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NET TECHNICAL ASSESSMENT-METHODOLOGIES FOR PROGRAM PLANNING WITHIN THE DEPARTMENT OF DEFENSE

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The subject of this study is Net Technical Assessment and the object is the formalization of a methodology which facilitates accomplishing the objectives of NTA. This effort has resulted in the formulation of a methodology - actually two - together with instructions and advice on their exercise. The focus of this research is upon the technological level - systems, subsystems, and supportive sciences level - as contrasted with force structure, strategic doctrine, budgetary, or national goals levels where assessments are also performed.

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In order to demonstrate methodological practicality, an experimental approach was selected. Two Net Technical Assessments were performed - albeit somewhat quickly and only superficially. An advantage of this approach has been the discovery of first level methodological oversights, an understanding of how problems of execution can be avoided, and a first level correction of major procedural flaws. The result is two procedures for accomplishing NTA - with accompanying advance to the potential applier gained from experience.

A method for performing NTA in the "directed research" areas correlates technology with definite missions and systems requirements. This technique is termed TECHNOLOGY SUBSCRIPTED and was developed during an assessment of logistical heavy lift helicopter systems and their related technologies. Another technique for performing NTA in the "pure research" areas correlates potential system derivatives with technology advancements. This process is termed TECHNOLOGY SUPERSCRIPTED and was developed during an assessment of power/energy technology and related systems.

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NET TECHNICAL ASSESSMENT -

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BOOK TWO FIGURES (cont.)

INTRODUCTION

The subject of this study is Net Technical Assessment and the object is the formalization of a methodology which facilitates accomplishing the objectives of NTA. This effort has resulted in the formulation of a methodology - actually two - together with instructions and advice on their exercise. The focus of this research is upon the technological level - systems, subsystems, and supportive sciences level - as contrasted with force structure, strategic doctrine, budgetary, or national goals levels where assessments are also performed.

Technological Net Technical Assessment is a process of aggregation of information regarding the relative current and projected technological positions of the U.S. and foreign powers. NTA is very decision related. It embraces the issues of impact assessment of the net technical differentials and formulation of program plans designed to improve the relative position of the U.S. in the future. NTA is therefore an INTERPRETATION process which is FUTURE oriented and directed toward PROGRAM PLANNING.

Technological NTA affects essentially all weapons quality planing activities within the Department of Defense. It is one central theme in national comparisons, in budget allocation and justification, and in program correlation and planning. Some of its primary functions are elucidation of: the manner in which technology and systems relate, the relative impacts of technological advances, the rationale supporting congressional funding requests, the differences between U.S. and foreign technological posture, and the resultant differences between likely future U.S. and foreign systems developments. The NTA process is intended to establish the basis for decisional ACTION. Section 2 relates further the appropriate context for this study.

This report documents a study of methodologies for consistent approach to the preceding NTA goals. The many existent formalisms pertinent to this process include relevance techniques, morphological analysis, technology forecasting, and system analysis techniques. Definition of a methodical approach to NTA by application of these and other techniques embraces the danger of becoming too academic. Certainly, such definition is largely subjective and judgemental. In order to minimize such dangers, this effort stresses demonstration that the formulated method is workable and that it indeed produces useful results. Section 3 discusses the program of this study effort in some detail.

In order to demonstrate methodological practicality, an experimental approach was selected. Two Net Technical Assessments were performed - albeit somewhat quickly and only superficially. An advantage of this approach has been the discovery of first level methodological oversights, an understanding of how problems of execution can be avoided, and a first level correction of major procedural flaws. The result is two procedures for accomplishing NTA - with accompanying advice to the potential applier gained from experience. Section 4 defines and discusses the developed methodologies in a step-by-step manner - facilitating application of these techniques in a consistent manner by others.

An overview of the conclusions resultant from this methodology development are contained within Section 1. This section rounds out the discussion of the methodology for NTA and completes the contents of Book 1 of this report - "Net Technical Assessment Methodology."

This book is intended to stand along - to provide an overview of NTA, its goals and techniques, and to serve as a text for the uninitiated.

Results of an experimental testing of the methodology designed to examine 6.3 and 6.4 category programs - systems related technology - are reported in book 2 entitled "Assessment to Heavy Lift Helicopters Systems". The test topic was logistical support helicopter systems and their related technology.

These discussions report the results of an eight month contracted effort involving 18 man months, ending February of 1974. Dr. B.J. Berkowitz acted as Principal Investigator during the early phase of study. The activity was contracted by the Defense Advanced Research Projects Agency and jointly directed by the Net Technical Assessment offices of DARPA and DDR&E. Significant assistance was rendered by the U.S.A.F. Foreign Technology Division and the U.S.A. Foreign Science and Technology Center.

BOOK ONE

NET TECHNICAL ASSESSMENT METHODOLOGY

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1.0 CONCLUSIONS

This comprises an overview of observations resulting from the methodology development process. A more rigorous title might be "impressions". Since certain of the following statements are yet to survive objective testing or comparison with alternate contentions, conclusions is an overly strong term. The contentions listed below are, however, the significant results of this study.

Concern regarding overstatement must be balanced by advantages gained by introduction of a hypothesis - demanding careful examination as an entity. These conclusions are often in the context of Bayesian hypotheses - future information will be examined to review validity.

The following points relate to the varied aspects of NTA - the methodology, its execution, related philosophy, and personnel aspects. This is what we believe can eventually be proven.

1. Two Different Methodologies are Warranted for R&D NTA

This study recommends two procedures for two related technology problems. A method for performing NTA in the "directed research" areas correlates technology with definite missions and systems requirements. This technique is termed TECHNOLOGY SUBSCRIPTED and is suggested for application to 6.3 and 6.4 category programs (Advanced and Engineering Development programs) to show how technology supports evolution of certain system capabilities. The choice of the "subscripted" terminology is intended to reflect the derivative position of technology relative to systems in these areas.

A second technique for accomplishing NTA in the more "pure research" areas, devoid of single mission or system orientation has been named TECHNOLOGY SUPERSCRIPTED. This process is intended for application to 6.1 and 6.2 category programs (Research and Exploratory Development) to show how technology advances can provide for wholly new systems. This method dwells upon anticipating technological advances of some significance and showing how such advances might be applied. The choice of "superscripted" was dictated by the recognition that technology itself is the forcing function upon systems for such programs.

These two NTA techniques span the Research and Development field with a methodological SAWTOOTH. Depicted on Figure 1.1 is this conceptualization of the sawtooth created by the two methods. The techniques span between the blade of technology and the wood of systems with Technology Subscripted cutting in one direction while Technology Superscripted cuts in the other.

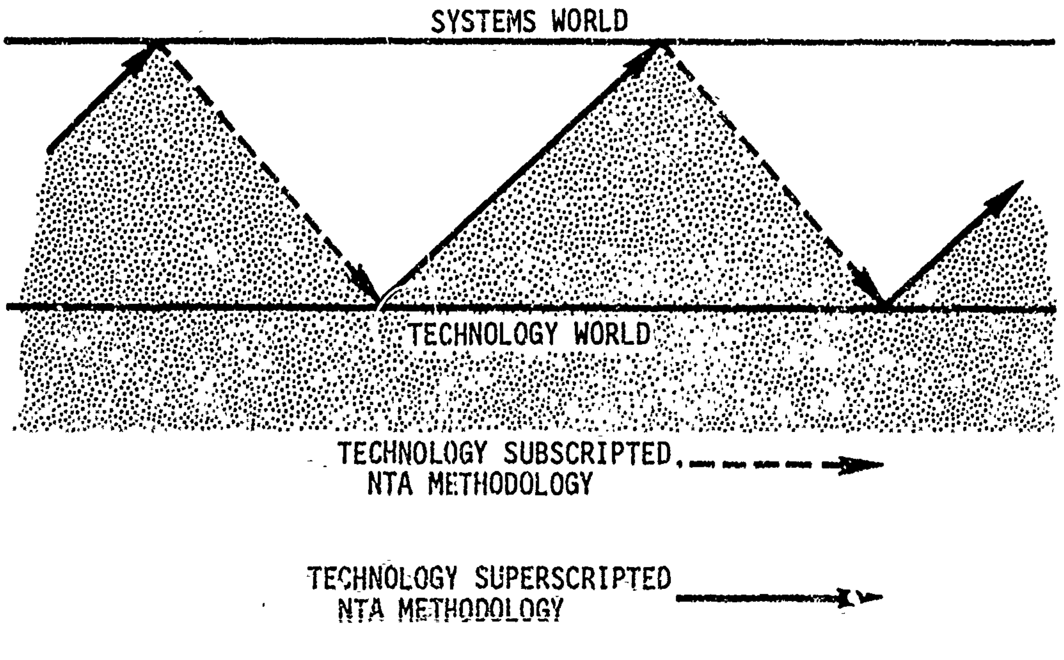

Figure 1.1 The "SAWTOOTH" of NTA methodology (from Walter McGough, Jr.).

2. The "Technology Subscripted" Method Nets System Evolutions

This technique tends to be most effective at identifying the more evolutionary technological impacts upon system advancement. The methodology is designed to initiate with a system, proceed to identify alternate system concepts impacting the mission of the original, and determine all relevant technologies for this set of systems.

The process is more than a disaggregation of the systems and supporting subsystems to technologies. It involves a degree of morphology or relevance testing at the beginning to "invent" the alternative system concepts. The main thrust of the methodology is to forcast developments in each technology to a set of prescribed dates in the future and reconfigure or synthesize a set of plausible, but nevertheless conjectured, systems for those dates. The end result is thus a set of systems with similar missions, each using a different dominant technology. Comparison of such systems quantitatively allows assessment of the relative impacts of the various technologies upon the mission and thus an idea as to the relative "future value" of funding each technology.

The NET context appears readily throughout such a procedure in the net difference between the two nations' current system capability, current technological state-of-the-art, future likely state-of-the-art, and future system performances. This procedure, portrayed in Figure 1.2, maximizes the relevances between the technologies and the system and mission.

An example of the form of the results of netting via the technology subscripted technique is portrayed on Figure 1.3. This Figure shows that the currently available technology (T_1) provides a range of system capability (dotted line) for both the U.S. (blue) and the S.U. (red). The figure also suggests that the current technology

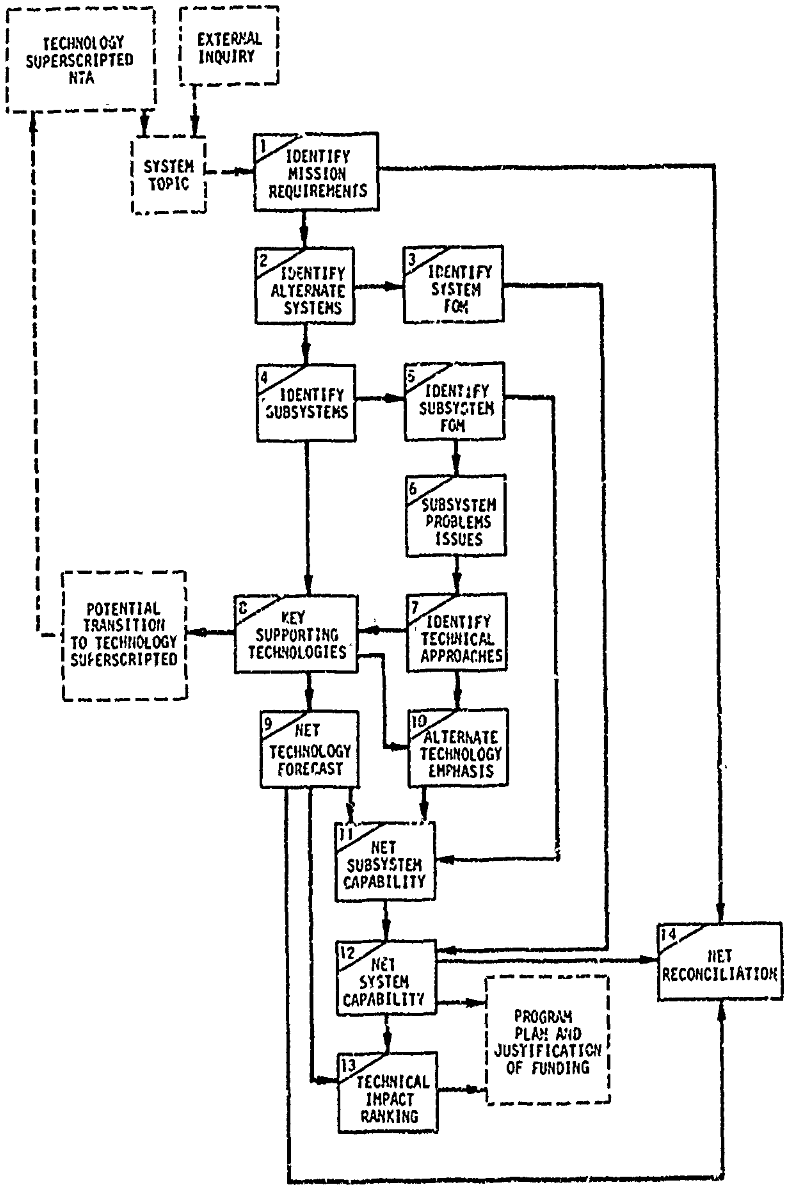

Figure 1.2. The "Technology Subscripted" Methodology

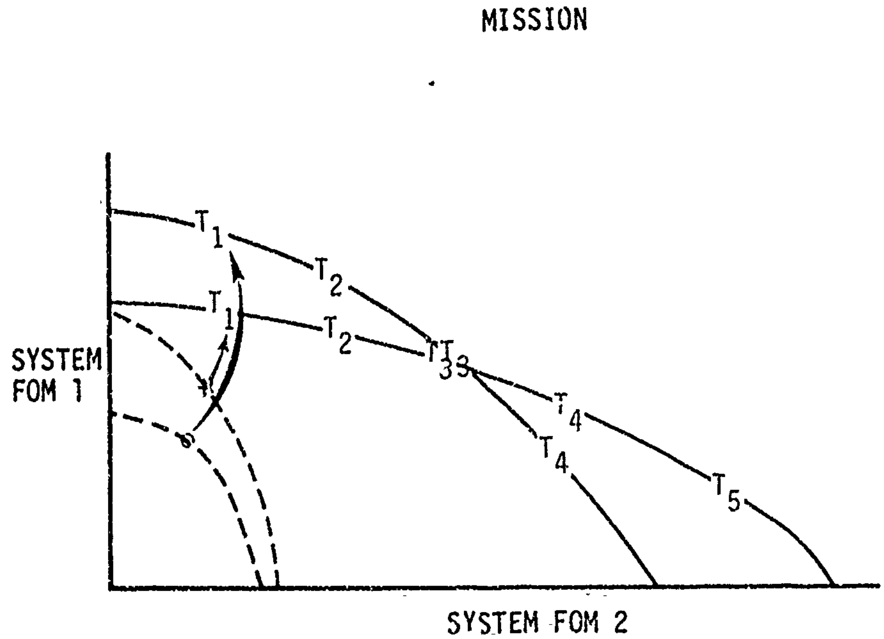

Figure 1.3. Form of technology subscripted method results.

will evolve and that it, combined with other anticipated technology options (T_2,T_3, etc). will provide a range of future system capabilities (solid line). The graph shows how those different technologies satisfy the system figure-of-merits (FOMs) to differing degrees - allowing assessment of relative funding importance depending upon mission requirements. Also evident is the net effect of different technical growth rates between the nations.

3. <u>The "Technology Superscripted " Method Nets Technology Revolutions</u>

The second procedure facilitates identification of potentially revolutionary technology sets which might result from technology growth by emphasizing morphological and relevance analyses. This process is initiated by definition of a technology or science level topic.

Such a topic is changed to more specific levels of technological specification - maintaining independence from specific mission or system constraints. The morphological and relevance techniques are used to play a word game using an association tree to focus attention at various branches within the technology breakdown. As the tree gets taller and broader, increasing specificity occurs in the terms used to describe technology. Eventually, a technology concept is "invented" through mental correlation of the displayed descriptive terms. Some inventions tend to be mere "recognitions" - existing or historical technical concepts. Some tend to be "natural" technology advancements - evolutions. But the intriguing payoff is attained with the conceptualization of a more revolutionary technological concept. These technological concepts are aggregations of technologies, usually with generic purposes, but lacking quantitative specifications. Apparent from the constructed tree is the technical base which requires expansion in order to realize the new technology concept.

With the advent of the technology innovation, various mis-misions may be added to the diagram and the resulting system concepts identified. At this point the tree portrays how a single broad science or technology might affect numerous systems - netting now produces intriguing results. It enables examination of current and future, U.S. and foreign technology status in terms of plausible technical growth with visibility into potential new system impacts. It allows visualization of the Net likelihood of technological "breakthrough" and the resulting system implications. This procedure is depicted in Figure 1.4.

An example of the association tree form of result available from the technology superscripted method is shown on Figure 1.5. The breakdown of the main technology topic to lower level and the resulting innovations are displayed. The relative U.S. and S.U. technical state of knowledge are overlayed - line width indicating effort. The subjective advantages and likelihood of success of research programs can be discussed.

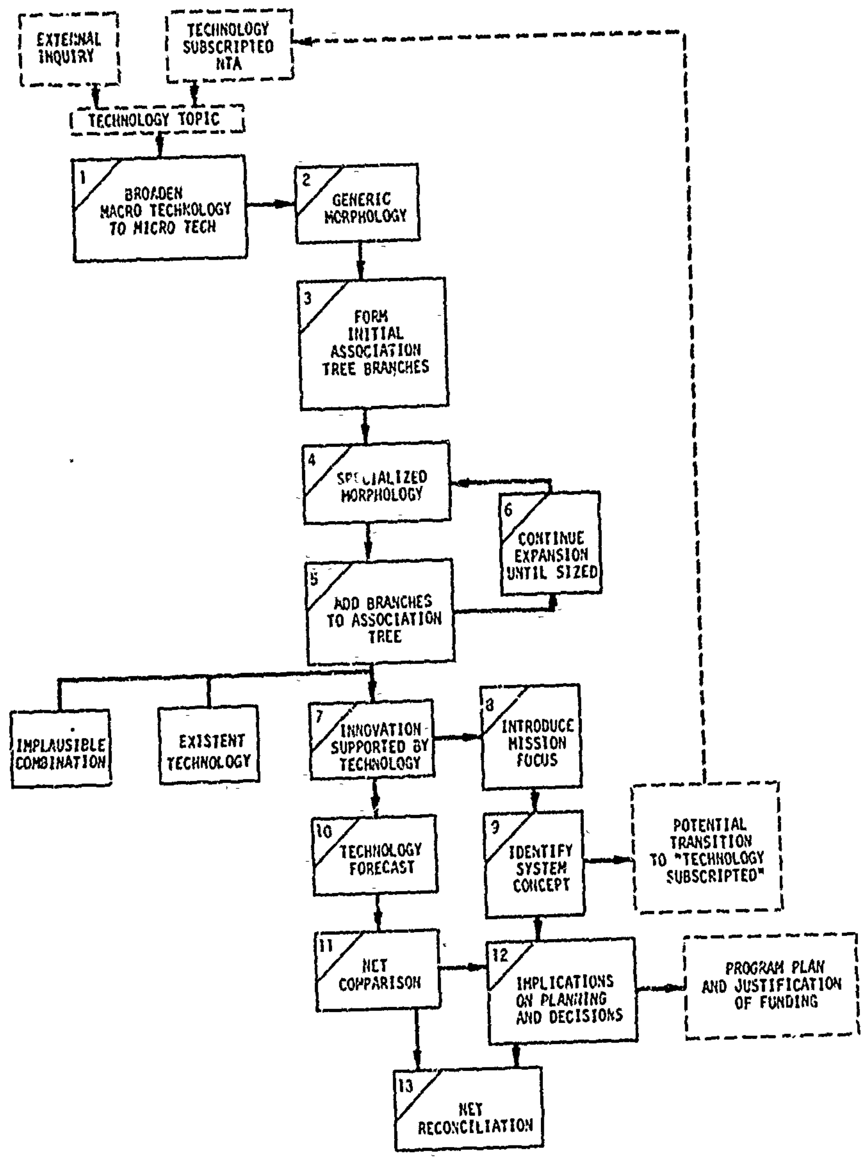

Figure 1.4. The Technology Superscripted Methodology

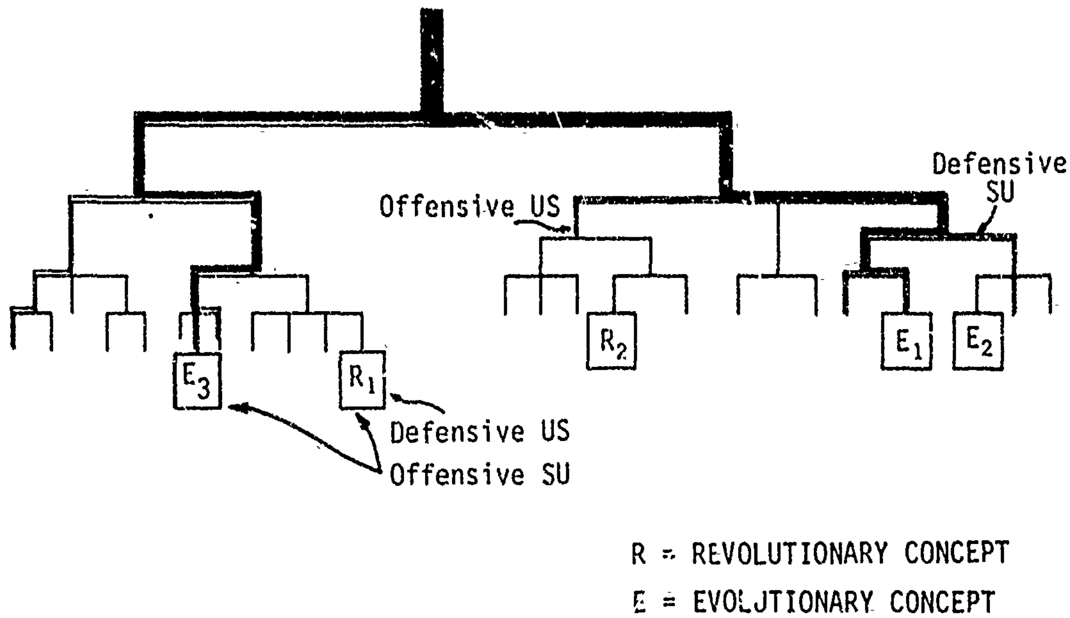

Figure 1.5. The Association Tree

4. Technology Field Overview Unlikely from Single Source

This study indicated that few, if any, technical fields have been comprehensively reported in a single open literature source. Narrow subject areas are covered in some sources. Broad conceptual discussions of the future are discussed in others. A single innovation is related in still another source. The most sophisticated of data retrieval systems and the most experienced of literature search personnel were applied to this study; a recurring absence of a single overview of technical past, present, and future topics was encountered, however.

The obvious inference is that few experts within a specific technology are capable, inclined, or funded to attempt to discern the "forest from the trees". This situation is, of course, quite disheartening for personnel setting out to perform Net Technical Assessment. It dictates that technical overview must be synthesized from several diverse literature sources by personnel whose familiarity with the field in question is low. Perhaps this situation is unavoidable and "natural" , however, it must be anticipated.

5. Readily Available Technological Forecasts are Inadequate

Experience gained during this study indicates that available technological forecasts tend to be too narrow in context, too near term, and utilize a disadvantageous figure-of-merit. These forecasts, a central tool for quantitative NTA, must be expanded upon and essentially redone during an assessment study. Proper forecasts will have to be generated unless the unexpected occurs.

However, these forecasts, performed by personnel comparatively uninitiated in the technical field, are prone to error. Certain fundamentals can be inadvertently overlooked resulting in a degree of overoptimism regarding the future technical growth. This tendency can be contained. With the properly broadened subject area introduced by NTA and an estimated forecast portrayed for review, a technique for aiding the thought process of the experts has been developed. Review by such experts is likely to result in productive gains in forecast accuracy - at least it will prevent catastrophic oversights.

6. Technology Level NTA is Concerned with the Distant Future

The true function of NTA is anticipatory. NTA is not needed to contend with a crisis event, such as the occurrence of a technological

S.U. breakthrough. Such a situation generally has a more or less obvious solution. NTA is designed to prevent untimely consequences of a breakthrough by anticipating it and planning for it BEFORE it occurs.

Military systems are expected to remain viable over a 10 to 30 year interval in spite of advances in enemy technology and countering systems. Additionally, the time interval from research or exploratory development to initial or final operating capability can range from 5 years up to 20 years. In light of such long range planning goals, NTA personnel must continue to focus attention on the wider eventualities of technology and strive to minimize preoccupation with current issues.

Because of such long range considerations, performers of technology level NTA cannot be expected to be extremely detailed in the definition of program plans. Detail is clearly more associated with a 1 to 5 year future visibility. Looking 5 to 50 years into the future more generic concepts are likely outputs of an assessment. Systems appearing in 5 to 10 years will use evolutions of today's technology while systems appearing 10 to 20 years from now may use as yet uninvented techniques. The sooner these technologies can be identified, the sooner program management can be expected to yield results.

7. The Generalist Can Prove Productive in NTA

In light of this concern with the more distant technological future and the apparent tendency of experts to examine the technological trees and ignore the forest, the generalist can provide productive insight to the future of technology. A generalist examining a technical field tends not to become preoccupied with details, allowing sifting the technological wheat from the chaff.

The generalist can often provide an important bravery - offering ideas BEFORE they have been checked for scientific accuracy. This unscientific willingness to "stick one's neck out" is a result of naivity in the field. This lack of scientific defensiveness is apparently an important quality during Net Technical Assessment studies. Arraying a large set of technical concepts before attempting to prove their viability is a significant aid to the innovative aspects of Net Technical Assessments. It is suggested that a larger danger in NTA is neglecting to mention an idea on how a system or technology might be advanced toward synergistic revolution.

As an illustration, an expert in the field of gas turbine power systems and technology is likely to think of current limitations on the number of compression stages, chamber pressure, cooling techniques, and material temperature tolerance. The expert will predict advances in these areas. The generalist is more likely to conceive of the possibility of introducing refractory materials and cryogenic fuels. The generalist is also more likely to be cognizant of past "archaic" diesels and reciprocating engines, thus orienting the thought process toward altogether different engine concepts - nuclear or fuel cell. Expert specialist attention tends to focus upon evolutionary trends while generalist attention turns toward revolutionary changes of technology and technique. EACH attitude is important to the NTA process.

One final observation may prove warranted in light of the above conclusions. While these previously mentioned impressions tended to treat personnel generically, falling prey to the danger of categorizing people, it is certainly true that individuals must actually perform Net Technical Assessments.

The methodologies have been designed to get the maximum results from each individual, independent of his background or specialization. Even if these methodologies are totally successful at this goal, expect differences in the abilities of individuals to innovate. No methodology can equalize individual talents - and if equalization did occur an AVERAGING would probably result. NTA is not different than turbine engine design in one respect - if superiority is desired one asks those with the appropriately demonstrated talents. Some individuals will thus prove more adept than others at accomplishing Net Technical Assessments - in spite of a well formulated methodology. We should not expect otherwise.

2.0 CONTEXT

An understanding of Net Technical Assessment as an entity is required in order to provide a context for technological assessment methodologies. The discussion in this section will facilitate an understanding of the various goals, users, divisions, and tools of NTA. Individuals experienced with NTA may react with some degree of boredom, but the uninitiated may gain important insight into the rationale and techniques inherent in Net Technical Assessment.

2.1 NET TECHNICAL ASSESSMENT

Net Technical Assessment is a contemporary example of progressively evolving analyses of a problem that has no fixed solution. A brief recollection of a sequence of basic questions and answers* serve to illustrate the dynamic problem that Net Technical Assessment addresses.

<u>Question</u>: What constitutes national security?

<u>Answer</u> "...ready agreement... A peaceful nation in a peaceful world... able to ensure that no other country will infringe on our rights or the rights of our peaceful friends."

<u>Question</u>: How do we achieve such security?

<u>Answer</u> "...wide agreement... by deterring war - by maintaining sufficient strength and determination . . . ."

The problem addressed by NTA begins at the level of the next question.

<u>Question</u>: What strength is sufficient for deterrence and how do we maintain that strength?

Dr. Foster maintained that this question must be answered in the context of a time-phased "deterrence and security". One can postulate that effective deterrence depends on quantity and quality of weapons as a function of time. Then weapons quantity is related to present deterrence (the quality having been previously determined) and future weapons quality is being determined by current technological decisions. A given year's DoD budget may be thought of as the Congressional resolution of the dilemma of funding tradeoffs between present quantity and future quality.

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* Statement of Dr. John S. Foster, Jr. Congress, House, Committee on Armed Services. Hearings: Appropriations FY 1974.

Future quality is a direct result of current and future technology capabilities. These capabilities are a function of the R&D decision process as indicated by Dr. Herbert D. Benington.* "The principal purpose for the Net Technical Assessment program is diagnosing and evaluating our own military capabilities relative to those of our potential adversaries in order to provide insight into how we should allocate our R&D resources and into what kind of capabilities should be pursued."

These and other descriptions of the purpose of Net Technical Assessment provide the basis for a definition of NTA. Net Technical Assessment is a process involving: (1) AGGREGATION of information regarding the relative current and projected technological postures of the U.S. and foreign nations, of (2) INTERPRETATION of the future impacts of asymmetries in these postures, (3) IDEA GENERATION to contend with the consequences of plausible future postures and of providing (4) ALLOCATION insight to development effort within imposed constraints.

NTA is more aggregated and applied than intelligence analysis. It embraces the issue of threat anticipation and evaluation at both technical and operational levels. It provides criteria for a balanced R&D effort and is therefore an input to the management of the R&D process. It is a consequence of widespread recognition of the need for planning R&D in a competitive environment in which each side's activity must be - to some extent - determined by the activity of the other side. NTA examines the similarities and asymmetries between the competitors, and forces evaluation of the future effects and possible responses to such similarities and differences.

A completed Net Technical Assessment study will result in: (1) comparisons of relative national technical status, (2) a menu of

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* Statement of Dr. Herbert D. Benington, Congress, House Committee on Armed Services. Hearings: Appropriations FY 1974.

ideas likely to improve the relative future U.S. condition, (3) evaluation of the relative value and importance of such technical concepts, (4) recommended allocation of effort for pursuit of such ideas, and (5) formalization of a program to bring the concept to fruition. In other words NTA encompasses significant data pertinent to the decision process, the management process, and the justification for congressional funding.

Within the past few years, there have been extensive and explicit attempts to translate abstract national needs into R&D allocation decision inputs. Contemporary Net Technical Assessment methodologies represent a significantly more mature manner of gaining international insight and using it for decision making. The NTA focus to put budgetry meaning into descriptors of the future quality of a sufficient deterrent has proceeded via several efforts. Figure 2.1.1 displays the breadth encompassed by these efforts.

ATTEMPTS TO MEASURE RELATIVE US/USSR POSTURE *		
● POLICY ENUNCIATION	● OUTPUT COMPARISONS	● UNKNOWNS
● INPUT COMPARISONS	• Basic Technology	● INVESTMENT ALLOCATION
• Scientist/Engineer Training	• Rate of Innovation	
• Soviet Funding	• Systems brought to IOC	● RDT&E RATIOS
• US-Equiv Soviet Funding	• Lead Time Comparison	
• Facilities Growth	• "Side-by-Side" Comparisons	

Figure 2.1.1. Scope of NTA efforts.

* Foster, op. cit.

Dr. John S. Foster Jr has described these NTA programs as follows:

"The pace of technological change in the world today requires that present and future prospects for the security of the United States be carefully assessed. The leaders of the Soviet Union continue to state publicly their dedication to technological strength.

"Analyzing the impact that this Soviet dedication to science and technology has on U.S. security is the main task facing the net technical assessment (NTA) program, to which we have given significant emphasis during the past few years. The program stresses the identification of military deficiencies so that the RDT&E program can be focused upon correcting them and thus improving our forces. Identifying critical deficiencies is extremely difficult. A military capability is a chain of many links--command, control, communications, logistics, trained personnel, weapons and their maintenance, and the strategy and tactics to be employed. The salient difficulty lies in the need to make a timely determination of weak links in military capability and either strengthen them or find a way around them.

"This NTA program helps us--

. to understand the technical capabilities of the forces that we now have, based on their demonstrated performance in conflict or in realistic operational tests;

. to explicitly describe deficiencies; and

. to attain better insight into the nature of technical changes required for future systems and tactics.

These assessments, which identify strengths and deficiencies in U.S., allied and adversary military capabilities, including deficiencies in intelligence data, go not only to the RDT&E community but also to the following:

. intelligence - as recommendations for the collection of new data and for increased emphasis on the analysis of existing information.

. technical military operations--as recommendations for improved training, changes in organization or control, etc.

. arms control--every major proposal for arms limitation or reduction requires many assessments, including a technical one, as part of decisions on possible arms agreements.

"As in the past, primary emphasis in the NTA program has been given to assessing the relative strengths of U.S. and Soviet strategic forces.

"The Soviet Union has long felt that, in the struggle between the two social systems, science and technology will be the most important field of competition and that whoever wins this race will end up being the predominant power."

The scope of NTA is so broad that its many aspects have been divided. Demitry Ivanoff has presented a hierarchy of NTA topics which assists in understanding the scope of NTA. Figure 2.1.2 displays this hierarchy which might be summarized by: National policies and goals, budgets and objectives, force structures, systems, and technologies. The aspects of NTA which address the upper hierarchy - above systems - will be discussed as an entity.

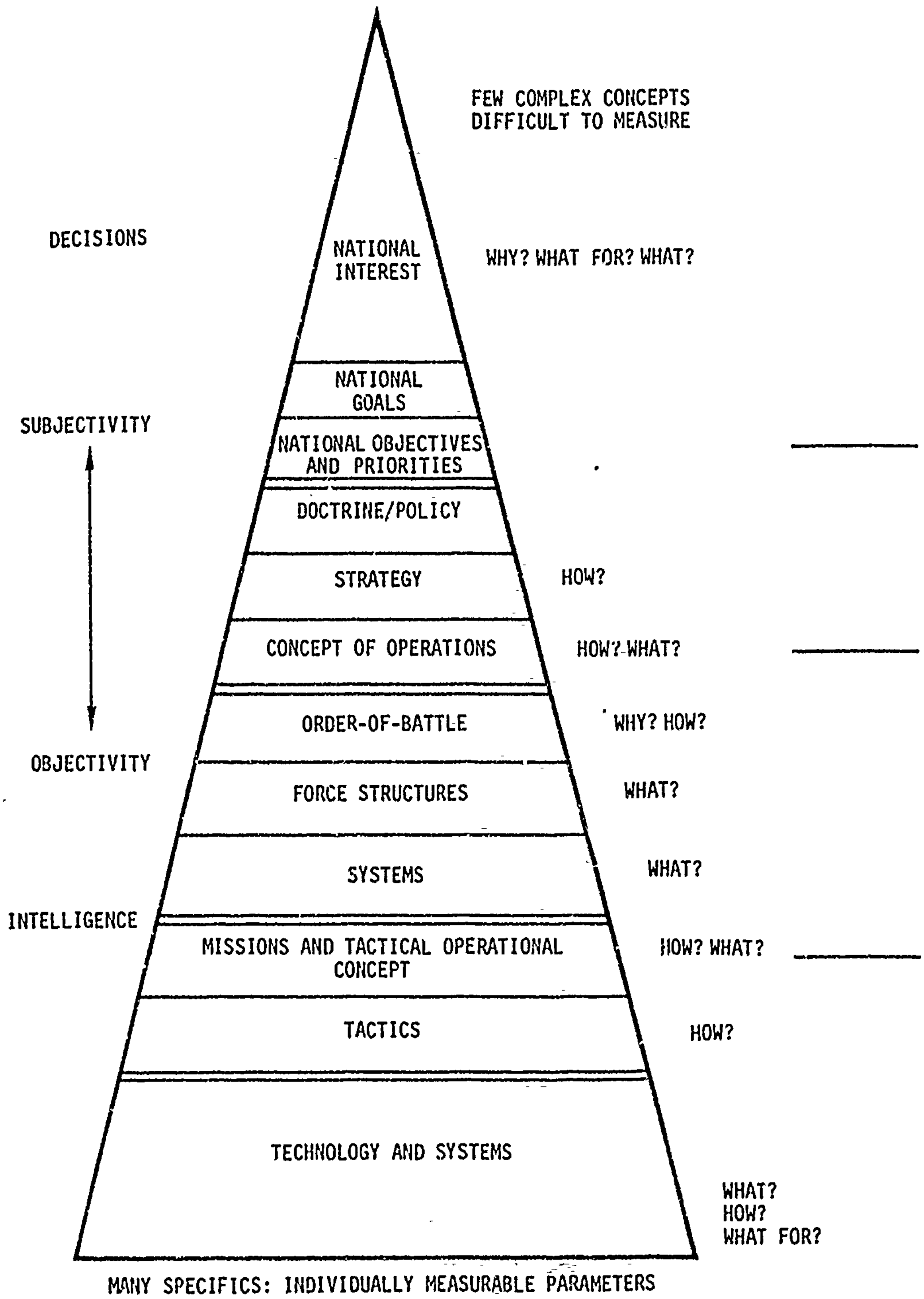

Figure 2.1.2. Hierarchy of NTA. *

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* Ivanoff

2.2 THE UPPER HIERARCHY

A brief description of the scope of Net Technical Assessments within the hierarchy above the systems level will provide a useful context for future elaboration of the technology level NTA.

Dr. John S. Foster, Jr. stressed in statements to the House and Senate that the conclusions reached by NTA analyses were directly related to the maintenance of national objectives. Some years ago an attempt to translate lofty national objectives into some degree of R&D allocation insight summarized the consensus of a test group in the following manner. A twelve point statement of national objectives, Figure 2.2.1, was subjectively prioritized, as depicted in Figure 2.2.2. Since the fulfillment of one objective generally contributed to the fulfillm. . of others, correlation analyses considered these interactions. The subsequent profiles of the relatedness and degree of fulfillment provided by the strategic and general purpose forces then presented a relative indication of needed areas of R&D emphases in the broadest sense. The results are summarized in Figure 2.2.3.

An example of how NTA relates national goals with missions towards which forces must be designed is portrayed in Figure 2.2.4. The analogous mission tree for the S.U. does not necessarily compare directly, giving rise to a net asymmetry at the mission level. Budgets must be allocated to support systems for each mission, and NTA provides the rationale for U.S. force structures based upon the status of the S.U. force structures.

Some NTA efforts have addressed ideological and political statements in an effort to determine an insight into the S.U. system of values and management concepts. Such statements indicate the Soviet view, and were cited by Foster, Kohler and Harvey.

U. S. NATIONAL MILITARY OBJECTIVES
(circa 1970)

Rank Order	
1	Deter military attacks against the U.S.
2	Limit damage to the U.S. if an attack against it has occurred.
3	Favorably terminate hostilities against the U.S.
4	Deter military attacks against essential U.S. allies.
5	Maintain surveillance over regions important to U.S. security.
6	Favorably terminate hostilities from attacks occurring against U.S. allies.
7	Minimize the damage to U.S. and allied interests resulting from attacks occurring against U.S. allies.
8	Ensure the U.S. freedom of access to sea, air and space; deny it to others when it is to the U.S. advantage.
9	Assist in the self-defense of selected foreign nations.
10	Support U.S. diplomatic undertakings.
11	Protect U.S. nationals and property interests outside of the U.S.
12	Assist civil forces to maintain U.S. domestic order.

Figure 2.2.1. U.S. National Military Objectives (circa 1970)

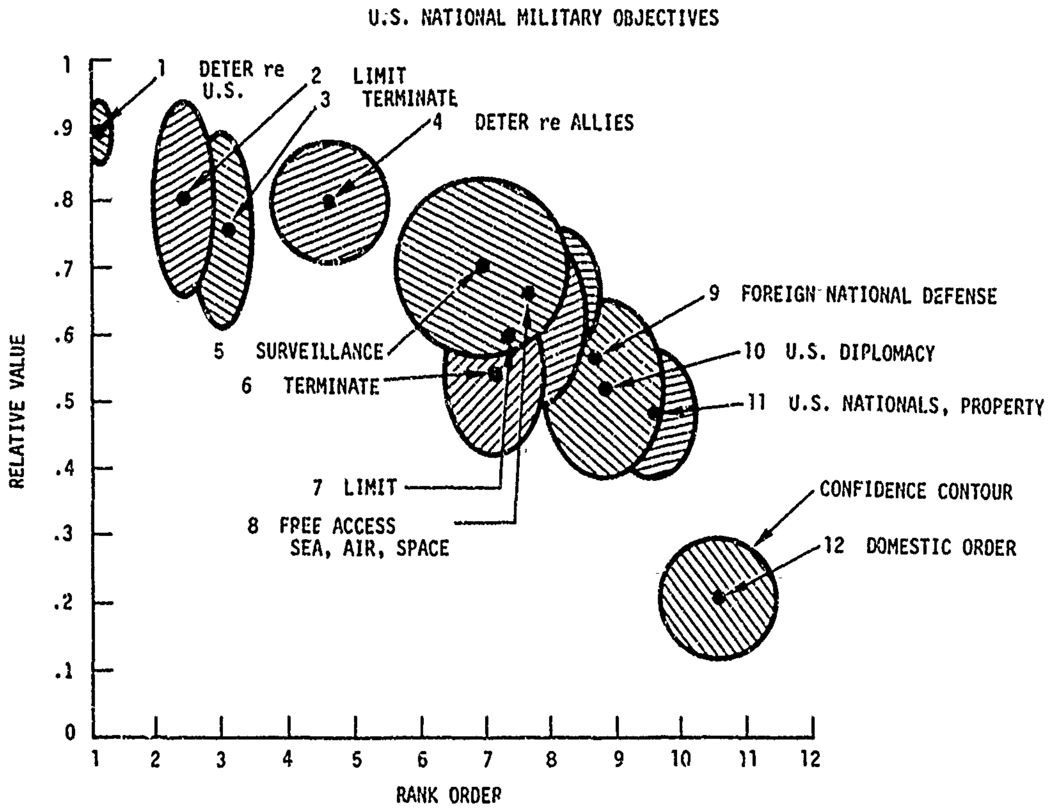


Figure 2.2.2. Priority Ranked Objectives *

> "Science and Technology have made it possible for us to create a powerful qualitative new material and technology base. -- Our superiority in the latest types of military technology is a fact, comrades, and one can't escape facts."
>
> (Leonid I. Brezhnev
> 23rd Party Congress, 1966)

> For our Party, the further intensive development of scientific-technological achievements...[has] decisive significance.
>
> (Brezhnev, December 1968)

* Hajic

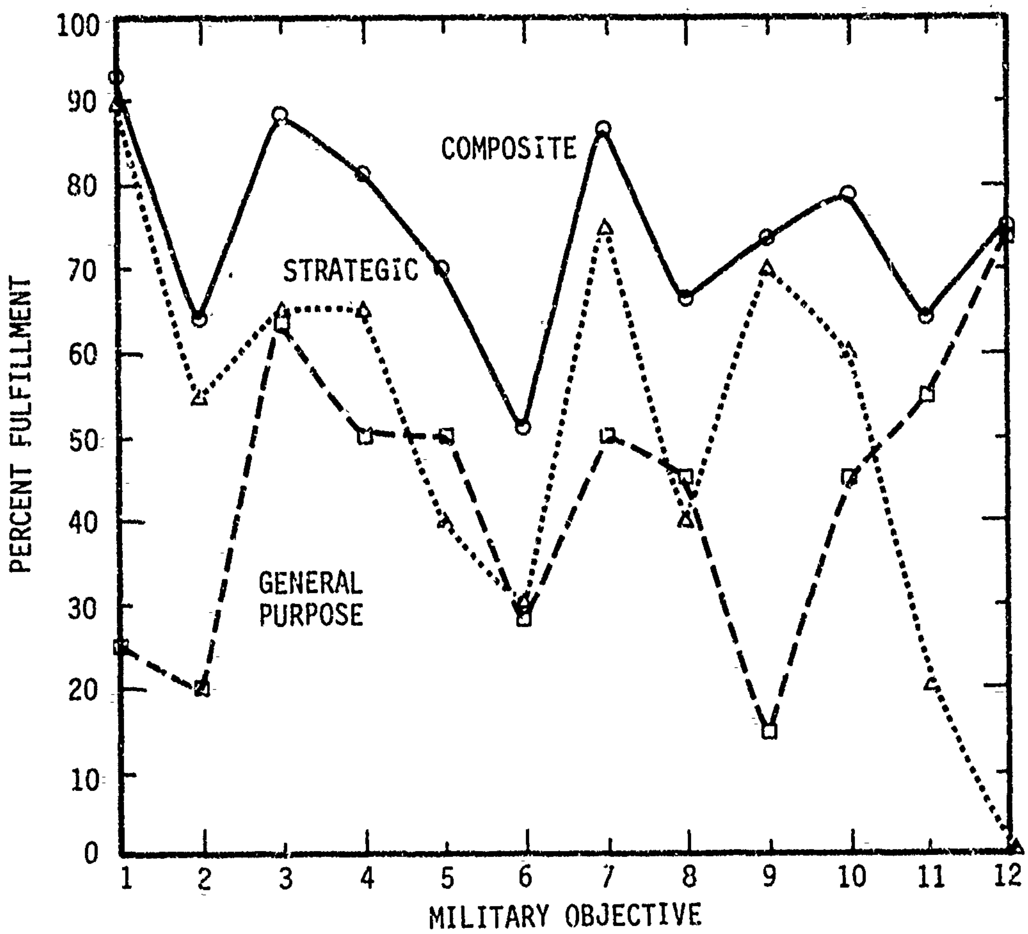


Figure 2.2.3. Subjective profile of objectives fulfillment. *

"The USSR not only occupies one of the first places in training of specialists with a higher education (we train many more engineers than does the USA), but courageously helps others."

(V.P. Aleksandrov, 1970)

"During the current Five-Year Plan, the expenditures of the State for science and technology will increase in comparison with the preceding Five-Year Plan by more than 60 percent.

(Kosygin, November 1971)

Additional study has been focused upon the Soviet strategies which give impetus to such statements by the S.U. leaders. These analyses compare

* Hajic

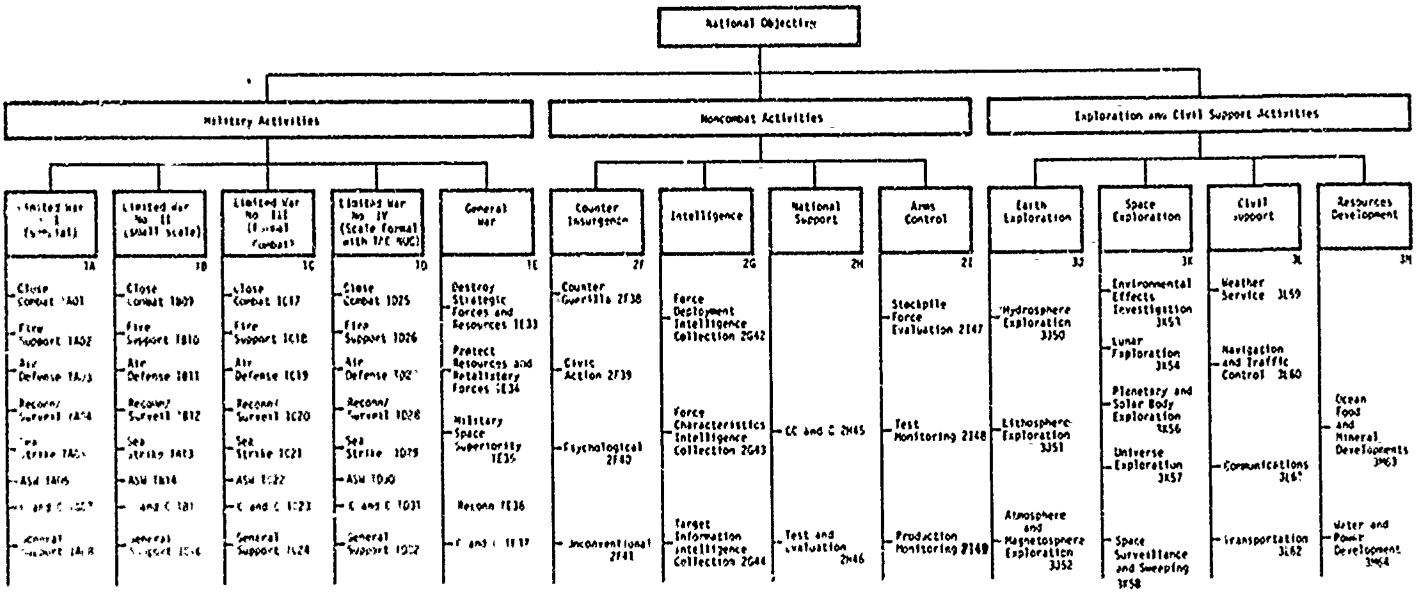
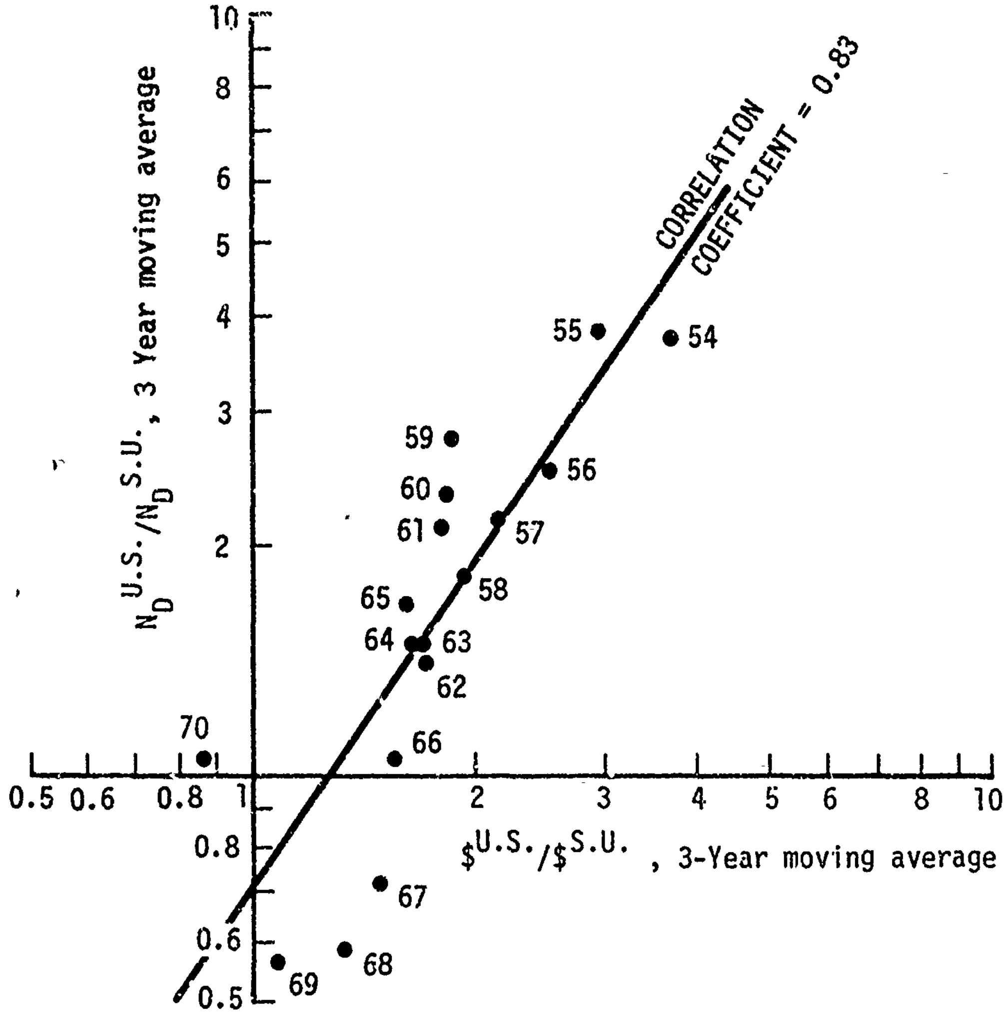


Figure 2.2.4. Mission Relevance Tree*

manpower and economic resources which have been allocated to the Defense Departments within the U.S. and S.U.

Net Technical Assessments have been performed of U.S. and S.U. RDT&E Resources, expenditures, manpower, plant capacities, productivities, and efficiencies of research. Figure 2.2.5 is an example of NTA from a study by Schultis. It displays an analysis of historical data showing that the U.S. is comparatively inefficient at developing systems when it is operating at budget levels similar to the S.U. This figure suggests also that the U.S. is lately losing the degree of lead in systems developments and that the S.U. is increasing its budget comparatively rapidly. These RELATIVE conclusions are the results of NTA.

* Maurice E. Esch (Honeywell) in Bright and Schoeman



U.S./S.U. Number of Developments Ratio versus U.S./Soviet Military R&D Budget Ratio (Logarithmic Form)

Figure 2.2.5. Relative U.S. and S.U. Developmental Efficiency. *

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* Schultis et. al. in S-397

A second example of NTA used by Dr. Foster is displayed in Figure 2.2.6 showing the decreasing trend in the U.S. lead time for comparable systems. NTA is charged with discovery of such trends the interpretation of severity, and the recommendation of corrective action.

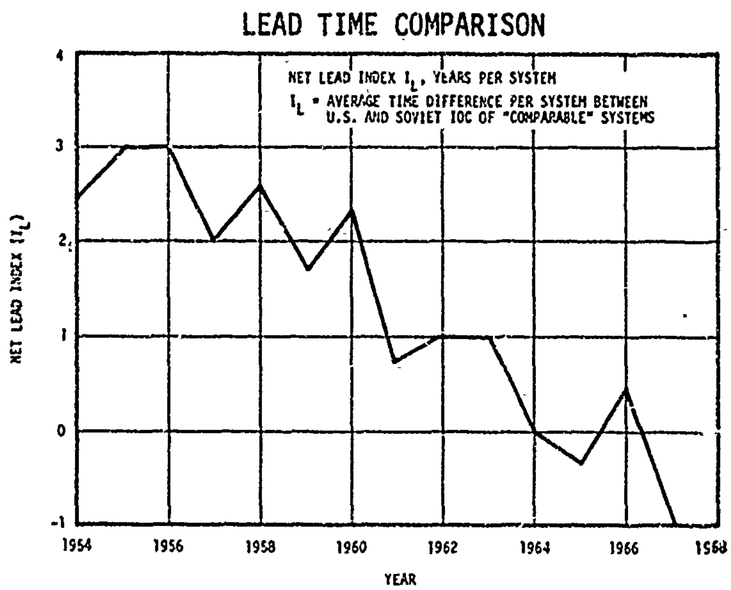

Figure 2.2.6. NET S.U. and U.S. lead times. *

Such examples tend to illustrate the scope of current NTA programs and the forcefulness of their message. It is evident, however, that even these and other detailed summaries of NTA studies cannot assure Congressional concurrence with the recommended R&D funding levels. The opposition exists for several reasons, these are:

- Some NTA results are not accepted
- Some NTA results are not used further in the decision process

* Schultis, et. al. in S-397

- The NTA has not been completely implemented
- NTA conclusions may be difficult to translate into specific resolution of allocation dilemmas i.e., no clearly defineable, agreed-to correlation functions exist between NTA, and R&D allocation increments.
- Subsequent Congressional opinions do not necessarily correlate with quantitative evaluations
- The composite of all NTA summaries do not represent all the Congressional decision making inputs and considerations.

Thus, some Congressional reactions have been voiced in the following way (e.g. by Senator McIntyre) speaking as Chairman of the Subcommittee on Research and Development:

> "I would like to focus attention on two problems. One involves the decision when to start major weapon system developments and the other, the technology race with the Soviets.
>
> In the past, Mr. President, the decision to produce a major weapons system marked the dramatic commitment to multi-billion dollar expenditures. In fact, as long as a program was progressing satisfactorily in research and development and the program was otherwise not subject to serious question, it was generally supported by the Congress. But the cost of developing a major weapon system now has grown so large that we no longer can afford to start new developments even in the interest of technology. We must ask hard questions as to need when a weapon is first proposed for advanced development, and before substantial contractual actions have been taken. Otherwise, these programs become progressively more difficult to turn off, even if they cannot be justified as required.
>
> Now the second problem is not new. We have been deluged with warnings about the acceleration of Soviet technology and the danger of being left behind in this vital race. I do not take this lightly, and this has been a matter of serious and specific consideration in our reviews. It also is specifically addressed under title II of the committee report on the bill.
>
> Let us examine this problem in its broadest context. To me it looks as if the right hand does not know what the left hand is doing.

> The United States permits industry to export technology to the Soviets, ------
>
> This problem goes beyond the Defense Department and requires positive and forceful action by the administration as well as Congress."

Again, it is evident that decisions about technology have of necessity been translated to levels of national objectives - indeed even to the extent of considering the significance to civil international trade.

2.3 THE TECHNOLOGY BASE

The national technology base depicted by Ivanoff as the base of the pyramid, supports system development which in turn fulfills missions and finally satisfies national objectives. Technological level Net Technical Assessment can become quite quantitative. This technology is a basis for future capabilities and as such it receives much attention.

Dr. Stephen J. Lukasik has identified three requirements for DARPA activity which serve to outline all of our concerns for preserving national security. These are:

1. The maintenance of leadership in forefront areas of technology. Relevant areas are selected and supported 'to the point where we feel we have exhausted their potentiality'.
2. Systematic development of (specific) advanced weapon concepts.
3. A continuing in-depth review of technology in the sense of how both we and others might apply it with differing advantages.

But what specifically is our technology base? Technology as a term is intentionally broad. It encompasses the realm of science and extends to systems. Technology embraces even generic subsystem and system capabilities. If it is desirable to separate actual systems from technology, it might be accomplished by drawing the line at the point where multiple performance specifications are introduced. For example, technology may be regarded as a continuous variable on which when multiple figures of merit are used, these describe a system capability.

Dr. Foster utilized a summary of NTA work by Dorough to illustrate comparisons of the U.S. and S. U. technology base. Figure 2.3.1 portrays this summary of 167 technology areas showing the results of a qualitative comparison of the two nations. This data has the characteristic of representing only the current situation. Mr. Dorough is also concerned with the future postures as indicated by quoting his paper (see references).

> "Sometimes there is a tendency to think of the future in terms of the present--to feel that the really important technological breakthroughs have been made and that our future capabilities will be improvements of our present ones. Many of them certainly will be, and the technology will be necessary to make those improvements possible. There is little or no reason to suppose, however, that major innovations--capable of drastically affecting our future economics and military capabilities--will abruptly cease in 1973! The history of the past several centuries, in fact, has shown an exponential increase in the rate of introduction of new technologies with revolutionary effects, and this trend has continued to the present moment. Technology acquired during the past 15 years, for example, makes possible today's compact, large capacity, high speed computers; surveillance and communications satellites; and laser guidance for "smart bombs." The enormous potential of lasers, for use in a great diversity of military weapon and communication applications, is only beginning to be realized now, as novel scientific and engineering concepts are brought to practical application as advanced technologies. What other revolutionary prospects may lie in the future--even the relatively near future--cannot be predicted accurately. It can be predicted with virtual certainty, however, that such breakthroughs will appear if we continue to work toward them. How many will appear, how soon, will be influenced profoundly by how much money and effort we devote to obtaining them. The same is true for the USSR."

Technological NTA is concerned with such qualitative aspects of the problems - with significant benefit. What systems need which technologies? What is the current and plausible future RELATIVE U.S. technical status? Which technologies offer the greatest prospects for providing revolutionary system capability? How should such technologies

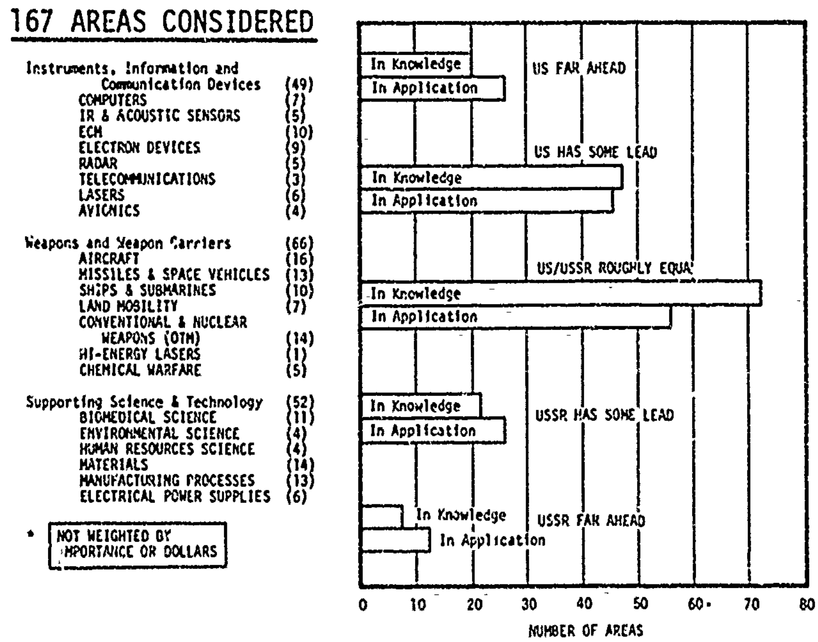

Figure 2.3.1. An overview of U.S. and S.U. Technology *

be focused to maximize the relative future U.S. capability? These are the questions for technological NTA. These are the questions to which the physical scientists and engineers can apply their quantitative techniques in order to provide answers.

Some of these techniques pertinent to quantitative technological NTA are trend extrapolation, technical forecasting, morphological analysis, relevance techniques, heuristic forecasting, and system analysis. NTA in the technological sense is a process which uses such techniques to allow comparisons, projections, and program formulation on the basis of intelligence regarding the two nation comparative state-of-the-art. There are a multiplicity of considerations to quantitative technological NTA, but at a minimum it consists of a two sided technical forecast with particular attention devoted toward

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* Foster

discerning implications of differences between the two sides and explanation of the causes behind those differences.

Thus technological NTA is charged with determining, for both competing nations, the likely quality of weapons which might be deployed in the future. These future weapon systems, resulting as they do from application of each nation's technology base, can be compared in a side-by-side context - similar systems being compared in terms of capabilities. But what are the subsystems and technologies which are likely to be applied to such systems? They can be compared also, future system capability against subsystem and future technological know how against technological know how. NTA must anticipate the direction and extent of technology evolution and revolution on both sides in order to anticipate or guide development of future systems.

The NTA process facilitates identification of the manner by which technologies relate to systems - the competing or alternate technological paths to achieve a given system capability being illuminated by the process of netting. The alternate technical approaches to advancing a given U.S. system capability can also be compared during NTA, allowing choice of the best path toward that capability. Differing national policies and technology status dictate differing approaches to advancing a particular capability - these differences are highlighted during the NTA process. The two nations will be likely to take differing but predictable approaches to achieve a desired capability.

The essential aspect to a quantitative NTA process is the technological forecast of the likely rate of future advancement of a specific technical state-of-art. Technological forecasting is a study and an art in itself, but is so central an issue to NTA that the relationship of forecasting to the NTA process must be dwelled upon. While in some cases the assessor might expect (hope) to find preexisting technological forecasts, more often than not he will have to modify such forecast data to suit his purpose. Thus assessment personnel are likely to have to perform such forecasts.

Another essential element of technological NTA is the anticipation of technical innovations, both evolutionary and revolutionary. The techniques of morphological and relevance analysis are thus also central to NTA since these are aids to inventiveness. They are formalisms directed toward assisting mental correlation of diverse technologies and requirements which provide the basis for an innovation. An understanding of morphology and relevance is not only essential to successful technological NTA but such understanding contributes to fuller understanding of NTA itself.

2.4 THE CENTRAL TOOLS OF TECHNOLOGICAL NTA

TECHNOLOGY FORECASTS

Technology forecasts are future projections of technical capabilities and as such are an integral part of quantitative NTA. A technology forecast is a graph consisting of the capability figure-of-merit (FOM) on the ordinate and calendar time on the abscissa. The plotted technology performance contours consist of several curves showing the capability created by evolutions of various special approaches and an overall capability trend curve which reflects continual transition through such approaches.

Examples of the particular approaches toward strength of aviation materials would include wood, steel, aluminum, and composite materials. Each has its characteristic curve of strength per unit weight versus time. The contour representing the overall trend of capability is called a macrovariable by Ayres, while contours of the capability of each supporting approach is referred to as a microvariable.

The central theme in the creation of a forecast of particular importance to NTA is the proper recognition of the technological macrovariable to be predicted. Figure 2.4.1 presents the concept of the macrovariable as the long term trend on top of several microvariables which are the capabilities of supportive technologies with comparatively short term trends. Both macrovariables and microvariables tend to have the form of a learning curve.

In focusing attention upon the currently vogue technological approach, a forecast anticipates the rate of technology evolution--and includes only the likely improvement to current techniques. This is

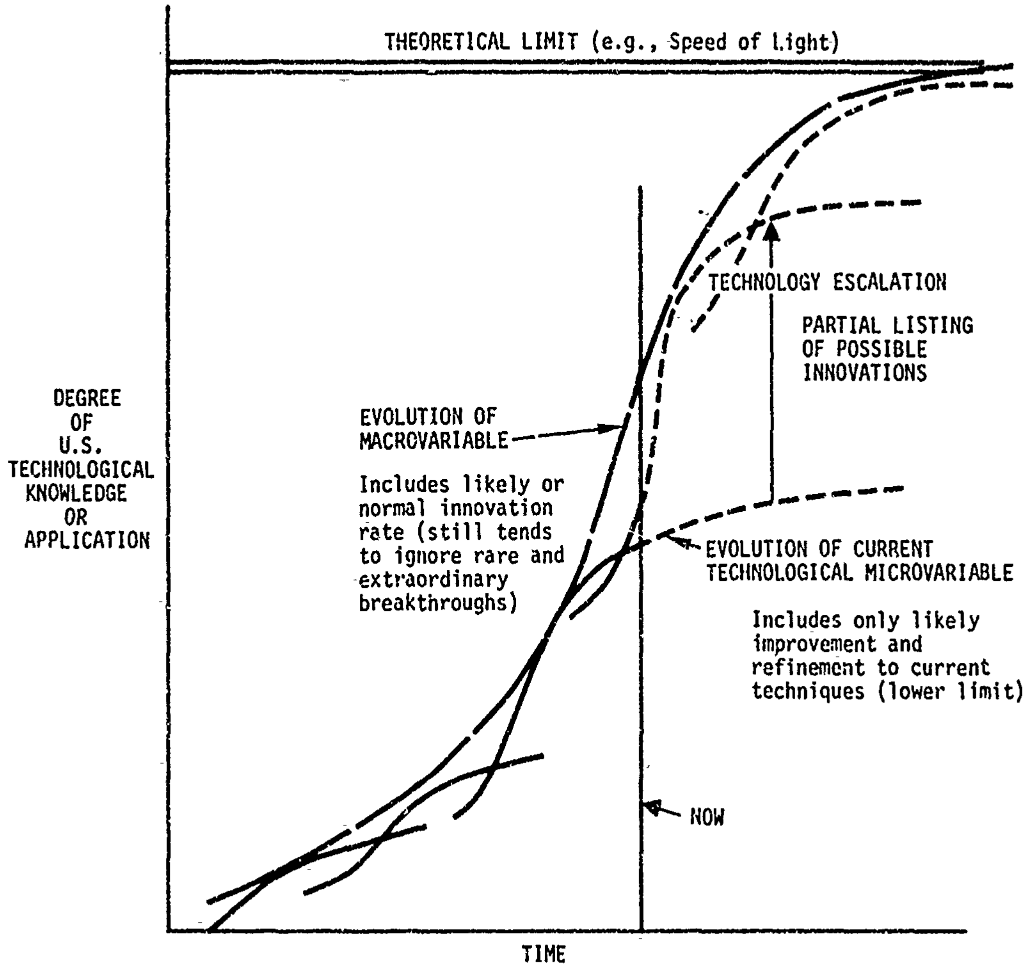

Figure 2.4.1. The Nature of a Technological Forecast.

usually the approach of "a little more and a little better". As such, the forecasted microvariable often can be regarded as the lower limit to the future technological capability.

The result of replacing one technical approach by another "invention" is referred to as "escalation" by Holtor and Ayres. The figure portrays this escalation as an anticipated future increase in the capability--but does not explicitly state HOW this new capability will be achieved. Instead, a partial listing of several plausible alternate ways is suggested in order to facilitate the process of planning a program design to expedite achieving the capability. The degree (magnitude) of the improvement in capability which is likely to be gained by escalation may be evident from theory or from the past history of the macrovariable trend.

Study of the macrovariable trends has shown that extrapolation of trend lines are good approximations as long as the microvariable trends and theoretical limits are observed. An example of theoretical limit is the speed of light limit to velocity. However, the maximum energy content per pound of chemical fuel is not an interesting limit to bomb technology since it ignores nuclear reactions. Obviously, ignoring a true theoretical limit is as potentially incorrect and embarrassing as accidentally treating a microvariable limit as the macrovariable limit. The macrovariable forecast by nature includes the capability of the "normal rate of technological innovation", but it generally still tends to ignore the performance escalation caused by rare and extraordinary breakthroughs of technology.

The conscious recognition of the existence and nature of micro- and macrovariables is as central to NTA as to technological forecasting. That is, great care is warranted in order to assure a sufficiently broad definition of the issue at hand. NTA becomes less useful to long range research planning as the emphasis upon microvariables increases. The more one asks about camshafts and piston sizes the less attention can be given to Wankels, diesels and turbines. Almost all major advances (or revolutions) in a capability involve totally new systems, subsystems, or technologies and could not have been anticipated by disaggregation of the old system to its component technologies.

The technological macrovariable is the technology figure-of-merit (FOM). Thus the choice of an FOM must not be made lightly and indeed the FOM should be normalized to the theoretical limits. Failure to take this precautionary step can lead to extremely misleading results as pointed out so well by Ayres. Figures 2.4.2 and 2.4.3 are displays of the same data but forecasts derived on the basis of 2.4.2 are invalid because of the asymptotic nature of the macrovariable. Figure 2.4.3 is a very appropriate example of judicious choice of the macrovariable (FOM) and an informative portrayal of microvariables. Figure 2.4.4 portrays particle accelerator microvariables in a particularly forceful example of the performance escalation from one technique to another. The envelope of these microvariables has not been drawn but it is evident that in the 1970 to 1975 time frame the macrovariable of energy (MEV) would predict on the order of 1,000,000 MEV capability. This has not occurred because of the existence of an exogenous limit--cost. Current accelerators simply cost a significant fraction of a gross national product.

NTA, like technological forecasting is an art in the selection of the proper study breadth. In the case of forecasting, where breadth is reflected in the choice of the macrovariable i.e., the figure-of-merit, normalization or an implicit mission relationship of the macrovariable is usually in order. Figure 2.4.5 is a useful example of a poorly chosen macrovariable, as is evidenced by the near asymptotic

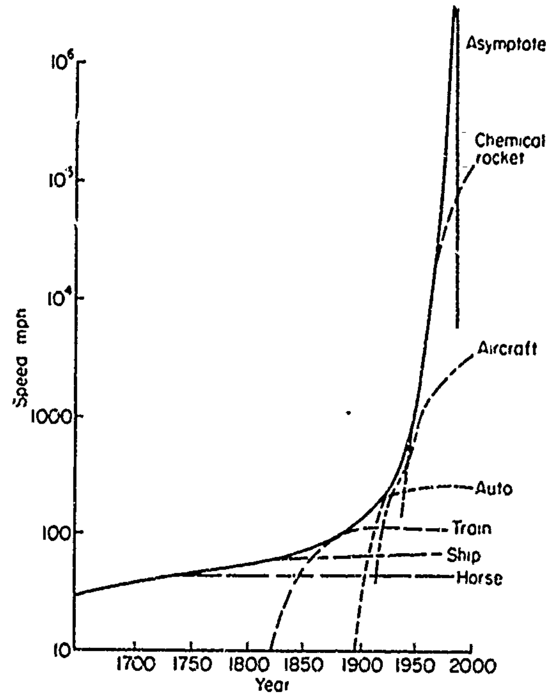

Figure 2.4.2. An Invalid Forecast*

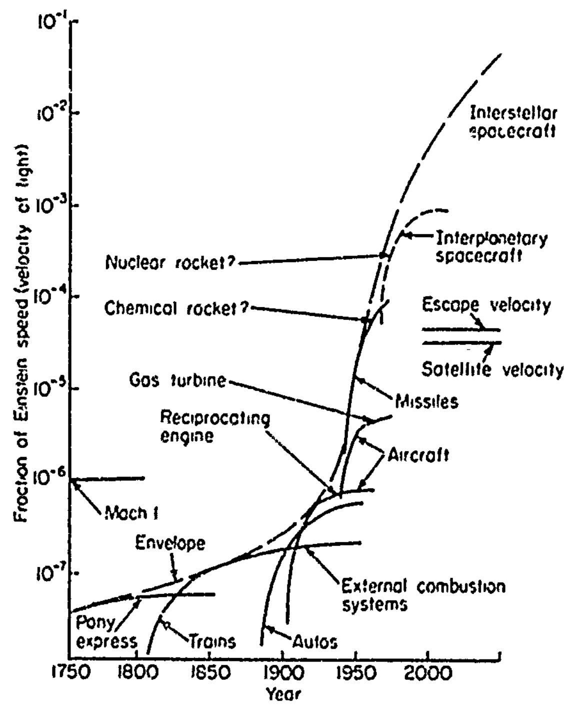

Figure 2.4.3. A Valid Forecast*

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* Ayres

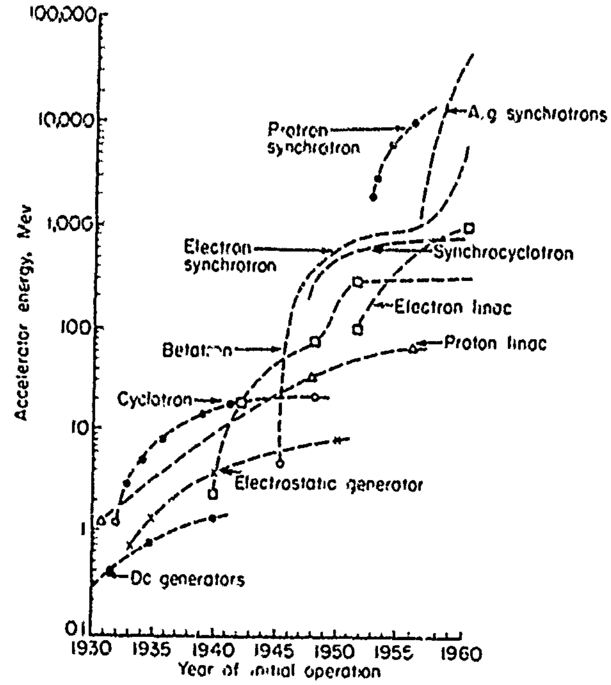


Figure 2.4.4. Particle Accelerator Microvariables*

nature of the curve. Improvement is feasible by recognizing classes of microvariables associated with the technologies of chemical bombs and nuclear bombs and normalizing performance to weight. The plot of delivered energy per pound of bomb would enlighten the forecast, but is likely to result in the question being raised--"what next?" There is no basis in physics for another escalation of class. The problem is in too narrow a study topic. Consider two subsets, however,--application to population or application to facilities and hardware. In each case, one of the primary deficiencies with bombs has been the poor allocation of energy -- the energy is too intense, but too confined. A better measure against people would be: Area coverage to a given calorie per square centimeter per unit bomb weight, or even fatalities per unit bomb weight. Recognition of these considerations and definition of the resulting FOM is crucial to a productive

* Ayres

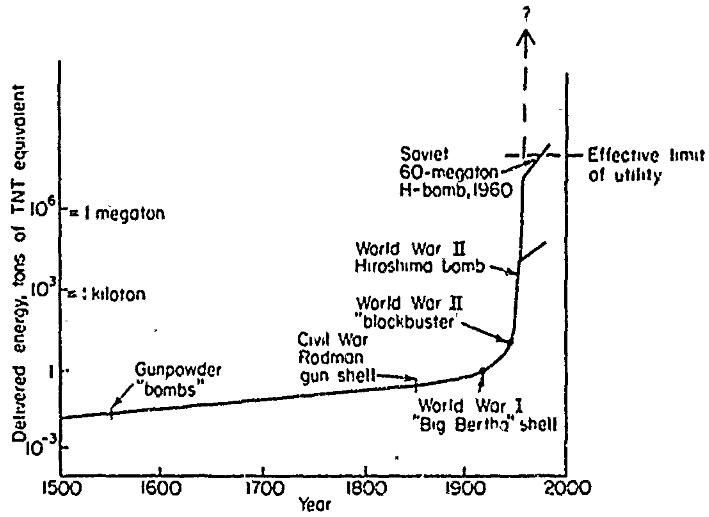


Figure 2.4.5. A Poor Weapons Macrovariable*

forecast since escalation is now feasible. Payloads of radiation darts, fuel air explosives, and CBW are now constituents of the same curve. The associated macrovariable curve now has a more functional and productive story to tell.

Another major forecasting consideration is that of data inference using leading indicators. Figure 2.4.6 and 2.4.7 show typical examples of how class capability may often be a precursor for another. The frequent situation is the diffusion of military capability into the commercial markets. Similar trends can be observed between the precursor of advanced engineering development performances and eventual production military hardware. In such a case the lag is often cited as development cycle time which, in the context of Net Assessment can be different for the two countries being netted.

If forecasts are regarded as inputs to NTA, intelligence data is similarly an input to development of technological forecasts.

* Ayres

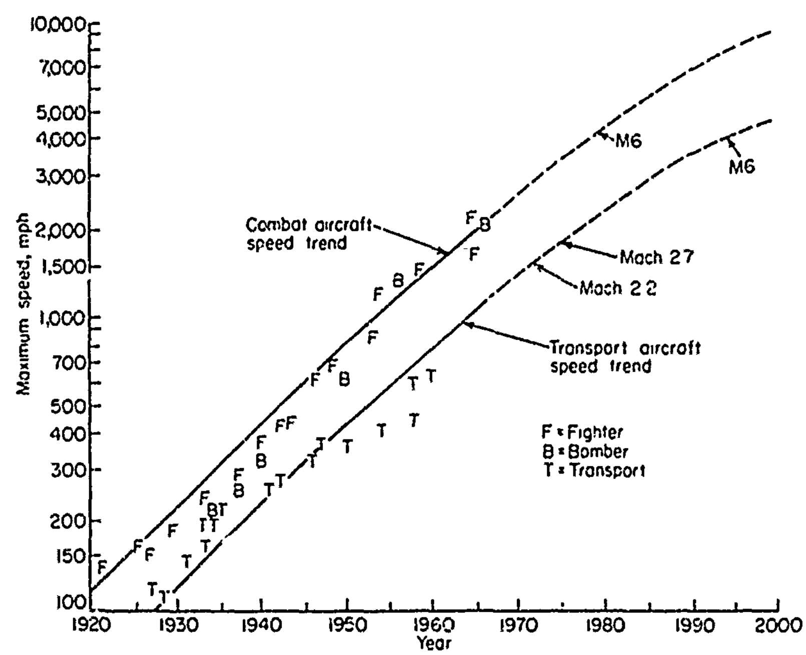


Figure 2.4.6. Aircraft Speed Precursor Forecast*

Furthermore, depending upon the relative leading or lagging position of the U.S. with respect to the other country, the intelligence data may dramatically affect the ability to forecast into the future. In the conceptual diagram on Figure 2.4.8, the U.S. (blue) is portrayed as being a precursor as compared to the S.U. (red). In other words, as a result of the high state of U.S. knowledge depicted, the future of the U.S. capability is somewhat predictable. Also, the S.U. capability is very predictable and "surprise free" for a period equal to the lag interval divided by the relative S.U. effort. Continued technological development on the part of the U.S. is warranted as an "offensive development effort" which strives to continue the lead, make maximum use of this capability, and causes concern on the part of S.U. Intelligence analysis information on the status of S.U. is the input which establishes the degree of lead and is an input to the determination of

*Ayres

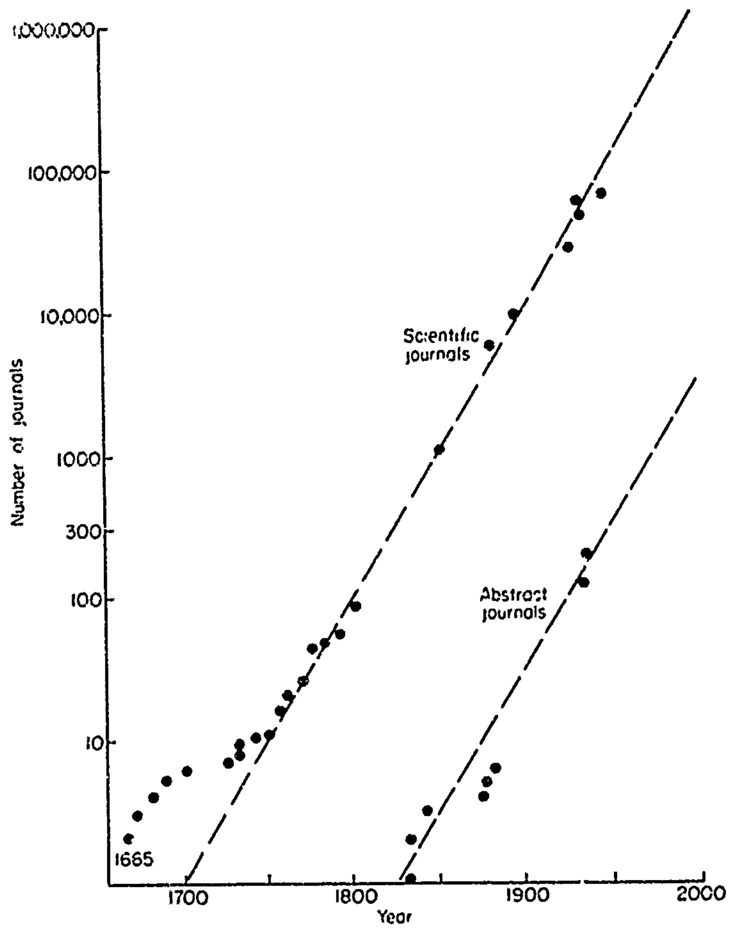


Figure 2.4.7. Document Quantity Precursor Forecast*

* Ayres

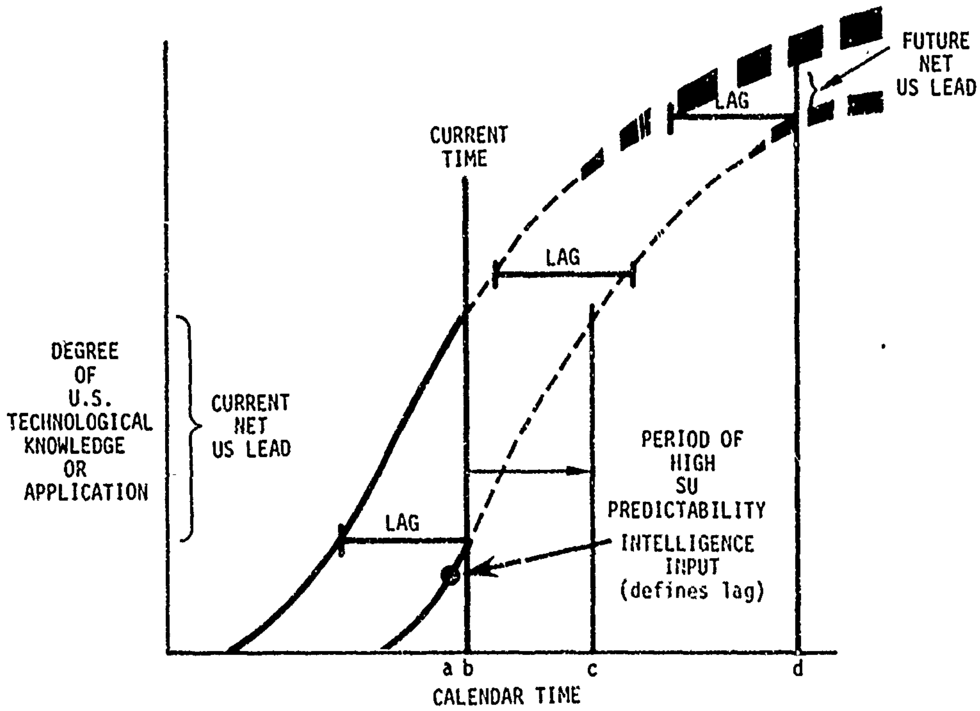


Figure 2.4.8. Role of intelligence with Net U.S. lead.

the Net capability. It is important to ascertain the relative S.U. level of effort as a function of time. Intelligence delay is critical; if the delay is many years--then the current lag or lead becomes more probabilistic. NTA and NET forecasting can be useful for illuminating the proper questions and tasks for the intelligence community as well as interpreting the resulting data.

Figure 2.4.9 displays the concept of a forecast with the U.S. lagging in development--a situation potentially justifying a "defensive" U.S. research program to learn enough to predict the potential S.U.

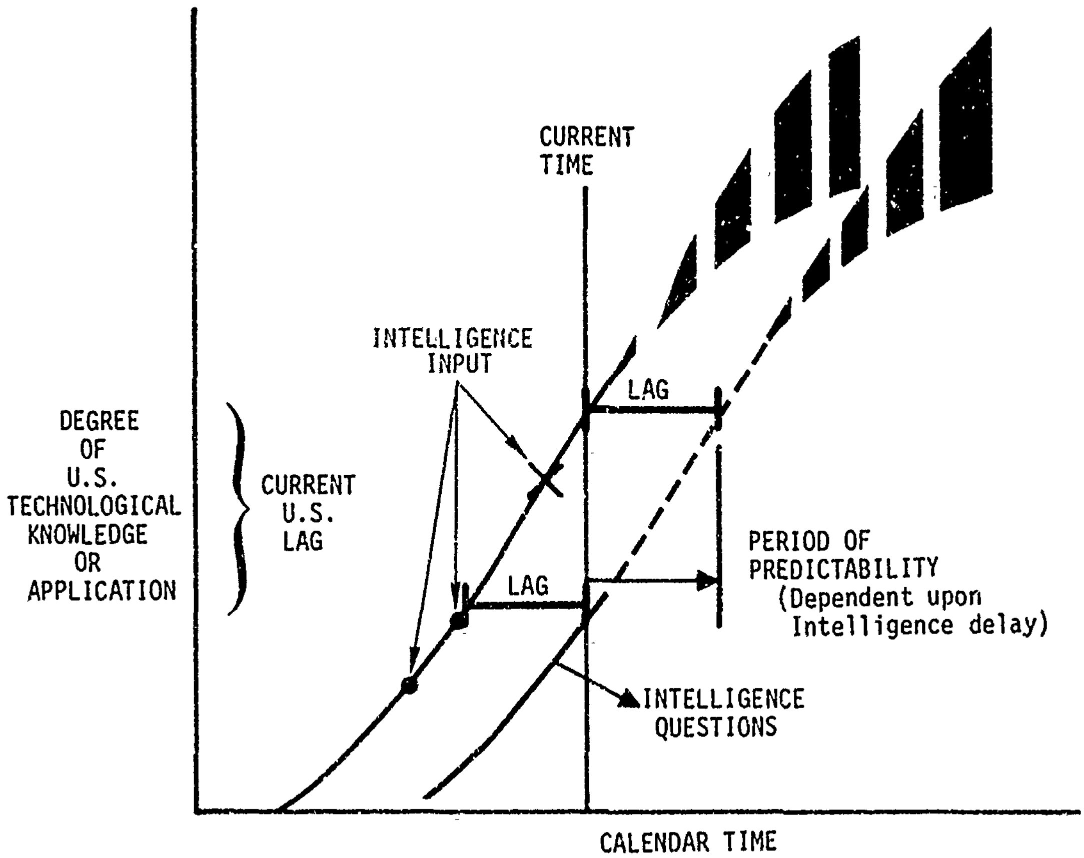


Figure 2.4.9. Role of intelligence with Net U.S. lag.

surprises. In this case, the role of expedient intelligence is even more important, since this is the data which prompts a projection of capability required on the part of the U.S. for 'balance'. For example, if the intelligence data marked X did not occur, the predictability of the U.S. and S.U. capability would need to be more disparate at much earlier times to be 'visible'.

Technological forecasts are a key to quantitative NTA, without which system synthesis, tradeoff studies, and impact ranking becomes more qualitative. The qualitative understanding, though, still satisfactorily aids association of systems and technology and anticipation of the NET capability--both useful in program planning.

MORPHOLOGICAL ANALYSIS

As indicated in the previous discussions, one of the goals of technological NTA is anticipation of the more revolutionary technical advances. In technology forecasting the analogous problem is identifying the plausible opportunities for escalation to another microvariable. Morphological analysis is a valuable means to this end.

A morphology is an array of terms in two dimensions. These terms are portrayed in successive rows with each row having a title (macroterm) and a set of subservient descriptive terms (microterms). These are analogous to the macrovariables and microvariables of forecasting. Each row of terms in a morphology embraces a totally independent consideration affecting the basic topic being examined. The concept of morphological analysis is to consider one term (microterm) from every row simultaneously - encouraging mental correlation of the set of terms and conception of a composite technological or system approach. Thus, morphological analysis is a formal word game with the possible reward of a revolutionary innovation being conceived. Each term in the morphology is intended to be a mental trigger firing the gun of the mind at the target of innovation.

The morphological method, according to its contemporary author, Zwicky, "is concerned with the totality of all the solutions to a given problem." There are six basic aspects to preparing and implementing a morphology.

1. Identify scope of the problem
2. Establish macroterms

3. Specify microterms
4. Synthesize concepts
5. Test completeness
6. Evaluate concepts.

Identifying the subject scope of the morphology is analogous to specifying the forecast FOM. Too narrow a scope tends to constrain the number of useful solutions, just as in forecasting it limited useful insight. On the other hand, too broad a subject definition risks a relatively complex, possibly confusing, morphology which generates a large quantity of trivial combinations. It is, therefore, important to carefully consider the scope of a morphological exercise before embarking upon model construction.

Each morphological subject must be characterized by a number of macroterms. Use, construction, physical properties, principles of operation, performance variables and environmental attributes are examples of macroterms describing the dimensions of a particular subject. A central theorem of morphology is that these macro terms be totally independent from one another. The macroterms, of course, vary with the subject under investigation and one art of morphological analysis is selection of appropriate macroterms. No limit is imposed on the number of macroterms. However, the fewer the macroterms the easier it will be to correlate microterms mentally.

For each macroterm, a complete set of microterms must be defined. Each microterm should be independent of the other microterms in the same macroterm. The choice of each microterm is a crucial one for this is to be the clue upon which the mind must conceptualize. The individual must feel comfortable with these microterms to maximize productivity. There is a pragmatic limit to the number of microterms in any one macroterm dimension. A generic morphology is illustrated in Figure 2.4.10. Microterms 1-1 through 1-N1 describe the various attributes of the macroterm 1 category. If, for example, macroterm 1 identified the category of "color", the microterms could be "red," "blue," "green," "orange," etc. Instead of colors, spectral frequency could be used. Synthesis of concepts proceeds via conceptual selection of one microterm from each macroterm. The morphological model displayed in Figure 2.4.10 is the basis for the generation of conceptual products. The concepts are derived by tracing paths through all macroterms intersecting one microterm from each macroterm and subsequently correlating them mentally.

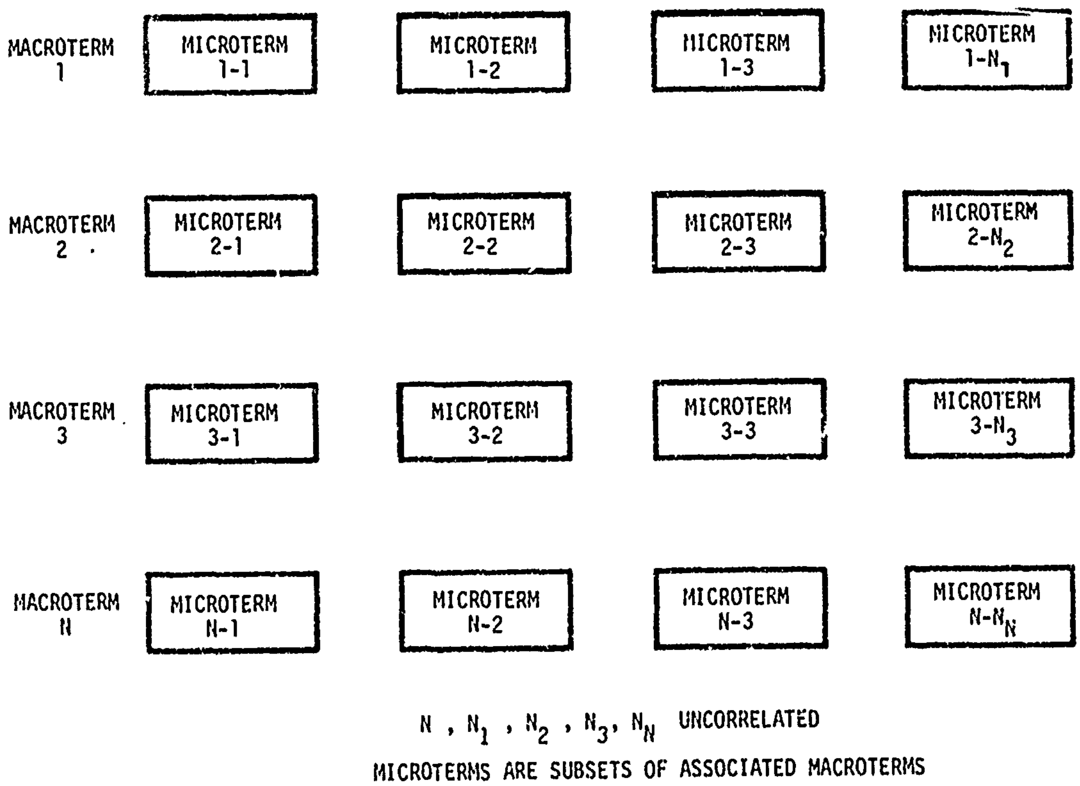
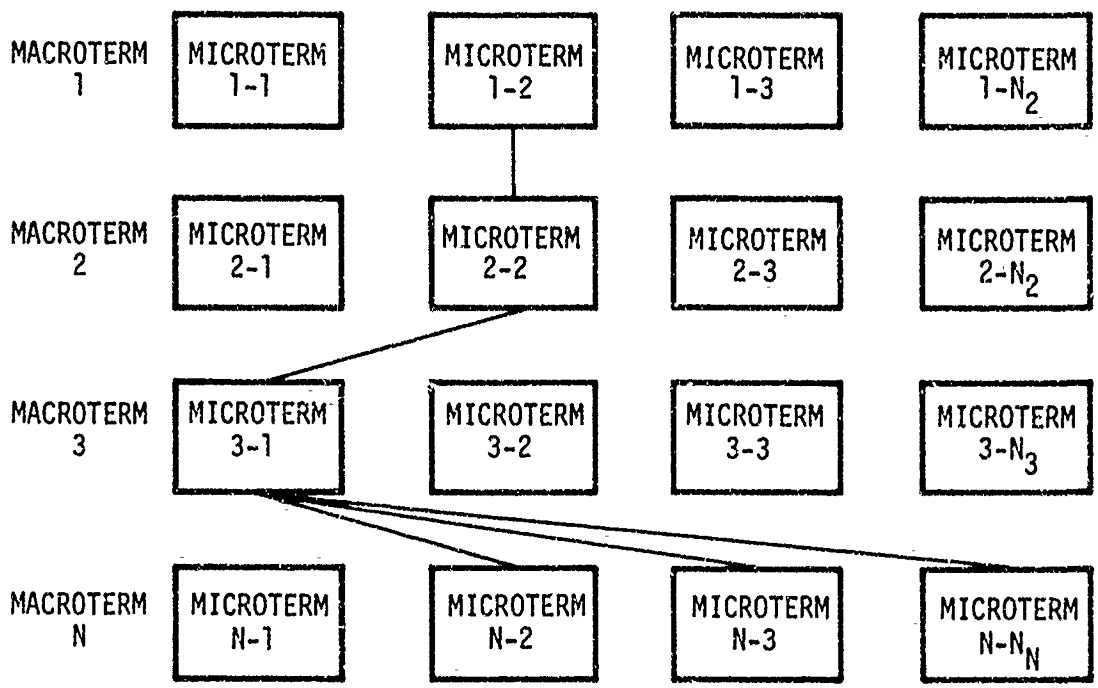


Figure 2.4.10. A Generic Morphology.

This process is illustrated in Figure 2.4.11 where three separate paths have been indicated. Each of the three lines shown passes through microterms 1-2, 2-2, and 3-1. The paths differ only in the last macroterm where three separate microterms are used to describe three distinct concept attributes. Having drawn or visualized one or more paths, the innovator attempts to conceive of the technologies or systems which are suggested by the set of microterms in each path.

To illustrate further, a simplistic morphology can be prepared to assist conceptualization as portrayed in Figure 2.4.12 by Martino. Addressing four prominent macroterms of aircraft, the quantities of wings, engines, fuselages, and tails are specified as microterms. This model has a total of $4 \times 13 \times 4 \times 4 = 832$ possible solutions. A path through 0 wings, 0 engines, 1 fuselage and 3 tails superficially suggests an unusual aircraft with doubtful utility. Upon closer inspection, however, the zero wing microterm suggests a device with lift capability in the body structure. Zero engines connotes a glider, taken aloft by a separate, powered vehicle. One fuselage seems more or less conventional. Three tails might suggest improved control, stability. The unusual concept suggested by this model is the HL-10 lifting body now under development. Conceivably, this model could have been used by the designers of the HL-10 to evaluate all possible design configurations.

Similarly, the model can be used to develop the configuration for the Boeing 707 by tracing another path through the macroterms. In this illustration, it should be noted that the path shown for the 707 also describes many other conventional 4 engine aircraft, indicating that the addition of one or more macroterm dimensions such as type of engine, range, etc., could enhance the utility of the morphological model.



ATTRIBUTES OF 3 PRODUCTS

1. (1-2) (2-2) (3-1) (N-2)
2. (1-2) (2-2) (3-1) (N-3)
3. (1-2) (2-2) (3-1) (N-N_N)

A TOTAL OF $N_1 \times N_2 \times N_3 \times N_N$ COMBINATIONS ARE POSSIBLE

Figure 2.4.11. Microterm Combinations

AIRCRAFT MORPHOLOGY EXAMPLE

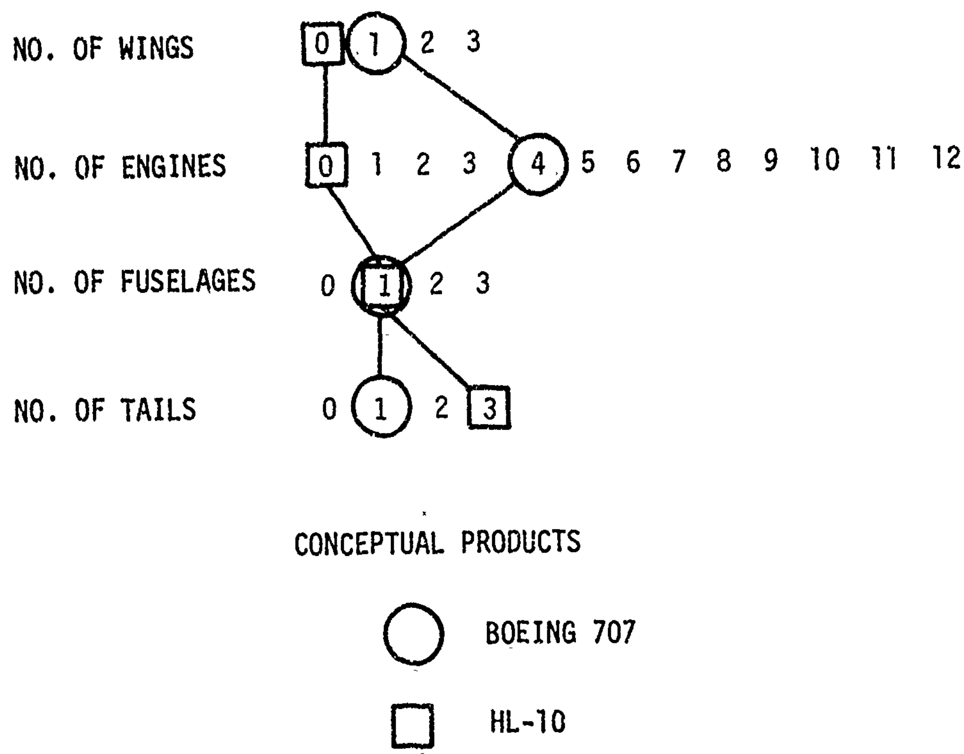


Figure 2.4.12. An Aircraft Morphology *

* Martino

Successful operations with the morphological method are dependent upon the completeness of the set of microterm variables within each macroterm. To assure that a maximum level of completeness has been achieved, the author can test the morphological model using conventional concepts. A reasonable assurance of model completeness exists if a quantity of conventional concepts can be accommodated.

An evaluation of each concept will reveal that not all of the combinations produced by a morphological model will be of interest. Some solutions will be trivial while others will be patently absurd. Nonetheless, in the interest of completeness, each solution is examined and analyzed for its utility and conceptual quality. Some will prove to be more or less revolutionary.

The morphological method provides a road map for the productive imagination. The method produces a variety of alternate, innovative solutions to specific problem areas. To a great extent, the success of the method depends upon the dedication of the individual in considering all the resulting concepts regardless of their apparent unreasonableness. Revolutionary concepts are likely to appear unreasonable for a period of time - but these are viable outputs of technological NTA.

RELEVANCE ANALYSIS

One of the primary characteristics of the morphology is the vertical independence between macroterms. While independence provides for maximum breadth per term, dependence would allow focusing upon progressively more detailed aspects of a particular dimension. Such dependence is the principle characteristic of a relevance tree. Where the morphology has a vertical correlation coefficient approaching zero, a relevance tree features a correlation of, or approaching, unity.

Figure 2.4.13 illustrates the form of a relevance tree showing the essential feature of vertical dependence. Each lower level is a subset of the higher. Relevance analysis allows focusing of attention at progressively lower levels until the mind conceives a system of technology product. Relevance analysis is favored by some as a technique for mapping options. Combinations of morphology and relevance techniques are particularly attractive and will be additionally discussed.

These central tools to technology level NTA are the building blocks from which it is possible to formalize a methodology. The following sections discuss the program which synthesized a procedure amendable to technological NTA.

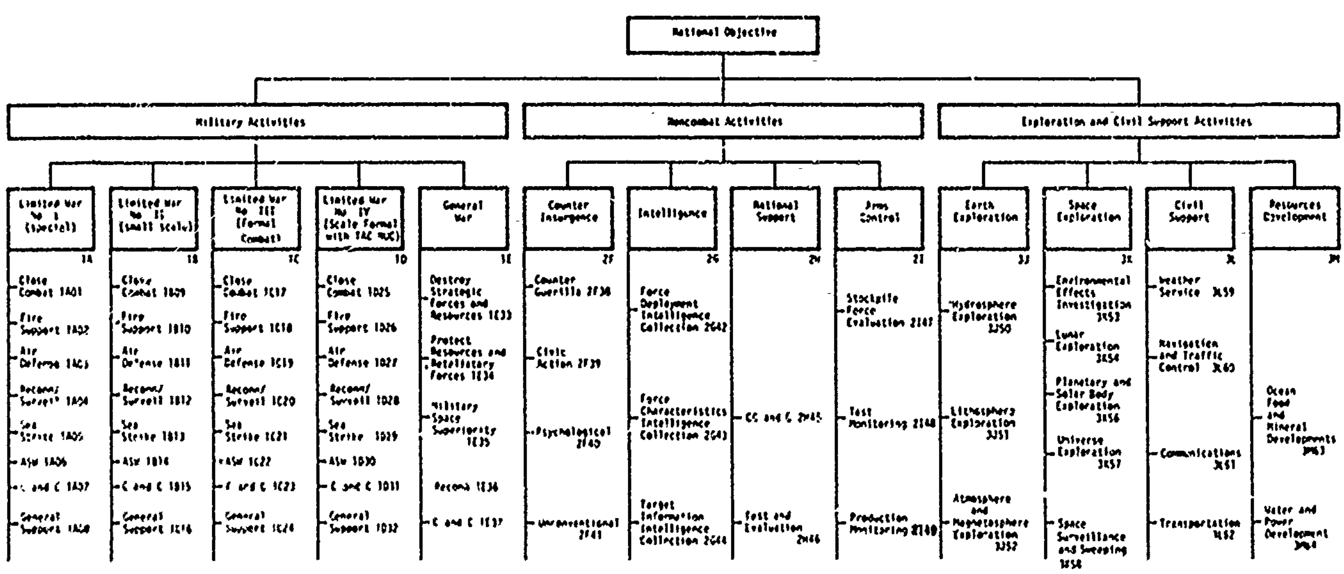


Figure 2.4.13. Relevance tree.

3.0 PROGRAM

This section describes the program used to define and test methodologies for technology level NTA. It summarizes the program, approaches, accomplishments and shortcomings.

GOALS

The intent of this study effort is that of formalizing a methodology which relates technological research and development programs to future systems and missions via Net Technical Assessment of U.S. and foreign technological status. The goal is thus to develop a viable technique for estimating how each U.S. and foreign technological advancement may provide for both evolutionary and revolutionary future systems. Two separate methods are sought which relate to the recurring issue of "directed" versus "pure" research. The first goal is to develop a method to evaluate the potential for evolution or replacement of each system due to technological growth. This encompasses subsystem technological evolution, wholly new subsystems, or system replacement. The method must differentiate between U.S. and S.U. technical approaches resulting from different current technological positions, growth rates, and mission requirements. As a matter of course, this process: identifies the technologies which are highly related to the system and its mission, suggests the impacts of technical growth, and thus relates technical research programs to system programs and mission requirements.

The second goal is to develop an NTA method capable of identifying the technology research programs which maximize chances of providing revolutionary new systems. This process must elucidate the effect of a given technological lead or lag on the competitive technological positions of the U.S. and foreign nations by suggesting likely new outgrowths of the technology. Anticipation of such revolutionary technology advancements is extremely relevant to NTA since future mission alternatives and system possibilities result from such a technological capability.

Beyond these primary goals, the intent is to provide some degree of assurance that such methodologies as are derived are truly practical. These techniques must be tested somewhat to provide evidence that they do not fall prey to accusations of being academic.

Finally, the methods must be accompanied with appropriate advice and commentary in order to enable an individual who is unfamiliar with NTA to use these techniques productively.

APPROACH

The approach selected to meet the study goals is experimental in nature. A different Net Technical Assessment was performed for each of the two primary goals.

During the assessment process introspection allowed definition of a workable series of steps which comprised the methodology. Problems encountered and subsequently solved allowed generation of practical advice based upon experience.

ACCOMPLISHMENTS

This study has defined a preliminary methodology which relates NTA to program definition. This procedure consists of step by step instructions and associated advice facilitating the accomplishment of NET technical assessments. The devised procedure combines several standard techniques into a set of steps which portray likely future technology advances, estimate the impacts of such advances in terms of potential system advances, and define the technical approaches suggestive of revolutionary advances. This process is specifified so as to portray the relative future capabilities of the U.S. and foreign powers side by side.

Two distinct methodologies have been formulated - one oriented toward use of NTA in defining new and validating existing research and exploratory development (funding categories 6.1 and 6.2) programs and the other toward defining advanced development and engineering development (funding categories 6.3 and 6.4) programs from NTA. While each technique is specialized, there is merit in evaluating each technological effort via both methods. Each of these procedures has been tested by way of experimentation. That is, each has been briefly applied to assess an issue of some military interest, in order to determine if the technique provided useful results, and to refine and definitize the procedure.

The methodology for 6.3 and 6.4 level funding was tested by performing a Net Technical Assessment of "heavy lift helicopters". This analysis of logistical heavy vertical lift helicopter systems was broadened to portray future U.S. and S.U. capabilities and to allow identification of alternate systems concepts to satisfy similar missions. This methodology thus facilitates identification of the plausible technology revolutions as well as evolutions which might impact future system performance.

The methodology for 6.1 and 6.2 level funding was tested via examination of power system technology and materials technology.

Relevance and morphological procedures were successfully applied toward identification of more or less revolutionary systems which could result from proceeding in various technical directions. The different current and possible future directions of U.S. and S.U. technical research have been portrayed and the plausible resulting system impacts identified and compared.

Some utilities and pitfalls in the performance of these methodologies are reported in order to assist other individuals in applying these, as yet formative, techniques. Each test case serves at the minimum to aggregate overview data pertaining to the field of study. At best, the conclusions regarding heavy lift helicopter systems, power system technology, and materials technology are valid in a general context.

CAVEATS

Obviously, after eight months of activity formulating NTA methodologies, no serious contention can be advanced that a nearly optimized or universal NTA technique has been developed or demonstrated. In fact, insufficient time has existed for fine tuning the developed methodology, let alone comparing it with other viable procedures. This methodology has been tested, but not "proved" in the acceptable sense. The testing process was also limited in breadth in general with little time for desired depth of analysis. These misfortunes are regarded as inevitable at this point in the NTA methodology development process.

PERSPECTIVE

The details of the derived methodologies are presented in Section 4 of this book. These descriptions, together with the details of the helicopter assessment of Book Two and power technology assessment of Book Three, should be viewed from a particular perspective.

This perspective may be characterized as that of a reader seeking to answer the following questions:

Does the context generally portray the necessity and utility of technological NTA?

Does the report describe a technique for performance of technological NTA?

Does this technique, although in the relatively early stages of development, appear to be a good one?

Do the examples reflect positively upon the role of generalists in technological NTA and the utility of quantifying plausible technology advancements?

4.0 RESULTANT METHODOLOGIES

The following describes methodologies for technology level Net Technical Assessment which (1) examine how technologies and systems correlate, (2) expose relative impacts of evolutionary and revolutionary technology advances, (3) portray the plausible present and future differences between U.S. and foreign technological postures, and (4) introduce the resulting likely differences between future U.S. and foreign system developments.

These techniques aid Net Technical Assessments from the two ends of the technology-system spectrum. From one aspect, technology responds to advancing system requirements. From another, technology advances create opportunities for more capable systems. The proper balance is the subject of the ageless dilemma of pure versus applied research.

Should research seek answers in general or answers to specific questions? There are sufficient arguments on each side to support both approaches and separate NTA techniques are warranted for each. These complementary approaches to achieving greater future capability are both employed within the U.S. Department of Defense as well as the Soviet Union.

In the U.S. the use of system requirements to define goals for technology programs is prevalent and is associated most strongly with category 6.3 and 6.4 development programs - advanced and engineering development programs. It is these technology programs where system and mission focus to technology goals is most strong. The analogous NTA problem is that of anticipating how a particular system might advance by drawing upon specialized technologies. To accomplish such NTA and subsequently definé technology goals for advanced and engineering development programs the TECHNOLOGY SUBSCRIPTED method is advanced.

Technology advancement which is relatively divorced from specific system needs and directed toward more general goals is managed within category 6.1 and 6.2 programs - research and exploratory development programs. (This is not to suggest that ALL 6.1 and 6.2 programs are so divorced.) The related NTA process is one of anticipating major technical advances, on their own merit, and indicating the systems impacts of such advances. The NTA method designed to assist recognizing and definition of the associated research and advanced development programs is called TECHNOLOGY SUPERSCRIPTED.

As an aid to the visualization of these two NTA processes, a spectral display is advanced. The form of this spectral display as portrayed in Figure 4.1, is applicable to both technologies and systems. As shown on the figure, a spectral line represents a specific description of a technology or system. Spectral amplitude represents technology or system maturity. Also, increased spectral width is equivalent to increasing the abstraction, or the term generality, to encompass many spectral lines. Thus, line widths allow for differentiation between macro and micro systems and technologies as in the analogous morphological and forecast useage.

One aspect of NTA which has been repeatedly stressed in these discussions is that of the need for proper study breadth. Whether this problem is one of systems or technologies, the scope of the assessment must be broadened to include a productive set of related issues. The

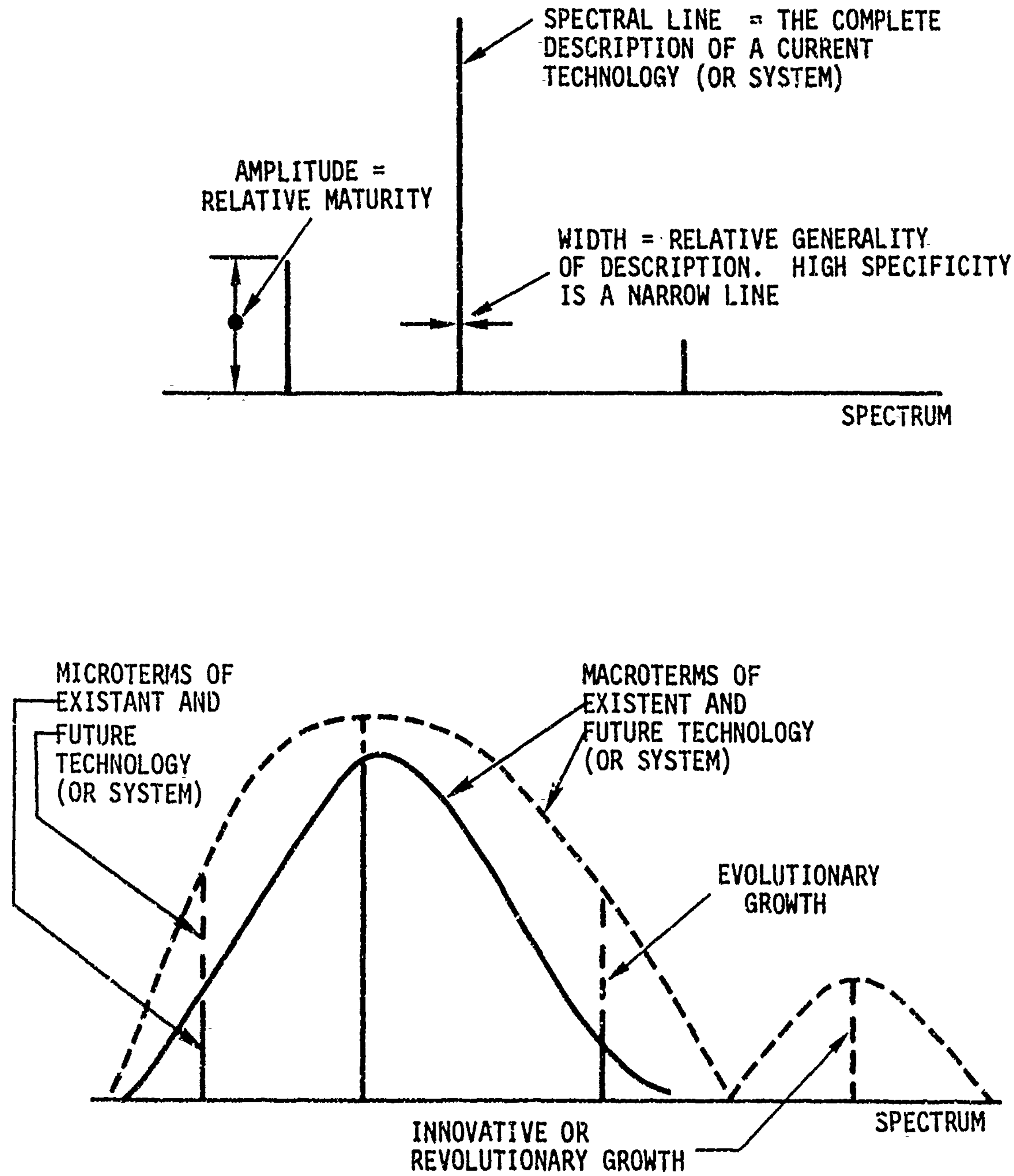


Figure 4.1. Spectral analogy definitions.

sequence of three spectral displays on Figure 4.2 illustrates this broadening process. Proceeding from the top where specific spectral lines (technologies) are introduced, the broadening of the spectral lines occurs, and finally the future evolutions and revolutions of technology are recognized and portrayed by dotted spectral lines. The heightening of the spectral line is an evolutionary process. The appearance of new spectral lines, especially in previously unoccupied regions of the spectrum, is representative of the innovative process.

These broadening and future advancement processes are central to both methodologies. Figure 4.3 portrays the peculiar aspects of the TECHNOLOGY SUBSCRIPTED process. The specific systems are broadened to include additional concepts. Then the transition to the set of contained technologies is made. These technologies are advanced in evolutionary and revolutionary ways as shown, and then the return transition to the systems realm is made. The greater future technological capability provides for evolutionary and revolutionary advances in systems capability as shown in the spectral analogy.

The TECHNOLOGY SUPERSCRIPTED process is analogous but different in that the procedure initiates with technology. Figure 4.4 illustrates this technique, showing how a single technical advance might provide for several differing system advances.

While the previous spectral diagrams portrayed only a single nation's technical assessment process, Figure 4.5 displays the visual (and implies the decisional) impact of a NET technical assessment. Shown are both the technical and system realms of the extrapolated future. Obvious are the comparative leads and lags in both system and technology realms of the future. Missing but definable are the ways in which these leads and lags can be correlated to the corresponding realm - systems to technology and technology to system.

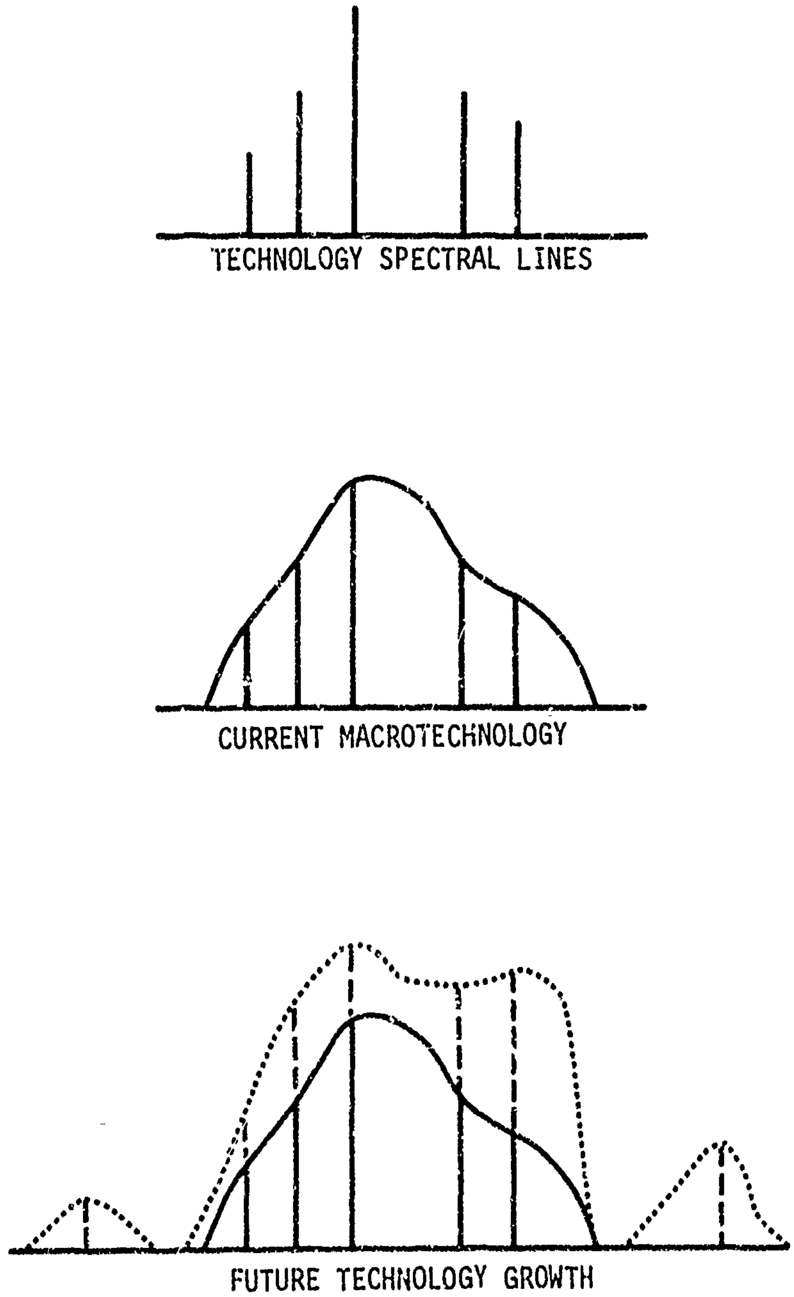


Figure 4.2. The spectral broadening process.

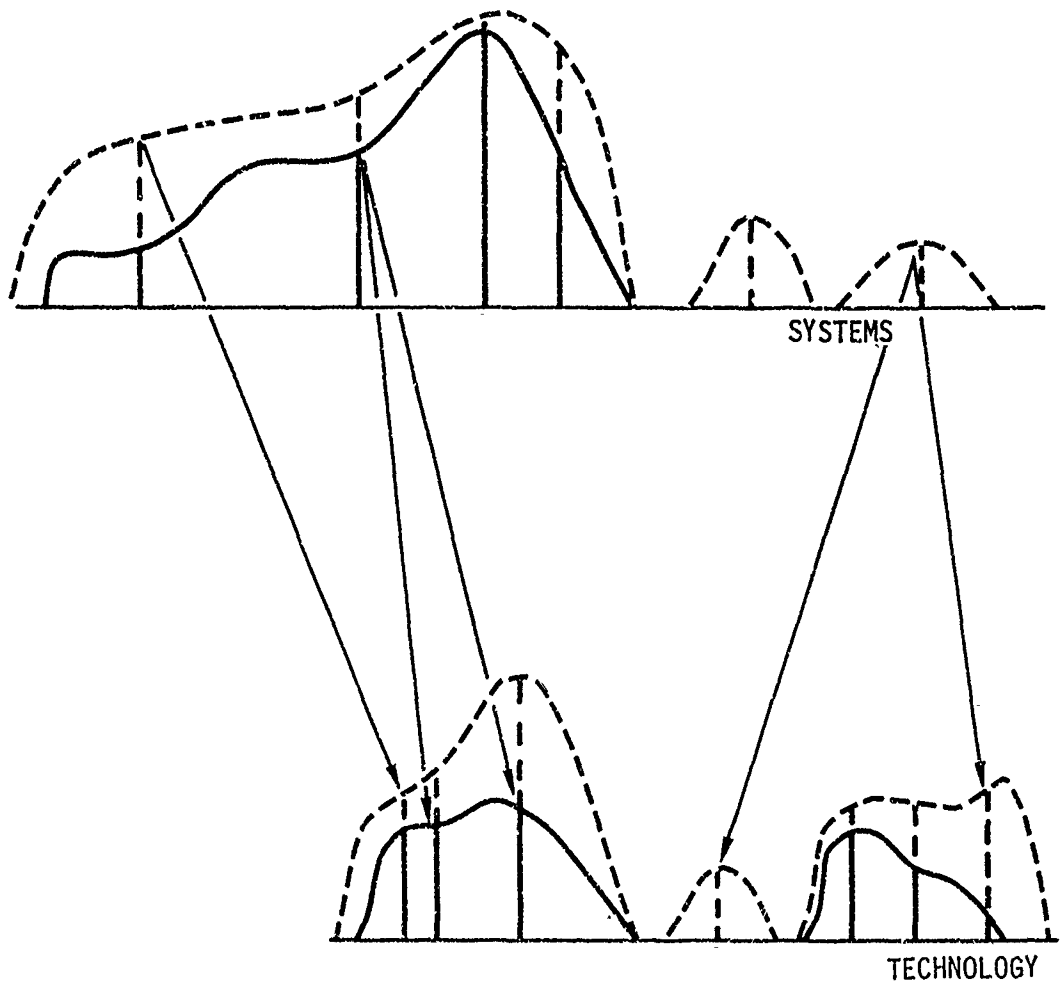


Figure 4.3. The spectra of the technology subscript process.

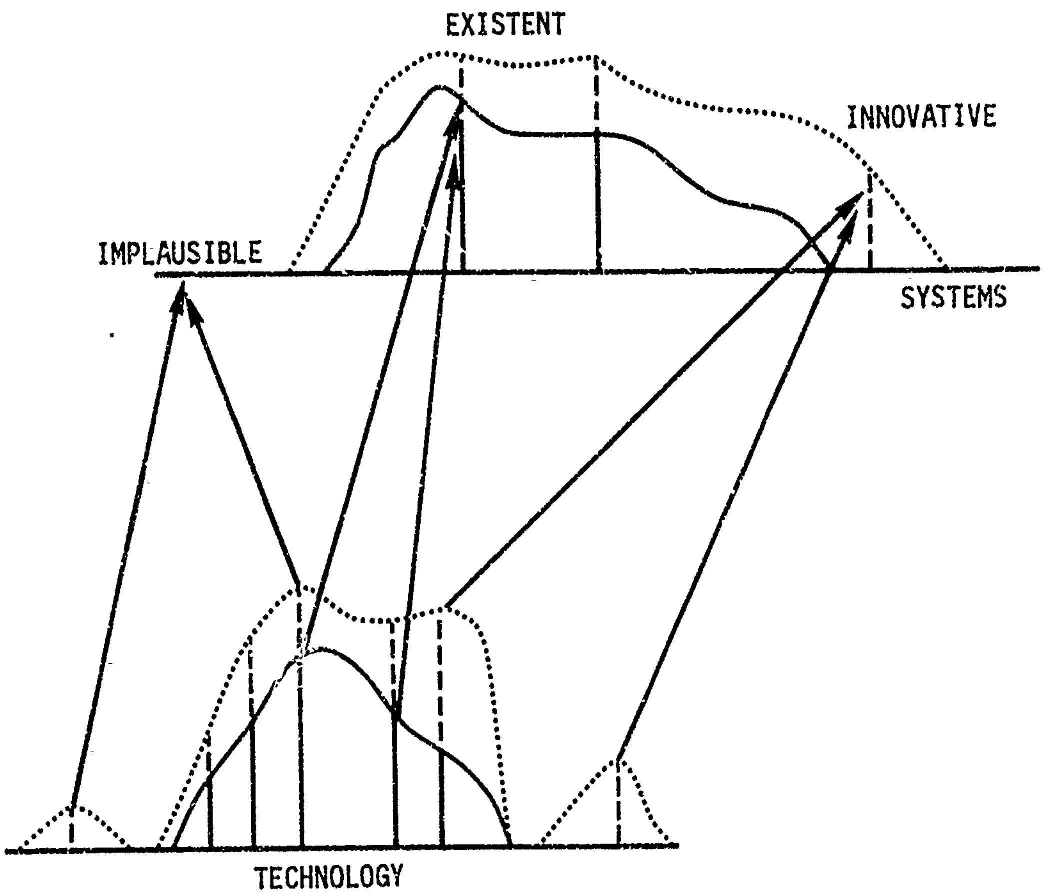


Figure 4.4. The spectra of the technology superscript process.

With this introduction complete, a discussion of these two methodologies may ensue. First we consider the "technology subscripted" method.

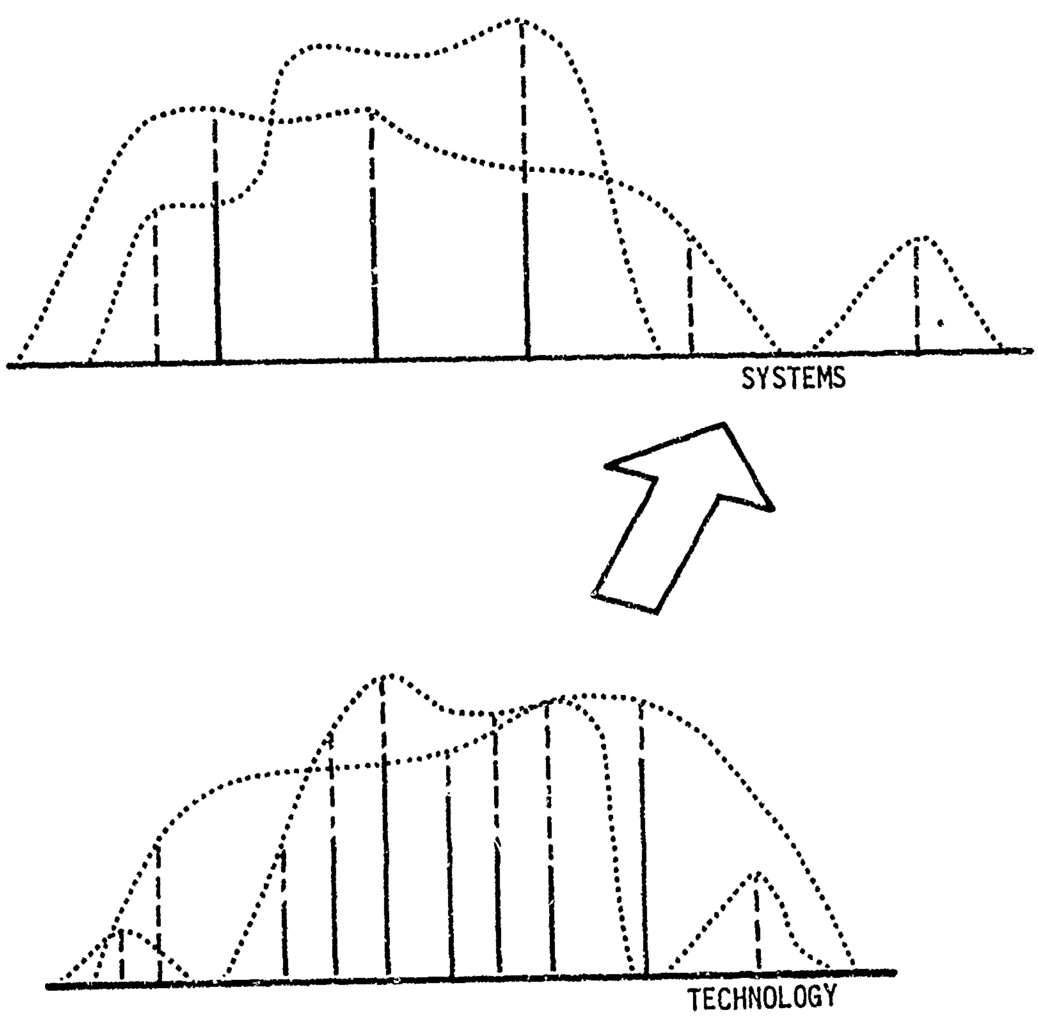


Figure 4.5. A Net Technical Assessment spectrum.

4.1 "TECHNOLOGY SUBSCRIPTED" METHODOLOGY FOR NTA

The TECHNOLOGY SUBSCRIPTED technique facilitates identification of technologies related to a specified mission. The methodology is pointedly designed to assist definition of program plans for advanced and engineering development, aiding the correlation of technology developments with category 6.3 and 6.4 funds.

The process involves application of relevance techniques, technology forecasting, and system synthesis to develop a taxonomy of all technologies which relate to future capability to satisfy a mission. The method also suggests the relative impact of each technology upon a plausible future system and its mission, allowing extrapolation of system capability into the future and assessment of alternate technical approaches. The process is intimately tied to reconciliation of differences in technical status, technical approach, and system choice between the two national interests being compared. Thus, netting is an integral feature of the methodology - providing decision inputs on the technological alternatives.

This method is designed to illuminate the various plausible system capabilities which could be achieved by each nation at a point in the future. Evolutionary advances of the technologies in current use for a specified system are forecasted and the resulting system capability identified. Also, more revolutionary systems with similar mission capability are examined for potential contribution to a future system. A side-by-side comparison of the two nations is performed at all possible levels - technology, subsystem, and system levels.

The concept behind this technique is displayed as a Venn diagram in Figure 4.1.1. At the top of this figure, the present set

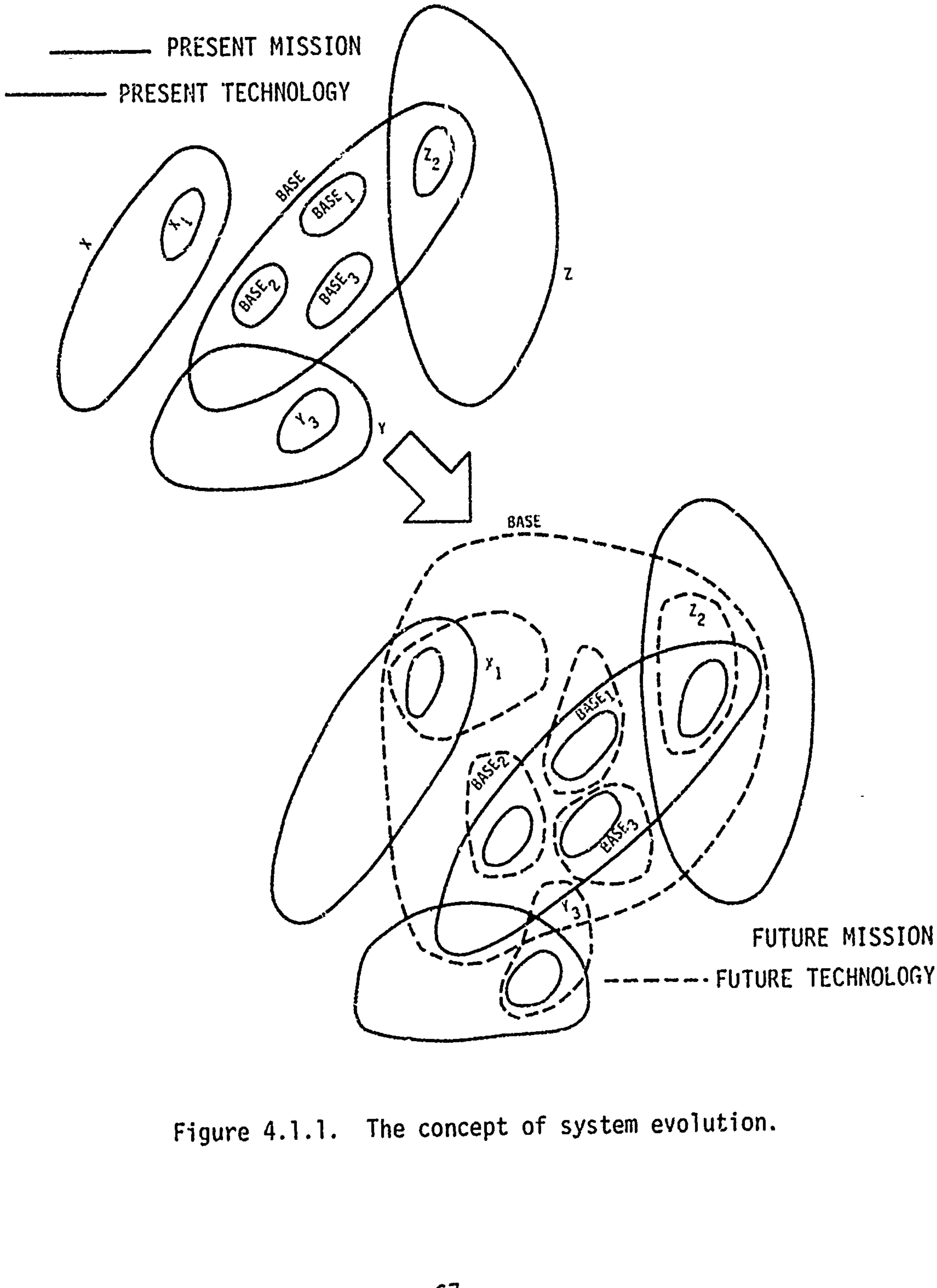


Figure 4.1.1. The concept of system evolution.

of similar systems are shown with partially overlapping mission capabilities. Recognition of this close relationship allows focusing attention upon the pertinent contained technologies as shown in blue. Toward the bottom of the figure, an illustration of how the advanced technologies (dotted) support a greater future mission capability is evidenced. Netting may be accomplished if these mission requirements are similar.

The TECHNOLOGY SUBSCRIPTED technique is portrayed in Figure 4.1.2 as a flow diagram of the key operations. The process identifies a set of technologies pertaining to a particular mission and thus the natural link to the technology superscript method. These steps are defined so as to provide a side-by-side Net Technical Assessment of U.S. and foreign technologies and systems without the incorporation of their potential countering systems and technologies.

While not detailed in a step-by-step manner, Figure 4.1.3 suggests the TECHNOLOGY SUBSCRIPTED technique might be extended to also provide a one-on-one analysis. Such extension would obviate the relationship of one offensive technology to the other nation's defense technology as indicated in the netting diagram of Figure 4.1.4. The general concept thus appears intriguing but experimentation with and development of such an idea is a future issue. The methodology for technology level NTA which has been developed for mission oriented technical issues (category 6.3 and 6.4 funds) is discussed as the diagramed fourteen point process.

STEP 1 - Identify Mission Requirements

The initial orientation of the effort must be to broaden the scope of thought beyond the introduced system. This can be done by first introducing the mission requirements and then a more general system term. It is impossible to overemphasize the importance to

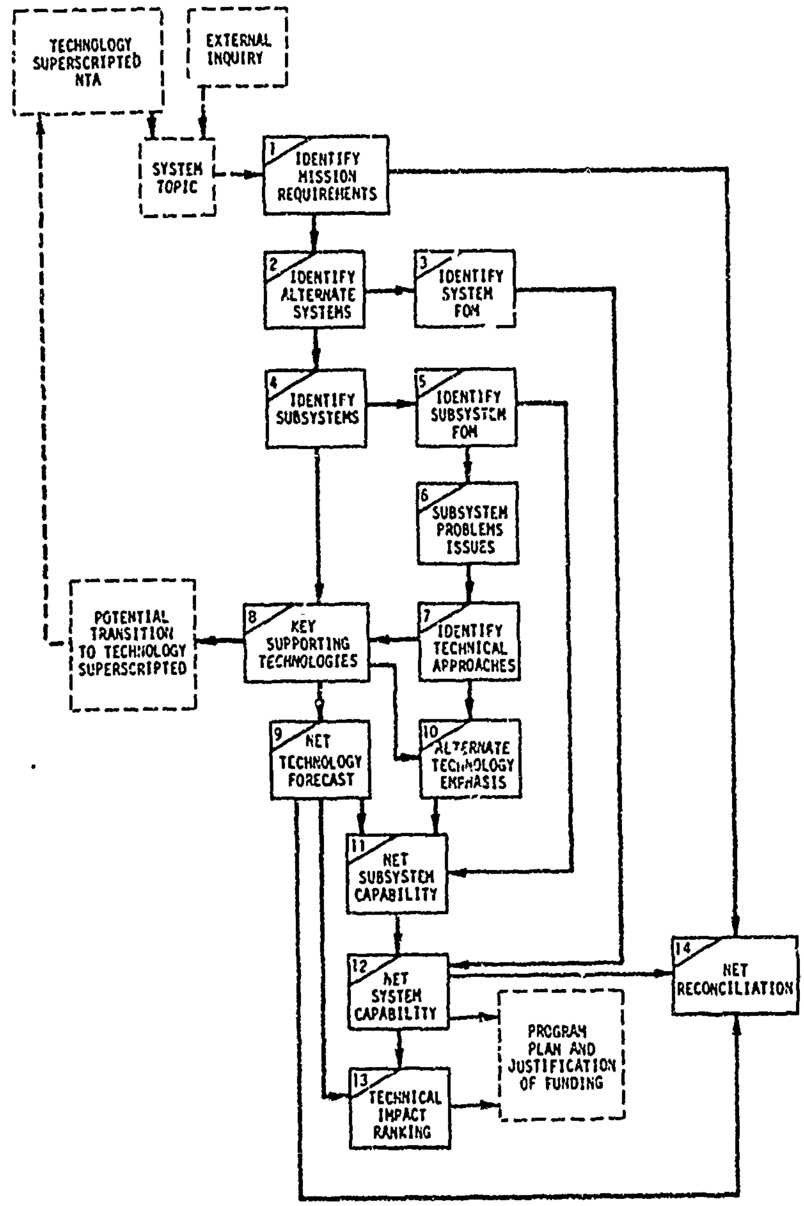


Figure 4.1.2. The steps of "Technology Subscripted"

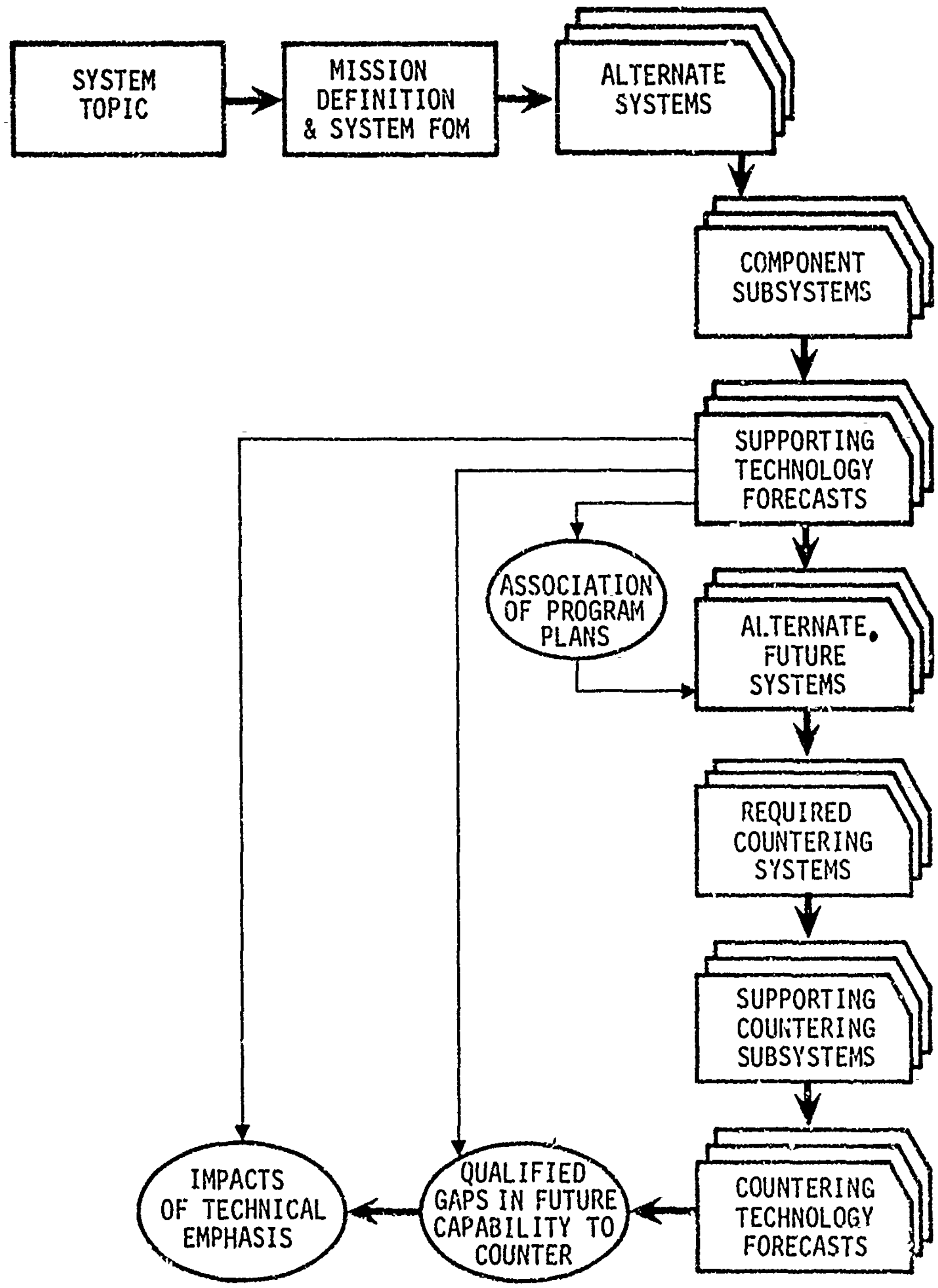


Figure 4.1.3. Extension to allow one-on-one net.

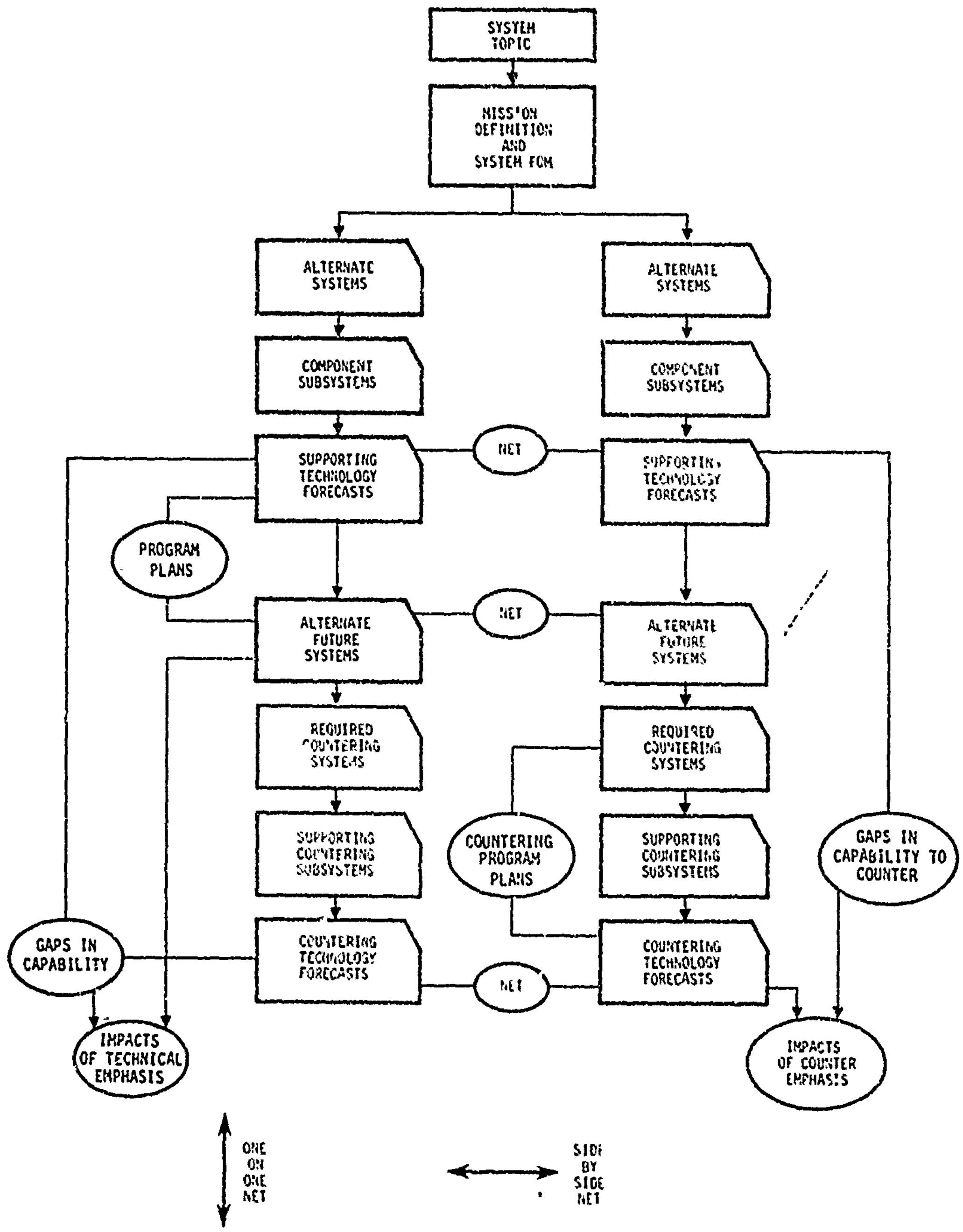


Figure 4.1.4. Multiplicity of netting techniques.

this process of defining an appropriate ruler by which to relate subsequently identified systems. The byword -- keep it broad! For example, if the system used to initiate the NTA study is the M-16 rifle, a more general system description might be hand held anti-personnel devices. A mission requirement might be: neutralize enemy personnel. This statement implies one man lightweight portable systems directed against opposing manpower (as opposed to weaponry). This sort of definition is admittedly - and intentionally - very loose. It is intended to allow other systems to enter into contention in order to satisfy the mission to which rifles, and the M-16 specifically, are currently the primary answer. The related mission statement leads directly to the choice of the macrovariable for the NTA forecasts. It, in one sense is the first step at a word game - encouraging introduction of lasers, microwave beams, and even biological weapons or forms of psychokinesis.

A sufficiently broad mission identification in this first step is the artful aspect of this NTA methodology. The art lies in choice of a broad but tractable mission subject. To limit the mission solution via a system using ordnance would in turn limit the technologies considered to merely evolutionary aspects of rifles or hand held munitions. It is far superior to overbroaden at this first step and contract the description as an afterthought. The reward will be an enriched set of technologies in the Net Technical Assessment.

STEP 2 - Induce Alternate Systems

This step will provide the dominant chance for innovative or revolutionary technology introduction. The intent of this step is to enrich the list of systems comprised within the umbrella of the mission statement of Step 1. Two techniques are known to be highly pertinent to innovating other systems which satisfy the mission. These are relevance analysis and morphological analysis. While both of these processes are applicable to developing a complete set of system alternatives to the mission, the former is favored for ease of execution by an uninitiated Net Technical Assessor. Morphological analysis, which was extensively discussed previously could be applied here when the user is knowledgeable enough to decide upon its use and confident enough to construct the network of system alternatives from the morphology. The relevance analysis lends itself to portrayal in a tree form - each successively lower branch displaying a group of terms which are subsets of the higher level.

An enriched set of alternate systems can be derived by placing the general mission requirement from Step 1 at the top of the relevance tree as illustrated in Figure 4.1.5. The original system which initiated the NTA study is then placed at any lower branch allowing for 1 or 2 intermediate branches to be filled in during this process. At this point,

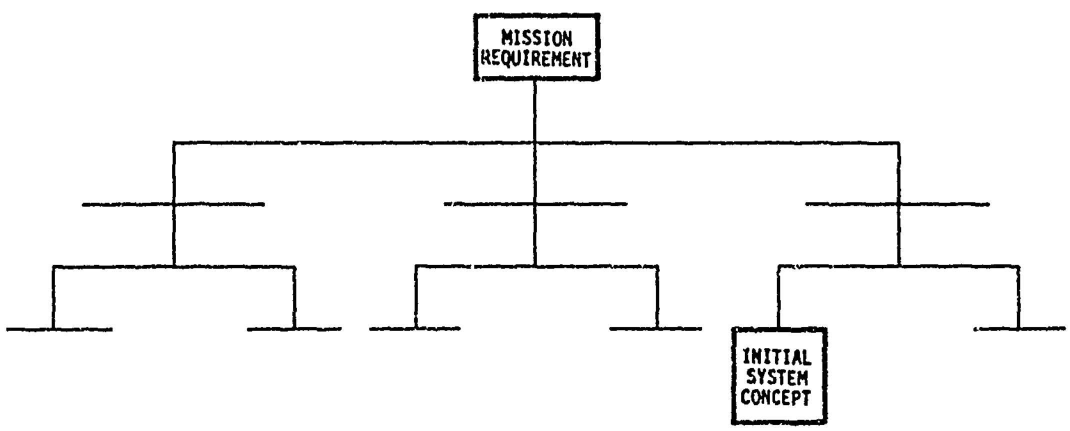


Figure 4.1.5. Relevance tree for identifying alternate systems.

it is entirely likely that one will have conceived at least one system alternate to the initial system - either by concerted attention or accidentally, while defining the mission during the first step. Since the mind uses exemplar terms as triggers in the innovative process, the second system alternative is quite useful in aiding the completion of the relevance tree. This second example should be placed on the lower branch of the tree at some horizontal separation from the initial system. Figure 4.1.6 shows the relevance tree at this point of its development. Other systems may come to mind and should be displayed similarly. If no more examples occur or if the second alternate is not even conceived, attention must be directed to the intermediate one or two branches between the mission and the system. If the M-16 is an example of a system performing the anti-personnel mission, then typical descriptors of intermediate system classes would likely be "rifle" at the first level upward and "projectile systems" at the next higher level upward. When such macro classes have been identified for each system

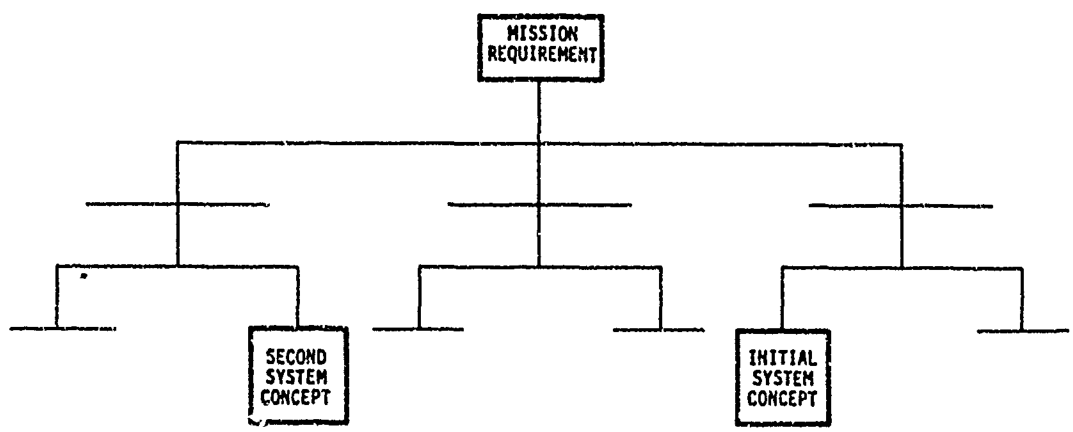


Figure 4.1.6. Prepared for identification of system classes.

already displayed upon the relevance tree, a test for completeness of each level is warranted. Thus, attention is directed toward expanding upon "non-projectile" systems to fill in the second level and "non rifle" systems on the third level in the case of the example. Since the mission implies some separation between the two soldiers the "non-projectile" term implies "non-material" and, in turn, "electromagnetic" as an appropriate descriptor in the second level. As in this example discussion, the antonym approach to this word game can be used productively. If antonyms are used exclusively the relevance tree will appear as a "binary logic diagram", which is a special subset of relevance trees with only two terms at each level.

With appropriate terms at all but the system level, the groundwork has been completed for facilitating mental correlation of the various terms in the relevance diagram. Now the mind more easily conceives of the alternate systems since more clues are provided at the various branches. Expansion from the three branched tree is quite allowable at this point, because the additional terms will have a known purpose. The suggesting of three branches thus serves as a point-of-departure. The completion of this step sees the Net Technical Assessor viewing the introductory system as a particular competitor at solving the mission requirement. The other competitors may or may not have been developed as systems at the current point in time. More likely some technological constraint has precluded development.

The balance of the steps in this methodology are designed to discover such technological constraints, determine the plausibility of their future removal, and reflect upon the impact of a future system availing itself of such "unconventional" technologies. Thus a mission context of some consistency is provided by this methodology to allowing comparisons of technologies and systems alternatives at some future time frame.

STEP 3 - Identify System Figure-Of-Merit (FOM)

At this point it is desirable to decide upon a system FOM so the various competing system concepts can be arrayed against a common measurement and so that the impact of a technological advance can be assessed in a system context. Several viable FOMs should be identified - at least one commonly associated with each system concept. Usually such system FOMs are selected for use in a narrow class of systems and are designed to elucidate relative subsystem efficiencies. The desired system FOM is different - it is generally applicable to a wide range of different systems. In fact, the FOM should reflect the degree to which the systems satisfy the mission requirement.

Some examples of good and bad system figure-of-merits seem warranted. The FOM of antipersonnel devices is most generally typified by lethality and range. The decrease in lethality with range for a rifle is a result of inaccuracy, and decreased momentum, but is typical of projectile devices and markedly different from lasers or biological weapons. Many arguments have been advanced that "fire power", cost, or weight are essential FOMs for evaluating rifles. Our contention must be that these descriptors are actually very important but second order criteria for an NTA study. The cost argument is of particular general importance, but to use it explicitly winnows too many technologies from the competition, too soon. Cost should generally be avoided as an explicit FOM since it is better used as a final decision criterion at the force structure level of analysis. Speed, vulnerability, and range are terms with almost universal applicability as figure-of-merits. Transport vehicles can be compared using payload-range curves. The system figure-of-merit must be capable of characterizing a wide variety of systems.

STEP 4 - Identify Subsystems

For each of the system concepts introduced in Step 2, the associated subsystems need identification. Here two desires argue for opposite approaches to this step. On one hand, in order to facilitate the process of learning about a system and its subsystems, it is useful to use subsystem breakdowns which are generally accepted within the associated "community". Beyond aid to the learning process this tends to facilitate dissemination of results of an NTA study to the community. Arguing against the "accepted" subsystem breakout is the fact that this encourages technological shortsightedness. Inadvertly, a subsystem descriptor can discourage inter-subsystem trades from being examined. Choice of subsystem descriptors should therefore be dictated by truly basic terms which connote the underlying technological considerations without reflection on the technical approach.

Examples in aircraft subsystems include differentiating between lifting movement, translational movement, and power subsystems instead of considering all movement as caused by a propulsion system. This is an attempt to use terminology to free the mind into allowing for power systems divorced from movement per se and from location upon the airframe. Separation of lifting and translational subsystems allows conceptualization around v/stol concepts as well as conventional take off and landing concepts. Choice of the terms "lethality subsystem" and "strategic warheads" tends to facilitate recognition of nuclear bombs, radioactive darts, or even biological warheads as viable alternatives. Application of the more unconventional subsystem terminology is deemed desirable when a conflict arises with the "in" or mentally constraining subsystem descriptor. It is more important to maintain open mindedness than to make the educational process easy. A useful working format exists in the relevance tree since subsystems can be separated at a level below the systems on the tree of Step 2. The relevance tree portrayal also allows use of "standard" subsystem forms at lower levels or branches.

STEP 5 - Identify Subsystem Figure-Of-Merit

This step is analogous to Step 3 for systems. An amplification of the discussion of Step 3 is in order. Choice of the subsystem FOM dictates the subsystem macrovariable as defined previously in the discussion of technological forecasting. For example, in the case of airborne power subsystems, use of power to weight ratio as the FOM encourages agglomeration of turbine engine power to weight together with fuel weight in the composite sense. Also, in the particular case of helicopters, the drive train weight can be added to this subsystem. This FOM encourages conceptual examination of new engines (nuclear), new fuels (cyrogenic), elimination of helicopter drive trains (hot cycle rotors), and even use of remote vehicle power generation (lasers transmitting power from the ground). Remember that the innovative process may, in part, be triggered by semantic clues. The situation can be likened to an important word game. The payoff is a new approach.

STEP 6 - Identify Subsystem Problems and Issues

With Steps 4 and 5 accomplished, effort can be directed toward review of literature and study of each subsystem. Very quickly, a good "feel" for the current state of the art can be achieved, together with a list of the present technical problem areas. While a subset of the stressing problems will generally be discussed in the available literature, the overview of the generalist in a new field is likely to more correctly represent the underlying issue. That is, where the literature is likely to leave the basic problem unstated, the generalist overview is likely to more appropriately state "the REAL issue is. . . . .". This is merely a matter of discovering the forest instead of the trees. The non-specialists display a higher propensity in such a direction.

STEP 7 - Identify Alternate Technical Approaches

Eventual solution of the problems identified in Step 6 is a result of success in pursuing at least one of several CONCEIVABLE alternate technical approaches. One can always surmount a problem, or go around it, providing the issue isn't a basic law of physics. The intent of this step is to itemize a comprehensive set of conceivable solutions to the varied problems facing a given type of system or subsystem. Often the possibility of totally replacing a particular subsystem should be examined.

By way of example, a better projectile (bullet) for a rifle might be achieved by improved aerodynamics, higher muzzle velocity, ablating materials, poisoned coatings, fragile materials (for breakup upon impact), or by replacing the bullet with pellets (like a shotgun). In a still different vein, perhaps better implies less lethal, rather than more lethal bullets. Thus, a technique for a chemically treated rubber pellet might be a rational approach. Many other such considerations can be identified in the context of subsystem concepts. The techniques for facilitating recognition of such alternate subsystem concepts can be similar to the relevance process discussed in Step 2 or the application of morphological analysis. Feasibility of concepts should be ignored at this point in favor of maximizing the number of concepts.

STEP 8 - Identify Key Supporting Technologies

With Step 7 completed, the deduction of the technologies which support the various alternate subsystem concepts is relatively straightforward. The key supporting technologies can obviously be as diverse as the subsystem concepts. The bullet example conjures up technologies ranging from aerodynamics and materials science, to physics and thermodynamics, and to biomedicine and chemistry. This diversity is a key aspect of NTA.

Even in a qualitative NTA study, one meritorious output is the tieing of a string from each subsystem to all its potentially supporting technologies. The program planners and even the U.S. Congress need to understand how many different technology development programs do relate to a single subsystem. A lack of such understanding is likely to result in a lack of justifiable program advocacy, a resultant cutoff of supporting funds, and a consequential limitation of subsystem and system performance growth.

STEP 9 - Develop Netted Technology Forecasts

At this point, the first chance to introduce quantification into the NTA process occurs. The chance of an extensive literature search turning up a well performed technology forecast in the area of interest and with the proper figure-of-merit, is very small at this date. Certain fields are well done, others totally lacking or hidden from access by the most professional researcher. The definition of well done must include reference to the FOM used. If it is not the desired one it is not particularly well done for the selected assessment context.

The choice of the forecast FOM remains to be done at the technological level. The cautions discussed within Section 2.4 are worth montic ing a second time. Choice of the properly broad FOM is critical to the end worth of the NTA.

Breadth of the macrovariable must encompass the implicit applications of the technology being forecasted. For example, the strength of materials issue probably should encompass tensile strength per unit weight and modulus per unit weight, since these variables dominate the utility of materials. A product of such terms is recommended in order to create a single FOM which incorporates both aspects - strength and modulus. Having established the general broad subject area and the dominant units, it remains to examine theoretical limits and the associated technological microvariable.

The macrovariable trend must be consistent with ultimate technical limits, like the strength of intra-atomic bond, rather than the limits of an approach. The existance of such limits can be reflected within the FOM in either of two ways. The physical limit can be plotted on the forecast as a separate, and impenetrable contour. The forecast can then bump into it. A second technique is to normalize the FOM by the limit. For example, strength of materials can be portrayed as a percent of the strongest conceivable covalent bonded, hexagonal close packed material - carbon in diamond form. Either technique assures proper recognition of technological limits.

In defining FOM and treating ultimate technical limits of the macrovariable, extreme caution is in order to avoid accidentally treating a microvariable. The upper limit in strength per unit weight of metals should be incidental to an analysis of materials. The microvariable of such an examination should include composite materials, aluminum alloys, steel alloys, and even wood. Wood is a rational addition since it lends credibility to the longer-term trend extrapolation of the macrovariable.

Once the U.S. technology status is plotted and subsequently extrapolated, the S.U. trend can be established from intelligence data. The overall slopes of the macrovariable might differ based upon relative differences in level of effort to the subject area. The relative horizontal locations of the trends might differ reflecting a lead or lag on the part of the U.S. In spite of such differences it is rational to expect the two countries to proceed along similar technological learning curves. This is a far more rational expectation than anticipation of proceeding along analogous system paths. That is, as the technology level is rigorously justifiable one is able to compare apples with apples. As one proceeds towards the upper hierarchy of subsystems, systems, and even missions it is progressively more difficult to make such rigorous comparisons. Differences in the decision criteria and decision processes affect the outcome at the upper hierarcy but science can be regarded as universal. Indeed, at the technological level, the escalation from microvariable to microvariable is likely to be the same for each country with only the timing being different.

The technology forecasts can be regarded as having three main purposes. The two quantitative ones have been discussed - the differences and the macrovariable trend extrapolation. The third function is more qualatitive but nevertheless dramatically useful to the NTA process. This function is the establishment of a plausible array of conceivable future escalations which are likely to support the macrovariable trend. This list represents the tie to the program planning function of NTA. Only one of the list needs to come to pass in order to support the macrotrend, but the list enables analysis of alternate approaches on a consistent basis. Probability of success, probable cost of research, even basic feasibility of approach can be addressed for each element of the array. A rational selection of a few approaches can then be made and funded accordingly.

STEP 10 - Establish Alternate Technology Emphasis

At this point, the resynthesis of future technological capabilities into plausible future subsystems and systems is initiated. It is recommended that this process begin with selection of several alternate technical emphases.

A technology emphasis is intended to guide the direction of subsystem conceptual construction along a specific path. Examples of alternate technology for bomber aircraft systems include advanced aerodynamic configuration, advanced structural materials, advanced propulsion, superior penetration aids, and improved bombardment and navigation techniques. Some such areas of emphasis are directed toward a specific subsystem while others (like structural materials) are applicable over a wide range of subsystems.

The establishment of alternate technical emphasis enables synthesis of system concepts which are based upon differing primary technical advancements. These system concepts, when compared, will provide quantitative insight into the relative importances of each emphasized technology to overall system capability.

STEP 11 - Net Alternate Subsystem Capabilities

On the basis of technology forecasts generated during Step 9, the capacity exists to forecast the capabilities of subsystems which were defined in Step 4. Such forecasts at the subsystem level should use the figure-of-merit derived in Step 5 and of course, the micro-variable descriptors should correspond to the different technical approaches toward subsystem synthesis.

In practice as well as concept, the technical advances forecasted as resulting from evolution and escalation of basic technologies can be combined into various subsystem advances. The conventional subsystem concept can be evolved or a wholly novel subsystem concept can directly escalate the subsystem macrovariable. By netting the U.S. and S.U. subsystem forecasts, a good understanding of the potential leads or lags can be derived at the subsystem level. However, since each subsystem is a combination of several technologies, point designs of subsystems for specific years are the only practical goal. These can be netted and can be used to synthesize systems.

STEP 12 - Determine Net System Capabilities

Integration of subsystem capabilities in the context of the technology emphasis of Step 10 allows synthesis of various systems which satisfy the basic mission requirements. This step is the culmination of integrating all known technology facts in the previous steps which bear upon achieving a system capability.

It is usually impractical to expect a continuous curve of such system capabilities as a function of time. Instead, in recognition of the time consuming nature of such continuous variable approaches, a set of point designs are developed for specific future years. These point designs use the analogous subsystem designs.

Comparing the future U.S. system capabilities with the future foreign capabilities provides the interesting perspective. At this point, the effects of a larger menu of technology options or a more advanced state of technology are apparent; the visibility of the military future is apparent. The information is available from which to select development programs from a comparable set. Also, the chance of a foreign technological surprise is reduced.

STEP 13 - Assess Technological Impact

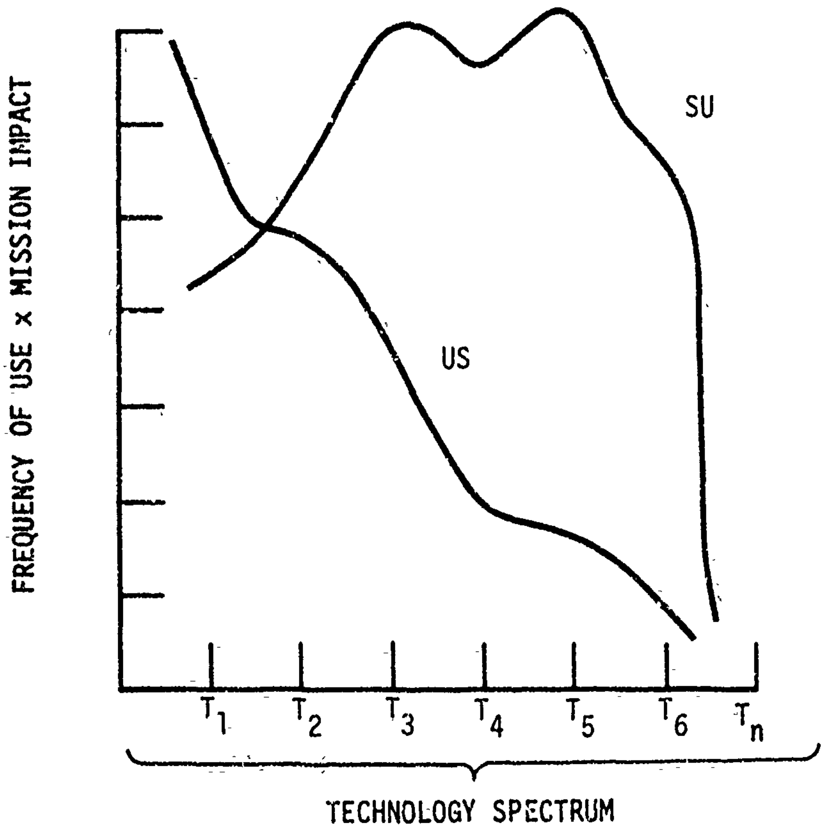
A wide variety of system capabilities are available from Step 12 each using a different primary technology emphasis for design. Generally, a single technology can be identified as primary to one system but supportive to several others. Thus, the importance of a technology can be measured by its breadth of applicability.

With the specific mission focus for technology inherent in this methodology, it is difficult to discern a wide breadth of application for any technology. Such breadth of application is more likely to be uncovered via the technology superscripted approach. However, the degree or magnitude of impact upon system capability can be comparatively assessed by consideration of the competitive systems. The central technology to the best system must h. e the greatest impact. This effect is potentially a result of combining technology advancement with system concept advancement. A synergism can be rationally anticipated.

Simultaneous consideration of technology breadth (frequency of use) and degree of technology impact (upon mission) allows overall assessment of technology importance. Figure 4.1.7 portrays the manner in which funding priority for various technology development programs might be assessed. Also represented is a different foreign technology endeavor. Such differences must be made visible and explained.

STEP 14 - Net Reconciliation

The rationalization of differences between U.S. and foreign choices of the technologies and systems developed is a significant goal of NTA. The "why are they" and "why aren't they" questions are important to knowledgeably answer. Lack of understanding is likely to



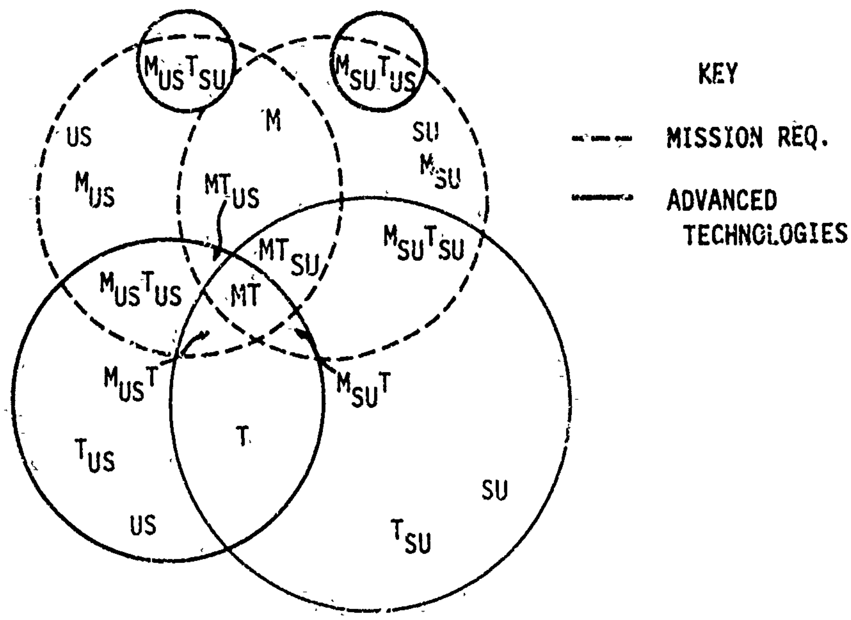
$$\text{FUNDING PRIORITY} = \sum_{T_i = 1}^{n} \text{FREQUENCY OF TECHNOLOGY USE x MISSION IMPACT}$$

Figure 4.1.7. Assessment of technology impact.

imply a major oversight - and a resulting high probability of technological surprise. Thus, a reconciliation of differences identified by NTA is important.

Upon detecting a significant and unexplained difference in system or technology development program choice, consistency of mission between the two nations should be examined. More than likely, as depicted on Figure 4.1.8, the difference in approach can be attributed to a difference in foreign mission definition. But what if the missions are common?

Indications of an anomalous technology development for common U.S. and foreign mission requirements may imply one of three conditions: Foreign technology breakthrough in a major sense, an error in the Net Technical Assessment execution, or erroneous input data. With such a dilemma, alternate Bayesian hypotheses should be developed and the intelligence community tasked for further amplification. Also, an independent Net Technical Assessment is warranted.



ASPECT/SYMBOL	MISSION REQ.	ADV. TECH. IMPACT	Δ = SIGNIFICANT NET ASSESS.
M	Common	None	
MT_{US}	Common	US only	Δ
MT_{SU}	Common	SU only	
MT	Common	US + SU	Δ*
T	None now	US + SU	
T_{US}	None now	US only	
T_{SU}	None now	SU only	
M_{US}	US only	None	
M_{SU}	SU only	None	
$M_{US}T_{US}$	US only	US only	⊃ Δ
$M_{SU}T_{SU}$	SU only	SU only	Δ
$M_{US}T_{SU}$	US only	SU only	⊃
$M_{SU}T_{US}$	SU only	US only	
$M_{US}T$	US only	US + SU	Δ
$M_{SU}T$	SU only	US + SU	Δ

* The category of assessment generally considered

Figure 4.1.8. The context for reconciling Net differences.

4.2 "TECHNOLOGY SUPERSCRIPTED" METHODOLOGY FOR NTA

The TECHNOLOGY SUPERSCRIPTED technique facilitates identification of the myriad of systems which a given technical pursuit might support. The process is designed to particularly assist definition of 6.1 and 6.2 category programs.

This NTA method is suggested as a desirable avenue for identifying how pursuit of a particular technology field might lead to various predictable, technologically revolutionary concepts. This procedure also facilitates identification of the various plausible system utilities of these technology innovations. Net comparison of U.S. and foreign technology status and future status are facilitated. Particular insight is gained into the effort-momentum, future direction of the technological growth of each nation from their current technology base. Thus this technique is particularly useful in elucidating likely future technology innovations and the resulting systems capabilities, for both nations being compared. The TECHNOLOGY SUPERSCRIPTED method assists generation of a suitable set of quantitative data which decision makers can use to direct technology research programs in the directions with maximum potential impact.

The concept behind this process is displayed upon Figure 4.2.1. At the top, a broad technology field is portrayed and present U.S. and S.U. knowledge is displayed within. While a portion of the knowledge is common to both countries, each knows something the other doesn't. The existing systems which this one technical field support are also indicated in appropriate colors.

As attention is directed toward the bottom of the figure, the plausible expansion of each country's knowledge is evidenced by dotted lines. This advancement of technological competence allows

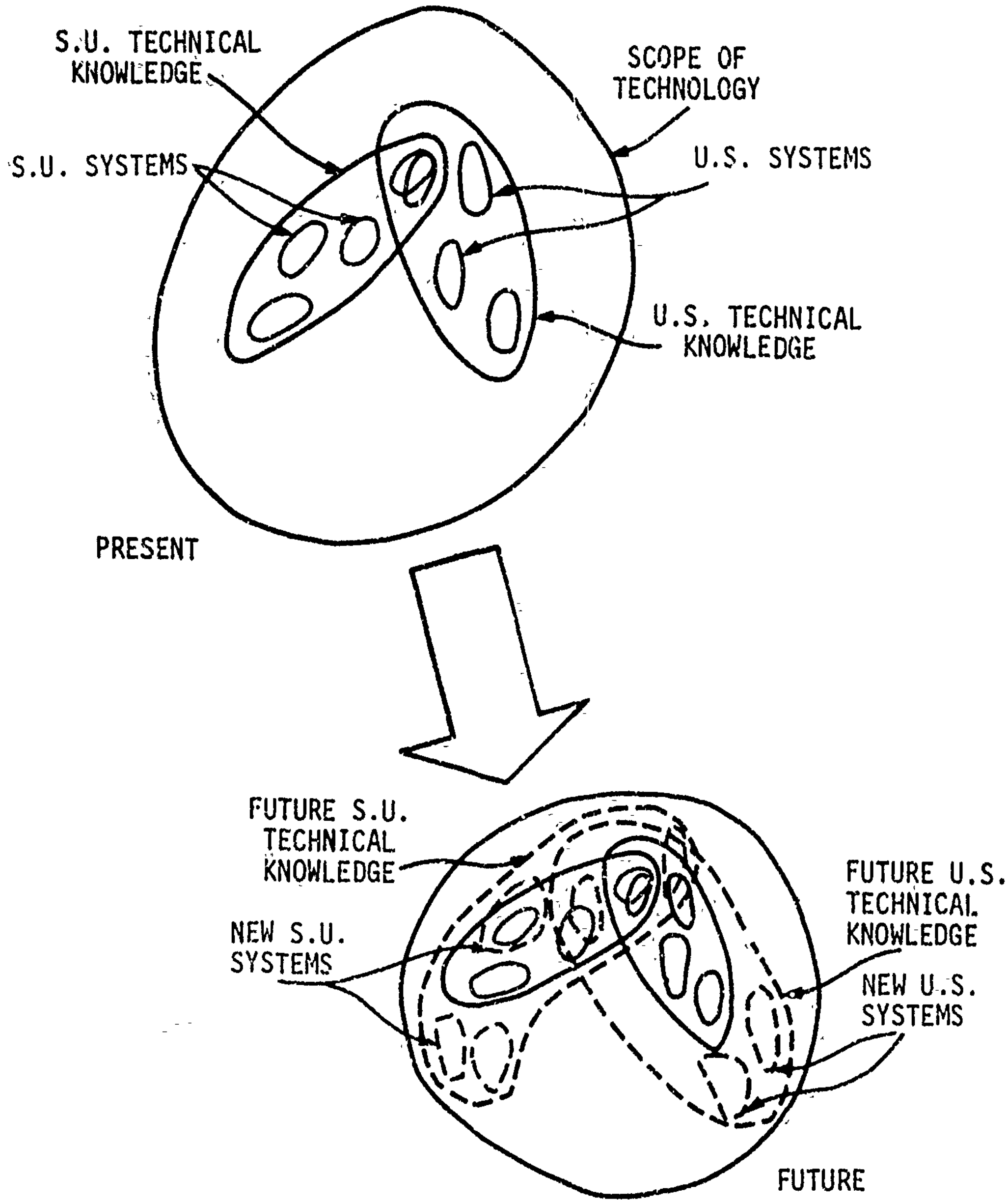


Figure 4.2.1. Comparative technological growth.

introduction of totally new systems as well as evolution of existing systems, as indicated. Also evidenced is the future ability of each country to duplicate a portion of the other's capability and create a capability completely out of reach of the other. These might be considered as stabilizing and destabilizing technology programs respectively.

The operations inherent in the TECHNOLOGY SUPERSCRIPTED methodology are portrayed in Figure 4.2.2 as a flow diagram. Since the technique identifies many systems which are related to the initial technology topic, the transition to the Technology Subscripted procedure allows following the chain of technologies inherent in these systems, as indicated. The thirteen steps of execution of the TECHNOLOGY SUPERSCRIPTED method is now presented.

STEP 1 - Broaden Microtechnology to Macrotechnology

As in the case of the Technology Subscripted process, the initial goal is to broaden the technology topic. Instead of a particular technology area like turbojet engine technology, it is advantageous to broaden the topic to air breathing propulsion technology, or propusive power, or energy supplies.

The suggested approach toward broadening the topic is one of applying the morphological techniques discussed in Section 2.4, in a reverse manner. For sake of an example, examine the broadening of the turbojet engine to energy supplies. Certain microterms come to mind which are generally associated with jets: airborne, chemical, manufactured, and propulsion. These microterms can be determined to be subsets of the macroterms: operating environment, process, energy source, and functional use. With macroterms so identified, the broadening of attention is accomplished and the value of the Net Technical Assessment will be increased. Figure 4.2.3 indicates a

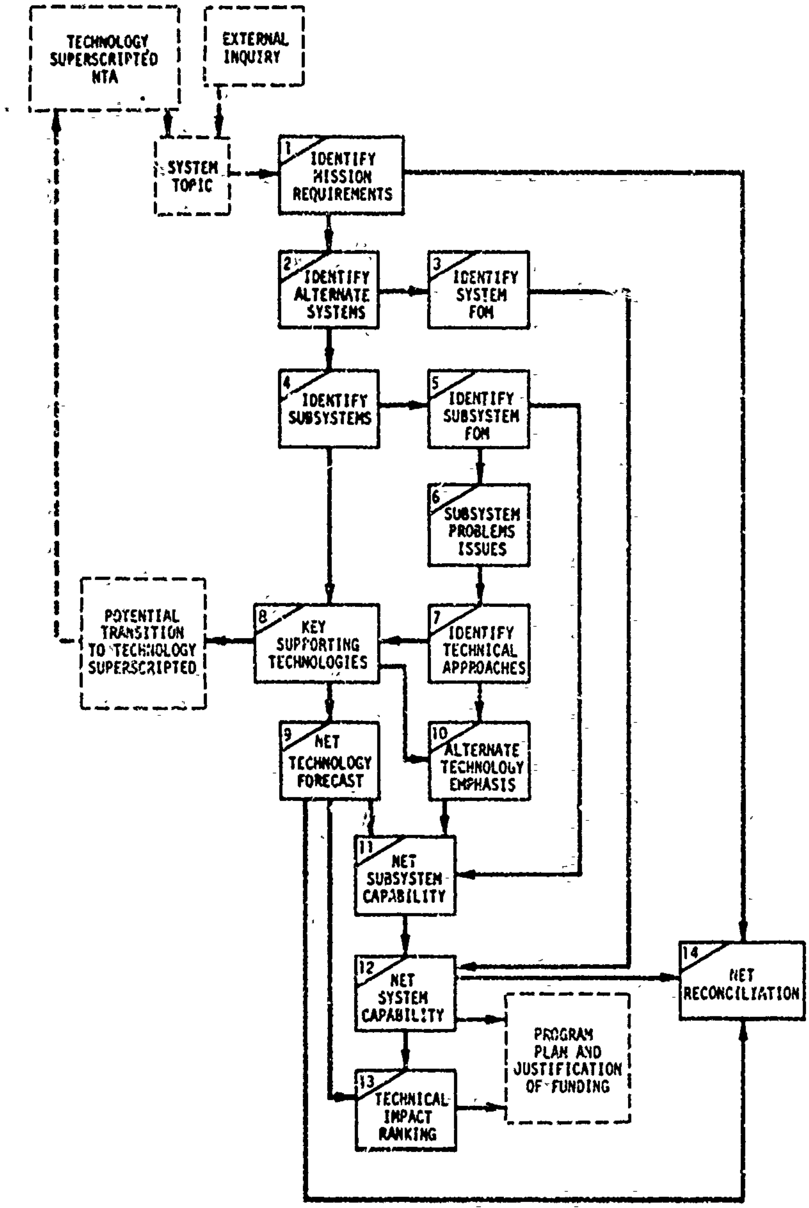


Figure 4.2.2. The steps of "Technology Subscripted".

status of the incomplete morphology at this point.

ENERGY SOURCES

MACROTERMS	
Operating Environment	Air
Process	Chemical
Energy Source	Manufactured
Functional Use	Propulsion
	TURBOJET

Figure 4.2.3. A preliminary morphology.

One aspect of this incomplete morphological model deserves elaboration. This aspect is the few number of macroterms - four. There exists a distinct advantage to minimizing the number of macroterms - especially if the analyst is comparatively inexperienced with morphological analysis. Figure 4.2.4 portrays the advantage of few macroterms - avoidance of mental confusion.

Zwicky used eleven macroterms in his jet engine morphology. He has a demonstrated competence at mentally correlating this prodigious number of terms and producing innovative concepts. The novice is better advised to start out slowly, building his correlative capability with experience.

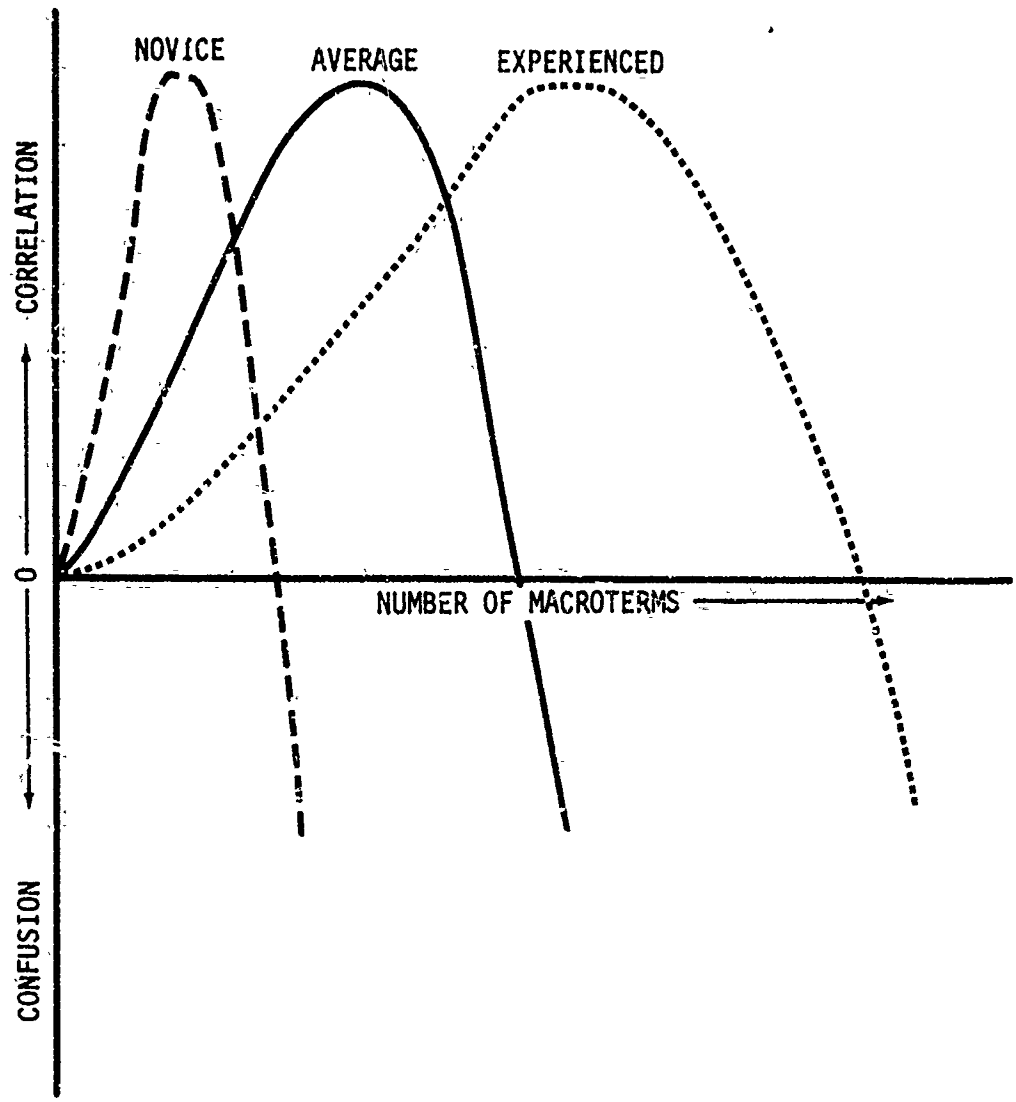


Figure 4.2.4. The subjective effect of macroterm quantity.

Use of such smaller morphologies will not necessarily restrict the novice's productivity. Numerous smaller morphologies may be performed in series allowing creation of the large morphology in a stepwise fashion.

STEP 2 - Form a Generic Morphology

Attention can now be focused toward the microterms which are missing from the morphological model started in Step 1. Completion of the model will result in a morphology termed generic because it will not contain the degree of specificity usually necessary for mental innovation. The combination of several morphologies is likely to be required prior to reaching a state aiding conceptualization.

The definition of microterms for the energy morphology might yield Figure 4.2.5. Here, the non-air, non-chemical, non-manufactured, and non-propulsion microterms are selected and placed opposite their respective macroterms.

ENERGY SOURCES				
Operating Environment	Air	Sea	Earth	Space
Process	Chemical	Mech.	Elec.	Nuclear
Energy Source	Manufactured		Natural	
Functional Use	Propulsion	Food	Light	Heat
	TURBOJET			

Figure 4.2.5. A simple energy source morphology.

There is no single CORRECT set of macroterms or microterms. Correctness is only a valid concept in the completeness of the set of microterms for any macroterm, and in the degree to which the individual is at ease with these terms. The individual's comfort with the selected terms is crucial to eventual innovative success, since in practice the morphology is a semantics game.

This "word game" aspect of morphology execution suggests that the process should be performed by individuals and not groups. It further implies a likelihood that a morphology is customized to the originating individual and not likely to be as useful to another.

STEP 3 - Form Initial Association Tree

At this point it is desirable to take a step designed to assist the visual impact of the morphological terms. This step involves the translation of the morphology into a tree format reminiscent of a relevance or decision tree.

This is accomplished by placing the topic and the first macrovariable at the top and each associated microvariable at the first branch down. This process is continued until the entire array of morphology terms is portrayed in tree form. Figure 4.2.6 show the correlation between terms of the morphology and the association tree.

The association tree has the following attributes. It visually enhances association of terms - a key aspect of conceptual innovation. It utilizes vertical independence of terms, since the microvariables are not subsets of one another. This latter characteristic is the opposite of a relevance tree, which usually displays higher vertical dependence. This concept of an association tree is compatible with relevance since division of a microterm into its lower terms is permitted. Combination of relevance and morphological concepts in this way is analogous to the concept introduced by S. R. Fields of partially folded trees.

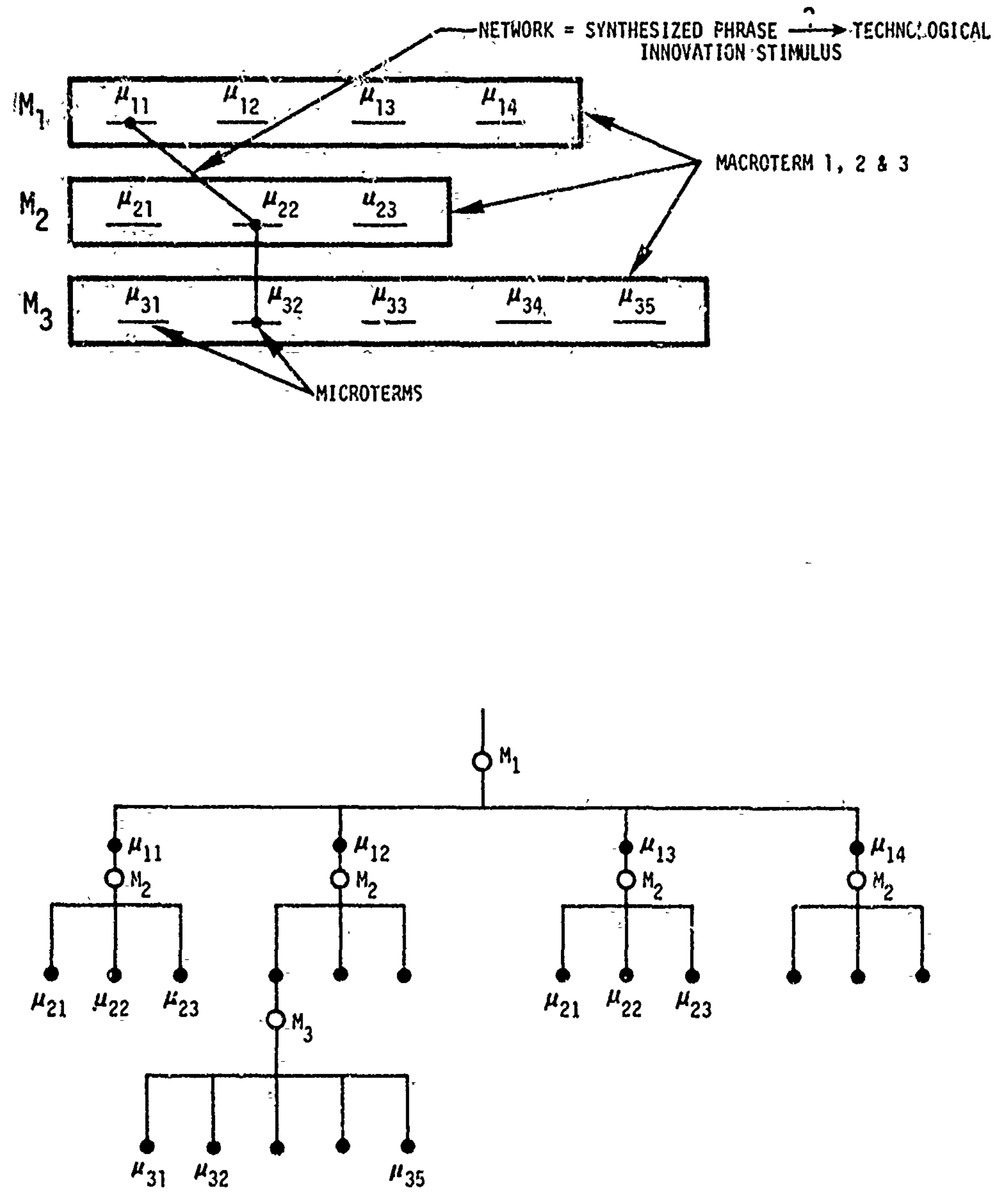


Figure 4.2.6. Morphology and association tree term relatedness.

Attempts to correlate the terms of this small generic association tree are not yet warranted. More terms are required before the clues for innovation are displayed in sufficient quantity.

STEP 4 - Create a Specialized Morphology

Another morphology consisting of two to four macroterms should be created. The intent of this second morphological model is increasing the detail in the terms.

The previously cited "energy" morphology has a counterpart association tree with an air-chemical-manufactured-propulsion path. This combination of terms can be used as a topic for the specialized morphology. New macroterms might include: fuel, reaction, and cycle. An associated microterm for each might be petrochemicals, exothermic, and Brayton, respectively. These terms are obviously leading to a greater degree of specificity and the examples cited are still oriented toward jet engine technology.

Consider the alternate branch of the energy association tree with descriptors space-electromagnetic-natural-propulsion. In developing the specialized morphology, use of fuel and cycle macroterms would be inappropriate. This points out the second attribute of using smaller morphologies. That is, one is able to apply the most specialized instead of the most generalized terms in reaching to the lower levels. A single large scale morphology tends to inhibit this and therefore, to some degree, inhibits the innovative process.

STEP 5 - Add Branches to the Association Tree

This step is again for the purpose of increasing visual impact of the morphological terms. The terms generated in Step 4 are merely transferred to the association tree below the branch used as a topic for the specialized morphology. This moves the tree toward completeness.

As terms are added to the association tree, contemplation of the aggregated terms is in order. After the incorporation of each morphological network, the decision whether to add a relevance branch should be examined. Finally, each new branch should be examined to determine if innovation is as yet feasible.

STEP 6 - Expand until Conceptualization

Steps 4 and 5 should be repeated until a "comfortable" level of detail exists at the lower level of the association tree. Nominally, the addition of two to four macroterms during each iteration is a reasonable rate of growth; however, the precise number of terms added depends principally on the conceptual ability of the morphologist. This incremental growth continues until the model is effectively sized for an individual's conceptualization.

The addition of terms in the morphological model is accompanied by a corresponding expansion in the association tree. The visual display afforded by the tree provides insight into the next iteration of the morphological expansion. (In the event the morphology is complete, the tree provides the appropriate clues to the genesis and character of each potentially innovative concept.)

A reminder is in order. Review each newly added branch "growth" as soon as it is included on the association tree. The goal is to conceive of technology concepts as early as convenient. Some situations will require only a few terms in order to trigger the conceptualization process. Other times, a dozen or more terms might be required in order to facilitate mental correlation. Do not attempt to generate a consistently "tall" tree - it might hinder the innovative process.

STEP 7 - Identify and Evaluate Technological Concepts

At such time as mental correlation of the microterm "clues" occurs, the resulting concept should be immediately noted below its branch on the association tree. At first glance, the form of the concept is either existing or revolutionary. Further examination of the more revolutionary concept may uncover a disagreement between the concept with basic laws of science. Only under this circumstance should the concept be discarded as implausible.

Innovations surviving this simple test should be retained for further consideration. No effort should be made at this time to judge their worth. There is a danger of eliminating solutions simply because the morphologist cannot visualize the design details of a particular innovation. For example, if a morphological exercise designed to conceive power generation systems produces an alternator powered by ocean surf, there may be a tendency on the part of some to dismiss the concept as untenable because it: (1) produces too little power, (2) is discontinuous, (3) requires large investment and (4) surf amplitude is variable. One premise of the morphologist is to offer for consideration a set of plausible solutions for detailed examination by experts. He is not concerned with efficiency, productivity, resource materials or design details; because he cannot be an expert in all fields nor can he reasonably devote the time to examine in detail all the promising solutions. Therefore, as in the case of the surf generator, if the innovation generally complies with the basic laws of physics, it should be retained for later evaluation.

It is now appropriate to relate directly to NTA. At this point in the TECHNOLOGY SUPERSCRIPTED process as the association tree hopefully displays all existent technology growth paths and those paths which promise evolutionary or revolutionary opportunities for technology growth. There has been no mission or systems orientation introduced to the tree and therefore it is equally applicable to both nations being compared. This association and "innovation" tree can be used as the basis for comparing the nations' technology prospects.

STEP 8 - Introduce Mission Focus

The technology innovations must be translated to system concepts by the application of a mission focus. At this point it is possible for the association tree to lose its national commonality since the countries could have differing national policies.

Introduction of alternate mission focuses for each technology concept implys a short diversion into the realm of missions and relevance trees. Relevance analysis is suggested as an excellent technique for providing good visibility into a large set of missions which satisfy broad national goals. Each technology innovation should be tested for compatability with each mission.

STEP 9 - Identify System Concept

In testing each technology innovation for compatability with all possible missions, some "fits" will occur. This fit results in qualitative system concept definition. In general, a truly innovative technology concept results in a revolutionary system concept.

Often a subjective evaluation of the system capability is extremely valuable. In fact, it is often difficult to quantify the prospective capability of a revolutionary system concept using a conjectured technological capability. There are a great number of very uncertain tradeoff curves which are associated with such a system quantification. The largest difficulty in quantifying revolutionary systems is that the time frame of introduction is totally unknown. What are other subsystems capabilities? Quantification of system parameters is probably only rational for evolutionary technologies and systems when technology forecasts can be generated with some confidence.

STEP 10 - General Technology Forecasts

Two types of forecasts are practical using this procedure. The first is quantitative and similar to the forecasting process discussed for the Technology Subscripted Method in Step 9. The other is qualitative and applicable to gaining a very broad perspective of technology propagation directions.

The only salient difference between forecasts for the Technology Subscripted process and this technique is that the extensive use of an association tree here provides assistance both in macrovariable definition and in development of the menu of plausible microvariable escalations.

The qualitative forecasting merit lies in projecting likely total effort for each nation and estimating to which branches such effort will likely be applied. Also, the qualitative forecasting of each revolutionary system concept is likely to prove to be the maximum practical.

STEP 11 - Perform Net Comparison

As in the Technology Subscripted process, net comparisons are feasible for all evolutionary technologies and their associated systems. Quantitative comparison of such forecasted capabilities will display relative U.S. leads and lags and allow focus of attention upon those technologies central to such lead or lag issues.

Almost by definition, however, no quantitative forecast data can exist in the revolutionary areas. No research has yet been performed in such areas and thus no objective estimate of learning rate is available.

A qualitative net comparison is conceivable, however, at the higher branches of the association tree. This netting can reflect the relative status of each nation in terms of technological status, in terms of research funding, and in terms of applied manpower. Portrayal of such "nontechnical" data can suggest the relative ability of each nation to push toward the revolutionary capabilities. The concept of such a netting is illustrated in Figure 4.2.7.

STEP 12 - Assess Technological Impact

The Net Technical Assessment performed using the TECHNOLOGY SUPERSCRIPTED method provides quantified or qualified perhaps (and tenuous) forecast data for budgetary considerations. Program planning for research and exploratory development programs uses this data.

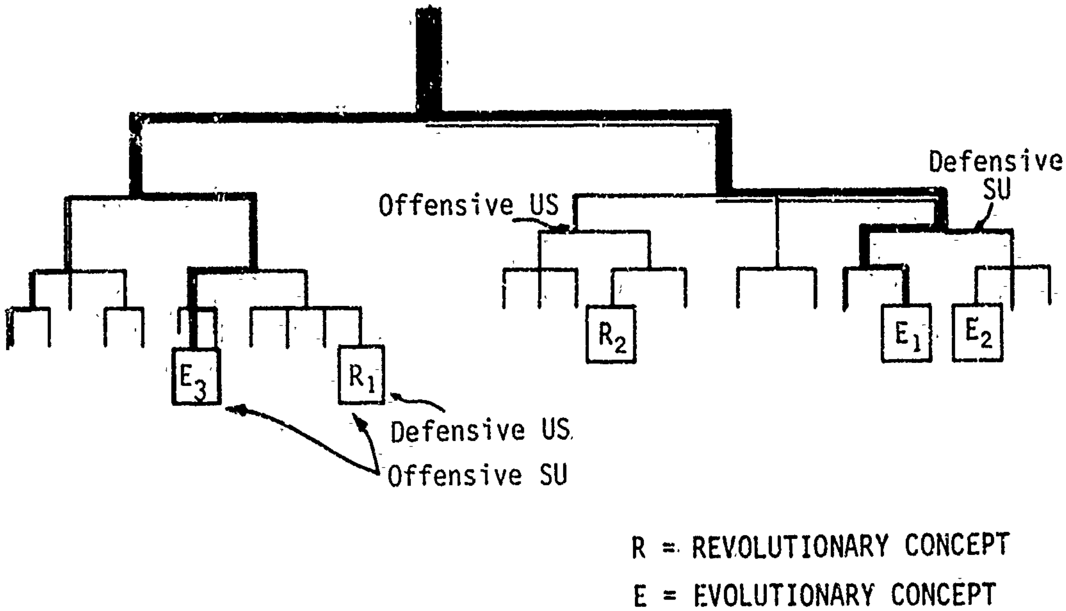


Figure 4.2.7. Use of association tree for Net display.

A rank ordering of funding priority is also feasible for the evolutionary technologies - but is difficult for the more qualitatively treated revolutionary technologies. Lasers were funded on a judgemental basis at first - other revolutionary technologies will follow this pattern.

Examination of the tree displayed in Figure 4.2.7 indicates a conceptual utility in funding both offensive and defensive research programs if the reward is significant enough. An offensive program is one the U.S. is likely to gain a lead in while a defensive program is one the U.S. is likely to lag in.

BOOK TWO

ASSESSMENT OF HEAVY LIFT HELICOPTER SYSTEMS

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STEP 13 - Reconcile Net Differences

Reconciliation of differences in technological pursuit is needed. The major problem to be alleviated is the determination of possible reasons for large foreign technology efforts in directions of no obvious revolutionary potential. This is likely to indicate an oversight in the construction of the association tree or the subsequent conceptual innovation process. Concerted attention can thus be directed toward that branch of the tree in order to conceive the likely foreign goal.

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1.0 CONCLUSIONS

This section relates the significant results of a 6 week effort by a 3 man team to examine the U.S. - Soviet competition in logistical heavy lift helicopter (HLH) systems and associated technologies. The examination of competing helicopter systems in such a side-by-side context accomplished a significant aggregation of related information from many diverse sources. Also, an interesting overview of the various alternate technical approaches to a heavy lift capability has resulted, providing a context for heavy lift helicopters.

In light of the extremely short duration of this analysis, the level of depth of the assessment was unavoidably, but understandably, less than desirable. Although many technical issues received inadequate detailed attention, a methodological approach to assessment was developed and several broad technical conclusions became evident. Since the level of detail available was limited, such conclusions are more properly termed impressions based upon available data from open literature sources. Limited Soviet data from open sources has constrained the opportunity for NET comparison of U.S. and Soviet capabilities at other than the systems level. Greater study intervals, enabling access to classified data, offer promise for elimination of the more conjectured of the following "conclusions".

1. The Mission Should be Characterized as Heavy Remote Lift

In order to objectively survey the technologies which could provide interesting alternatives to a future heavy lift helicopter, a rather abstract mission definition is a necessity. It seems reasonable that any system which can provide a surface independent, lifting capability should be examined. Heavy lift helicopters then fit within this mission envelope as ONE alternative solution with its attendant technologies.

2. Lighter Than Air, Other VTOL Aircraft ard Surface Effect Vehicles are also Candidates

Potentially viable alternatives t , or modifiers of, heavy lift helicopter systems involve some very different supporting technologies. While no known application of such concepts to the HLH mission have yet occurred, the future could see introduction of one or several of these competing concepts to augment or replace the HLH. Thus, in projecting this U.S. or Soviet mission capability into the future, the growth rates of these "new" technologies must be considered.

3. Lighter Than Air (LTA) Concepts Offer Unique Capabilities

While LTA applications have been largely dormant (some might say dead) militarily since the Civil War, recent advances in thin film polymers, nuclear propulsion, structural design, materials and hydrogen handling safety warrant reexamination of such devices. LTA systems could offer viable competition to HLH systems in two distinct ways.

First, the tethered balloon concept, now in limited forestry use, could compete with HLH systems for unloading ships at the beachhead. Conceptually, a line can be easily run from ship to shore (typically less than one nautical mile) and a sizeable balloon affixed to it by a slipring. Winches located at both the ship and shore ends could be rigged to provide translational energy to the balloon and the payload (attached to the slip ring). This offers the potential of an economical concept for short distances. The concept is in limited use for hauling timber down mountainsides - a use substantiating economic arguments. Details of a tactical mission profile, such as nearness to enemy positions and the associated vulnerability problem, are likely to dominate the decision about eventual application - rather than feasible technology.

A second LTA concept at the opposite end of the mission range spectrum is intriguing. Dirigibles or blimps offer performance characteristics pertinent to the medium and long range very heavy lift mission. The argument about viable use centers around technology evolutions in materials and nuclear propulsion technologies. Previously, safety, payload fraction, speed, and specific fuel consumption were considerations which 'argued' that dirigible systems were obsolete. Technology growth over several decades has all but eliminated concerns over low payload fraction and high specific fuel consumption. The dominant, remaining argument is slow speed.

4. VTOL Fixed Wing Aircraft Offer Promise

The development of progressively higher thrust to weight ratio turbines has enhanced VTOL fixed wing aircraft feasibility. Such devices would use wings as the lifting surface in horizontal flight and one of various types of propulsors during vertical take-off and landing. While jet, fan, propeller, and rotor propulsors are all plausible solutions, heavy payloads and moderate to short range missions focus interest upon the propeller or rotor. Hover efficiency considerations favor the rotor while translational drag considerations favor the propeller. The tilt wing propeller driven plane is one solution. A current preferred Army solution is the tilt rotor concept.

5. Surface Effect Vehicles Could Provide Significant Capability

Surface effect vehicles (SEVs) share with the fully airborne concepts some significant fraction of insensitivity to surface conditions. SEVs are able to operate over ice, water, marsh, sand, and rock. They are, depending upon size, able to remain insensitive to moderate grades and ridge heights. However, such SEV systems cannot operate in mountainous and forested areas as can other airborne systems.

Recognizing the penalty for lack of complete independence from surface conditions there are however, several advantages of SEVs pertinent to the HLH mission. Compared to helicopters, a SEV has desirable operating economics at moderate mission ranges. A SEV requires less thrust (and therefore engine weight) for a given payload lifting capability. Also a SEV requires less fuel per unit distance than the equivalent helicopter. Thus, the limitations upon operating surface must be weighted against mission range capability when comparing SEV and HLH.

Instead of a strict comparison of surface effect with helicopter, an examination of a composite of the two is interesting. The surface effect principle has been demonstrated as a landing gear replacement for conventional aircraft. Adding a surface effect landing gear to a compound (winged) helicopter suggests a capability for payload augmentation when a reasonably open area exists for STOL take-off. Furthermore, complete insensitivity to terrain as provided with normal payload by the helicopter, can be coupled with the long range SEV cruise capability when the mission flight profile permits. Finally, this composite vehicle provides an all weather, over water capability by operating as a SEV when conditions prohibit helicopter operation.

6. Helicopter Evolutions Provide for up to Triple Payload in 10 Years

A concerted effort to evolve helicopter technology could yield payload capabilities approaching 150,000 lb. by 1987 for systems with gross weights near 300,000 lb. This will bring VTOL payloads into near equivalence with current CTOL payloads and can therefore be expected to represent an upper limit to sensible helicopter mission requirements.

To accomplish such a threefold improvement requires a concerted effort in all dominant, contributive HLH technologies. Total rotor swept area must increase. Turbine power systems must achieve higher inlet temperatures, use more exotic fuels (hydrogen), and apply more efficient drive train concepts. Materials strength weight ratios must be improved and incorporated in more of the airframe. Advanced aerodynamic techniques must be applied to helicopter rotors, featuring efficient configurations and boundary layer shaping by blowing. The choice of such an evolutionary potential is additionally dependent on mission requirements and alternate system solutions.

7. Future U.S. Heavy Lift Helicopters are Likely to be Hybrids

With U.S helicopter payloads currently one order of magnitude below CTOL payloads and growing, other requirements such as increased range and better economics are likely to dictate choice of compound or composite aircraft in the future. For example, the addition of a fixed wing obtains STOL loading performance; the slowed or stowed rotor permits higher horizontal speed. Less specialized performance envelope designs are the more likely future evolution.

The Soviet Mi-12 heavy lift helicopter, introduced in the late 1960s is an example of the above trend. This is more properly termed a compound aircraft with a wing, an aircraft fuselage, and a pair of very large rotors. It offers VTOL, higher loading STOL, and extended range performance.

8. The U.S. Lags Dramatically in Heavy Lift Capability

The Soviet heavy lift helicopter program has significantly outpaced the U.S. Depending upon one's perspective the U.S. is up to 12 years behind and can lift only a fourth as much payload vertically as the best Soviet system. The U.S. could reduce these numbers to 7 years and around half the payload by means of successful completion of the "heavy lift helicopter" program in 1977.

It is important to recognize that the above statements are very sensitive to definition of lifting conditions. The U.S. prefers to design to high altitudes during hot days whereas the Soviets apparently design for near sea level and cooler conditions. Open literature sources did not specify Mi-12 lifting conditions - only the payloads lifted. Some sources suggest the Mi-12 may not be significantly different from the U.S. HLH when operated at similar conditions. Also, at Soviet conditions the U.S. HLH may be more capable than its nominal design lifting capacity. The following statements pertain most closely to Soviet lifting conditions.

The most capable Soviet heavy lift helicopter system is the Mi-12 compound. This is a dual rotor winged aircraft. Data from "Aviation Week" and other open sources suggest this system to have a VTOL payload around 75,000 pounds and a useful load (payload, crew, fuel) near 104,000 pounds. This Soviet system was introduced around 1968 placing it close to 7 years ahead of the planned U.S. HLH. The Soviet Mi-12 uses 26,000 installed horse power in the form of four turbine engines. The immense Soviet lifting capability is via two very large (115 foot) diameter rotors which provide a swept disc area of 20,800 square feet.

The U.S. HLH will exhibit somewhat lesser capabilities in 1975. It is expected to have a payload of 45,000 to 55,000 pounds and an useful load around 59,000 pounds. The HLH will use 24,000 hp and have two rotors 92 feet in diameter. The slightly shorter rotors make the disc area of the 1975 HLH close to 69% of the Mi-12.

9. The Rotor Appears to be the Cause of the Soviet Lead

The Soviet lifting subsystem has remained essentially unchanged over a 20 year period. Variants of the same 115 foot diameter rotor have been used on all Soviet heavy lift helicopter systems since the Mi-6 which was introduced in the early 1950s. A single one of these very large rotors was applied to the Mi-6 in 1958, the Mi-10 in 1962, the Mi-10K in 1967, and finally two of these rotors culminated in the Mi-12. The U.S. still has not developed such a large rotor - the HLH rotor being 23 feet smaller in diameter.

A comparative trend of U.S. and Soviet disc area suggests the U.S. is 13 years behind when the HLH is included as an operational point. This is somewhat greater than the U.S. lag in total payload lifting capability.

The Soviets have exhibited a willingness to rely on the same lifting subsystem for increasing heavy lift mission requirements on the basis of their long existing capability. The Soviets accomplished one design 20 years ago which is still providing immense capability. The U.S. in contrast usually reoptimizes its smaller rotors to meet evolving requirements.

10. Mission Emphasis Might Explain Some of Soviet Lead

During the 1960 to 1970 time frame, U.S. active development of advanced heavy lift helicopters enjoyed a low priority while the Soviets continued emphasis of HLH programs. This low priority U.S. effort was true of new tactical weapon developments in general as a result of strategic procurements and the Vietnam war. By 1977 close to 15 years will have passed since the U.S. fielded a new logistical helicopter.

The Soviets have established a comparatively high priority mission requirement on the basis of exploration of oil and gas reserves in Western and Northern Siberia. From 1960 to present this has culminated in 4 new heavy lift helicopters.

11. A Difference in U.S. and Soviet Development Philosophy is Evident

The example of Soviet rotor development has, in the authors' limited perspective, many corroborating analogies. The Soviet approach to system development appears to consist of designing subsystems, placing them "on the shelf", and designing many systems from them. These systems may consist of several overdesigned subsystems and several underdesigned ones which limit system performance. This approach may have been dictated by past shortages of key design talent. Such an approach tends to facilitate the deployment of many different systems, with a high degree of commonality, and with a resulting emphasis on fabrication.

The U.S., in contrast, displays a strong tendency toward optimized designs with each mission requirement being used to justify wholly new supporting subsystems. This may be largely due to planning based upon large production runs, to the availability of system engineering talent, and/or an abiding concern over every last ounce of performance. The result is that many U.S. helicopter design evolutions feature a rotor and an engine which are each optimized specifically for the new system. This optimization inherently makes each system prototype very expensive by comparison with the Soviet "off the shelf" approach.

While the above impressions of the 1960 to 1970 time frame are believed warranted, there are indications that a reexamination is underway of the value of system design from the off-the-shelf subsystems. As a case in point, a U.S. Air Force pilotless strike aircraft program is expected to provide a prototype 2 to 3 years after program inception. It will use currently available components rather than designing a new system with optimum subsystems from scratch - a process estimated to require 7 to 8 years.

12. Recent U.S. HLH Prototype Experience is Lacking

While the significant gap in U.S. - Soviet heavy remote lift operational capability exists, no obvious gap in scientific knowledge is evident. The U.S. helicopter-related research does not display obvious lags but is rather generally equal to or somewhat ahead of the equivalent Soviet knowledge in aerodynamics, in materials, in power technology, and in control systems. The U.S. has not tried to put this scientific knowledge into the development of a heavy lift capability similar to the Mi-12 until just 3 years ago.

13. Diverse Research Avenues are Pertinent

In helicopter related technologies alone there are several distinct directions for productive research in areas of advanced aerodynamics, strength of composite materials, turbine inlet temperature advances, cryogenic fuels, and turbine exhaust ducting for propulsion. With the potential of LTA, VTOL aircraft and SEV concepts as already identified, further diversity of pertinent research is evident. Future heavy remote lift capability might be dominated by any one of these technology pursuits. Thus, detailed comparison of the expected technology growth in each area, together with comparative assessments of the resulting design impacts, are significant objective means for identifying an optimal future U.S. (or Soviet) heavy remote lift capability. The selected option may be other than a helicopter.

14. Lighter Than Air Research Directions

LTA concepts become ever more promising HLH competitors as thin film polymer composite materials, nuclear propulsion technologies, and hydrogen safety research progress. Thin film and materials technologies are sources for significantly improved payload fractions. They allow for a very large degree of gas compartmentation with associated safety and survivability improvements. Nuclear reactor power systems may provide for a lower fuel plus engine weight at interesting mission ranges. Significant interest in hydrogen as a fuel for commercial aircraft and as an automobile fuel is stimulating research in hydrogen safety. Successful research results can provide the key to eliminating helium as the only viable lifting gas. Design research and successful prototype tests are necessary before this conceptual competitor to the HLH can be considered viable.

15. VTOL Aircraft Research Directions

The many variants proposed for VTOL transport aircraft are basically design optimizations based upon different propulsion decisions. Choices of engines range through turbojets, turbofans, ducted fans, propellers, and rotors. Each has a different set of pros and cons, based upon the design mission range, and assumptions relative to need for dash speed and hover efficiency. Each requires research in the area of transition stability - hover to translational movement. Each is in need of further prototype proof of claims. The particular case of a composite using either a stowed or stopped rotor also requires further research into the implementation of such capability.

Perhaps the exotic in heavy remote lift research concepts is represented by the very intriguing rotating wing idea. This VTOL aircraft would attempt to demonstrate that a set of large scale wings (*a la* CTOL aircraft) could be rotated for hover and locked for horizontal flight. The hub of such an aircraft would carry the cargo and/or crew. This concept poses a significant challenge for materials and aerodynamic research.

16. Surface Effect Vehicle Research Directions

SEVs exhibit one dominant deficiency beyond the needs for improved prototype demonstration and design optimization. Specifically, SEV skirt materials demand significant advances in erosion resistance from the abrasive impacts of dust and dirt during overland operation. Successful testing of the surface effect landing concept recently suggests a high state of confidence in aerodynamic design capability.

17. HLH Rotor Research Directions

Materials research results are providing increased rotor stiffness at lower rotor weights. Continuation of such research offers promise in the context of rigid rotor development. Rigid rotor development in turn offers promise toward decreased drag and the associated induced air turbulence.

Aerodynamic research is yielding advanced rotor tip configurations with improved lift to drag ratios at higher tip speeds. These advanced chord designs suppress drag onset which is caused by boundary layer separation near Mach 1. Further research and prototype testing of internal and external blowing techniques promise further boundary layer control. Internal blowing (ejecting air from within the rotor to the top of the rotor blade) can advantageously impart momentum to the boundary layer. Tip mounted turbines on extremely stiff rotors can be used to blow down across the top of such rotors to control boundary separation and inhibit drag increases.

Stiffer rotors promise larger diameter rotors. Lower drag permits greater tip speeds for more lift. As lower drag reduces air turbulence, wider rotors with greater lifting area are plausible. Thus, materials research and aerodynamic research can reasonably provide greater disc area and greater solidity ratios in future HLH designs. The resulting increase in allowable disc loading and payload is of significance to the heavy remote lift mission.

18. HLH Power Research Directions

The development of future HLH systems may find design of the power generation and drive system to be highly integrated with the rotor design. As an effort to eliminate the extremely heavy drive train and transmission, research into techniques for piping gases through the rotor and out the trailing edge of the rotor tip offer promise as a propulsion concept. Such tip jet concepts are typically referred to as hot, cold, or warm cycle depending upon whether the gases are hot turbine exhaust, impelled cold air from a high bypass turbo fan, or a combination of both. Research efforts center on minimizing the effect of a tip jet upon rotor weight and rotor chord configuration.

Another power subsystem research area is that of exotic fuels with higher specific heat content (calories per unit weight). Examination of methane and hydrogen is warranted for HLH missions since the volumetric inefficiency of such fuels can be ignored at low translational speeds. Research into borate fuels has apparently reached an environmental impasse. Cryogenic fuels offer additional advantages by facilitating turbine transpiration cooling, allowing higher inlet temperatures and lower specific fuel consumption and by creating attendent lower total fuel weight requirements. Storage and handling of such fuels is an area for productive research.

The gas turbine engine, itself, offers significant room for improvement in terms of greater specific power output via increased inlet temperature. Research in high temperature technology centers on transpiration cooling techniques, the eventual development of columbium and chromium alloys with high temperature performance attributes, and the possibilities of refractory materials.

More exotic engine concepts are also worthy of at least some examination. Fuel cells are evolving toward interesting power densities. Batteries such as lithium-chloride or lithium-floride are progressing toward interesting power densities for moderate durations. Research into R.F. induction jets using argon as a catalyst could provide concepts which are at least worth investigation.

19. HLH Structural Research Directions

Research into composite materials with greater specific strength and specific modulus offers promise of greater structural efficiency in future U.S. HLH designs. Projections include fiber in metal composites which, by 1990, might display specific strength - specific modulus products near 3×10^{16} square inches - near the theoretical limit.

20. HLH Control Research Directions

As payload requirements evolve for HLH systems, newer design concepts can be applied to provide greater inherent stability. Multiple rotor concepts are being compared to single rotors with a tail stabilizer. Swiveled tail rotors are being examined to provide translational thrust as well as stability. High impulse to weight ratio elements such as rockets or high mass flow air jets might also deserve research attention. Fly-by-wire concepts are currently being proven in test conditions.

In summary, research in several revolutionary technical areas offers the potential for an evolutionary improvement in heavy lift helicopter capability. Furthermore, evolutionary improvements in several other technologies might precipitate the introduction of a revolutionary competitive system to the HLH.

2.0 ASSESSMENT OF HEAVY LIFT HELICOPTER FUTURES

This section will portray the development of the TECHNOLOGY SUBSCRIPTED methodology for technology level Net Technical Assessment. The heavy lift helicopter (HLH) system is assessed in order to demonstrate this NTA method for relating future U.S. and Soviet systems capabilities to their respective development rates in the key supporting technologies.

The reported Net Technical Assessment of HLH systems and other competitive system concepts has a distinct technology emphasis. Technology growth is forecasted. Relative technology growths are netted comparatively. The apparent significance of technology evolution upon future system capability is assessed. Potentials for revolutionary introduction of wholly new technologies to provide significant increments of system capability are considered.

In essence this effort correlates technology research areas with future HLH system performance. Furthermore, this effort correlates other system concepts and research into their peculiar technologies with the HLH mission. It is hoped that this produces a degree of confidence of SURPRISE FREE heavy lift capabilities on both the U.S. and Soviet sides.

Within the 6 week time frame during which this effort was performed a limited although extensive amount of open literature sources were uncovered pertinent to the HLH. While greater technical detail was sought unsuccessfully, a team of uninitiated generalists were able to array the CONCEPTUAL OPTIONS available for HLH system development and associated technology research. A longer study, using this procedure, would provide for many quantitative trades and comparisons. This effort has at least provided a qualitative OVERVIEW.

2.1 STEP 1 - IDENTIFY MISSION REQUIREMENTS

Initial activity is directed toward examination of the various missions which might be satisfied by a heavy lift helicopter system. This effort allows early identification of system concepts with capabilities similar to the HLH. The mission requirement defined within this initial step must remain broad enough to open the door for other competitive system concepts.

The development of a mission definition is aided by examination of Figure 2.1. This artist's concept of the future U.S. Heavy Lift Helicopter in an operational setting illustrates two key mission requirements. Firstly, the system is shown operating over both water

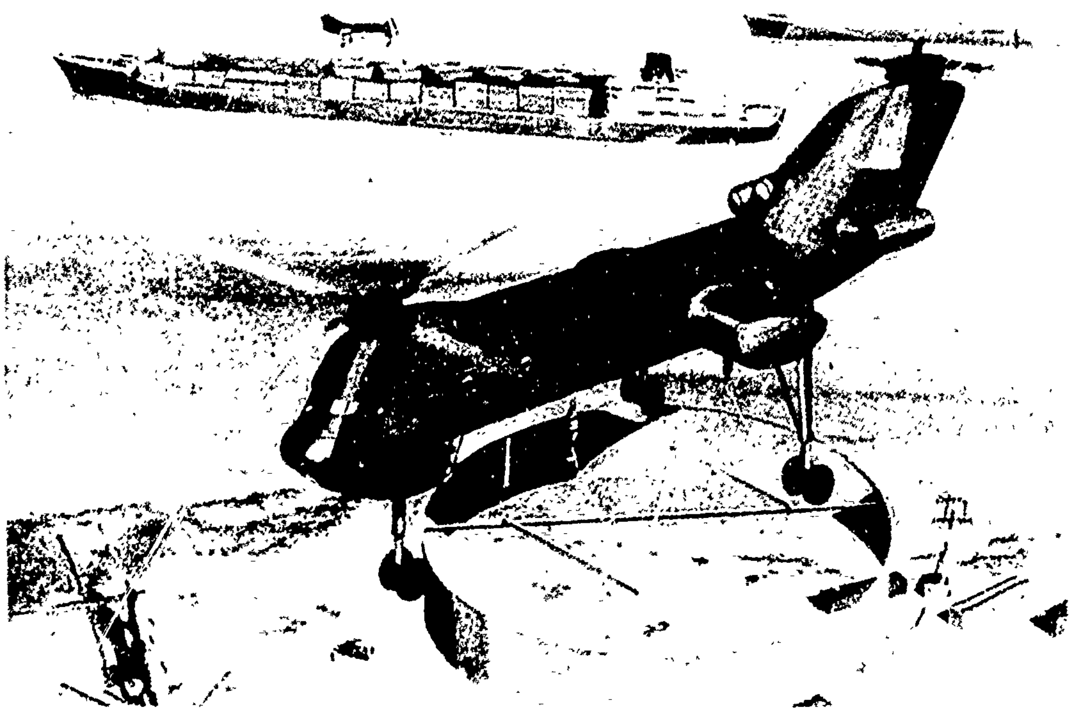


Figure 2.1: The U.S. heavy lift helicopter for 1975.

and land - demanding insensitivity to surface conditions. Secondly, the area of operation is portrayed as remote with essentially no site preparation or ancillary equipment (such as docks or cranes).

Other details of the U.S. HLH mission are evident from the figure. The aircraft are obviously lifting very large payloads. These large payloads are being carried over very short distances implying the major design requirement is large payload not long range operation. Also, the figure implies quite low speeds. Furthermore, the system is apparently expected to operate well away from the front lines without concern to survivability (who would shoot at a helicopter compared to a ship?).

These considerations suggest generalizing the HLH mission requirements as on Figure 2.2. A concise term for such a mission definition might well be "heavy remote lift". Very important also is the insensitivity to surface conditions reflecting the desire to operate over water, sand, marsh, and mountains. Recognized as secondary areas of interest are noise, speed, rotor downwash, and operating economics. Of these, downwash, is treated as the most pertinent since it affects the ability to operate over unprepared land surfaces without destruction of the landing site.

Figure 2.2 also portrays the criteria by which future HLH or alternate system concepts should be measured - payload and range. These factors are the ones with maximum impact upon utility of heavy remote lifting systems.

Treating payload and range as the primary mission figures-of-merit (FOM) is consistent with the goal of comparing U.S. and Soviet present and future capabilities. The competitive Soviet HLH system is

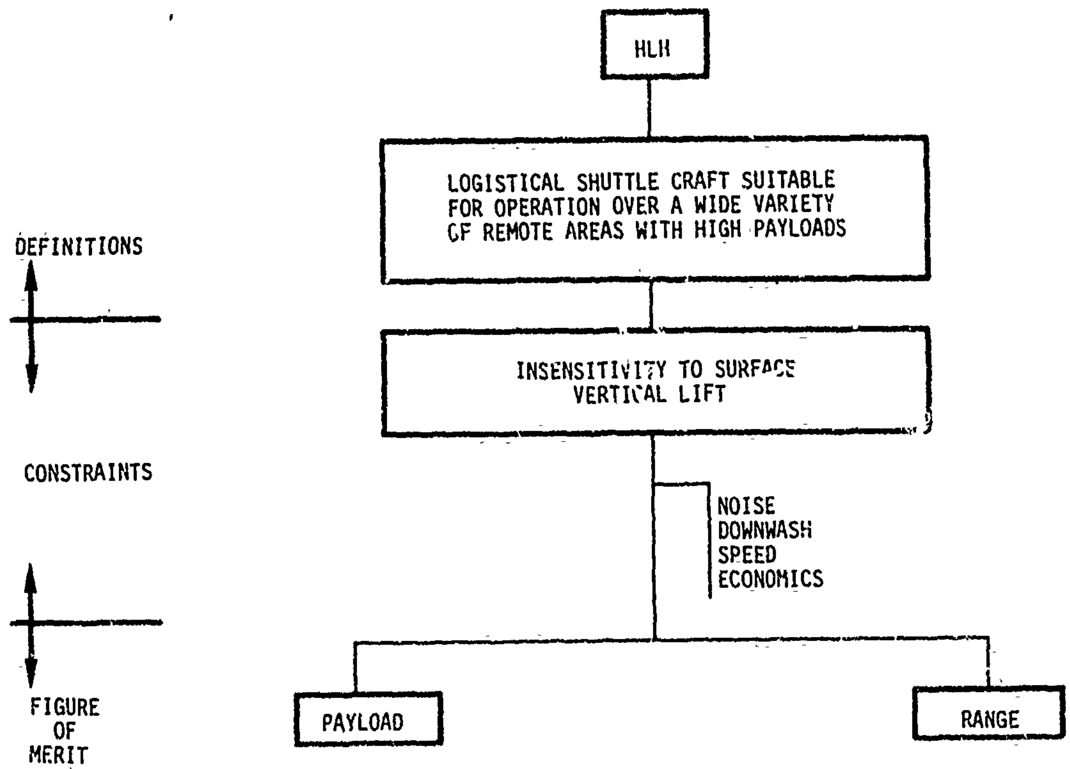


Figure 2.2: HLH mission generalization

the Mi-12 illustrated on Figure 2.3. This existing system enjoys a range and payload advantage over the proposed U.S. HLH. Adoption of these FOMs allows comparison of system mission capability as in Figure 2.4, drawn for 1978. This format shows the net differences between the U.S. HLH and the Soviet Mi-12 and allows portrayal of other systems with different range and payload profiles. The effort in following steps of this procedure shall attempt to anticipate what system concepts will facilitate achievement of the two illustrated goals - higher future payloads and longer future range capability. The quantitative degree of such system advances should be predicted

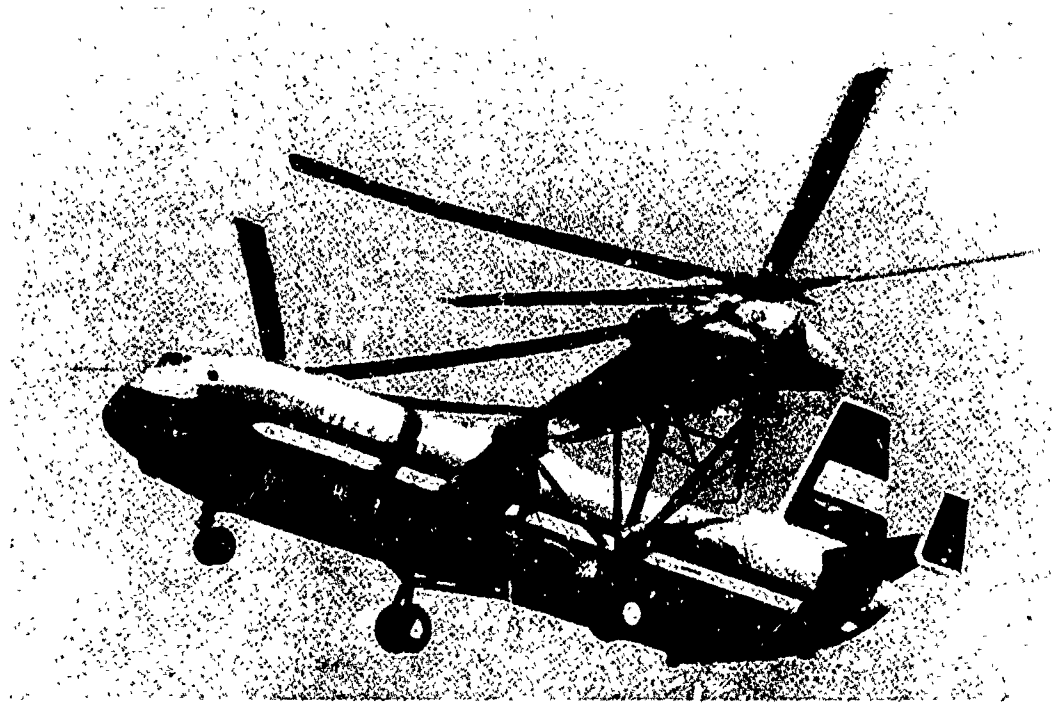


Figure 2.3: The Soviet Mi-12 introduced in 1968.

for both the U.S. and U.S.S.R. Also, the technology research programs which are necessary to bring such capabilities to fruition should be identified by type and degree.

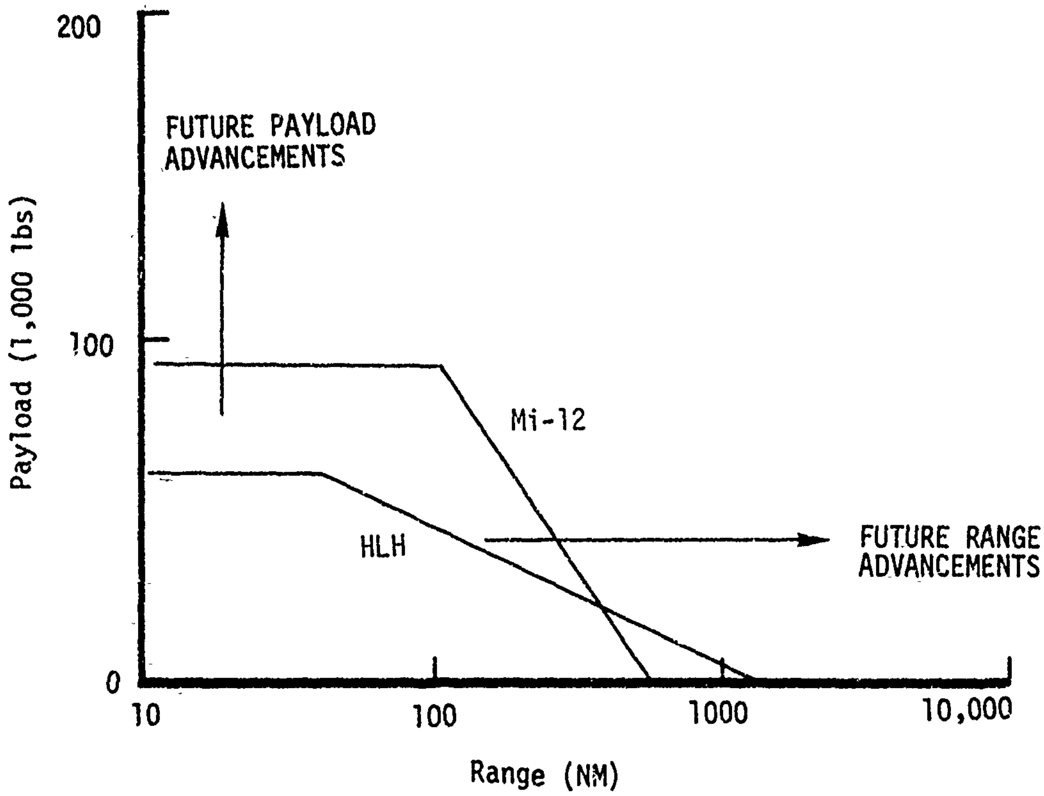


Figure 2.4: A goal of NTA - anticipating relative future mission capabilities.

2.2. STEP 2 - INDUCE ALTERNATE SYSTEMS

Having generalized the HLH system mission, the issue becomes identification of alternate system concepts which do, or which might in the future, offer similar or superior mission capability. A relevance tree approach toward identification was attempted and found to be successful. Major categories of system concepts are identified as compatible with the mission requirements. These categories are lighter than air (LTA) vehicles, surface effect vehicles (SEVs), and vertical take off and landing (VTOL) aircraft.

The technique for identifying such unconventional concepts as offering similar capabilities at some point in the future warrants attention. During this study the concept of surface effect vehicles is introduced for debate because of past experience on the part of one of the study participants. A debate is unavoidable over the pros and cons of such a system in light of the mission requirement of operation over ALL types of surfaces. The decision can be made to retain the concept until further ideas are identified for comparison.

To assist identifying other system concepts a relevance tree format is adopted with the mission at the top and the two concepts - HLH and SEV at separate lower branches of the tree as shown in Figure 2.5. The intervening branches of the relevance tree and the associated question marks serve to focus attention toward the generic differences between SEVs and helicopters. The parallel boxes tend to focus attention upon system concepts which are similar to its neighbors. This format is only one of several viable ones. It serves to guide the mental process into lucrative areas by combining the inductive and deductive reasoning techniques.

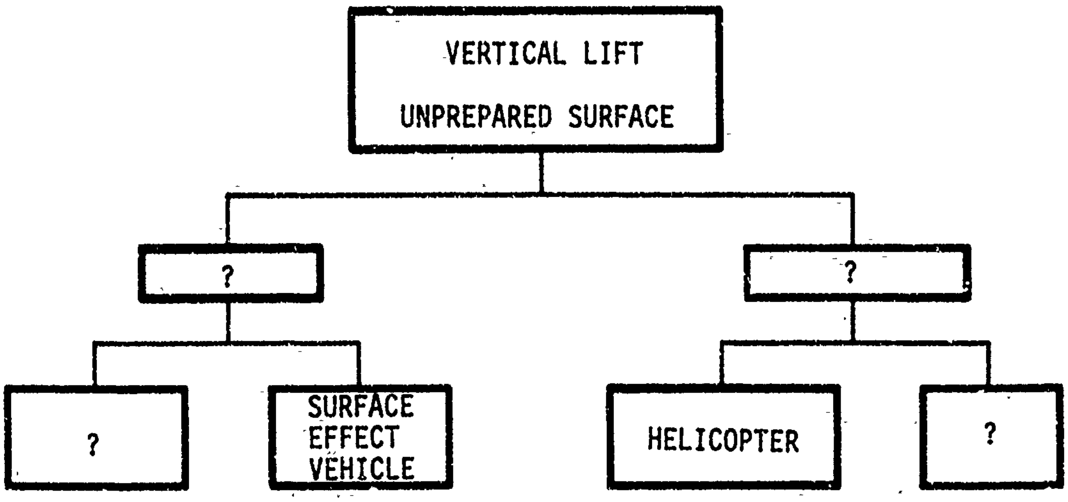


Figure 2.5: Initial relevance format.

Portrayed on Figure 2.6 is the next phase of relevance tree development. Here the generic difference between SEVs and HLH is recognized as deriving from aerostatic versus aerodynamic principles. That is, surface effect vehicles are often termed air cushion vehicles which properly imply operation based upon a steady state (or static) pressure differential. On the other hand, helicopters utilize rotors dependent upon air dynamics. Other aerodynamic vehicles are represented by conventional (CTOL) and STOL aircraft. The CTOL and STOL aircraft assist the thought process and are therefore displayed but with dotted corrections to indicate inability at satisfying "vertical" and "unprepared" mission criteria.

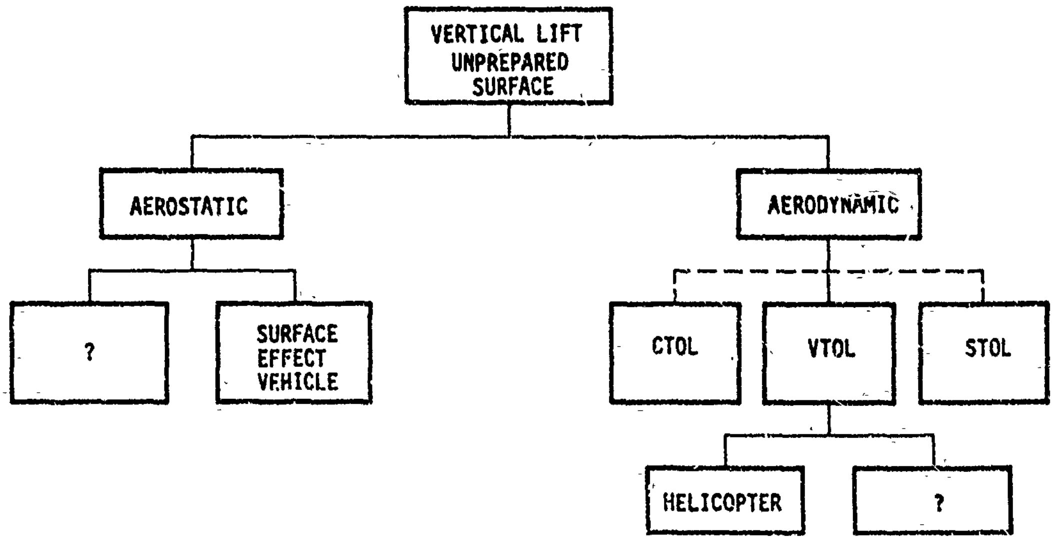


Figure 2.6: Identification of generic categories

As attention is directed toward other aerostatic devices which operate upon pressure differentials the lighter than air concepts eventually come to mind. Furthermore, such concepts are determined to be separable into very short range and very long range devices. Specifically, for unloading ships to a nearby shore, a tethered balloon concept is thought to be pertinent. In principle this device would use a balloon for lifting the payload and a ship to shore line for guidance. Translational power might be supplied by winches at the end points. This technique is in current use in commercial logging operations for bringing timber down mountainsides.

Additionally, a dirigible or blimp LTA concept is identified for moving large payloads very long distances. Such vehicles might employ nuclear power supplies to achieve good operating economics at very long ranges.

Literature surveys also identified a tilt wing propeller driven VTOL aircraft for development. This device would swivel the wing and its wing mounted turbo props to provide both vertical hover and also horizontal flight. Figure 2.7 is formed to draw attention toward additional VTOL concepts and displays the LTA systems.

At this point attempts are in order to assure a high degree of completeness in the set of identified system concepts. A morphology

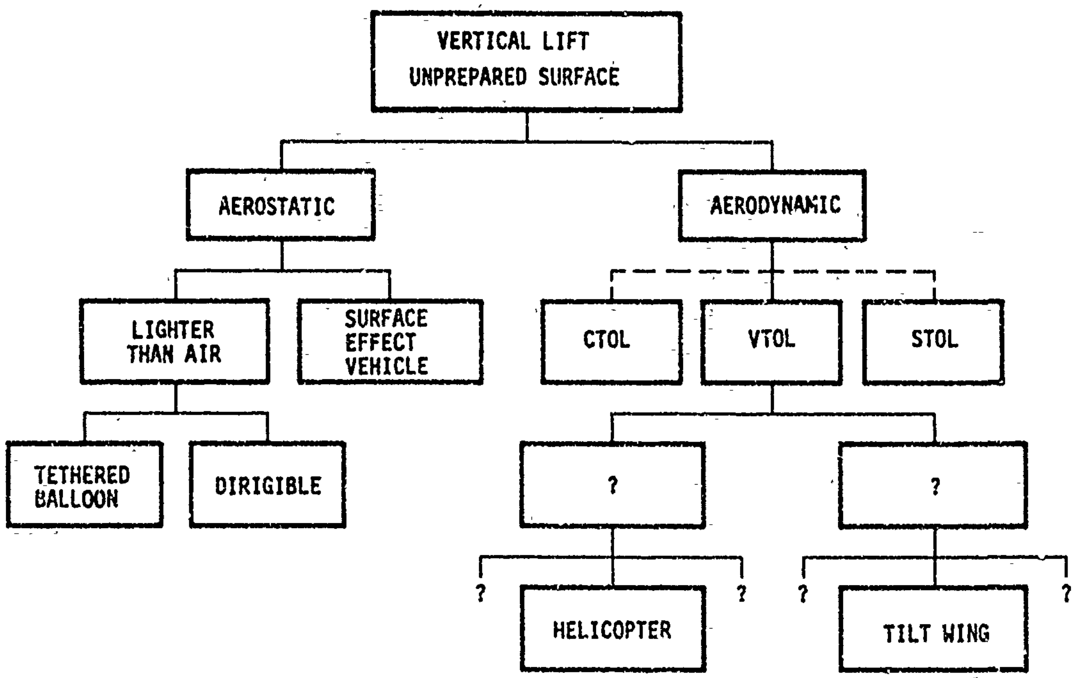


Figure 2.7: Enriching the set of system concepts.

is useful toward this end. Figure 2.8 shows an elementary morphology assisting tests for completeness of the set of reasonable systems for the heavy remote lift mission. The rationale for this diagram centers on testing each vehicular concept against both the operational environment list and the figure-of-merit (FOM) list. It is evident that trucks, trains, and CTOL aircraft require extensive surface preparation for activity in remote areas. Also, boats are unacceptably limited to over water operation. The morphology also aids review of vehicles already included, such as the SEVs. The SEV does not offer potential for mountain or forest operation as do LTA, HLH, and VTOL aircraft, but it is far more versatile than the options discarded above. The SEV offers superior payload, hover, and range capabilities relative to the remaining options. On this basis the SEV is retained as being reasonably consistent with the gross mission requirements.

As system concept identification reaches a conclusion VTOL concepts are segregated into two classes - rotary winged aircraft and fixed wing aircraft using directed thrust for lift. Figure 2.9 shows this expansion of VTOL concepts with pertinent systems chained with solid lines and correlative thoughts chained by dashed lines. A composite helicopter-SEV is identified as a result of recognition of

VEHICLE	HELICOPTER	V/STOL	BOAT	TRUCK	LTA	TRAIN	SEV	CTOL
ENVIRONMENT	MOUNTAIN	FOREST	PLAIN	DESERT	BOG	RIVER	OCEAN	
FOM	RANGE	PAYLOAD	HOVER	SPEED				

Figure 2.8: Morphology for testing completeness of system set.

the surface effect landing system (SELS) concept which has been tested on the deHavilland C-8 Buffalo STOL aircraft (Aviation Week, January 8, 1973). This SELS promises to extend an interesting STOL payload overload capability to helicopters as well as extending cruise range if terrain is suitable.

The pure helicopter is recognized as providing greater capability through design of larger vehicles or by combining the lifting capacity of multiple smaller helicopters. This "tethered helicopter" concept was conceived as a result of the recognition of the tethered balloon LTA system. Subsequent research uncovered the fact that two Sikorsky Skycranes (CH54) have successfully completed a joint lift.

A compound helicopter consists of a rotor and a wing and is exemplified by the Soviet Mi-12. The wing is used to provide load bearing capability during longer range horizontal flights and allows for possible slowing of the rotor speed during such cruise flight.

A class of composite helicopter/aircraft is shown on Figure 2.9 as using rotor and wing but with a change in propulsion for cruise. These systems seek to combine the hover efficiency of rotors with longer range cruise.

Finally, a class of composite aircraft which use directed thrust for hover to the exclusion of rotors are introduced. Such devices emphasize long range cruise aspects of the mission and sacrifice hover efficiency for propulsion systems with lower drag characteristics.

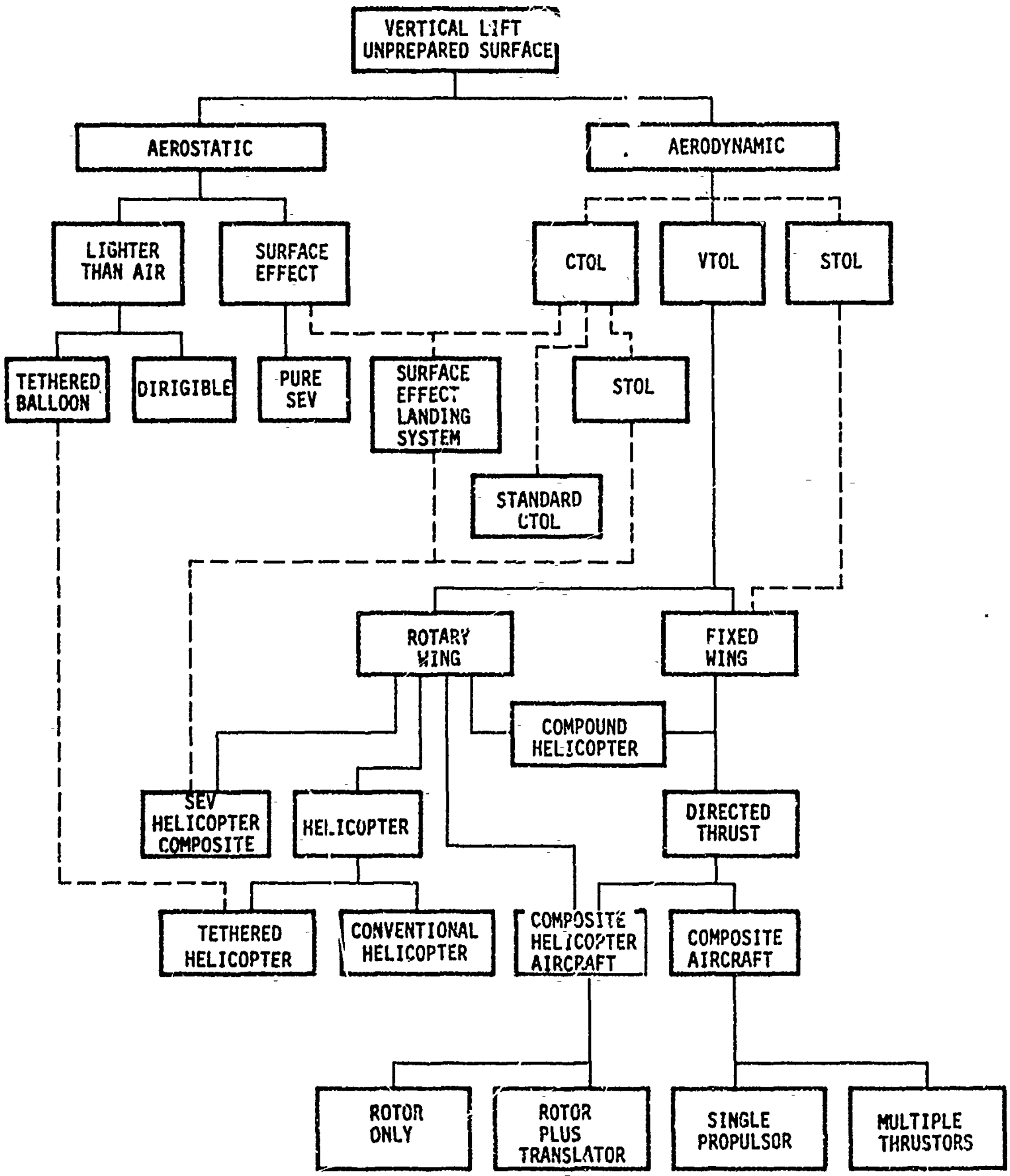


Figure 2.9: Correlation between alternate concepts.

Figure 2.10 shows the results of step 2 without the clutter of the analogous system concepts which don't really apply to the mission. Examples of some of the concepts are identified for illustrative purposes.

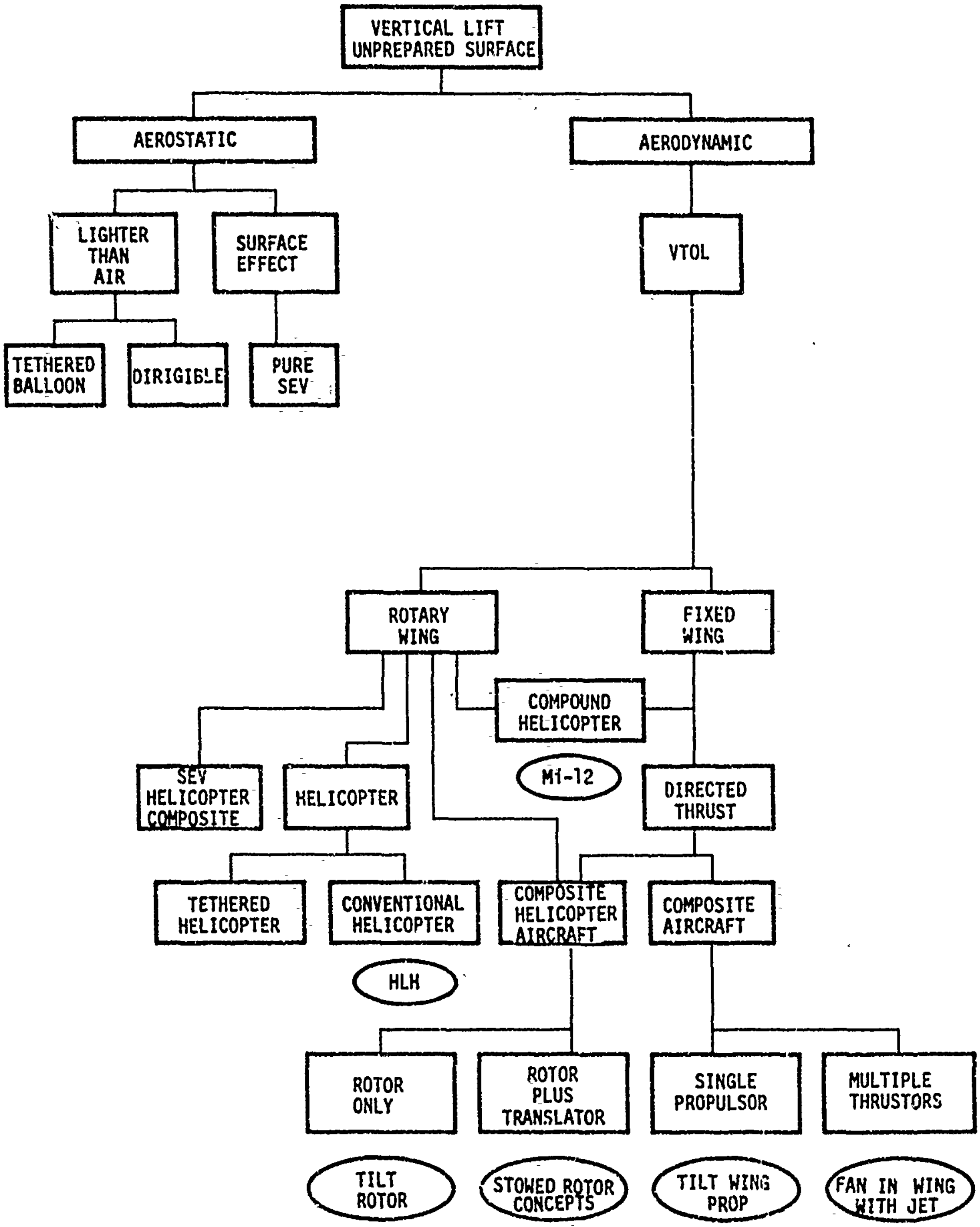


Figure 2.10: Identification of alternate concepts complete.

2.3 STEP 3 - IDENTIFY SYSTEM FIGURE OF MERIT

The eventual objective of the TECHNOLOGY SUBSCRIPTED method for NTA is to assess the quantitative impact of plausible technology advances upon system performance. A sufficiently general system figure-of-merit is required to serve as a general ruler against which the various system capabilities can be measured and compared. The FOM must have the characteristic of representing fairly the capability of all system concepts, without favoring any one class. A major issue is whether to measure performance amplitude or performance efficiency.

An operational military system with the highest amplitude performance FOM provides the best military capability. However, the design of particular systems with similar performance amplitudes should be copared with the basis of design efficiency. In the sense of performance magnitude, the area under the payload versus range curve is an interestingly general FOM applicable to all heavy remote lift system concepts. Figure 2.11 displays the payload-range FOM as well as several

PAYLOAD VS RANGE
USEFUL LOAD/GROSS WEIGHT
GROSS WEIGHT/POWER
GROSS WEIGHT/(PAYLOAD × RANGE)
(GROSS WEIGHT × SPEED)/POWER
COST PER TON MILE

Figure 2.11. Candidate system figures of merit.

reasonable efficiency FOMs. The economic measure of cents per ton mile is listed last since it is usually of somewhat lesser importance than system performance for military systems and since it does not measure technology state-of-the-art.

Useful load fraction is good for measuring the overall design efficiency of one system with another. It succeeds in measuring the effectiveness of power, lift, and structural subsystems in the combined sense. The efficiency of the lifting and power subsystem combination is measured well by power loading (gross weight/power). Figure 2.12 displays an extremely large variation of transport system

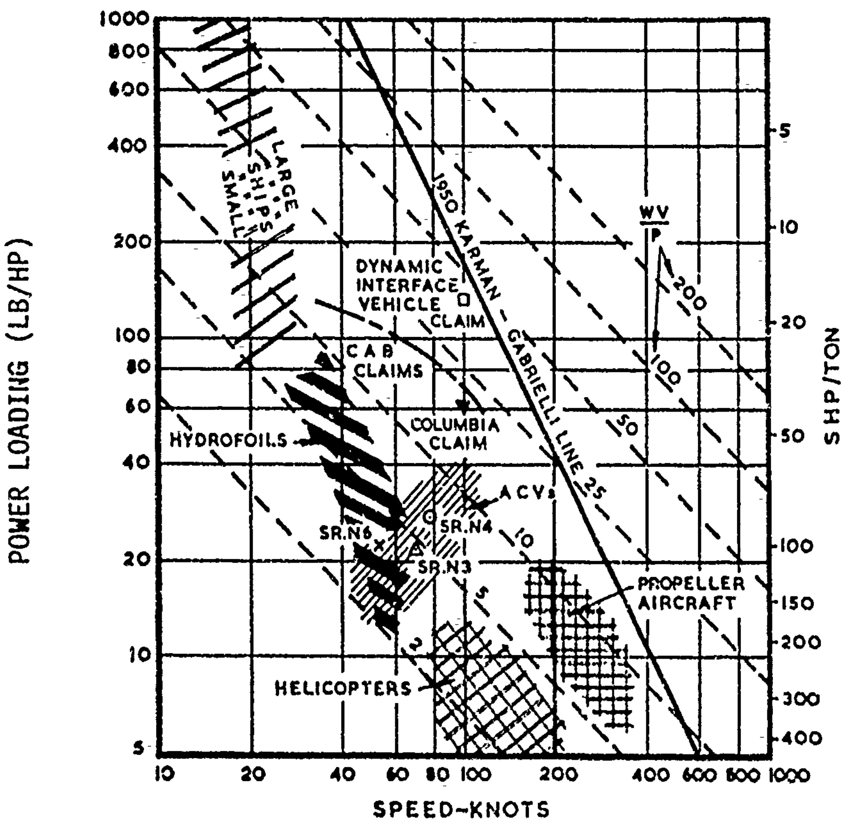


Figure 2.12: Arraying diverse concepts in terms of power loading.

types in terms of the power loading versus speed capability. This figure shows surface effect vehicles (labeled ACVs) to have a significantly better power loading than helicopters. Dirigibles, although unplotted, would fall somewhat to the right of the area labeled "ships". VTOL aircraft would appear worse than helicopters in terms of power loading - falling somewhat below propeller aircraft.

The dotted lines of constant WV/P shown on Figure 2.12 reflect the product of power loading and speed. This is another interesting figure-of-merit which tends to relate to economics of operation. The Karman-Gabrielli line for 1950 is a theoretical representation of the 1950 state-of-art limit.

Still another measure of system efficiency is system gross weight divided by payload-range as exemplified on Figure 2.13. This FOM is used to compare the trend of STOL aircraft versus helicopters, showing that helicopters are approaching the efficiency of STOL aircraft.

Figure 2.14 displays the trend of helicopter and directed thrust aircraft in terms of system gross weight. This plot conveys an impression of the rapid evolution in these states-of-the-art. It is evident that the helicopter "learning curve" is maturing as typified by the very steep ascent. However, the directed thrust state-of-the-art is evolving more rapidly - implying overlap in the 1970 time frame. The lead in relative technological know how which once was enjoyed by the helicopter designer is being yielded. Directed thrust aircraft systems are becoming viable competitors to the helicopter.

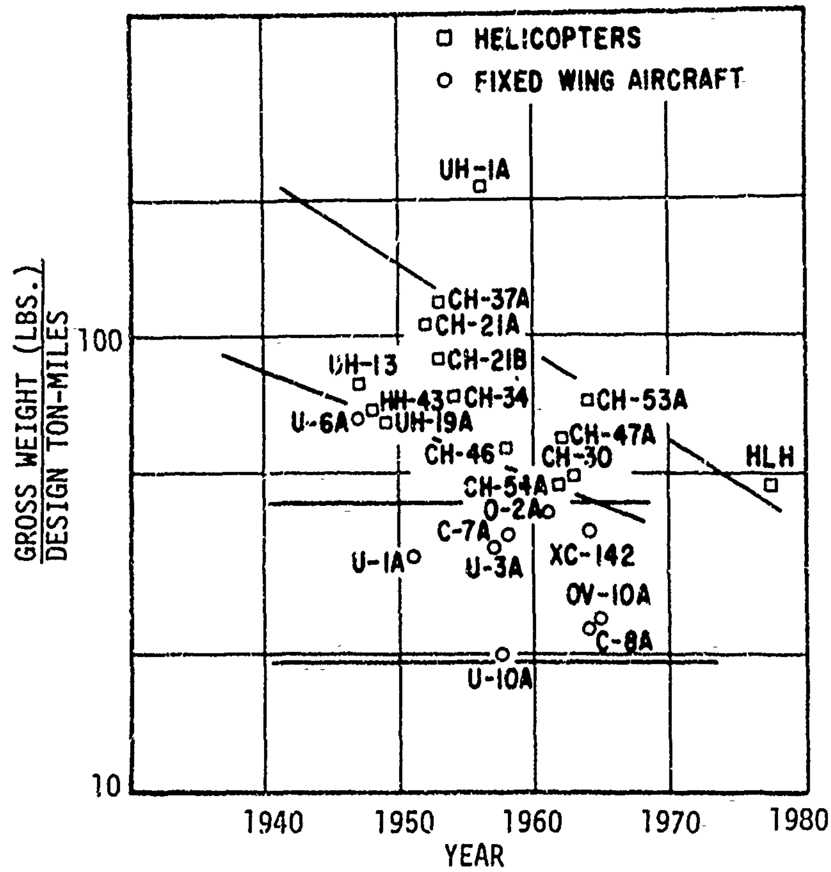


Figure 2.13: Relative efficiency of helicopters and STOL aircraft.

While these many measures of system efficiency have found extensive use, the magnitude of capability is best used for comparison of a wide var' :y of systems. Bigger is better. Payload times range and gross weight are pr.ferred figures of merit.

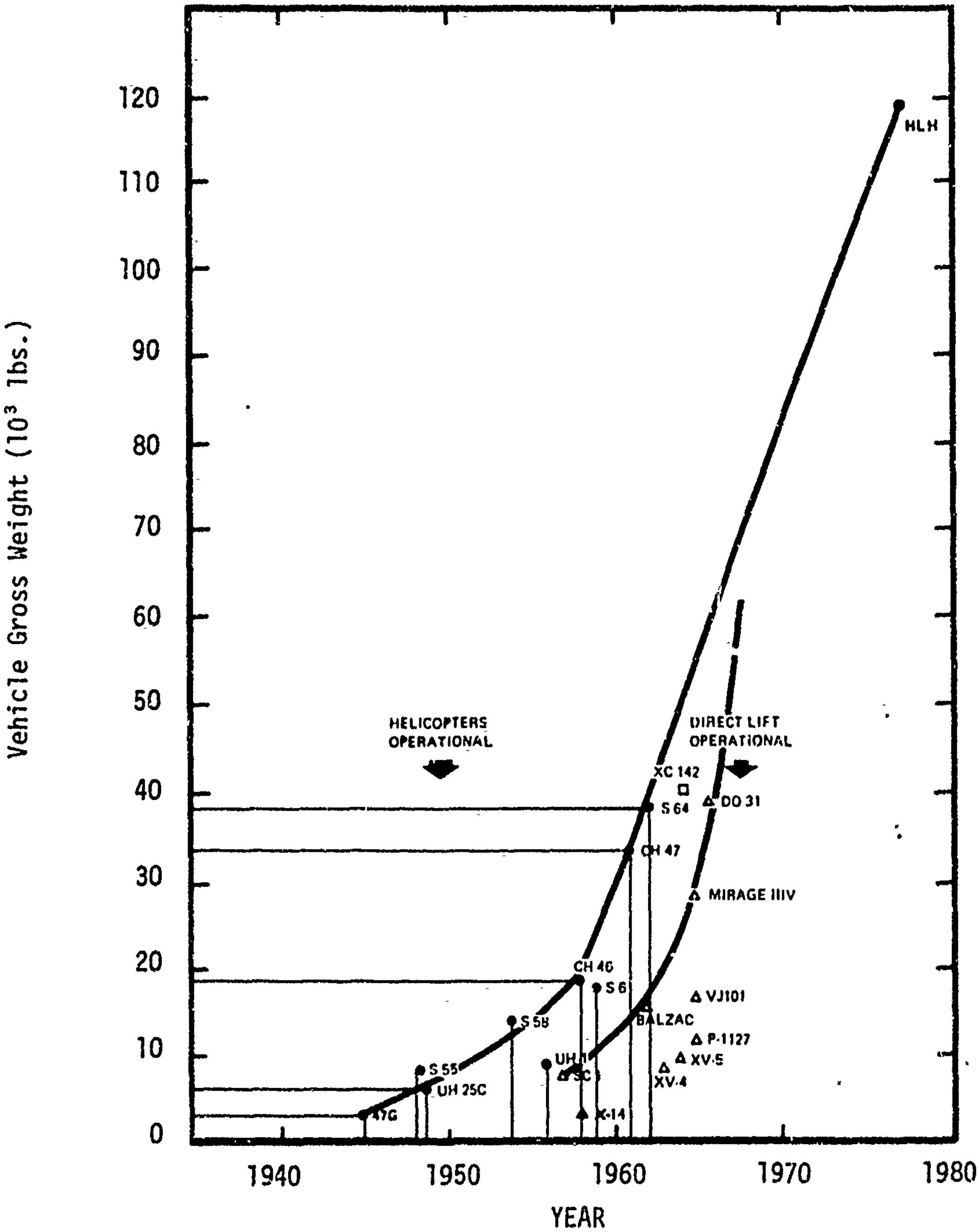


Figure 2.14: A vertical lift, vehicle gross weight trend.

2.4. STEP 4 - IDENTIFY SUBSYSTEMS

Attention is now focused upon each of the generic system concepts in order to identify subsystem groups which are logically related. Previous selection of system concepts allows subdividing the crucial literature review, facilitating efficient application of available manpower. Four classes of systems are reviewed - winged VTOL aircraft, surface effect vehicles, lighter than air craft, and helicopters.

The subsystems associated with winged VTOL aircraft may be identified as shown on Figure 2.15. The major emphasis is the dissociation of the lift and the cruise subsystems to focus attention upon the different role of the engine and propulsor. The commonly used FOMs for the major subsystems are also shown on this figure, as precursors to their full discussion in the next section of this report.

The SEV system is broken down and its subsystems are portrayed on Figure 2.16. In the case of SEV concepts attention centers upon the possibility of different power systems for cruise and for lift. LTA concepts are portrayed upon Figure 2.17 showing the extreme simplicity of the lifting subsystem - gas. The cruise and control subsystems are actually quite related for essentially neutral bouyancy LTAs. The tethered balloon concept uses a guide wire for both control and cruise power, while the dirigible uses the propeller for both control and cruise.

The pure helicopter subsystems are displayed on Figure 2.18. The key subsystem areas are shown as lifting subsystem, power subsystem, airframe, and control. Within the power system are grouped engine, fuel, and drive elements since these are closely interrelated The interesting function is overall power to weight ratio - with fuel weight being dependent upon engine efficiency, etc.

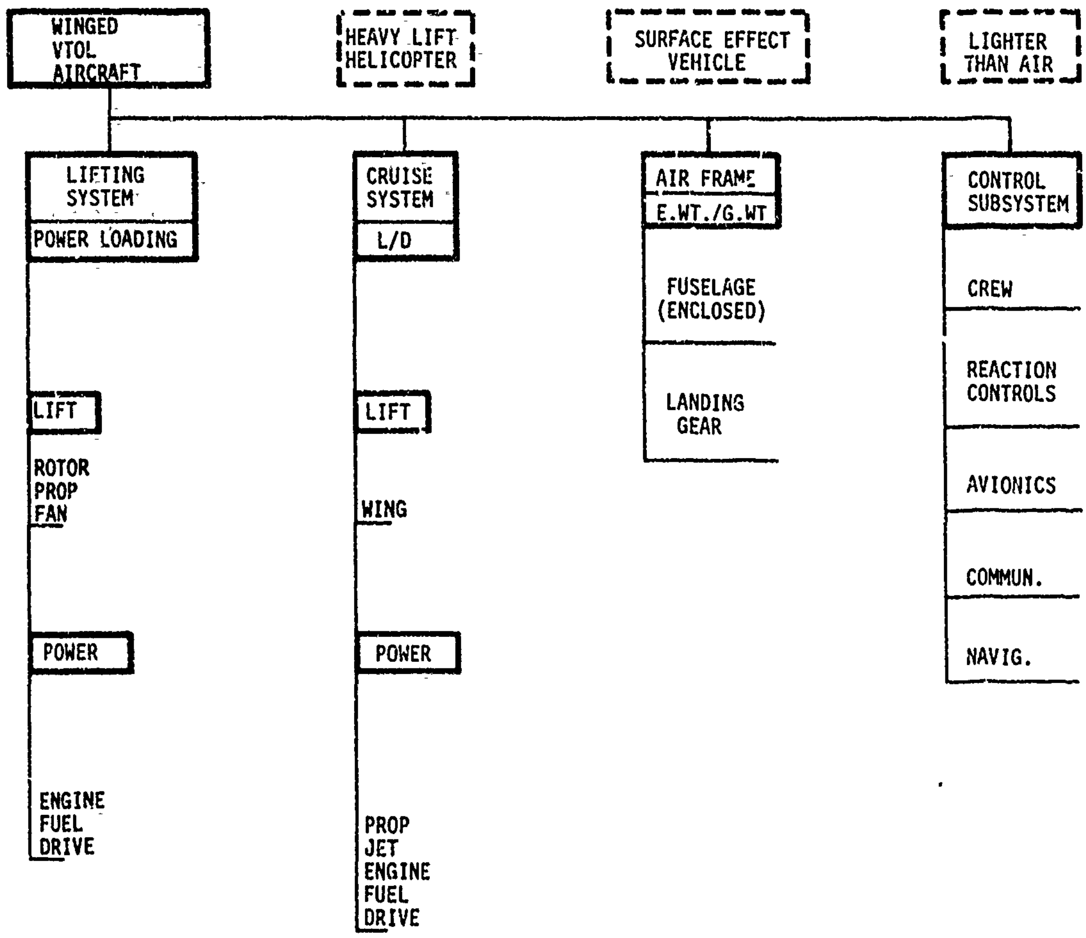


Figure 2.15: Major subsystems for winged VTOL aircraft.

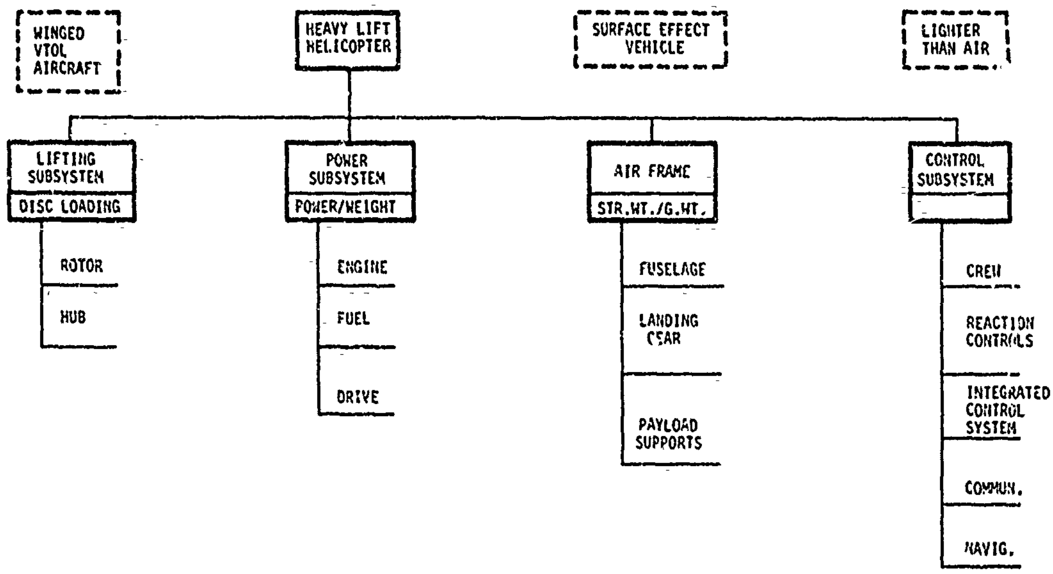


Figure 2.16: Major subsystems for heavy lift helicopter.

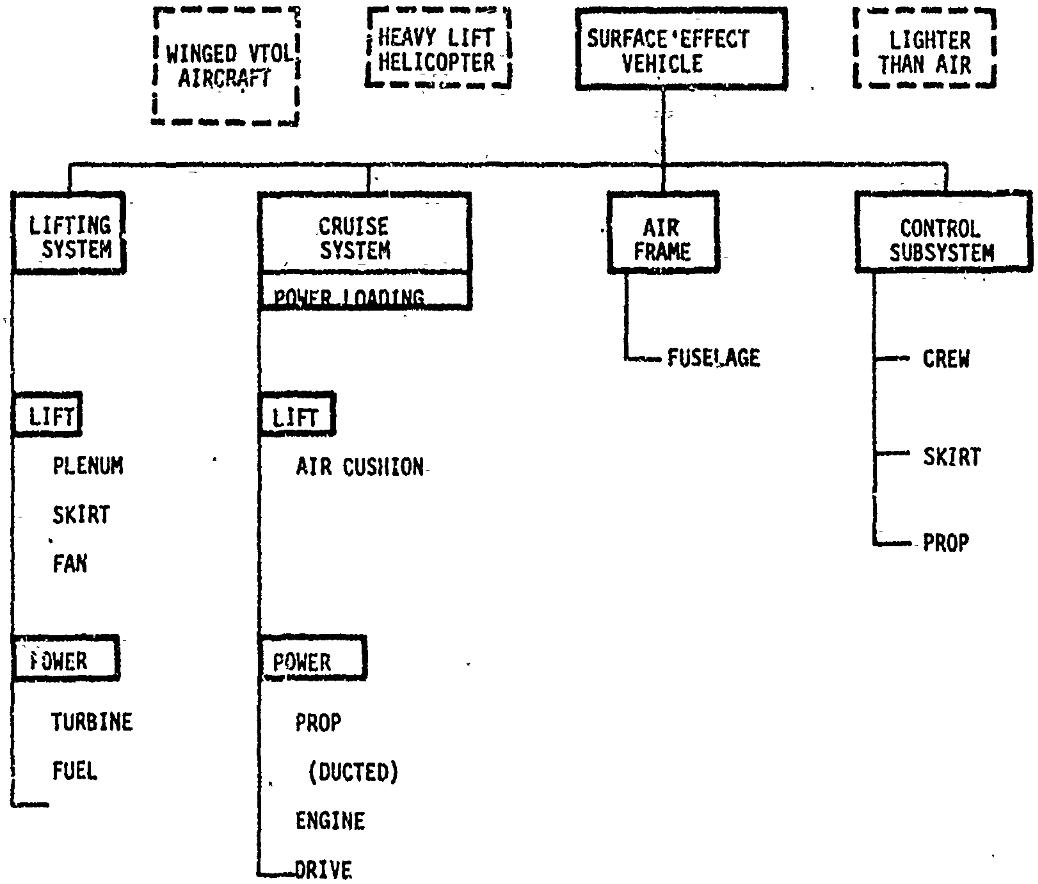


Figure 2.17: Major subsystems for SEV.

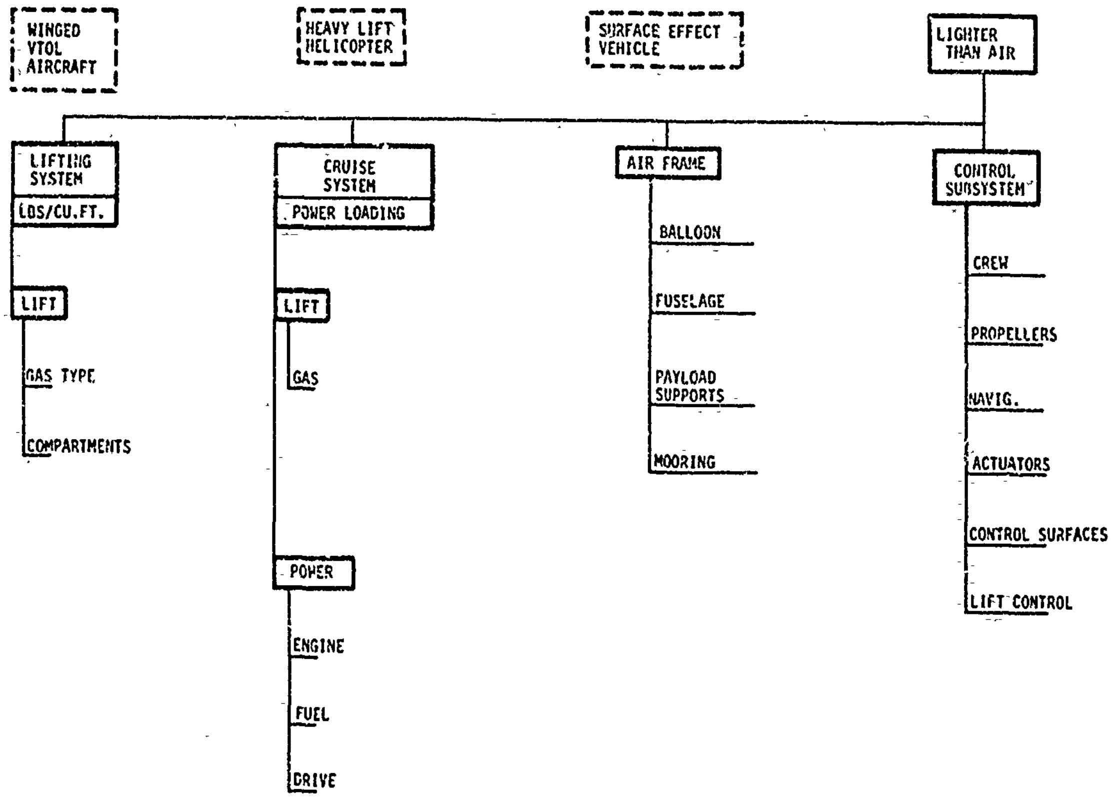


Figure 2.18: Major subsystems for lighter than air craft

2.5 STEP 5 - IDENTIFY SUBSYSTEM FIGURE OF MERIT

Upon study of the various subsystems it becomes evident that several figures of merit have been used to describe the different aspects of subsystem performance. This section describes commonly applied measure of subsystem performance which are pertinent to helicopter subsystems. The other system concepts - winged VTOL aircraft, SEVs, and LTA - were not examined to the comparable degree due to the time limitations of this study.

The helicopter lifting subsystem is examined on Figure 2.19. Two key FOMs are uncovered - disc loading and disc area. Disc area is the measure of total area swept by all rotors and as such reflects upon the brute force lifting magnitude. Disc loading is the gross vehicle weight divided by disc area (usually in lbs/sq. ft.). This factor reflects upon the efficiency of the rotor area use - ability to lift per unit disc area. High disc loading tends to have the disadvantage of creating high downwash which could injure the landing site for further use. Disc loadings in typical use range from 7 psf to 12 psf.

The two key aspects of disc loading are the solidity ratio and blade loading. Solidity ratio is the fraction of the disc area which is actual rotor blades. Blade loading is the lifting capacity of a rotor blade per unit blade area. This of course, is a function of blade cross sectional area and configuration, tip speed, and lift to drag ratio. Power loading is the weight lifted per unit installed horsepower and as such is a measure of the efficiency of the lifting subsystem in coupling power into the air.

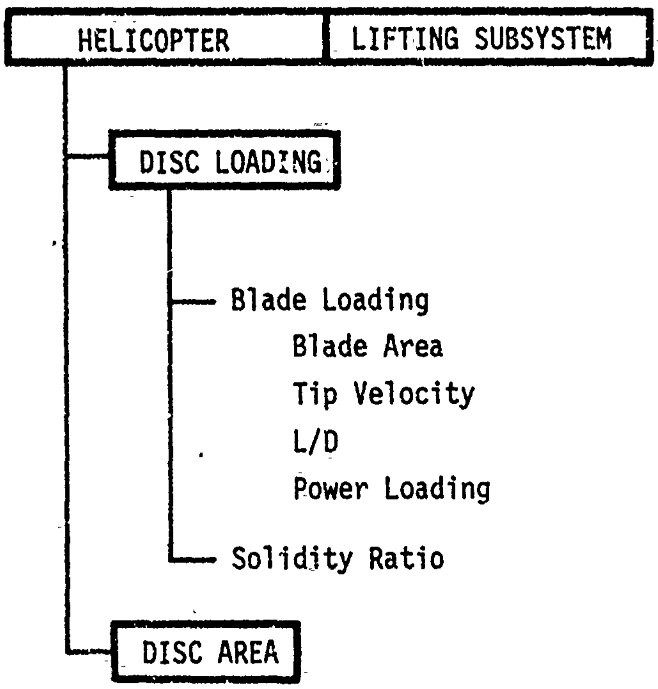


Figure 2.19: Figures of merit for the helicopter lifting subsystem.

The helicopter power subsystem is evaluated as shown in Figure 2.20, by examination of how drive train, fuel, and engine affect power loading and power to weight ratio (of this subsystem). The drive train may be examined by the lowness of weight per unit horsepower transmitted. Fuel may be measured by means of its heat content per unit weight and volume. The engine itself is evaluated in terms of its power to weight ratio, its specific power, and the rate at which it uses fuel. Specific power measures the ability at burning air in horsepower per pound of air per second. Specific fuel consumption is a ruler for determining the fuel consumption efficiency and is dependent upon engine operating characteristics as well as fuel type. High turbine combustion chamber inlet temperatures and high chamber pressures lead to better specific power and specific fuel consumption. Engine bypass ratio is the ratio of uncombusted mass flow to combusted mass flow. Turbine engines have trended toward higher bypass ratios, using high velocity exhaust gases to accelerate large relative quantities of uncombusted air.

As portrayed in Figure 2.21, the airframe subsystem is often measured in amplitude by the useful load and in efficiency by the ratio of structural weight to gross weight. Useful load is the weight devoted to fuel, crew and payload. Structural efficiency is a function of design optimization and materials technology.

The key aspects of the control subsystem are portrayed on Figure 2.22. They are inherent stability, righting moment efficiency, and control response time. Helicopter moment of inertia measures inherent design stability, while control moment per unit control system weight measures reaction thrustor efficiency. Also of paramount importance is safety as measured by the reaction response time (sec).

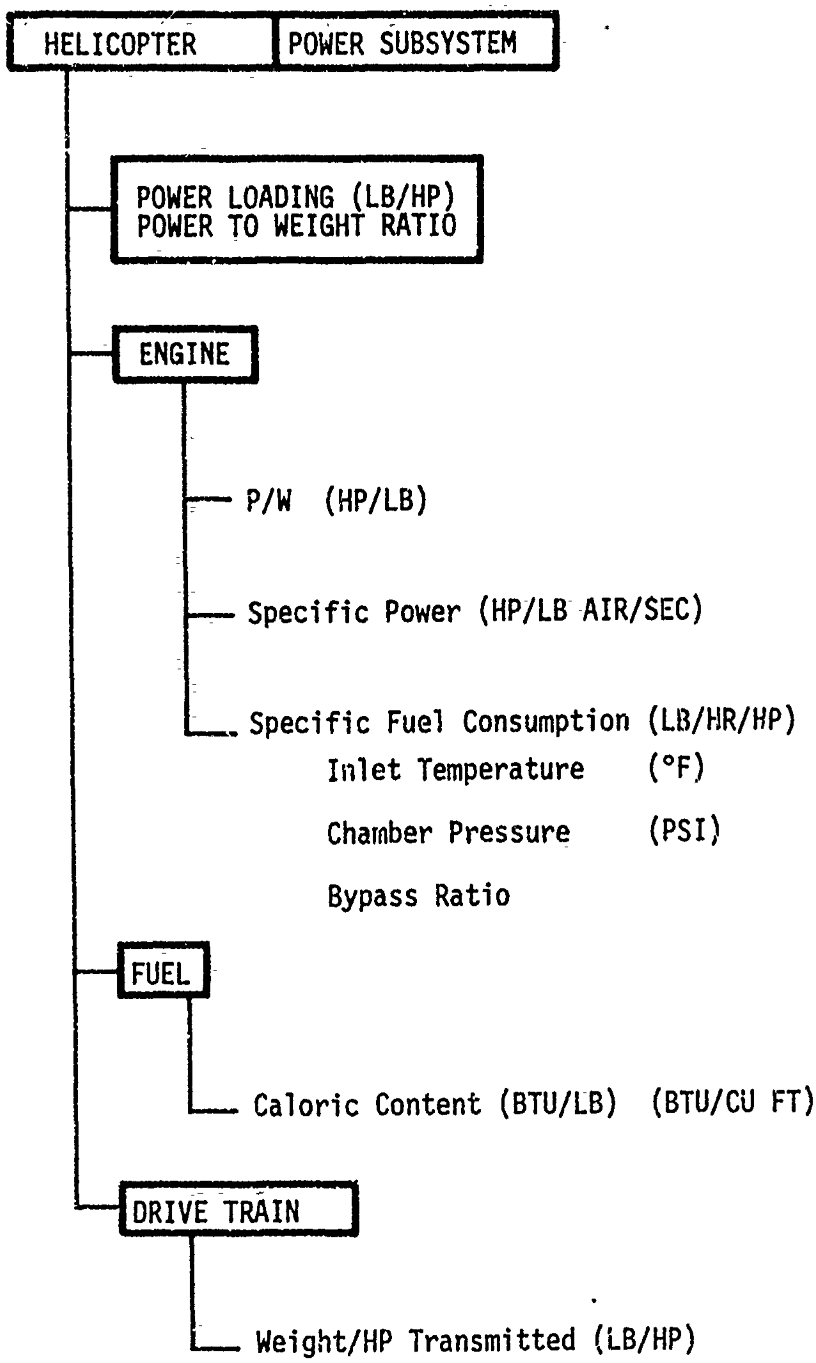


Figure 2.20: Figures of merit for the helicopter power subsystem.

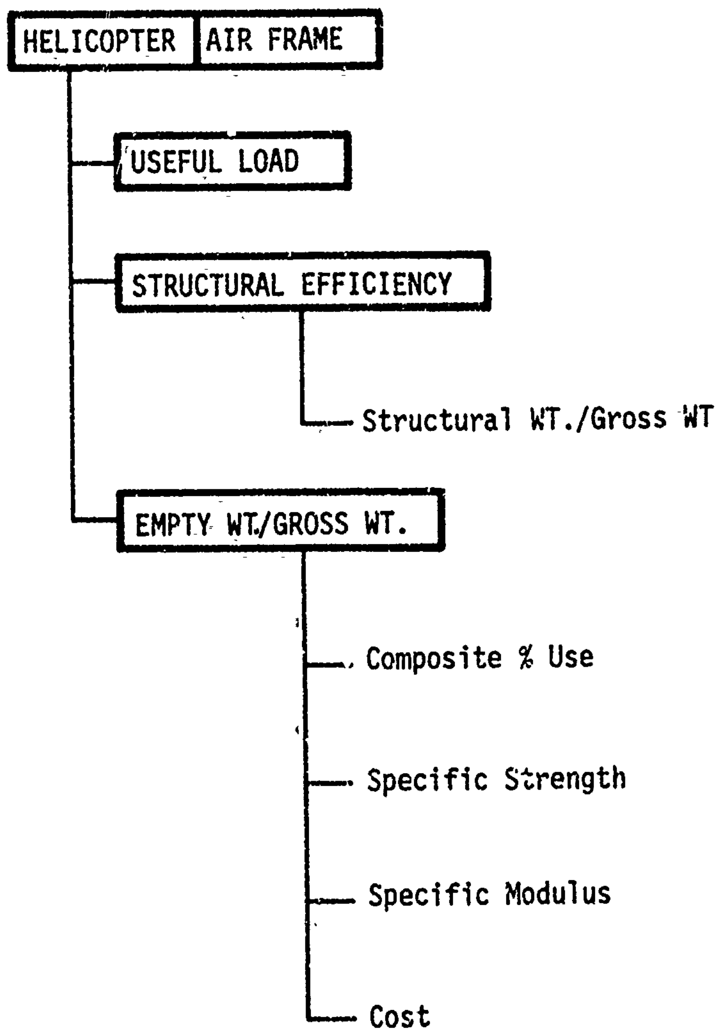


Figure 2.21: Figures of merit for the helicopter airframe subsystem.

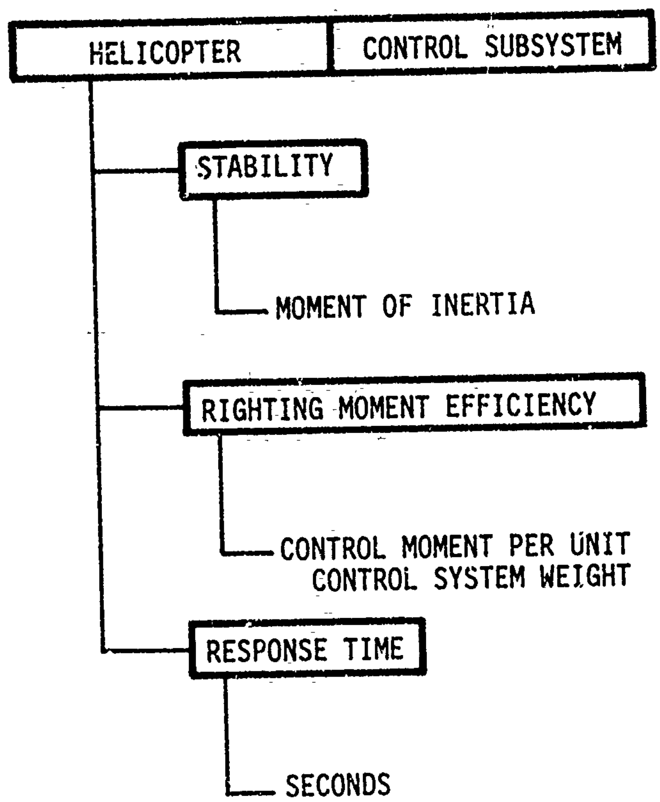


Figure 2.22: Figures of merit for the helicopter control subsystem.

2.6. STEP 6 - IDENTIFY SUBSYSTEM PROBLEMS AND ISSUES

Many technology problems can be uncovered as sources of constraint in a confined state-of-the-art. Open literature provides frank discussion of these problems and issues - usually in a piece-meal fashion. A discussion of the problems and issues facing each helicopter subsystem follows, as aggregated from many articles.

The lifting subsystem of helicopters has several problems associated with materials technology and aerodynamics technology. Figure 2.23 suggests that several of the more overriding issues for the lifting subsystem. Materials stiffness limits give rise to the types of issues portrayed in Figures 2.24 and 2.25. A large number of

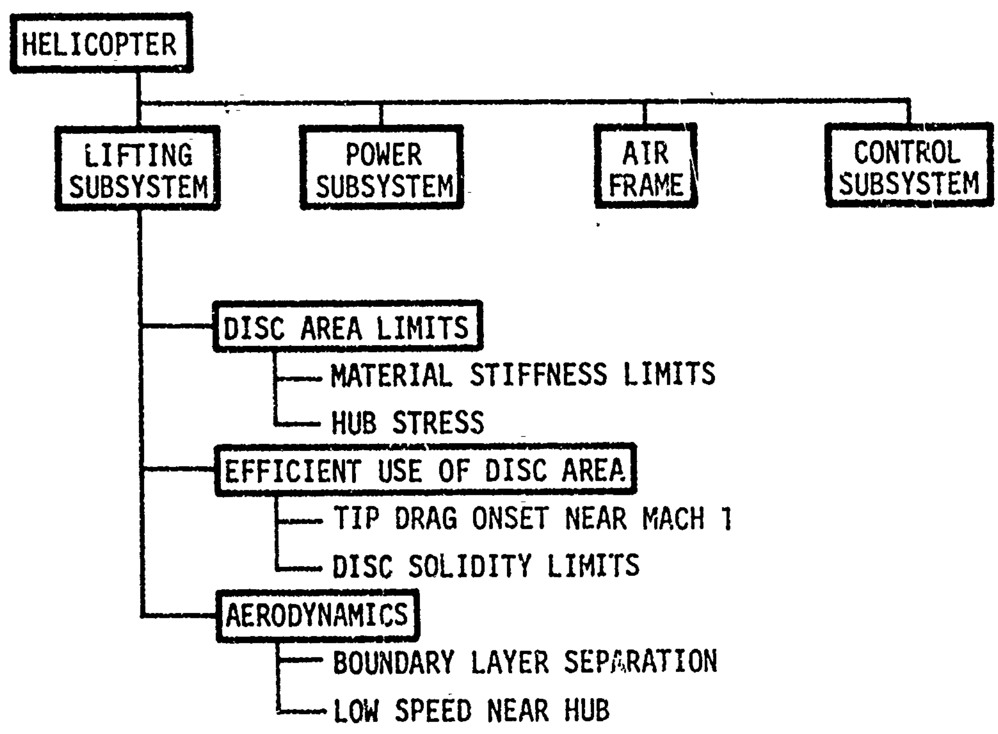


Figure 2.23: Helicopter lifting subsystem problems and issues.

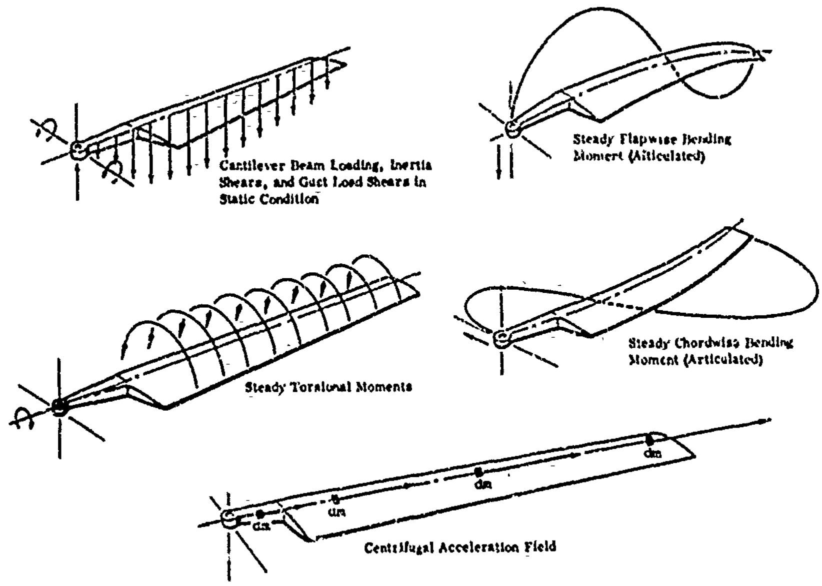


Figure 2.24: Principles of rotor blade static loading.

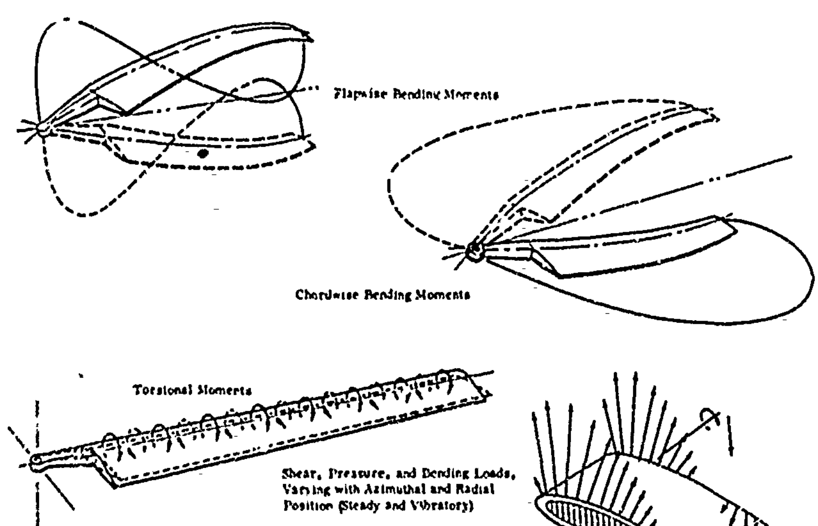


Figure 2.25: Principles of rotor blade cyclic loading.

moments are imparted to rotor blades which contort them in many ways. Stiffer materials would tend to alleviate these problems. Material stiffness limits, if alleviated would allow for a combination of a stiffer, more aircraft-like airfoil and longer rotors which improve disc area. As materials allow higher blade loading, higher disc loading, and larger disc areas the problem becomes one of coupling such loads through the rotor hub. Every rotor advance demands an equivalent hub advance in order to be practical.

One of the stressing relationships is that of rotor blade coning angle as a function of rotor diameter. Centrifugal forces are used to hold the flexible blades at minimum coning angles, with a practical current stability limit near 8 degrees as shown on Figure 2.26. High tip speeds and weights help to allow maximum rotor size, but stiffer blades are the straightforward approach.

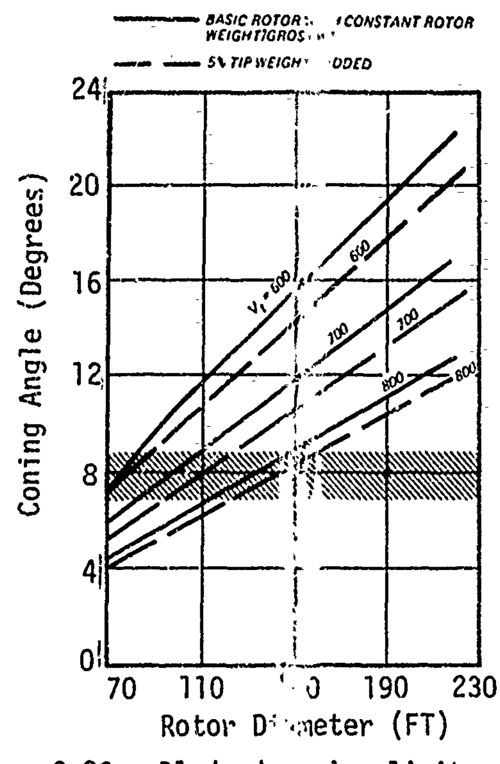


Figure 2.26: Blade dynamics limit rotor size.

A comparison of rotors with props, prop-fans, and jets is made on Figure 2.27. Rotors are noted to be very efficient at coupling horsepower into the air as indicated by power loadings (thrust to power ratios) of from 7 to 12 lbs. per horsepower. One is led to ponder a shrouded rotor concept which uses a raceway-ring surrounding the rotor. The figure suggests this device would offer comparable power loadings at higher disc loadings. Such a device would pose a significant challenge to wear resistance characteristics of high strength to weight ratio, advanced materials. If useful and feasible it might use electromagnetic levitation to guide the rotor tip without physical contact. Such a rotor tip guide promises to increase disc loading via ducting while controlling rotor coning and thus allowing greater disc area.

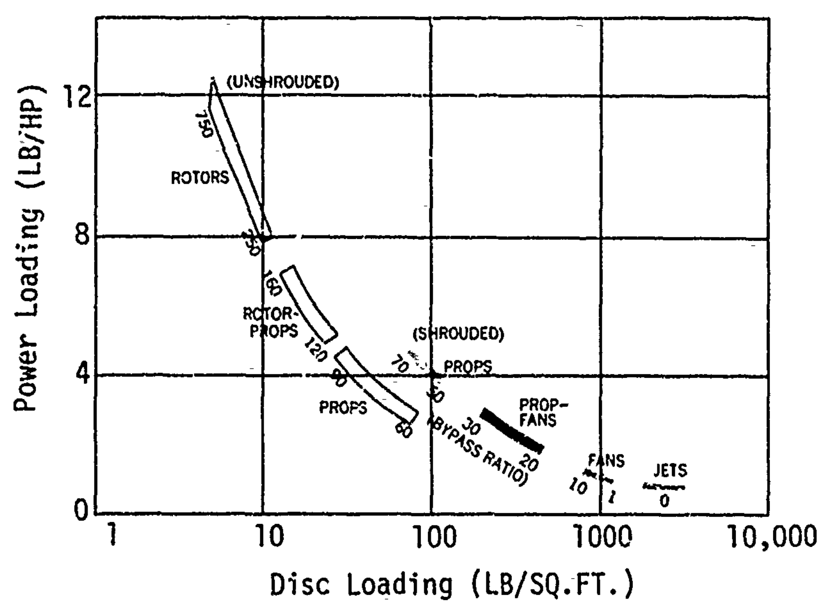


Figure 2.27: Rotor hover efficiency.

Figure 2.28 shows that the associated increases in rotor disc loading are minor with respect to increasing surface wear after repeated landings. Even ducted lift fans exerting nearly 500 psf can reasonably be applied to the HLH mission without significant surface preparation. To the degree the landing site is expected to need minor repair after repeated use, a fast curing polyurethane bomb might be developed for "real time" surface preparation.

Since load lifting capacity is proportional to tip velocity squared there is much interest in maximizing tip speed - at least toward a Mach 1 capability. The problem with maximizing tip speed is that the coefficient of drag rises steeply near Mach 0.8 as shown in Figure 2.29. This drag onset is caused by separation of the boundary layer flowing over the top of the blade. Various techniques are being examined for control of the near sonic boundary layer which delay the velocity of drag onset. Figure 2.30 shows how rotor angle of the attack and lift to drag ratio (L/D) are related. Also displayed

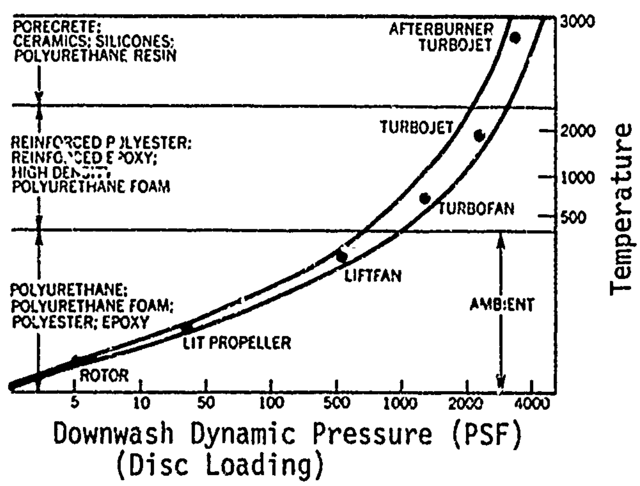


Figure 2.28: Turbofans and jets need extensive surface preparation.

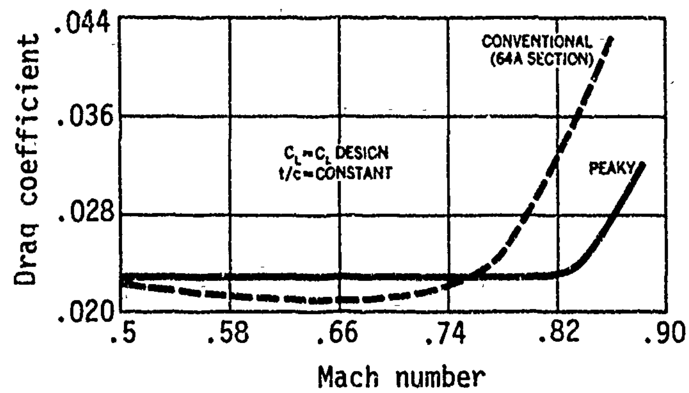


Figure 2.29: Drag onset near Mach 1 can be delayed.

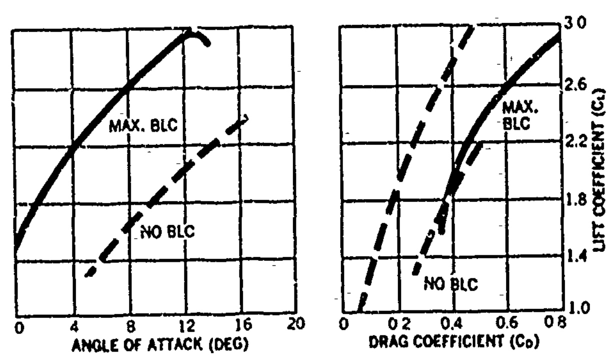


Figure 2.30: Control of boundary layer advances L/D.

are the limits of current boundary layer control techniques as they affect L/D. Of significant interest is the apparent trend toward lower angles of attack with boundary layer control.

Of additional note is the correlation of TIP boundary layer separation, induced drag, air turbulence, and disc solidity limits. Air turbulence is caused by boundary layer separation and the total blade area per unit disc area (solidity) is limited by turbulence. Reduction of air turbulence via boundary layer control should facilitate higher solidity ratios and greater disc loading.

Of remaining interest is the relatively large disc area nearer the hub which moves at comparatively slow speeds. This produces little lift due to the low speed. As shown on Figure 2.31 advances in low speed lifting devices have paced development of commercial aircraft. Potential application of such wing configurations

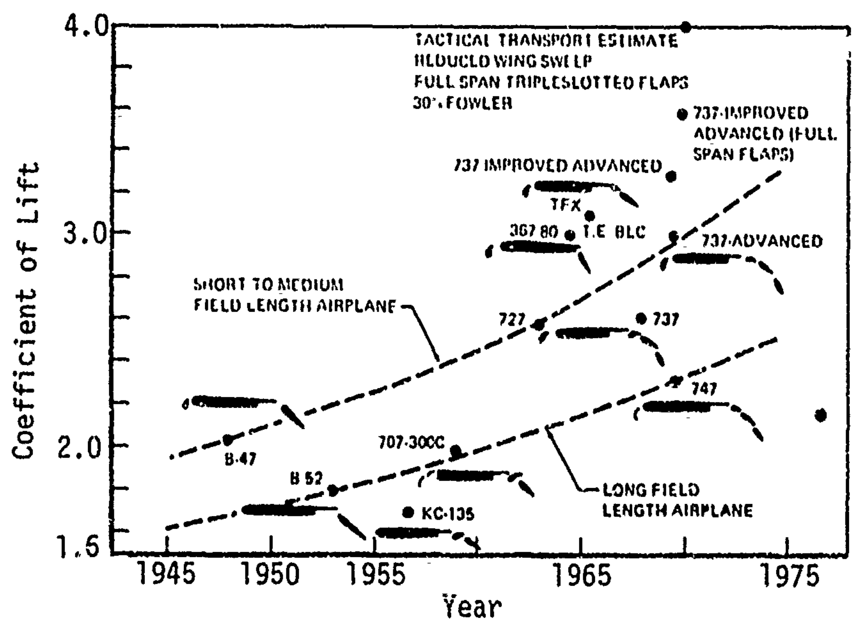


Figure 2.31: Advances in low speed lift.

to the inner portions of the rotor may provide interesting lift augmentation without undue drag. Perhaps, with sufficiently stiff rotors, actual flaps become attractive in spite of weight increases to the rotor. In any event, one issue is that of utilizing the low speed portion of the rotor productively.

As suggested in Figure 2.32, helicopter power subsystems are sensitive to turbine engine combustion chamber temperature and drive train and fuel weights. The turbine engine performance is maximized by high inlet temperatures and high combustion chamber

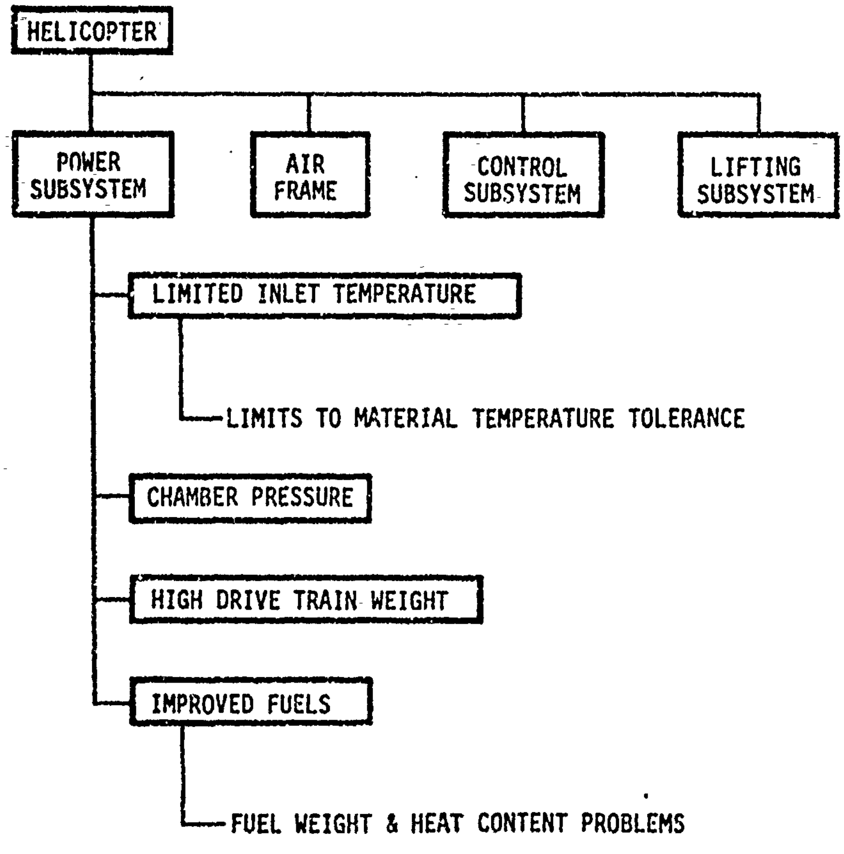


Figure 2.32: Helicopter power subsystem problems and issues.

pressures as shown in Figure 2.33. Currently, materials and cooling techniques limit operation to 2400°F. Eventual goals near 3600°F would allow specific power to double along with a modest improvement in specific fuel consumption. To achieve such temperature advances alloys need to be researched which tolerate large temperature gradients and are machinable to provide ports and ducts for coolants. Figure 2.34 displays the relationship between temperature, temperature gradient, cooling technique, and machining complexity for a 2300°F class material. Issues are the proper alloys for 3600°F operation.

The issue of high drive train weight is addressed in Figure 2.35. Selection of a drive concept is particularly complex since the more novel ideas create weight problems in the rotor. Concepts 3 through 6 essentially eliminate drive train weight but do have lower efficiency and higher rotor weights. These concepts stress materials

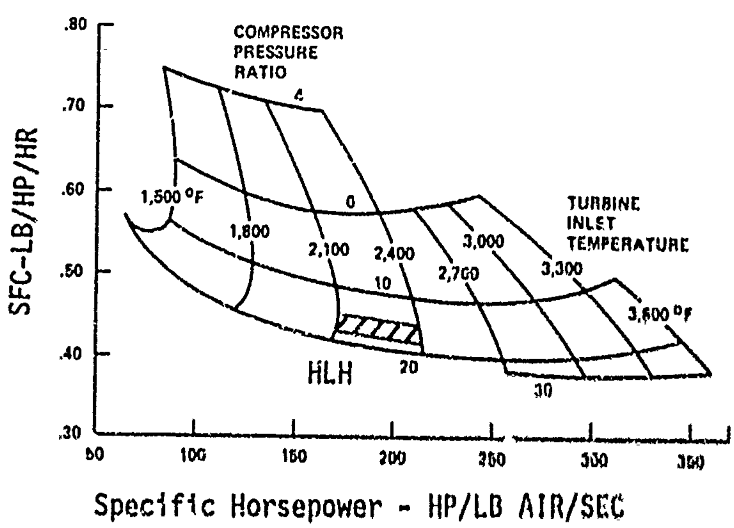


Figure 2.33: Turbine temperature and pressure effects.

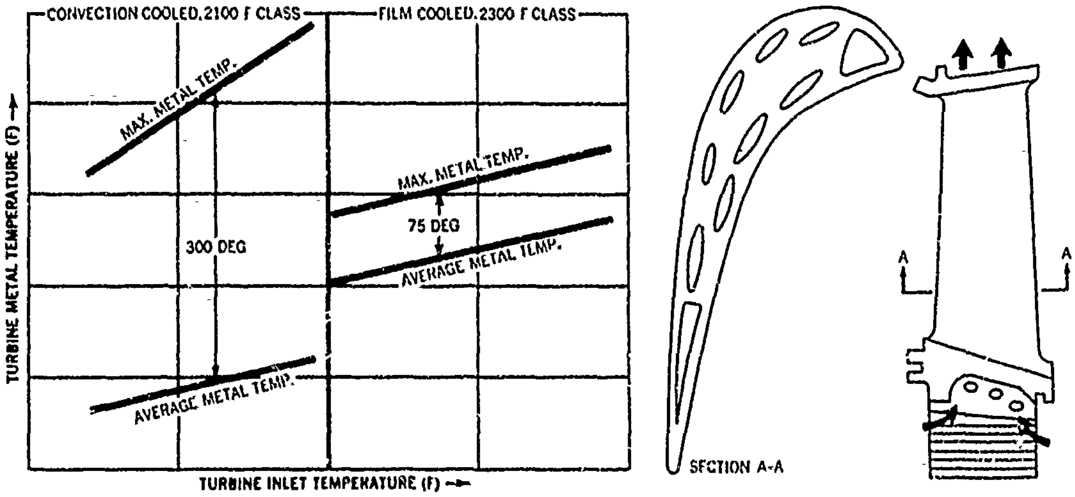


Figure 2.34: Turbine materials and cooling conditions

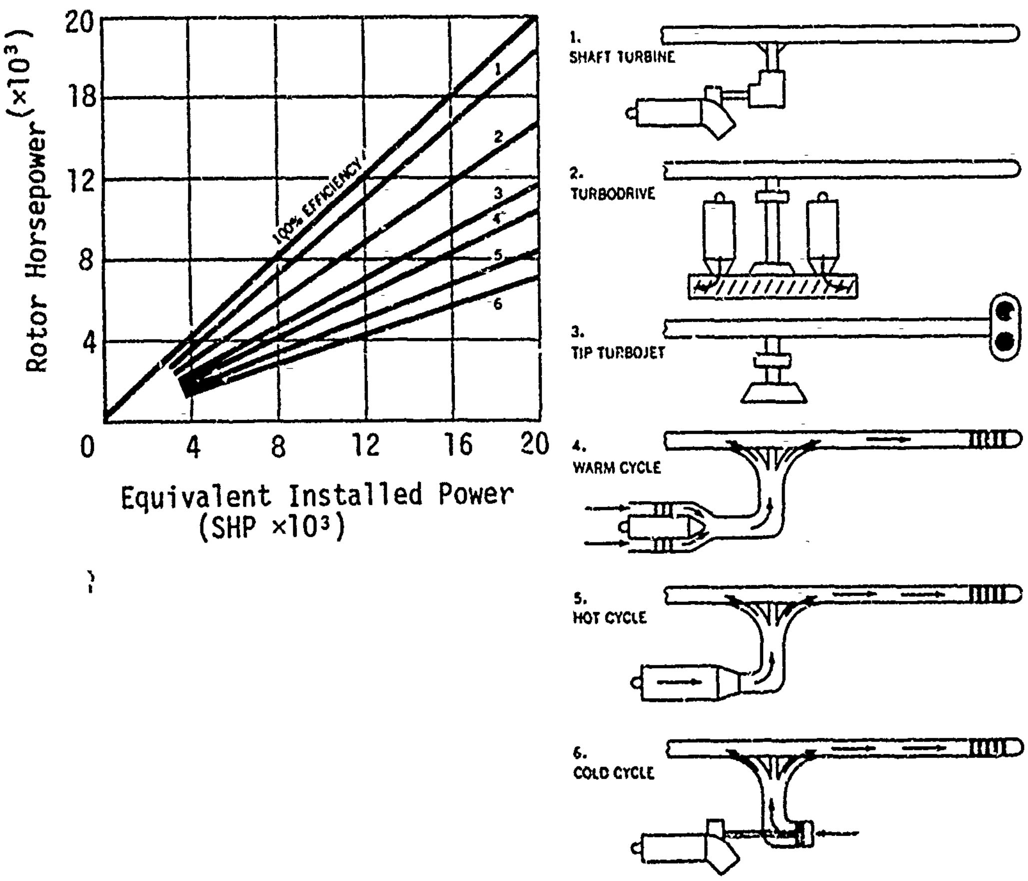


Figure 2.35: The issue of drive train weight versus efficiency.

state-of-the-art in many ways. Concepts 1 and 2 are very heavy. Figure 2.36 shows a weight trend forecast for concept 1 which reflects materials advances. Composite materials using fibers promise to lower the weight of conventional drive systems providing catastrophic failure problems can be resolved.

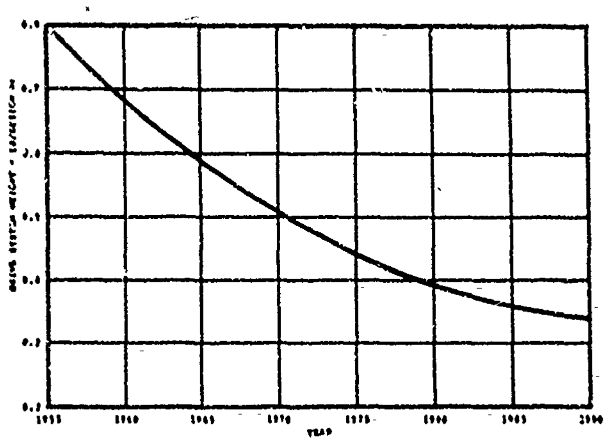


Figure 2.36: Shaft turbine drive system weight trend

The air frame subsystem issues are primarily contained within design and materials sciences areas as indicated by Figure 2.37. In order to remove practical limits upon structural efficiency higher strength to weight materials are needed. While past efforts have produced tremendous improvements in structural characteristics via composite materials (see Figure 2.38), the degree of future advances is unclear. Furthermore, costs of such composites dominate the eventual degree of application to the air frame. The cost-benefit issue is of significant interest to the determination of the proper volume of usage on helicopters as indicated on Figure 2.39.

The air frame design concept merits optimization. Issues are numbers of rotors, location of rotors, interior or exterior

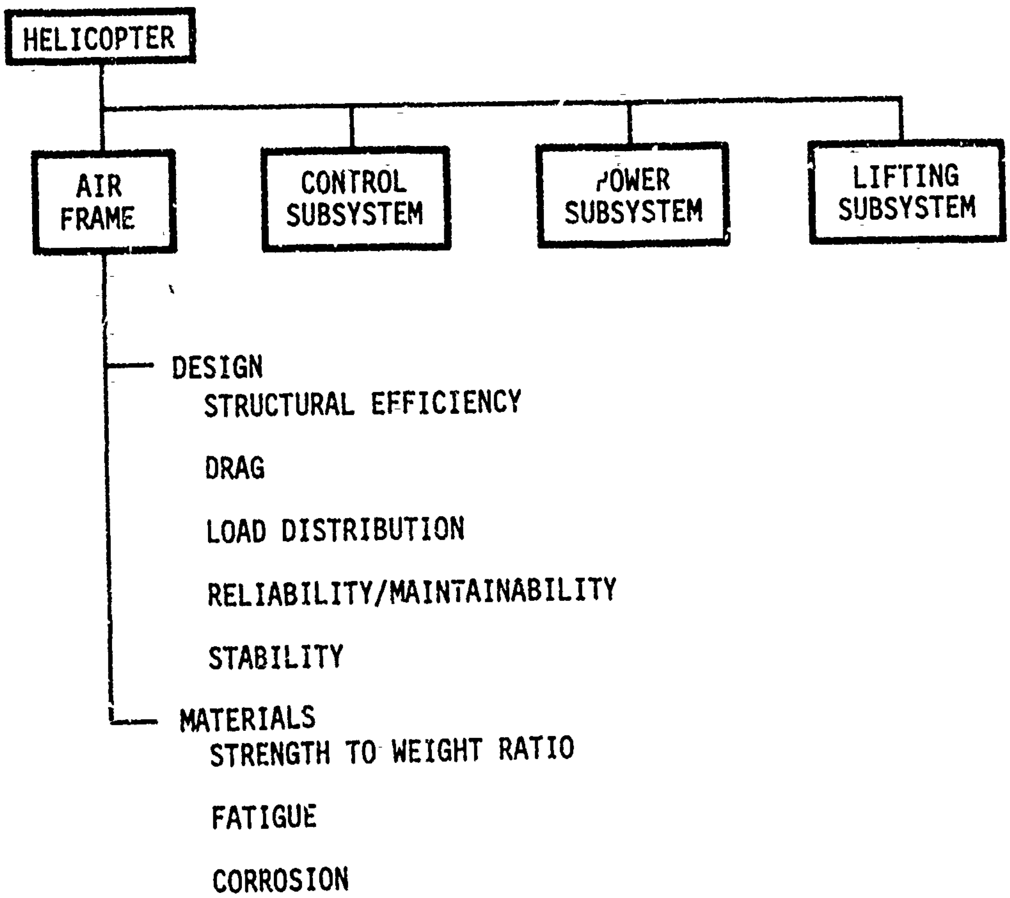


Figure 2.37: Helicopter airframe problems and issues.

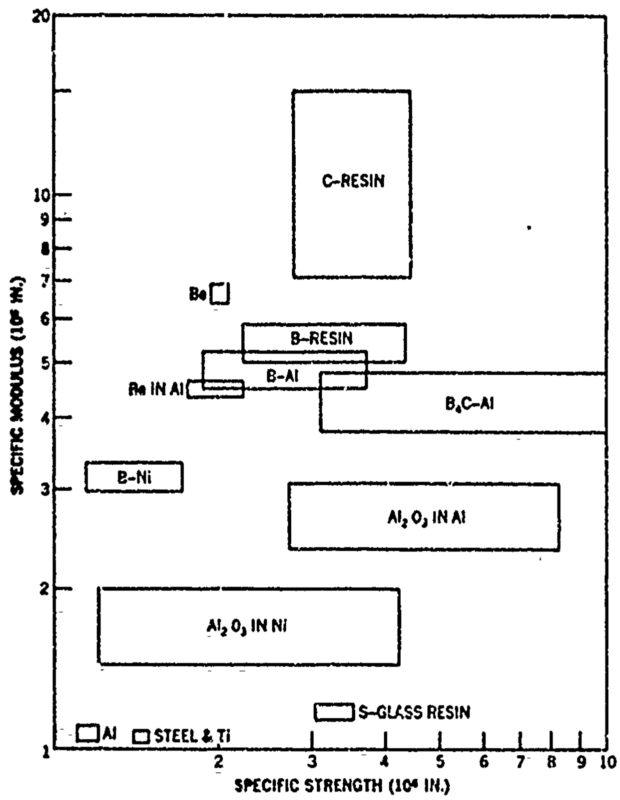


Figure 2.38: Advances in composite structural materials.

COMPONENT PROGRAMS IN APPLICATION OF COMPOSITES TO AIRCRAFT STRUCTURES
COMPLETED AND CURRENT

COMPONENT	NUMBER OF PROGRAMS	WEIGHT SAVING, PERCENT
WINGS	11	9 TO 15
FUSELAGES	5	19 TO 25
STABILIZERS AND STABILATORS	10	15 TO 25
FINS AND RUDDERS	5	20 TO 35
SLATS AND FLAPS	8	22 TO 47
SPEED BRAKES, FENCES, AND FAIRINGS	13	23 TO 32
LANDING-GEAR DOORS	5	29 TO 36
HELICOPTER BLADES	4	
HELICOPTER AND V/STOL SHAFTS AND HUBS	3	30 TO 43
MISCELLANEOUS	15	
TOTAL :	79	

Figure 2.39: Evolution in material application to design.

payload, design maximum cruise speed, and landing gear load carrying members.

The major control system issues are displayed on Figure 2.40. The dominant safety aspects are all related by the helicopter moments of inertia and the damping moment produced by the control

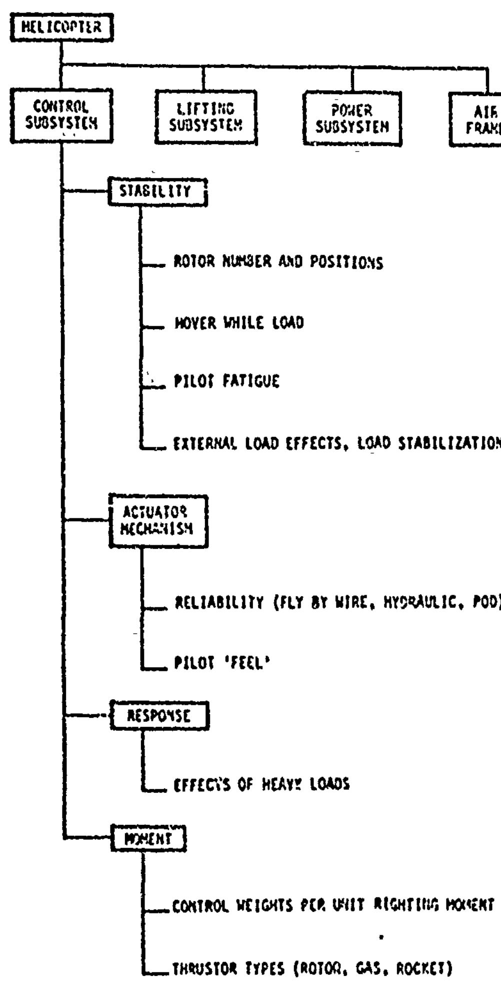


Figure 2.40: Helicopter control subsystem problems and issues.

thrustors. Figures 2.41 and 2.42 show the HLH design points for control system effectiveness. One issue of potential interest for future designs is the freedom of design offered by use of compressed air and/or rocket control thrustors. In order to apply such unconventional control techniques, multiple redundancy electronic control is preferable as indicated in Figure 2.43.

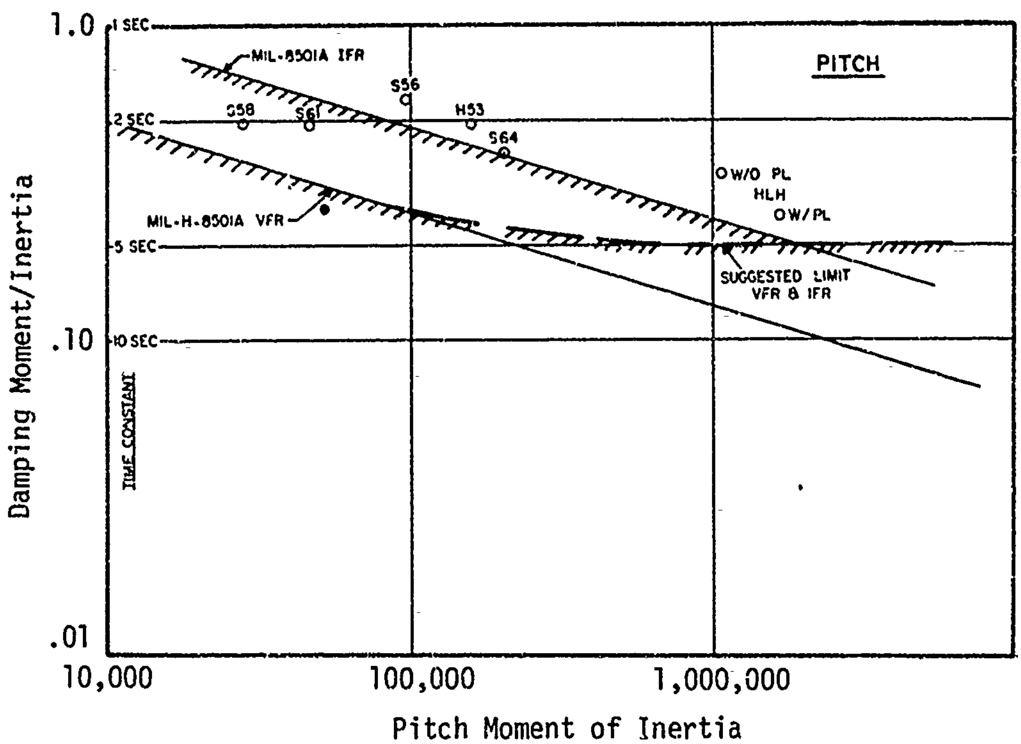


Figure 2.41: Pitch control parameters.

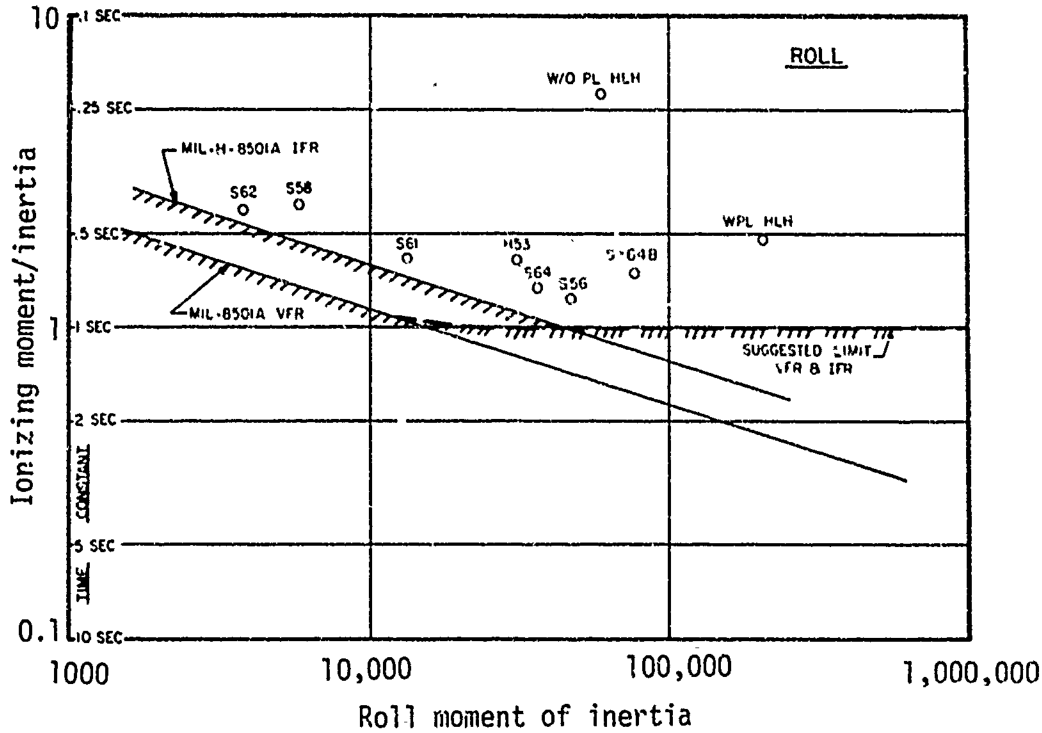


Figure 2.42: Roll control parameters.

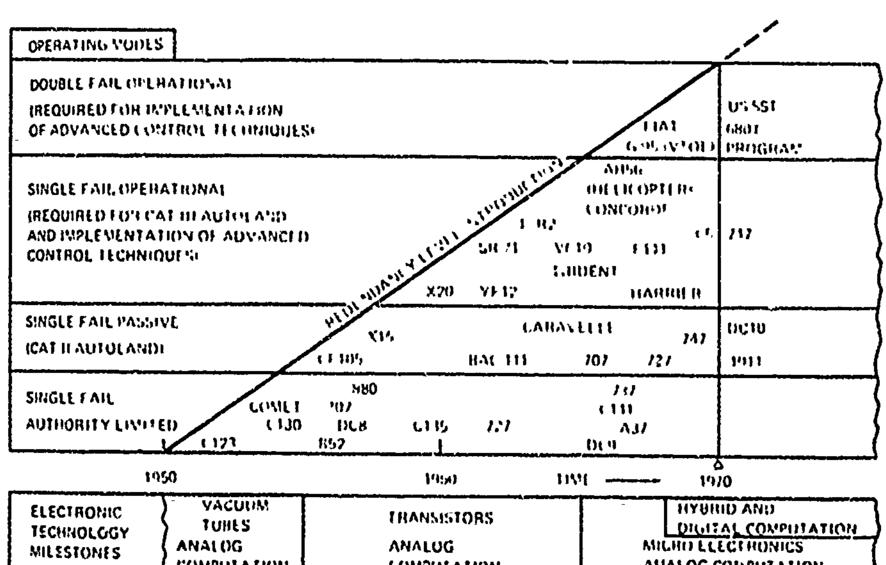


Figure 2.43: Flight control safety issues.

2.7 STEP 7 - IDENTIFY ALTERNATE TECHNICAL APPROACHES

On the basis of recognition of the problems and issues identified in Step 6, many alternate technical approaches may be suggested for providing better future subsystem capabilities. Most of the solution approaches are outlined in the available literature. Many have been researched to a significant degree. However, many of these technical approaches were developed for non helicopter applications. The authors therefore are responsible for any overoptimistic application of such technical concepts to the elimination of helicopter problems.

The helicopter lifting subsystem can be improved by future success in the application of the concepts portrayed on Figure 2.44. Many

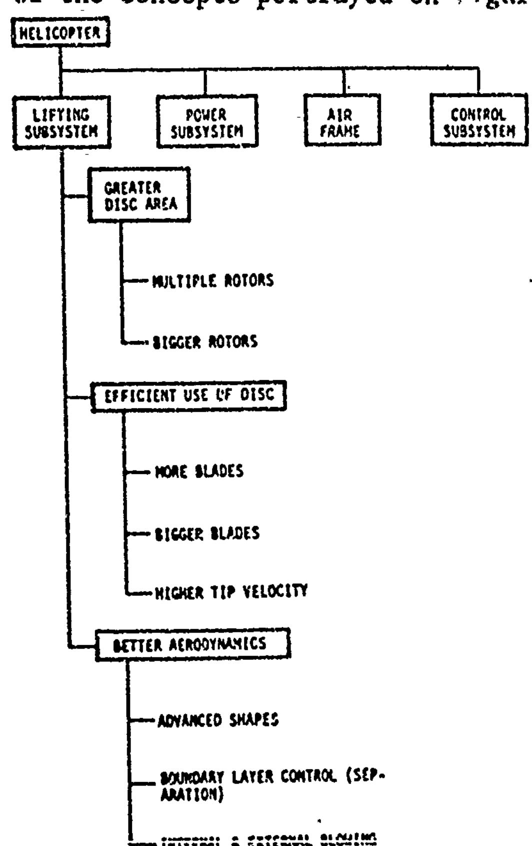


Figure 2.44: Technical approaches to improved lifting subsystem.

designers favor multiple rotors as the best technique for increasing disc area, but if the rapid development of composite materials continues, larger rotors may prove more efficient by eliminating multiple transmissions and drive trains. Blade stiffness resulting from composites could decrease the need for tip weights which control droop coning. Materials advances may allow redrawing Figure 2.45 when incorporating 1975 or 1980 technology. Since the data on Figure 2.45 shows a basically quadratic weight increase vs. rotor diameter, decreased rotor weight suggests the use of bigger, rather than more rotors for the future.

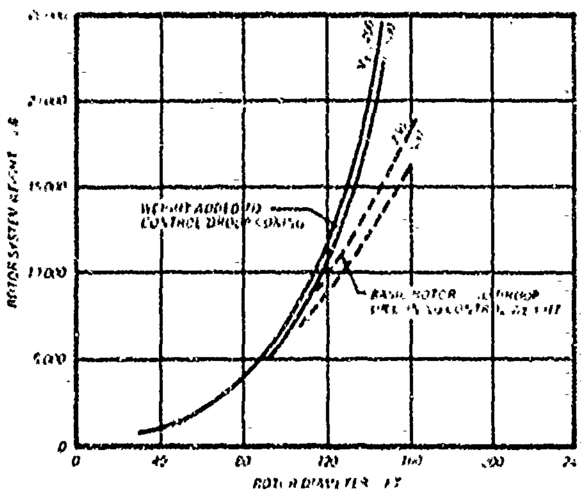


Figure 2.45: Composites might decrease weight of large rotors

Stiffer composite blades promise to alleviate rotor contortions, reducing drag and smoothing the air near the disc. The smoother air should allow for increased solidity ratio via more blades or wider blades. Composites also allow for more advance shaping of the high speed rotor tip. The combination of such effects leads to higher lift to drag ratios as portrayed in Figure 2.46. Higher lift can also be gained by an increase of the tip speeds. The dilema of tip speeds versus forward cruise speed is displayed on Figure 2.47. This shows the need for keeping the advancing

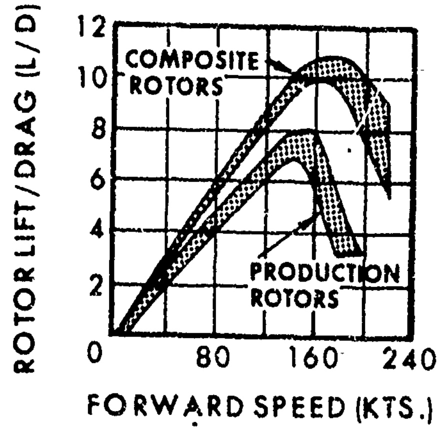


Figure 2.46: Composite rotors lead to lower drag.

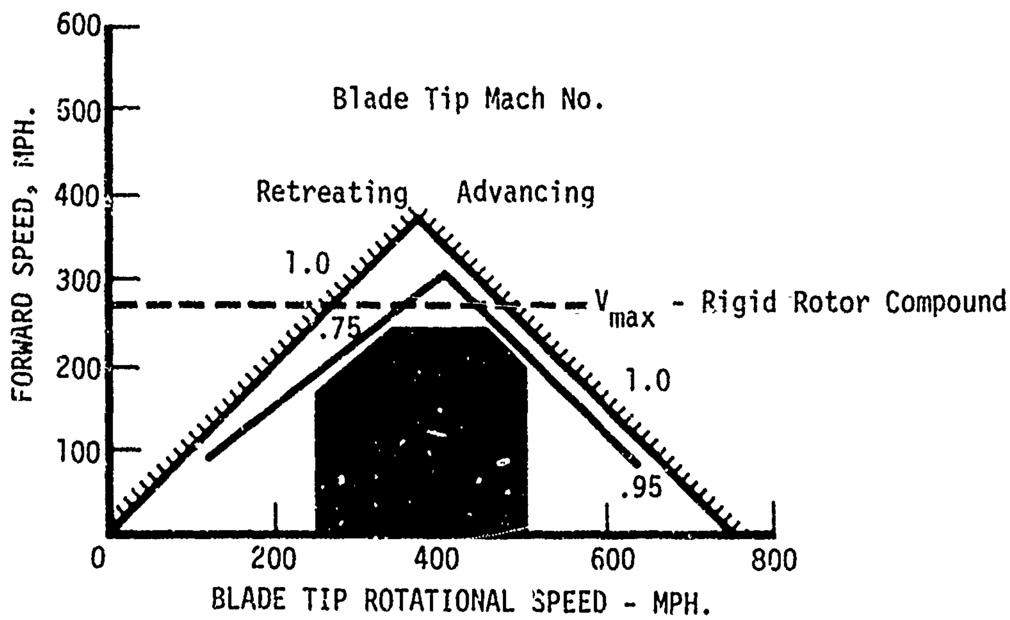


Figure 2.47: Tip speed trades off with cruise speed.

tip subsonic while the retreating tip is kept from stalling. By removing a high speed cruise capability in favor of hover efficiency, tip speeds could be increased from near 500 mph to near 650 mph. To regain a cruise capability with this condition a compound helicopter is one answer - using a wing to provide lift so that the rotor can be slowed during horizontal flight.

In order to achieve higher lifting capacity via maximum tip speeds, tip drag must be limited by control of boundary layer flows. While advanced chord shapes have proved helpful toward this end, direct interaction with the boundary layer is desirable. Figure 2.48 shows various alternate approaches to boundary layer control, including internal and external blowing. If materials advances permit placing a jet at the rotor tip, external blowing at the rotor tip solves both the boundary layer and the drive train problems. The lower speed portions of the rotor might utilize the techniques portrayed on Figure 2.49 to provide lift. While such approaches were developed for STOL aircraft, eventually they might be productively applied to helicopter rotors.

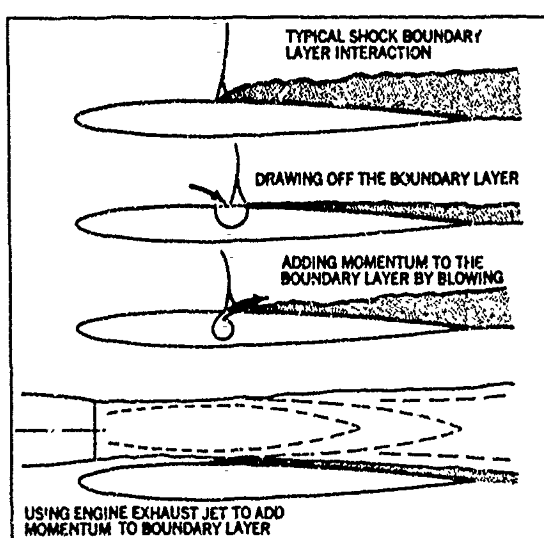


Figure 2.48: Boundary layer control approaches.

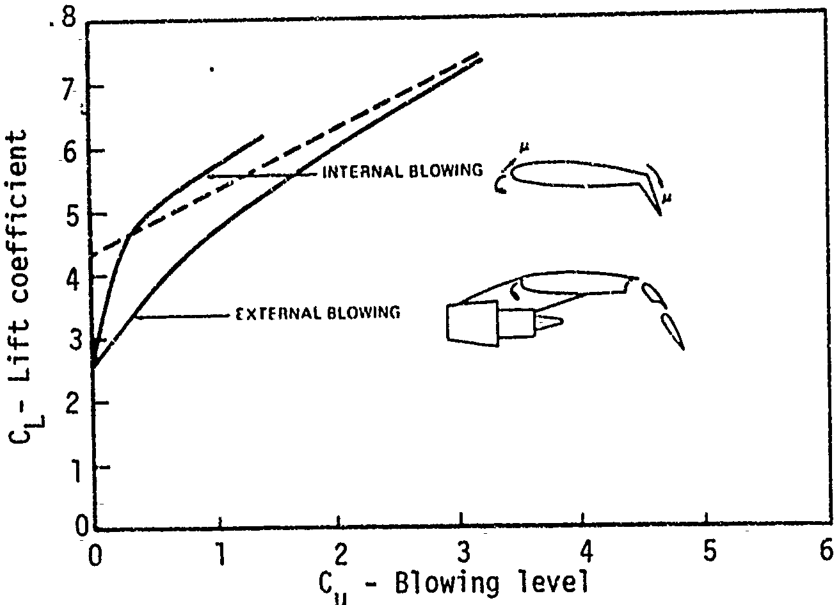


Figure 2.49: Low speed lift enhancement approaches.

The key approaches to improving the power subsystem power to weight ratio are displayed in Figure 2.50. The first approach to improvement in engine efficiency via cooling techniques is amplified in Figure 2.51. Current turbine engine designs apply covection cooling and the trend is toward transpiration. The trend suggests 3600°F designs by 1970. The realization of materials with higher temperature tolerance is an important avenue to improve power to weight ratios. The potential and characteristics of higher temperature turbine materials are outlined on Figure 2.52.

Evolution in turbine temperatures has allowed development of ever more efficient turbine engines. Figure 2.53 shows how turbines have achieved ever lower weights per unit design horsepower. Also evident is the revolutionary performance of turbine introduction as compared to reciprocating engines. Figure 2.54 shows that fuel consumption has also dropped dramatically for turbines, due largely to the higher inlet temperatures. Also evident is the flatness of the curve in the post 1970 time

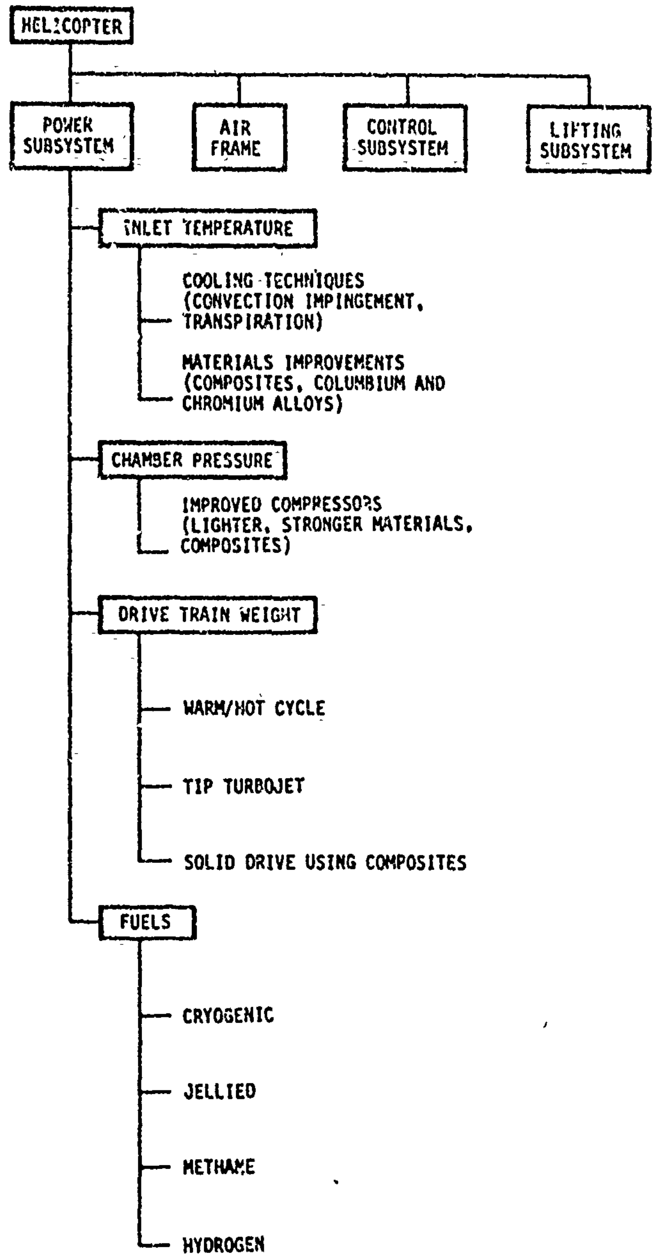


Figure 2.50: Technical approaches to improved power subsystem

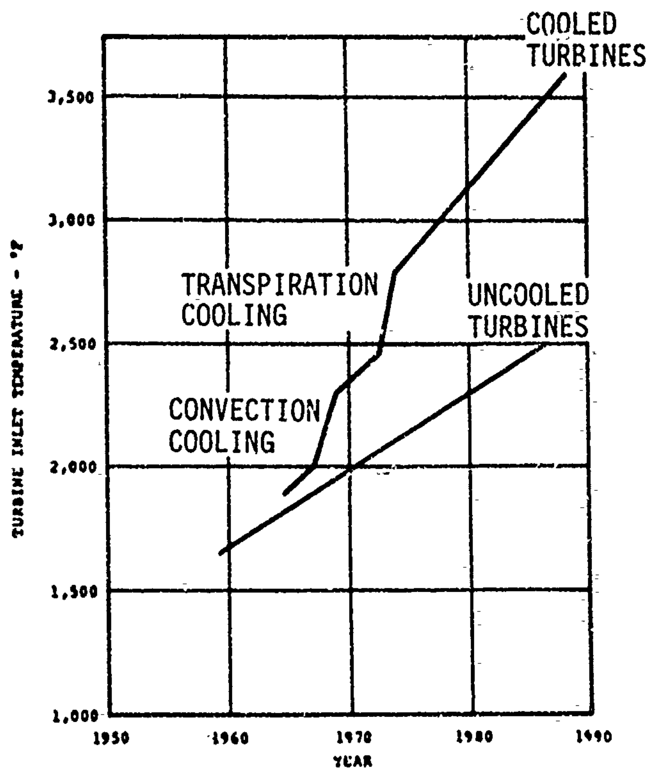


Figure 2.51: Cooling approaches to improved power subsystem.

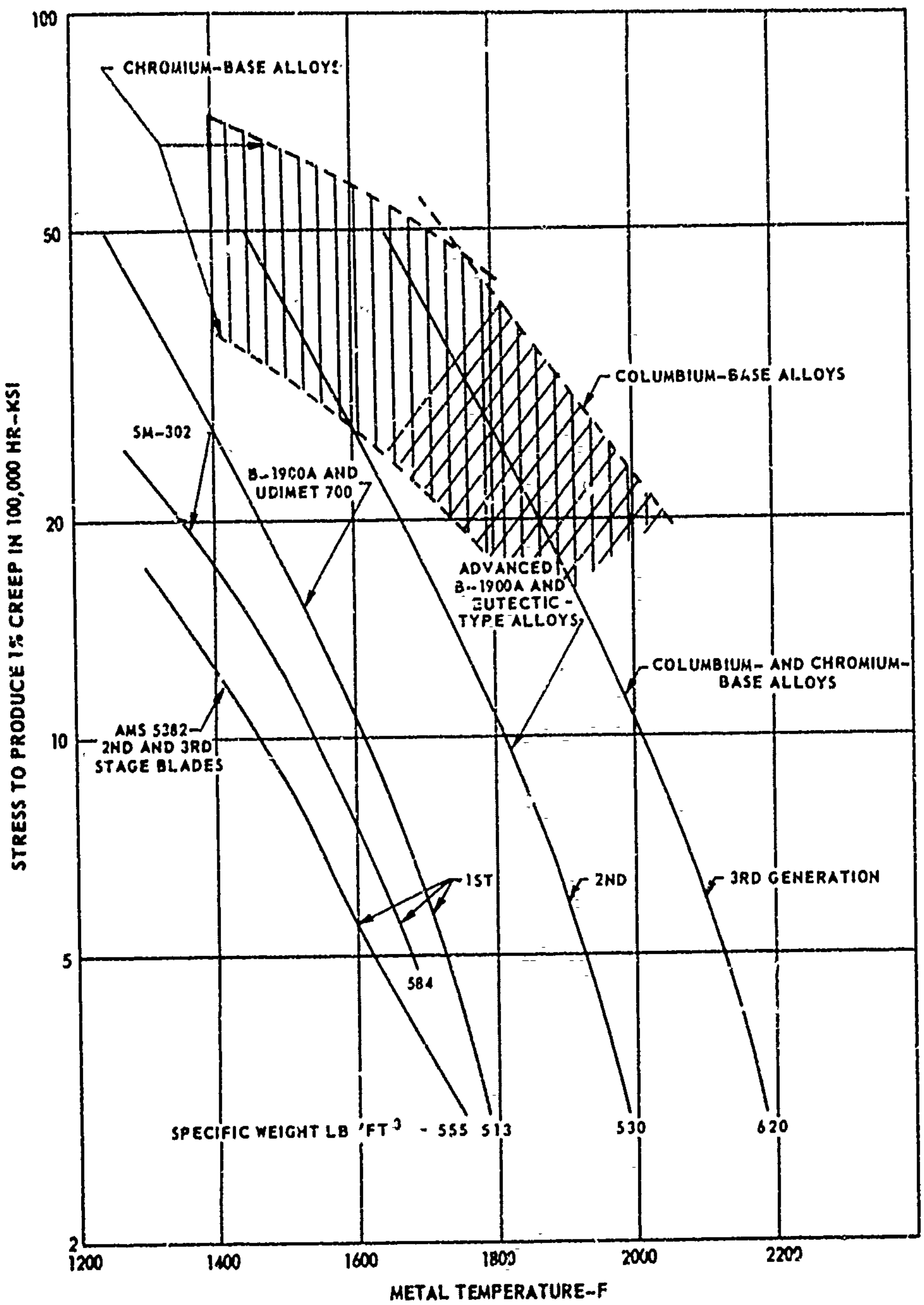


Figure 2.52: Materials approaches to improved power subsystem.

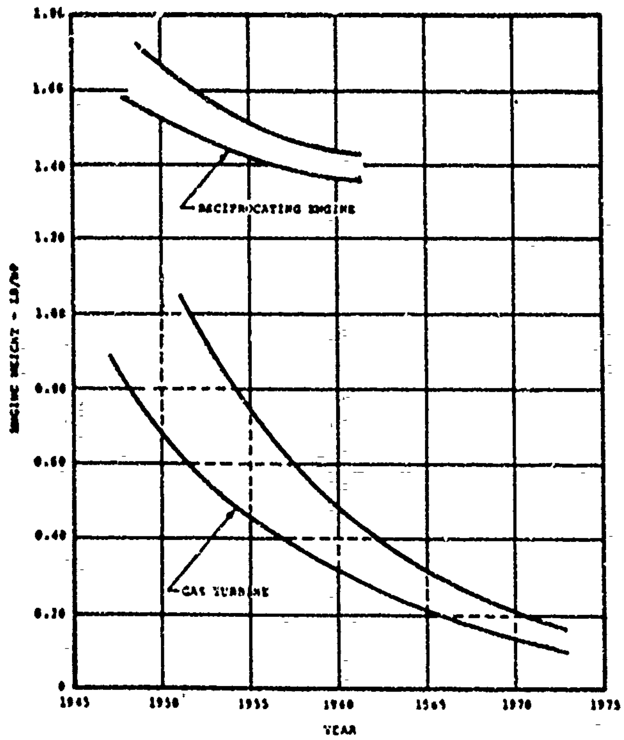


Figure 2.53: Turbine efficiency trends.

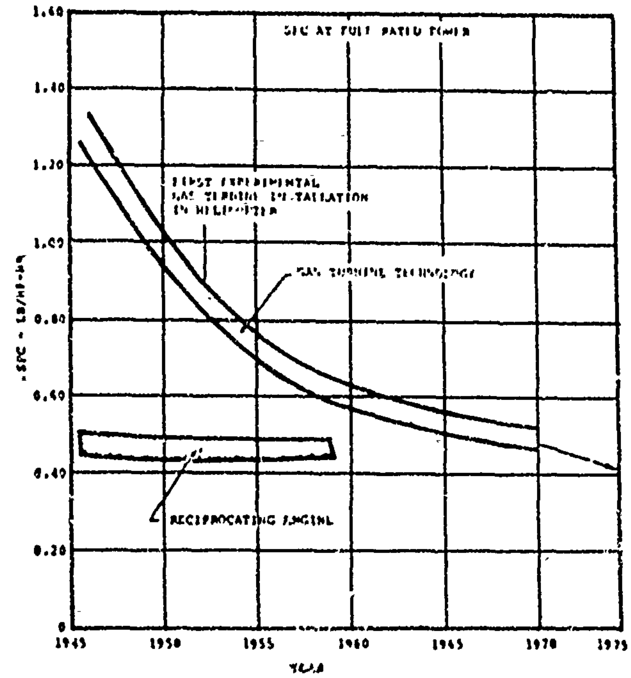


Figure 2.54: Specific fuel consumption is not declining rapidly.

frame assuming the use of kerosene fuel. The SFC curve is assymptotic to 0.4 lb/hp.-hr.

In addition to turbine efficiency, the drive system is of extreme importance. The drive system weight is greater than 10% of helicopter gross weight as indicated on Figure 2.55. Exception to these shaft drive concepts are the hot and warm cycle concepts which weigh about 3% of the gross weight. The tip jet drive is even a lower fraction.

Many alternate fuels have been examined for eventual turbine application. Of critical concern to HLH missions is the fuel weight. Fuel volume is also a concern to longer range VTOL aircraft concepts where low drag is important. Figure 2.56 displays weight-volume characteristics of

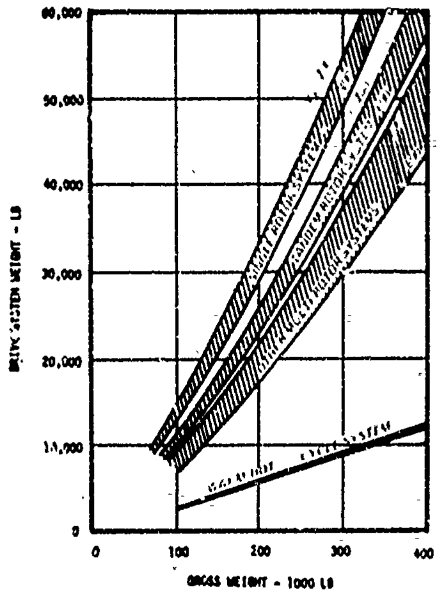


Figure 2.55: Alternate drive train approaches.

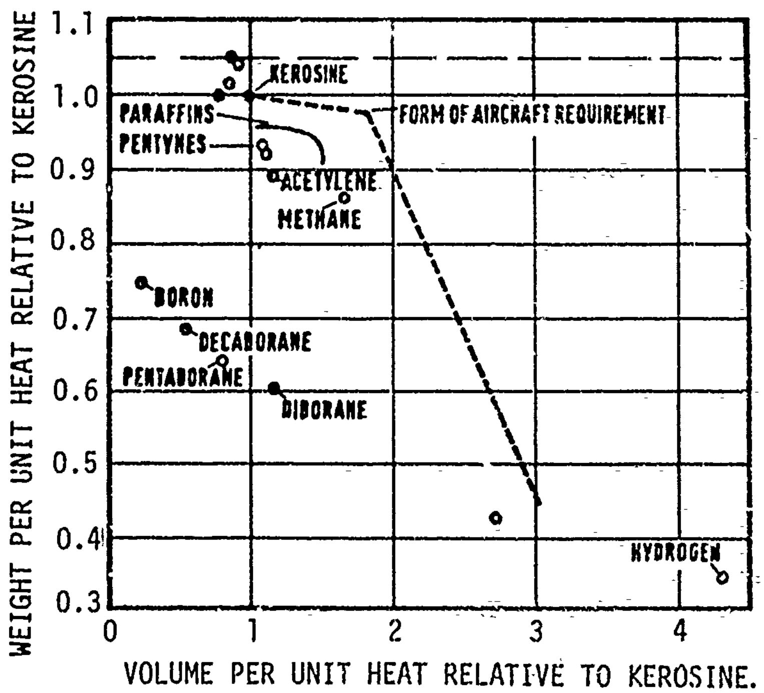


Figure 2.56: Alternate fuels.

several alternate fuels. The borates have major environmental impacts. Methane and hydrogen appear viable t hnical approaches to better power system characteristics.

Figures 2.57 and 2.58 indicate some of the key approaches to the development of superior air frames and control subsystems.

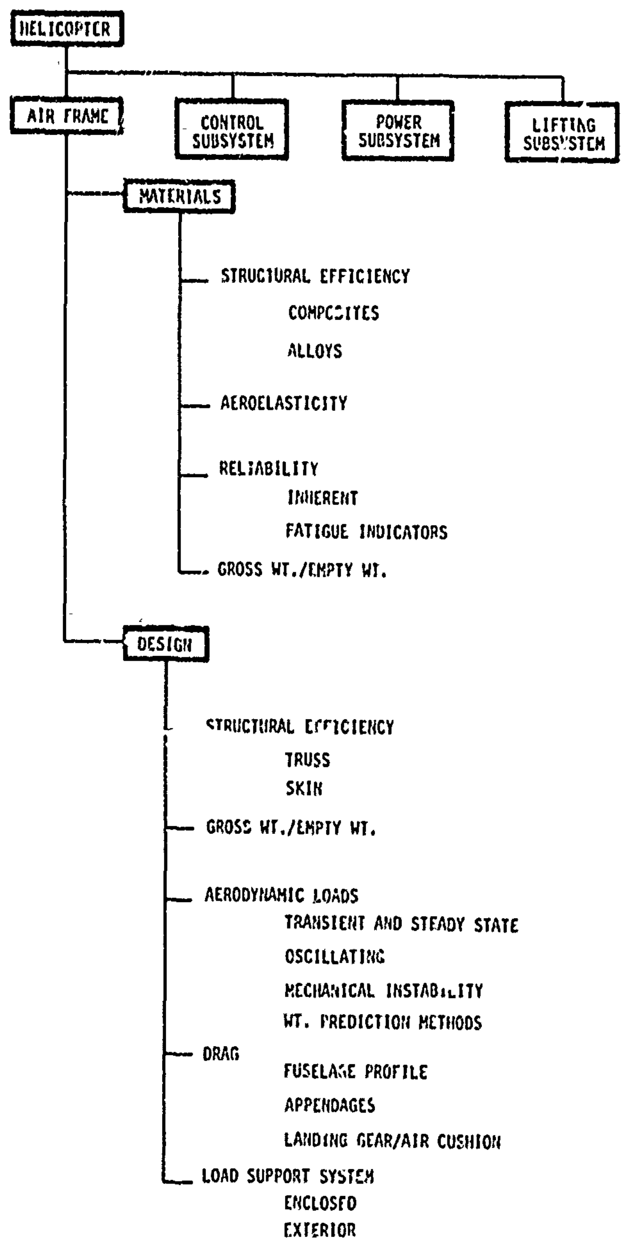


Figure 2.57: Technical approaches to an improved air frame.

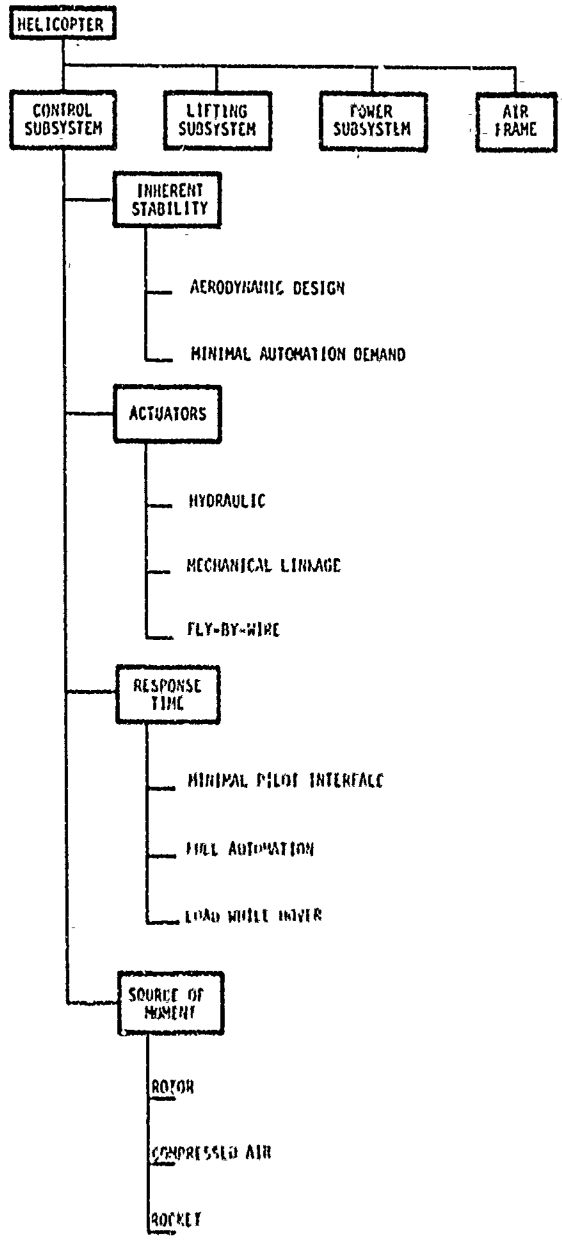


Figure 2.58: Technical approaches to an improved control subsystem.

2.8 STEP 8 - IDENTIFY KEY SUPPORTING TECHNOLOGIES

By this point it is obvious which scientific disciplines support evolution of capability for each subsystem. It is possible to identify the scientific disciplines which should be represented on a team for comprehensive technology expertise. Heavy lift helicopter systems aerodynamics, materials, thermodynamics, and design are the key sciences. One rationale for detailed identification of these technology areas is to correlate research efforts being conducted by NASA as well as DoD with future HLH capability. Some programs use commercial CTOL or commercial STOL aircraft as research test beds and proving grounds. The pertinence of such programs to helicopters should not be overlooked. In fact, advocacy of such research program budgets can rationally be based upon potential DoD benefits.

Figures 2.59 through 2.62 display the key technologies supporting future HLH capability and describe the likely thrust of significant research. It is unfortunate that the study time frame did not allow equivalent treatment of the technologies supporting winged VTOL aircraft, LTAs, and SEVs. However, a few comments can be made of these systems even without detailed quantitative evidence.

In the case of winged VTOL aircraft, the development of high power to weight turbines is more critical than it is for helicopters since the provision of direct lift thrust has the constraint of less efficient hovering propulsors. Hydrogen is a somewhat less intriguing fuel technology solution since VTOL aircraft, optimized for longer range and higher speed would be penalized more by the hydrogen volumetric characteristics and hence the higher drag. Winged VTOL aircraft also require significant

HELICOPTER LIFTING SUBSYSTEM

MATERIALS

- LIGHT, STRONG COMPOSITES
  Metals, Alloys, Machining Technology

AERODYNAMICS

- CONFIGURATIONS
  Number of Blades
  Blade Size
  Blade Shape

- ADVANCED TECHNIQUES
  Boundary Layer
  Blowing
  Hot/Warm Cycle
  Tip Drive

Figure 2.59: Technologies supporting evolution of lifting subsystem.

HELICOPTER POWER SUBSYSTEM

MATERIALS

- ENGINE-LIGHER, HEAT RESISTANT
    - Composites
    - Refractories
- DRIVE TRAIN-LIGHTER, STRONGER
    - Composites
    - Hot/Warm Cycle

THERMODYNAMICS

- EXOTIC FUELS
    - Methane
    - Hvdroaen
    - Boron
    - Acetvlene
    - Jellies
- COOLING
    - Convection
    - Impinaement
- DESIGN
    - Afterburners
    - Burners
    - Compressors
    - By-pass
    - Air Inlets
    - Hybrid Enaines

Fiaure 2.60: Technoloaies supportina evolution of power subsystem.

HELICOPTER AIR FRAME

DESIGN-LIGHTER STRONGER

Enclosed-Truss

MATERIALS

Composites
Titanium
Alloys

Figure 2.61: Technologies supporting evolution of air frame.

FLY-BY-WIRE PRIMARY CONTROLS
MULTIAXIS COMPUTERS FOR AUTOMATIC FLIGHT CONTROL
NAVIGATION AND GUIDANCE COMPUTER
LOAD STABILITY CONTROL
HOVERING CONTROL

Figure 2.62: Technologies supporting evolution of control subsystem.

further aerodynamic research concerning the in-flight transition between hover and cruise.

Lighter than air craft such as dirigibles and blimps are sensitive to materials research in thin film polymers for gas containment. In addition, hydrogen gas safety research is extremely important to plausible, heavy lifting LTA's. Finally, nuclear reactor propulsion concepts appear intriguing as LTA power systems. Research into lightweight cooling concepts for such reactors promises to provide very good long range LTA economics.

The key surface effect vehicle technology is materials. New materials with comparatively high erosion and wear resistance characteristics are needed for SEV skirts. Such skirts are necessary for overland operation in dust environments. SEV engines need similar protection.

2.9 STEP 9 - DEVELOP NETTED TECHNOLOGY FORECASTS

A forecast of future U.S. and Soviet capabilities in each of the key supporting technologies is desired at this point. Past, present and forecasted future capabilities are desired for high temperature and structural materials, for cooling efficiency, and for lift to drag ratios of high and low speed optimal airfoils. These are the minimum desired to encompass helicopter technologies. A forecast of L/D was unattainable within the duration of this study. Inlet technology forecasts are available instead of forecasts of high temperatures materials and cooling technologies. No Soviet technology level information was uncovered in the open literature.

Figure 2.63 displays data forecasting U.S. turbine inlet temperatures of 3600°F by 1990. This data suggests an 8 to 10 year interval is

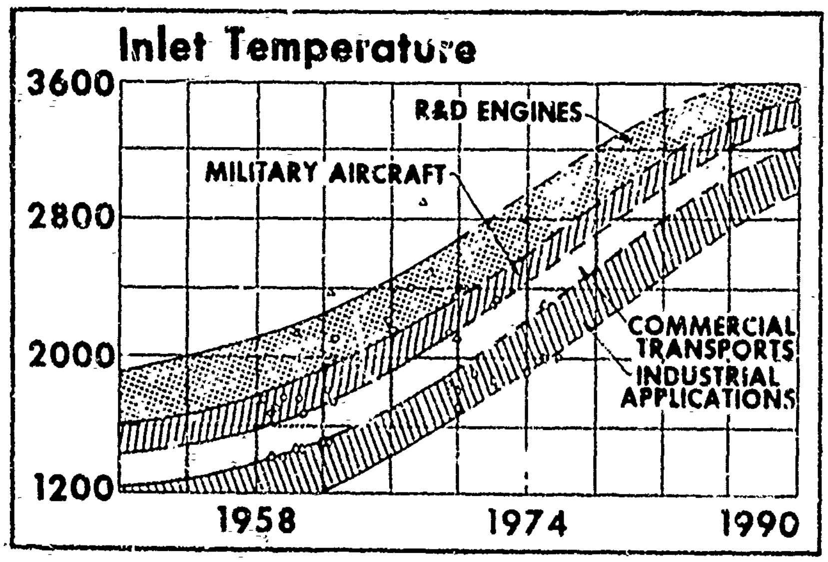


Figure 2.63: A forecast of U S. turbine inlet technology.

required to move from R&D engines to commercial operational engines. Figure 2.64 portrays a net forecast via U.S. data from the previous figure, and conjectured Soviet data. This curve is offered as an example only, illustrating the information content available with regard to relative U.S. and Soviet states-of-the-art.

In order to forecast evolution of composite structural materials a new figure-of-merit is useful. Both specific strength and specific modulus are key attributes of such materials and capability has grown by large degrees in each of these variables. To facilitate development of trend data a FOM is suggested which is the product of specific strength and specific modulus. When plotted the data appears as on Figure 2.65 with many different composites being introduced per unit time. It is less significant that each composite, once introduced, evolves toward somewhat higher FOM's. It is more noticable that the steep U.S. trend line is caused by frequent invention of new composites. Again, the exemplar Soviet data has no known basis in fact, but serves as an illustration until such Soviet data is available. Of importance is the limiting FOM near $3 \times 10^{16} in^2$ representing a covalent bond in hexagonal, close packed structure (carbon fibers in carbon).

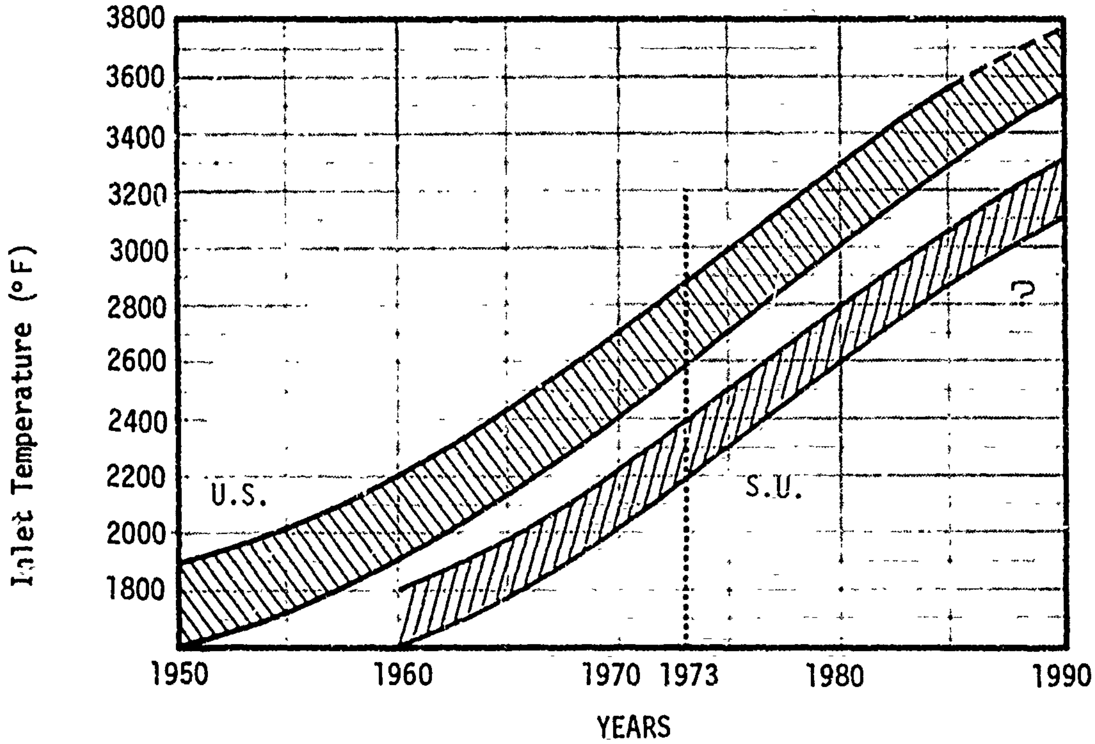


Figure 2.64: Net forecast of inlet temperature (Soviet data assumed).

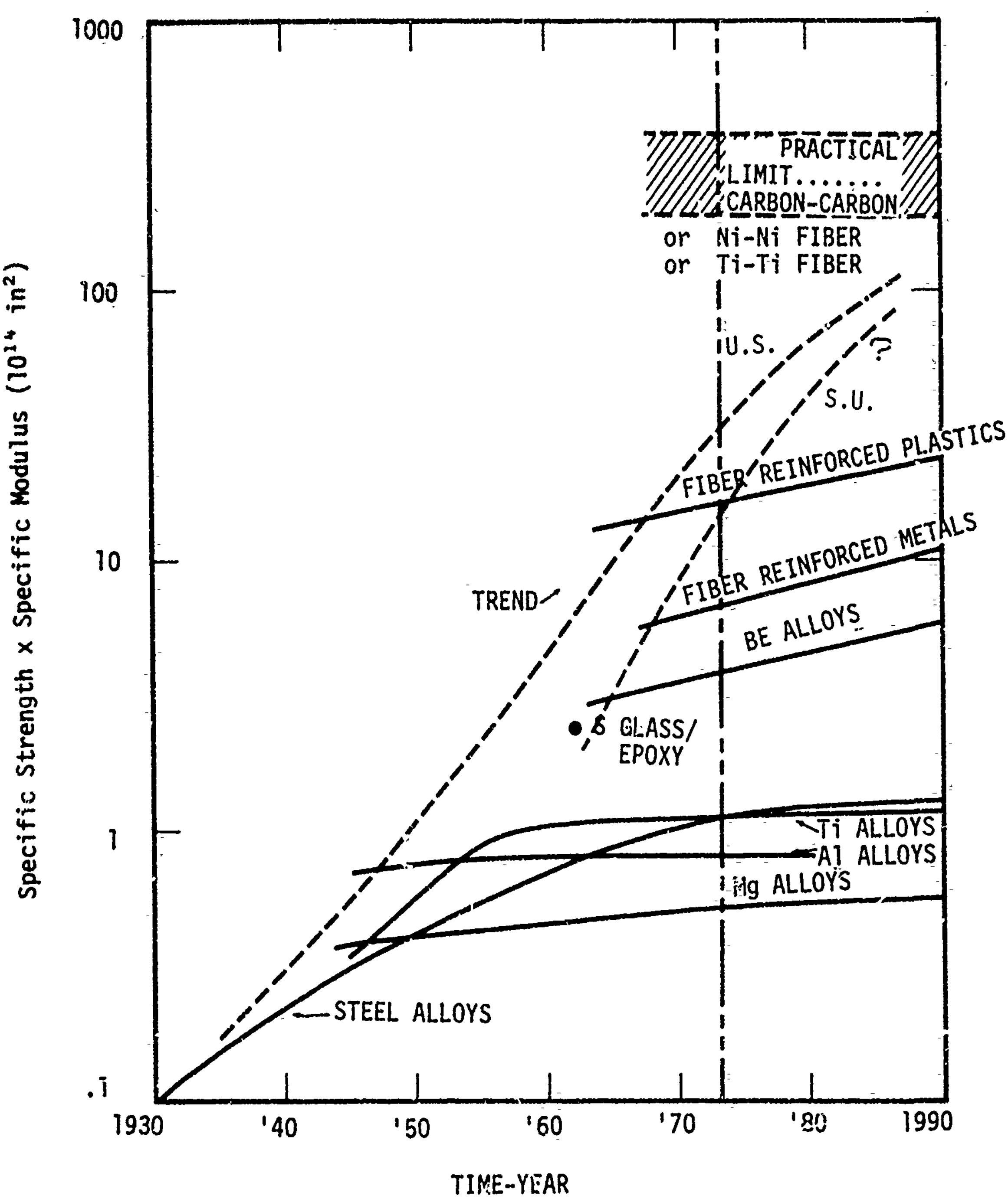


Figure 2.65: Net forecast of structural materials (Soviet data assumed).

2.10 STEP 10 - ESTABLISH ALTERNATE TECHNOLOGY EMPHASES

It is now feasible to define many alternate system concepts, each different due to the emphasis of a different subsystem and different technology. For example, it is reasonable to anticipate an advance in materials strength technology alone, without significant evolution in high temperature materials or turbine cooling technology or nuclear reactor cooling or others. Such advances in materials could be used solely for improving lifting subsystems or only air frame structural efficiency. Further, each single technology advance can be applied to several subsystems to assess the overall impact of an advance upon each system concept. Finally, all technologies may be funded and show the progress as forecasted in Step 9, and thus provide significant subsystem and system evolutions as a result of the possible synergisms.

Figure 2.66 shows the technology path to several helicopter system concepts with emphasis on increased lifting subsystem sophistication. The diagram is intended to display plausible options warranting detailed examination - not proven concepts. The figure displays four system concepts which are primarily candidates for future payload lifting growth. Three concepts are connected with the longer range mission requirements. Choosing the helicopter and its lifting system in the context of the very short range mission, the avenues of larger disc area and higher disc loading are identified. The emphasis is upon higher disc loading aerodynamic areas as well as one dependent upon materials-that of external blowing. From the conglomeration of techniques (most would agree the term is appropriate) a system concept which maximizes the emphasis on aerodynamic evolutions is established.

An analogous process can be applied to the helicopter power subsystem as exemplified by Figure 2.67. In this figure a wholly different

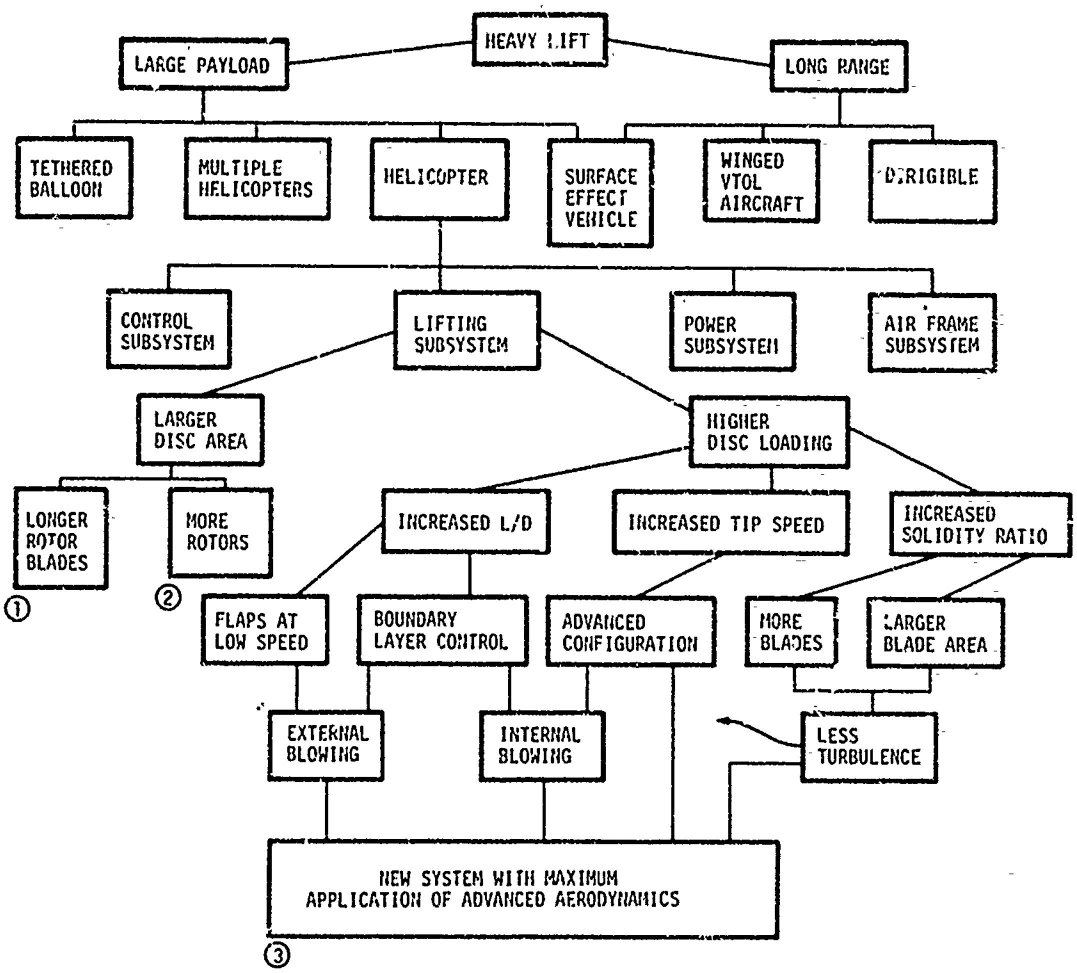


Figure 2.66: Helicopter with emphasis upon lifting subsystem.

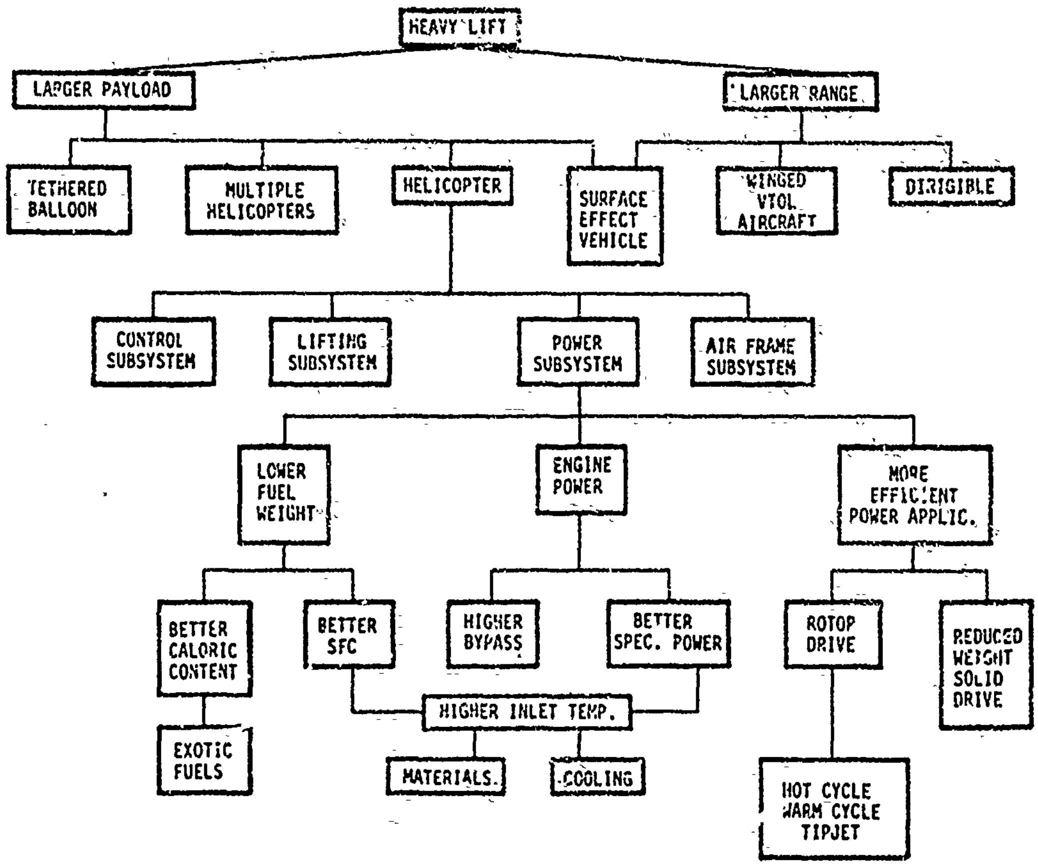


Figure 2.67: Helicopter with emphasis upon power subsystem.

helicopter is derived - one emphasizing an advanced power subsystem. The system derived is thus one with a conventional lift subsystem, perhaps multiple rotors, driven by a very efficient power package.

As an attempt to outline a system with an unique breadth of mission capability, a winged SEV helicopter composite is presented in Figure 2.68. The system achieves hover efficiency through high speed

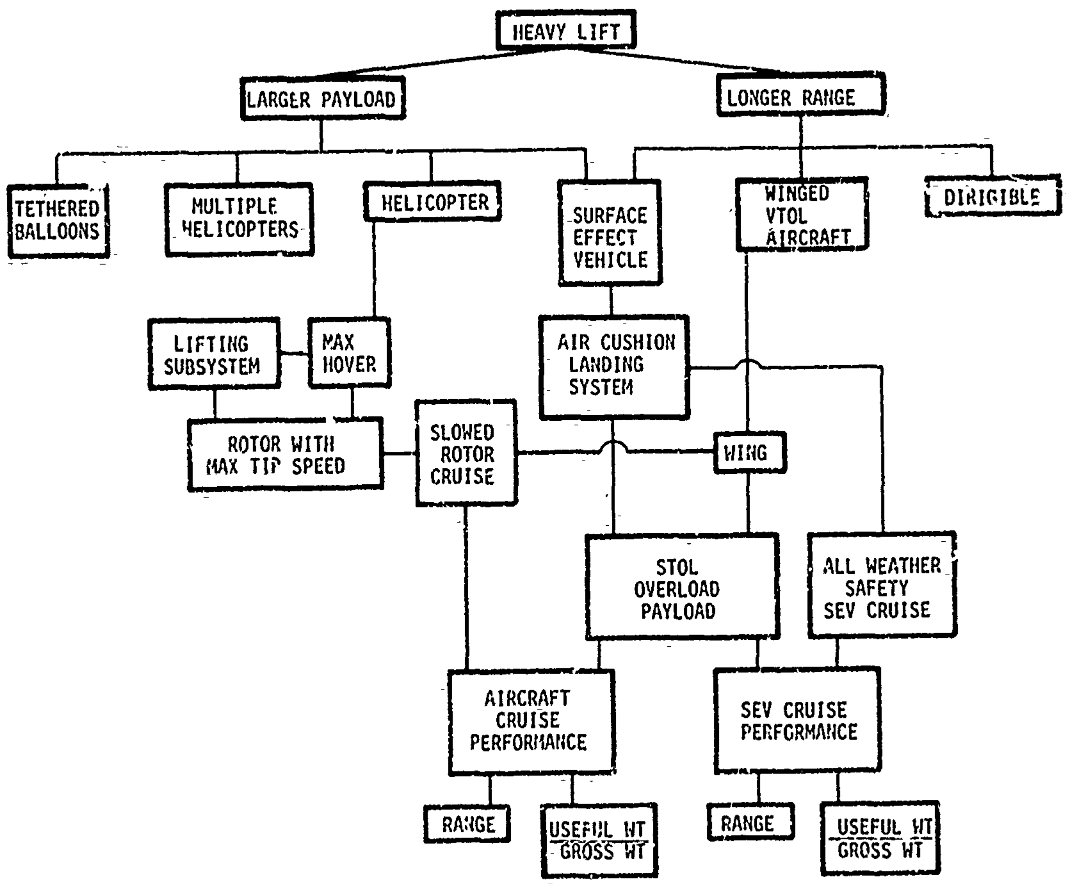


Figure 2.68: Helicopter with emphasis upon surface effect adjunct.

rotors. It achieves a high speed cruise by the addition of a wing and the use of slowed rotor propulsion. In addition, it achieves an economical long range cruise capability, a STOL takeoff from unprepared surfaces, and all weather operation by the incorporation of a surface effect system. The SEV plenum might be formed efficiently via a skirt surrounding a cargo container. In this way the cargo container can fill the unneeded plenum chamber volume and form an air ducting system.

Finally, alternate approaches to realizing a long range dirigible are examined in Figure 2.69. One concept uses hydrogen gas for both lift and as a cryogenic fuel for highly efficient turbines. Another concept uses a nuclear reactor for propulsion. The reactor coolant may add a significant weight penalty. Perhaps the same cryogenic hydrogen may significantly decrease that penalty.

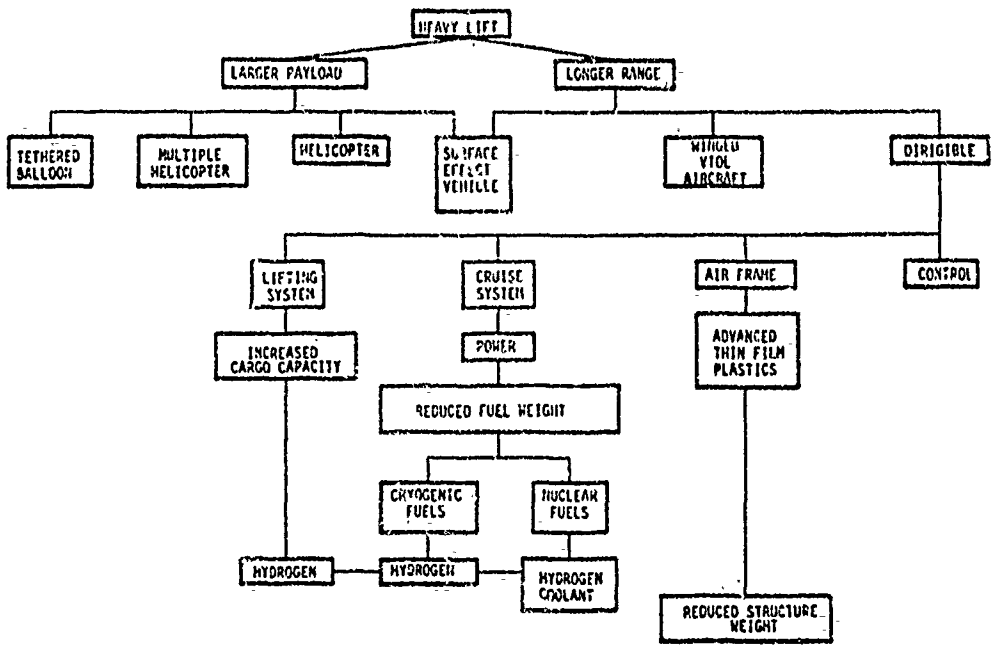


Figure 2.69: Technology emphasis for dirigibles.

2.11 STEP 11 - NET ALTERNATE SUBSYSTEM CAPABILITIES

Trends in the design of the subsystems show different U.S. and Soviet applications of their available technologies. This section compares U.S. - Soviet subsystem capabilities on the basis of the previously identified subsystem figures of merit. Some net comparisons are made on the basis of past subsystem design trends. While this provides interesting data, it is not desirable. In contrast, time permitting, this step provides a quantitative subsystem performance forecast for each country based upon the technology evolutions. Both netting techniques are desired. The former tends to reflect design philosophy and is close to the lower bound of subsystem capability. The latter technique yields a plausible upper bound in capability.

U.S. and Soviet heavy lift helicopters display slightly different lifting subsystem characteristics, as indicated by Figure 2.70. The U.S.

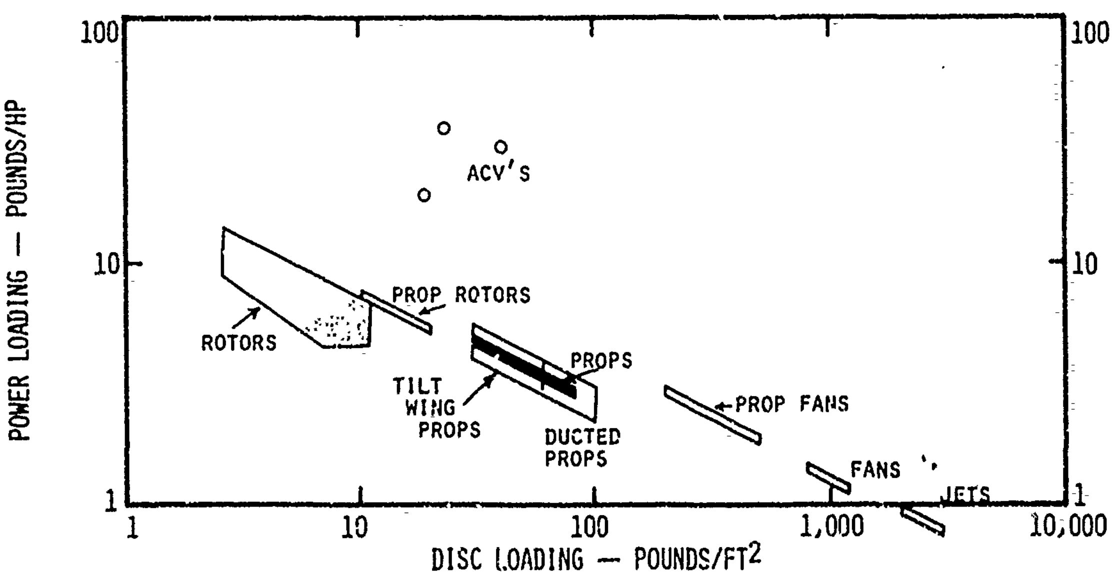


Figure 2.70: Comparison of U.S. and Soviet rotor design history.

tends to use slightly lower disc loadings and slightly lower power loadings. While such an observation may be insignificant, it could also imply more efficient Soviet rotor systems.

U.S. and Soviet helicopters were examined for total disc area and rotor size in order to determine if a net U.S. lag does exist in the lifting subsystem. Figure 2.71 displays the U.S. and Soviet trends in disc area. The data suggests that the HLH will not close a 13 year U.S. lag in total disc area as compared to the Soviet helicopter disc area The figure also shows that the U.S. is closing the previously large gap in single rotor size, since the Soviet rotor has remained at constant size for 15 years. These significantly higher Soviet disc areas suggest a

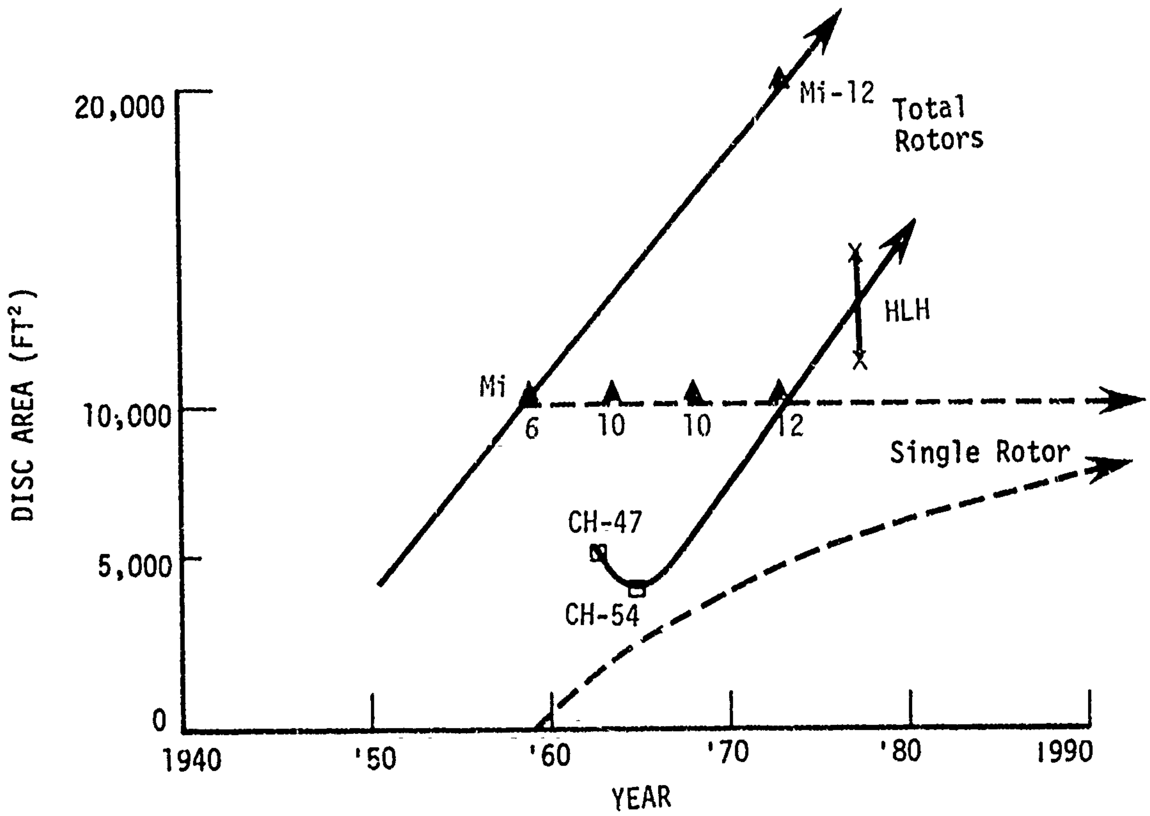


Figure 2.71: Comparative disc area trends.

proportionally higher Soviet payload capability. In the technology of applied rotor size, it is surprising to note that the Soviets demonstrated a capability in the 1950s that the U.S. has yet to duplicate.

Comparison of disc loading trends is shown in Figure 2.72. It suggests that the U.S. trend is flat or declining with the Soviet trend moving upward. Admittedly there are very few data points, but the U.S. is not tending to increase the weight per unit disc area.

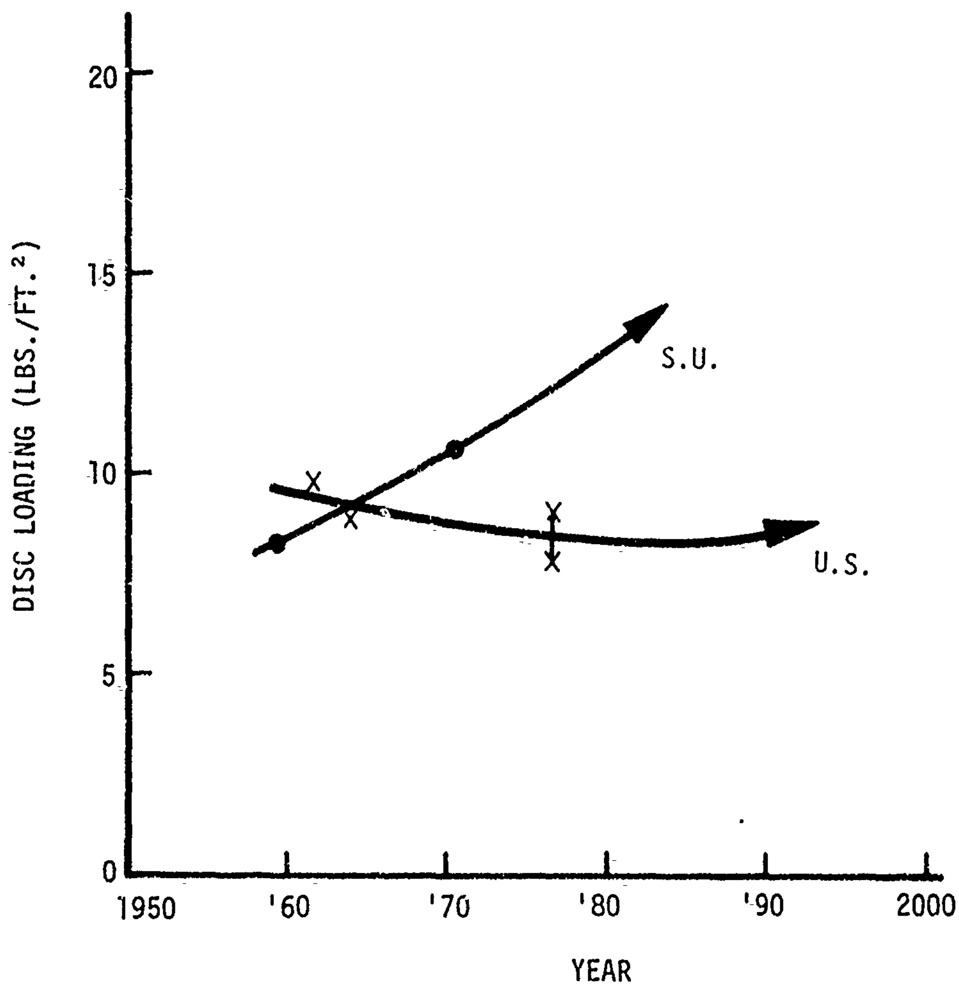


Figure 2.72: Comparison of disc loading trends.

The overall lift subsystem capability can be measured by disc loading and disc area. Figure 2.73 shows the directions of U.S. and Soviet programs. Evident from this figure is the fact that both countries are not evolving orthogonal to lines of constant gross weight. In fact, if the derived trends continue, significantly higher gross weight capability will be difficult to achieve. A far more rational approach is to evolve toward higher disc loadings with the attendent requirement to emphasize rotor aerodynamics technology research and hub materials technology.

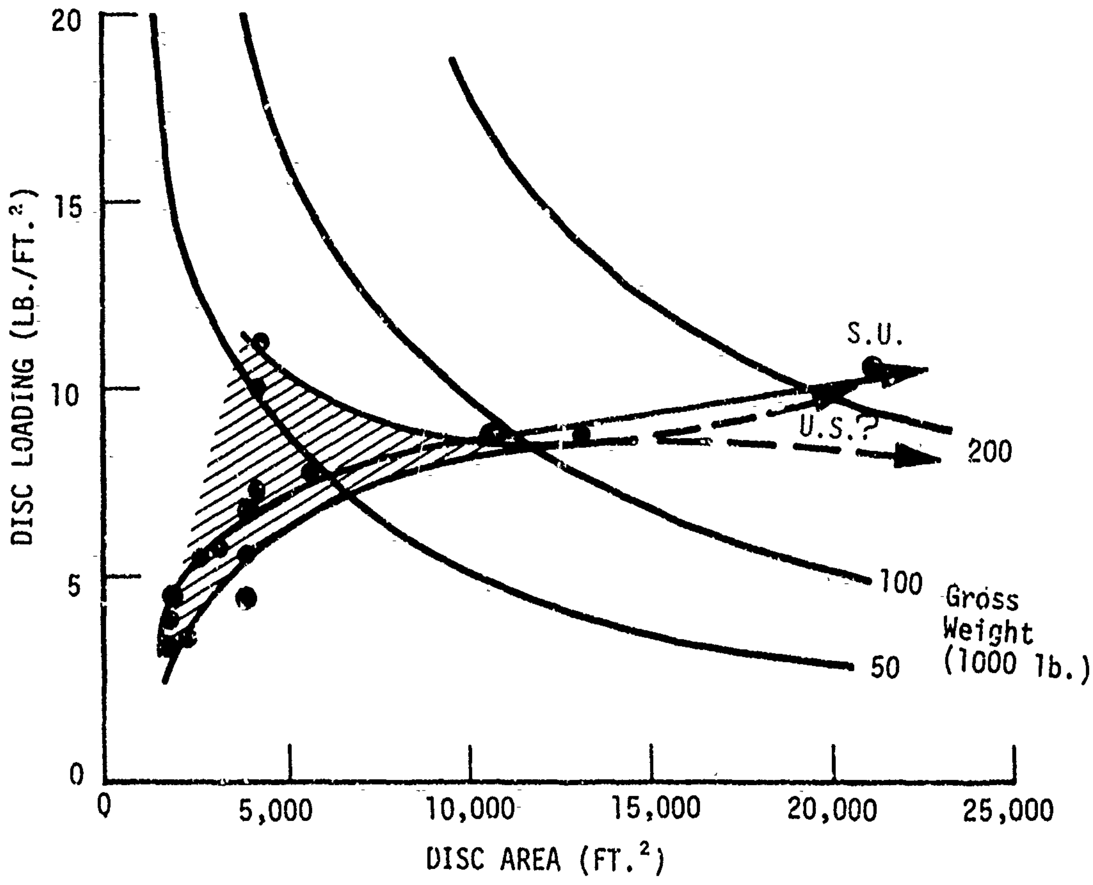


Figure 2.73: Comparative lifting subsystem trends.

The U.S. and Soviet power subsystems can be compared on the basis of the underlying technologies as desired. Figure 2.74 compares the two nations in terms of turbine specific power. The data suggests that the U.S. is likely to increase specific power output by 50 to 100 percent by 1990. This improvement is predicated upon the turbine inlet temperature advances discussed earlier. Unfortunately, the Soviet data is merely hypothetical.

With turbine chamber pressure increases following the temperature rise, specific fuel consumption is expected to show modest improvement.

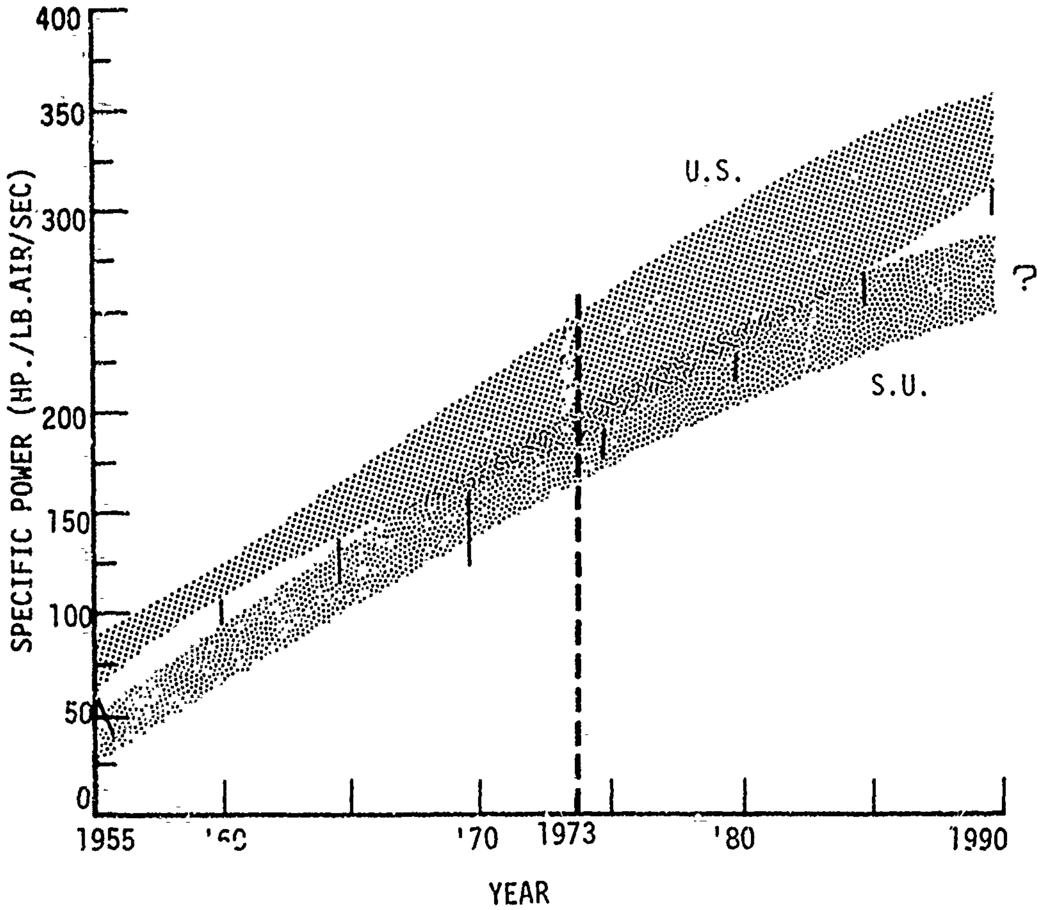


Figure 2.74: Comparison of turbine specific power trends.

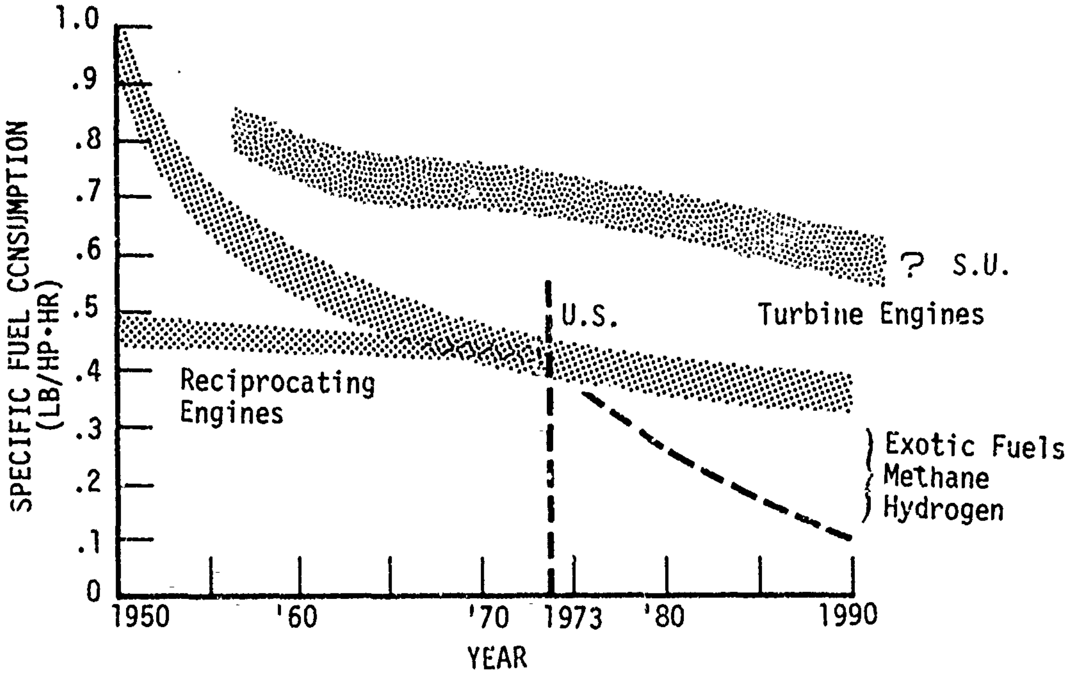


Figure 2.75: Comparison of specific fuel consumption trends.

Figure 2.75 portrays a U.S. SFC forecast showing a minor decrease in SFC using JP fuel. The significant improvement awaits introduction of hydrogen fuel. The turbine efficiency in terms of power to weight ratio is displayed on Figure 2.76. The data suggests that inlet temperature and materials evolutions will continue the increasing straight line trend in U.S. efficiency. If so, the current power to weight ratio will double by 1990. Analogous Soviet data is sparse and little credibility can be attached to the hypothetical Soviet plot.

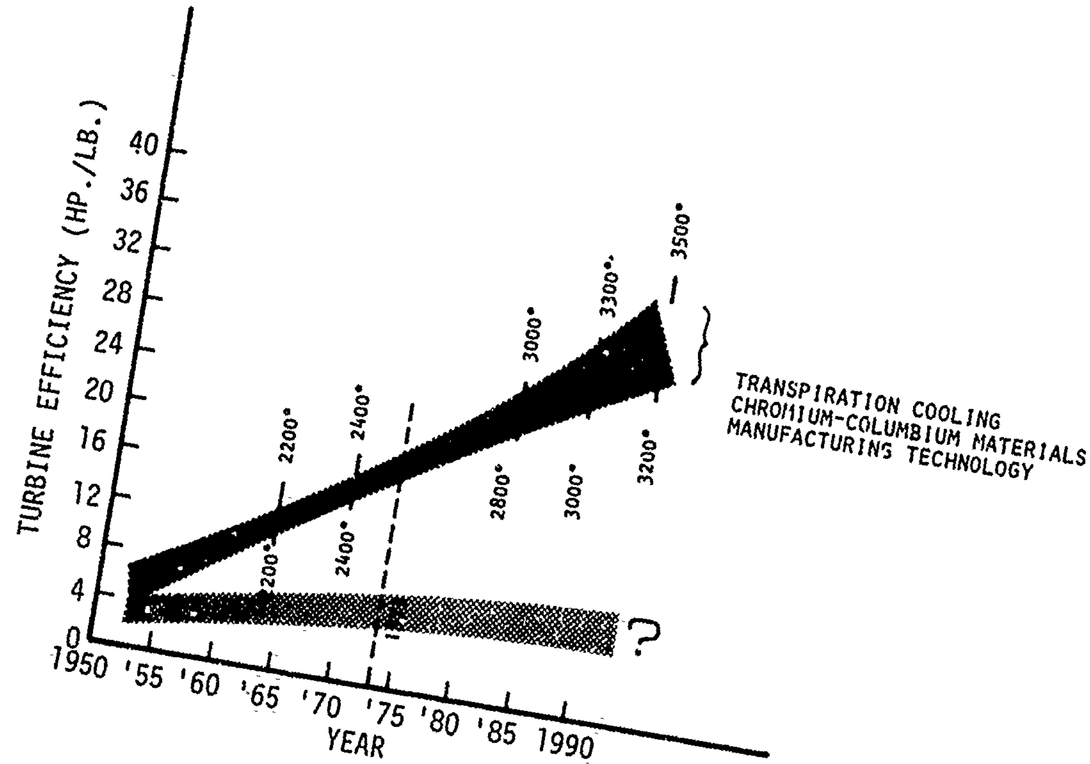


Figure 2.76: Comparison of turbine efficiency trends.

With the turbine forecasts defined, the other major power subsystem is the drive train/transmission. Figure 2.77 displays the significant reduction in weight of this subsystem which is expected from application of composites and from eventual hot or warm cycle rotor drive introduction. Combining the turbine and drive elements, the total power subsystem (sans fuel) may be represented as on Figure 2.78. The overall U.S. power to weight capability is likely to improve by 50 to 100% within 25 years. For longer range missions where fuel is an important factor the improvement can be accelerated by the introduction of hydrogen fuels. The Soviet data is again conjectured in this figure.

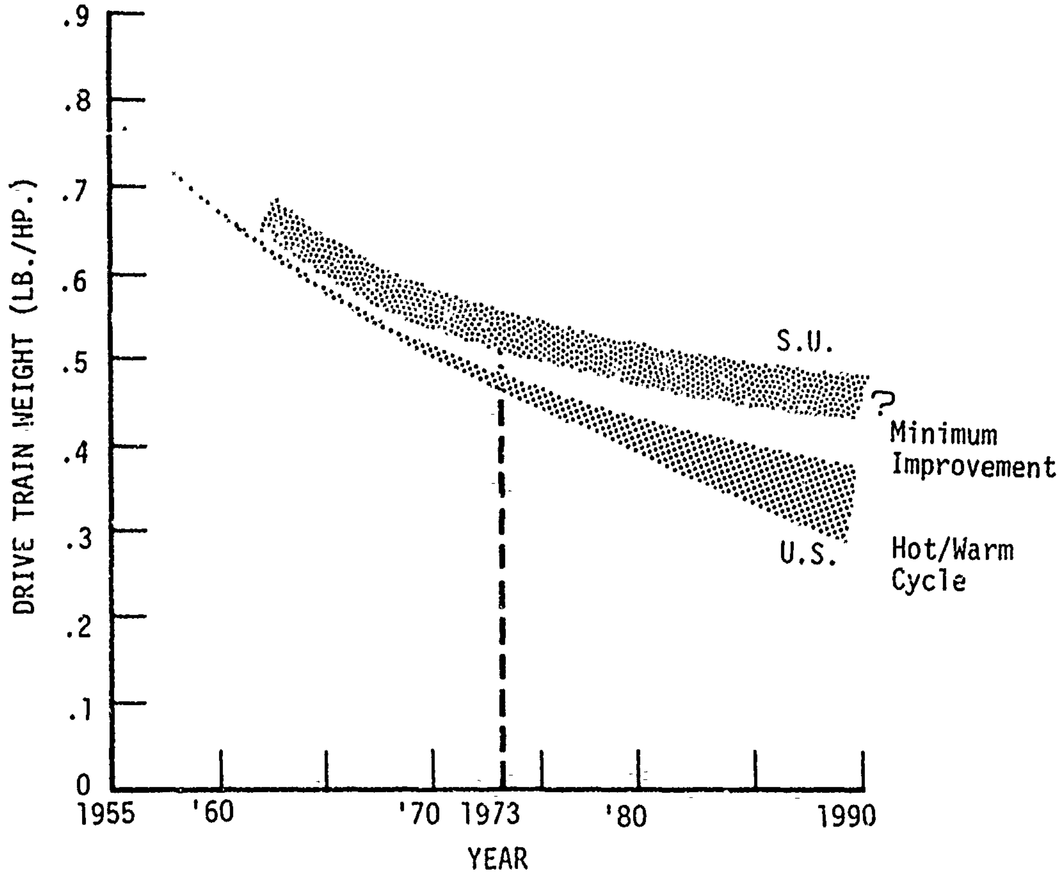


Figure 2.77: Comparison of drive train weight trends.

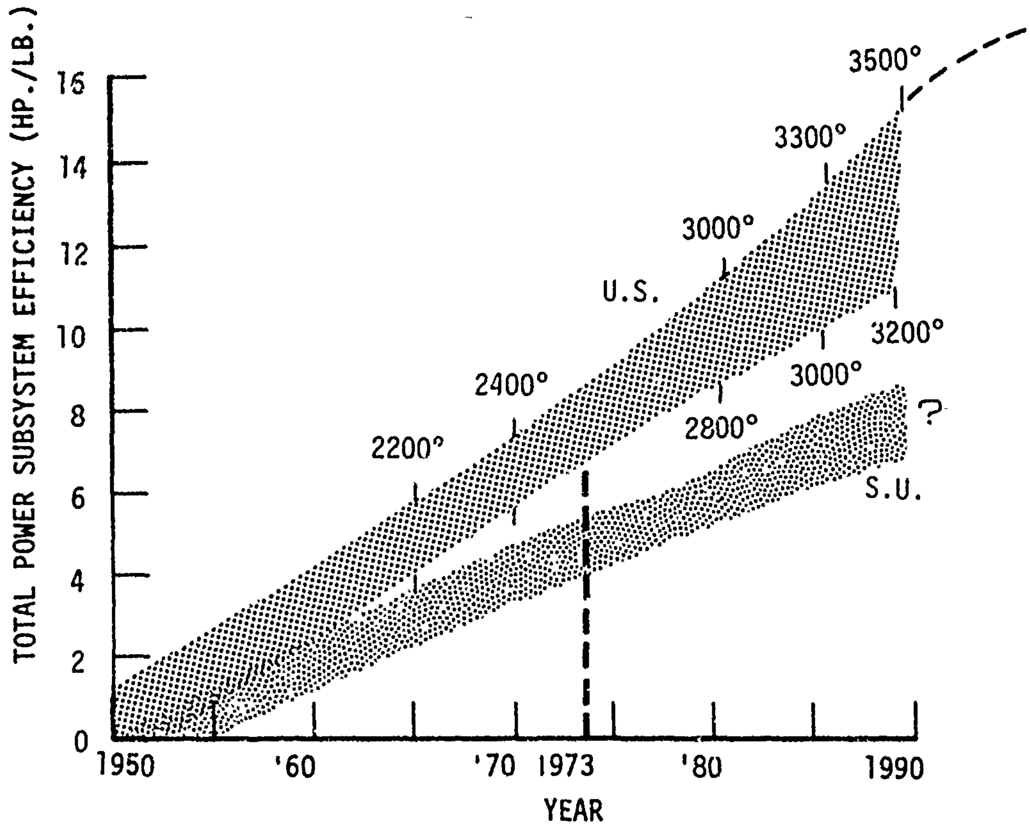


Figure 2.78: Comparison of overall power subsystem trends.

The air frame subsystem is undergoing an evolution of its own on the basis of developments in composite materials. Figure 2.79 displays past and expected future decreases in the structure dead weight. This is predicted upon composite materials developments and introduction.

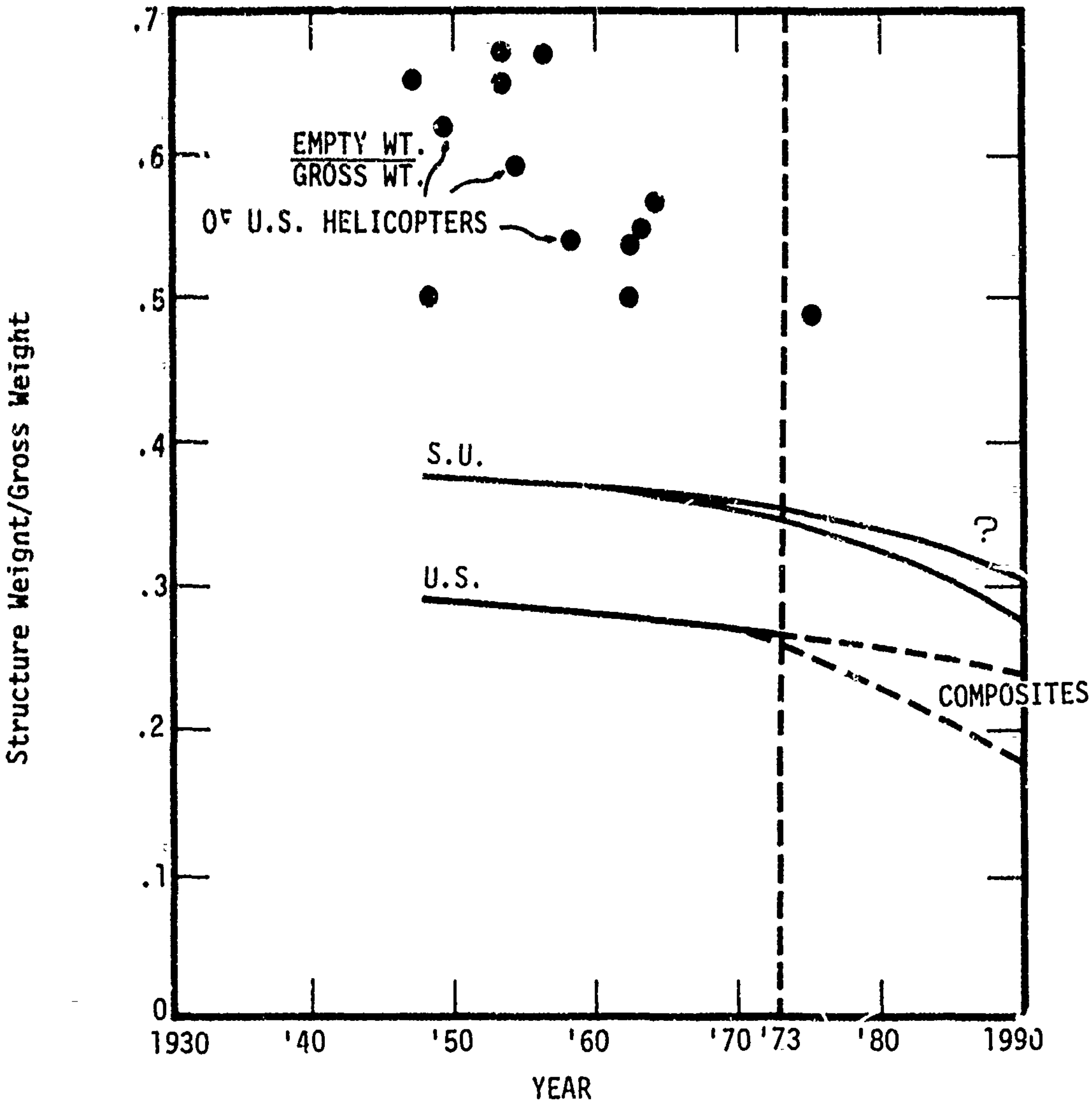


Figure 2.79: Comparison of air frame trends.

2.12 STEP 12 - DETERMINE NET SYSTEMS CAPABILITY

U.S. and Soviet systems can be compared on the basis of the system figures of merit defined in Step 3. As in the case of subsystems, quantitative comparisons are limited to extrapolation of readily available observations due to time constraints of this study. A quantitative synthesis of various helicopter systems, VTOL aircraft, LTA's, and SEV's could be accomplished in an analogous fashion on the basis of data from Step 11.

Comparison of U.S. and Soviet helicopter design efficiencies shows the U.S. to be more efficient. Data on Figure 2.80 shows many U.S. helicopters possess payload to gross weight ratios near 0.35 while Soviets approximate 0.22. More importantly, however, the trend in helicopter payload shows that the U.S. is lagging.

Figure 2.81 suggests that the rapid U.S. development of helicopter payload capability from the late 1940s through early 1960 has trailed off markedly. In contrast, the Soviets, starting in the 1960's have rapidly surpassed the U.S. payload capability with projected payloads nearing the CTOL capability. Ignoring the trend lines in favor of data points it is evident that U.S. capability is around one quarter that of the Soviets. The advent of the U.S. HLH promises to at least halve this difference. From another point of view, Figure 2.82 shows the U.S. lagging Soviet useful load growth trends currently by 12 years. The data suggests this will be reduced to 10 years by introduction of the U.S. HLH.

While quantitative data is lacking on the alternate vertical lift systems conceived during previous steps, a qualitative assessment of their post 1980 capabilities can be conjectured. Figure 2.83 suggests the relative payload and range capabilities for nine types of system concepts.

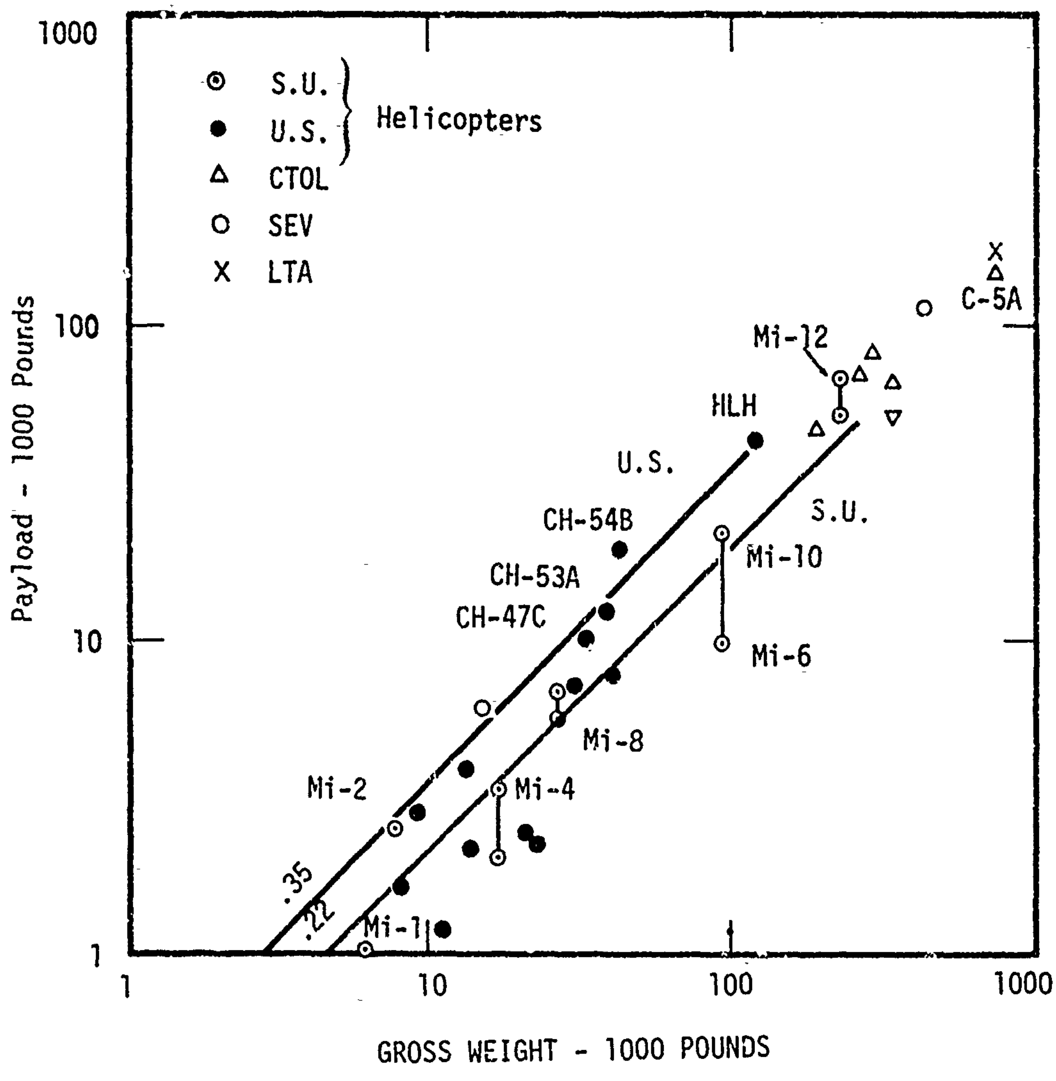


Figure 2.80: Comparison of design efficiencies.

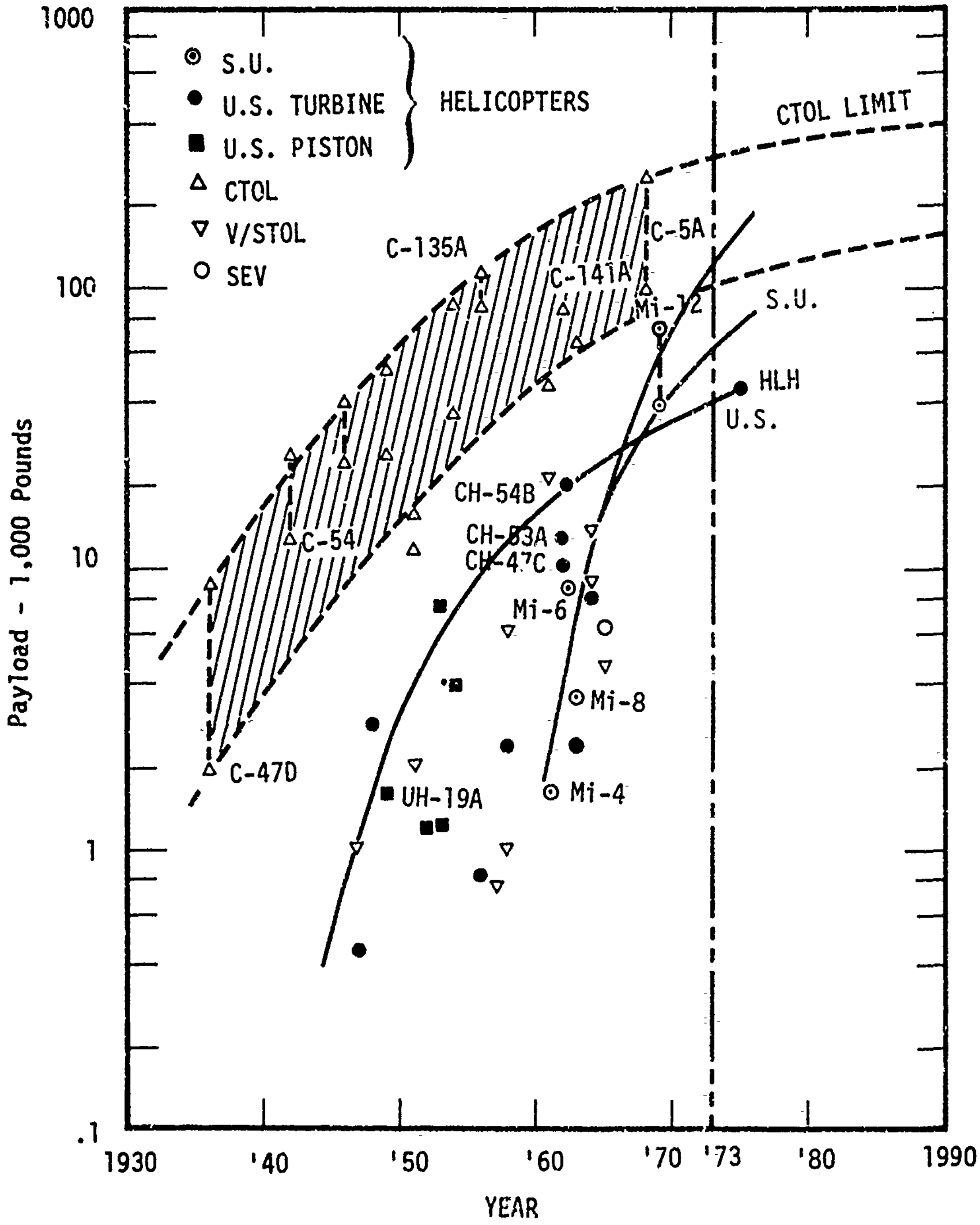


Figure 2.81: Comparison of VTOL payload trends.

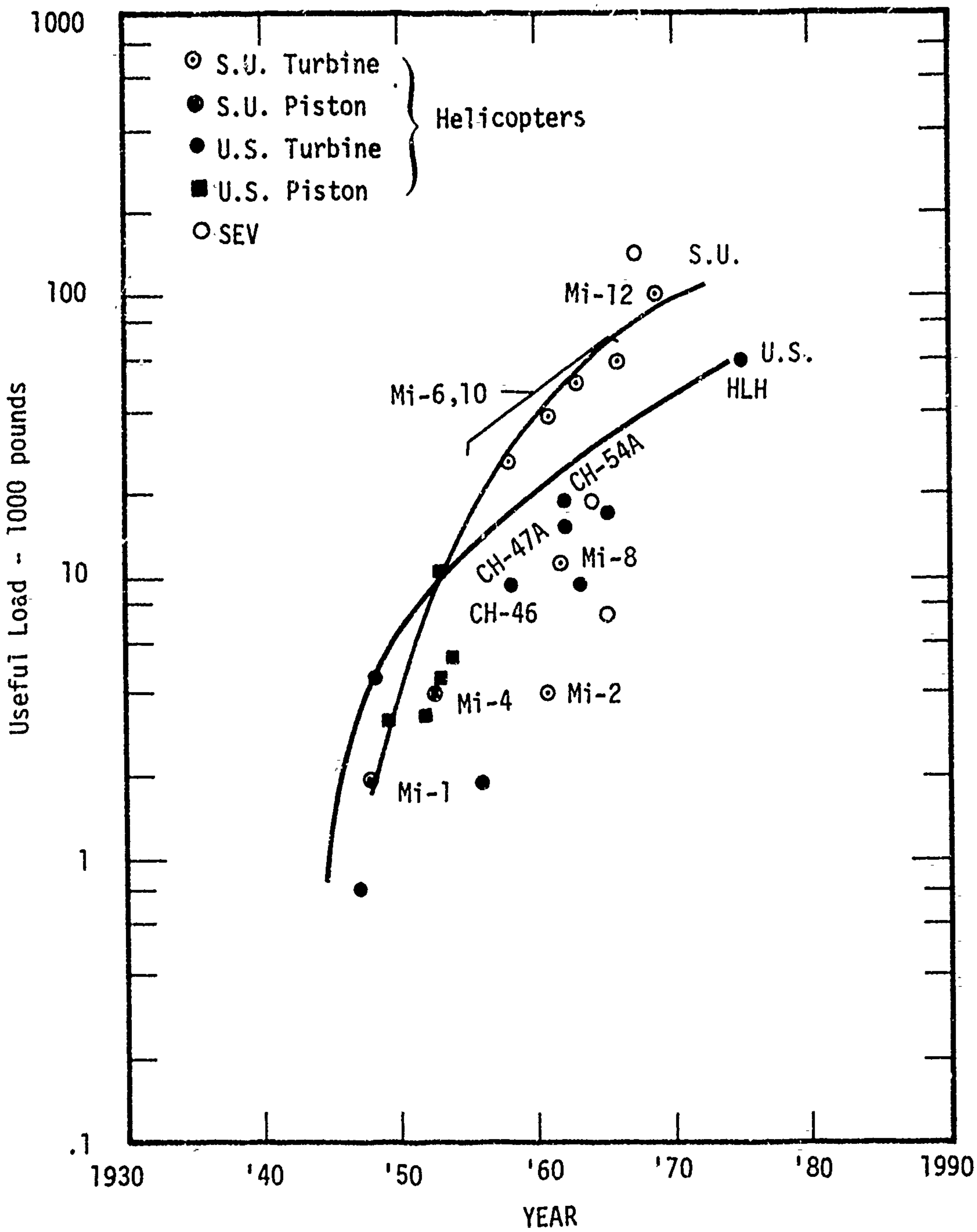


Figure 2.82: Comparison of VTOL useful load trends.

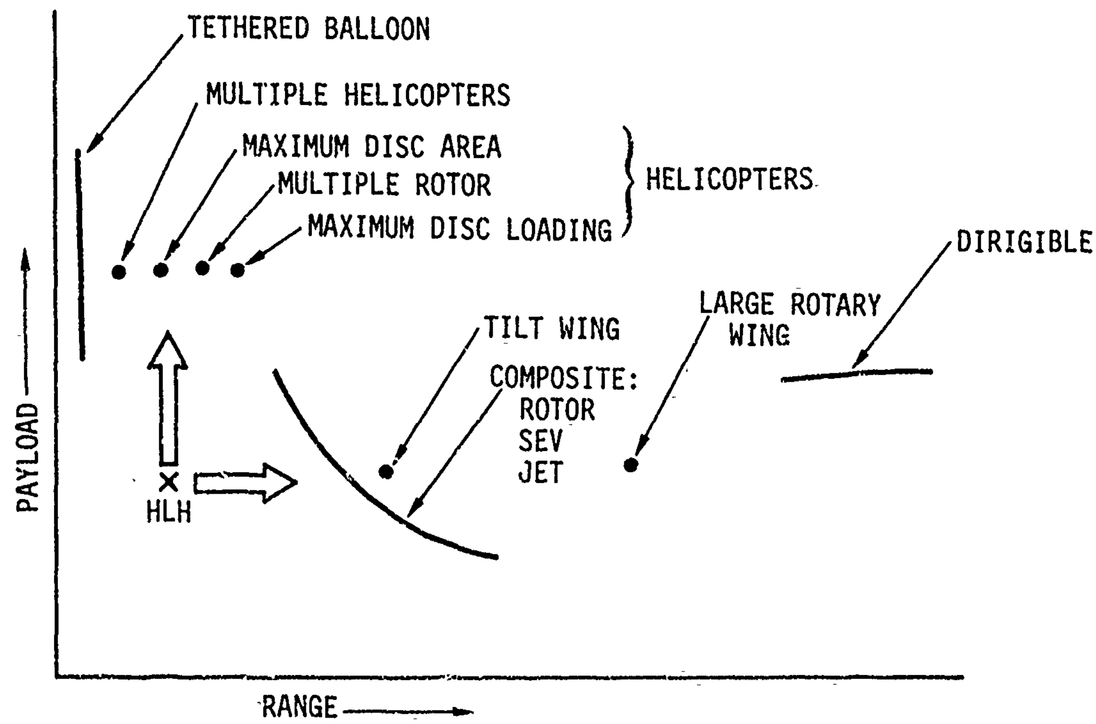


Figure 2.83: Alternate system concepts for the post 1980 HLH mission.

The tethered balloon shown on Figure 2.84 is the shortest range concept and may be useful for unloading cargo vessels. Payload weight potentials appear very high for such a concept - 40 to 100 tons could prove realizable; 20 ton lifts are a present capability. The next higher range, heavy lift concept is that of multiple helicopters lifting in unison. As shown in

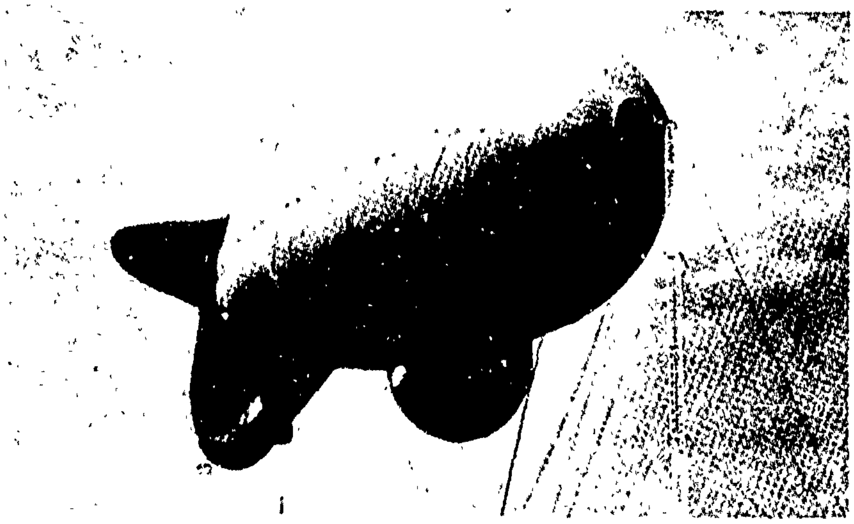


Figure 2.84: A tethered balloon.

Figure 2.85, this concept would, however, be comparatively difficult to use for extensive cruise distances. Next, three helicopter evolutions are depicted which emphasize different techniques for the attainment of a very heavy lifting capability. Figure 2.86 amplifies upon one of these helicopter systems, showing the compound nature (for range capability) and the application of tip jets for improved aerodynamic performance and weight reduction purposes.

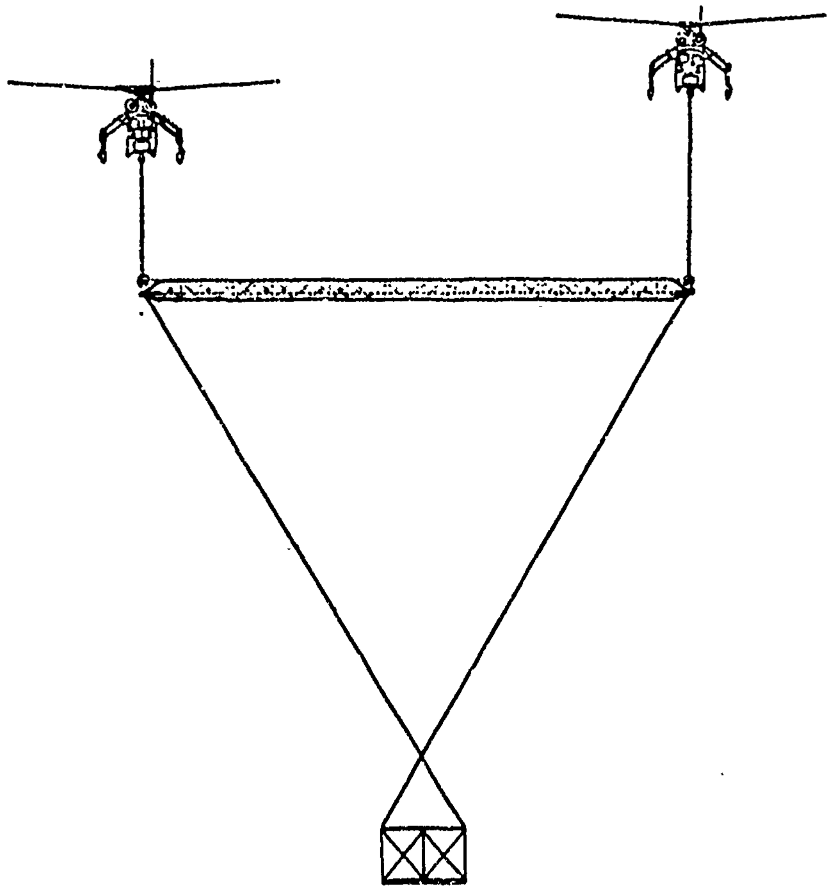


Figure 2.95: The multiple helicopter lift concept.

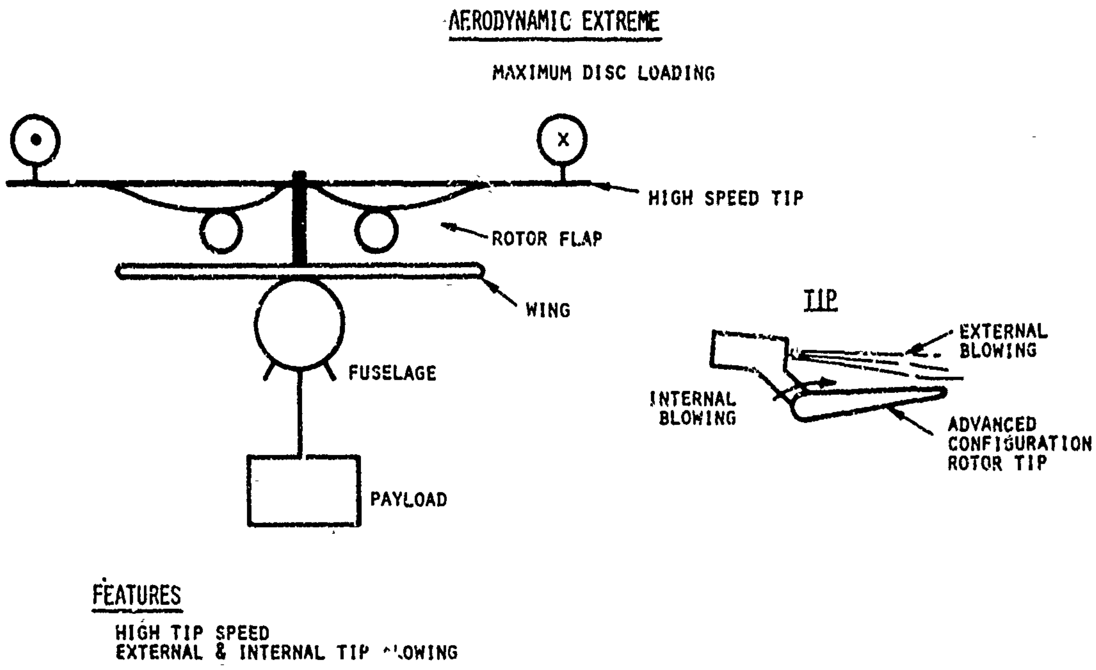


Figure 2.86: The helicopter for maximum disc loading.

Several longer range system concepts are also identified in Figure 2.83. For moderate range missions the propellor driven, tilt wing VTOL aircraft is cited (see Figure 2.87). Other VTOL concepts such as the composite shown on Figure 2.88 lead to consideration of a composite helicopter-SEV. Figure 2.89 shows an example of an SEV, specifically designed for water use. The same basic principles are used in the surface effect landing subsystem shown on Figure 2.90. This device has been tested during land and water landings and takeoffs. Incorporation of SEV principles into a helicopter composite could produce a system with diverse, flexible mission capabilities - large payload or long range as indicated on Figure 2.83.

Figure 2.87: A tilt wing VTOL aircraft concept.

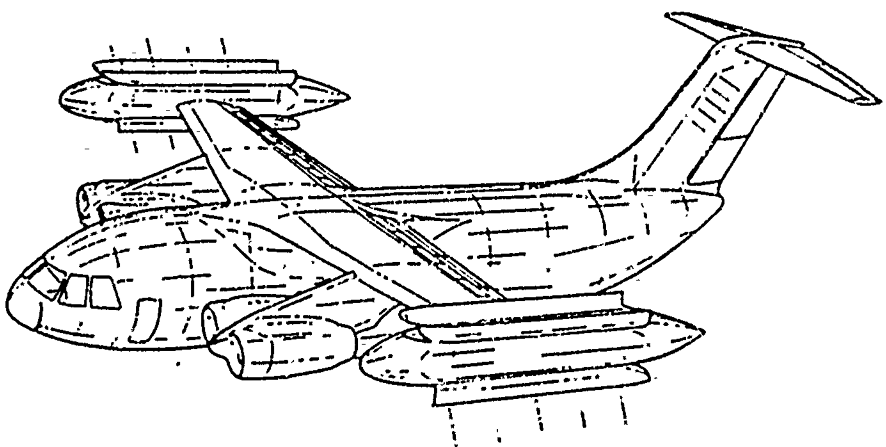


Figure 2.88: A composite VTOL aircraft concept.

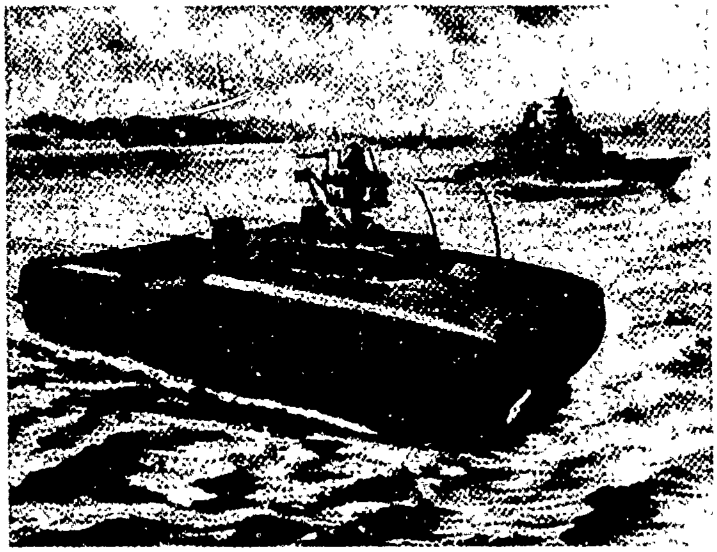


Figure 2.89: A naval surface effect vehicle concept.

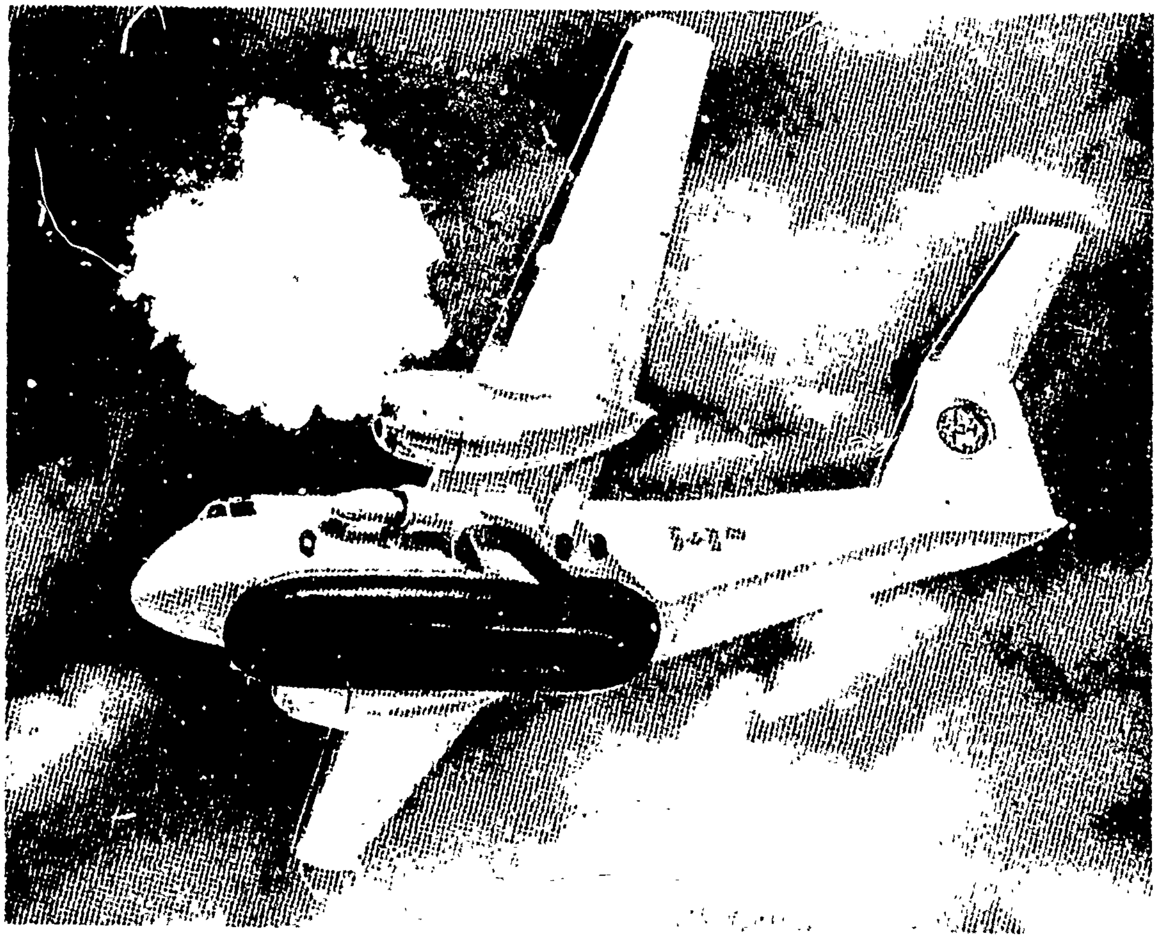


Figure 2.90: A surface effect landing system.

Two very long range concepts are identified on Figure 2.83. One, the large chord, rotary wing aircraft shown on Figure 2.91, proposes to use conventional wing configurations as rotors to lift vertically and to lock these wings for jet propelled long range cruise. The cargo area is essentially within the rotor hub. Last, a hydrogen lift dirigible of huge proportions is suggested for both long range and large payload. Propulsion sufficient for the large drag is a key issue. Either nuclear or hydrogen fueled turbine power is an attractive conjecture. Dirigible advocates in both the U.S. and S.U. have recently spoken of the revival of large (e.g., 22,000,000 cu. ft., 300 ton payload) airships.

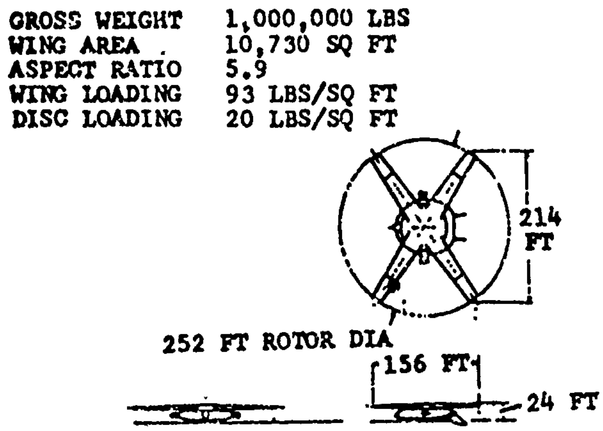


Figure 2.91: A 500 ton rotary wing aircraft.

2.13 STEP 13 - ASSESS TECHNOLOGICAL IMPACT

The significance of each technological advance should be assessed quantitatively to allow rank ordering of the associated and competing research programs. This step is therefore intended to provide the basis for the support of each key technology development effort for each system concept. The degree to which each alternate system concept viably competes with helicopters is dependent upon the success of meeting particular research milestones. Thus, the technological assessment data should facilitate cancelling development of competing systems wherein key technology milestones prove unattainable.

Time constraints have focused our effort on only qualitative estimates of the relative impacts of various technology developments upon each system concept. However, in the particular case of helicopters, quant' ative impact assessments have been possible.

Figure 2.92 portrays a qualitative assessment of the importance of several technologies upon each system concept. The importance of rotor disc loading improvement suggests a high ranking for aerodynamics of helicopters. The turbine efficiency is of relatively high importance for the longer range mission profiles associated with compound helicopters and composite aircraft. SEVs are critically dependent upon wear resistant skirt materials being developed for overland operation. Significant growth potential may be realized via the use of nuclear propulsion. The dirigible concepts are dominated by the potential of thin polymer gas bags and the concern over hydrogen safety. An informed awareness of the relative likelihood of success of each technology gives the decision maker a good capability for picking the best future system.

SYSTEM \ TECHNOLOGY	AERODYNAMICS	MATERIALS: STRUCTURAL	MATERIALS: HIGH TEMP	MATERIALS: THIN FILM	COOLING	SAFETY	NUCLEAR
HELICOPTER	H	M-H	L	N	L	L	N
COMPOUND	M	L	H	N	H	L	N
COMPOSITE	M	L	H	N	H	L	N
SEV	L	H WEAR	L	N	L	L	N-M
DIRIGIBLE	L	L	M-H	H	M-H	H	M-H
TETHERED BALLOON	L	L	N	M-H	N	L	N

H-HIGH
M-MODERATE
L-LOW
N-NONEXISTENT

Figure 2.92: Relative impacts of technologies upon systems.

Figure 2.93 displays the likely paylood fractions attainable for various helicopter designs as a function of technology status. Shown are three bars - one for each of three types of helicopter designs. At the left is a single large disc area design. In the center is a single warm cycle rotor design. At the right is the two tandem rotor design - similar to the U.S. HLH design. As one moves from left to right across each bar the gross weight varies from 100,000 to 350,000 pounds. The cross hatched lower portion of each bar represents 1970 technology capability. The top clear area is the contribution expected from technology evolution to 1980.

The assumptions for 1980 technology are disc loadings of 15 psf and a turbine power to weight ratio of 22 HP/LB, based upon inlet temperatures near 2800°F. Furthermore, composite materials were assumed to allow drive train weight per unit horsepower to approach .4 LB/HP and reduction of structure weight to 20% of gross weight. The rotor weight was assumed to decrease by 25% in addition. Hydrogen fuel was also taken as representative of 1980 technology.

Inspection of this figure suggests the best 1970 design to be the tandem rotor - independent of gross weight. This is totally consistent with the U.S. HLH design choice. In general, 1980 offers significantly improved payload fractions, independent of design choice. In fact, all three concepts are near 50% payload fractions at 350,000 lb. gross weights. Certainly, consistent within the accuracy of the technology forecasts and the data, all concepts are equally competitive in 1980. Other details will decide the choice of design, but the data suggests possible attainment of a 150,000 lb. payload operational capability in 1985 via helicopters using 1980 technology.

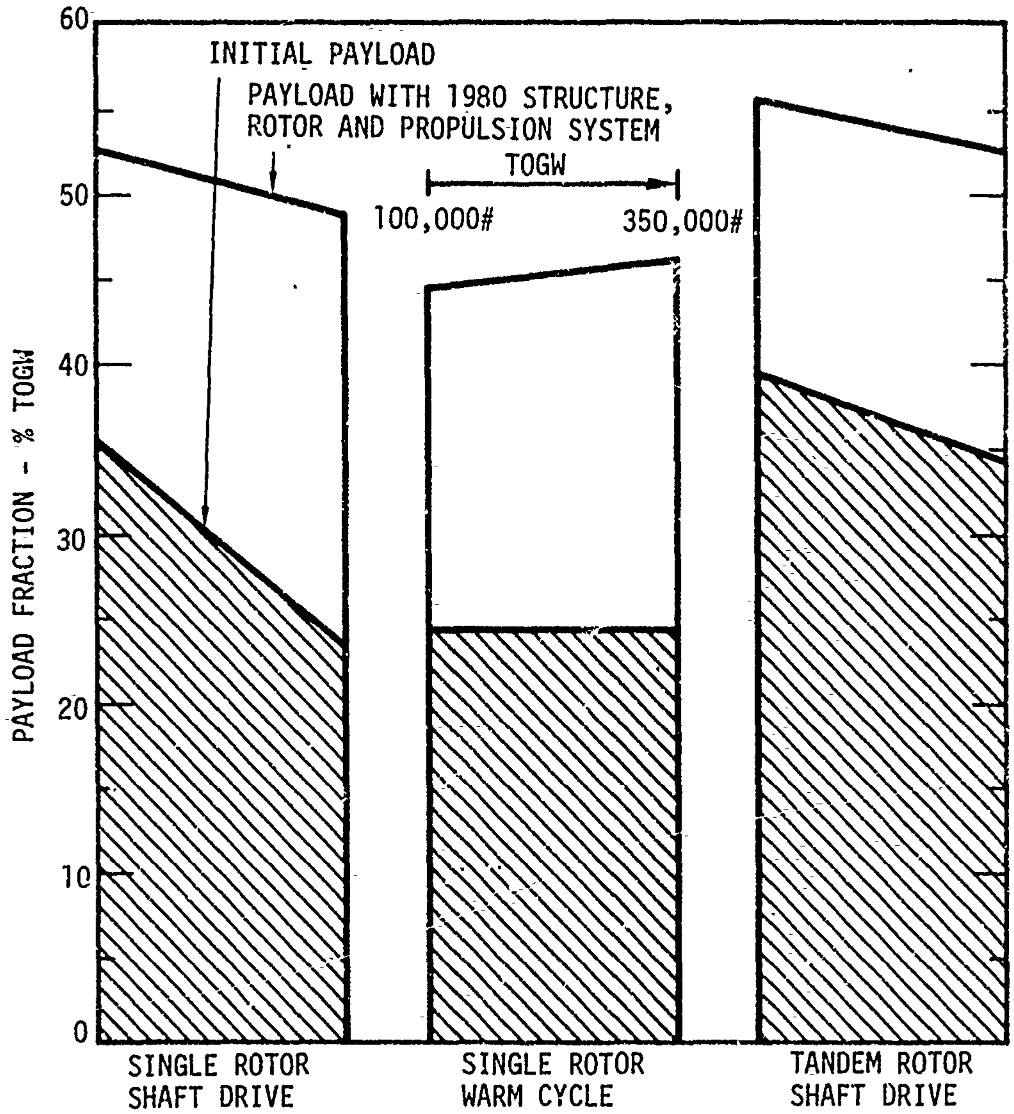


Figure 2.93: Sensitivity of helicopters to technology and design.

2.14 STEP 14 - NET RECONCILIATION

A final and key step in the TECHNOLOGY SUBSCRIPTED process is the reconciliation of comparative U.S. and Soviet heavy lift helicopter differences. The goal is to answer the degree to which different systems can be compared, and the composite of reasons for such differences which are found in the milieu of mission, technology, and policy.

The analysis of certain net differences between the Soviet Union Mi-12 and the U.S. HLH can yield important information on mission priorities and national technological strengths and weaknesses. Rationalization of some of the significant net differences between U.S. and Soviet approaches to heavy lift helicopters are displayed in Figures 2.94 and 2.95. These are qualitative precursors of a recommended quantitative, interactive 'dissection' of the total relevant environment.

SIGNIFICANT NET DIFFERENCES	MISSION RECONCILIATION
SU WING OFF LOADING	SU: PREPARED SURFACE TAKEOFF; UNPREPARED SURFACE LAND US: UNPREPARED SURFACE TAKEOFF AND LAND
SU HIGHER TOGW	SU: HIGH LOADS INTO ARCTIC US: BASIC MODULE SIZE LIMITS; DISTRIBUTIONS OF LOAD SIZE AND FREQUENCY OF DEMAND
SU DEICING (TECHNOLOGY)	SU: DOMINANT ARCTIC ENVIRONMENT US: DOMINANT TEMPERATE ENVIRONMENT
SU HIGHER DISC AREA (TECHNOLOGY)	SU: DOMINANT LIFT REQUIREMENT US: MIX OF LIFT/SPEED REQUIRED IN TECHNOLOGY HISTORY

Figure 2.94: Examplar net reconciliations of U.S.-Soviet differences.

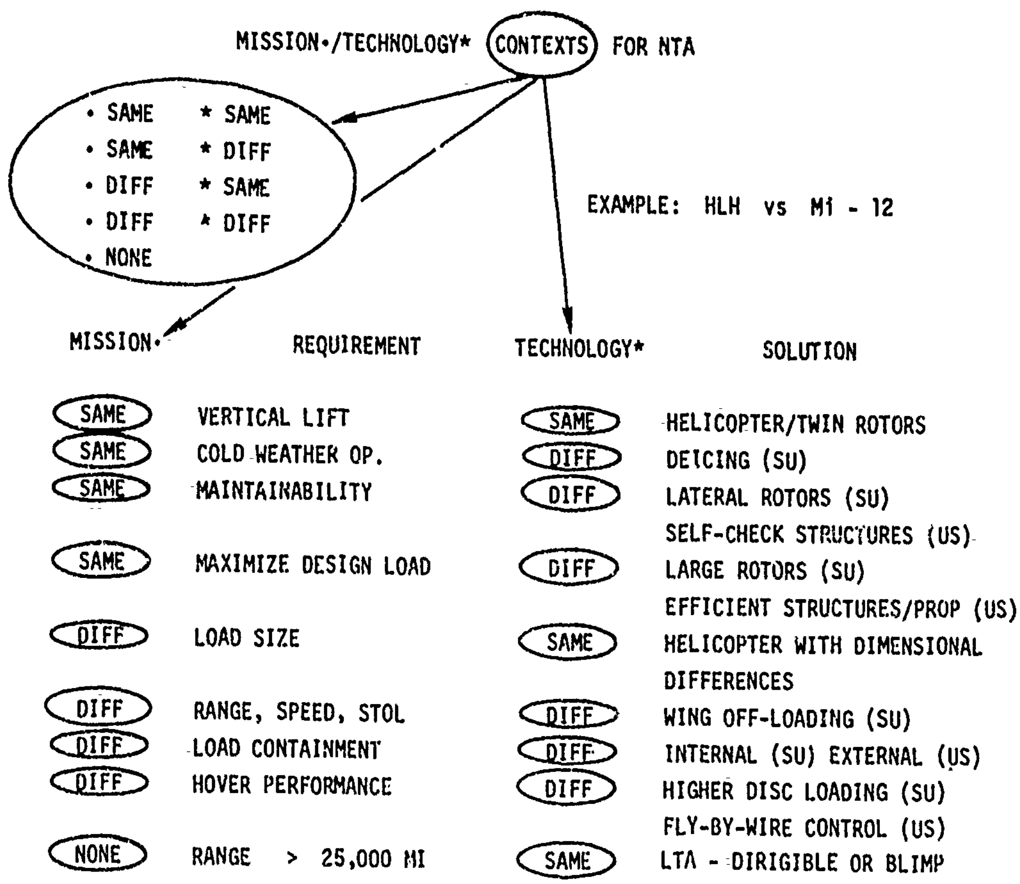


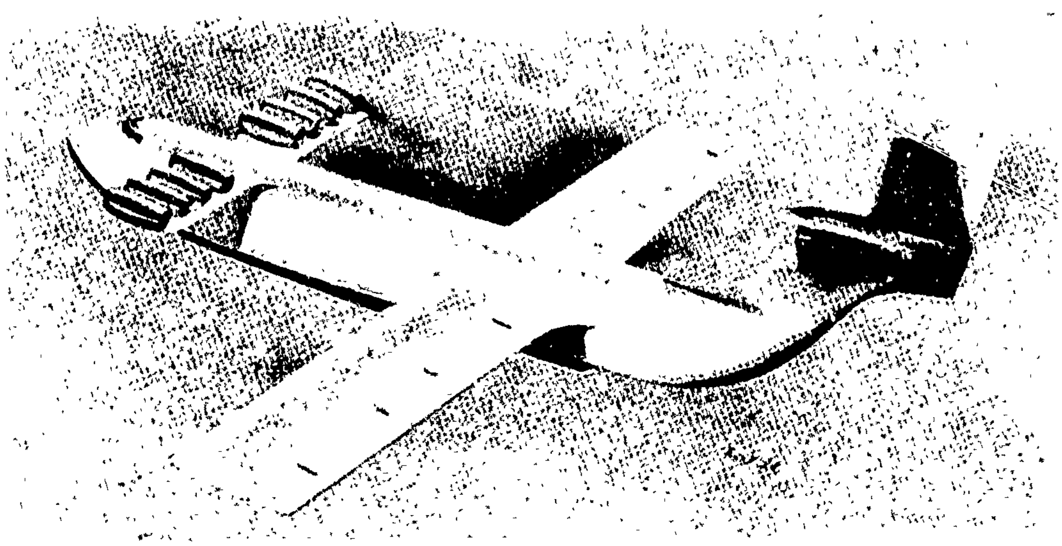
Figure 2.95: Reconciling missions and technologies for diverse concepts.

3.0 POST SCRIPT

Several months after completion of the HLH study effort, during the documentation process, new events occurred which are pertinent to this study. Because the press information tended to corroborate views expressed in the preceding sections, a brief citation here appears warranted. The press releases demonstrate that a significant benefit is accrued by even qualitative studies such as the very quick assessment reported in Section 2.0. The SURPRISE FREE nature of even qualitative net technical assessment is a major aspect of the TECHNOLOGY SUBSCRIPTED methodology. Thus, the following two items are noteworthy.

The Soviet aircraft portrayed on Figure 3.1 embraces the hybrid design philosophy offered in the SEV helicopter discussions of Section 2.0. Further, the aircraft incorporates two of the unconventional technologies identified as 'intriguing' in previous sections of this volume. These are: external blowing (for drag control via boundary layer control) and surface effect principles. An inference to be drawn from such information is that the Soviets appear to be ahead of the U.S. in willingness to apply such principles.

Figure 3.2, a newspaper clipping, cites a truly large scale Soviet LTA design or development effort. The scale of the craft discussed - 180 ton payload - is somewhat larger than our assessment team's bravery allowed for consideration. Perhaps the Soviets have already chosen their future HLH replacement.



New Soviet Hybrid Aircraft Depicted

Artist's conception shows a giant new Soviet hybrid aircraft combining aerodynamic lift with ground effect. The prototype is being flight tested on the Caspian Sea and is capable of operating from 25 to 50 ft. above the water at speeds up to 300 kt. Thrust from the eight turbojet engines on the forward stub wing is deflected downward on takeoff to provide an air bubble creating extra lift under the main wing. After takeoff, the thrust is re-deflected over the top of the wing to create additional aerodynamic lift. The main wingspan is about 125 ft. with the stub wing about 40 ft. long. Two other turbojets are mounted on each side of the empennage just below the V tail. A Soviet design bureau has been working on this hybrid approach for about 10 years and has flight-tested extensively on the Caspian Sea smaller vehicles that have been gradually scaled up to the million-pound gross weight prototype depicted above. Soviets are believed to be interested in the hybrid aircraft for both military transport and anti-submarine warfare applications.

Figure 3.1: A Soviet SEV composite using external blowing.

Russia Held Developing Nuclear-Powered Blimp

LONDON (AP)—The Soviet Union is working to develop a nuclear-powered blimp capable of carrying freight or huge numbers of passengers, according to the 1973-74 edition of Jane's Freight Containers published today.

Jane's said the projected airship, as reported in the Bulgarian newspaper Trud, has won the backing of a number of Soviet ministries.

It would have a freight payload of 180 tons, a passenger capacity of 1,800 and a cruising speed of 190 m.p.h., Jane's said.

Jane's also drew attention to reports from East Germany that Leningrad designers have recently developed prototype drawings for a smaller airship with a maximum range of almost 10,000 miles and room for 200 passengers or 20 tons of cargo.

It did not say whether the smaller airships would be nuclear powered. Nor did it give details of what nuclear system would be used in the larger airship.

But it published an artist's impression of the craft issued by the Soviet news agency Novosti. The drawing showed an enormous torpedo-shaped dirigible with fins. Passengers and freight would be carried inside its vast bulk and not in a suspended gondola.

Ukrainian engineers working with designers of the protoype heavy-lift airships have developed a new type of suspension system or "aerocrane" to enable the airship to transport general cargo and bulky engineering equipment, Jane's said. It gave no description of the crane.

It said Soviet engineers and economists have estimated it would be nearly two-thirds cheaper to use airships in place of helicopters for this type of work.

Jane's Freight Containers is one of the series of authoritative reference books that includes world navies and aircraft. All are published by Sampson Low, Marston & Co., Ltd.

Figure 3.2: Soviet development in the LTA area.

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