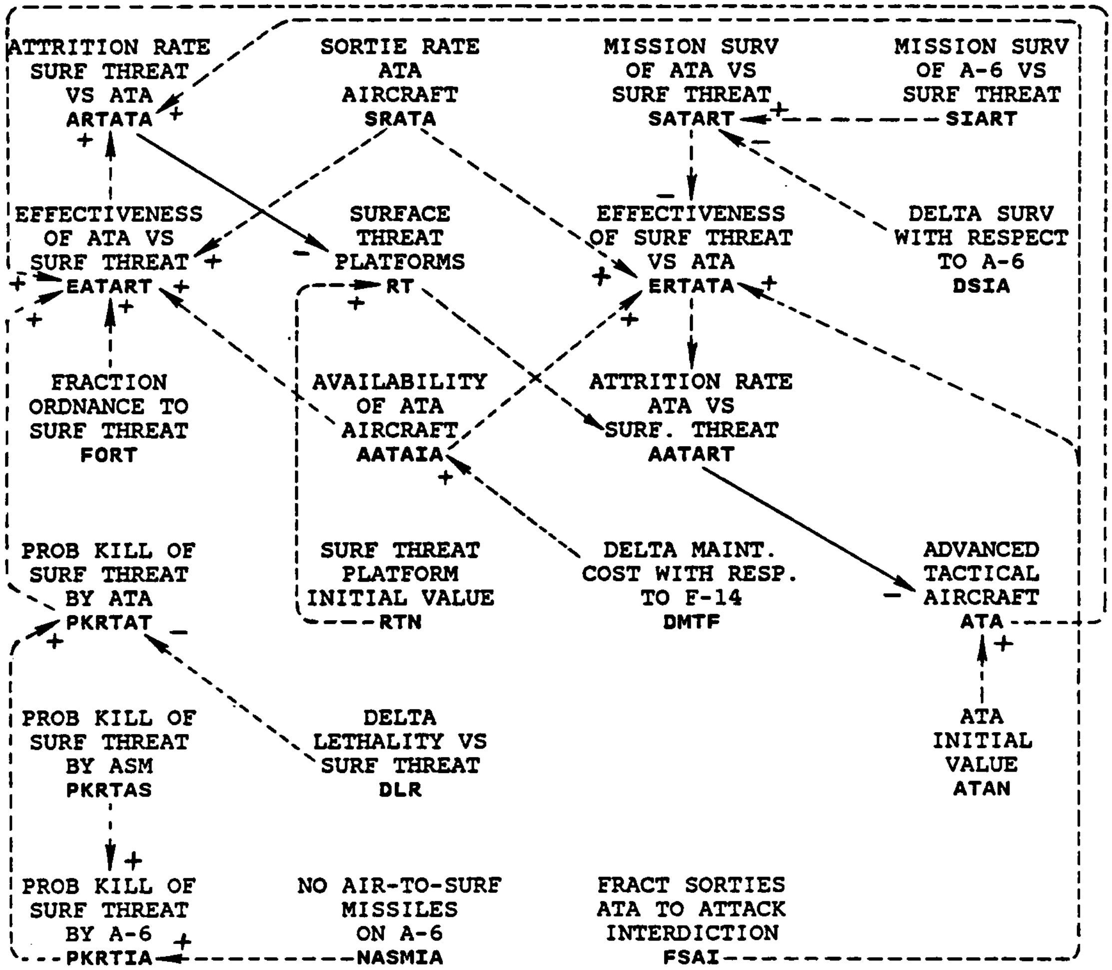

Figure 27. CAUSAL DIAGRAM FOR REPLACEMENT ATTACK/INTERDICTION AIRCRAFT

```
NOTE ********************************************************************
NOTE * SURVIV/LETHALITY TRADEOFF ANALYSIS (ATTACK INTERDICTION MISSION) *
NOTE ********************************************************************
L    ATA.K=ATA.J-(DT)(AATART.JK)
N    ATA=ATAN
NOTE ATA - ADVANCED TACTICAL AIRCRAFT (AIRCRAFT)
C    ATAN=1200
NOTE ATAN - ADVANCED TACTICAL AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    AATART.KL=CLIP(RT.K*ERTATA.K,0,RT.K,0)
NOTE AATART - ATTRITION RATE ATA VS SURFACE THREAT (AIRCRAFT/DAY)
A    ERTATA.K=SRATA*AATAIA*FSAI*(1-SATART)
NOTE ERTATA - EFFECTIVENESS OF SURF THREAT VS ATA (FRACT/DAY)
N    SRATA=SRIA
NOTE SRATA - SORTIE RATE ATA (NUMBER/DAY)
C    SRIA=4
NOTE SRIA - SORTIE RATE A-6 (NUMBER/DAY)
N    AATAIA=AIA/(1-DMIA)
NOTE AATAIA - AVAILABILITY OF ATA REPLACING A-6 (PROB)
C    FSAI=0.6
NOTE FSAI - FRACTION OF SORTIES TO ATTACK/INTERDICTION (DIM)
N    SATART=SIART*(1-DSIA)
NOTE SATART - SURV OF ATA VS SURFACE THREAT (PROB)
L    RT.K=MAX(0,RT.J-(DT)(ARTATA.JK))
N    RT=RTN
NOTE RT - SURFACE THREAT (PLATFORMS)
NOTE RTN=IAN*SQRT(EIART/ERTIA)
N    RTN=2409
NOTE RTN - SURFACE THREAT INITIAL VALUE (PLATFORMS)
N    IAN=ATAN*(1-DAIA)*FSAI/FSIAAI
NOTE IAN - A-6 INTRUDER ATTACK AIRCRAFT INITIAL VALUE (AIRCRAFT)
C    FSIAAI=1.0
NOTE FSIAAI - FRACT SORTIES A-6 TO ATTACK/INTERDICTION (DIM)
N    ERTIA=SRIA*AIA*FSIAAI*(1-SIART)
NOTE ERTIA - EFFECTIVENESS OF SURFACE THREAT VS A-6 (FRACT/DAY)
C    AIA=.5
NOTE AIA - AVAILABILITY OF A-6 (PROB)
N    EIART=SRIA*AIA*FSIAAI*PKRTIA*FORT
NOTE EIART - EFFECTIVENESS OF A-6 VS SURF THREAT (FRACT/DAY)
R    ARTATA.KL=CLIP(ATA.K*EATART.K,0,ATA.K,0)
NOTE ARTATA - ATTRITION RATE OF SURF THREAT VS ATA (PLATFORM/DAY)
A    EATART.K=SRATA*AATAIA*FSAI*PKRTAT*FORT
NOTE EATART - EFFECTIVENESS OF ATA VS SURF THREAT (FRACT/DAY)
C    0=0.000000001
NOTE 0 - ZERO
N    PKRTAT=PKRTIA*(1-DLR)
NOTE PKRTAT - PROB KILL  OF SURF THREAT BY ATA (PROB)
N    DLR=DOIA*NASMIA*PKRTAS
NOTE DLR - DELTA LETHALITY VS SURF THREAT (DIM)
N    PKRTIA=1-EXP(-NASMIA*PKRTAS)
NOTE PKRTIA - PROB KILL OF SURF THREAT BY A-6 (PROB)
C    NASMIA=10
```

```
NOTE NASMIA - EFFECTIVE NUMBER OF AIR-TO-SURFACE MISSILES ON IA (DIM)
C    FORT=0.25
NOTE FORT - FRACT OF ORDNANCE TO SURFACE THREATS (DIM)
N    EIAAD=SRIA*AIA*FSIAAI*PKXAIA*FOAD
NOTE EIAAD - EFFECTIVENESS OF A-6 FOR DESTROYING SURFACE AIRCRAFT
X              (FRACT/DAY)
N    FOAD=1-FORT
NOTE FOAD - FRACT OF ORDNANCE TO AIRFIELD DESTRUCTION (DIM)
N    ERTIAI=SRIA*AIA*FSIAAI*(1-SIART)*FOAD
NOTE ERTIAI-EFFECTIVENESS OF SURF THREAT VS A-6 IN AIRFIELD
X             INTERDICTION (FRACT/DAY)
L    XA.K=MAX(0,XA.J-(DT)(ARXAAD.JK))
N    XA=XAN
NOTE XA - SOVIET ATTACK AIRCRAFT XA(AIRCRAFT)
N    XAN=IAN*SQRT(EIAAD/ERTIAI)
NOTE XAN - SOVIET ATTACK AIRCRAFT INITIAL VALUE (AIRCRAFT)
R    ARXAAD.KL=ATA.K*EATASA.K
NOTE ARXAAD - ATTRITION RATE XA VS AIRFIELD DESTRUCTION (AIRCRAFT/DAY)
A    EATASA.K=SRATA*AATAIA*FSAI*PKXAAI*FOAD
NOTE EATASA - EFFECTIVENESS OF ATA FOR DESTROYING SURFACE
X              AIRCRAFT (FRACT/DAY)
A    ERTAAI.K=SRATA*AATAIA*FSAI*(1-SATART)*FOAD
NOTE ERTAAI-EFFECTIVENESS OF SURF THREAT VS ATA IN AIRFIELD
X              INTERDICTION (1/DAY)
N    PKXAAI=PKXAIA*(1-DLA)
NOTE PKXAAI - PROB KILL OF SURFACE XA BY AIRFIELD INTERDICTION (PROB)
N    DLA=DOIA*NASMIA*PKXAAS
NOTE DLA - DELTA LETHALITY VS SURFACE AIRCRAFT (DIM)
N    PKXAIA=1-EXP(-NASMIA*PKXAAS)
NOTE PKXAIA - PROB KILL OF SURFACE XA BY A-6 (PROB)
N    PKXAAS=0.02
NOTE PKXAAS - PROB KILL OF PARKED XA BY AIR-TO-SURFACE MISSILE (PROB)
C    PKRTAS=0.10
NOTE PKRTAS - PROB KILL OF SURFACE THREAT VS AIR-TO-SURFACE
X              MISSILE (PROB)
NOTE ********************************************************************
NOTE *********** INPUTS FROM SURVIVABILITY/LETHALITY ASSESSMENT ***********
NOTE ********************************************************************
C    DSIA=0
NOTE DSIA - DELTA SURVIVABILITY (SIA-SATA)/SIA (DIM)
C    DAIA=-0.6666
NOTE DAIA - DELTA ACQUISITION COST (ACIA-ACATA)/ACIA (DIM)
C    DMIA=0
NOTE DMIA - DELTA MAINTENANCE COST (MCIA-MCATA)/MCIA (DIM)
C    DOIA=0
NOTE DOIA - DELTA ORDNANCE (OIA-OATA)/OIA (DIM)
C    SIART=.960775
NOTE SIART - SURV OF A-6 VS SURFACE THREAT (PROB)
NOTE ********************************************************************
NOTE ************ MOE FOR ATTACK/INTERDICTION MISSION ********************
NOTE ********************************************************************
```

```
N    CVIATS=(IAN/RTN)*SQRT(EIART/ERTIA)
NOTE CVIATS - COMBAT VALUE RATIO OF A-6 IN SURF THREAT INTERDICTION (DIM)
A    CVATAT.K=(ATAN/RTN)*SQRT(EATART.K/ERTATA.K)
NOTE CVATAT - COMBAT VALUE RATIO OF ATA IN SURF THREAT INTERDICTION (DIM)
A    CVIAAI.K=(IAN/XAN)*SQRT(EIAAD/ERTIAI)
NOTE CVIAAI - COMBAT VALUE RATIO OF A-6 IN AIRFIELD INTERDICTION (DIM)
A    CVATAI.K=(ATAN/XAN)*SQRT(EATASA.K/ERTAAI.K)
NOTE CVATAI - COMBAT VALUE RATIO OF ATA IN AIRFIELD INTERDICTION (DIM)
A    KLRIAT.K=(IAN*EIART)/(RTN*ERTIA)
NOTE KLRIAT - KILL-LOSS A-6 IN SURF THREAT INTERDICTION (RT/A-6)
A    KLRIAI.K=(IAN*EIAAD)/(RTN*ERTIAI)
NOTE KLRIAI - KILL-LOSS A-6 IN AIRFIELD INTERDICTION (XA/A-6)
A    KLATAT.K=(ATAN*EATART.K)/(RTN*ERTATA.K)
NOTE KLATAT - KILL-LOSS ATA IN SURF THREAT INTERDICTION (RT/ATA)
A    KLATAI.K=(ATAN*EATASA.K)/(RTN*ERTAAI.K)
NOTE KLATAI - KILL-LOSS ATA IN AIRFIELD INTERDICTION (XA/ATA)
A    EXATAI.K=KLATAI.K/(RTN/ATAN)
NOTE EXATAI - EFFECTIVE EXCHANGE RATIO FOR ATA IN AIRFIELD
X             INTERDICTION (DIM)
A    EXRIAI.K=KLRIAI.K/(RTN/IAN)
NOTE EXATAT - EFFECTIVE EXCHANGE RATIO FOR A-6 IN AIRFIELD
X             INTERDICTION (DIM)
A    EXATAT.K=KLATAT.K/(RTN/ATAN)
NOTE EXATAI - EFFECTIVE EXCHANGE RATIO FOR ATA IN SURF THREAT
X             INTERDICTION (DIM)
A    EXRIAT.K=KLRIAT.K/(RTN/IAN)
NOTE EXRIAT - EFFECTIVE EXCHANGE RATIO FOR A-6 IN SURF THREAT
X             INTERDICTION (DIM)
A    IXRIAT.K=EXATAT.K/EXRIAT.K
NOTE IXRIAT - INC IN EXCHANGE RATIO FOR A-6 IN SURF  THREAT
X             INTERDICTION (DIM)
A    IXRIAI.K=EXATAI.K/EXRIAI.K
NOTE IXRIAI - INC IN EXCH RATIO FOR A-6 IN AIRFIELD INTERDICTION (DIM)
A    FFRATA.K=ATA.K/ATAN
NOTE FFRATA - FRACT FORCE REMAINING ATA (DIM)
A    FFRRT.K=RT.K/RTN
NOTE FFRRT - FRACT FORCE REMAINING SURFACE THREATS (DIM)
A    FFRXA.K=XA.K/RTN
NOTE FFRXA - FRACT FORCE REMAINING XA (DIM)
S    ITDPAL.K=(OTATAL.K-OTPIAL.K)/OTPIAL.K
NOTE ITDPAL - INC TARGETS DESTROYED PER AIRCRAFT LOST (DIM)
A    OTATAL.K=MAX(0,COTATA.K/CLATA.K)
NOTE OTATAL - ORDNANCE TO TARGET PER ATA LOST (LBS/AIRCRAFT)
A    OTPIAL.K=MAX(0,COTIA.K/CLIA.K)
NOTE OTPIAL - ORDNANCE TO TARGET PER A-6 LOST (LBS/AIRCRAFT)
L    COTATA.K=COTATA.J+(DT)(OATADR.JK)
N    COTATA=0
NOTE COTATA - CUM ORDNANCE TO TARGET BY ATA (LBS)
L    COTIA.K=COTIA.J+(DT)(OIADR.JK)
N    COTIA=0
NOTE COTIA - CUM ORDNANCE TO TARGET BY A-6 (LBS)
```

```
R    OATADR.KL=SRATA*AATAIA*FSAI*FOAD*OATA
NOTE OATADR - ORDNANCE A-6 DELIVERY RATE (LBS/DAY)
R    OIADR.KL=SRIA*AIA*FSAI*FOAD*OIA
NOTE OIADR - ORDNANCE A-6 DELIVERY RATE (LBS/DAY)
L    CLATA.K=CLATA.J+(DT)(AATART.JK)
N    CLATA=0
NOTE CLATA - CUM LOSSES ATA (AIRCRAFT)
L    CLIA.K=CLIA.J+(DT)(ARIART.JK)
N    CLIA=0
NOTE CLIA - CUM LOSSES A-6 (AIRCRAFT)
R    ARIART.KL=CLIP(RT.K*ERTIA,0,RT.K,0)
NOTE ARIART - ATTRITION RATE A-6 VS SURF THREAT (AIRCRAFT/DAY)
C    OIA=15000
NOTE OIA - ORDNANCE CARRIED BY A-6 (LBS/DAY)
N    OATA=OIA*(1-DOIA)
NOTE OATA - ORDNANCE CARRIED BY ATA (LBS)
NOTE *************************************************************************
NOTE ******************* CONTROL STATEMENTS *********************************
NOTE *************************************************************************
SPEC  DT=0.05/LENGTH=50/PLTPER=1/PRTPER=10
PRINT ATA,RT,XA
PRINT RTN,XAN,CVIATS,IXRIAI
PRINT CVATAT,CVIAAI,CVATAI,KLRIAT
PRINT KLRIAI,KLATAT,KLATAI,EXRIAI
PRINT EXATAI,EXRIAT,EXATAT,IXRIAT
PRINT OATA,FFRATA,FFRRT,ITDPAL
PRINT OTATAL,OTPIAL,ARTATA,COTATA
PRINT COTIA,OATADR,OIADR,CLATA
PRINT CLIA,FFRATA,FFRRT,FFRXA
PLOT  FFRATA=A,FFRRT=X(0,1)
RUN   RERUN
C     DAIA=-0.6656
RUN
QUIT
```

Figure 28. DYNAMO MODEL FOR ATTACK/INTERDICTION MISSION

```
  TIME=     .00    ATA=   1200.     RT=   1445.     XA=   1548.
   RTN=   1445.    XAN=   1548.    IAN=   720.0 CVIATS=   1.000
CVATAT=   1.667 CVIAAI=   1.000 CVATAI=   1.667 KLRIAT=   2.007
KLRIAI=   2.302 KLATAT=   3.345 KLATAI=   3.837 EXRIAI=   1.147
EXATAI=   3.186 EXRIAT=   1.000 EXATAT=   2.778 IXRIAT=   2.778
  OATA=  15.00T FFRATA=   1.000   FFRRT=   1.000 ITDPAL=   .0000
OTATAL=      0. OTPIAL=      0. ARTATA=   227.6 COTATA=      .0
 COTIA=      .0 OATADR=  13.50T  OIADR=  13.50T  CLATA=      .0
  CLIA=      .0 FFRATA=   1.000   FFRRT=   1.000   FFRXA=   1.071
IXRIAI=   2.778
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=   10.00    ATA=    958.     RT=      0.     XA=      0.
   RTN=   1445.    XAN=   1548.    IAN=   720.0 CVIATS=   1.000
CVATAT=   1.667 CVIAAI=   1.000 CVATAI=   1.667 KLRIAT=   2.007
KLRIAI=   2.302 KLATAT=   3.345 KLATAI=   3.837 EXRIAI=   1.147
EXATAI=   3.186 EXRIAT=   1.000 EXATAT=   2.778 IXRIAT=   2.778
  OATA=  15.00T FFRATA=    .799   FFRRT=    .000 ITDPAL=   .6666
OTATAL=    559. OTPIAL=    335. ARTATA=   181.7 COTATA=  135.0T
 COTIA=  135.0T OATADR=  13.50T  OIADR=  13.50T  CLATA=   241.6
  CLIA=   402.6 FFRATA=    .799   FFRRT=    .000   FFRXA=    .000
IXRIAI=   2.778
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=   20.00    ATA=    958.     RT=      0.     XA=      0.
   RTN=   1445.    XAN=   1548.    IAN=   720.0 CVIATS=   1.000
CVATAT=   1.667 CVIAAI=   1.000 CVATAI=   1.667 KLRIAT=   2.007
KLRIAI=   2.302 KLATAT=   3.345 KLATAI=   3.837 EXRIAI=   1.147
EXATAI=   3.186 EXRIAT=   1.000 EXATAT=   2.778 IXRIAT=   2.778
  OATA=  15.00T FFRATA=    .799   FFRRT=    .000 ITDPAL=   .6666
OTATAL=   1118. OTPIAL=    671. ARTATA=   181.7 COTATA=  270.0T
 COTIA=  270.0T OATADR=  13.50T  OIADR=  13.50T  CLATA=   241.6
  CLIA=   402.6 FFRATA=    .799   FFRRT=    .000   FFRXA=    .000
IXRIAI=   2.778
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=   30.00    ATA=    958.     RT=      0.     XA=      0.
   RTN=   1445.    XAN=   1548.    IAN=   720.0 CVIATS=   1.000
CVATAT=   1.667 CVIAAI=   1.000 CVATAI=   1.667 KLRIAT=   2.007
KLRIAI=   2.302 KLATAT=   3.345 KLATAI=   3.837 EXRIAI=   1.147
EXATAI=   3.186 EXRIAT=   1.000 EXATAT=   2.778 IXRIAT=   2.778
  OATA=  15.00T FFRATA=    .799   FFRRT=    .000 ITDPAL=   .6666
OTATAL=   1676. OTPIAL=   1006. ARTATA=   181.7 COTATA=  405.0T
 COTIA=  405.0T OATADR=  13.50T  OIADR=  13.50T  CLATA=   241.6
  CLIA=   402.6 FFRATA=    .799   FFRRT=    .000   FFRXA=    .000
IXRIAI=   2.778
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=   39.99    ATA=    958.     RT=      0.     XA=      0.
   RTN=   1445.    XAN=   1548.    IAN=   720.0 CVIATS=   1.000
CVATAT=   1.667 CVIAAI=   1.000 CVATAI=   1.667 KLRIAT=   2.007
KLRIAI=   2.302 KLATAT=   3.345 KLATAI=   3.837 EXRIAI=   1.147
EXATAI=   3.186 EXRIAT=   1.000 EXATAT=   2.778 IXRIAT=   2.778
  OATA=  15.00T FFRATA=    .799   FFRRT=    .000 ITDPAL=   .6666
OTATAL=   2235. OTPIAL=   1341. ARTATA=   181.7 COTATA=  540.0T
```

```
  COTIA=  540.0T OATADR=  13.50T  OIADR=  13.50T  CLATA=   241.6
   CLIA=  402.6 FFRATA=    .799  FFRRT=    .000  FFRXA=    .000
 IXRIAI=  2.778
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=  49.99     ATA=    958.     RT=      0.     XA=      0.
   RTN=  1445.     XAN=   1548.    IAN=   720.0 CVIATS=   1.000
CVATAT=  1.667 CVIAAI=   1.000 CVATAI=   1.667 KLRIAT=   2.007
KLRIAI=  2.302 KLATAT=   3.345 KLATAI=   3.837 EXRIAI=   1.147
EXATAI=  3.186 EXRIAT=   1.000 EXATAT=   2.778 IXRIAT=   2.778
  OATA= 15.00T FFRATA=    .799  FFRRT=    .000 ITDPAL=   .6666
OTATAL=  2794.  OTPIAL=  1676. ARTATA=   181.7 COTATA=  674.9T
 COTIA= 674.9T OATADR=  13.50T  OIADR=  13.50T  CLATA=   241.6
  CLIA=  402.6 FFRATA=    .799  FFRRT=    .000  FFRXA=    .000
IXRIAI=  2.778
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
          DAIA
 PRESENT -.6666
ORIGINAL    0.
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=    .00     ATA=   1200.     RT=   2409.     XA=   2580.
   RTN=  2409.     XAN=   2580.    IAN=   1200. CVIATS=   1.000
CVATAT=  1.000 CVIAAI=   1.000 CVATAI=   1.000 KLRIAT=   2.007
KLRIAI=  2.302 KLATAT=   2.007 KLATAI=   2.302 EXRIAI=   1.147
EXATAI=  1.147 EXRIAT=   1.000 EXATAT=   1.000 IXRIAT=   1.000
  OATA= 15.00T FFRATA=   1.000  FFRRT=   1.000 ITDPAL=   .0000
OTATAL=     .0 OTPIAL=      .0 ARTATA=   227.6 COTATA=      .0
 COTIA=     .0 OATADR=  13.50T  OIADR=  13.50T  CLATA=      0.
  CLIA=     0. FFRATA=   1.000  FFRRT=   1.000  FFRXA=   1.071
IXRIAI=  1.000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=  10.00     ATA=    466.     RT=    934.     XA=   1311.
   RTN=  2409.     XAN=   2580.    IAN=   1200. CVIATS=   1.000
CVATAT=  1.000 CVIAAI=   1.000 CVATAI=   1.000 KLRIAT=   2.007
KLRIAI=  2.302 KLATAT=   2.007 KLATAI=   2.302 EXRIAI=   1.147
EXATAI=  1.147 EXRIAT=   1.000 EXATAT=   1.000 IXRIAT=   1.000
  OATA= 15.00T FFRATA=    .388  FFRRT=    .388 ITDPAL=   .6667
OTATAL=  183.8 OTPIAL=   110.3 ARTATA=    88.3 COTATA=  135.0T
 COTIA= 135.0T OATADR=  13.50T  OIADR=  13.50T  CLATA=    734.
  CLIA=  1224. FFRATA=    .388  FFRRT=    .388  FFRXA=    .544
IXRIAI=  1.000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=  20.00     ATA=    181.     RT=    362.     XA=    819.
   RTN=  2409.     XAN=   2580.    IAN=   1200. CVIATS=   1.000
CVATAT=  1.000 CVIAAI=   1.000 CVATAI=   1.000 KLRIAT=   2.007
KLRIAI=  2.302 KLATAT=   2.007 KLATAI=   2.302 EXRIAI=   1.147
EXATAI=  1.147 EXRIAT=   1.000 EXATAT=   1.000 IXRIAT=   1.000
  OATA= 15.00T FFRATA=    .151  FFRRT=    .150 ITDPAL=   .6667
OTATAL=  264.9 OTPIAL=   158.9 ARTATA=    34.3 COTATA=  270.0T
 COTIA= 270.0T OATADR=  13.50T  OIADR=  13.50T  CLATA=   1019.
  CLIA=  1699. FFRATA=    .151  FFRRT=    .150  FFRXA=    .340
IXRIAI=  1.000
```

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   30.00     ATA=      70.      RT=     140.      XA=    628.
    RTN=   2409.     XAN=    2580.     IAN=    1200.  CVIATS=   1.000
 CVATAT=   1.000  CVIAAI=    1.000  CVATAI=    1.000  KLRIAT=   2.007
 KLRIAI=   2.302  KLATAT=    2.007  KLATAI=    2.302  EXRIAI=   1.147
 EXATAI=   1.147  EXRIAT=    1.000  EXATAT=    1.000  IXRIAT=   1.000
   OATA=  15.00T  FFRATA=     .059   FFRRT=     .058  ITDPAL=   .6667
 OTATAL=   358.5  OTPIAL=    215.1  ARTATA=     13.3  COTATA=  405.0T
  COTIA=  405.0T  OATADR=   13.50T   OIADR=   13.50T   CLATA=   1130.
   CLIA=   1883.  FFRATA=     .059   FFRRT=     .058   FFRXA=    .261
 IXRIAI=   1.000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   39.99     ATA=      28.      RT=      53.      XA=    553.
    RTN=   2409.     XAN=    2580.     IAN=    1200.  CVIATS=   1.000
 CVATAT=   1.000  CVIAAI=    1.000  CVATAI=    1.000  KLRIAT=   2.007
 KLRIAI=   2.302  KLATAT=    2.007  KLATAI=    2.302  EXRIAI=   1.147
 EXATAI=   1.147  EXRIAT=    1.000  EXATAT=    1.000  IXRIAT=   1.000
   OATA=  15.00T  FFRATA=     .023   FFRRT=     .022  ITDPAL=   .6667
 OTATAL=   460.8  OTPIAL=    276.5  ARTATA=      5.3  COTATA=  540.0T
  COTIA=  540.0T  OATADR=   13.50T   OIADR=   13.50T   CLATA=   1172.
   CLIA=   1953.  FFRATA=     .023   FFRRT=     .022   FFRXA=    .230
 IXRIAI=   1.000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   49.99     ATA=      13.      RT=      17.      XA=    522.
    RTN=   2409.     XAN=    2580.     IAN=    1200.  CVIATS=   1.000
 CVATAT=   1.000  CVIAAI=    1.000  CVATAI=    1.000  KLRIAT=   2.007
 KLRIAI=   2.302  KLATAT=    2.007  KLATAI=    2.302  EXRIAI=   1.147
 EXATAI=   1.147  EXRIAT=    1.000  EXATAT=    1.000  IXRIAT=   1.000
   OATA=  15.00T  FFRATA=     .011   FFRRT=     .007  ITDPAL=   .6667
 OTATAL=   568.6  OTPIAL=    341.1  ARTATA=      2.4  COTATA=  674.9T
  COTIA=  674.9T  OATADR=   13.50T   OIADR=   13.50T   CLATA=   1187.
   CLIA=   1978.  FFRATA=     .011   FFRRT=     .007   FFRXA=    .217
 IXRIAI=   1.000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 29. COMPUTER OUTPUT FOR ATTACK/INTERDICTION MISSION

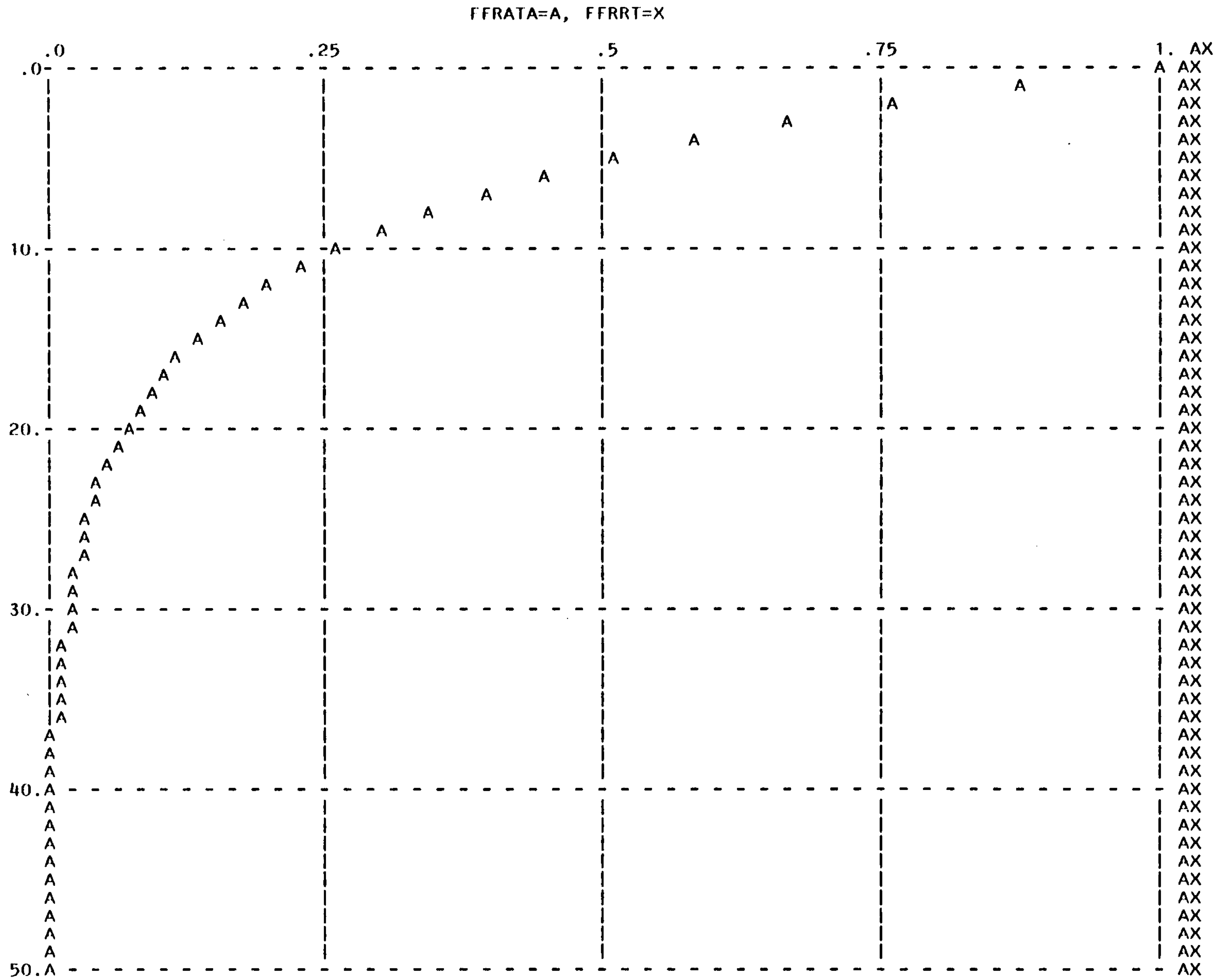

Figure 30. PLOT OF FFRATA AND FFRRT FOR EQUILIBRIUM CASE

3.10 ANALYSIS OF THE ATTACK/INTERDICTION MISSION COMPONENT

In this section the analytical solution for the component's level variables is arrived at. Also, the initial value of RTN is calculated and the value of DAIA is calculated for the equilibrium condition.

Surface Threat Normal (RTN) is taken as that value which makes Effective Exchange Ratio for A-6 in Airfield Interdiction (EXRIAI) equal to one.

Equating the equation for EXRIAI to one we get

$$EXRIAI = KLRIAI_t/(RTN/IAN) = 1 \tag{3.78}$$

$$KLRIAI = RTN/IAN \tag{3.79}$$

$$\begin{aligned} RTN &= IAN*KLRIAI \\ &= IAN*(IAN/RTN)*(EIART/ERTIA) \\ &= IAN*SQRT(EIART/ERTIA) \end{aligned} \tag{3.80}$$

where

$$\begin{aligned} EIART &= SRIA*AIA*FSIAAI*PKRTIA*FORT \\ &= 4*0.5*1.0*0.6321*0.25 \\ &= 0.3161 \end{aligned} \tag{3.81}$$

$$\begin{aligned} ERTIA &= SRIA*AIA*FSIAAI*(1-SIART) \\ &= 4*0.5*1.0*(1-0.9608) \\ &= 0.0784 \end{aligned} \tag{3.82}$$

IAN = ATAN*(1-DAIA)*FSAI/FSIAAI

= 1200*(1-0)*0.6/1.0

=720 (3.83)

RTN = IAN*SQRT(EIART/ERTIA)

= 720*SQRT(0.3161/0.0784)

= 1446 (3.84)

The equations in this analysis are in the continuous subscript notation. The level equation for ATA can be written as

$dATA_t/dt = -AATART_t = -ERTATA_t*RTt = -B*RT_t$ (3.85)

The level equation for Surface Threat (RT) can be written as

$dRT_t/dt = -ARTATA_t = -EATART_t*ATA_t = -C*ATA_t$ (3.86)

(Although ERTATA and EATART have subscript t, they do not vary with time in this situation).

where

$B = ERTATA_t$ = SRATA*AATAIA*FSAI*(1-SATART)

= 4*0.5*0.6*(1-0.9608)

= 0.0471 (3.87)

$C = EATART_t$ = SRATA*AATAIA*FSAI*PKRTAT*FORT

= 4*0.5*0.6*0.6321*0.25

= 0.18963 (3.88)

From equations 3.83 and 3.84 the equations ATA_t and RT_t can be written as:

$ATA_t = ATAN*Cosh(\sqrt{B*C})t - RTN*(\sqrt{B/C})*Sinh(\sqrt{B*C})t$ (3.89)

$RT_t = RTN*Cosh(\sqrt{B*C})t - ATAN*(\sqrt{C/B})*Sinh(\sqrt{B*C})t$ (3.90)

Since all the parameters on the right hand side of the above two equations can be calculated, we can calculate ATA and RT at any time

t. The model is not in equilibrium for the case when all the deltas are equal to zero. Equilibrium can be achieved at a particular value of Delta Acquisition Cost (DATF). The combat value ratio of ATA is higher for the run with deltas equal to zero. The delta acquisition cost has to be negative in order for the model to go into equilibrium. For the model to go into equilibrium the following condition should be satisfied

$$\mathrm{FFRATA} = \mathrm{FFRRT} \tag{3.91}$$

$$\mathrm{ATA}_t/\mathrm{ATAN} = \mathrm{RT}_t/\mathrm{RTN} \tag{3.92}$$

$$\mathrm{ATA}_t/\mathrm{RT}_t = \mathrm{ATAN}/\mathrm{RTN} \tag{3.93}$$

$$\mathrm{ATAN}\ \mathrm{Cosh}(\sqrt{C})t - \mathrm{RTN}*(\sqrt{B/C})*\mathrm{Sinh}(BC)t/\mathrm{ATAN}$$

$$= \mathrm{RTN}\ \mathrm{Cosh}(\sqrt{BC})t - \mathrm{ATAN}*(\sqrt{C/B})*\mathrm{Sinh}(BC)t/\mathrm{RTN} \tag{3.94}$$

Simplifying the above equation we get

$$\mathrm{RTN}^2*(B/C) = \mathrm{ATAN}^2*(C/B) \tag{3.95}$$

$$\mathrm{RTN} = \mathrm{ATAN}*(C/B)$$

$$= 1200*(0.18963/0.0471)$$

$$= 2409 \tag{3.96}$$

Thus equilibrium is achieved if RTN is equal to 2409. This can be done in two ways: (1) redefine RTN as an initial value equal to the constant 2409 (2) by varying Delta Acquisition (DAIA). From 3.86 and 3.87 we have

$$\mathrm{RTN} = \mathrm{ATAN}*(C/B)$$

$$\mathrm{IAN}*\mathrm{SQRT}(\mathrm{EIART}/\mathrm{ERTIA}) = \mathrm{ATAN}*(C/B)$$

$$\mathrm{ATAN}*(1-\mathrm{DAIA})*\mathrm{FSAI}/\mathrm{FSIAAI}*\mathrm{SQRT}(\mathrm{EIART}/\mathrm{ERTIA}) = \mathrm{ATAN}*(0.1896/0.04707)$$

$$(1-\mathrm{DAIA}) = (0.1896/0.04707)*1*\mathrm{SQRT}(0.07845/0.3161)/(0.6)$$

$$1-\mathrm{DAIA} = 1.6664$$

DAIA = -0.6664 (3.97)

Equilibrium is achieved by changing DAIA from 0 to -0.6664

3.11 OUTPUTS OF THE ATTACK/INTERDICTION MISSION COMPONENTS

The variables that can be obtained as outputs from this model are presented In Table 3.2, along with the outputs obtained from the other two models. In this model the outputs are of two kinds. One concerned with the surface threat suppression and the other with the airfield bombardment. In Table 3.2 the two outputs are given in seperate columns.

In Table 3.5 a comparison of outputs has been made. Scenario 1 is compared to the Scenario 2. In Scenario 1 the delta acquisition cost is equal to equal to zero. In Scenario 2 the delta acquisition cost is a constant that achieves balanced attrition, which is equal to -0.666 Figure 29 shows the computer output for the attack/interdiction mission. Figure 30 shows the plot for FFRATA and FFRRT for the equilibrium case.

Table 5. OUTPUTS OF ATTACK/INTERDICTION SUBMODEL

	SCENARIO 1	SCENARIO 2		SCENARIO 1	SCENARIO 2
CVIATS	1.000	1.000	CVIAAI	1.000	1.000
CVATAT	1.667	1.000	CVATAI	1.667	1.000
KLRIAT	2.007	2.007	KLRIAI	2.302	2.302
KLATAT	3.345	2.007	KLATAI	3.837	2.302
EXRIAT	1.000	1.000	EXRIAI	1.147	1.147
EXATAT	2.778	1.000	EXATAI	3.186	1.147
IXRIAT	2.778	1.000	IXRIAI	2.778	1.000

3.12 SUMMARY

The models presented in this chapter are simple. These models can be expanded to include more variables which may affect the model directly or indirectly. Analytical solution will not be possible in such complex models. Our aim is to go from a simple system to a more complex system. Although the model is simple, the inputs and outputs are very realistic. The inputs are obtained from survivability/lethality assessment analyses -- a standard military procedure.

All through the models the baseline and replacement aircraft are compared to one another. For all the models the replacement aircraft is the Advanced Tactical Aircraft (ATA). For the air superiority and fleet defense missions the baseline aircraft is Tomcat Fighter F-14

(TF) and for the attack/interdiction mission the baseline aircraft is Intruder Attack IA (A-6).

In each of the models two scenarios are presented. Scenario 1 is the case where the acquisition cost for both the baseline and the replacement are the same. In Scenario 2, a value of acquisition cost is calculated so that the effective exchange ratio of ATA against its threat is equal to one. In the models the initial number of the counterpart of the ATA aircraft increases with increase in cost of acquisition of ATA over baseline aircraft. The initial number of baseline aircraft remain constant in both the cases. Thereby the models take cost into account. When the cost of ATA is the same as that of baseline aircraft, the aircraft ATA is very effective. In Scenario 2 the cost of ATA relative to baseline aircraft is increased, thus raising the initial number of baseline aircraft and thereby making the effective exchange ratio of baseline aircraft against enemy aircraft in Scenario 1 equal to the effective exchange ratio of replacement aircraft against enemy aircraft in Scenario 2.

The other deltas remain constant in both the models. Deltas can be varied according design parameters and the corresponding outputs obtained. Thus even these simple models are powerful ards to understanding.

4.0 CHAPTER 4 - DEVELOPMENT OF COMPOSITE MODEL

4.1 INTRODUCTION

System dynamics is a methodology specifically conceived for analyzing complex, dynamic systems to show how the system components and policies affect the behavior of the whole system. In this chapter the combined model is formulated, analyzed and discussed. It is a combination of the three models discussed in Chapter 3- the air superiority model, the fleet defense model and the attack interdiction model.

The composite model will definitely behave differently from it's components. For example the system will not reach equilibrium for the same deltas we used in achieving equilibrium for individual models in chapter 3. There are obviously more variables when compared to individual models. Although the order of the feedback system is the same as the individual models, the feedback is more complex. In the composite model the XA aircraft is not affected by the Attrition Rate of XA Against Airfield Destruction (ARXAAD). This has been done so as to reduce complexity and to provide an analytical solution. However this could be taken into account by just replacing Z=0 with Z=1.

In Section 4.2 the air superiority and fleet defense composite modules are discussed for the baseline case, and in Section 4.3 for the replacement case. Section 4.4 involves the discussion of the multimission tradeoff model. Section 4.5 is the analyses for the composite model and Section 4.6 involves the discussion of the outputs obtained.

Unlike the individual models, the equilibrium in the composite model is achieved by varying the initial values of the threats. For any initial value of ATA in this model there is one combination of initial values of surface threats (RTN), Attack Aircraft (XAN) and Fighter Aircraft (XFN) that will achieve balanced attrition.

4.2 AIR SUPERIORITY-FLEET DEFENSE BASELINE COMPOSITE MODULE

This section is a first step in the direction of moving towards a complex system. The air superiority and the fleet defense missions are combined in this section.

Figure 31 shows the causal diagram for air superiority-fleet defense baseline composite module. The baseline aircraft is Tomcat Fighter F-14 fighting the Soviet attack aircraft, XA and Soviet fighter aircraft XF.

The two models are basically tied up by the F-14 aircraft. The module wouldn't have had any change from the individual models if the baseline aircraft for air superiority and fleet defense were different. The module will behave differently from the individual models because of the tying together of the individual models.

Figure 33 gives the Dynamo Model for Air Superiority-Fleet Defense Composite module. As the equation for Initial Value of F-14 (TFN) shows, TFN depends on the replacement aircraft, delta acquisition and fraction sorties.

Advanced Tactical Aircraft is the replacement aircraft for both the missions. A computer run has been presented in Figure 34. Combat value ratios of F-14 in fleet defense is 2, which indicates the superiority over it's threat. Combat value ratio of F-14 in air superiority is equal to 0.67 for the run shown, which indicates inferiority of F-14 over XF in fleet defense mission. A kill loss ratio for F-14 in air superiority mission is 1.36. The kill loss ratio for F-14 in fleet defense mission is 7.5.

4.3 AIR SUPERIORITY-FLEET DEFENSE REPLACEMENT COMPOSITE MODULE

Figure 32 shows the causal diagram for the air superiority-fleet defense replacement composite module. The basic difference in Figure 31 and Figure 32 is that the Tomcat Fighter F-14 is replaced by Advanced Tactical Aircraft. Delta survivability and delta maintenance cost come into picture in this diagram.

Figure 34 shows the output for the equilibrium run. Equilibrium is achieved when there is balanced attrition. For any initial value of ATA (ATAN) there is a combination of XAN and XFN which would put the system into equilibrium. XAN and XFN have been achieved for ATAN equal to 1200. The inputs to this model are the same as that in the individual models described in Chapter 3. The outputs are also the same as in individual models Figure 35 shows the plot of Fraction Force Remaining XF(FFRXF) and Fraction Force Remaining XA(FFRXA). For balanced attrition FFRATA, FFRXF and FFRXA are the same as shown in the plot.

The combat value ratio of ATA in Fleet Defense (CVATAD) is equal to 3.1777 which is higher than that of the corresponding baseline aircraft. Kill Loss Ratio of ATA in Fleet Defense (KLATAD) for the run is equal to 7.504 (the corresponding value for baseline aircraft is 7.504). Effective Exchange Ratio for ATA in Fleet Defense is 10.09 and the corresponding value for the baseline aircraft is 4.037. The Increase in Exchange Ratio over Fleet Defense is equal to 2.5.

Similarly, in the air superiority mission the Combat Value Ratio for ATA is 1.053 (the corresponding value for baseline aircraft is 0.67), Kill Loss Ratio for ATA is 1.36 (same as that for baseline aircraft), Increase in Exchange Ratio is 2.50. All the measures of effectiveness show the potential superiority of replacement aircraft when compared to the baseline aircraft.

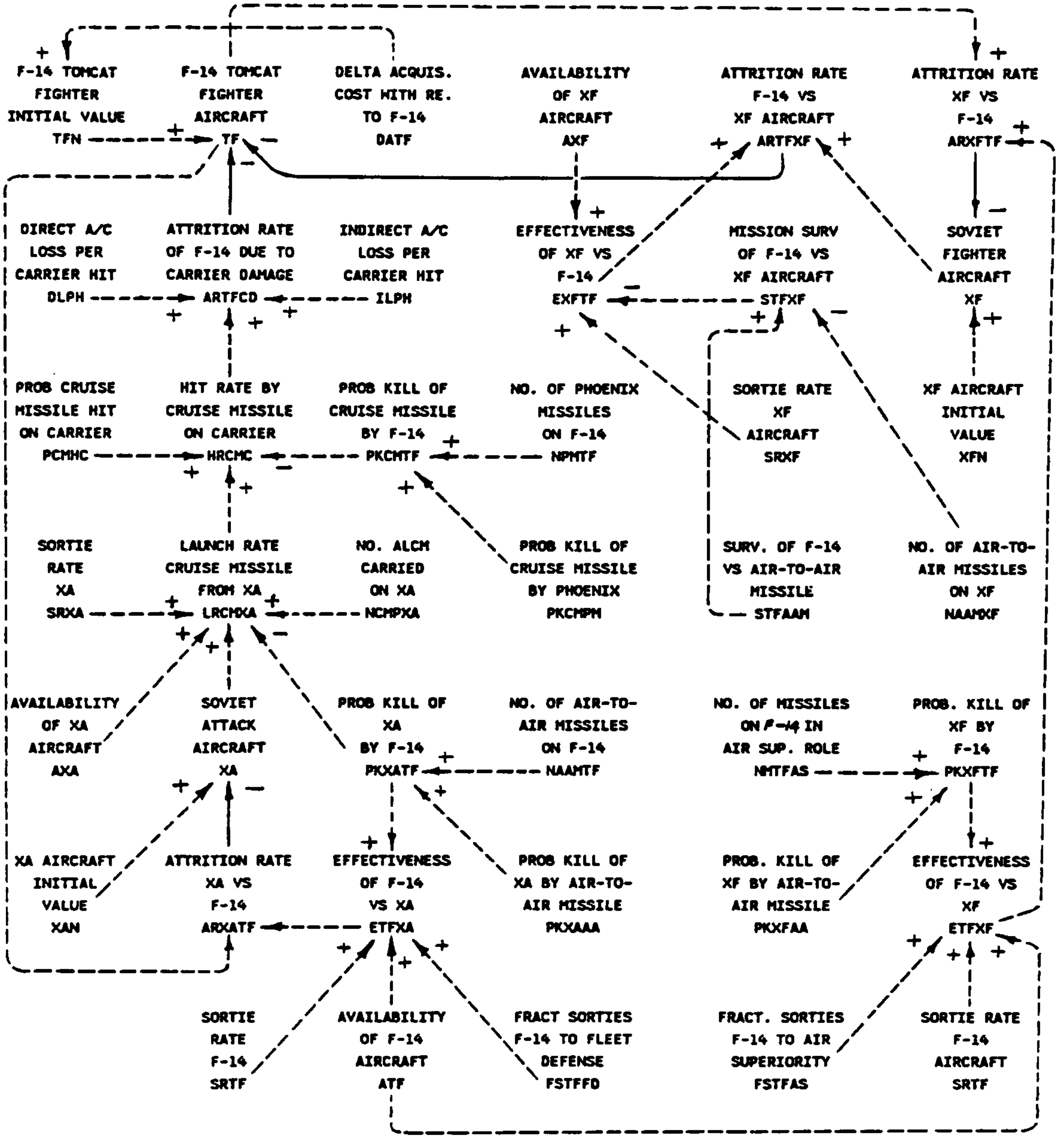

Figure 31. CAUSAL DIAGRAM FOR BASELINE CASE

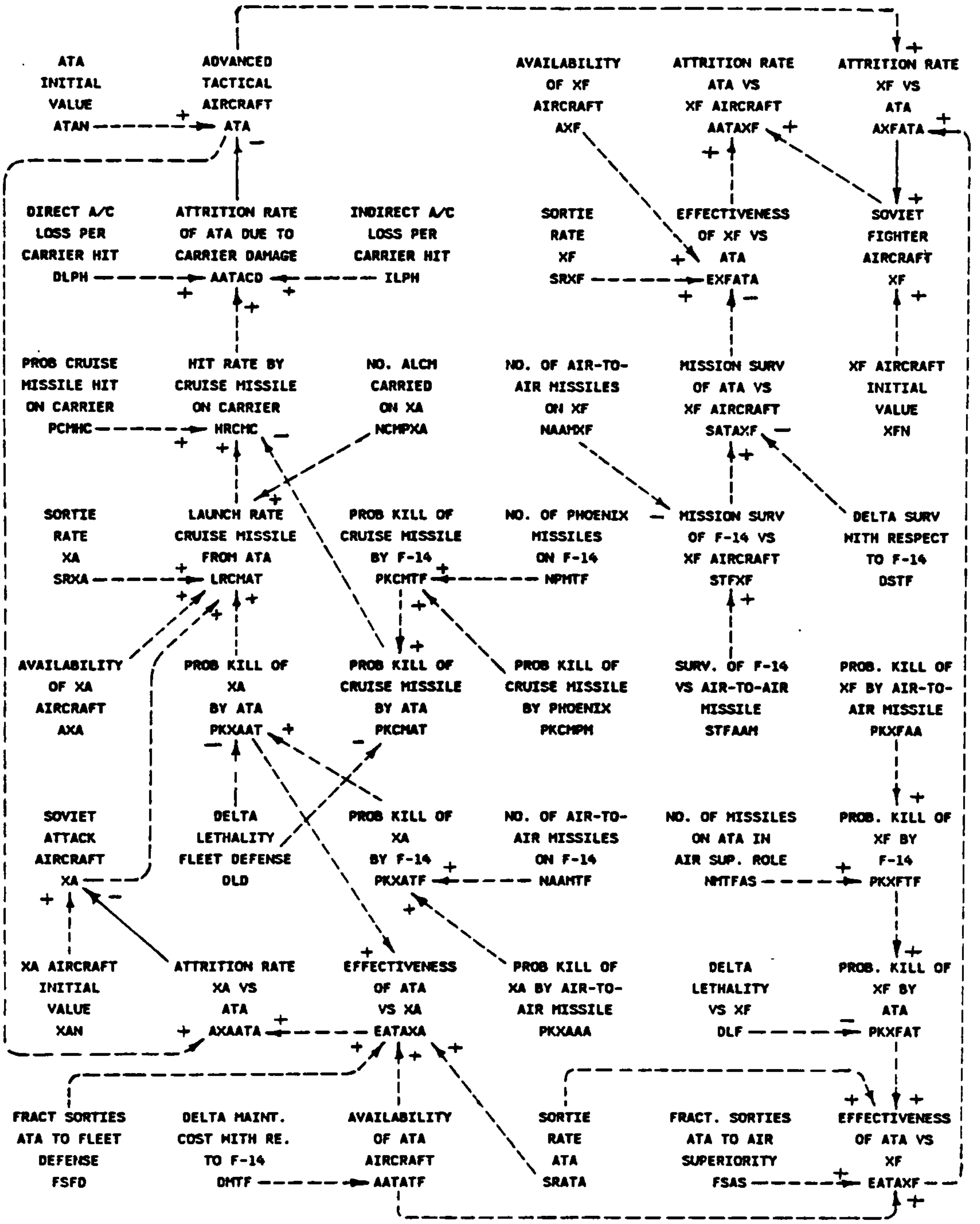

Figure 32. CAUSAL DIAGRAM FOR REPLACEMENT CASE

4.3.1 ANALYSIS OF AIR SUPERIORITY-FLEET DEFENSE COMPOSITE MODULE

In this analysis, reference has been made to Figure 33. The equations are in the continuous subscript notation. As in any other analysis in Chapter 3 the analysis here is made to get the equations for level variables and to get initial values of XA and XF so as to send the system into equilibrium.

The level equation for ATA can be written as

$$dATA_t/dt = -(B_A * XA_t + B_F * XF_t) \qquad (4.1)$$

where,

$$B_A = (DLPH+ILPH)*PCMHC*(1-PKCMAT)*(SRXA)*AXA*NCMPXA*(1-PKXAAT)$$

$$= (3+1)*0.01*(1-0.9502)*4*0.5*2*(1-0.10)$$

$$= 7.1693E-03 \qquad (4.2)$$

$$PKCMAT = PKCMTF*(1-DLM)$$

$$= (1-e^{-NPMTF*PKCMPM})*(1-DOTF*NPMTF*PKCMPM)$$

$$= (1-e^{-6*0.5})*(1-0)$$

$$= 0.9502 \qquad (4.3)$$

$$PKXAAT = PKXATF*(1-DLA)$$

$$= (1-e^{-NAAMTF*PKXAAA})*(1-DLA)$$

$$= (1-e^{-2*0.5268})*(1-0)$$

$$= 0.10 \qquad (4.4)$$

$$B_F = SRXF*AXF*(1-SATAXF)$$

$$= 4*0.5*(1-0.9802)$$

$$= 0.0396 \qquad (4.5)$$

The level equation for XA can be written as

$$dXA_t/dt = -(AXAATA_t)$$

$$= -C_A*ATA_t \tag{4.6}$$

where,

$$C_A = SRATA*FSFD*AATATF*PKXAAT$$

$$= 4*0.2*0.5*0.10$$

$$= 0.04 \tag{4.7}$$

The level equation for XF can be written as

$$dXF_t/dt = -(AXFATA_t)$$

$$= -C_F*ATA_t \tag{4.8}$$

$$C_F = SRATA*FSAS*AATATF*PKXFAT$$

$$= 4*0.2*0.5*0.16473$$

$$= 0.06589 \tag{4.9}$$

Differentiating 4.1 with respect to t and substituting 4.6 and 4.8 in it we get

$$d^2ATA_t/dt^2 = (B_A*C_A+B_F*C_F)*ATA_t \tag{4.10}$$

$$d^2ATA_t/dt^2-(B_A*C_A+B_F*C_F)*ATA_t = 0 \tag{4.11}$$

The above equation can be represented in a more standard form of representation of second order positive feedback equation as

$$d^2ATA_t/dt^2-\omega^2*ATA_t = 0 \tag{4.12}$$

where,

$$\omega = SQRT(B_A*C_A+B_F*C_F) \tag{4.13}$$

Solution for the level variable ATA can be written as

$$ATA_t = C_1e^{\omega t}+C_2e^{-\omega t} \tag{4.14}$$

At time t=0, 4.14 becomes

$$ATA_0 = C_1+C_2 \tag{4.15}$$

Differentiating 4.14 with respect to t we have

$$dATA_t/dt = \omega*(C_1*e^{\omega t}-C_2e^{-\omega t}) \tag{4.16}$$

Again differentiating 4.16 with respect to t we have

$$d^2ATA_t/dt^2 = (C_1e^{\omega t}+C_2e^{-\omega t})*\omega^2 \quad (4.17)$$

Comparing 4.1 and 4.16 at time t=0, we have

$$-(B_A*XA_0+B_F*XF_0) = \omega\ (C_1-C_2) \quad (4.18)$$

Rearranging the above equation we have

$$C_1-C_2 = -(B_A*XA_0+B_F*XF_0)/\omega \quad (4.19)$$

Adding 4.15 and 4.19 and dividing both sides by 2 we get

$$C_1 = (ATA_0-(B_A*XA_0+B_F*XF_0)/\omega)/2 \quad (4.20)$$

Subtracting 4.21 from 4.17 and dividing both sides by 2 we get

$$C_2 = (ATA_0+(B_A*XA_0+B_F*XF_0)/\omega)/2 \quad (4.21)$$

From equation 4.14 we can see that for ATA to tend to zero as time tends to infinity, C_1 should be equal to zero.

Therefore,

$$ATA_0 = C_2 \text{ (from 4.15)} \quad (4.22)$$

Substituting 4.24 in 4.23 and rearranging we get

$$ATA_0 = (B_A*XA_0+B_F*XF_0)/\omega \quad (4.23)$$

The following condition should be satisfied for balanced attrition (equilibrium)

$$\frac{dXA_t/dt}{XA_t} = \frac{dXF_t/dt}{XF_t} = \frac{dATA_t/dt}{ATA_t} \quad (4.24)$$

At time t=0, equation 4.24 becomes

$$\frac{dXA_0/dt}{XA_0} = \frac{dXF_0/dt}{XF_0} = \frac{dATA_0/dt}{ATA_0} \quad (4.25)$$

Substituting 4.8, 4.9 and 4.10 in 4.27 we get

$$\frac{C_A*ATA_0}{XA_0} = \frac{-C_F*ATA_0}{XF_0} = \frac{dATA_0/dt}{ATA_0} \quad (4.26)$$

Since C_1=0, from 4.15 and 4.23 we get

$$ATA_0 = C_2 = (B_A{*}XA_0+B_F{*}XF_0)/\omega \tag{4.27}$$

Also from 4.18 and 4.28 we get

$$\begin{aligned} dATA_0/dt &= -C_2\omega \\ &= -(B_A{*}XA_0+B_F{*}XF_0) \end{aligned} \tag{4.28}$$

From 4.26, 4.28 and 4.23 we have

$$\frac{C_A{*}ATA_0}{XA_0} = \frac{-C_F{*}ATA_0}{XF_0} = \frac{-(B_A{*}XA_0+B_F{*}XF_0+B_R{*}RT_0)}{ATA_0} = \omega \tag{4.29}$$

From equation 4.31 we can write the following relationships

$$XA_0 = C_A{*}ATA_0/\omega \tag{4.30}$$

$$XF_0 = C_F{*}ATA_0/\omega \tag{4.31}$$

where,

$$ATA_0 = 1200$$

$$\begin{aligned} \omega &= SQRT(B_A{*}C_A+B_F{*}C_F+B_R{*}C_R) \\ &= 0.10873 \end{aligned} \tag{4.32}$$

Values of C_A and C_F are obtained from 4.7 and 4.9.

Substituting the above values in 4.30 and 4.31 we get

$$XA_0 = 892 \tag{4.33}$$

$$XF_0 = 1469 \tag{4.34}$$

These values when used achieve equilibrium as shown in Figure 35. The plot is for FFRATA, FFRXA, and FFRXF. All four variables are equal at all times. We will see in the analysis of multimission model that, the analysis here is just a special case.

```
* ATA CONCEPT EVALUATION
NOTE *******************************************************************
NOTE SURVIVABILITY/LETHALITY TRADEOFF ANALYSIS (AIR SUPERIORITY MISSION)
NOTE *******************************************************************
L    ATA.K=MAX(0,ATA.J-(DT)(AATACD.JK+AATAXF.JK))
N    ATA=ATAN
NOTE ATA - ADVANCED TACTICAL AIRCRAFT (AIRCRAFT)
N    ATAN=NAC*ATAPC*ARC
NOTE ATAN - ADVANCED TACTICAL AIRCRAFT INITIAL VALUE (AIRCRAFT)
C    NAC=15
NOTE NAC - NO OF AIRCRAFT CARRIERS (SHIPS)
C    ATAPC=60
NOTE ATAPC - NO OF ATA PER CARRIER (AIRCRAFT/SHIP)
C    ARC=1.333
NOTE ARC - ATTRITION REPLACEMENT CONSTANT (DIM)
R    AATAXF.KL=CLIP(XF.K*EXFATA.K,0,XF.K,0)
NOTE AATAXF - ATTRITION RATE ATA VS XF (AIRCRAFT/DAY)
A    EXFATA.K=SRXF*AXF*(1-SATAXF)
NOTE EXFATA - EFFECTIVENESS OF XF VS ATA (FRACT/DAY)
C    SRXF=4
NOTE SRXF - SORTIE RATE XF (NUMBER/DAY)
C    AXF=0.5
NOTE AXF - AVAILABILITY OF XF (PROB)
L    XF.K=MAX(0,XF.J-(DT)(AXFATA.JK))
N    XF=XFN
NOTE XF - SOVIET FIGHTER AIRCRAFT XF (AIRCRAFT)
N    XFN=1469
NOTE XFN - SOVIET FIGHTER AIRCRAFT XF INITIAL VALUE (AIRCRAFT)
N    EXFTF=SRXF*AXF*(1-STFXF)
NOTE EXFTF - EFFECTIVENESS OF XF VS F-14 (FRACT/DAY)
N    ETFXF=SRTF*FSTFAS*ATF*PKXFTF
NOTE ETFXF - EFFECTIVENESS OF F-14 VS XF (FRACT/DAY)
C    SRTF=4
NOTE SRTF - SORTIE RATE F-14 (NUMBER/DAY)
C    ATF=0.5
NOTE ATF - AVAILABILITY OF F-14 (PROB)
C    FSAS=0.2
NOTE FSAS - FRACTION OF SORTIES TO AIR SUPERIORITY (DIM)
N    PKXFTF=1-EXP(-NMTFAS*PKXFAA)
NOTE PKXFTF - PROB KILL XF BY F-14 (PROB)
C    NMTFAS=6
NOTE NMTFAS - NO OF AIR-TO-AIR MISSILES ON TF IN
X             AIR SUPERIORITY ROLE (DIM)
R    AXFATA.KL=CLIP(ATA.K*EATAXF.K,0,ATA.K,0)
NOTE AXFATA - ATTRITION RATE XF VS ATA (AIRCRAFT/DAY)
A    EATAXF.K=SRATA*FSAS*AATATF*PKXFAT
NOTE EATAXF - EFFECTIVENESS OF ATA VS XF (FRACT/DAY)
N    SRATA=SRTF
NOTE SRATA - SORTIE RATE OF ATA (NUMBER/DAY)
N    AATATF=ATF/(1-DMTF)
NOTE AATATF - AVAILABILITY OF ATA REPLACING F-14 (PROB)
```

```
N    PKXFAT=PKXFTF*(1-DLF)
NOTE PKXFAT - PROB KILL OF XF BY ATA (PROB)
N    DLF=DOTF*NMTFAS*PKXFAA
NOTE DLF - DELTA LETHALITY VS XF AIRCRAFT (DIM)
N    SATAXF=STFXF*(1-DSTF)
NOTE SATAXF - SURV OF ATA VS XF (PROB)
N    STFXF=EXP(-NAAMXF*(1-STFAAM))
NOTE STFXF - SURV OF F-14 VS XF (PROB)
C    NAAMXF=4
NOTE NAAMXF - NO OF AIR-TO-AIR MISSILES ON XF (DIM)
N    TFN=ATAN*(1-DATF)*(FSAS+FSAD)/(FSTFAS+FSTFFD)
NOTE TFN - F-14 TOMCAT FIGHTER INITIAL VALUE (AIRCRAFT)
C    FSTFAS=0.5
NOTE FSTFAS - FRACT SORTIES F-14 TO AIR SUPERIORITY ROLE (DIM)
C    PKXFAA=0.03
NOTE PKXFAA-PROB KILL OF XF AIRCRAFT BY AIR-TO-AIR MISSILE ON F-14 (PROB)
NOTE *******************************************************************
NOTE ********** INPUTS FROM  SURVIVABILITY/LETHALITY ASSESSMENT **********
NOTE *******************************************************************
C    DOTF=0
NOTE DOTF - DELTA ORDNANCE (OTF-OATA)/OTF (DIM)
C    DSTF=0
NOTE DSTF - DELTA SURVIVABILITY (STF-SATA)/STF (DIM)
C    DMTF=0
NOTE DMTF - DELTA MAINTENANCE COST (MCTF-MCATA)/MCTF (DIM)
C    DATF=0
NOTE DATF - DELTA ACQUISITION COST (ACTF-ACATA)/ACTF (DIM)
C    STFAAM=0.9950
NOTE STFAAM - SURV OF F-14 VS SOVIET AIR-TO-AIR MISSILE (PROB)
NOTE *******************************************************************
NOTE **************** MOE FOR AIR SUPERIORITY MISSION ******************
NOTE *******************************************************************
A    CVATAS.K=(ATAN/XFN)*SQRT(EATAXF.K/EXFATA.K)
NOTE CVATAS - COMBAT VALUE RATIO OF ATA IN AIR SUPERIORITY ROLE (DIM)
A    CVTFS.K=(TFN/XFN)*SQRT(ETFXF/EXFTF)
NOTE CVTFS - COMBAT VALUE RATIO OF TF IN AIR SUPERIORITY ROLE (DIM)
A    KLATAS.K=(ATAN*EATAXF.K)/(XFN*EXFATA.K)
NOTE KLATAS - KILL LOSS RATIO OF ATA IN AIR SUPERIORITY MISSION (XF/ATA)
A    KLRTFS.K=(TFN*ETFXF)/(XFN*EXFTF)
NOTE KLRTFS - KILL LOSS RATIO OF TF IN
X             AIR SUPERIORITY MISSION (XF/TF) (DIM)
A    EXATAS.K=KLATAS.K/(XFN/ATAN)
NOTE EXATAS - EFFECTIVE EXCHANGE RATIO FOR ATA
X             OVER XF IN AIR SUPERIORITY (DIM)
A    IXRTFS.K=EXATAS.K/EXRTFS.K
NOTE IXRTFS - INC IN EXCHANGE RATIO FOR ATA
X             OVER F-14 IN AIR SUPERIORITY (DIM)
A    EXRTFS.K=KLRTFS.K/(XFN/TFN)
NOTE EXRTFS - EFFECTIVE EXCHANGE RATIO FOR F-14
X             OVER XF IN AIR SUPERIORITY (DIM)
A    FFRATA.K=ATA.K/ATAN
```

```
NOTE FFRATA - FRACT FORCE REMAINING ATA (DIM)
A    FFRXF.K=XF.K/XFN
NOTE FFRXF - FRACT FORCE REMAINING XF (DIM)
R    AATACD.KL=CLIP(HRCMC.K*(DLPH+ILPH),0,XA.K,0)
NOTE AATACD - ATTRITION RATE ATA DUE TO CARRIER DAMAGE (ATA/DAY)
C    DLPH=3
NOTE DLPH - DIRECT LOSS PER HIT (ATA/CM)
C    ILPH=1
NOTE ILPH - INDIRECT LOSS PER HIT (ATA/CM)
A    HRCMC.K=LRCMXA.K*(1-PKCMAT)*PCMHC
NOTE HRCMC - HIT RATE OF CRUISE MISSILES ON CARRIER (CM/DAY)
C    PCMHC=0.01
NOTE PCMHC - PROB OF CRUISE MISSILE HITTING CARRIER (PROB)
N    PKCMAT=PKCMTF*(1-DLM)
NOTE PKCMAT - PROB KILL OF XA CRUISE MISSILE BY ATA (PROB)
N    PKCMTF=1-EXP(-NPMTF*PKCMPM)
NOTE PKCMTF - PROB KILL OF XA CRUISE MISSILE BY F-14 (PROB)
N    DLM=DOTF*NPMTF*PKCMPM
NOTE DLM - DELTA LETHALITY VS CRUISE MISSILE (DIM)
C    NPMTF=6
NOTE NPMTF - NO OF PHOENIX MISSILES ON F-14 FLEET DEFENSE MISSION (DIM)
A    LRCMXA.K=SRXA*AXA*XA.K*NCMPXA*(1-PKXAAT)
NOTE LRCMXA - LAUNCH RATE CRUISE MISSILES FROM XA'S (CM/DAY)
C    NCMPXA=2
NOTE NCMPXA - NO CRUISE MISSILES PER XA (CM/XA)
C    SRXA=4
NOTE SRXA - SORTIE RATE XA (NUMBER/DAY)
C    AXA=0.5
NOTE AXA - AVAILABILITY OF XA (PROB)
N    PKXAAT=PKXATF*(1-DLA)
NOTE PKXAAT - PROB KILL OF XA BY ATA (PROB)
N    PKXATF=1-EXP(-NAAMTF*PKXAAA)
NOTE PKXATF - PROB KILL OF XA BY F-14 (PROB)
C    NAAMTF=2
NOTE NAAMTF - NO OF AIR-TO-AIR MISSILES ON F-14 (DIM)
N    DLA=DOTF*NAAMTF*PKXAAA
NOTE DLA - DELTA LETHALITY VS XA AIRCRAFT (DIM)
L    XA.K=MAX(0,XA.J-(DT)(AXAATA.JK))
N    XA=XAN
NOTE XA - SOVIET ATTACK AIRCRAFT XA (AIRCRAFT)
N    XAN=892
NOTE XAN - SOVIET ATTACK AIRCRAFT XA INITIAL VALUE (AIRCRAFT)
N    ETFXA=SRTF*FSTFFD*ATF*PKXATF
NOTE ETFXA - EFFECTIVENESS OF F-14 VS XA (FRACT/DAY)
N    EXATF=(DLPH+ILPH)*PCMHC*(1-PKCMTF)*SRXA*AXA*(1-PKXATF)*NCMPXA
NOTE EXATF - EFFECTIVENESS OF XA VS F-14 (FRACT/DAY)
C    FSTFFD=0.5
NOTE FSTFFD - FRACT SORTIES F-14 TO FLEET DEFENSE (DIM)
R    AXAATA.KL=CLIP(ATA.K*EATAXA.K,0,ATA.K,0)
NOTE AXAATA - ATTRITION RATE XA VS ATA (XA/DAY)
A    EATAXA.K=SRATA*FSFD*AATATF*PKXAAT
```

```
NOTE EATAXA - EFFECTIVENESS OF ATA VS XA (FRACT/DAY)
C    FSFD=0.2
NOTE FSFD - FRACTION OF SORTIES TO FLEET DEFENSE (DIM)
C    PKCMPM=0.5
NOTE PKCMPM - PROB KILL OF XA CRUISE MISSILE BY
X             AIM-54 C PHOENIX MISSILE (PROB)
C    PKXAAA=0.05268
NOTE PKXAAA - PROB KILL OF XA AIRCRAFT BY AIR-TO-AIR
X             MISSILE ON F-14 (PROB)
NOTE ******************************************************************
NOTE **************** MOE FOR FLEET DEFENSE MISSION *******************
NOTE ******************************************************************
A    DCMHC.K=(CHCATA.K-CHCTF.K)/CHCTF.K
NOTE DCMHC - DECREASE IN CRUISE MISSILE HITS ON CARRIER NORMALIZED (DIM)
L    CHCATA.K=CHCATA.J+(DT)(HRCATA.JK)
N    CHCATA=0
NOTE CHCATA - CUM HITS ON CARRIER VS ATA (HITS)
L    CHCTF.K=CHCTF.J+(DT)(HRCTF.JK)
N    CHCTF=0
NOTE CHCTF - CUM HITS ON CARRIER VS F-14 (HITS)
C    0=0.00000001
NOTE 0 - ZERO
R    HRCATA.KL=HRCMC.K
NOTE HRCATA - HIT RATE ON CARRIER DEFENDED BY ATA (HITS/DAY)
R    HRCTF.KL=(1-PKCMTF)*PCMHC*SRXA*AXA*XA.K*NCMPXA*(1-PKXATF)
NOTE HRCTF - HIT RATE ON CARRIER DEFENDED BY TF (HITS/DAY)
A    EXAATA.K=(DLPH+ILPH)*PCMHC*(1-PKCMAT)*SRXA*AXA*(1-PKXAAT)*NCMPXA
NOTE EXAATA - EFFECTIVENESS OF XA VS ATA (FRACT/DAY)
A    CVATAD.K=(ATAN/XAN)*SQRT(EATAXA.K/EXAATA.K)
NOTE CVATAD - COMBAT VALUE RATIO OF ATA IN FLEET DEFENSE (DIM)
A    KLATAD.K=(ATAN*EATAXA.K)/(XAN*EXAATA.K)
NOTE KLATAD - KILL LOSS RATIO ATA IN FLEET DEFENSE MISSION (DIM)
A    CVTFD.K=(TFN/XAN)*SQRT(ETFXA/EXATF)
NOTE CVTFD - COMBAT VALUE RATIO OF TF IN FLEET DEFENSE (DIM)
A    KLRTFD.K=(TFN*ETFXA)/(XAN*EXATF)
NOTE KLRTFD - KILL LOSS RATIO TF IN FLEET DEFENSE MISSION (XA/TF) (DIM)
A    EXRTFD.K=KLRTFD.K/(XAN/TFN)
NOTE EXRTFD - EFFECTIVE EXCHANGE RATIO FOR F-14 OVER
X             XA IN FLEET DEFENSE (XA/TF)
A    EXATAD.K=KLATAD.K/(XAN/ATAN)
NOTE EXATAD - EFFECTIVE EXCH RATIO FOR ATA OVER
X             F-14 IN FLEET DEFENSE MISSION (XA/ATA)
A    IXRTFD.K=EXATAD.K/EXRTFD.K
NOTE IXRTFD - INC IN EXCHANGE RATIO FOR ATA OVER F-14 IN
X             FLEET DEFENSE (DIM)
A    FFRXA.K=XA.K/XAN
NOTE FFRXA - FRACT FORCE REMAINING XA (DIM)
NOTE ******************************************************************
NOTE *********************    CONTROL STATEMENTS     ******************
NOTE ******************************************************************
SPEC DT=0.05/LENGTH=100/PLTPER=2/PRTPER=20
```

```
PRINT ATA,XA,DCMHC
PRINT CHCATA,CHCTF,HRCTF,EXAATA
PRINT CVATAD,KLATAD,CVTFD,KLRTFD
PRINT EXRTFD,EXATAD,IXRTFD,EATAXA
PRINT FFRATA,FFRXA,HRCATA,HRCMC
PRINT XF,XAN,EXATAS,EXRTFS
PRINT XFN,CVATAS,CVTFS,KLATAS
PRINT KLRTFS,IXRTFS,FFRATA,FFRXF
PLOT  FFRATA=A,FFRXA=X,FFRXF=F(0,1)
RUN
QUIT
```

Figure 33. AIR SUPERIORITY-FLEET DEFENSE COMPOSITE MODULE

```
  TIME=      .00    ATA=   1200.      XA=    892.0  DCMHC=   -1.000
CHCATA=      .00  CHCTF=     .00   HRCTF=    1.599 EXAATA=   7.169A
CVATAD=    3.177 KLATAD=   7.504   CVTFD=    2.009 KLRTFD=    7.504
EXRTFD=    4.037 EXATAD=   10.09  IXRTFD=    2.500 EATAXA=   40.00A
FFRATA=    1.000  FFRXA=   1.000  HRCATA=    1.599  HRCMC=    1.599
    XF=    1469.    TFN=   479.9     XAN=    892.0 EXATAS=    1.110
EXRTFS=    .4439
   XFN=    1469. CVATAS=   1.053   CVTFS=    .6662 KLATAS=    1.359
KLRTFS=    1.359 IXRTFS=   2.500  FFRATA=    1.000  FFRXF=    1.000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=    25.00    ATA=    312.      XA=    232.2  DCMHC=     .000
CHCATA=    21.99  CHCTF=   21.99   HRCTF=     .416 EXAATA=   7.169A
CVATAD=    3.177 KLATAD=   7.504   CVTFD=    2.009 KLRTFD=    7.504
EXRTFD=    4.037 EXATAD=   10.09  IXRTFD=    2.500 EATAXA=   40.00A
FFRATA=     .260  FFRXA=    .260  HRCATA=     .416  HRCMC=     .416
    XF=     382.    TFN=   479.9     XAN=    892.0 EXATAS=    1.110
EXRTFS=    .4439
   XFN=    1469. CVATAS=   1.053   CVTFS=    .6662 KLATAS=    1.359
KLRTFS=    1.359 IXRTFS=   2.500  FFRATA=     .260  FFRXF=     .260
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=    49.99    ATA=     80.      XA=     61.2  DCMHC=     .000
CHCATA=    27.73  CHCTF=   27.73   HRCTF=     .110 EXAATA=   7.169A
CVATAD=    3.177 KLATAD=   7.504   CVTFD=    2.009 KLRTFD=    7.504
EXRTFD=    4.037 EXATAD=   10.09  IXRTFD=    2.500 EATAXA=   40.00A
FFRATA=     .067  FFRXA=    .069  HRCATA=     .110  HRCMC=     .110
    XF=     100.    TFN=   479.9     XAN=    892.0 EXATAS=    1.110
EXRTFS=    .4439
   XFN=    1469. CVATAS=   1.053   CVTFS=    .6662 KLATAS=    1.359
KLRTFS=    1.359 IXRTFS=   2.500  FFRATA=     .067  FFRXF=     .068
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=    74.99    ATA=     17.      XA=     18.9  DCMHC=     .000
CHCATA=    29.29  CHCTF=   29.29   HRCTF=     .034 EXAATA=   7.169A
CVATAD=    3.177 KLATAD=   7.504   CVTFD=    2.009 KLRTFD=    7.504
EXRTFD=    4.037 EXATAD=   10.09  IXRTFD=    2.500 EATAXA=   40.00A
FFRATA=     .014  FFRXA=    .021  HRCATA=     .034  HRCMC=     .034
    XF=      31.    TFN=   479.9     XAN=    892.0 EXATAS=    1.110
EXRTFS=    .4439
   XFN=    1469. CVATAS=   1.053   CVTFS=    .6662 KLATAS=    1.359
KLRTFS=    1.359 IXRTFS=   2.500  FFRATA=     .014  FFRXF=     .021
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  TIME=    99.98    ATA=      0.      XA=     13.9  DCMHC=     .000
CHCATA=    29.95  CHCTF=   29.95   HRCTF=     .025 EXAATA=   7.169A
CVATAD=    3.177 KLATAD=   7.504   CVTFD=    2.009 KLRTFD=    7.504
EXRTFD=    4.037 EXATAD=   10.09  IXRTFD=    2.500 EATAXA=   40.00A
FFRATA=     .000  FFRXA=    .016  HRCATA=     .025  HRCMC=     .025
    XF=      22.    TFN=   479.9     XAN=    892.0 EXATAS=    1.110
EXRTFS=    .4439
   XFN=    1469. CVATAS=   1.053   CVTFS=    .6662 KLATAS=    1.359
KLRTFS=    1.359 IXRTFS=   2.500  FFRATA=     .000  FFRXF=     .015
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 34. OUTPUT FOR AIR SUPERIORITY-FLEET DEFENSE COMPOSITE MODULE

4.4 DESCRIPTION OF THE ATA MULTIMISSION TRADEOFF MODEL

The Advanced Tactical Aircraft (ATA) fights against all the enemy threats. The rate of decrease of ATA is directly proportional to Attrition Rate due to Soviet Fighter Aircraft (ARAXF) and the Attrition Rate Due to Surface Threat (AATART). The initial number is equal to the product of Number of Aircraft Carriers, Number of Aircrafts per Carrier (ATAPC) and the Attrition Replacement Constant (ARC). The model also considers if the F-14 are to replaced by ATA along with A-6 or the A-6 will be replaced by ATA. At present there are 24 fighter aircrafts and 36 attack aircraft on each carrier. If the F-14's are not to be replaced by ATA then the decrease of ATA is only affected by Attrition Rate Due to Surface Threat (AATART). Figure 36 represents the causal diagram for the multimission tradeoff analysis.

The attrition rate of ATA Due to Carrier Damage (AATACD) is equal to the product of Hit Rate of Cruise Missiles on Carrier (HRCMC) and the sum of Direct Loss Per Hit (DLPH) and Indirect Loss Per Hit (ILPH). The clip function makes the attrition rate equal to zero when is no threat which should be obvious. If the equation was not defined by a clip function, XA may become negative making AATACD negative and thus uncreasing the ATA aircraft for no reason. Other clip functions may be interpreted similarly.

The Hit Rate of Cruise Missiles on Carrier (HRCMC) increases with increase in Launch Rate of Cruise Missiles from XA's (LRCMXA) and Probability of Cruise Missiles Hitting the Carrier (PCMHC). HRCMC

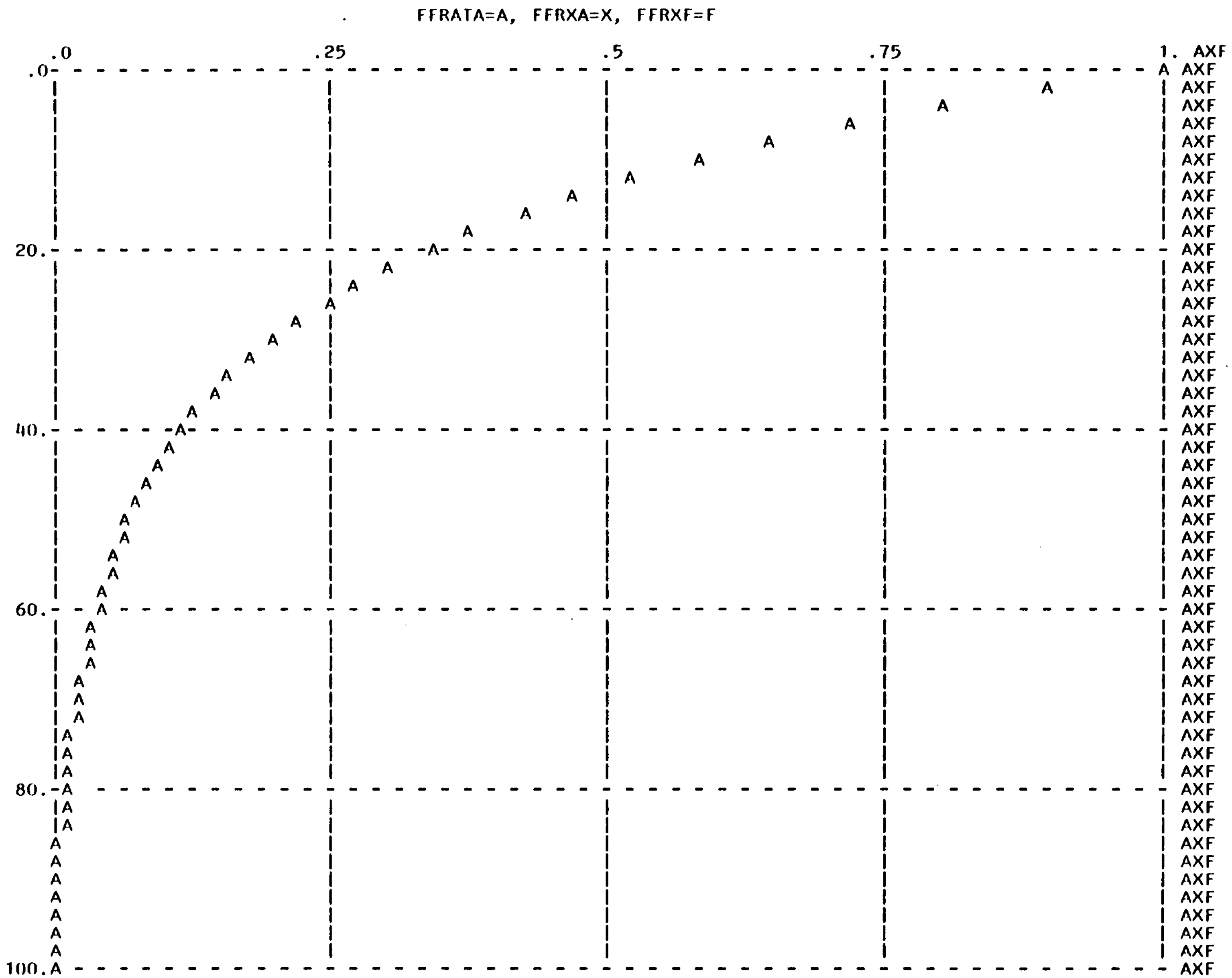

Figure 35. PLOT OF FFRATA, FFRXA AND FFRXF FOR EQUILIBRIUM CASE

decreases with increase in Probability Kill of Cruise Missile of ATA (PKCMAT). PKCMAT is equal to the product of Probability Kill of Cruise Missile by Baseline Aircraft (PKCMTF) and one minus the Delta Lethality Against Cruise Missile (DLM). DLM is the product of Delta Ordnance (DOTF), Number of Phoenix Missiles on F-14 (NPMTF) and Probability Kill of Cruise Missile by Phoenix Missile (PKCMPM). PKCMTF increases with increase in Number of Phoenix Missiles Per F-14 (NPMTF) and PKCMPM.

Launch Rate of Cruise Missiles from XA (LRCMXA) is equal to the product of Sortie Rate of XA (SRXA), Availability of XA (AXA), Number of XA Aircraft (XA), Number of Cruise Missiles Per XA (NCMPXA) and of one minus the Probability Kill of XA by ATA (PKXAAT). PKXAAT is equal to the product of Probability Kill of XA by ATA and one minus Delta Lethality Versus XA Aircraft (DLA). The Probability Kill of XA by F-14 (PKXATF) increases directly with increase in Probability Kill of XA by an Air-to-Air Missile (PKXAAA). Delta Lethality versus XA Aircraft (DLA) is equal to the product of Delta Ordnance (DOTF), NAAMTF and PKXAAA.

The rate of decrease of XA is directly proportional to the Attrition Rate of XA versus ATA (AXAATA). The Initial value of XA (XAN) is calculated by making the Effectiveness Exchange Ratio for F-14 Against XA equal to one (EXRTFD). But for the equilibrium case XAN is given a certain value so as to send the system into equilibrium. AXAATA is equal to product of Effectiveness of ATA Against XA (EATAXA). EATAXA equal to product of Sortie rate of ATA (SRATA), Availability of ATA Replacing F-14 (AATATF), Fraction Sorties to

Fleet Defense (FSFD) and Probability Kill of XA by ATA (PKXAAT). The variables -- Number of Aircraft Carriers (NAC), Number of F-14 Per Carrier (TFPC), Number of A-6 Intruder Attack Aircraft (IAPC), Attrition Replacement Constant (ARC), Direct Loss Per Hit (DLPH), Indirect Loss Per Hit (ILPH), Probability of Cruise Missile Hitting Carrier (PCMHC), Number of Phoenix Missiles on F-14 in Fleet Defense Mission (NPMTF), Number of Cruise Missiles Per XA (NCMPXA), Sortie Rate of XA (SRXA), Availability of XA (AXA), Number of Air-to-Air Missiles on F-14, Fraction Sorties F-14 to Fleet Defense, Sortie Rate of F-14 (SRTF), Availability of ATA Replacing F-14 (AATATF), Availability of F-14 (ATF), Fraction of Sorties to Fleet Defense (FSFD), Probability Kill of XA Cruise Missile by AIM-54C Phoenix Missile (PKCMPM) and Probability Kill of XA by Air-to-Air Missile on F-14 (PKXAAA)are constants obtained from military handbook, from other DOD models or based on information given by experienced DOD personnel. Of all the variables DLPH, ILPH, PKXAAA, PKCMPM and PKCMTF act as inputs. The other input parameters are Delta Survivability of ATA (DSTF), Delta Lethality of ATA (DLTF), Delta Acquisition Cost (DATF) and Delta Maintenance Cost (DMTF) -- all Deltas are with respect to the baseline aircraft F-14. The measures of effectiveness will be discussed in section 3.6.

Another variable affecting the Attrition Rate of ATA versus XF is (AATAXF). AATAXF is the product of Number of XF Aircraft and the Effectiveness of XF Against ATA (EXFATA). EXFATA is equal to the product of Sortie Rate of XF (SRXF), Availability of XF (AXF) and one minus Survivability of ATA Against XF (SATAXF).

The attrition rate of Soviet Fighter (XF) is directly proportional to the Attrition Rate of XF by ATA (AXFATA). The initial value of XF (XFN) is taken as 727. This is value required for balanced attrition when initial number of ATA is equal to 1200.

The Effectiveness of XF versus F-14 (EXFTF) is equal to the product of Sortie Rate of XF (SRXF), Availability of XF (AXF) and one minus Survivability of F-14 against XF (STFXF). Effectiveness of TF against XF is equal to the product of Sortie Rate of F-14 (SRTF), Fraction Sorties of F-14 to the Air Superiority (FSTFAS), Availability of F-14 (ATF) and Probability Kill of XF by F-14 (PKXFTF). Probability Kill of XF by F-14 (PKXFTF) increases with increase in Number of Air-to-Air Missiles on F-14 in Air Superiority Role (NMTFAS) and with Probability Kill of XF by Air-to-Air Missile on F-14 (PKXFAA).

The Attrition Rate of XF by ATA is equal to the product of Sortie Rate of ATA (SRATA), Fraction Sorties Against Air Superiority (FSAS), Availability of ATA Replacing F-14 (AATATF) and Probability Kill of XA by ATA (PKXFAT). PKXFAT is equal to the product of Probability Kill of XF by F-14 and one minus Delta Lethality versus XF (DLF). In all the cases Probability Kill of a threat by the replacement aircraft is equal to the probability kill of threat by the baseline aircraft multiplied by one minus delta lethality. DLF is equal to the product of Delta Ordnance (DOTF), Number of Air-to-Air Missiles on F-14 in Air Superiority Role (NMTFAS) and Probability Kill of XF Aircraft by Air-to-Air Missile on F-14.

The Survivability of Replacement Aircraft against a threat is equal to the survivability of baseline aircraft against a threat multiplied by one minus delta survivability. Survivability of ATA against XF(SATAXF) is equal to the Survivability of F-14 Against XF multiplied by one minus Delta Survivability (DSTF). STFXF decreases with increase in Number of Air-to-Air Missiles on XF (NAAMXF) and increases with increase in Survivability of F-14 Against Air-to-Air Missiles. The third variable which is responsible for destruction of ATA Against Surface Threat (AATART). AATART is equal to the product of Surface Threats (RT) and Effectiveness of Surface Threat Against ATA (ERTATA). ERTATA is equal to the product of Sortie Rate of ATA (SRATA), Availability of ATA Replacing A-6 (AATAIA), Fraction Sorties Against Attack Interdiction (FSAI) and one minus Survivability of ATA Against Surface Threat (SATART). AATAIA increases with the increase in Availability of A-6 (AIA) and also increases with the increase in Delta Maintenance Cost (DMIA). The Survivability of ATA against the Surface Threat (SATART) is equal to the product of Survivability of A-6 Against Surface Threat (SIART) and one minus Delta Survivability.

The rate of decrease of Surface threats is equal to the Attrition Rate of Surface Threat Against ATA (ARTATA). The initial value of RTN is taken as 2092 to achieve balanced attrition. ARTATA is equal to the product of Number of ATA and Effectiveness of ATA Against Surface Threat (EATART). The Probability Kill of Surface Threat by ATA is equal to the product of Probability Kill of Surface Threat by A-6 and one minus Delta Lethality versus Surface Threat (DLR). DLR is equal to the product of Delta Ordnance (DOIA), Effectiveness Number of Air-to-Surface Missiles on A-6 (NASMIA) and Probability Kill of Surface Threat by Air-to-Surface Missile (PKRTAS). Figure 38 shows the outputs for multimission model.

4.5 ANALYSIS OF THE ATA MULTIMISSION TRADEOFF MODEL

In this section, analytical solutions for level variables are arrived at and a combination of values for all three threats is calculated (when ATAN=1200) so as to achieve equilibrium.

The basic equations in this analysis are obtained from Figure 37. Expressing the level equation for ATA in continuous subscript notation, we have

$$
\begin{aligned}
dATA_t/dt &= -(AATACD_t+AATAXF_t+AATART_t) \\
&= -(B_A*XA_t+B_F*XF_t+BR*R_Tt) \qquad (4.36)
\end{aligned}
$$

where,

$$
\begin{aligned}
B_A &= (DLPH+ILPH)*PCMHC*(1-PKCMAT)*SRXA*AXA*NCMPXA*(1-PKXAAT) \\
&= (3+1)*0.01*(1-0.9502)*4*0.5*2*(1-0.10) \\
&= 7.1693E-03 \qquad (4.37)
\end{aligned}
$$

$$
\begin{aligned}
PKCMAT &= PKCMTF*(1-DLM) \\
&= (1-e^{-NPMTF*PKCMPM})*(1-DOTF*NPMTF*PKCMPM) \\
&= (1-e^{-6*0.5})*(1-0) \\
&= 0.9502 \qquad (4.38)
\end{aligned}
$$

$$
\begin{aligned}
PKXAAT &= PKXATF*(1-DLA) \\
&= (1-e^{-NAAMTF*PKXAAA})*(1-DLA) \\
&= (1-e^{-2*0.5268})*(1-0)
\end{aligned}
$$

$= 0.10$ (4.39)

B_F = SRXF*AXF*(1-SATAXF)

$= 4*0.5*(1-0.9802)$

$= 0.0396$ (4.40)

B_R = SRATA*AATAIA*FSAI*(1-SATART)

$= 4*0.5*0.6*(1-0.960775)$

$= 0.04707$ (4.41)

SATART = SIART*(1-DSIA)

$= 0.960775*(1-0)$

$= 0.960775$ (4.42)

The level equations for XA, XF and RT can be expressed similar to that for ATA as shown below

$dXA_t/dt = -(AXAATA_t)$

$= -C_A*ATA_t$ (4.43)

$dXF_t/dt = -(AXFATA_t)$

$= -C_F*ATA_t$ (4.44)

$dRT_t/dt = -(ARTATA_t)$

$= -C_R*ATA_t$ (4.45)

Differentiating 4.36 with respect to t we get

$d^2ATA_t/dt^2 = -(B_A*dXA_t/dt+B_F*dXF_t/dt+B_R*RT_t/dt)$ (4.46)

Substituting 4.43,4.44 and 4.45 in 4.46 we get

$d^2ATA_t/dt^2 = (B_A*C_A+B_F*C_F+B_R*C_R)*ATA_t$ (4.47)

$d^2ATA_t/dt^2-(B_A*C_A+B_F*C_F+B_R*C_R)*ATA_t = 0$ (4.48)

The above equation can be compared to the standard form of second order positive feedback equation

$$d^2ATA_t/dt^2-\omega^2*ATA_t = 0 \qquad (4.49)$$

where

$$\omega^2 = (B_A*C_A+B_F*C_F+B_R*C_R) \qquad (4.50)$$

$$\omega = SQRT(B_A*C_A+B_F*C_F+B_R*C_R) \qquad (4.51)$$

Solution for the level variable ATA can be written as

$$ATA_t = C_1e^{\omega t}+C_2e^{-\omega t} \qquad (4.52)$$

At time t=0, 4.52 becomes

$$ATA_0 = C_1+C_2 \qquad (4.53)$$

Differentiating 4.52 with respect to t we have

$$dATA_t/dt = \omega*(C_1*e^{\omega t}-C_2e^{-\omega t}) \qquad (4.54)$$

Again differentiating 4.54 with respect to t we have

$$d^2ATA_t/dt^2 = (C_1e^{\omega t}+C_2e^{-\omega t})*\omega^2 \qquad (4.55)$$

Comparing 4.36 and 4.54 at time t=0, we have

$$-(B_A*XA_0+B_F*XF_0+B_R*RT_0) = \omega\ (C_1-C_2) \qquad (4.56)$$

Rearranging the above equation we have

$$C_1-C_2 = -(B_A*XA_0+B_F*XF_0+B_R*RT_0)/\omega \qquad (4.57)$$

Adding 4.53 and 4.57 and dividing both sides by 2 we get

$$C_1 = (ATA_0-(B_A*XA_0+B_F*XF_0+B_R*RT_0)/\omega)/2 \qquad (4.58)$$

Subtracting 4.57 from 4.53 and dividing both sides by 2 we get

$$C_2 = (ATA_0+(B_A*XA_0+B_F*XF_0+B_R*RT_0)/\omega)/2 \qquad (4.59)$$

From equation 4.52 we can see that for ATA to tend to zero as time tends to infinity, C_1 should be equal to zero.

Therefore,

$$ATA_0 = C_2 \text{ (from 4.53)} \qquad (4.60)$$

Substituting 4.60 in 4.59 and rearranging we get

$$ATA_0 = (B_A*XA_0+B_F*XF_0+B_R*RT_0)/\omega \qquad (4.61)$$

The following condition should be satisfied for balanced attrition (equilibrium)

$$\frac{dXA_t/dt}{XA_t} = \frac{dXF_t/dt}{XF_t} = \frac{dRT_t/dt}{RT_t} = \frac{dATA_t/dt}{ATA_t} \tag{4.62}$$

At time t=0, equation 4.62 becomes

$$\frac{dXA_0/dt}{XA_0} = \frac{dXF_0/dt}{XF_0} = \frac{dRT_0/dt}{RT_0} = \frac{dATA_0/dt}{ATA_0} \tag{4.63}$$

Substituting 4.43, 4.44 and 4.45 in 4.63 we get

$$\frac{C_A*ATA_0}{XA_0} = \frac{-C_F*ATA_0}{XF_0} = \frac{-C_R*ATA_0}{RT_0} = \frac{dATA_0/dt}{ATA_0} \tag{4.64}$$

Since $C_1=0$, from 4.53 and 4.61 we get

$$ATA_0 = C_2 = (B_A*XA_0+B_F*XF_0+B_R*RT_0)/\omega \tag{4.65}$$

Also from 4.54 and 4.64 we get

$$\begin{aligned} dATA_0/dt &= -C_2\omega \\ &= -(B_A*XA_0+B_F*XF_0+B_R*RT_0) \end{aligned} \tag{4.66}$$

From 4.64, 4.66 and 4.61 we have

$$\frac{C_A*ATA_0}{XA_0} = \frac{-C_F*ATA_0}{XF_0} = \frac{-C_R*ATA_0}{RT_0} = \frac{-(B_A*XA_0+B_F*XF_0+B_R*RT_0)}{ATA_0} = \omega \tag{4.31}$$

From equation 4.67 we can write the following relationships

$$XA_0 = C_A*ATA_0/\omega \tag{4.68}$$

$$XF_0 = C_F*ATA_0/\omega \tag{4.69}$$

$$RT_0 = C_R*ATA_0/\omega \tag{4.70}$$

where,

$ATA_0 = 1200$

$$\begin{aligned} C_A &= SRATA*FSFD*AATATF*PKXAAT \\ &= 4*0.2*0.5*0.10 \\ &= 0.04 \end{aligned} \tag{4.71}$$

$C_F = SRATA*FSAS*AATATF*PKXFAT$

$= 4*0.2*0.5*0.16473$

$= 0.06589$ (4.72)

C_R = SRATA*AATAIA*FSAI*PKRTAT*FORT

$= 4*0.5*0.6*0.6321*0.25$

$= 0.18963$ (4.73)

$\omega = \mathrm{SQRT}(B_A*C_A+B_F*C_F+B_R*C_R)$

$= 0.10873$ (4.74)

Substituting the above values in 4.68, 4.69 an 4.70 we get

$XA_0 = 441.46 \sim 441$ (4.75)

$XF_0 = 727.23 \sim 727$ (4.76)

$RT_0 = 2092.9 \sim 2093$ (4.77)

These values when used achieve equilibrium as shown in Figure 39. The plot is for FFRATA, FFRXA, FFRXF and FFRRT. All four variables are equal at all times.

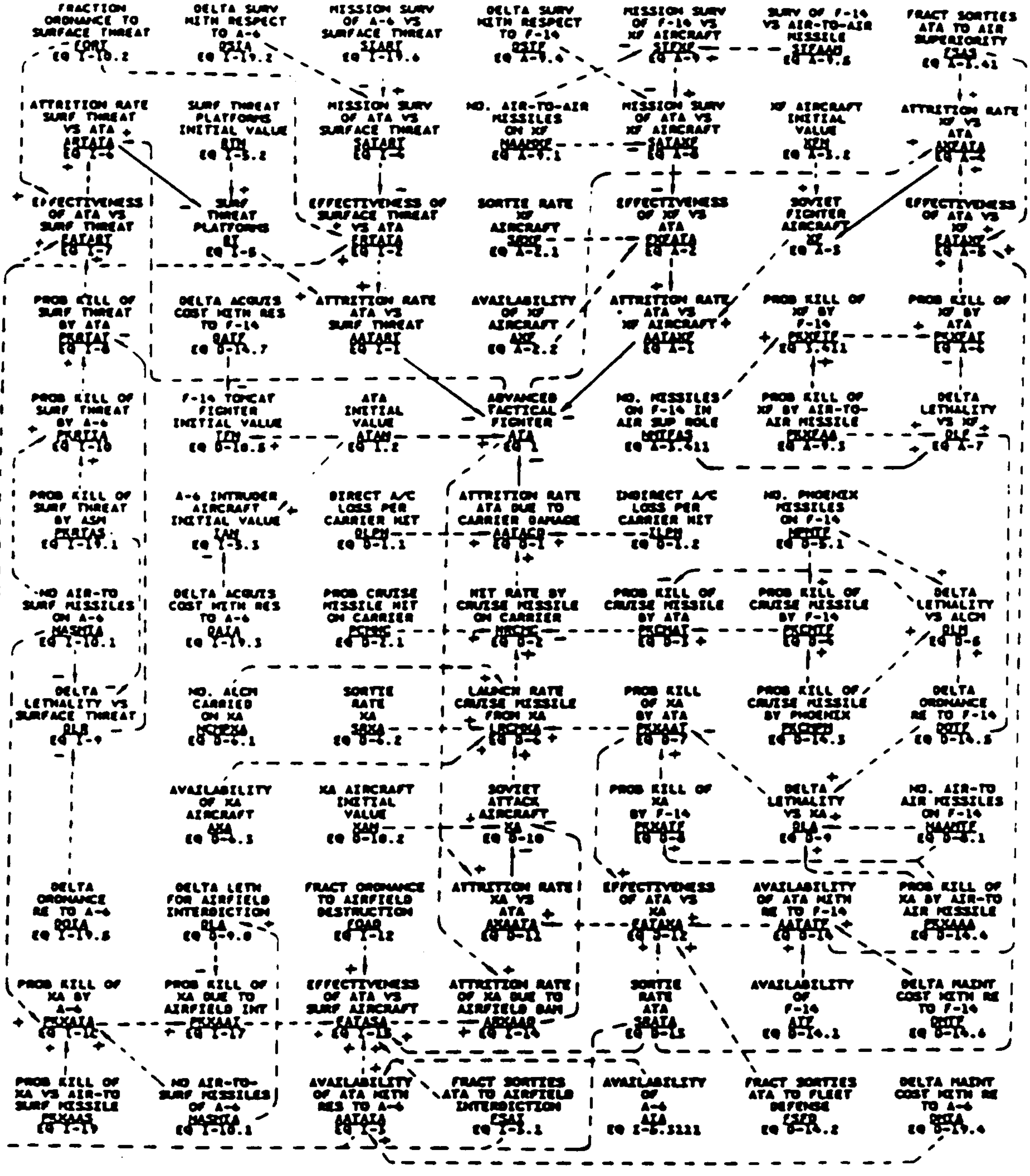

Figure 36. CAUSAL DIAGRAM FOR MULTIMISSION TRADEOFF MODEL

```
* ATA CONCEPT EVALUATION MULTIMISSION TRADEOFF ANALYSIS
NOTE ****************************************************************************
NOTE  SURVIVABILITY/LETHALITY TRADEOFF ANALYSIS (FLEET DEFENSE MISSION)
NOTE ****************************************************************************
L   ATA.K=MAX(0,ATA.J-(DT)(ATARTF*AATACD.JK+ATARTF*AATAXF.JK+AATART.JK))
NOTE     AATAXF.JK+AATART.JK))                                          (1)
N     ATA=ATAN                                                         (1.1)
NOTE ATA - ADVANCED TACTICAL AIRCRAFT (AIRCRAFT)
N     ATAN=NAC*ATAPC*ARC                                               (1.2)
NOTE ATAN - ADVANCED TACTICAL AIRCRAFT INITIAL VALUE (AIRCRAFT)
C     NAC=15                                                           (1.21)
NOTE NAC - NO OF AIRCRAFT CARRIERS (SHIPS)
N     ATAPC=ATARTF*TFPC+IAPC                                           (1.22)
NOTE ATAPC - NO OF ATA PER CARRIER (AIRCRAFT/SHIP)
C     TFPC=24                                                          (1.221)
NOTE TFPC - NO OF F-14 TOMCAT FIGHTER AIRCRAFT PER CARRIER (AIRCRAFT)
C     IAPC=36                                                          (1.222)
NOTE IAPC - NO OF A-6 INTRUDER ATTACK AIRCRAFT PER CARRIER (AIRCRAFT)
C     ATARTF=1                                                         (1.223)
NOTE ATARTF - ATA REPLACEMENT FOR F-14 (1 IF YES, 0 IF NO)
C     ARC=1.333                                                        (1.23)
NOTE ARC - ATTRITION REPLACEMENT CONSTANT (DIM)
R     AATACD.KL=CLIP(HRCMC.K*(DLPH+ILPH),0,XA.K,0)                      D-1
NOTE AATACD - ATTRITION RATE ATA DUE TO CARRIER DAMAGE (ATA/DAY)
C     DLPH=3                                                            D-1.1
NOTE DLPH - DIRECT LOSS PER HIT (ATA/CM)
C     ILPH=1                                                            D-1.2
NOTE ILPH - INDIRECT LOSS PER HIT (ATA/CM)
A     HRCMC.K=LRCMXA.K*(1-PKCMAT)*PCMHC                                 D-2
NOTE HRCMC - HIT RATE OF CRUISE MISSILES ON CARRIER (CM/DAY)
C     PCMHC=0.01                                                        D-2.1
NOTE PCMHC - PROB OF CRUISE MISSILE HITTING CARRIER (PROB)
N     PKCMAT=PKCMTF*(1-DLM)                                             D-3
NOTE PKCMAT - PROB KILL OF XA CRUISE MISSILE BY ATA (PROB)
N     PKCMTF=1-EXP(-NPMTF*PKCMPM)                                       D-4
NOTE PKCMTF - PROB KILL OF XA CRUISE MISSILE BY F-14 (PROB)
N     DLM=DOTF*NPMTF*PKCMPM                                             D-5
NOTE DLM - DELTA LETHALITY VS CRUISE MISSILE (DIM)
C     NPMTF=6                                                           D-5.1
NOTE NPMTF - NO OF PHOENIX MISSILES ON F-14 FLEET DEFENSE MISSION (DIM)
A     LRCMXA.K=SRXA*AXA*XA.K*NCMPXA*(1-PKXAAT)                          D-6
NOTE LRCMXA - LAUNCH RATE CRUISE MISSILES FROM XA'S (CM/DAY)
C     NCMPXA=2                                                          D-6.1
NOTE NCMPXA - NO CRUISE MISSILES PER XA (CM/XA)
C     SRXA=4                                                            D-6.2
NOTE SRXA - SORTIE RATE XA (NUMBER/DAY)
C     AXA=0.5                                                           D-6.3
NOTE AXA - AVAILABILITY OF XA (PROB)
N     PKXAAT=PKXATF*(1-DLA)                                             D-7
NOTE PKXAAT - PROB KILL OF XA BY ATA (PROB)
N     PKXATF=1-EXP(-NAAMTF*PKXAAA)                                      D-8
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NOTE PKXATF - PROB KILL OF XA BY F-14 (PROB)
C    NAAMTF=2                                                     D-8.1
NOTE NAAMTF - NO OF AIR-TO-AIR MISSILES ON F-14 (DIM)
N    DLA=DOTF*NAAMTF*PKXAAA                                       D-9.0
NOTE DLA - DELTA LETHALITY VS XA AIRCRAFT (DIM)
L    XA.K=MAX(0,XA.J-(DT)(AXAATA.JK+Z*ARXAAD.JK))                 D-10
N    XA=XAN                                                       D-10.1
NOTE XA - SOVIET ATTACK AIRCRAFT XA (AIRCRAFT)
NOTE XAN=TFN*SQRT(ETFXA/EXATF)+Z*IAN*SQRT(EIAAD/ERTIAI)           D-10.2
N    XAN=441.30
NOTE XAN - SOVIET ATTACK AIRCRAFT XA INITIAL VALUE (AIRCRAFT)
C    Z=0
NOTE Z - ZERO
N    ETFXA=SRTF*FSTFFD*ATF*PKXATF                                 D-10.3
NOTE ETFXA - EFFECTIVENESS OF F-14 VS XA (FRACT/DAY)
N    EXATF=(DLPH+ILPH)*PCMHC*(1-PKCMTF)
X       *SRXA*AXA*(1-PKXATF)*NCMPXA                               D-10.4
NOTE EXATF - EFFECTIVENESS OF XA VS F-14 (FRACT/DAY)
N    TFN=ATAN*(1-DATF)*(FSFD+FSAS)/(FSTFFD+FSTFAS)                D-10.5
NOTE TFN - F-14 TOMCAT FIGHTER INITIAL VALUE (AIRCRAFT)
C    FSTFFD=0.5                                                   D-10.51
NOTE FSTFFD - FRACT SORTIES F-14 TO FLEET DEFENSE (DIM)
R    AXAATA.KL=CLIP(ATA.K*EATAXA.K,0,ATA.K,0)                     D-11
NOTE AXAATA - ATTRITION RATE XA VS ATA (XA/DAY)
A    EATAXA.K=SRATA*FSFD*AATATF*PKXAAT                            D-12
NOTE EATAXA - EFFECTIVENESS OF ATA VS XA (FRACT/DAY)
N    SRATA=SRTF                                                   D-13
NOTE SRATA - SORTIE RATE ATA (NUMBER/DAY)
C    SRTF=4                                                       D-13.1
NOTE SRTF - SORTIE RATE F-14 (NUMBER/DAY)
N    AATATF=ATF/(1-DMTF)                                          D-14
NOTE AATATF - AVAILABILITY OF ATA REPLACING F-14 (PROB)
C    ATF=0.5                                                      D-14.1
NOTE ATF - AVAILABILITY OF F-14 (PROB)
C    FSFD=0.2                                                     D-14.2
NOTE FSFD - FRACTION OF SORTIES TO FLEET DEFENSE (DIM)
C    PKCMPM=0.5                                                   D-14.3
NOTE PKCMPM - PROB KILL OF XA CRUISE MISSILE BY AIM-54 C
X             PHOENIX MISSILE (PROB)
C    PKXAAA=0.05268                                               D-14.4
NOTE PKXAAA - PROB KILL OF XA A/C BY AIR-TO-AIR MISSILE ON F-14 (PROB)
NOTE ******************************************************************
NOTE ********* INPUTS FROM  SURVIVABILITY/LETHALITY ASSESSMENT *********
NOTE ******************************************************************
C    DOTF=0                                                       D-14.5
NOTE DOTF - DELTA ORDNANCE (OTF-OATA)/OTF (DIM)
C    DMTF=0                                                       D-14.6
NOTE DMTF - DELTA MAINTENANCE COST (MCTF-MCATA)/MCTF (DIM)
C    DATF=0                                                       D-14.7
NOTE DATF - DELTA ACQUISITION COST (ACTF-ACATA)/ACTF (DIM)
NOTE ******************************************************************
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NOTE ***************** MOE FOR FLEET DEFENSE MISSION *********************
NOTE ************************************************************************
A    DCMHC.K=(CHCATA.K-CHCTF.K)/CHCTF.K                              D-15
NOTE DCMHC - DECREASE IN CRUISE MISSILE HITS ON CARRIER NORMALIZED (DIM)
L    CHCATA.K=CHCATA.J+(DT)(HRCATA.JK)                               D-16
N    CHCATA=0                                                        D-16.1
NOTE CHCATA - CUM HITS ON CARRIER VS ATA (HITS)
L    CHCTF.K=CHCTF.J+(DT)(HRCTF.JK)                                  D-17
N    CHCTF=0                                                         D-17.1
NOTE CHCTF - CUM HITS ON CARRIER VS F-14 (HITS)
C    0=0.00000001                                                    D-17.11
NOTE 0 - ZERO
R    HRCATA.KL=HRCMC.K                                               D-18
NOTE HRCATA - HIT RATE ON CARRIER DEFENDED BY ATA (HITS/DAY)
R    HRCTF.KL=(1-PKCMTF)*PCMHC*SRXA*AXA*XA.K*
X        NCMPXA*(1-PKXATF)                                           D-19
NOTE HRCTF - HIT RATE ON CARRIER DEFENDED BY TF (HITS/DAY)
A    EXAATA.K=(DLPH+ILPH)*PCMHC*(1-PKCMAT)*SRXA*AXA*(1-PKXAAT)*NCMPXA
NOTE   -PKCMAT)*SRXA*AXA*(1-PKXAAT)*NCMPXA                           D-20
NOTE EXAATA - EFFECTIVENESS OF XA VS ATA (FRACT/DAY)
A    CVATAD.K=(ATAN/XAN)*SQRT(EATAXA.K/EXAATA.K)                     D-21
NOTE CVATAD - COMBAT VALUE RATIO OF ATA IN FLEET DEFENSE (DIM)
A    KLATAD.K=(ATAN*EATAXA.K)/(XAN*EXAATA.K)                         D-22
NOTE KLATAD - KILL LOSS RATIO ATA IN FLEET DEFENSE MISSION (DIM)
A    CVTFD.K=(TFN/XAN)*SQRT(ETFXA/EXATF)                             D-23
NOTE CVTFD - COMBAT VALUE RATIO OF TF IN FLEET DEFENSE (DIM)
A    KLRTFD.K=(TFN*ETFXA)/(XAN*EXATF)                                 D-24
NOTE KLRTFD - KILL LOSS RATIO TF IN FLEET DEFENSE MISSION (XA/TF) (DIM)
A    EXRTFD.K=KLRTFD.K/(XAN/TFN)                                      D-25
NOTE EXRTFD - EFF EXCH RATIO FOR F-14 OVER XA IN FLEET DEFENSE (XA/TF)
A    EXATAD.K=KLATAD.K/(XAN/ATAN)                                    D-26
NOTE EXATAD - EFF EXCH RATIO FOR ATA OVER XA IN FLEET DEFENSE
X             MISSION (XA/ATA)
A    IXRTFD.K=EXATAD.K/EXRTFD.K                                      D-27
NOTE IXRTFD - INC IN EXCH RATIO FOR ATA OVER F-14 IN FLEET DEFENSE (DIM)
NOTE ************************************************************************
NOTE SURVIVABILITY/LETHALITY TRADEOFF ANALYSIS (AIR SUPERIORITY MISSION)
NOTE ************************************************************************
R    AATAXF.KL=CLIP(XF.K*EXFATA.K,0,XF.K,0)                          A-1
NOTE AATAXF - ATTRITION RATE ATA VS XF (AIRCRAFT/DAY)
A    EXFATA.K=SRXF*AXF*(1-SATAXF)                                    A-2
NOTE EXFATA - EFFECTIVENESS OF XF VS ATA (FRACT/DAY)
C    SRXF=4                                                          A-2.1
NOTE SRXF - SORTIE RATE XF (NUMBER/DAY)
C    AXF=0.5                                                         A-2.2
NOTE AXF - AVAILABILITY OF XF (PROB)
L    XF.K=MAX(0,XF.J-(DT)(AXFATA.JK))                                A-3
N    XF=XFN                                                          A-3.1
NOTE XF - SOVIET FIGHTER AIRCRAFT XF (AIRCRAFT)
NOTE XFN=TFN*SQRT(ETFXF/EXFTF)                                       A-3.2
N    XFN=727.0
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NOTE XFN - SOVIET FIGHTER AIRCRAFT XF INITIAL VALUE (AIRCRAFT)
N    EXFTF=SRXF*AXF*(1-STFXF)                                       A-3.3
NOTE EXFTF - EFFECTIVENESS OF XF VS F-14 (FRACT/DAY)
N    ETFXF=SRTF*FSTFAS*ATF*PKXFTF                                   A-3.4
NOTE ETFXF - EFFECTIVENESS OF F-14 VS XF (FRACT/DAY)
C    FSAS=0.2                                                       A-3.41
NOTE FSAS - FRACTION OF SORTIES TO AIR SUPERIORITY (DIM)
N    PKXFTF=1-EXP(-NMTFAS*PKXFAA)                                   A-3.411
NOTE PKXFTF - PROB KILL XF BY F-14 (PROB)
C    NMTFAS=6                                                       A-3.4111
NOTE NMTFAS - NO OF AIR-TO-AIR MISSILES ON TF IN AIR SUP ROLE (DIM)
R    AXFATA.KL=CLIP(ATA.K*EATAXF.K,0,ATA.K,0)                       A-4
NOTE AXFATA - ATTRITION RATE XF VS ATA (AIRCRAFT/DAY)
A    EATAXF.K=SRATA*FSAS*AATATF*PKXFAT                              A-5
NOTE EATAXF - EFFECTIVENESS OF ATA VS XA (FRACT/DAY)
N    PKXFAT=PKXFTF*(1-DLF)                                          A-6
NOTE PKXFAT - PROB KILL OF XF BY ATA (PROB)
N    DLF=DOTF*NMTFAS*PKXFAA                                         A-7
NOTE DLF - DELTA LETHALITY VS XF AIRCRAFT (DIM)
N    SATAXF=STFXF*(1-DSTF)                                          A-8
NOTE SATAXF - SURV OF ATA VS XF (PROB)
N    STFXF=EXP(-NAAMXF*(1-STFAAM))                                  A-9
NOTE STFXF - SURV OF F-14 VS XF (PROB)
C    NAAMXF=4                                                       A-9.1
NOTE NAAMXF - NO OF AIR-TO-AIR MISSILES ON XF (DIM)
C    FSTFAS=0.5                                                     A-9.2
NOTE FSTFAS - FRACT SORTIES F-14 TO AIR SUPERIORITY ROLE (DIM)
C    PKXFAA=0.03                                                    A-9.3
NOTE PKXFAA-PROB KILL OF XF AIRCRAFT BY AIR-TO-AIR MISSILE ON F-14 PROB)
NOTE ***************************************************************************
NOTE ********** INPUTS FROM  SURVIVABILITY/LETHALITY ASSESSMENT **********
NOTE ***************************************************************************
C    DSTF=0                                                         A-9.4
NOTE DSTF - DELTA SURVIVABILITY (STF-SATA)/STF (DIM)
C    STFAAM=0.9950                                                  A-9.5
NOTE STFAAM - SURV OF F-14 VS SOVIET AIR-TO-AIR MISSILE (PROB)
NOTE ***************************************************************************
NOTE ****************** MOE FOR AIR SUPERIORITY MISSION ********************
NOTE ***************************************************************************
A    CVATAS.K=(ATAN/XFN)*SQRT(EATAXF.K/EXFATA.K)                   A-10
NOTE CVATAS - COMBAT VALUE RATIO OF ATA IN AIR SUPERIORITY ROLE (DIM)
A    CVTFS.K=(TFN/XFN)*SQRT(ETFXF/EXFTF)                           A-11
NOTE CVTFS - COMBAT VALUE RATIO OF TF IN AIR SUPERIORITY ROLE (DIM)
A    KLATAS.K=(ATAN*EATAXF.K)/(XFN*EXFATA.K)                       A-12
NOTE KLATAS - KILL LOSS RATIO OF ATA IN AIR SUPERIORITY MISSION (XF/ATA)
A    KLRTFS.K=(TFN*ETFXF)/(XFN*EXFTF)                               A-13
NOTE KLRTFS - KILL LOSS RATIO OF TF IN AIR SUP MISSION (XF/TF) (DIM)
A    EXATAS.K=KLATAS.K/(XFN/ATAN)                                  A-14
NOTE EXATAS - EFFECTIVE EXCHANGE RATIO FOR ATA OVER XF IN AIR SUP (DIM)
A    IXRTFS.K=EXATAS.K/EXRTFS.K                                    A-15
NOTE IXRTFS - INC IN EXCHANGE RATIO FOR ATA OVER F-14 IN AIR SUP (DIM)
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A    EXRTFS.K=KLRTFS.K/(XFN/TFN)                                   A-16
NOTE EXRTFS - EFF EXCH RATIO FOR F-14 OVER XF IN AIR SUPERIORITY (DIM)
A    FFRXF.K=XF.K/XFN                                              A-17
NOTE FFRXF - FRACT FORCE REMAINING XF (DIM)
NOTE ********************************************************************
NOTE * SURVIV/LETHALITY TRADEOFF ANALYSIS (ATTACK INTERDICTION MISSION) *
NOTE ********************************************************************
R    AATART.KL=RT.K*ERTATA.K                                       I-1
NOTE AATART - ATTRITION RATE ATA VS SURFACE THREAT (AIRCRAFT/DAY)
A    ERTATA.K=SRATA*AATAIA*FSAI*(1-SATART)                         I-2
NOTE ERTATA - EFFECTIVENESS OF SURF THREAT VS ATA (FRACT/DAY)
C    SRIA=4                                                        I-2.1
NOTE SRIA - SORTIE RATE A-6 (NUMBER/DAY)
N    AATAIA=AIA/(1-DMIA)                                           I-3
NOTE AATAIA - AVAILABILITY OF ATA REPLACING A-6 (PROB)
C    FSAI=0.6                                                      I-3.1
NOTE FSAI - FRACTION OF SORTIES TO ATTACK/INTERDICTION (DIM)
N    SATART=SIART*(1-DSIA)                                         I-4
NOTE SATART - SURV OF ATA VS SURFACE THREAT (PROB)
L    RT.K=MAX(0,RT.J-(DT)(ARTATA.JK))                              I-5
N    RT=RTN                                                        I-5.1
NOTE RT - SURFACE THREAT (PLATFORMS)
N    RTN=2092.0                                                    I-5.2
NOTE RTN - SURFACE THREAT INITIAL VALUE (PLATFORMS)
N    IAN=ATAN*(1-DAIA)*FSAI/FSIAAI                                 I-5.3
NOTE IAN - A-6 INTRUDER ATTACK AIRCRAFT INITIAL VALUE (AIRCRAFT)
C    FSIAAI=1.0                                                    I-5.31
NOTE FSIAAI - FRACT SORTIES A-6 TO ATTACK/INTERDICTION (DIM)
N    ERTIA=SRIA*AIA*FSIAAI*(1-SIART)                               I-5.311
NOTE ERTIA - EFFECTIVENESS OF SURFACE THREAT VS A-6 (FRACT/DAY)
C    AIA=.5                                                        I-5.3111
NOTE AIA - AVAILABILITY OF A-6 (PROB)
N    EIART=SRIA*AIA*FSIAAI*PKRTIA*FORT                             I-5.31111
NOTE EIART - EFFECTIVENESS OF A-6 VS SURF THREAT (FRACT/DAY)
R    ARTATA.KL=CLIP(ATA.K*EATART.K,0,ATA.K,0)                      I-6
NOTE ARTATA - ATTRITION RATE SURF THREAT VS ATA (PLATFORM/DAY)
A    EATART.K=MAX(0,SRATA*AATAIA*FSAI*PKRTAT*FORT)                 I-7
NOTE EATART - EFFECTIVENESS OF ATA VS SURF THREAT (FRACT/DAY)
N    PKRTAT=PKRTIA*(1-DLR)                                         I-8
NOTE PKRTAT - PROB KILL  OF SURF THREAT BY ATA (PROB)
N    DLR=DOIA*NASMIA*PKRTAS                                        I-9
NOTE DLR - DELTA LETHALITY VS SURF THREAT (DIM)
N    PKRTIA=1-EXP(-NASMIA*PKRTAS)                                  I-10
NOTE PKRTIA - PROB KILL OF SURF THREAT BY A-6 (PROB)
C    NASMIA=10                                                     I-10.1
NOTE NASMIA - EFFECTIVE NUMBER OF AIR-TO-SURFACE MISSILES ON A-6 (DIM)
C    FORT=0.25                                                     I-10.2
NOTE FORT - FRACT OF ORDNANCE TO SURFACE THREATS (DIM)
N    EIAAD=SRIA*AIA*FSIAAI*PKXAIA*FOAD                             I-11
NOTE EIAAD - EFFECTIVENESS OF A-6 FOR DESTROYING SURF AIRCRAFT (FRACT/DAY)
N    FOAD=1-FORT                                                   I-12
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NOTE FOAD - FRACT OF ORDNANCE TO AIRFIELD DESTRUCTION (DIM)
N    ERTIAI=SRIA*AIA*FSIAAI*(1-SIART)*FOAD                         I-13
NOTE ERTIAI-EFFECTIVENESS OF SURF THREAT VS A-6
X           IN AIRFIELD INTERDICTION (1/DAY)
R    ARXAAD.KL=ATA.K*EATASA.K                                      I-14
NOTE ARXAAD - ATTRITION RATE XA VS AIRFIELD DESTRUCTION (AIRCRAFT/DAY)
A    EATASA.K=SRATA*AATAIA*FSAI*PKXAAI*FOAD                        I-15
NOTE EATASA - EFFECTIVENESS OF ATA FOR DESTROYING SURF
X             AIRCRAFT (FRACT/DAY)
A    ERTAAI.K=SRATA*AATAIA*FSAI*(1-SATART)*FOAD                    I-16
NOTE ERTAAI - EFFECTIVENESS OF SURF THREAT VS ATA
X             IN AIRFIELD INTERDICTION (FRACT/DAY)
N    PKXAAI=PKXAIA*(1-DLA)                                         I-17
NOTE PKXAAI - PROB KILL OF SURFACE XA BY AIRFIELD INTERDICTION (PROB)
N    PKXAIA=1-EXP(-NASMIA*PKXAAS)                                  I-18
NOTE PKXAIA - PROB KILL OF SURFACE XA BY A-6 (PROB)
N    PKXAAS=0.2                                                    I-19
NOTE PKXAAS - PROB KILL OF PARKED XA BY AIR-TO-SURFACE MISSILE (PROB)
C    PKRTAS=0.10                                                   I-19.1
NOTE PKRTAS - PROB KILL OF SURF THREAT VS AIR-TO-SURFACE MISSILE (PROB)
NOTE ********************************************************************
NOTE ********** INPUTS FROM SURVIVABILITY/LETHALITY ASSESSMENT **********
NOTE ********************************************************************
C    DSIA=0                                                        I-19.2
NOTE DSIA - DELTA SURVIVABILITY (SIA-SATA)/SIA (DIM)
C    DAIA=0                                                        I-19.3
NOTE DAIA - DELTA ACQUISITION COST (ACIA-ACATA)/ACIA (DIM)
C    DMIA=0                                                        I-19.4
NOTE DMIA - DELTA MAINTENANCE COST (MCIA-MCATA)/MCIA (DIM)
C    DOIA=0                                                        I-19.5
NOTE DOIA - DELTA ORDNANCE (OIA-OATA)/OIA (DIM)
C    SIART=.960775                                                 I-19.6
NOTE SIART - SURV OF A-6 VS SURFACE THREAT (PROB)
NOTE ********************************************************************
NOTE *********** MOE FOR ATTACK/INTERDICTION MISSION ********************
NOTE ********************************************************************
NOTE ********************************************************************
NOTE *********** MOE FOR ATTACK/INTERDICTION MISSION ********************
NOTE ********************************************************************
A    CVIATS.K=(IAN/RTN)*SQRT(EIART/ERTIA)                          I-20
NOTE CVIATS - COMBAT VALUE RATIO OF A-6 IN SURF THREAT INTERDICTION (DIM)
A    CVATAT.K=(ATAN/RTN)*SQRT(EATART.K/ERTATA.K)                   I-21
NOTE CVATAT - COMBAT VALUE RATIO OF ATA IN SURF THREAT INTERDICTION (DIM)
A    CVIAAI.K=(IAN/XAN)*SQRT(EIAAD/ERTIAI)                         I-22
NOTE CVIAAI - COMBAT VALUE RATIO OF A-6 IN AIRFIELD INTERDICTION (DIM)
A    CVATAI.K=(ATAN/XAN)*SQRT(EATASA.K/ERTAAI.K)                   I-23
NOTE CVATAI - COMBAT VALUE RATIO OF ATA IN AIRFIELD INTERDICTION (DIM)
A    KLRIAT.K=(IAN*EIART)/(RTN*ERTIA)                              I-24
NOTE KLRIAT - KILL-LOSS A-6 IN SURF THREAT INTERDICTION (RT/A-6)
A    KLRIAI.K=(IAN*EIAAD)/(RTN*ERTIAI)                             I-25
NOTE KLRIAI - KILL-LOSS A-6 IN AIRFIELD INTERDICTION (XA/A-6)
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A    KLATAT.K=(ATAN*EATART.K)/(RTN*ERTATA.K)                         I-26
NOTE KLATAT - KILL-LOSS ATA IN SURF THREAT INTERDICTION (RT/ATA)
A    KLATAI.K=(ATAN*EATASA.K)/(RTN*ERTAAI.K)                         I-27
NOTE KLATAI - KILL-LOSS ATA IN AIRFIELD INTERDICTION (XA/ATA)
A    EXATAI.K=KLATAI.K/(RTN/ATAN)                                    I-28
NOTE EXATAI - EFF EXCH RATIO FOR ATA IN AIRFIELD INTERDICTION (DIM)
A    EXRIAI.K=KLRIAI.K/(RTN/IAN)                                     I-29
NOTE EXATAT - EFF EXCH RATIO FOR A-6 IN SURF THREAT INTERDICTION (DIM)
A    EXATAT.K=KLATAT.K/(RTN/ATAN)                                    I-30
NOTE EXATAI - EFF EXCH RATIO FOR ATA IN SURF THREAT INTERDICTION (DIM)
A    EXRIAT.K=KLRIAT.K/(RTN/IAN)                                     I-31
NOTE EXRIAT - EFF EXCH RATIO FOR A-6 IN SURF THREAT INTERDICTION (DIM)
A    IXRIAT.K=EXATAT.K/EXRIAT.K                                      I-32
NOTE IXRIAT - INC IN EXCH RATIO FOR A-6 IN SURF THREAT INTERDICTION (DIM)
A    FFRATA.K=ATA.K/ATAN                                             I-33
NOTE FFRATA - FRACT FORCE REMAINING ATA (DIM)
A    FFRRT.K=RT.K/RTN                                                I-34
NOTE FFRRT - FRACT FORCE REMAINING SURFACE THREATS (DIM)
A    FFRXA.K=XA.K/XAN                                                I-35
NOTE FFRXA - FRACT FORCE REMAINING XA (DIM)
S    ITDPAL.K=(OTATAL.K-OTPIAL.K)/OTPIAL.K                           I-36
NOTE ITDPAL - INC TARGETS DESTROYED PER AIRCRAFT LOST (DIM)
A    OTATAL.K=MAX(0,COTATA.K/CLATA.K)                                I-38
NOTE OTATAL - ORDNANCE TO TARGET PER ATA LOST (LBS/AIRCRAFT)
A    OTPIAL.K=MAX(0,COTIA.K/CLIA.K)                                  I-39
NOTE OTPIAL - ORDNANCE TO TARGET PER A-6 LOST (LBS/AIRCRAFT)
L    COTATA.K=COTATA.J+(DT)(OATADR.JK)                               I-40
N    COTATA=0                                                        I-40.1
NOTE COTATA - CUM ORDNANCE TO TARGET BY ATA (LBS)
L    COTIA.K=COTIA.J+(DT)(OIADR.JK)                                  I-41
N    COTIA=0                                                         I-41.1
NOTE COTIA - CUM ORDNANCE TO TARGET BY A-6 (LBS)
R    OATADR.KL=SRATA*AATAIA*FSAI*FOAD*OATA                           I-42
NOTE OATADR - ORDNANCE A-6 DELIVERY RATE (LBS/DAY)
R    OIADR.KL=SRIA*AIA*FSAI*FOAD*OIA                                 I-43
NOTE OIADR - ORDNANCE A-6 DELIVERY RATE (LBS/DAY)
L    CLATA.K=CLATA.J+(DT)(AATART.JK)                                 I-44
N    CLATA=0                                                         I-44.1
NOTE CLATA - CUM LOSSES ATA (AIRCRAFT)
L    CLIA.K=CLIA.J+(DT)(ARIART.JK)                                   I-45
N    CLIA=0                                                          I-45.1
NOTE CLIA - CUM LOSSES A-6 (AIRCRAFT)
R    ARIART.KL=CLIP(RT.K*ERTIA,0,RT.K,0)                             I-45.2
NOTE ARIART - ATTRITION RATE A-6 VS SURF THREAT (AIRCRAFT/DAY)
C    OIA=15000                                                       I-45.3
NOTE OIA - ORDNANCE CARRIED BY A-6 (LBS/DAY)
N    OATA=OIA*(1-DOIA)                                               I-45.4
NOTE OATA - ORDNANCE CARRIED BY ATA (LBS)
NOTE ********************************************************************
NOTE ****************** CONTROL STATEMENTS ******************************
NOTE ********************************************************************
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SPEC DT=0.05/LENGTH=50/PRTPER=25/PLTPER=1
PRINT ATA,XF,XA
PRINT RT,CVATAS,CVTFS,XAN
PRINT KLRTFS,IXRTFS,DCMHC,CHCATA
PRINT CHCTF,HRCTF,EXATAI,CVATAD
PRINT KLATAS,EXRTFS,EXATAT,IXRTFD
PRINT EXATAI,CVTFD,KLRTFD,CVIATS
PRINT CVATAT,CVIAAI,CVATAI,KLRIAT
PRINT KLRIAI,KLATAI,KLATAI,EXRIAT
PRINT IXRIAT,OATA,EXATAT,EXATAI
PRINT ITDPAL,OTATAL,OTPIAL,EXRIAI
PRINT COTATA,COTIA,OATADR,OIADR
PRINT CLATA,CLIA,FFRATA,FFRXF
PRINT FFRXA,FFRRT,RTN,XAN
PRINT IAN,KLATAD,KLATAT,EXRTFD
PRINT EXATAS,EXATAD,EXAATA,EATAXA
PLOT  FFRATA,FFRXF,FFRXA,FFRRT(0,1)
RUN
QUIT
```

Figure 37. DYNAMO EQUATIONS FOR MULTIMISSION TRADEOFF MODEL

```
   TIME=     .00     ATA=   1200.      XF=   727.0      XA=   441.3
     RT=   2092.  CVATAS=   2.129   CVTFS=   1.346     XAN=   441.3
 KLRTFS=   2.746  IXRTFS=   2.500   DCMHC=  -1.000  CHCATA=    .000
  CHCTF=    .000   HRCTF=   .7910  EXATAI=   7.249  CVATAD=   6.421
 KLATAS=   2.746  EXRTFS=   1.812  EXATAT=   1.325  IXRTFD=   2.500
 EXATAI=   7.249   CVTFD=   4.061  KLRTFD=   15.17  CVIATS=   .6906
 CVATAT=   1.151  CVIAAI=   7.658  CVATAI=   12.76  KLRIAT=   1.386
 KLRIAI=   7.585  KLATAI=   12.64  KLATAI=   12.64  EXRIAT=   .4770
 IXRIAT=   2.778    OATA=  15.00T  EXATAT=   1.325  EXATAI=   7.249
 ITDPAL=   .0000  OTATAL=      .0  OTPIAL=      .0  EXRIAI=   2.610
 COTATA=      .0   COTIA=      .0  OATADR=  13.50T   OIADR=  13.50T
  CLATA=      .0    CLIA=      0.  FFRATA=   1.000   FFRXF=   1.000
  FFRXA=   1.000   FFRRT=   1.000     RTN=   2092.     XAN=   441.3
    IAN=   719.8  KLATAD=   15.17  KLATAT=   2.310  EXRTFD=   16.49
 EXATAS=   4.531  EXATAD=   41.23  EXAATA=  7.169A  EATAXA=  40.00A
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   25.00     ATA=     80.      XF=    46.9      XA=    28.5
     RT=    135.  CVATAS=   2.129   CVTFS=   1.346     XAN=   441.3
 KLRTFS=   2.746  IXRTFS=   2.500   DCMHC=    .000  CHCATA=   6.791
  CHCTF=   6.791   HRCTF=   .0510  EXATAI=   7.249  CVATAD=   6.421
 KLATAS=   2.746  EXRTFS=   1.812  EXATAT=   1.325  IXRTFD=   2.500
 EXATAI=   7.249   CVTFD=   4.061  KLRTFD=   15.17  CVIATS=   .6906
 CVATAT=   1.151  CVIAAI=   7.658  CVATAI=   12.76  KLRIAT=   1.386
 KLRIAI=   7.585  KLATAI=   12.64  KLATAI=   12.64  EXRIAT=   .4770
 IXRIAT=   2.778    OATA=  15.00T  EXATAT=   1.325  EXATAI=   7.249
 ITDPAL=   .6667  OTATAL=   399.2  OTPIAL=   239.5  EXRIAI=   2.610
 COTATA=  337.5T   COTIA=  337.5T  OATADR=  13.50T   OIADR=  13.50T
  CLATA=   845.4    CLIA=   1409.  FFRATA=    .067   FFRXF=    .065
  FFRXA=    .064   FFRRT=    .064     RTN=   2092.     XAN=   441.3
    IAN=   719.8  KLATAD=   15.17  KLATAT=   2.310  EXRTFD=   16.49
 EXATAS=   4.531  EXATAD=   41.23  EXAATA=  7.169A  EATAXA=  40.00A
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   TIME=   49.99     ATA=     20.      XF=      .0      XA=      .0
     RT=      0.  CVATAS=   2.129   CVTFS=   1.346     XAN=   441.3
 KLRTFS=   2.746  IXRTFS=   2.500   DCMHC=    .000  CHCATA=   7.155
  CHCTF=   7.155   HRCTF=   .0000  EXATAI=   7.249  CVATAD=   6.421
 KLATAS=   2.746  EXRTFS=   1.812  EXATAT=   1.325  IXRTFD=   2.500
 EXATAI=   7.249   CVTFD=   4.061  KLRTFD=   15.17  CVIATS=   .6906
 CVATAT=   1.151  CVIAAI=   7.658  CVATAI=   12.76  KLRIAT=   1.386
 KLRIAI=   7.585  KLATAI=   12.64  KLATAI=   12.64  EXRIAT=   .4770
 IXRIAT=   2.778    OATA=  15.00T  EXATAT=   1.325  EXATAI=   7.249
 ITDPAL=   .6667  OTATAL=   757.9  OTPIAL=   454.7  EXRIAI=   2.610
 COTATA=  674.9T   COTIA=  674.9T  OATADR=  13.50T   OIADR=  13.50T
  CLATA=   890.5    CLIA=   1484.  FFRATA=    .017   FFRXF=    .000
  FFRXA=    .000   FFRRT=    .000     RTN=   2092.     XAN=   441.3
    IAN=   719.8  KLATAD=   15.17  KLATAT=   2.310  EXRTFD=   16.49
 EXATAS=   4.531  EXATAD=   41.23  EXAATA=  7.169A  EATAXA=  40.00A
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 38. OUTPUT FOR MULTIMISSION TRADEOFF MODEL

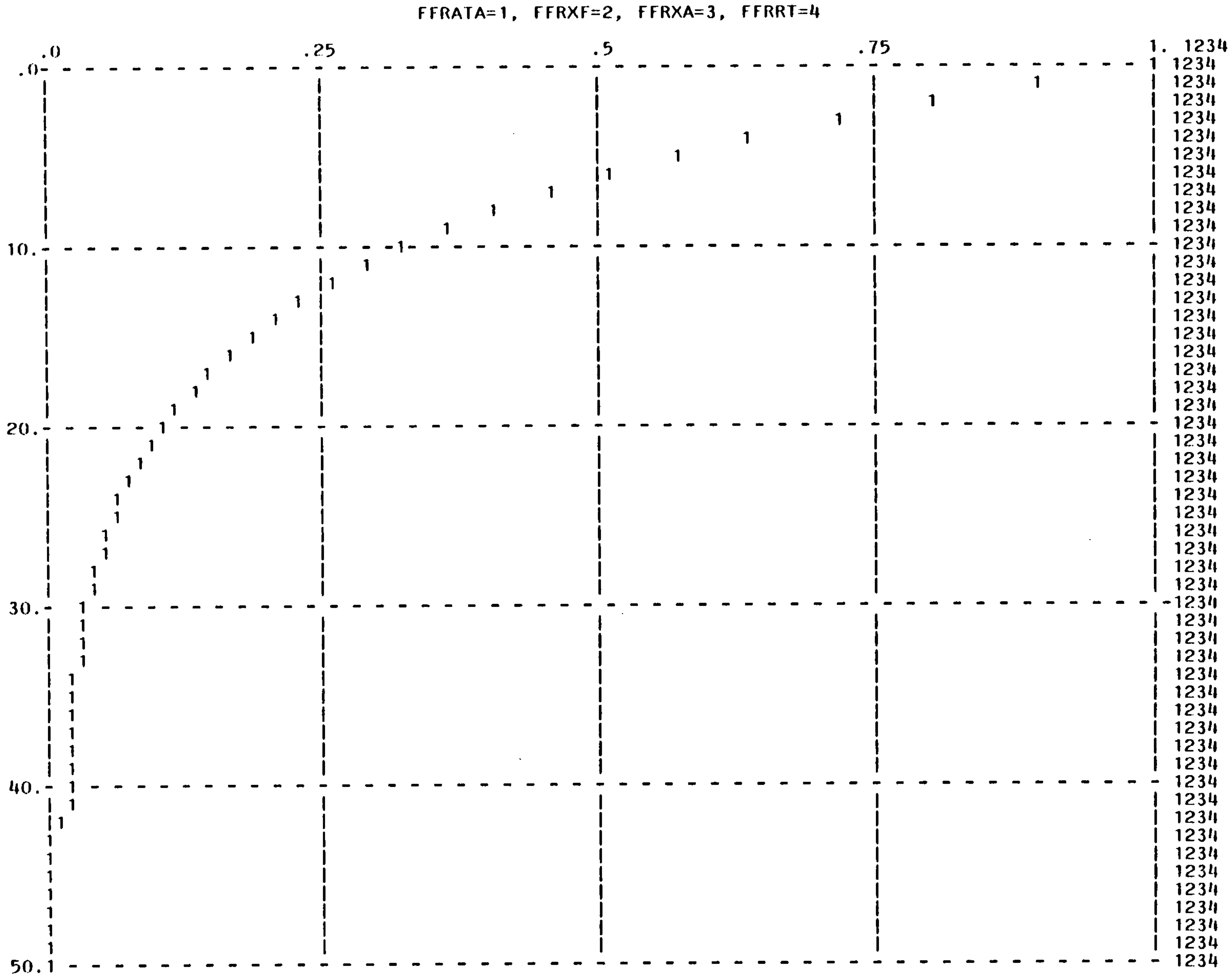

Figure 39. PLOT OF FFRATA, FFRXA, FFRXF AND FFRRT FOR EQUILIBRIUM CASE

4.6 SUMMARY

This research should act as a strong base for further improvement of the final model. The sequence of Chapters 3 and 4 set the direction in which further study moves. The third chapter was the case of simple individual models. In the initial part of this chapter we had dual mission model and then we moved on to the model with all three missions. The model will be extended so as to incorporate more variables affecting and affected by the present system.

In the models presented in this chapter, an analytical solution while more complex than the analysis of individual models in Chapter 3, is still within reach. The combined model does not incorporate the attack of parked aircraft of the enemy by attack/interdiction aircraft. This is one example of the direction in which a model should be expanded.

The measures of effectiveness have been presented for each of the models. These measures of effectiveness will be discussed as a whole system in Chapter 5.

5.0 CHAPTER 5 - RESULTS AND DISCUSSION

5.1 THE STRATEGIC CONTEXT

The typical American Nuclear aircraft carrier is an 52,000 ton air base that can move hundreds of miles a day probing enemy defenses and carrying a war to the heartland of an aggressor. Nowhere on Earth are so many complicated actions, involving so many forces and energies, and requiring so much mechanical agility and allowing so small a margin for error, performed with such skills as on a carrier. It is performance appropriate to, and vital in, an era of "violent peace."

The Soviet Union is a self-sufficient land power in minerals and energy, with no defensive need for the enormous navy it is building. The Soviets have offense in mind and have three times as many ships as the United States - more conventional and nuclear submarines, more cruisers, more destroyers. The U.S. advantage is its carriers, 14 to 3. Last year, a single Soviet exercise involved 200 ships, including 70 submarines. The Soviet Pacific fleet alone has 575 ships, including 134 submarines. Consider those numbers when hearing complaints about U.S. plans for a 600 ship Navy by 1989 (up from 479 in 1980).

For the United States, with 40 treaty undertakings, commercial dependencies and global-power responsibilities, naval superiority is a necessity. In the last 40 years, presidents have maneuvered or otherwise used forward-deployed Navy and Marine units 250 times to further policy objectives. And today, the West lacks the merchant tonnage to sustain heavy losses in a submarine war of attrition as in World War II. (Hitler nearly won the war in 1942 with about 60 operational submarines.) Thus the United States needs a "forward strategy" to engage the enemy closer to his border than ours. Carriers, with their young crews of more than 5,000, are the key to that [45].

America can go with aircraft carriers or go without them, like the British in the Falklands, but go it must. Those who believe that cruisers, destroyers, amphibious ships, army transports and supertankers are safer without a carrier's 90 aircraft, or believe such an air wing could provide 24-hour coverage from land-bases, are acquainted with the laws of physics and facts of geography.

The role of the navy, and the aircraft carrier in particular, then, is not to defend itself against Soviet attacks, but rather to defend Western lifelines against those attacks. The Navy is also a potent instrument to project force in support of U.S. national security objectives short of war. And it has the capability to bring force to bear in land war.

In all these missions, the navy and marines must go where U.S. security indicates, and the carrier must go along to protect the navy and marines. With its 600-mile radius of coverage below, on and above the sea, the carrier group commands that sea, the carrier group commands that sea. Obviously one must be concerned about cruise missiles and other such weapons that might be used against U.S. ships. There is no such thing as an invulnerable carrier, just as there is no such thing as an invulnerable air force base or army division. Nonetheless, the carriers provide a margin of superiority that can make the difference between a successful resupply and an unsuccessful one, that protects men and equipment, and that makes U.S. commitments credible. [46]

The tactical aviation picture for the Navy and Marine Corps is fraught with problems. Throughout the Carter Administration, these services did not even receive enough aircraft to replace operational losses and new aircraft development. While the numbers problem is being redressed during the Reagan administration, there are other uncertainties. The Navy's fighter force is supposed to shift several squadrons from the F-4 Phantom to the F/A-28 Hornet, and 24 attack squadrons from the A-7 Corsair to the F/A-18 during the 1980s. However, the F/A-18 is experiencing significant problems, while Marine desires to buy the AV-8B Harrier VSTOL aircraft instead of the F/A-18 for eight attack squadrons could further increase the already higher-than-expected costs of the F/A-18 program. If the F/A-18 is delayed, or even canceled, the Navy could accelerate or expand the F-14 production, but the attack-aircraft situation requires further consideration.

A Stealth aircraft to replace its A-6E medium, all-weather bomber fleet has popped up high among the Navy's top priority programs-where it had not been a year ago. The Naval Air Systems Command was set to select, as this issue went to press, about four contractors from six or more bidders for further design work on its so-called Advanced Tactical Aircraft (ATA) program.

The Navy now has a surfeit of programs to modernize or replace its Grumman A-6E fleet-the "A-6E upgrade" program (Jun AFJ), the "visible" ATA program for an entirely new plane, and a "black" Stealth development being funded under the ATA guise. The Navy's Request for Proposals on ATA hinted that as many as 1,300 such planes may be bought, depending on the final procurement plan. One alternative calls for ATA to replace not only the A-6E, but also to serve as a new medium, allweather fighter/attack plane which, although optimized for air-to-ground work, would also fill a possible need for a fighter somewhere between the F-14 and the F/A-18 [47].

While little more than reported above is known about this top secret program, this much can be concluded:

1. The ATA will be the most expensive program in the DOD for next decade, the estimated price tag being 100 billion dollars;
2. There is, at present no methodology for evaluating alternative concepts of what the ATA should be;
3. Needed is an evaluation tool that is comprehensive and flexible enough to address the multidisciplinary implications of the program from with a transdisciplinary perspective;
4. In the words of an internal DOD memo, "such a tool is possible using the work performed by Professor Drew and Tran of the Virginia Polytechnic Institute and State University" under NASA project NASI-17256 -- a tool called SURMAN [19].

5. The Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS) has prepared a statement of work for a Project to be performed by the VPI&SU Team called "ATA Concept Evaluation -- A "SURMAN" Application" which is to start October 1, 1985 and continue for two years [48].
6. This Thesis reports on the research performed over the past six months to establish the viability of the survivability/lethality tradeoff concept which will be the cornerstone of the ATA evaluation methodology.

5.2 SUMMARY OF RESULTS

In Chapter 3, three component models corresponding to three basic missions flown by carrier combat aircraft -- (1) attack/interdiction, (2) air superiority, and (3) fleet defense -- are developed, analyzed and reported upon. For the attack/interdiction mission model, the "baseline" aircraft is the Intruder A-6; for the other two mission models, the "baseline" aircraft is the Tomcat F-14. The "replacement" aircraft in both cases is the ATA.

In Chapter 4, first of all the air superiority and fleet defense components are combined to provide the basis for comparing the ATA to the F-14 for the dual missions; then the composite model is developed that for evaluating the replacement of both the A-6 and F-14 by the ATA. All candidate versions of the ATA can then be compared to the A-6/F-14 baseline condition and, using the measures of effectiveness developed in this research, ranked against each other. In this section we summarize the results of five computer outputs separately in Chapters 3 and 4.

We are interested mainly in the measures of effectiveness, the initial values of level variables, and the level variables themselves. In Table 3.2 outputs were presented for all three individual models. Table 5.1 gives the initial values of corresponding threat required for the model to go into equilibrium.

In Table 5.2, again, is given the initial values for corresponding threats required for the model to go into equilibrium. The difference between Table 5.1 and Table 5.2 is that, in Table 5.1 the equilibrium for individual models was reached by altering the Delta Acquisition Costs. This change in deltas would give new initial values, which are presented in Table 5.1. In Table 5.2 the deltas remain as zero throughout. The initial values for threat were adjusted so as to achieve equilibrium. We see that the initial number of replacement aircraft and the initial number of baseline aircraft remain the same for all five models.

Table 5.3 summarizes the measures of effectiveness for all the models. In the attack interdiction model there are two categories of effectivenesses. One of them - interdiction, is not considered in the multimission case as interdiction has not been taken into account in the multimission model. This will be a task in the development of the ultimate model during the next two years of research on this project.

Table 6. INITIAL VALUES AT EQUILIBRIUM

Variables	1 (Air Sup)	2(Fl. def.)	3(Att/Int)	4(Dual Mi.)	5(Multimi)
ATAN	1200	1200	1200	1200	1200
TFN	758		758	480	480
XFN	1548			1469	727
XAN		2834	1311	892	441
RTN			2409		2092
IAN			1200		720

Table 7. INITIAL VALUES AT EQUILIBRIUM

Variables	1(Air Sup.)	2 (Fleet D)	3(Att/Int.)	4(Dual Mi.)	5 (Multimi)
ATAN	1200	1200	1200	1200	1200
TFN	758		758	480	480
XFN	1548			1469	727
XAN		2834	1548	892	441
RTN			2409		2092
IAN			720		720

Table 8 (Part 1 of 2). OUTPUTS OF SURVIVABILITY/LETHALITY TRADEOFF MODELS

Air Super.	Fleet Defense	Attack/ Interdiction		Dual Mission		Multimission		
CVTFS	CVTFD	CVIATS	CVIAAI	CVTFS	CVTFD	CVTFS	CVTFD	CVIATS
1.0000	1.0000	1.0000	1.0000					
0.6324	0.6324	0.6000	1.0000	0.6662	2.009	1.346	4.061	0.6906
CVATAS	CVATAD	CVATAT	CVATAI	CVATAS	CVATAD	CVATAS	CVATAD	CVATAT
1.0000	1.0000	1.0000	1.0000					
1.0000	1.0000	1.0000	1.6670	1.053	3.177	2.129	6.421	1.151
KLRTFS	KLRTFD	KLRIAT	KLRIAI	KLRTFS	KLRTFD	KLRTFS	KLRTFD	KLRIAT
2.039	1.592	2.007	2.302					
1.2900	2.3620	1.2040	1.3810	1.359	7.504	2.746	15.17	1.386
KLATAS	KLATAD	KLATAT	KLATAI	KLATAS	KLATAD	KLATAS	KLATAD	KLATAT
1.2900	1.0070	2.007	2.302					
1.2900	2.3620	2.0070	2.3020	1.359	7.504	2.746	15.17	2.310
EXRTFS	EXRTFD	EXRIAT	EXRIAI	EXRTFS	EXRTFD	EXRTFS	EXRTFD	EXRIAT
1.0000	1.0000	1.0000	1.1470					
0.4000	0.4000	0.3600	0.4128	0.4440	4.0370	1.8120	16.49	0.477
EXATAS	EXATAD	EXATAT	EXATAI	EXATAS	EXATAD	EXATAS	EXATAD	EXATAT

Table 8 (Part 2 of 2). OUTPUTS OF SURVIVABILITY/LETHALITY TRADEOFF MODELS

Air Super.	Fleet Defense	Attack/ Interdiction		Dual Mission		Multimission		
1.0000	1.0000	1.0000	1.1470					
1.0000	1.0000	1.0000	1.1470	1.1100	10.090	4.531	41.23	1.325
IXRTFS	IXRTFD	IXRIAT	IXRIAI	IXRTFS	IXRTFD	IXRTFS	IXRTFD	IXRIAT
1.0000	1.0000	1.0000	1.0000					
2.5000	2.5000	2.7780	1.0000	2.5000	2.5000	2.5000	2.5000	2.7780

5.3 DISCUSSION OF RESULTS

The results have been summarized in in the above section. We proceed with the discussion based on the results summarized.

Table 5.2 shows the initial number of aircraft for each of the five cases to achieve equilibrium. In the individual models the number of Soviet aircraft required for balanced attrition is greater than those for the combined models. As we see, in the dual mission case, 1469 Soviet fighters and 892 Soviet attack aircraft are allocated, whereas in individual models the corresponding numbers are 1548 and 2934 to achieve balanced attrition. In the combined model the same number of ATA aircraft are present as in other individual models. In the dual mission the fighter aircraft initial value XFN is a little less than that for individual models.At the same time, in the case of dual mission the ATA also balance about 892 attack aircraft. The combined mission appears better since it kills a large number of aircraft on the whole. Looking into Table 5.3 we find that the kill loss ratios for baseline and replacement aircraft are greater in the dual mission when compared to the single mission. Similarly the effective exchange ratios are also higher for baseline and replacement aircraft in dual mission when compared to single missions.

However when comparing the increase in exchange ratio for ATA over F-14, it remains the same in both the individual mission and dual mission.

Coming to the multimission model, we see that the same number of ATA's as in attack/interdiction model balance almost the same amount of surface threats as in attack/interdiction model. Apart from balancing surface threats the ATA's also balance 727 enemy fighter aircraft and 441 enemy attack aircraft. This again seems to demonstrate the superiority of ATA in a multimission capacity rather than in single mission tasks. Referring to measures of effectiveness tabulated in Table 5.3, we find that the combat value ratios for baseline and replacement aircraft have risen considerably over the single and dual missions. Similarly kill loss ratios for baseline and replacement aircraft have increased when compared to the individual and dual mission models. The effective exchange ratios for baseline aircraft have improved. Effective exchange ratios have also risen considerably. Increase in exchange ratio for ATA over baseline aircraft remains the same irrespective of the model type (single or multimission).

5.4 CONCLUSIONS

From the discussion of results in the previous section the ATA multimission concept appears to be potentially superior to the single mission baseline aircraft concept. A detailed study has to be carried to define the various aerodynamics, avionic and armament concepts necessary to realize this advantage (see Figure block diagram).

It appears that the exploitation of the multimission capability of the ATA would be more effective than several single missions. This logic can be compared to the tellers at a bank. The two most common activities demanded by customers at a bank is to withdraw and to deposit. Let's say that a Bank A, has separate tellers for deposits and separate tellers for withdrawals. In Bank B, the tellers perform both the activities-service for withdrawals and deposits. Let's further assume that the total number of tellers for both A and B is the same and also that the number of customers at both the banks are the same for both withdrawals and deposits. It is a known fact that Bank B would service its customers better than Bank A. The situation presented in the example above is analogous to aircraft responding to different mission requirements. With this analogy a multimission aircraft seems to be better. It should be kept in mind that, in the above example, the tellers (individually) at Bank A may perform better due to obvious specialization of tasks. This fact should be kept in mind for aircraft in a combat situation too, i.e. aircraft capable of undertaking only one particular type of mission may be superior to aircraft that are forced to undertake multimissions. The inputs from the survivability/vulnerability assessment tell us if a multi-mission ATA has the same survivability/lethality of the baseline aircraft it replaces.

As already mentioned, the research done here is the initial stage of two year research project. The research done here is meant to be expanded. It will act as a solid foundation for further study in this area.

It was mentioned in the discussion in previous chapters that the models presented here are simple, with an analytical solution within reach. As an example, as to direction in which future research will be carried out is: In the individual model of attack/interdiction it was considered that in airfield destruction of the enemy air bases only the attack aircraft are destroyed, whereas in realty other aircraft will also be destroyed. In the same model, a fraction of the ordnance could be allocated to destruction of enemy infrastructure. The level variable which can come into picture because of this aspect may be represented by some parameter such as "infrastructure value". In the fleet defense mission, it was considered that only the fighter aircraft get destroyed, whereas in reality both the fighter and attack get destroyed. When the research is extended in this direction the models will become more complex and more realistic. Like solving most problems in modeling, here also we move from simple models towards complex models.

5.5 RECOMMENDATIONS FOR FUTURE RESEARCH: PROJECT DESCRIPTION

Based in part on the results of this research the following project description/assessment for the next two-year effort is presented. It considers objectives, background, approach, transition plans and benefits.

The main objective is to develop a working, computer simulation model which can easily and quickly be used to evaluate different performance concepts (such as susceptibility, vulnerability, lethality, and inventory) for a new or modified combat aircraft; and to perform trade-off analyses between the aircraft's design/operational features and its mission requirements.

The need for a new Advanced Tactical Aircraft (ATA) is based on previous studies of the VFMX (Vertical Take-Off-Landing Fighter Experimental Aircraft and VMX (Vertical Take-Off-Landing) Multimission Experimental Aircraft, and the recommendations of the SECNAV Blue Ribbon Panel. The ATA should be an advanced technology, affordable and lethal force within the Navy, capable of meeting the Circa 2000 threats.

In the present and embryonic stage of the ATA's development, many questions concerning its survivability, mission effectiveness, force effectiveness, affordability, and technological achievability need to be answered in a systematic and rational way. The main concern now is not in searching for the right answers but in formulating the right questions due to the interdisciplinary nature required to develop a new and sophisticated weapons system.

To develop a means to formulate the appropriate questions and criteria for the ATA and to gain analytical insights into its future performance is the main purpose of this study.

To fulfill the objective of the study, system dynamics methodology will be employed for model development. The strength of the methodology lies mainly in its ability to represent causalities and feedbacks within a system, and in its capability to incorporate and synthesize interdisciplinary inputs.

There are five major areas of emphasis to be covered in the model: susceptibility, vulnerability, lethality, inventory, and systems evaluation. Susceptibility focuses on those mechanisms that lead to the detection and hit of the aircraft; vulnerability addresses the ability of the aircraft to withstand different levels of damage; lethality addresses the effectiveness of the aircraft's defensive and offensive weapons, and the ability of the aircraft to inflict damage. Inventory concerns such issues as procurement and affordability since one of the objectives of the study is to provide a mechanism for performing trade-off analyses among technology, costs and numerical strength so as to maximize the overall force effectiveness. Finally, the systems evaluation part of the model synthesizes the results of the other parts to provide a means for evaluating the effectiveness of the ATA at the tactical level as well as the force-on-force level.

It should be noted that the first three of the five areas mentioned above are engineering oriented. Our purpose is to synthesize the engineering knowledge for making management decisions. Thus, the model will be structured in order to identify technological changes that have leverage on the overall performance of the aircraft. Additionally, the model will be able to receive outputs of other studies as inputs.

The modeling of the above five areas of emphasis is divided into two tiers. The first tier provides the mechanisms for relating the engineering/design parameters (e.g., speed, signatures, weight, excess energy, etc.) and the operational parameters (e.g., payload, range, flight profile, etc.) to the aircraft's survivability. In the second tier, the thrust area is in relating the aircraft survivability to the parameters that describe the overall force effectiveness so that the changes in technology, operations and/or management can be evaluated.

A time frame of two years is proposed for this effort. This time frame allows for the development of the model, including the coordination with other organizations involved in formulating or developing technology for the ATA.

There will be no transition plans but there are benefits to the survivability program. The benefits may be realized in two general areas. First, the effort will give a concise description of the survivability discipline within the total scope of air defense. This is important in synthesizing interdisciplinary inputs and in coordinating joint RDT&E efforts. The second area of benefits is in the ability to document, test, analyze and evaluate the existing knowledge on aircraft survivability. Using the developed model as a tool, one can perform many exercises pertaining to the sensitivity of the data and thus can develop needs assessment and prioritization for future R&D activities.

The final product of the effort will be a working computer simulation model (along with documentations) that can be used to analyze the benefits of different concepts to be incorporated in the ATA. The model may also be extended to other tactical aircraft for evaluating modification options [48].

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