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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

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DATA BASE TOMOGRAPHY APPLIED TO AN AIRCAFT SCIENCE AND TECHNOLOGY INVESTMENT STRATEGY

by

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21 September 2000

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(The views in this report are solely those of the authors and do not represent the views of the Department of the Navy, any of its components, SEMCOR, RSIS, Inc., or NOESIS, Inc.)

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14. ABSTRACT

Data Base Tomography (DT) is a textual data base analysis system consisting of two major components: 1) algorithms for extracting multiword phrase frequencies and phrase proximities (physical closeness of the multiword technical phrases) from any type of large textual data base, and 2) applying interpretative capabilities of the expert human analyst. DT was used to obtain technical intelligence from aircraft data bases derived from the Science Citation Index and the Engineering Compendex. Phrase frequency analysis by the technical domain expert provided the pervasive technical themes of the aircraft data bases, and the phrase proximity analysis provided the relationships among the pervasive technical themes. Bibliometric analysis of the aircraft literature supplemented the DT results with author/journal/institution publication and citation data. Comparisons of the aircraft data base results with past analyses of similarly structured near-earth space, chemistry, and hypersonic/supersonic flow data bases are made.

15. SUBJECT TERMS

Aircraft, Technology, Avionics, Aeromechanics, Structures, Systems Engineering, Subsystems

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1.0 INTRODUCTION

Science and technology (S&T) are assuming an increasingly important role in the conduct and structure of domestic and foreign business and government. In the highly competitive civilian and military worlds, there has been a concomitant increase in the need for scientific and technical information to insure that government and industry are fully aware of current technology thrusts, who is doing what work, and possibly where investment in a technology could provide significant advantages. While there is no substitute for direct human assessments, there have become available many techniques, which can support and complement the information gathering processes. In particular, techniques which identify, select, gather, cull, and interpret large amounts of technological information semi-autonomously can greatly expand the capabilities of human beings for performing these technology assessments.

One such technique is Data Base Tomography (DT) [Kostoff, 1991, 1992, 1993, 1994, 1995], a system for analyzing large amounts of textual computerized material. It includes algorithms for extracting multiword phrase frequencies and phrase proximities from the textual data bases, coupled with the topical expert human analyst to interpret the results and convert large volumes of disorganized data to ordered information. Phrase frequency (occurrence frequency of multiword technical phrases) analysis provides the source of pervasive technical themes within a data base, and the phrase proximity (physical closeness of the multiword technical phrases to a selected theme word or phrase) analysis provides relationships among pervasive technical themes, as well as between authors/journals/institutions/countries, etc. and the selected theme phrase. This report describes the use of the DT process, supplemented by literature bibliometric analyses, to derive technical insight into the published literature on aircraft science and technology as provided in the Science Citation Index (SCI) and the Engineering Compendex (EC) data bases. The SCI accesses mainly the basic research literature, and the EC accesses mainly the applied research/technology development literature. The combination of the SCI and EC covers open literature science and technology reasonably well.

In particular, aircraft science and technology, as defined by the authors for this study, consists of development of different aircraft/helicopter components or technologies to improve system performance, safety, or reduce costs. Use of aircraft for purposes other than platform S&T development, such as crop dusting or as an instrument platform for geophysical experiments, was typically excluded unless an extrapolation to improving military aircraft performance could be identified. An example of an early query developed specifically for the SCI data base to identify applicable papers in aircraft S&T was as follows:

> (aircraft or air vehicle* or helicopter* or rotorcraft or UAV or UCAV or VTOL or V/STOL or ASTOVL or STOVL or avionic* or cockpit) **NOT** (atmos* or geophys* or meteorol* or tropospher* or stratospher* or cloud* or ozone or lightning or ocean or vegetation or wildlife or toxicology or forensic or aerial or aircrew or antenna* or care or droplet or emergency or female* or groups or injuries or injury or KM or male* or medical or neutron* or patient* or population* or river or scene or screening or smoke or species or surveys or survival or trauma or women or battery or microgravity or acids or heart or sleep or storm* or terminal or mental or weather or imagery or job or tropical or routing or batteries or brain or mesoscale or gate or fatty or concrete or rabies or workforce or receptors or supercell* or cannabinoid or orbital)

Note that the asterisk after a word or prefix allows the search routine to automatically add additional suffixes or plural forms of the word. For example, vehicle* can also be read as vehicles and atmos* can be read as atmosphere or atmospheric. The NOT terms have the effect of removing the nonrelevant aircraft application hits.

To execute the study detailed in this report, a data base of relevant aircraft articles was generated using the unique iterative search approach of Simulated Nucleation [Kostoff, 1997a, 1997c]. The final query included over 200 terms. To further purify the records retrieved, a number of abstracts still had to be removed by hand to develop the final data base upon which the phrase frequency analysis was done. This front-end effort with the SCI data base allowed the words and phrases resulting from the phrase frequency analysis to be directly and efficiently linked to, or grouped by, the aircraft technology areas of interest for this study.

The EC produced a very high quality aircraft data base with the following limited query: (aircraft or air vehicle* or helicopter* or rotorcraft or UAV or UCAV or VTOL or V/STOL or ASTOVL or STOVL or avionic* or cockpit or aircrew*). Very few abstracts that were extraneous to the focus of the study were produced, and the EC data base did not require the same number of iterations used for the SCI data base. This derives from the fact that the platform technology focus of the study is better aligned with the platform technology orientation of the EC data base than the platform-based science orientation of the SCI data base.

Each data base was then analyzed to produce the following characteristics and key features of the aircraft field:

- Recent prolific aircraft authors;
- Journals which contain numerous aircraft papers;
- Institutions which produce numerous aircraft papers;
- Keywords most frequently specified by the aircraft authors;
- Authors whose works are cited most frequently;
- Particular papers and journals cited most frequently;
- Pervasive themes for the data bases;
- Relationships among the pervasive themes and subthemes.

What is the importance of applying DT and bibliometrics to a topical field such as aircraft? The insight into this field produced by DT and bibliometrics provides the demographics and a macroscopic view of the total field in the global context. This allows specific starting points to be chosen rationally for more detailed investigations into a specific topic of interest. DT and bibliometrics do not obviate the need for detailed investigation of the full text literature or interactions with the main performers of a given topical area in order to make a substantial contribution to the understanding or the advancement of this topical area, but rather allow these detailed efforts to be executed more efficiently. DT and bibliometrics are quantity-based measures (number of papers published, frequency of technical phrases, etc.), and correlations with intrinsic quality are less direct. The direct quality components of detailed full text literature investigation and interaction with performers, combined with the DT and bibliometrics analysis, can result in a product highly relevant to program managers and other members of the user community.

2.0 BACKGROUND

2.1 Development of DT

Since many readers of this journal may not be familiar with DT, a brief overview of the process is provided. For readers interested in more details, see the first author's web site [Kostoff, 1997c] and recent published papers [Kostoff, 1997b, 1998a, 1999a].

In 1990-1991, experiments were performed at the Office of Naval Research [Kostoff, 1991] which showed that the frequency with which phrases appeared in full text narrative technical documents was related to the main themes of the text. The phrases with the highest frequency of appearance represented the main, "pervasive" themes. In addition, the experiments showed that the physical proximity of the phrases was related to the thematic proximity. These experiments formed the basis of DT.

The DT method in its entirety requires generically three distinct steps. The first step is identification of the main themes of the text being analyzed. The second step is determination of the quantitative and qualitative relationships among the main themes and their secondary themes. The final step is tracking the evolution of these themes and their relationships through time. The first two steps will be summarized now. Time evolutions of themes have not yet been performed.

First, the frequency of each single word phrase (e.g., Matrix), adjacent double word phrase (e.g., Metal Matrix), and adjacent triple word phrase (e.g., Metal Matrix Composites) is computed. The highest frequency significant technical content phrases are selected as the pervasive themes of the full data base. Topical experts are used to confirm the technical significance of the high frequency phrases.

Second, for each desired theme phrase, the frequency of phrases within +/- M (nominally 50) words of the theme phrase for every occurrence in the full text is computed, and a phrase frequency dictionary is constructed. This dictionary contains the phrases closely related to the theme phrase. Numerical indices are employed to quantify the strength of this relationship. Both quantitative and qualitative analyses are performed for each dictionary (hereafter called cluster) yielding, among many results, those subthemes closely related to and supportive of the main cluster theme.

Third, threshold values, based on experience, are assigned to the numerical indices and these indices are used to filter out the most closely related phrases to the cluster theme. However, because numbers are limited in their ability to portray the conceptual relationships among themes and subthemes, the qualitative analyses of the extracted data have been at least as important as the quantitative analyses. The richness and detail of the extracted data in the full text analysis allow an understanding of the theme interrelationships not heretofore possible with previous text abstraction techniques (e.g., using index words, keywords, etc.).

At this point, a variety of different analyses can be performed. For data bases of nonjournal technical articles [Kostoff, 1992, 1993], the final results have been identification of the pervasive technical themes of the data base, the relationship among these themes, and the relationship of supporting subthrust areas (both high and low frequency) to the high-frequency themes. For the more recent studies in which the data bases are journal article abstracts and associated bibliometric information (authors, journals, addresses, etc), the final results have also included relationships among the technical themes and authors, journals, institutions, etc [e.g., Kostoff, 1998a, 1999a].

The study presented in this report has elements of both categories, i.e., nonjournal and journal technical articles with weighting toward the latter (journal article abstract) category. It differs from the most recent published paper in this category [Kostoff, 1999a] in two significant respects. First, the topical domain is different (aircraft S&T versus HSF over aerodynamic bodies). The present topic is focused on the assemblage of technologies, which constitute the study of aircraft versus a single technology (HSF). Second, there was much heavier involvement by a technical expert in examining the raw data, and the emphasis in this report has shifted from the information science details to the technical domain details. The computerized analyses served as guidelines for the more detailed examination of the raw data.

2.2 Evolution of DT into Textual Data Mining

Recent evaluations of real-world textual Data Mining research and applications (unpublished) across a number of organizations showed a strong decoupling of the Data Mining performer from the technology user. The performer tended to focus on the development of exotic automated techniques, to the relative exclusion of the components of judgement necessary for user credibility and acceptance. Consequently, Data Mining techniques actually employed by most of the potential users examined consisted of reading copious numbers of articles obtained by the simplest of queries, with no supporting analyses to provide insight and structure for the reading. The DT process detailed in this report represents the framework and the first published example [Kostoff, 1999b] of a Data Mining approach that will couple the Data Mining research and associated computer technology processes much more closely with the Data Mining user. Strategic data base maps were developed on the front end of the process using bibliometrics and DT, with heavy involvement from topical domain experts (either users or their proxies) in the DT component of strategic map generation. The strategic maps themselves will then be used as guidelines for detailed expert analysis of segments of the total data base. The authors believe that this is the proper use of automated techniques for Data Mining: to augment and amplify the capabilities of the technologist by providing insights to the data base structure and contents, not to replace the technologist by a combination of machines and nonexperts.

3.0 METHODS

Now, the present study methods and results will be described. The key step in the aircraft literature analysis is the generation of the data base. For the present study, the data base consists of selected journal and conference proceeding records (including authors, titles, journals, author addresses, author keywords, abstract narratives, and references cited for each paper) obtained by searching the Web version of the SCI, and the CD-ROM version of the EC for aircraft articles. The Web version of the SCI accesses about 5,300 journals (mainly in physical, life, and engineering sciences basic research) and the CD-ROM version of the EC accesses about 2,600 journals and conference proceedings (mainly in applied research and technology).

The records retrieved represent a fraction of the available aircraft literature. They do not include the large body of classified literature, or company proprietary technology literature. They do not include the large body of technical reports on aircraft. They cover a finite slice of time (1991 to mid-1998 for the SCI; 1990 to mid-1998 for the EC). The records used, however, represent the bulk of the peer-reviewed high quality aircraft science and technology literature, and are a representative sample of all aircraft science and technology literature in recent times.

To extract the relevant articles from the SCI and EC, the search used the process of Simulated Nucleation [Kostoff, 1997a]. The initial query of Aircraft produced a data base that was then divided into two groups. One group was judged to be applicable to the subject matter by a domain expert, the other was judged to be nonapplicable. An initial data base of Titles, Keywords, and Abstracts was created for each of the two groups of papers. Phrase frequency analyses were performed on this textual data base for each group. The high frequency single, double, and triple word phrases characteristic of the applicable group, and their Boolean combinations, were then added to the query to expand the papers retrieved. Similar phrases characteristic of the nonapplicable group were added to the query (to the NOT Boolean) to contract the papers retrieved. The process was repeated on the new data base of Titles, Keywords, and Abstracts obtained from the search. A few more iterations were performed until the number of records retrieved stabilized to where 85% or more of the records were directly applicable to the study. This iterative process was typically applied to a 1 or 2 year sample data base, and the resultant query was then used on the total data base.

As part of the current study, a computer program was developed that permitted the rapid comparison of the applicable and nonapplicable phrases. A list could then be produced for the single, double, and triple word phrases that appeared in the nonapplicable parts of the initial data base, but not in the applicable parts (or vice versa). From these lists, additional NOT Boolean terms could be generated to eliminate unwanted articles (or terms could be added to retrieve new articles).

For the SCI data base, the final query used contained over 200 terms. The authors believe that a query of this magnitude and complexity is required to provide a tailored data base of relevant records which encompass the broader aspects of aircraft S&T. As indicated previously, the EC data base was much more related to the focus of this study and NOT Boolean terms were not required to achieve the 85% applicability criterion. If it is desired to enhance the transfer of ideas across disparate disciplines, and thereby stimulate the potential for innovation and discovery from complementary literatures [Kostoff, 1998b], then even more complex queries using Simulated Nucleation may be required. The reader should contrast the aircraft query for the SCI data base in the Introduction with standard library literature search queries for aircraft-related topics, and be aware of the enhanced data base completeness and purity, and subsequent utility, of the present approach.

The authors further believe that the "purity" and completeness of the two data bases of topically relevant records obtained using Simulated Nucleation approach is a key reason that the invariance of most of the normalized bibliometric distributions across different topical domains can be displayed (see sections 4.1 and 4.2 for the normalized bibliometric distribution functions). One beneficial value of using the Simulated Nucleation process is that the search terms are obtained from the words of the authors in the data bases, not by guessing on the part of the searcher.

4.0 RESULTS

The results from the SCI and EC bibliometric analyses are presented in section 4.1, followed by the results from the citations bibliometrics analysis in section 4.2. Results from the DT analyses are shown in section 4.3. The bibliometric fields for both the SCI and EC data bases included, for each paper, the author, journal, organization, and country. In addition, the SCI provided citations for papers that had them.

The bibliometrics sections (4.1 and 4.2) have two components. Important numerical indicators are presented which illuminate some aspect of the aircraft research literature (e.g., average number of authors per paper, number of journals, papers per institution), and distribution functions of publication and citation parameters (e.g., numbers of authors f(n) who publish "n" papers) are compared with those of other technical discipline studies which used a similar approach.

The DT sections contain four components. First, the high frequency phrases from the Abstracts are grouped into a Strategic Taxonomy, and the picture they provide of the aircraft literature is presented. Second, the high frequency Keywords are grouped into the same major categories of the Strategic Taxonomy, and the picture they provide of the aircraft data base is described. Third, the high numerical indicator phrases from the proximity analyses of the Abstracts and other portions of the data base (Author Names, Article Titles, Journal Names, Author Addresses) are grouped into categories, and the picture they provide of the aircraft literature is shown. Fourth, the technical expert's analysis and interpretation of all the abstracts, enhanced by the computer-driven results from the three previous components, is summarized.

The analytical approaches taken for the first three components are based on their fundamental data structures. The Abstract and Keyword phrase frequencies are essentially quantity measures. They lend themselves to "binning" or "grouping," and addressing adequacies and deficiencies in levels of effort. They do not contain relational information and, therefore, offer little insight into S&T linkages. The phrase proximity results are essentially relational measures, although some of the proximity results imply levels of effort that support specific S&T areas. Thus, the Keyword and Abstract phrase frequency analyses will be addressed to adequacy of effort, and the phrase proximity analyses will be addressed to relationships primarily and supporting levels of effort secondarily.

Also, one might expect that each of the four components that contain the same types of information would produce the same overall conclusions, with perhaps the level of detail and some relational information differing among the components. This was not always the case; sometimes there were substantially different conclusions drawn from the components, and reasons for these differences are discussed. In particular, phase frequency analyses of the Keywords and Abstracts provided different perspectives on some key aspects of Aircraft S&T.

These reasons have strong implications ***for how the literature should be accessed***, and perhaps other implications as well.

The Aircraft study bibliometric results are also compared to three other DT studies that were previously performed, to provide some perspective. Table 1 lists all the studies, the number of papers retrieved in the data base of each, and range of years that each data base covers.

Table 1: DT Studies of Topical Fields

Topical Area	No. of Articles	Years Covered
Chemistry (JACS)	2,150	1994
Near-Earth Space (NES)	5,481	1993 – mid-1996
Hypersonic and Supersonic Flow (HSF)	1,284	1993 – mid-1996
Aircraft - SCI (AIR-SCI)	4,346	1991 – mid-1998
Aircraft - EC (AIR-EC)	15,673	1990 – mid-1998

4.1 Bibliometrics

4.1.1 Most Published Authors, Journals, Organizations, and Countries

The first group of metrics presented is counts of papers published by different entities. These metrics can be viewed as output and productivity measures. They are not direct measures of research quality, although there is some threshold quality level inferred due to their publication in the (typically) high caliber of journals accessed by the two data bases.

4.1.2 Prolific Aircraft-Related Authors

The author field was separated from the data base, and a frequency count of author appearances was made. In the Aircraft-SCI data base results, there were 6,619 different authors, and 9,085 author listings (the occurrence of each author's name on a paper is defined as an author listing). While the average number of listings per author is about 1.37, the most prolific authors of papers (e.g., Chopra, I., Atluri, S. N., Chattopadhgay, A., Ford, T., Hess, R., Ericsson, L. E.) have listings about an order of magnitude greater than the average. A number of prolific authors in the raw data are various editors of news articles in magazines, most notably Aviation Week and Space Technology, and have been eliminated from the above listing. There were 4,346 papers retrieved, yielding an average of 2.09 authors per paper.

In the case of the Aircraft-EC data base, where there were 15,673 papers retrieved, there were 25,586 different authors and 34,973 author listings. This produced an average number of listings per author of 1.37 (the same as the SCI data base) and an average of 2.23 authors per paper (slightly higher than the SCI data base). Because of the greater number of applicable (to the focus of the present study) papers in the EC data base, the number of prolific authors is proportionately higher. In the case of the EC data base, there were 17 authors (not including magazine/journal editors) that were an order of magnitude greater than the average in the number of papers per author. The five highest, related to aircraft (one was primarily involved in remote sensing from aircraft), were: Chopra, I; Celi, R; Ray, A.; Parkinson, B; and Sridhar, B. Only Chopra appears in both the SCI and EC data base lists. Of the remaining 12 in the EC list, only Ericsson, L. appears in both the SCI and EC data base lists.

Previous studies of the technical fields of NES [a, 1998], HSF [Kostoff, 1999a], and of Chemistry [Kostoff, 1997b] as represented by the Journal of the American Chemical Society (JACS) yielded 3.37 authors per paper for the space results, 2.63 for the HSF, and 3.79 authors per paper for the Chemistry results. See Table 2 for summary statistics of these previous studies.

Table 2: Author Bibliometrics

STUDY	**AIR**	**AIR**	**NES**	**HSF**	**JACS**
DATA BASE	**SCI**	**EC**	**SCI**	**SCI**	**SCI**
No. of Authors	6,619	25,586	12,453	2,483	6,535
No. of Author Listings	9,085	3,4973	18,474	3,372	8,151
Average No. of Listings Per Author	1.37	1.37	1.5	1.38	1.2
No. of Papers Retrieved	4,346	1,5673	5,481	1,284	2,150
Average No. of Author Listings Per Paper	2.09	2.23	3.37	2.63	3.79

One might expect that the Aircraft papers from the present study would reflect large collaborative groups. In particular, large groups would be expected in the wind tunnel and flight experiments, where large facilities, efforts, and costs are involved and typically many different experiments are performed. Many of these efforts would also tend to involve multiple disciplines as well. The presence of a moderate number of collaborators per Aircraft paper means that these large experimental research projects do not dominate what is reported to the literature, and that individual small-scale projects play an important role in Aircraft research. Later results from the Keyword phrase frequency analyses and other phrase frequency results seem to support this conclusion, and substantiate the picture of much Aircraft research as smaller analytical study efforts.

Figure 1 shows the distribution function of author listing frequency for the Aircraft, HSF, NES, and Chemistry data bases. The abscissa is the number of author listings n, and the ordinate is the number of authors who have author listing n. In each case, the distribution function has been normalized to the number of authors who have one listing in the respective data bases. The graph is plotted on a semi-log scale to stretch the lower ordinate region.

The dotted line on figure 1 is the nominal (1/n^2) Lotka's Law [Lotka, 1926] distribution. All of the experimental data decline much steeper than the (1/n^2) law predicts. The Aircraft (both SCI and EC), HSF and NES data essentially follow a curve which can be approximated by a (1/n^3) distribution. The Chemistry data would appear to follow a slightly steeper curve. However, since the Chemistry data represents 1 year of publications, while the Aircraft data represents 7 years of publications, a skewing of the Chemistry data to lower numbers because of the limited time frame for publications would be expected.

The difference in the two curves represents the fact that Lotka's data reflects a time period (early 1900's) where there were a significantly lower number of researchers publishing. It is not until after the 1960's that there was a significant growth in the scientific community, as well as the number of journals available for publishing technical results. Because of this dramatic increase in opportunity, the number of technologists that may publish only one journal article increases, producing a normalized curve that is much steeper than that seen by Lotka. Also, some recent unpublished studies suggest that technical fields with a substantial technology component, such as aircraft, can have a substantial number of nondiscipline end-applications oriented technologists publishing in the applications literature sporadically, further steepening the curve.

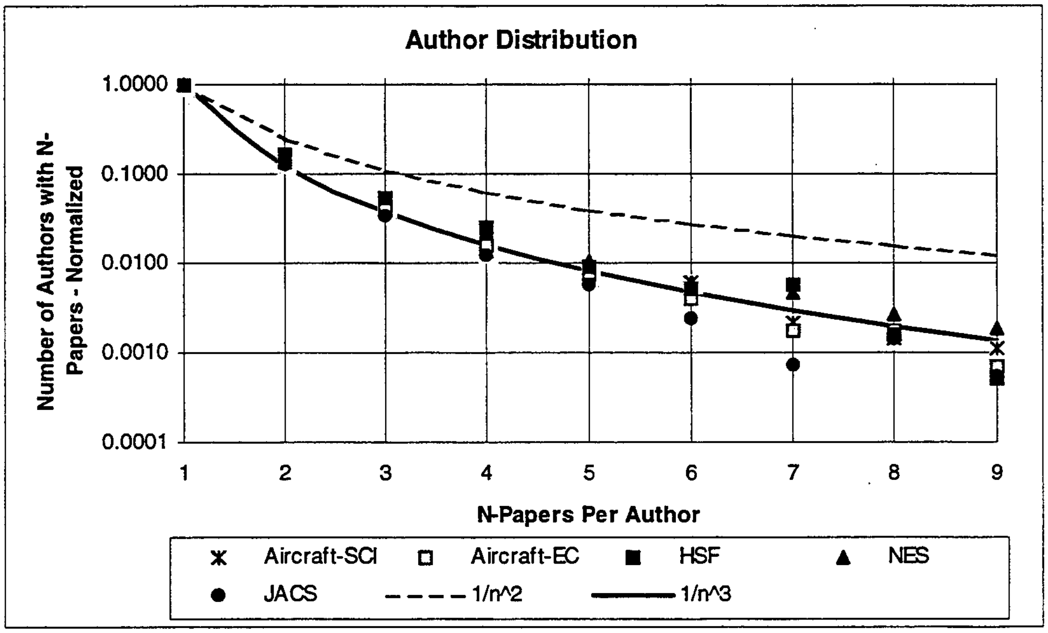

Figure 1: Distribution Function of Author Listing Frequency

4.1.3 Journals Containing Most Aircraft-Related Papers

A similar process was used to develop a frequency count of journal appearances. Table 3 summarizes the data and compares the results to the three other studies. In the SCI data base, there were 713 different journals represented, with the median journal containing two papers, and an average of 6.1 papers per journal. Eleven of the journals containing the most applicable aircraft related papers (i.e., Journal of Aircraft, Aviation Week and Space Technology, Journal of Guidance Control and Dynamics, Aircraft Engineering and Aerospace Technology, Journal of the American Helicopter Society (AHS), AIAA Journal, Aeronautical Journal, Izvestiya Vysshikh Uchebnykh Zavedenii Aviatsionaya Tekhnika, Aerospace Engineering, Aerospace America, and Nouvelle Revue Aeronautique Astronautique) had an order of magnitude more papers than the average.

Table 3: Journal Bibliometrics

STUDY	AIR	AIR	NES	HSF	JACS
DATA BASE	SCI	EC	SCI	SCI	SCI
No. of Papers Retrieved	4,346	15,673	5,481	1,284	2,150
No. of Journals	713	1,876	628	277	1
Average No. of Papers Per Journal	6.1	8.4	8.73	4.6	2,150
Bradford's law – Ratio Between Groups	3.1	2.5	2	3	-----

In the case of the EC, there were 1,876 journals and conference proceedings in the selected Aircraft data base with the median journal again containing two articles and an average of 8.4 articles per journal. Within this data base, there were 25 journals that had an order of magnitude greater than the average number of articles per journal. Of the 11 highest in the in the SCI, all but 3 appear in the top 25 of the EC listing. They were: Aircraft Engineering and Aerospace Technology (#38), Aerospace America (#40) and Nouvelle Revue Aeronautique (did not appear in the EC listing at all). This overlap between aircraft science and aircraft technology journals reflects the blurred distinction between aircraft science and technology. Much of aircraft science, like much of engineering science in general, tends to be relatively applied in an absolute scale. In the NES study, the SCI journal set was relatively independent of the EC journal set. This reflects the real-world deep stratification between space science and space technology.

Bradford's law [Bradford, 1934] for journal publications can be stated as: if the journals for a bibliography are grouped in order of decreasing publications, such that each group of journals contains the same number of papers, then the ratio of number of journals in each successive group will be a constant greater than unity. For the Aircraft-SCI data base, the first group selected contains three journals with 857 papers (Journal of Aircraft, Aviation Week and Space Technology, Journal of Guidance Control and Dynamics); the second group has 10 journals with 864 papers; third group 34 journals; fourth group 104 journals; and so on. The ratio of numbers of journals per group between successive groups is approximately 3.1, in excellent agreement with Bradford's law. Similar analysis for the Aircraft-EC data base, however, does not produce nearly the consistency of results as seen with the Aircraft-SCI data base but still appears to have an average ratio of approximately 2.5.

The fundamental observation, as a result of Bradford's law, is the fact that considerable insight into the specific technology of interest can be obtained by examining a relatively small number of journals within the first and second grouping. Although this does not necessarily guarantee that the highest quality and most innovative papers appear within this group, they will provide an opportunity to quickly gain insight into a specific field. For a more complete discussion of Bradford's law related to cited journals, see section 4.1.6.3.

Figure 2 shows the distribution function of journal frequency for the Aircraft (SCI and EC), HSF and NES data bases. The Chemistry data base was derived from one journal only, The Journal of the American Chemical Society, therefore, it was not applicable to this chart. The abscissa is the number of papers n from the applicable data base published in a given journal, and the ordinate is the number of journals which contain n papers. In each case, the distribution function has been normalized to the number of journals which contain one relevant paper. Again, because of the strong initial gradients, the graph is plotted on a semi-log scale. The solid line in figure 2 is a (1/n^1.75) distribution and is included to mathematically characterize the average of the four data bases for ease of comparison with other distributions within the report.

Of the three topical areas, Aircraft is the most generic, covering a wide range of disciplines, and HSF is the most focused, covering a rather narrow range of disciplines. Therefore, it would be expected that hypersonics would be characterized by a very few core or nucleus journals (277) in which the hypersonics practitioners strive to publish, while a broader group of core journals would be acceptable to the multidiscipline aircraft researchers (715 for the SCI and 1,876 for the EC). The normalized data for the Number of Journals with n papers, however, is surprisingly consistent.

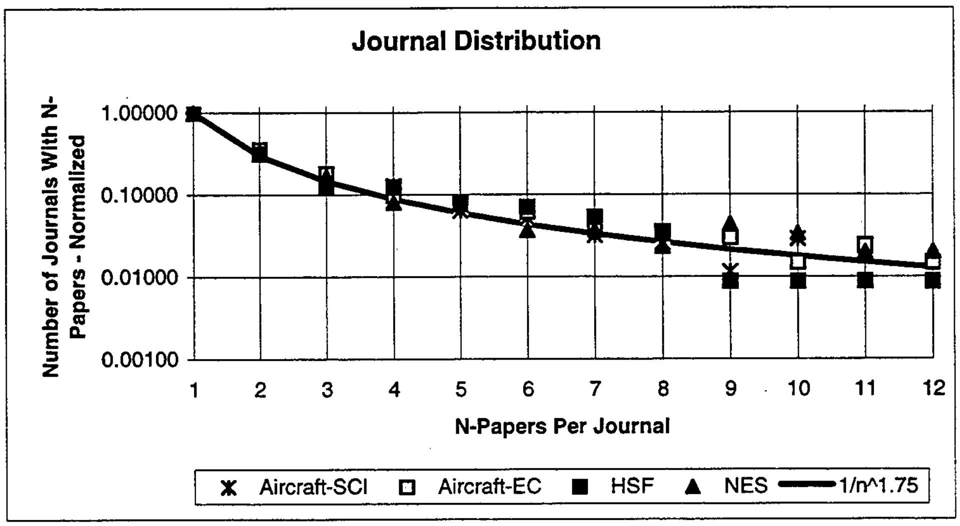

Figure 2: Distribution Function of Journal Frequency for the Aircraft (SCI and EC), HSF and NES Data Bases

4.1.4 Organizations Producing Most Aircraft Papers

A similar process was used to develop a frequency count of organizational address appearances. There were 1,486 different organizations listed in the Aircraft-SCI author address organizations, with the median organization producing one paper, and an average of 2.93 papers per organization. The organizations producing the most aircraft papers (e.g., NASA, USAF, USN, Georgia Institute of Technology, General Electric, U.S. Army, VPI, Technion {Israel}, Boeing, Purdue University, McDonnell Douglas, Penn State University, DLR {Germany}, and the Indian Inst. Tech. {India}) were more than an order of magnitude more productive than the average. The NASA laboratories are, by far, the most productive of any of the organizations in terms of papers published. It should also be noted that many different organizational components may be included under the single organizational heading (e.g., Georgia Institute of Technology could include the Aerospace Department, Materials Department, Physics Department, etc.).

For the Aircraft-EC data, there were 4,759 different organizations represented with an average of 3.29 papers per organization. There were 34 organizations that produced an order of magnitude or more papers than the average. Of these, 26 were in the U.S. The 10 most prolific organizations in the Aircraft-EC data base were (NASA, McDonnell Douglas, Boeing, Lockheed Martin, Georgia Institute of Technology, General Electric, University of Maryland, USAF, Northwestern Polytechnical University{China}, University of California).

Figure 3 shows the distribution function of organization frequency for the Aircraft-SCI and EC data bases compared to the HSF, NES, and Chemistry data bases. The abscissa is the number of papers n in the data base produced by a given organization, and the ordinate is the number of organizations that produced n relevant papers. In each case, the distribution function has been normalized to the number of organizations that produced one relevant paper.

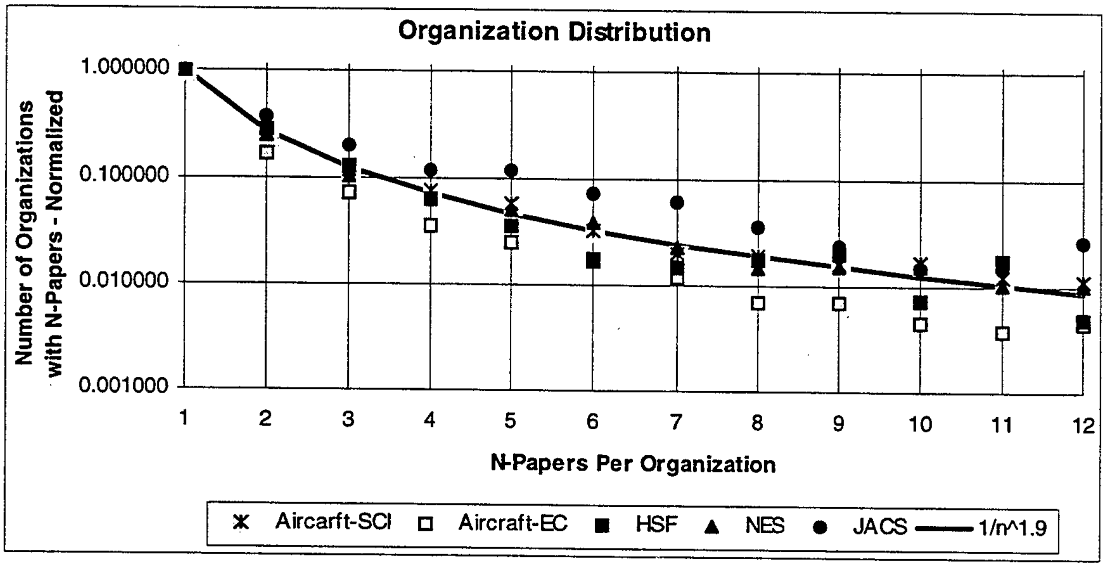

Figure 3: Distribution Function of Organization Frequency for the Aircraft-SCI and EC Data Bases Compared to the HSF, NES, and Chemistry Data Bases

It will be noted that there is significant scatter of this data around a nominal 1/n^1.9 curve, used to mathematically characterize the data for comparison purposes, particularly the Aircraft-EC and Chemistry data. The Aircraft-EC data shown in figure 3 tend to be somewhat lower, in the normalization process, because of the large number of organizations with only one paper (3406). In fact, of the organizations represented in the Aircraft-EC data base, 72% have one paper and 89% have three papers or less. This compares to the Aircraft-SCI data where 59% of the organizations have one paper and 80% have three papers or less. In research, people/organizations tend to be discipline-focused, with more discipline papers per author/organization. In technology, papers will be written on the aircraft application by people/organizations that are not necessarily aircraft-focused organizations. Thus, in technology, there will be more one-of-a-kind papers from authors and organizations relative to the science areas. On the other hand, the Chemistry data shown in figure 3 is somewhat higher because it represents only one journal and probably has many of the same organizations submitting papers for publication. A summary of the Organizational Bibliometric data is provided in table 4.

Table 4: Organization Bibliometrics

STUDY	AIR	AIR	NES	HSF	JACS
DATA BASE	SCI	EC	SCI	SCI	SCI
No. of Papers Retrieved	4,346	15,673	5,481	1,284	2,150
No. of Authors	6,619	25,586	12,453	2,483	6,535
No. of Institutions	1,484	4,759	10,435	661	750
Average No. of Papers Per Institution	2.93	3.29	0.53	1.94	2.9
Average No. of Authors Per Institution	4.46	5.37	1.19	3.76	8.7

4.1.5 Countries Producing Most Aircraft-Related Papers

There were 56 and 71 different countries listed in the Aircraft-SCI and Aircraft-EC results, respectively. The dominance of a handful of countries is clearly evident. Table 5 shows the 10 most prolific countries in aircraft related research for the SCI and EC data bases, as well as the comparison to other similar studies. This U.S. dominance in publications, particularly as noted within the EC data base, where the focus is on technology as opposed to basic research, is important to and reflective of the subsequent commercialization and application of the technology to aircraft. The U.S. is 5 times (SCI) and 10 times (EC) more prolific than its nearest competitor (U.K.). In both the Aircraft-SCI and Aircraft-EC data bases, when one considers the total number of papers retrieved, the U.S. is as prolific as all its competitors combined.

In the four separate studies performed so far using the present approach (i.e., Chemistry, NES, HSF, and Aircraft), a dominant relationship between the U.S. and its nearest competitors is observed. A 1997 study [Anwar, 1997] listed the papers contributed by the top 50 nations to the world science literature; i.e., numbers of publications in the SCI data base (see table 6). The top performers are in line with the bibliometric results of the five data bases highlighted in table 5.

Table 5: Most Prolific Countries

RANK	AIR-SCI	AIR-EC	JACS	NES	HSF
1	US-2771	US-8527	US-2040	US-5266	US-1677
2	UK-507	UK-875	JP-276	UK-660	RU-230
3	GR-250	CH-567	CN-168	FR-614	JP-224
4	FR-218	GR-468	GR-148	JP-549	FR-161
5	JP-218	CN-363	FR-116	CN-476	GR-143
6	RU-163	FR-326	UK-109	GR-471	UK-143
7	CN-133	RU-306	IT-97	RU-370	IT-66
8	ID-112	JP-303	SP-58	IT-274	TW-57
9	AU-86	AU-212	ST-53	AU-207	CH-52
10	IS-84	IT-145	IS-48	ID-203	ID-49/CN-49

Legend

U.S.-United States; U.K.-United Kingdom; CN-Canada; NL-Netherlands; GR-Germany; FR-France; JP-Japan; RU-Russia; CH-China; IT-Italy; ID-India; AU-Australia; SP-Spain; ST-Switzerland; IS-Israel

Table 6: Countries Producing Most Papers in the Science Citation Index World Science SCI (x1000) (1990-1994) [Anwar, 1997]

U.S. 995	U.K. 241	Japan 200	Germany 170
France 137	Canada 119	Russia 118	Italy 82
Netherlands 58	Australia 56	India 52	Spain 47
Sweden 44	Switzerland 40	China 30	Israel 28

4.1.6 Cited Authors, Papers, Years, and Journals

The second group of metrics presented are counts of citations to papers published by different entities. While citations are ordinarily used as impact or quality metrics, much caution needs to be exercised in their frequency count interpretation, since there are numerous reasons why authors cite or do not cite particular papers [Kostoff, 1997d, 1997e; 1998c, MacRoberts, 1996]. In addition, it will be noted that Aircraft-EC data is not presented since the EC does not include citation information.

4.1.6.1 Most Cited Aircraft-Related Authors

The citations for all 4,346 aircraft related SCI papers were aggregated into a file of 45,744 entries, yielding an average of 10.5 references per paper. There were 21,868 different authors cited, with an average of 2.09 citations per author. A few percent received relatively large numbers of citations. The highest five are Ericsson, L.E.-117; Johnson, W.-97; Miele, A.-96; Doyle, J.C.-82; and Tischler, M.B.-80. In addition, the most cited authors, while prolific, are not the most prolific authors, and vice versa. For example, the authors listed above (Ericsson, Johnson, Miele, Doyle, and Tischler) ranked 14, 918, 87, not listed, and 35, respectively, in the prolific authors list. Doyle appears to have stopped publishing in the late 1980's and the current Aircraft-SCI data base only goes back to 1991. The five most prolific technical paper authors (Chopra, I.; Atluri, S. N.; Chattopadhyay, A.; Ford, T.; and Hess, R.) ranked 91, 41, 11, not listed, and 9, respectively, in citability. All of the authors, except for T. Ford, ranked relatively high in the number of citations of their work out of the 21,868 authors cited.

Table 7 provides a summary of the Aircraft-SCI author citation results and compares them to the three other previously conducted studies.

Clearly, the Aircraft data is significantly below that of the other three studies in terms of "Average Number of Citations per Paper," and "Average Number of Citations per Author." This result may be due to the difference between the more fundamental and applied areas. The more fundamental papers, in general, will have more references than the applied papers. The fundamental papers tend to be more research-literature oriented, and are dependent on published documents, whereas the applied papers tend to be technology-product oriented , with a reduced dependence on literature precedents and acknowledgements. Also, contrast the authors who received the greatest number of citations (Ericsson-117, Johnson-97) in the Aircraft study with those who received the greatest number of citations in a similar DT and Bibliometric study performed at the Office of Naval Research (ONR) in the area of "Fullerenes" (a particular construct of carbon atoms) [Kostoff, 2000). In the case of fullerenes, one finds a significant increase in the number of total author citations (e.g., Kroto-4328, Kratschmer-3472). The difference reflects, for the most part, the high level of fullerenes research activity relative to aircraft research activity.

Table 7: Author Citation Bibliometrics

STUDY	AIR	AIR	NES	HSF	JACS
DATA BASE	SCI	EC	SCI	SCI	SCI
No. of Papers Retrieved	4,346	N/A	5,481	1,284	2,150
No. of Citations	45,744	N/A	140,662	26,768	85,000+
Average No. of Citations Per Paper	10.5	N/A	25.7	20.9	39.5
No. of Authors Cited	21,868	N/A	42,094	11,138	32,450
Average No. of Citations Per Author Cited	2.09	N/A	3.34	2.4	2.62
No. of Authors	6,619	N/A	12,453	2,483	6,535
Average No. of Citations Per Author	6.9	N/A	11.3	10.8	13

Figure 4 shows the distribution function of author citation frequency for the Aircraft-SCI, HSF, NES, and Chemistry data bases. The abscissa is the total number of citations n received by a given paper, and the ordinate is the number of papers that received n total citations. In each case, the distribution function has been normalized to the number of papers that received one citation. It can be seen that the data is closely represented by a {1/n^2} function although the aircraft data tends to fall somewhat lower for the higher values of n indicating a higher percentage of authors having a single citation.

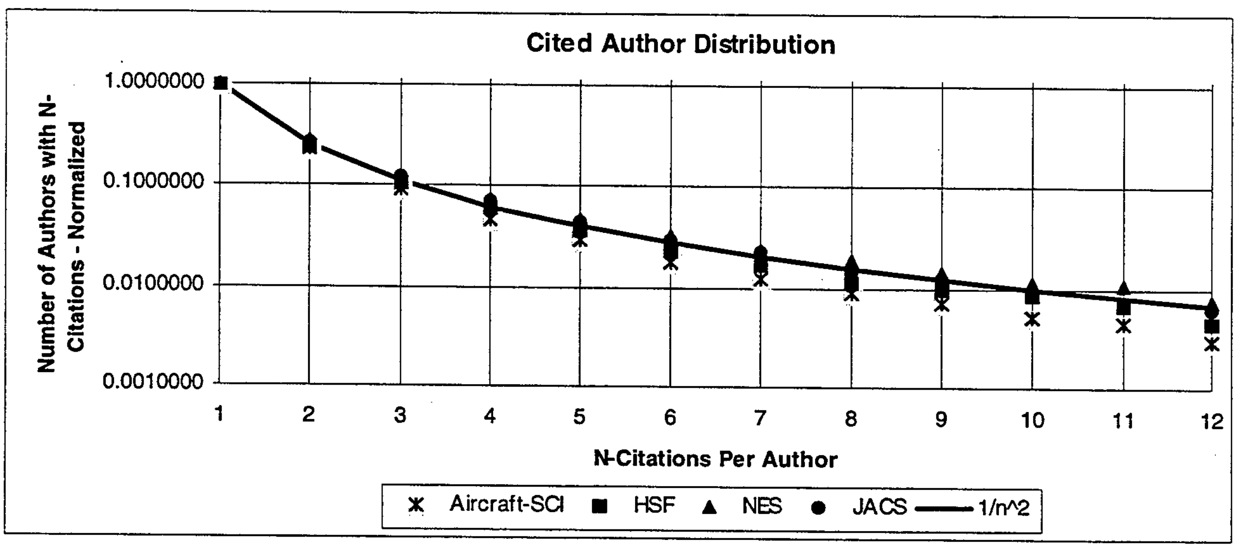

Figure 4: Distribution Function of Author Citation Frequency for the Aircraft-SCI, HSF, NES, and Chemistry Data Bases

Some caveats are in order at this point. The citation data for tables 7, 8, and 9 represents citations generated only by the papers in the data base being examined. It does not represent all the citations received by the references in the aircraft papers; the references could have been cited additionally by papers in other technical disciplines. In addition, since very recent papers are included in the references, there is probably some skewing of the distribution function toward lower numbers of citations in these figures relative to distribution functions which do not include very recently published references. Recent papers do not have sufficient time to accumulate more than a small number of citations.

4.1.6.2 Most Cited Aircraft-Related Papers

Within the Aircraft-SCI data base there were 38,792 different papers cited, with an average of 1.18 citations per cited paper. Relatively few papers were highly cited (e.g., Johnson, 1980 - 28; Snell, 1992 - 25; Doyle, 1989 - 23; Lane, 1988 - 22; Isidori, 1989 - 20). Essentially all the highly cited papers (e.g., 13 out of the first 15) were from guidance and control related journals. The citation numbers for even the very highly cited papers are very modest in an absolute sense; none exceed 30. This reflects the relatively low level of effort in aircraft research as contrasted with some other fields. For example, the previously cited ONR study of "Fullerenes" shows some highly cited papers receiving two orders of magnitude greater citations than the "highly" cited aircraft papers. In addition, from the citation year results for the fullerene study, the most recent papers are the most highly cited. This reflects a rapidly evolving field of research, as well as the newness of fullerenes. In contrast, the Aircraft-SCI data base indicates that the highly cited papers were published in the 1970's and 1980's with only a few in the early 1990's.

Table 8 provides a summary of the Cited Paper Bibliometrics for the Aircraft-SCI as well as the NES, HSF, and Chemistry studies for comparison.

Table 8: Paper Citation Bibliometrics

STUDY	**AIR**	**AIR**	**NES**	**HSF**	**JACS**
DATA BASE	**SCI**	**EC**	**SCI**	**SCI**	**SCI**
No. of Citations	45,744	N/A	140,662	26,768	85,000+
No. of Different Papers Cited	38,792	N/A	93,194	20,950	64,800
Average No. of Citations Per Paper Cited	1.18	N/A	1.51	1.27	1.31
No. of Authors Cited	21,868	N/A	42,094	11,138	32,450
Average No. of Papers Cited Per Author Cited	1.77	N/A	2.21	1.88	2

As shown in recent S&T Data Mining studies [Kostoff, 1998a, 1999a], the more fundamental papers tend to receive more citations than the applied papers, and the more fundamental journals consequently receive more citations than the more applied journals. Thus, in an S&T field such as aircraft, which has a substantial ratio of applied to fundamental papers, there are fewer papers that are realistic candidates for high numbers of citations. The ratio of aircraft papers that receive large numbers of citations to those that receive one citation are relatively small.

Figure 5 shows the distribution function of paper citation frequency for the Aircraft-SCI, HSF, NES, and Chemistry data bases. The abscissa is the total number of citations n received by a given paper, and the ordinate is the number of papers that received n total citations. In each case, the distribution function has been normalized to the number of papers that received one citation.

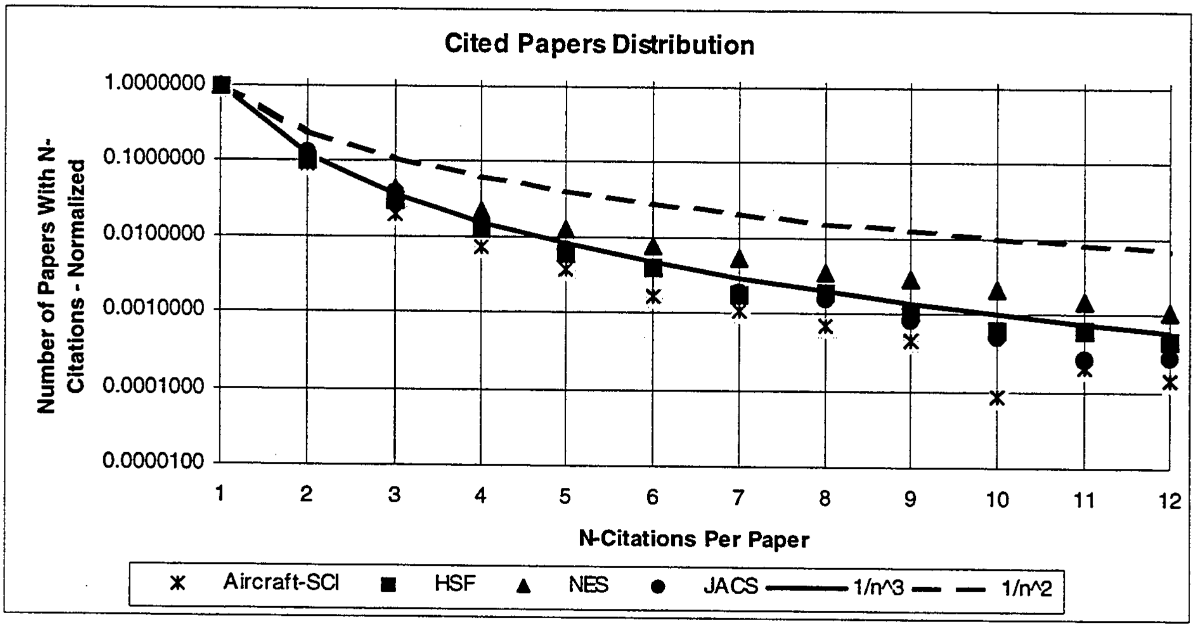

Figure 5: Distribution Function of Paper Citation Frequency for the Aircraft-SCI, HSF, NES, and Chemistry Data Bases

For the four topical fields presented, the data closely approximated a {1/n^3} distribution, as contrasted with the {1/n^2} distribution for author citations. Examination of the four topical studies (Aircraft/HSF/NES/Chemistry) showed that each of the highly cited authors had a wide range of citations for his different papers. For any given highly cited author, most papers will receive few citations. It is the infusion of numbers of lowly cited papers from the highly cited authors that expands the pool of lowly cited papers in figure 5, and results in the conversion of the 1/n^2 distribution of figure 4 to the 1/n^3 distribution of figure 5. This effect appears to transcend topical fields, and to be universal based on the limited data presented. This relation, the Kostoff-Eberhart-Toothman (KET) Law [Kostoff, 1999a], can be stated as follows: for a topical field, the ratio of the normalized number of authors with n citations per author to the normalized number of papers with n citations per paper is n, for low to moderate values of n.

4.1.6.3 Most Cited Aircraft-Related Journals

The 12 sources most highly cited, represented in the Aircraft-SCI data base, were: Journal of Aircraft, AIAA Journal, Journal of Guidance Control and Dynamics, Journal of the AHS Society, IEEE Transactions In Automatic Control, Journal of Sound and Vibration, Journal of Fluid Mechanics, Vertica, International Journal of Control, Journal of the Acoustic Society of America, Automatica, and ASTM-STP. Each of the above journals and standards is cited two orders of magnitude greater than the average journal in the Aircraft-SCI data base. There is more correlation between journals that are highly cited and contain large numbers of aircraft papers than between highly prolific and cited authors. The time span over which a journal develops and maintains a reputation for high quality is long compared to the gap between publication and citation, and one should expect that in the steady state the journals that publish many aircraft papers would also publish the higher quality papers. To the degree that the most highly cited papers have the highest quality, the voluminous content journals should contain a larger share of the higher cited papers. This does not appear to be true of the nonEnglish language journals. Very few nonEnglish language journals are highly cited, even though several are publishing extensively in aircraft technology. This could be due to some combination of: 1) inaccessibility deriving from the language barrier; 2) reduced prestige because of the U.S. and U.K. dominance of the publications; and 3) poorer quality work accepted by these journals.

Journal of Aircraft, AIAA Journal, Journal of Guidance Control and Dyanmics, Journal of the AHS, Journal of Sound and Vibration and the International Journal of Control tended to publish many aircraft related papers and be highly cited. Journals that are highly cited but publish somewhat fewer aircraft related papers are Automatica, IEEE Transactions on Automatic Control and Journal of Fluid Mechanics. The journals Vertica, Journal of the Acoustic Society of America and ASTM-STP were highly cited but did not appear as part of the journals within the aircraft related data base. One possible explanation is that the aircraft published papers are slightly more applied than some of their references. For example, the Journal of Fluid Mechanics tends to contain very fundamental papers typically. It would serve mainly as a citing source for aircraft papers, but not a publishing source for aircraft papers. The more fundamental journals (IEEE Transactions in Automatic Control, Automatica, Journal of Fluid Mechanics) rank higher on citations relative to their publication rankings, while the more applied journals (Journal of Aircraft, AIAA Journal, Journal of the AHS) tend to rank high in both citations and publications.

Table 9 provides a summary of the Cited Journal Bibliometrics for the Aircraft-SCI,as well as the NES, HSF, and Chemistry studies for comparison.

Table 9: Journal Citation Bibliometrics

STUDY	**AIR**	**AIR**	**NES**	**HSF**	**JACS**
DATA BASE	**SCI**	**EC**	**SCI**	**SCI**	**SCI**
No. of Citations	45,744	N/A	140,662	26,768	85,000+
No. of Different Journals/Sources Cited	21,518	N/A	28,740	9,498	6,725
Average No. of Citations Per Journal Cited	2.13	N/A	4.89	2.82	12.6
No. of Authors	6,619	N/A	12,453	2,483	6,535
Average No. of Journals Cited Per Author	3.25		2.31	3.83	1.03
No. of Authors Cited	21,868		42,094	11,138	32,450
Average No. of Authors Cited Per Journal Cited	1.02	N/A	1.49	1.17	4.83

Figure 6 shows the distribution function of journal citation frequency for the Aircraft-SCI, HSF, NES, and Chemistry data bases. The abscissa is the total number of citations n received by a given journal, and the ordinate is the number of journals that received n total citations. In each case, the distribution function has been normalized to the number of journals that received one citation.

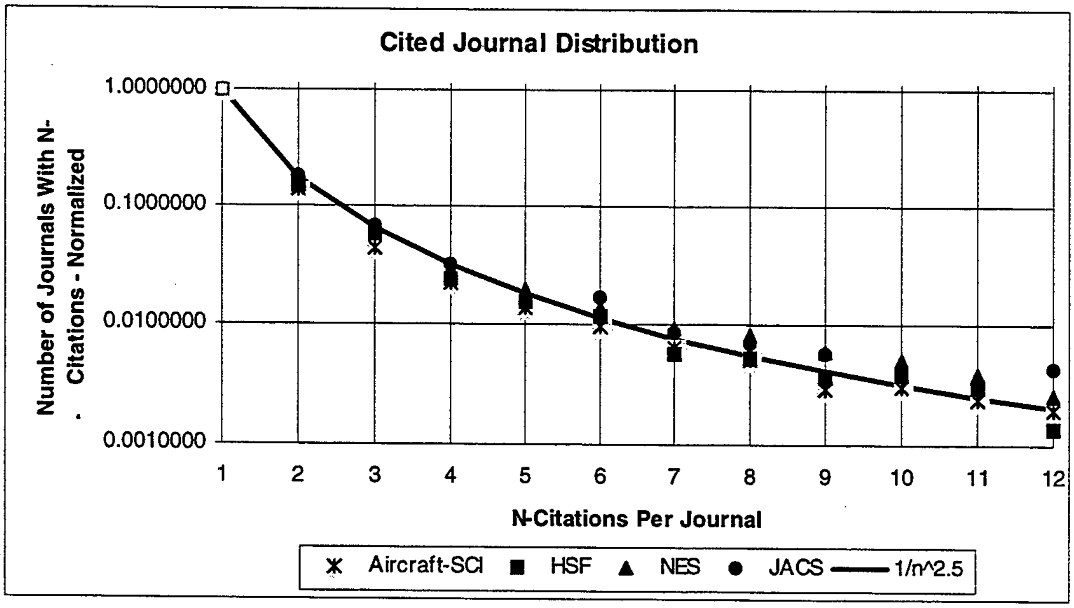

Figure 6: Distribution Function of Journal Citation Frequency for the Aircraft-SCI, HSF, NES, and Chemistry Data Bases

The data follow approximately a {1/n^2.5 } distribution. As Bradford's law suggests, there is a concentration of papers in the higher-quality core journals. When this is coupled with the strong nonlinearity of the distribution of cited papers as shown in the previous section, a further separation among journals (than the {1/n^1.75} average distribution of figure 2) based on citations received would be expected. This effect is strongly muted because the wide disparity in citations per paper within a given journal is integrated out to arrive at the citations per journal for all papers published by the journal.

There are some important implications to be drawn from these journal distribution functions and tabulated metrics with regard to data mining, and these conclusions will be addressed briefly. In developing the Bradford's law metric of table 2, the number of journals in successive iso-paper groups was computed. In addition, the number of journals in successive iso-citation groups was computed for NES, AIR, and HSF, to ascertain whether a Bradford's law for citations was operable. The ratio between iso-citation groups was less regular than the ratio between iso-paper groups, and seemed to vary between 1.5 and 2 for the three studies.

However, a very important message can be extracted from this data, namely, that a potential substantial capability increase (for an organization involved in S&T) from a successful data mining program is possible. Consider the aircraft results as an example (while actual numbers may differ among disciplines, the conclusions drawn are probably applicable to any technical discipline). There are over 700 different journals which contain aircraft-related papers.

The core (first) journal group (for the Bradford's law computation) contains three journals. There are about six journal groups which contain the total number of over 700 journals, the first five groups being iso-paper, and the last somewhat less (essentially, the remainder). Thus, the core journal group contains about 18-20% of the total number of papers. For a technical manager or performer to be considered a true expert in all aspects of aircraft, this individual would have to be familiar with the results from the aircraft papers in most of the more than 700 journals. One would suspect that bench-level aircraft experts, such as field managers, do not read more than the first two core groups on a regular basis, and this is probably a very generous estimate.

Thus, these experts may be familiar with 30-40% of the relevant literature within the focused field; they would be far less familiar with complementary disparate-discipline literatures from which novel concepts could be extrapolated to benefit aircraft S&T.

In addition, one would suspect that program managers, at the Federal level or in the field, who have broad responsibilities for aircraft S&T development (or of any technical discipline/multidiscipline development), do not have time to read much more than the main core group, if that much. Thus, they are probably familiar with 10% of the relevant literature, or less, and probably far less familiar with the disparate discipline literature.

One might argue that most of the good papers are contained in the first or second core journal groups, and all that is required for effective coverage is to read the journal papers in the first one or two groups. However, if citations are used as one measure of quality, the results show that citations are at least as widely spread out among the journals as actual publications. In fact, because the most highly cited journals are not necessarily those with the most publications, the spreading among journals may be broader than the results above suggest.

One might further argue that the previous paragraph aggregates citations over papers to draw journal citation conclusions; that the most highly cited papers are contained in the first or second core groups, and all that is required for effective coverage is to read the first one or two groups. Again, the data do not support this assertion.

The 10 most highly cited papers in the aircraft study were examined. It was found that none of these 10 were contained in the first core group journals, and only 1 of these 10 was contained in the second core group. One could argue that aircraft is a very broad field, and citations would more likely be aimed at papers in focused specialty journals in the lower groups than at the broader coverage journals in the higher groups. The 10 most highly cited papers in the hypersonics study were then examined.

Hypersonics constituted a more focused technical area. It was found that 2 of these 10 were contained in the first core group, and 4 of these 10 were contained in the first and second core group. If one assumes that literature coverage should encompass the more basic highly cited papers/journals, as well as the more applied perhaps less cited papers/journals, then it is important that all these types of journals be included in maintaining cognizance of the technical field of interest.

Obviously, citations are not the only measure of quality, and journal research papers accessed by the SCI are not the only source of useful literature information. Technical reports accessed by National Technical Information Service, technology papers/conference proceedings accessed by EC, program narratives accessed by RADIUS, and patents accessed by the patent data base are other sources of useful information. The presence of these other quality measures besides citations, and the presence of other data sources, further expands the number of articles/documents to be read to maintain currency in the quality S&T, and results in even a smaller fraction of the literature accessed by any individual.

Thus, based on the results from these three different SCI bibliometric approaches (publications, aggregate citations, highly cited papers), one can conclude that (at least for the fields examined) confining one's reading to the first one or two core journal groups will exclude many high quality documents. Data mining can make the user aware of these omitted papers in the target field, and, equally important, can make the user aware of papers in disparate disciplines which could impact the target field.

The argument could then be made that the literature is only one source of information. All the other useful sources are in fact accessed through proposals, workshops, site visits, and contacts. However, all these other sources are limiting as well. Consider workshops, for example. They contain a small fraction of the technical community; they tend to attract many repeat performers; they may or may not be representative of the community, depending on how they were selected and the size of the workshop. In most workshops, the focus is on a limited target discipline. Representatives from disparate disciplines who could impact the target discipline with innovative concepts are usually not present. The attendees tend to use the workshop, or expert panel, as a forum to sell their own approaches. Their willingness to share real cutting-edge approaches in an open forum (or any forum) is questionable. Workshops tend to be dominated by forceful personalities, adding further skewing their results.

However, data mining could potentially support and add value to workshops and expert panels as well, and complement their strengths to provide a more comprehensive and balanced product. In conclusion, this brief discussion shows by example that data mining allows informed access to a wide body of literature not accessed presently. It demonstrates further that this nonaccessed literature has high quality components and is important; therefore, its availability through data mining offers a potential new or enhanced capability to support program management.

Recommend that the reader interested in researching a specific aircraft-related technology would be well-advised to peruse not only those journals which contain large numbers of recently published aircraft papers but also those sources (papers) that are highly cited.

4.2 Data Base Tomography Results

4.2.1 Phrase Frequency Analysis - Pervasive Themes

High frequency double and triple word phrases (from the Abstracts' texts within the data bases) whose technical content were deemed to be significant were identified and mapped to a strategic taxonomy that addressed all the major aircraft related technologies. Nontechnical content and trivial phrases (e.g., The paper stated, Results were obtained) were eliminated from the analysis.

In this particular exercise, the data base was split into two parts, Titles and Abstracts, and the analysis was done on each part. Only raw data outputs from the Abstract data base will be presented here. As this mapping process took place, if it was determined that an additional category was required because of the content of the word phrases, it was added to the strategic taxonomy. In the end, the taxonomy had 163 categories identified. These were grouped into 13 major headings as follows: Systems Engineering, Costing, Aeromechanics, Flight Dynamics, Structures, Materials, Subsystems, Propulsion/Power, Avionics, Crew Systems, Support/Logistics, Training, and Manufacturing. Within each of these major headings, appropriate technical phrases could be grouped, and their associated frequencies of occurrence were then totaled to give a picture of the data base as a whole or, looking at a specific category out of the 163, a sense of the relative emphasis of the technical work that was represented by the data base in that specific area. Analysis of the SCI and the EC produced the results shown in table 10.

Table 10: Highest Aircraft-Related Interest Areas by Major Grouping Based on Phrase Frequency Analysis of Text Abstracts Showing Highest Subcategories

Science Citation Index	Engineering Compendex
Structures: Strength; Design/Analysis; Crack Initiation and Growth; Loads and Dynamics; Fatigue	Aeromechanics: Aerodynamics; Design/ Analysis; Performance (Aircraft); Wing Design; Wind Tunnel; Drag Reduction
Aeromechanics: Aerodynamics; Design/Analysis; Performance (Aircraft); Drag Reduction; Wing Design; Unsteady Flow; High Lift; Wind Tunnel	Structures: Design/Analysis; Loads and Dynamics; Structures (General); Crack Initiation and Growth; Strength; Structural Life; Aeroelastic Effects
Subsystems: Control Systems; Neural Nets; Environmental Control Systems; Landing Gear; Subsystems (General); Actuators	Subsystems: Control Systems; Environmental Control Systems; Neural Nets; Landing Gear; Subsystems (General); Fuzzy Logic; Actuators
Flight Dynamics: Stability and Control; Helicopter Rotors; Handling Qualities	Systems Engineering: Conceptual Design; Fighter/Attack; Patrol/Transport; Air Traffic Control; Rotorcraft; UAV/UCAV; V/STOL
Systems Engineering: Fighter/Attack; Cockpit Noise; Patrol/Transport; Conceptual Design; Air Traffic Control; Airport Noise	Avionics: GPS; Navigation and Guidance; Avionics (General); Communication Systems; Artificial Intelligence; INS; Software/Hardware (Software); Decision Aids (Processing); Information Management
Propulsion and Power: Gas Turbine Engine; Fuels/Lubricants; Electrical Generation; Coatings; Blades/Disks; Propeller/Propfan; Electrical Power (General); Contrails	Flight Dynamics: Stability and Control; Helicopter Rotors; Handling Qualities
Avionics: Navigation and Guidance; Decision Aids (Processing); Avionics (General); Software Development; GPS; Neural Nets; Air Data; Software/Hardware (Software)	Propulsion and Power: Gas Turbine Engine; Engines (General); Electrical Power (General); Fuels/Lubricants; Electrical Generation; Blades/Disks

Science Citation Index	**Engineering Compendex**
Materials: Composites; Metals/Alloys; NDI/NDT; Corrosion; Adhesives; Ceramics	Materials: Composites; Metals/Alloys; NDI/NDT; Materials (General); Corrosion; Smart Materials
Support/Logistics: Maintenance; Takeoff and Landing; Safety (Maintenance); Platform Interface; Deicing	Support/Logistics: Maintenance; Reliability; Takeoff and Landing; Support/ Logistics (General); Runways/Airfields.
Manufacturing: Joints; Processes; Structural(Mfg.); Concurrent Engineering; Composites(Mfg.)	Crew Systems: Displays; Decision Aids; Human/Machine Interface; Data/Information Fusion; Crew Workload; Cockpit
Training: Local Simulation; Manned Flight Simulation; Types (Instruction)	Manufacturing: Processes; Composites (Mfg.); Concurrent Engineering; Joints
Costing: Life Cycle Costs; Affordability of New Systems	Costing: Life Cycle Costs; Affordability of New Systems
Crew Systems: Human/Machine Interface; Decision Aids; Loss of Consciousness	Training: Simulation (General); Manned Flight Simulation; Instruction (General); Distributed Simulation

Examining the above chart provides some insight into the high, as well as low, interest areas in the technical community and where, over the past 6 or 7 years, the majority of effort has been focused. For example, the highest categories for both the SCI and EC data bases tend to be related to aircraft performance issues. That is, Structures, Aeromechanics, and Subsystems. It is also noted that the Systems Engineering and Avionics tended to be of somewhat greater interest in the EC than the SCI, which is probably to be expected. On the other hand, the Flight Dynamics and Propulsion and Power issues tended to be of greater interest in the SCI data base. The Flight Dynamics work tends to be highly mathematical and coupled with control systems. The Propulsion work in recent years has been very intense in support of the Integrated High Performance Turbine Engine Technology (IHPTET) program. In both cases, one might suspect that the work would more likely be published in the fundamental journals, represented by the SCI data base.

The lowest categories in both data bases tended to be in the Costing, Training, Crew Systems, Manufacturing, and Support/Logistics areas. It is interesting to note that despite all the discussion in requirements documents over the past few years for reducing costs and enhancing training, particularly within the military, the lowest reported emphasis areas are those related to Costing, Manufacturing, maintenance related work (Support/Logistics), and Training. This might suggest that these areas are in fact being neglected by the technical community despite all the rhetoric to the contrary. If there is increased focus in these areas, it does not appear to be with improved technologies that would warrant research and a published paper or it is being worked in the engineering community that does not generally publish its work in open literature and journals. From an aircraft technology perspective this is unfortunate, since a growth in the fundamental knowledge base through publications would quickly provide a catalyst for new and even better ideas for life cycle cost reductions and improved maintenance and reliability.

Why the Crew Systems area was so poorly represented is not clear. Based on a parallel data mining analysis of DoD requirements/strategy documents and the authors' personal experience, this is an area that should be receiving a great deal of interest, particularly in the areas of Decision Aids, Data/Information Fusion, and Crew Workload. These areas are important to both military and commercial aircraft. Either work is not being pursued in this and other under-represented areas, or it is not being reported in the literature, or it is being reported in journals or report literature not accessed by the SCI or EC data bases.

Within each of the major groupings listed in table 10 the subcategories of interest and focus for the most part appear to be very consistent. A few of the differences for the highest categories can be pointed out as follows: Aeromechanics – the SCI data base picks up on work in the Unsteady Flow arena. Structures – the EC data base has additional efforts in the Aeroelastic areas. Subsystems – the EC data base has additional focus on Fuzzy Logic work (primarily in the area of control systems). Systems Engineering – the SCI data base has a significant focus on both Cockpit and Airport Noise whereas the EC data base tends to highlight rotorcraft, UAV/UCAV, and V/STOL efforts.

If one does not group the phrase frequency results into the 13 major categories above but rather examines each of the 163 subcategories (in the overall taxonomy) separately, a slightly different picture emerges. For example, table 11 illustrates the 15 highest subcategories for both the SCI and EC data bases, showing the results for the summation of the two- and three-word phrases within each of the subcategories. The complete listing for all 163 subcategories of each data base is provided in appendix A.

Examining table 11 shows that there is considerable consistency between the two data bases, as well as the two-word and three-word phrase frequencies for the highest 10% of the overall taxonomy. There are a few subcategories within this group, however, that only appear once. For example, the SCI three-word phrase summary data shows Patrol/Transport and Unsteady Flow as single subcategories with no other match within the group. The EC two-word phrase data lists Conceptual Design, Structrues (General), and Environmental Control Systems as stand-alone items. The EC three-word data has five standalone categories within the top 10%. They are: Global Positioning System (GPS), Air Traffic Control, Takeoff and Landing, Maintenance, and Displays.

Table 11: Highest Frequency Subcategories within Strategic Taxonomy for Aircraft-SCI and EC Data Bases

Highest Frequency Topics within SCI (2-word phrase)	Highest Frequency Topics within SCI (3-word phrase)	Highest Frequency Topics within EC (2-word phrase)	Highest Frequency Topics within EC (3-word phrase)
Control Systems	Control Systems	Control Systems	Control Systems
Aerodynamics	Stability and Control	Aerodynamics	Aerodynamics
Stability and Control	Aerodynamics	Design/Analysis (Platform)	Design/Analysis (Platform)
Strength (Structural)	Design/Analysis (Structural)	Helicopter Rotors	GPS
Helicopter Rotors	Helicopter Rotors	Composites	Helicopter Rotors
Design/Analysis (Structural)	Gas Turbine Engines	Design/Analysis (Structural)	Stability and Control
Gas Turbine Engines	Strength (Structural)	Loads and Dynamics	Gas Turbine Engines
Composites	Loads and Dynamics	Conceptual Design	Composites
Crack Initiation and Growth	Crack Initiation and Growth	Gas Turbine Engines	Air Traffic Control
Design/Analysis (Platform)	Patrol /Transport	Fighter and Attack	Loads and Dynamics
Performance (Aircraft)	Handling Qualities	Stability and Control	Takeoff and Landing
Loads and Dynamics	Drag Reduction	Structures (General)	Design /Analysis (Structural)
Fighter/Attack	Unsteady Flow	Performance (Aircraft)	Maintenance
Fatigue	Fatigue	Environmental Control System	Displays
Handling Qualities	High Lift	Wing Design	Performance (Aircraft)

Clearly, the two dominant subcategories are Control Systems and Aerodynamics. Three others that are consistently high are Stability and Control, Helicopter Rotors, and Structural Design and Analysis. Carrying these five down one additional level provides the insight into the specifics of the subcategory and the particular topics that dominate.

Note that the numbers following the phrase represent the frequency with which the phrase appears in the Abstracts of the particular data base. In each subcategory above, as the frequencies come down the phrases tend to be more technical and specific. For example, under Control Systems, a sampling of the high frequency phrases from the two data bases is as follows: **SCI** (Control System(s), 329; Flight Control System(s), 114; Optimal Control, 69; Active Control, 48; Control Design, 45; Control Problem, 39; Control Surfaces, 34; Nonlinear Control, 28; Robust

Control, 24; Adaptive Control, 20; Quantitative Feedback Theory, 18; Higher Harmonic Control, 11) and for the **EC** (Control System(s), 1212; Kalman Filter, 139; Optimal Control, 137; Feedback Control, 85; Augmentation System, 63; Transfer Function, 59). Lack of space precludes showing phrases from other categories.

The complete summary of the phrase frequencies for each of the data bases is provided in appendices B through E.

4.2.2 Most Frequently Used Keywords/Descriptors

An interesting picture of aircraft S&T emerges from examination of the SCI data base Keywords and the EC data base descriptors using a phrase frequency analysis. The Keywords or Descriptors field is provided in the data base to allow authors/indexers the ability to categorize their paper and allow for ease of search routines.

In the following, a phrase frequency run was conducted on both the SCI Keyword field and the EC Descriptor field. The results of these runs were then analyzed and grouped into 1 of the 13 major Aircraft Strategic Map categories. These categories are as follows: 1) Systems Engineering, 2) Costing, 3) Aeromechanics, 4) Flight Dynamics, 5) Structures, 6) Materials, 7) Subsystems, 8) Propulsion and Power, 9) Avionics, 10) Crew Systems, 11) Support Logistics, 12) Training, and 13) Manufacturing. The phrase frequency analysis was carried down to the point that an emphasis order could be established for the 13 categories. In the case of the SCI data base, the cutoff frequency was 4, whereas for the much larger EC data base the cutoff frequency was 60. As can be seen in table 12, the focus of the two data bases is not identical, particularly in the highest categories, although the categories with the least emphasis in each data base appear to be very consistent. The number following each of the major categories is the sum of the word and phrase frequencies grouped into that particular category. This allows one to get a sense of the relative magnitude of interest of a category within a given data base.

Table 12: Keyword and Descriptor Categorization

Aircraft-SCI Data Base	Aircraft-EC Data Base
Systems Engineering (512)	Avionics (8,708)
Structures (354)	Aeromechanics (6,812)
Materials (194)	Structures (6,644)
Aeromechanics (191)	Systems Engineering (5,914)
Subsystems (183)	Subsystems (4,579)
Flight Dynamics (173)	Materials (4,102)
Avionics (124)	Flight Dynamics (3,858)
Support/Logistics (87)	Propulsion and Power (3,264)
Training (44)	Crew Systems (2,394)
Propulsion and Power (35)	Support/Logistics (1,116)
Crew Systems (29)	Manufacturing (787)
Manufacturing (8)	Training (639)
Costing (0)	Costing (619)

Although one would not expect to obtain identical results because of the fundamental differences in the data bases, what is surprising is the difference in priorities or emphasis compared to the previously developed Abstract phrase frequency analysis for each data base. For example, in table 13, the priorities of the Abstracts and Keywords (or Descriptors) analysis is examined for each data base.

Table 13: Comparison of Category Emphasis by Abstract and Keyword/Descriptor for Each Data Base

Aircraft-SCI Data Base		Aircraft-EC Data Base	
Abstract	**Keywords**	**Abstract**	**Descriptors**
Structures	Systems Engineering	Aeromechanics	Avionics
Aeromechanics	Structures	Structures	Aeromechanics
Subsystems	Materials	Subsystems	Structures
Flight Dynamics	Aeromechanics	Systems Engineering	Systems Engineering
Systems Engineering	Subsystems	Avionics	Subsystems
Propulsion and Power	Flight Dynamics	Flight Dynamics	Materials
Avionics	Avionics	Propulsion and Power	Flight Dynamics
Materials	Support/Logistics	Materials	Propulsion and Power
Support/Logistics	Training	Support/Logistics	Crew Systems
Manufacturing	Propulsion and Power	Crew Systems	Support Logistics
Training	Crew Systems	Manufacturing	Manufacturing
Costing	Manufacturing	Costing	Training
Crew Systems	Costing	Training	Costing

For the Aircraft-SCI data base, there was significant movement in emphasis from the Abstract Analysis to the Keywords in two areas: Systems Engineering and Materials. Both of these categories appeared to have significantly greater emphasis in the Keywords. This increased emphasis in the Keywords is, in all likelihood, due to the individual journal authors trying to capture the overall sense of the paper. As a result, Keywords that would fall into broad categories such as Systems Engineering or Materials would more likely appear. This is not true, however, for the Aircraft-EC data base. In this case, there appears to be little or no movement in the emphasis on Materials and Systems Engineering categories but a substantial movement in Avionics. Why the Avionics category appears to have such considerable focus in the EC data base Descriptors is not altogether clear. Two possible explanations are: 1) the journal authors must feel that Avionics related issues are an important aspect of the technical articles and therefore include those issues in the Descriptors, and 2) because of the central avionics role in potential total system cost reduction, the authors may believe that categorizing a paper under Avionics will increase data base retrieval access. Based on the phrase frequency analysis of the actual text in the Abstracts, this emphasis on Avionics is not nearly so strong.

4.2.3 Validation Effort

In an effort to validate the results of the various phrase frequency analysis efforts, the participating technical expert sampled individual abstracts from each data base. Based on the abstract contents and paper focus, the paper was then placed into one of the 13 major categories of the Strategic Map. For the SCI, the complete data base was used and every tenth abstract was read and categorized. In the case of the EC, because of its size, only half the data base was reviewed and every tenth abstract was read and categorized. This, however, was sufficient to see a distinct trend in the results. Table 14 compares the results of this validation study with the previous studies for the SCI data base. Similarly, table 15 presents the results for the EC data base.

Table 14: Comparison of Major Category Emphasis Areas Based on Phrase Frequency Analysis of Abstracts and Keywords with Reading and Classifying the Abstract Text within the SCI Data Base

Aircraft-SCI Data Base		
Abstracts	**Keywords**	**Validation**
Structures	Systems Engineering	Systems Engineering
Aeromechanics	Structures	Aeromechanics
Subsystems	Materials	Structures
Flight Dynamics	Aeromechanics	Flight Dynamics
Systems Engineering	Subsystems	Materials
Propulsion and Power	Flight Dynamics	Avionics
Avionics	Avionics	Subsystems
Materials	Support/Logistics	Propulsion and Power
Support/Logistics	Training	Crew Systems
Manufacturing	Propulsion and Power	Support/Logistics
Training	Crew Systems	Manufacturing
Costing	Manufacturing	Training
Crew Systems	Costing	Costing

Each of these analysis approaches provides a slightly different viewpoint. The phrase frequency analysis of the abstract text provides an insight into and the ability to characterize the actual detailed technical content in the abstracts. The phrase frequency of the Keywords or Descriptors allows for the collection, grouping and counting of commonly used words or phrases that have been used by the author to characterize the actual work. For each article, there may be as many as five to eight Keywords or Descriptors. The validation analysis, however, allows the reader only the single choice of either grouping the paper into 1 of 13 categories within the predetermined Aircraft Strategic Map or putting it into a "nonapplicable" category.

Table 15: Comparison of Major Category Emphasis Areas Based on Phrase Frequency Analysis of Abstracts and Keywords with Reading and Classifying the Abstract Text within the EC Data Base

Aircraft-EC Data Base		
Abstracts	**Descriptors**	**Validation**
Aeromechanics	Avionics	Avionics
Structures	Aeromechanics	Structures
Subsystems	Structures	Subsystems
Systems Engineering	Systems Engineering	Systems Engineering
Avionics	Subsystems	Materials
Flight Dynamics	Materials	Propulsion and Power
Propulsion and Power	Flight Dynamics	Aeromechanics
Materials	Propulsion and Power	Flight Dynamics
Support/Logistics	Crew Systems	Crew Systems
Crew Systems	Support/Logistics	Support/Logistics
Manufacturing	Manufacturing	Manufacturing
Costing	Training	Training
Training	Costing	Costing

As one might suspect, the Keywords and the Validation study tend to track reasonably well in both the SCI and EC cases, since both are based on higher-level judgements of the total paper. The one exception is the category of "Aeromechanics" within the EC data base. "Aeromechanics" drops significantly in the validation assessment. One of the main reasons for this drop was that, in many cases, the journal article focused on a specific topic but the text of the abstract concentrated on the specific technical details and never mentioned the theme of the paper again. For example, there were numerous papers related to "Noise" or "Helicopter Rotor Blades" and would be classified by the reader in those two categories within the defined Aircraft Strategic Map. The actual text, however, was filled with discussions of vortex flow fields, computational fluid dynamic analysis, shock waves, Navier-Stokes equations, etc. In this case, the phrase frequency analysis of the abstract would find a large number of aerodynamic-related words and cause the frequency count in this category (Aeromechanics) to increase. (This fact can be confirmed when one looks at the highest category under the Abstract phrase frequency.) The journal article author, however, in specifying his or her Descriptors would have the opportunity to list multiple words that included such things as the main topic focus, i.e., "Noise" or "Rotor Blades," as well as other related and supporting Descriptors that characterize the overall work done, i.e., "Aerodynamics, Vortex Flow, CFD," etc. The validation study, on the other hand, forced the reader to select the single theme of the paper and apply it to 1 of the 13 categories or list it as nonapplicable. In the example used above, the topic theme of "Noise" would have been categorized under "Systems Engineering" within the Strategic Map and probably not under "Aeromechanics." With this one major discrepancy, the order of emphasis of the Descriptors is actually quite consistent with the Validation analysis for the EC data base.

Except for the Avionics and Aeromechanics issue within the EC data base, and the Systems Engineering and Materials issue within the SCI data base, the priorities of the emphasis areas are reasonably consistent across the three sets of results. What is very clear are the five lowest categories in terms of published work. They are Costing, Training, Manufacturing, Support/Logistics, and Crew Systems.

4.2.4 Phrase Proximity Analysis - Relationships Among Themes and Subthemes

To obtain the theme and subtheme relationships, a phrase proximity analysis is performed about major theme phrases. For this study, approximately 18 multiword phrase themes were selected and applied to both the SCI and EC Aircraft data bases. The specific themes examined were: Structures, Composites, Composite Materials, Finite Element, Control, Flight Control Systems, Performance, Angle of Attack, Boundary Layer, Flight Test, Gas Turbine, Power, Noise, Avionics, Neural Network, Air Traffic Control, Helicopter, and Aircraft. For each theme phrase, the occurrence of phrases that appear within ±50 words of the theme phrase in the full text is computed. A phrase frequency dictionary is then constructed which shows the phrases closely related to the selected theme phrase. Numerical indices are employed to quantify the strength of this relationship, as discussed below. Both quantitative and qualitative analyses of each phrase frequency dictionary (hereafter called cluster) yield those subthemes closely related to the selected main theme.

An example of this cluster development is illustrated in table 16. In this example, the selected theme is "Structures," and the SCI abstracts are used as the data base. Threshold values are assigned to the numerical indices. These indices are used to filter out the most closely related phrases to the cluster theme. Only selected lines are shown from the output in table 12 to illustrate the results over a range of Ii (The ratio of the number of times a phrase appears ±50 words of the selected theme to the number of times that phrase appears in the total text) and to conserve space. The complete list contains 44 entries with values of Ii $\geq$ 0.50 that are grouped in a later section of this report.

Because of space limitations in this document, only one theme was chosen to illustrate the results of the phrase proximity analysis. Structures was selected because it is a major theme of both the SCI and EC data bases, as can be seen from the phrase frequency analysis. In addition, it is high frequency in the abstracts and titles, which will provide good statistics for the Abstract and Title/block data bases (see next paragraph).

The full text data base was split into two data bases. One was the Abstract narrative data base (referred to as ABSTRACT in the phrase proximity analysis below), and phrase proximity analysis of this data base yielded mainly topical theme relationships. The other data base (referred to as BLOCK below) consisted of records (one for each published paper) containing four fields: author(s), title, journal name, and author(s) institutional address(es). Phrase proximity analysis of this data base yielded not only topical theme relationships from the proximal title words, but also relationships among technical themes and authors, journals, and organizations.

For purposes of analysis, the cluster members in a given theme were segregated by their values of Inclusion Indices Ii and Ij. Ii is the ratio of Cij to Ci, and is the Inclusion Index based on the cluster member. Ij is the ratio of Cij to Cj, and is the Inclusion Index based on the theme word. Ii and Ij are categorized as either high or low. The dividing points between high and low Ii and Ij are the middle of the "knee" of the distribution functions of numbers of cluster members vs. values of Ii and Ij, and are approximately 0.5 for Ii and 0.02 for Ij.

Table 16: Theme Phrase "Structures" – SCI Abstract Data Base - Sort by Ii
Structures: Cj = 397

Cij	Ci	Ii (Cij/Ci)	Ij (Cij/Cj)	Eij (Ii*Ij)	Cluster Member
6	6	1.000	0.015	0.0151	Multiwall
4	4	1.000	0.010	0.0101	Fiber-Optic Sensors
3	3	1.000	0.008	0.0076	Carbon Fiber-Epoxy Composite
4	5	0.800	0.010	0.0081	Reinforced Composite
3	4	0.750	0.008	0.0057	Nondestructive Evaluation (NDE)
4	6	0.667	0.010	0.0067	Box Beams
4	6	0.667	0.010	0.0067	Adhesive Bonds
8	13	0.615	0.020	0.0124	Delaminations
10	20	0.500	0.025	0.0126	Structural Optimization

CODE:

Cij IS CO-occurrence frequency, or number of times cluster member appears within ±50 words of cluster theme in total text; Ci is absolute occurrence frequency of cluster member; Cj is absolute occurrence frequency of cluster theme; Ii, the cluster member inclusion index, is ratio of Cij to Ci; Ij, the cluster theme inclusion index, is ratio of Cij to Cj, and Eij, the equivalence index, is product of inclusion index based on cluster member Ii (Cij/Ci) and inclusion index based on cluster theme Ij (Cij/Cj). Eij bears some similarity to the mutual information method from computational linguistics, that compares the probability of two words occurring together with the probability of the words occurring separately.

A high value of Ii (i.e., ≥ 0.50) means that, whenever the cluster member appears in the total data base text, there is a high probability that the theme phrase will appear within ±50 words of the cluster member. A high value of Ij means that, whenever the theme phrase appears in the total data base text, there is a high probability that the cluster member will appear within ±50 words of the theme phrase. See Kostoff [1998a, 1999a] for further discussion of phrases in different Ii-Ij quadrants.

In the following section, the cluster theme Structures is analyzed for the Aircraft-SCI, as well as the Aircraft-EC Block and Abstract data base components. Further, for each of these data base components, the cluster theme is analyzed from the two perspectives of high Ii low Ij and low Ii high Ij. The phrase proximity analysis process for Structures consisted of the technologist examining two lists of cluster members, one sorted by Ii and the other by Ij, then constructing categories of related items. These relationships are reported below.

4.2.4.1 Phrase Proximity Analysis - Structures

4.2.4.1.1 BLOCK data base; low Ii high Ij

These phrases tend to describe the more generic associations with Structures. The Block cluster data can be conveniently grouped into six areas: Technologies, Journals, Institutions, Authors, States, and Countries. The number following each phrase below is the Cij value and represents the frequency of the phrase appearing within ±50 words of the theme phrase (Structures) in the specific data base. For the Aircraft-SCI data base, the following sample results were obtained:

Technologies: (**Composites** [Composite(s)-112, Damage-26, Repair(s)-15, Impact Damage-6, Laminates-6]; **Airframes** [Aircraft-92, Rotor-16, Composite Aircraft-8, Disks-7, Actuators-7]; **Materials** [Material(s)-64, Behavior-12, Alloy-7, Optical-7, Piezoelectric-6]; **Analysis/Modeling** [Design-32, Analysis-29, Computers-28, Modeling-15, Finite Element-7]; **Fatigue/Fatigue Life** [Fatigue-41, Fracture-28, Crack(s)-27, Fatigue Fracture-14, Crack Growth-7]; **Loads and Dynamics** [Testing-15, Failure-12, Response-10, Strain-7]; **Smart Structures** [Smart-37, Smart Materials-21, Optical, Intelligent-6]; **NDI** [Nondestructive-10, Detection-9]; **System Development** [Engineering-41, Tolerance-5])

The technology terms above are derived from the Title/Block data within the Aircraft-SCI data base, and fall naturally into nine subcategories: Composites, Airframes, Materials, Analysis/Modeling and Fatigue/ Fatigue Life, Loads and Dynamics, Smart Structures, NDI, and Systems Development. Within each of these nine subcategories, examples are provided of the phrases occurring within ±50 of the theme word and its frequency. In order to conserve space in the technology results, each of the subcategories was limited to a maximum of five phrases presented here, usually the highest inclusion indices (Ij) in that subcategory. In some cases, however, phrases with lower Ij values were selected to give a broader view of the technology area. These nine areas are also the same subcategories used with the Aircraft-SCI Abstract data base analysis, as well as the Aircraft-EC data base, as will be shown later in this section. The lower tier technology terms identified in the phrase proximity analysis of the Aircraft-SCI Abstract data base (e.g., Structural Optimization, Aeroelastic, Adhesives, Delaminations, Cost, Reliability, Al-Li alloys, Eddy and Squid) do not surface in the present (Title/Block) section. The relation of the Titles to the Abstract may parallel the relation of the Keywords to the Abstract. The Abstract details may be viewed as the means to an end in some cases, and not the end in itself. The Title may reflect an integrated view of the larger purpose of the paper. However, as in the Keywords case, in some cases the Title may also be used to convey a message other than the detailed technical contents of the paper.

Journals: (Journal of Solids-12)

Only one journal was identified in the high Ij category. Whenever the Structures theme phrase as well as the cluster member, Journal of Solids, appear in the total data base text there is a high probability that they will be physically close.

Organizations: (Georgia Institute of Technology-15, India Polytechnic Institute-11, University of Maryland- 8, FAA-7, Virginia Polytech. Institute-5, Rensselaer Polytech Institute-5)

The organization listings essentially reflect levels of effort tied to Structures. Five of the six organizations are American, and one is Indian. The absence of European organizations is surprising.

Authors: (none listed in high Ij category)

States: (Georgia-18, Maryland-9, Arizona-8, Ohio-6, Virginia-5, New York-5)

Countries: (U.S.-40, England-24, Germany-19, Singapore-18, Australia-16, India-11, Korea-9, Wales-8, Canada-7). The significant presence of England and Germany, coupled with the absence of European organizations listed above, means the effort in those countries is widely distributed among organizations.

In a similar fashion, the results from the Aircraft-EC data base can be shown as follows:

Technologies: (**Composites** [Composite(s)-1152, Fiber-197, Reinforced-153, Composite Structures-149, Repair-131]; **Airframes** [Aircraft-1309, Helicopter-326, Rotor(s)-245, Panels-130, Wings-115]; **Materials** [Materials-1170, Flexible-108, Plastics-103, Aluminum-101, Alloys-94]; **Analysis/Modeling** [Analysis-618, Design-380, Mathematical Models-278, Computer-253, Finite Element-225]; **Fatigue/Fatigue Life** [Fatigue-217, Failure-125, Crack-99, Fracture-80, Life-65]; **Loads and Dynamics** [Control-447, Dynamics-398, Structural Dynamics 241, Testing-234, Loads-227]; **Smart Structures** [Optical-180, Smart-152, Optical Engineering-127, Intelligent-121]; **NDI** [Acoustic-99, Sensors-99, Nondestructive-93, Inspection-91, Instrumentation-85]; **System Development** [Applications-128])

What is not shown here, because of limiting the subcategory to a maximum of five phrases, is the significant increase in phrases related to Loads and Dynamics. For example, the total number of phrases in the Aircraft-SCI data base was 4. This number jumps to 25 in the Aircraft-EC data base reflecting the more engineering approach of the EC.

Journals: (Proceedings of SPIE-119, Structural Dynamics Materials Conference-107, International Sampe Symposium and Exhibition-35)

There were no journals identified in the high Ij category. There were, however, several conferences, with a high inclusion index, from which papers were drawn. One can see the differences in the two data bases with the journals but even more so with the organizations represented below. The predominance of technical societies would also reinforce the fact that the Aircraft-EC data base contains a large number of conference proceedings.

Organizations: (AIAA-466, ASME-312, AIAA/ASME-229, ASCE-183, AIAA/ASME/ASCE/AHS-175, ASCE/AHS/ASC-120, SAMPE-104, and University of Maryland-39)

In this case, only one organization appears that was also listed in the Aircraft-SCI data base analysis (University of Maryland). All of the other organizations are technical societies, some of which have sponsored joint conferences. This clearly reflects the EC primarily as an engineering data base.

Authors: (none listed in high Ij category)

States: (New York-264, Virginia-134, California-140, Washington-113)

Countries: (U.S.-1218, Australia-96)

It can be seen that the U.S. dominates the literature with respect to Structures work. Again, this is likely due to both the large number of American technical societies that have their conference proceedings catalogued in the EC data base and the sheer volume of American effort in advancing aircraft technology.

4.2.4.1.2 BLOCK data base; high Ii low Ij.

These phrases tend to describe the more specific associations with Structures. Again the cluster data can be readily grouped into the same six areas: Technologies, Journals, Organizations, Authors, States,and Countries. The number following each phrase represents the frequency of the cluster member phrase appearing within ±50 words of the theme phrase (Structures) in the specific data base. For the Aircraft-SCI data base, the following results were obtained:

Technologies: (**Composites** [Impact Damage-6, Composite Aircraft-8]; **Airframes** [Engine Disks-4, Conditions in Aircraft-3, Damage in Aircraft-3, Airframes Engines-4]; **Materials** [Piezoelectric-6]; **Analysis/Modeling** [Computat Modeling Aircraft-5, Elastic-Plastic Finite Element Alternating Method Epfeam-3, Analysis of Composite-3]; **Fatigue/Fatigue Life** [Fracture under WFD-3, Prediction of Fracture-3, Crack Growth-7, Fatigue Fracture-14, Fatigue Crack Growth-4]; **Loads and Dynamics** [Flexible Multibody System-3]; **Smart Structures** [Intelligent Material Systems-4, Smart Materials-21, Smart-37]; **NDI** [none]; **System Development** [none]).

These cluster members will tend to be of low frequency, multiword and focused technically. The number of cluster members in each subcategory is low or nonexistent.

Journals: (Journal of Solids-12, Journal of Intelligent Material Systems-4)

Organizations: (Australian Def. Force Academy-4, Northwestern Univ. Center-4, Motoren Turbin Union Munchen GMBH-4, FAA Center of Excellence in Computing-3)

The organization listings essentially reflect levels of effort tied to Structures. That is, whenever the cluster member appears in the total data base text, there is a high probability that the theme phrase will appear physically close. One could conclude, for example, that Northwestern

University's focus on aircraft is in the Structures area. Why the above organizations, most of which do not appear to be intrinsically Structures organizations, have this close association with Structures is a question whose answer is not obvious.

Authors: (Heslehurst, R.B.-4; Atluri, S.N.-3; Measures, R.M.-3; Brust, F.W.-3; Rubin, A.M.-3; Tang, D.M.-3; Dowell, E.H.-3)

States: (South Carolina-3, Georgia-4, Illinois-4)

Countries: (Australia-4, Russia-3, Germany-3, Canada-4, Korea-3)

In this case, the U.S. does not appear. Whenever the U.S. appears in the total data base text, the probability that the Structures theme phrase will appear physically close is low, since the U.S. is heavily involved with many other Aircraft technologies and is not dominated by the Structures theme.

In a similar fashion, the results from the Aircraft-EC data base can be shown as follows:

Technologies: (**Composites** [Composite Structural-9, Structures Sandwich-7, Stiffened Composite-10, Structural Panels Composite-9, Repair Composite-8]; **Airframes** [Cylindrical Shell(s)-22, Actuators Piezoelectric-12, Panels Composite-9, Flexbeams-11, Composite Aircraft-23]; **Materials** [Aluminum Honeycomb-8, Reinforced Concrete-9, Shape Memory-19, Piezoelectric Materials-15, Honeycomb Structures-18]; **Analysis/Modeling** [CST-8, Materials Structural Analysis-11, Structural Analysis Aircraft-19, Element Method Composite-10, Structural Design-12]; **Fatigue/Fatigue Life** [Structural Health-9, Fatigue and Fracture-14]; **Loads and Dynamics** [Dynamics Materials-107, Structural Dynamics-241, Free Vibration-8, Post Buckling-14, Cantilevered-9]; **Smart Structures** [Structures Intelligent-9, Smart Wing-8, Smart Materials-27, Smart-152, Smart Structures-36]; **NDI** [none]; **System Development** [none]).

Again, the high Ii index provides low frequency of occurrence, multiword phrases with greater technical focus and content. When these phrases appear in the data base, they are physically close to the Structures theme phrase. In this case, as previously noted for the EC data base, the subcategory of Loads and Dynamics has become very active compared to the SCI. NDI and System Development remain as nonplayers. Since the data is based on Titles only, the phrases remain relatively broad in their descriptions although more specific than the high Ij phrases for the equivalent data base.

Journals: (Journal of Solids-7)

As in the SCI data base, the Journal of Solids shows the highest relationship to the Structures theme. The journal straddles the two regions of basic and applied research.

Organizations: (ASC-120, AHS-175)

The Aeronautical Systems Center (ASC) at the USAF Wright Laboratories and the AHS when appearing in the data base have a high probability of being physically close to the Structures theme word. Again, no universities or major corporations appear.

Authors: (Varadan, V.K and V.V.-12, Chamis, C.C.-9, Heslehurst, R.B.-10)

R. B. Heslehurst is the only author in both the Aircraft-SCI and Aircraft-EC data bases who is closely associated with structures. V.K and V.V. Varadan appear to be a husband and wife team working at Penn State in the structures area. For every paper, their last name appears twice and, as a result, has a relatively high frequency of occurrence with the Structures theme word.

States: (No standalone States for the high Ii case within the Aircraft-EC data base.)

Countries: (Cardiff, Wales)

This reflects work at the University of Wales at Cardiff, UK, and implies that this institution's involvement in the aircraft field is primarily through Structures. In this case, the U.S. does not appear, since the U.S. is heavily involved with many other Aircraft technologies and is not dominated by the Structures theme.

4.2.4.1.3 Abstract data base; low Ii high Ij.

These phrases tended to describe the more generic associations with Structures, and would be the most directly comparable with the high frequency Keyword and Title phrases of the previous two sections. The numbers following the phrases are the number of occurrences of the phrase within ±50 words of the Structures theme word. Again, nine technology subcategories represent an inclusion index, Ij ≥ 0.02, and are shown first for the SCI data base and then for the EC data base for ease of comparison. In this section, only the technology phrases have significance, since author(s), institutions, journals, and countries generally do not appear in the abstracts.

i) **Composites –SCI:** (Composite(s)-178, Composite Materials-36, Damage-61, Repair(s)-50, Impact-34, Laminates-23, Adhesive-21, Fiber-18, Bonding-12, Bonded-12, Reinforced-11, Bond-10, Fibre-9, Delaminations-8); **EC:** (Composite(s)-631, Fiber-116, Repair(s)-134, Impact-89, Composite Structures-61, Matrix-61, Bonded-59, Reinforced-57, Epoxy-51, Laminates-47)

ii) **Airframe – SCI:** (Aircraft-258, Test-48, Fuselage-38, Aircraft Structures-20, Beam-20, Joints-18, Primary-18, Plate-15, Shell-13, Full-Scale-12, Aircraft Fuselage-12, Box-10, Composite Aircraft-9, Truss-8); **EC:** (Aircraft-739, Wing-116, Components-113, Fuselage-95, Beam-70, Primary-63, Skin-49, Panels-49, Airframe-45, Joints-41, Structural Integrity-28)

iii) **Materials – SCI:** (Material(s)-162, Alloys-35, Properties-27, Weight-22, Aluminum-21, Metallic-16, Piezoelectric-11, High-Temperature-10, AL-LI Alloys-8); **EC:** (Material(s)-495, Performance-167, Advanced-145, Corrosion-114, Properties-102, Aluminum-89, Alloys-86, Metal-69, Carbon-41, Honeycomb-27)

iv) **Design/Analysis - SCI:** (Design-108, Analysis-66, Optimization-25, Element-24, Finite Element-21, Analytical-19, Structural Optimization-10, Finite Element Analysis-8); **EC:** (Design-434, Analysis-301, Model-200, Element-86, Evaluation-84, Finite Element-63)

v) **Fatigue/Fatigue Life – SCI:** (Fatigue-61, Crack-43, Failure-23, Growth-22, Life-21, Cracks-18, Crack Growth-15, Fracture-15, Fatigue Crack-11, Flaws-11, Fatigue Crack Growth-9); **EC:**

(Damage-200, Fatigue-166, Crack(s)-121, Failure-73, Aging-40, Damage Tolerance-31, Defects-31)

vi) **Loads and Dynamics – SCI:** (Test-48, Strength-42, Dynamic-38, Response-32, Aeroelastic-17, Strain-15); **EC:** (Control-251, Test-182, Dynamic-130, Strength-110, Response-106, Testing-106, Experimental-96, Stress(es)-135, Vibration-89, Loads-88, Strain-64, Modal-41)

vii) **Smart Structures – SCI:** (Smart-13); **EC:** (Smart-117, Embedded-38)

viii) **NDI –SCI:** (Sensors-20, Inspection-19, Nondestructive-12, NDE-9, Squid-8, Eddy-8); **EC:** (Inspection-114, Sensors-81, Nondestructive-42, Ultrasonic-40)

ix) **Systems Development – SCI:** (Application(s)-73, Systems-68, Technology-41, Development-35, Research-30, Cost-22, Reliability-20, Manufacturing-19, Safety-19, Commercial-19, Tolerance-19, Safety Factor-9); **EC:** (System(s)-503, Application(s)-304, Technology-192, Development-181, Program-124, Research-118, Process-117, Cost-91, Manufacturing-77, Fabrication-41)

All but three of the above subcategories appear to be relatively consistent between the SCI and EC data bases. The Materials subcategory within the SCI data base seems to highlight more advanced technologies such as piezoelectric, high-temperature and Al-Li alloys. The EC data base on the other hand focuses on the more traditional issues of corrosion, metal, carbon, and honeycomb. Similarly, the Fatigue/Fatigue Life subcategory for the SCI data base focuses on more fundamental issues of crack growth, flaws and fracture. The EC data base in this same subcategory highlights the engineering areas of failure, aging, damage tolerance, and defects. Sensors in the NDI subcategory for the SCI data base highlight Squids and Eddy current technology compared to the EC data base which only lists ultrasonics. These differences are reflective of the research nature of the SCI data base versus the technology focus of the EC.

It is interesting to note that the Systems Development subcategory has a substantial number of relevant phrases for both the SCI and the EC data bases. In fact, they are quite similar. This was not true for the Block data previously examined for both the SCI and EC. This would lead one to conclude that the titles do not highlight system development issues, but the actual abstracts make considerable reference to system related issues when discussing structures.

For the high Ij index being used in this section, whenever the theme word Structures appears in the data base there is a high probability that it will be physically close to the cluster member phrases. In the case of Systems Development, when the theme word Structures appears one would expect to find phrases such as application, development, program, process, cost, manufacturing, and fabrication in close proximity. As will be seen in the section for Low Ij and High Ii (4.3.4.1.4), the reverse is not true. That is, if one of the cluster phrases, such as Application, Cost, or Manufacturing appears there is a low probability of it being in close proximity to the theme word Structures. This is because the phrases, e.g., application, development, program, processes, cost, etc., have much broader relationships with other theme areas.

4.2.4.1.4 Abstract data base; high Ii low Ij.

The listed phrases describe the more specific associations of the cluster members with the Structures theme. The number following each phrase is the number of occurrences of the cluster member within ±50 words of the Structures theme word. The same nine major groupings of technology were used. Note that the number of closely related cluster members is significantly reduced in all but two areas: Composites and Airframes. The number of multiword phrases and the technical content of the phrases that remain, however, tend to be greater than the previous section (4.3.4.1.3).

i) **Composites – SCI:** (Multiwall-6, Carbon Fiber-Epoxy Composite-3, Use of Thermoplastic-3, Reinforced Composite-4, Use of Composite(s)-9, Glare-5, Adhesive Bonds-4, Composite Aircraft-9, Delaminations-8, Advanced Composite Materials-6, Bonds-5, Composite Structures-19); **EC:** (Multiwall-6, Weaving-8, Preform-14, Reinforced Plastics-11).

ii) **Airframe – SCI:** (Plate and Shell-4, Harrier II-4, Repair of Aircraft-3, Primary Aircraft-3, Resonators-5, Point Connections-5, Truss-8, Box Beams-4, Piezoelectric Actuators-6); **EC:** (Aircraft Primary-8, Metallic Aircraft-8, Subfloor-20, Aircraft Structures-9, Bridges-13, Truss-12).

iii) **Materials – SCI:** (SPF DB*-4, Applicatin of AL-LI Alloys-3, Nondestructive Evaluation NDE-3, Materials in Aircraft-3, Reinforced Concrete-4, Allowables-5, Nondestructive Testing-6); **EC:** (none). * Superplastic Forming Diffusion Bonding

iv) **Design/Analysis – SCI:** (Aircraft Structural Analysis-3, Structural Optimization-10); **EC:** (CST-12, Technology CST-6, Crash Analysis-9).

v) **Fatigue /Fatigue Life – SCI:** (Flaws in Aircraft-3); **EC:** (none).

vi) **Loads and Dynamics – SCI:** (Static Aeroelastic Response-3); **EC:** (Response-Control-10, Multimodal-7, Active Vibration Control-14).

vii) **Smart Structures – SCI:** (Fiber-Optic Sensors-4, Fiber-Optic Sensors-3); **EC:** (none).

viii) **NDI – SCI:** (Nondestructive Evaluation-4, Nondestructive Testing-6); **EC:** (Inspect-16, Damage Detection-14, Lamb-13).

ix) **Systems Development – SCI:** (Safety Factor-9); **EC:** (Safety Factor-9).

All of the above phrases are low frequency, multiword cluster members that, when they appear within the data base, will be physically close to the Structures theme. The high Ii index has the potential to uncover some of the highest technology efforts within the data base supporting structures. For example: advanced composite materials, weaving, resonators, piezoelectric actuators, application of Al-Li alloys, active vibration control, fiber optic sensors, and Lamb waves.

5.0 CONCLUSIONS

5.1 Aircraft Bibliometrics

Within the two aircraft data bases developed from the SCI and the EC, the SCI data base is based on journals that are more aligned with basic research in the physical and life sciences. The EC data base, on the other hand, tends to be more focused on journals and conference proceedings that are technology oriented. Clearly, these are general statements, since both data bases have a large number of journals in common. The SCI data base, in general, draws from a much larger range of journals (5,300+) whereas the EC draws from some 2,600+ journals. Focusing the SCI on the specific aircraft technology data base required significant work in developing a query. The final query developed in the SCI data base case incorporates over 200 terms, most of which are Boolean NOT terms to eliminate nonapplicable records. The EC data base produced a very clean and applicable data base with a query of only13 terms, essentially the portion of the SCI query that did not include the negative terms.

For the Aircraft-SCI data base developed for this study, there were 4,346 articles written by 6,619 different authors from 1,486 different organizations representing 56 countries publishing in 713 journals. In a similar fashion, the Aircraft-EC data base produced 15,673 articles written by 25,585 different authors from 4,759 different organizations representing 71 countries publishing in 1,876 journals. Because of the differences in the SCI and EC data bases, the most prolific authors, organizations, and journals related to aircraft technologies are not identical and in some cases can be quite different. One factor that is consistent throughout, however, is the fact that the United States dominates the aircraft publications and has been shown to out publish all of the other countries combined.

5.2 Phrase Frequency Analysis

DT phrase frequency allows for the complete data base to be categorized and analyzed. The overall technology focus of the publishing community can be determined, as well as a sense of which technologies have not received the same level of effort. By grouping the phrases within a defined taxonomy and using the frequencies of the phrases appearing within the data base, a quantitative summary can be obtained. The phrase frequency approach allows the flexibility of either a "top-down" or "bottom-up" taxonomy to be used. While the taxonomy used in the present study was initially "top-down" driven (predetermined categories), some "bottom-up" categories derived from the text phrases were eventually added.

Specifically, in the case of aircraft technologies, independent of the two data bases examined, the primary focus of the published work has been in Structures, Aeromechanics, and Subsystems. Similarly, areas with the least effort applied appear to be Costing, Training, Crew Systems, Manufacturing, and Support/Logistics. This should be of particular interest to the military where the latter five have been receiving increasing emphasis for greater funding and attention. The highest interest areas, on the other hand, are probably to be expected because of their impact on performance and technology resulting in an increased opportunity to be published in technical journals.

Going one step lower in the taxonomy, the dominant technology efforts are in the areas of Control Systems, Aerodynamics, Stability and Control, Helicopter Rotors, and Structural Design and Analysis. Again these areas are particularly ripe for publishing in the technical literature.

5.3 Phrase Proximity Analysis

This technique allows for the quantitative determination of closely associated technology themes and subthemes. Once a theme is chosen and the phase proximity analysis applied to the data base, it is possible to determine the technologies, authors, institutions, and journals physically most closely associated with the theme phrase within the data base. In the example provided, where Structures was the theme and the Aircraft-SCI data base was examined, the nine most closely associated technology subcategories related to Composites, Airframes, Materials Design/Analysis, Fatigue/Fatigue Life, Loads and Dynamics, Smart Structures, NDI, and System Development. The most closely related authors were: R. B. Hestehurst, S. N. Atluri, R. M. Measures, and F. W. Brust. Similarly, it was possible to determine the most closely related organizations (Georgia Institute of Technology, India Polytechnic Institute, University of Maryland, and the FAA), journals (Journal of Solids, Journal of Intelligent Material, and Journal of Fluids) and countries (U.S., England, Germany, and Australia) with what would appear to be a concentrated focus on Structures because of their close proximity to the theme word Structures within the aircraft SCI data base.

Similarly, for the Aircraft-EC data base, the most closely associated technology subcategories were the same as for the SCI data base (indicated above) but now included a more significant presence in the Loads and Dynamics area. The most closely related authors were: V. K and V. V. Varadan, C. C. Chamis, and R. B. Heslehurst. Organizations within the EC that were most closely tied to the Structures theme were the ASC Wright Laboratories and the AHS although, based on the high Ij analysis, many technical societies, such as, AIAA, ASME, ASCE, and SAMPE publish extensively in the aircraft structures area. The Journal of Solids was the only journal that showed a close relationship to the Structures theme. Although the U.S. and Australia both demonstrated a strong relationship to the theme of Structures, it was Wales (University of Wales at Cardiff) that had the most direct relationship within the Aircraft-EC data base.

5.4 Potential Areas of Additional Technology Effort for Naval Aviation

Based on the distribution of effort represented by the published papers over the past 7 or 8 years, it would appear that there are several areas which, in conjunction with currently expressed Naval Aviation priorities [Nathman, (1998)], could benefit from increased attention and deserve a hard look for additional investment. These would include such areas as: Helicopter drive systems and gear boxes (longer life bearings); corrosion detection and prevention for both aircraft and support equipment; wireless sensors for aircraft health usage monitoring; advanced catapult designs; robotic systems for weapons and store handling; Nuclear, Biological, and Chemical (NBC) protection systems; and training with increased use of simulation. All of the above aircraft platform-related efforts have been listed by the Naval Aviation community as priority areas for increased capability but, based on the published literature, have been receiving little in the way of technology support and effort.

6.0 RECOMMENDATIONS

In summary, DT and Bibliometrics would appear to be an extremely effective tool for technology program managers in the development of an investment strategy. The process allows for the development of a very focused data base which can be used for a variety of searches permitting the program manager to query the state-of-the-art in a given technology (over the time span of data base articles). In addition, through bibliometric analysis, the techniques allow for the determination of the most active and prolific researchers and organizations in the technical area. Highly cited authors, organizations and journals can be determined, all of which will greatly assist the program manager as he or she develops a new program plan by identifying and allowing for the possible interaction with the best talent in a given technology. Linchpin papers for a specific technology area can be identified as those most highly cited and can provide a current perspective on the state-of-the-technology. One of the most powerful tools is the ability, through phrase frequency analysis, to summarize, categorize, and quantify large amounts of textural technical information so that a global picture or perspective emerges. Lastly, through the use of DT, closely related themes to a given technology can be identified and pursued.

The application of DT, however, is fairly time-consuming and it is recommended that a program manager, to make best use of the DT tools and his/her time, may want to use an agent familiar with the process as well as a technologist familiar with the area to be examined to assist in the data mining effort.

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APPENDIX A
DATA MINING STRATEGIC MAP (AIRCRAFT)

Ref. No.	Major Categories	Phrases	Frequency
1	**SYSTEMS ENGINEERING**		
2	Conceptual Design		
3	Aircraft Carrier		
4	Fighter/Attack		
5	Hypersonic Aircraft		
6	Patrol/Transport		
7	Rotorcraft		
8	V/STOL		
9	UAV/UCAV		
10	General Aviation		
11	Ground Traffic Control		
12	Air Traffic Control		
13	Noise		
14	Cockpit		
15	Airport		
16	**COSTING**		
17	Affordability of New Systems		
18	Life Cycle Costs		
19	**PLATFORM/VEHICLE**		
20	**Aeromechanics**		
21	Design/Analysis		
22	Performance		
23	Aerodynamics		
24	Wing Design		
25	High Lift		
26	Vortex Flow		
27	Unsteady Flow		
28	Wing Rock		
29	Drag Reduction		
30	Wind Tunnel		
31	Icing Conditions		
32	**Flight Dynamics**		
33	Stability and Control		
34	Handling Qualities (Flight Test)		
35	Dynamic Interface (Helicopters and V/STOL with Ships)		
36	Flight/Propulsion Control		
37	Helicopter Rotors		
38	Signature (Configuration/Shaping)		
39	**Structures**		
40	Design/Analysis - Finite Element		
41	Loads and Dynamics		
42	Aeroelastic Effects		
43	Strength		
44	Impact Damage		
45	Structural Life		
46	Fatigue		
47	Crack Initiation and Growth		
48	Aging Aircraft		

Ref. No.	Major Categories	Phrases	Frequency
49	Signature (Composite Construction – RAS) Materials		
50	Smart Materials		
51	**Materials**		
52	Metals/Alloys		
53	Composites		
54	Ceramics		
55	Sealants		
56	Adhesives		
57	Chemicals		
58	Corrosion		
59	Chemical Analysis		
60	NDI/NDT		
61	Powder Metallurgy		
62	Signature (Electromagnetic)		
63	Smart Structures		
64	**Subsystems**		
65	Control Systems		
66	Neural Nets		
67	Actuators		
68	Fuzzy Logic		
69	Hydraulics		
70	Environmental Control Systems		
71	Landing Gear		
72	Fuel Systems		
73	Lightning Protection		
74	Fasteners		
75	Ice Removal		
76	**PROPULSION/POWER**		
77	Controls/Diagnostics		
78	Fuel Control System		
79	Engines		
80	Gas Turbine		
81	Propeller/Propfan		
82	Blades/Discs		
83	Coatings		
84	Diesel		
85	Spark Ignition		
86	Rotary		
87	Electrical Power		
88	Generation		
89	Distribution and Control		
90	Fuels/Lubricants		
91	Additives		
92	Pollution		
93	Contrails		
94	Mechanical Drive		
95	Gear Boxes		
96	Helicopter Drive Systems		
97	**AVIONICS**		
98	Modular		
99	Flight Info		
100	Data Fusion		

Ref. No.	Major Categories	Phrases	Frequency
101	Fiber Optics		
102	Air Data		
103	Artificial Intelligence Systems		
104	Information Management		
105	Decision Aids (Processing)		
106	Neural Nets		
107	Case Based Reasoning		
108	Fuzzy Logic		
109	Navigation/Guidance		
110	GPS		
111	INS		
112	Communication Systems		
113	Electronic Warfare (Self Protection)		
114	Software/Hardware		
115	Development		
116	Validation		
117	Reliability		
118	**CREW SYSTEMS**		
119	Emergency Egress		
120	Ejection		
121	Seating		
122	Protection Systems		
123	Loss of Consciousness		
124	CBR		
125	Human/Machine Interface		
126	Displays		
127	Data/Information Fusion		
128	Decision Aids		
129	Cockpit		
130	Crew Workload		
131	**SUPPORT LOGISTICS**		
132	Launch and Recovery		
133	Runways/Airfields		
134	Platform Interface		
135	Reliability		
136	Maintenance		
137	Costs		
138	Safety		
139	Inventory Management		
140	Environmental		
141	Hazmats		
142	Deicing		
143	**TRAINING**		
144	Simulation		
145	Local		
146	Distributed		
147	Manned Flight Simulation		
148	Software		
149	Development		
150	Validation		
151	Instruction		
152	Techniques		
153	Types		

Ref. No.	Major Categories	Phrases	Frequency
154	**MANUFACTURING**		
155	Processes		
156	Joints		
157	Structural		
158	Composite		
159	New Alloys		
160	Powder Metallurgy		
161	Electronic Devices		
162	Concurrent Engineering		

APPENDIX B
DATA MINING THE SCIENCE CITATION INDEX
STRATEGIC MAP (AIRCRAFT)

** Two-Word Phrases; f ≥ 8 **

Ref. No.	Major Categories	Phrases	Frequency
1	**SYSTEMS ENGINEERING**		
2	Conceptual Design	Design Process	41
		Advanced Aircraft	36
		Future Aircraft	27
		Conceptual Design	26
		Next Generation	18
		Design Concepts	8
3	Aircraft Carrier	Aircraft Carrier	12
		Naval Air	11
		Aircraft Carriers	8
4	Fighter/Attack	Fighter Aircraft	81
		Military Aircraft	60
		High Speed	46
		Combat Aircraft	39
		Supersonic Aircraft	23
		High-Performance Aircraft	19
		F-18 Aircraft	11
5	Hypersonic Aircraft	Hypersonic Aircraft	25
6	Patrol/Transport	Transport Aircraft	93
		Low Speed	20
		Large Aircraft	14
		Large Transport	13
		Subsonic Transport	10
		Supersubsonic Transport	9
		High-speed Civil	8
7	Rotorcraft	Tail Rotor	25
		Ground Resonance	14
		Rotorcraft Flight	12
		Attack Helicopter	11
		Helicopter Model	8
		Helicopter System	8
		Rotary Wing	8
		Rotor Noise	8
		Rotor Power	8
		Rotor Thrust	8
8	V/STOL	Vertical Landing	12
		STOL Aircraft	11
		Tilt Rotor	10
		Ventral Nozzle	10
		Moving Wall	9
		Short Takeoff	9
		STOVL Aircraft	9
		VTOL Aircraft	9
9	UAV/UCAV		
10	General Aviation		
11	Ground Traffic Control		
12	Air Traffic Control	Air Traffic	65
		Traffic Control	22
		Traffic Management	17

Ref. No.	Major Categories	Phrases	Frequency
		Traffic Control Traffic Flow	9 9
13	Noise	Sonic Boom Noise Source Noise Prediction Low Frequencies Low-frequency Noise Acoustic Excitation Acoustic Pressure Noise Attenuation Acoustic Signals Acoustic Source	17 13 12 11 11 10 10 10 8 8
14	Cockpit	Noise Reduction Aircraft Noise Interior Noise Active Noise Noise Levels Helicopter Noise Noise Transmission Impulsive Noise Interaction Noise Noise Suppression Cabin Noise Noise Exposure	25 23 22 20 20 14 13 12 12 11 9 8
15	Airport	Noise Control Sound Pressure Sound Field Noise Exposure	43 27 15 8
16	**COSTING**		
17	Affordability of New Systems	Cost Function Low Cost	19 11
18	Life Cycle Costs	Life Cycle Cost Effective Cost Savings Operating Cost Operating Costs	15 12 11 11 10
19	**PLATFORM/VEHICLE**		
20	**Aeromechanics**		
21	Design/Analysis	Aircraft Design Numerical Simulation Design Method Design Methodology Design Optimization Preliminary Design Aircraft Configuration Aircraft Configurations Design Criteria Design Requirements Numerical Simulations Computer Simulation Design Objectives Computer Simulations Design Issues Aircraft Designs Design Specifications Gross Weight	46 28 27 26 22 20 19 19 18 18 18 16 14 11 10 8 8 8

Ref. No.	Major Categories	Phrases	Frequency
		Takeoff Weight	8
22	Performance	High Performance	55
		High Angles	44
		Aerodynamic Performance	21
		Performance Aircraft	21
		Aircraft Performance	20
		Performance Requirements	20
		Performance Characteristics	16
		Flight Performance	14
		Flight Trajectory	14
		Pitch Angle	14
		Roll Rate	14
		Vehicle Dynamics	13
		Flight Dynamics	11
		Pitch Attitude	10
		Pitch Rate	10
		Sideslip Angle	10
		Climb Rate	9
		Highly Maneuverable	8
		Maneuvering Aircraft	8
23	Aerodynamics	Flow Field	42
		Fluid Dynamics	42
		Reynolds Number	42
		Computational Fluid	37
		Euler Equations	35
		Dynamic Stall	34
		Wind Shear	31
		Navier-stokes Equations	30
		Aerodynamic Characteristics	28
		Surface Pressure	28
		Dynamic Pressure	27
		Pressure Distributions	25
		Pressure Distribution	22
		Aerodynamic Effects	21
		Aerodynamic Model	21
		Finite Difference	21
		Aerodynamic Forces	19
		Reynolds Numbers	19
		Dynamics CFD	17
		Flow Separation	17
		Panel Method	17
		Aerodynamic Coefficients	16
		Separated Flow	16
		Surface Pressures	16
		Aerodynamic Design	15
		Flow Visualization	15
		Transonic Flow	15
		Turbulence Model	15
		Pressure Measurements	14
		Flow fields	13
		Flow Regime	13
		Static Pressure	13
		Dynamic Pressures	11
		Turbulent Flow	11
		Flow Features	10
		Flow Regimes	10

Ref. No.	Major Categories	Phrases	Frequency
		Grid Generation	10
		Pressure Drop	10
		Pressure Gradient	10
		Velocity Field	10
		Flow Solver	9
		Potential Flow	9
		Pressure Field	9
		Shock Wave	9
		Shock Waves	9
		Turbulence Models	9
		Viscous Flows	9
		Aerodynamic Data	8
		Flow Pattern	8
		Flow Simulation	8
		K-Epsilon Turbulence	8
		Thin-layer Navier-Stokes	8
		Three-dimensional Euler	8
24	Wing Design	Leading Edge	36
		Aircraft Wing	32
		Delta Wing	24
		Aircraft Wings	23
		Aspect Ratio	21
		Trailing Edge	16
		Base Wing	11
		Delta Wings	10
		Wing Surface	10
		Lift Coefficient	9
		Wing Loading	9
25	High Lift	Maximum Lift	11
		Leading-edge Extension	9
26	Vortex Flow	Tip Vortex	29
		Tip Vortices	15
		Vortex Wake	13
		Vortex Core	11
		Vortex System	11
		Vortex Breakdown	9
		Vortex Flow	9
		Wake Vortex	8
27	Unsteady Flow	Unsteady Aerodynamic	31
		Unsteady Aerodynamics	13
		Unsteady Flow	8
		Unsteady Separated	8
28	Wing Rock	Wing Rock	27
29	Drag Reduction	Boundary Layer	100
		Laminar Flow	23
		Turbulent Boundary	23
		Induced Drag	18
		Drag Reduction	13
		Lift Drag	13
		Skin Friction	12
30	Wind Tunnel	Wind Tunnel	101
		Wind Tunnels	18
		Tunnel Tests	10
		Wind Tunnel Tests	9
		Tunnel Data	8
31	Icing Conditions		

Ref. No.	Major Categories	Phrases	Frequency
32	**Flight Dynamics**		
33	Stability and Control	Control Law	105
		Control Laws	70
		Control Theory	29
		System Identification	29
		Pitching Moment	23
		Response Characteristics	18
		Stability Robustness	18
		Longitudinal Motion	16
		Longitudinal Dynamics	15
		Nonlinear Model	15
		Nonlinear Simulation	15
		Parameter Estimation	15
		Robust Stability	15
		Transfer Functions	15
		Linear Systems	14
		Nonlinear System	14
		Dynamic Analysis	13
		Longitudinal Control	12
		Parameter Identification	12
		Stability Analysis	12
		Transfer Function	12
		Vertical Tail	12
		Dynamic Characteristics	11
		Forced Response	11
		Frequency Responses	11
		Lateral Directional	11
		Nonlinear Aircraft	11
		Shear Downdraft	11
		System Dynamics	11
		Dynamic Behavior	10
		Stability Margins	10
		State Variables	10
		Longitudinal Stability	9
		Rate Command	9
		Rolling Moment	9
		Stability Characteristics	9
		Unstable Aircraft	9
		Vertical Tails	9
		Aeromechanical Stability	8
		Aircraft Motion	8
		Dynamic System	8
		Dynamics Model	8
		Lateral Dynamics	8
		Longitudinal Flight	8
		Short Period	8
		Stability Derivatives	8
		Yawing Moment	8
34	Handling Qualities (Flight Test)	Flight Test	58
		Handling Qualities	95
	(Flight Test, Flight Tests and	Flight Tests	19
	Flight Testing adjusted to Reflect	Flying Qualities	25
	handling qualites related abstracts~ 20%)	Aircraft Dynamics	17
		Flight Testing	9
		Pilot Inputs	11
		Control Effort	9

Ref. No.	Major Categories	Phrases	Frequency
		Handling Quality	9
35	Dynamic Interface (Helicopters and V/STOL with Ships)		
36	Flight/Propulsion Control		
37	Helicopter Rotors	Helicopter Rotor	101
		Rotor Blade	21
		Rotor Blades	49
		Rotor System	34
		Main Rotor	30
		Helicopter Rotors	24
		Blade-Vortex Interaction	21
		Helicopter Blades	20
		Rotor Model	17
		Hingeless Rotor	14
		Rotor Performance	14
		Blade Tip	13
		Rotor Wake	13
		Rotor Tip	12
		Individual Blade	11
		Interference Effects	11
		Rotor Systems	11
		Blade Pitch	10
		Rotor Helicopter	10
		Rotor Speed	10
		Articulated Rotor	9
		Blade Dynamics	9
		Blade Loads	9
		Blade Root	9
		Coupled Rotor	9
		Helicopter Blade	9
		Bearingless Rotor	9
		Blade Element	9
		Blade Model	9
		Blade Response	9
		Blade Vortex	9
38	Signature (Configuration/Shaping)		
39	**Structures**		
40	Design/Analysis-Finite Element	Finite Element	211
		Natural Frequencies	25
		Frequency Domain	22
		Frequency Response	22
		Finite Elements	20
		Nonlinear Dynamic	20
		Structural Model	20
		Structural Optimization	20
		Rigid Body	19
		Structural Response	19
		Structural Design	17
		Natural Frequency	14
		Multibody Systems	13
		Strain Energy	12
		Dynamic Creep	9
		Vibration Analysis	9
		Elastic-Plastic Finite	8

Ref. No.	Major Categories	Phrases	Frequency
		Linear Elastic	8
		Stress Field	8
41	Loads and Dynamics	Hub Loads	22
		Transverse Shear	22
		Vibration Reduction	22
		Vibration Control	16
		Bending Moment	15
		Vibratory Hub	15
		Bending Moments	14
		Flight Loads	14
		Aerodynamic Loads	13
		Maximum Load	13
		Load Factor	12
		Structural Dynamics	12
		Hub Shear	11
		Loading Conditions	11
		Gust Loads	9
		Load Distribution	9
		Plastic Deformation	9
		Structural Acoustic	9
		Surface Deflections	9
		Unsteady Airloads	9
		Wing Loading	9
		Vibratory Loads	8
42	Aeroelastic Effects	Dynamic Response	37
		Aeroelastic Stability	36
		Aeroelastic Analysis	15
		Aeroelastic Response	10
		Flexible Aircraft	10
		Tail Buffet	10
		Resonance Frequency	9
		Static Aeroelastic	9
		Aeroelastic System	8
		Load Alleviation	8
43	Strength	Aircraft Structures	76
		Residual Strength	42
		Aircraft Fuselage	40
		Stress Intensity	33
		Aircraft Structural	27
		Fracture Toughness	26
		Aircraft Structure	24
		High Strength	22
		Intensity Factors	22
		Residual Stresses	20
		Rivet Holes	20
		Adhesively Bonded	18
		Residual Stress	17
		Tensile Strength	17
		Minimum Weight	16
		Stress Amplitude	16
		Structural Analysis	16
		Fastener Holes	15
		Structural Elements	15
		Fuselage Structures	14
		Shear Stress	13
		Shear Deformation	11

Ref. No.	Major Categories	Phrases	Frequency
		Stress Concentration	11
		Tensile Stress	11
		Aerospace Structures	9
		Aircraft Fuselages	9
		Strain Rate	9
		Stress Analysis	9
		Box Beam	8
		Honeycomb Core	8
		Plane Strain	8
		Structural Performance	8
		Structural Properties	8
44	Impact Damage	Impact Damage	23
		Site Damage	12
45	Structural Life	Structural Integrity	26
		Service Life	23
		Life Prediction	19
		Cumulative Damage	9
		Damage Accumulation	9
		Usage Monitoring	9
		Life Extension	8
46	Fatigue	Fatigue Life	66
		Fatigue Damage	36
		Fatigue Strength	27
		Fatigue Test	15
		Fatigue Lives	13
		Fatigue Resistance	12
		Fatigue Tests	12
		Low Frequency	12
		Fretting Fatigue	11
		Fatigue Data	10
		Widespread Fatigue	9
		Cyclic Loading	8
		Fatigue Behaviour	8
		Fatigue Endurance	8
		Limit Cycle	9
47	Crack Initiation and Growth	Crack Growth	91
		Fatigue Crack	47
		Damage Tolerance	38
		Fracture Mechanics	31
		Crack Propagation	16
		Crack Tip	16
		Stable Crack	16
		Fatigue Cracks	14
		Fault Detection	14
		Crack Extension	13
		Crack Initiation	13
		Failure Modes	12
		Growth Rate	11
		Catastrophic Failure	10
		Damage Detection	10
		Damage MSD	10
		Failure Criteria	9
		Fatigue Failure	9
		Multiple Cracks	9
		Crack Front	8
		Multisite Damage	---

Ref. No.	Major Categories	Phrases	Frequency
48	Aging Aircraft	Aging Aircraft	34
		Ageing Aircraft	8
		Multisite Damage	8
49	Signature (Composite Construction – RAS) Materials		
50	Smart Materials	Smart Structures	9
51	**Materials**		
52	Metals/Alloys	Aluminum Alloys	34
		Aluminium Alloys	24
		Aluminum Alloy	20
		Heat Treatment	17
		Titanium Alloy	14
		Titanium Alloys	14
		Structural Materials	12
		Al-Li Alloys	11
		Aluminium Alloy	8
		Titanium Aluminide	8
53	Composites	Composite Materials	79
		Composite Structures	36
		Composite Material	23
		Graphite Epoxy	32
		Composite Laminates	19
		Matrix Composites	19
		Composite Structure	17
		Fiber Reinforced	17
		Advanced Composite	14
		Composite Aircraft	14
		New Materials	13
		Advanced Materials	12
		Carbon Fiber	12
		Laminated Composite	12
		Structural Materials	12
		Advanced Composites	11
		Boron Epoxy	10
		Carbon Fibre	10
		Composite Rotor	10
		Composite Box	8
		Composite Components	8
		Composite Panels	8
		Composite Patches	8
		Composite Structural	8
		Epoxy Composite	8
54	Ceramics		
55	Sealants		
56	Adhesives	Adhesive Bonding	9
		Bond Strength	9
		Bonded Joints	9
57	Chemicals		
58	Corrosion	Corrosion Resistance	18
		Stress Corrosion	12
		Coating Systems	9
		Corrosion Inhibitor	8
59	Chemical Analysis		
60	NDI/NDT	Eddy Current	29
		Damage Detection	10

Ref. No.	Major Categories	Phrases	Frequency
		Failure Detection	10
		Nondestructive Testing	10
		Visual Inspection	9
		Wear Debris	8
61	Powder Metallurgy		
62	Signature (Electromagnetic)		
63	Smart Structures		
64	**Subsystems**	Aircraft Systems	23
65	Control Systems	Control System	222
		Flight Control	----
		Control Systems	107
		Optimal Control	69
		Active Control	48
		Control Design	45
		Control Problem	39
		Aircraft Control	35
		Control Inputs	34
		Control Surfaces	34
		Closed-Loop System	32
		Feedback Control	31
		Optimization Problem	31
		Optimization Procedure	30
		State Feedback	29
		Kalman Filter	28
		Nonlinear Control	28
		Open Systems	26
		Control Surface	24
		Controller Design	24
		Robust Control	24
		Control Problems	23
		Nonlinear Systems	23
		Thrust Vectoring	22
		Adaptive Control	20
		Quantitative Feedback	20
		Augmentation System	19
		Control Techniques	18
		Feedback Theory	---
		Fuzzy Logic	18
		Stability Augmentation	18
		Optimum Design	17
		Rate Saturation	16
		Control Strategy	14
		Gain Scheduling	14
		Control Input	13
		Control Synthesis	13
		Feedback Linearization	13
		Controller Performance	12
		Genetic Algorithms	12
		Transfer Function	12
		Harmonic Control	11
		Highly Nonlinear	11
		Optimization Process	11
		Outer Loop	11
		Performance Robustness	11
		Response Time	11
		Extended Kalman	10

Ref. No.	Major Categories	Phrases	Frequency
		H-2 H-Infinity	10
		Multidisciplinary Optimization	10
		Nonlinear Feedback	10
		Optimization Algorithm	10
		Feedback Gains	9
		Learning Algorithm	9
		Optimal Design	9
		Optimization Method	9
		Optimization Methods	9
		Pitch Control	9
		Augmented Aircraft	8
		Fuzzy Controller	8
		Highly Augmented	8
		Nonlinear Behavior	8
		Nonlinear Response	8
		Numerical Optimization	8
		Optimization Techniques	8
66	Neural Nets	Neural Network	103
		Neural Networks	45
		Artificial Neural	22
		Genetic Algorithm	22
		Using Neural	8
67	Actuators	Piezoelectric Actuators	11
		Actuator Dynamics	10
68	Fuzzy Logic		
69	Hydraulics		
70	Environmental Control Systems	Heat Transfer	74
		Heat Exchanger	21
		Heat Flux	15
		Heat Generation	10
		Thermal Cycling	10
		Heat Exchangers	9
71	Landing Gear	Landing Gear	47
		Landing System	18
		Landing Systems	8
72	Fuel Systems	Fuel System	8
73	Lightning Protection		
74	Fasteners		
75	Ice Removal		
76	**PROPULSION/POWER**		
77	Controls/Diagnostics	Propulsion Control	10
78	Fuel Control System	Fuel Consumption	17
79	Engines		
80	Gas Turbine	Gas Turbine	99
		Aircraft Engine	70
		Aircraft Engines	55
		Aircraft Gas	---
		Turbine Engines	42
		Gas Turbines	37
		Turbine Engine	29
		Jet Engine	22
		Propulsion System	22
		Bypass Ratio	12
		Jet Engines	12
		Pressure Ratio	11

Ref. No.	Major Categories	Phrases	Frequency
		Propulsion Systems Propulsive Efficiency Power Plants Engine Performance Engine Thrust	11 11 9 8 8
81	Propeller/Propfan		
82	Blades/Discs	Turbine Blades Turbine Blade	26 9
83	Coatings	Thermal Barrier Barrier Coatings	20 17
84	Diesel		
85	Spark Ignition		
86	Rotary		
87	Electrical Power	Power System	8
88	Generation	Power Generation Switched Reluctance Electrical Power Electric Power	14 13 12 9
89	Distribution and Control		
90	Fuels/Lubricants	Jet Fuel Aircraft Fuel Jet Fuels Engine Fuel Oil Analysis	21 17 9 8 8
91	Additives		
92	Pollution	Engine Exhaust Exhaust Gas	9 8
93	Contrails	Exhaust Plume Engine Exhaust	10 9
94	Mechanical Drive		
95	Gear Boxes	Helical Gears Helicopter Gearbox Wear Debris	10 9 8
96	Helicopter Drive Systems		
97	**AVIONICS**	Avionic Systems Avionics Systems Avionics System Fault Diagnosis Signal Processing	12 12 10 9 8
98	Modular	Modular Avionics Integrated Modular	18 10
99	Flight Info		
100	Data Fusion		
101	Fiber Optics		
102	Air Data		
103	Artificial Intelligence Systems	Artificial Intelligence	10
104	Information Management		
105	Decision Aids (Processing)	Expert System Collision Avoidance Expert Systems Fuzzy Knowledge Voting Algorithms	23 18 18 9 8
106	Neural Nets	Machine Learning	13
107	Case Based Reasoning		

Ref. No.	Major Categories	Phrases	Frequency
108	Fuzzy Logic		
109	Navigation/Guidance	Navigation System Positioning System Navigation Systems Aircraft Position Proportional Navigation	26 25 16 10 8
110	GPS	Global Positioning Satellite Navigation Differential GPS	20 10 8
111	INS	Inertial Navigation	15
112	Communication Systems	Speech Intelligibility	10
113	Electronic Warfare (Self Protection)		
114	Software/Hardware	CPU Time Software System	10 8
115	Development	Software Package Massively Parallel Nonlinear Programming Linear Programming	16 15 11 9
116	Validation		
117	Reliability		
118	**CREW SYSTEMS**		
119	Emergency Egress		
120	Ejection		
121	Seating		
122	Protection Systems		
123	Loss of Consciousness		
124	CBR		
125	Human/Machine Interface	Pilot Workload Human Factors Mental Workload	13 12 11
126	Displays		
127	Data/Information Fusion		
128	Decision Aids	Decision Making Decision Support	20 16
129	Cockpit		
130	Crew Workload		
131	**SUPPORT LOGISTICS**		
132	Launch and Recovery	Aircraft Landing Precision Approach Landing Aircraft	23 9 9
133	Runways/Airfields	Runway Length	8
134	Platform Interface	Aircraft Carrier Aircraft Carriers	12 8
135	Reliability		
136	Maintenance	Condition Monitoring Health Monitoring Maintenance Personnel Reliability Maintainability Aircraft Maintenance Composite Patches	11 10 9 9 8 8
137	Costs		
138	Safety	Engine Failure Aircraft Safety	13 8
139	Inventory Management		

Ref. No.	Major Categories	Phrases	Frequency
140	Environmental		
141	Hazmats		
142	Deicing	Anti-Icing Fluids	9
143	**TRAINING**		
144	Simulation		
145	Local	Simulation Results Simulation Model Simulation Studies In-Flight Simulator In-Flight Simulator	49 17 9 8 8
146	Distributed		
147	Manned Flight Simulation	Flight Simulator Flight Simulation Simulated Flight	14 12 8
148	Software		
149	Development		
150	Validation		
151	Instruction		
152	Techniques		
153	Types	On-Line Learning	8
154	**MANUFACTURING**		
155	Processes	Manufacturing Process Process Control	21 11
156	Joints	Lap Joint Lap Joints	24 17
157	Structural	Structural Components	24
158	Composite		
159	New Alloys		
160	Powder Metallurgy		
161	Electronic Devices		
162	Concurrent Engineering	Concurrent Engineering	10

APPENDIX C
DATA MINING FOR SCIENCE CITATION INDEX
STRATEGIC MAP (AIRCRAFT)

** Three-Word Phrases; f ≥ 4 **

Ref. No.	Major Categories	Phrases	Frequency
1	**SYSTEMS ENGINEERING**		
2	Conceptual Design	Conceptual Aircraft Design	4
3	Aircraft Carrier		
4	Fighter/Attack	High Performance Aircraft Highly Maneuverable Aircraft Modern Combat Aircraft Modern Fighter Aircraft High Performance Fighter Modern High Performance Modern High-Performance Aircraft	18 6 5 5 4 --- 4
5	Hypersonic Aircraft		
6	Patrol/Transport	Large Transport Aircraft High Speed Civil Speed Civil Transport Civil Transport Aircraft High-Speed Civil Transport Subsonic Transport Aircraft High Speed Cruise Supersonic Transport Aircraft Transport HSCT Aircraft Twin-Jet Transport Aircraft	13 10 --- --- 8 8 6 6 6 6
7	Rotorcraft	Wings and Helicopter Design of Helicopter Hover and Cruise Hover Forward Flight Used in Helicopter	5 4 4 4 4
8	V/STOL	Moving Wall Effect Landing VTOL Aircraft Takeoff and Vertical Vertical Landing Stovl	7 6 6 5
9	UAV/UCAV	Unmanned Air Vehicle	5
10	General Aviation	General Aviation Aircraft	10
11	Ground Traffic Control	Gate Assignment Operations Aircraft Ground Movements	5 4
12	Air Traffic Control	Air Traffic Control Air Traffic Management Air Traffic Flow Traffic Flow Management	21 15 8 4
13	Noise	Blade-Vortex Interaction Noise	9
14	Cockpit	Active Noise Control Noise and Vibration Aircraft Interior Noise Aircraft Noise Exposure Interior Noise Control Structure-Borne Noise Transmission	12 11 5 4 4 4

Ref. No.	Major Categories	Phrases	Frequency
		Vibration and Noise	4
15	Airport	Sound Pressure Level Noise Control Engineering Overall Sound Pressure Sound Pressure Levels Sound Power Radiated	12 10 -- 6 4
16	**COSTING**		
17	Affordability of New Systems	Reduce the Cost Technical and Economical Cost and Weight	5 5 4
18	Life Cycle Costs	Direct Operating Cost Cost of Ownership Life Cycle Cost Key to Affordability	10 7 6 4
19	**PLATFORM/VEHICLE**		
20	**Aeromechanics**		
21	Design/Analysis	Design of Aircraft Anhedral and Planform Computer Aided Design Minimum Weight Design	14 4 4 4
22	Performance	Rate of Climb Altitude and Speed Entire Flight Envelope Flight Trajectory Available Predict the Performance Significant Performance Improvements	8 6 4 4 4 4
23	Aerodynamics	Angle of Attack Angles of Attack Turbulent Boundary Layer Fluid Dynamics CFD K-Epsilon Turbulence Model Free Wake Analysis Aerodynamic Design Variables Surface Pressure Distributions High Reynolds Number Loss of Lift Surface Pressure Data Tangential Slot Blowing Thin-Layer Navier-Stokes Equations Using Computational Fluid	88 88 20 17 7 6 5 5 4 4 4 4 4 4
24	Wing Design	Twist and Camber Aerodynamic Control Surfaces Using the Lifting-Line Wing Leading Edge	6 5 4 4
25	High Lift	Takeoff and Landing Lift and Drag Drag and Lift Lift and Pitching	23 16 5 5
26	Vortex Flow	Leading-Edge Extension Lex Tip Vortex Geometry	6 4
27	Unsteady Flow	Steady and Unsteady Unsteady Aerodynamic Effects	13 9

Ref. No.	Major Categories	Phrases	Frequency
		Aerodynamic and Acoustic	6
		Unsteady Aerodynamic Forces	5
		Unsteady Pressure Measurements	5
		Aerodynamics and Acoustics	
		Unsteady Euler Equations	4
		Unsteady Separated Flow	4
			4
28	Wing Rock		
29	Drag Reduction	Lift and Drag	16
		Drag and Pitching	9
		Drag and Lift	5
		Skin Friction Drag	6
		Laminar Flow Control	5
		Induced Drag Factor	4
		Natural Laminar Flow	4
		Reduce Induced Drag	4
30	Wind Tunnel	Wind Tunnel Tests	10
		Low-Speed Wind Tunnel	9
		Wind Tunnel Data	8
		Wind Tunnel Test	7
		Tunnel at NASA	4
		Wind Tunnel Model	4
31	Icing Conditions		
32	**Flight Dynamics**		
33	Stability and Control	Equations of Motion	68
		Degrees of Freedom	32
		Control Law Design	15
		Linear and Nonlinear	15
		Force and Moment	13
		Longitudinal and Lateral	13
		Stability and Control	13
		Static and Dynamic	13
		Shear Downdraft Factor	11
		Flight Control Laws	10
		Pitch and Roll	10
		Partial Differential Equations	8
		Degree of Freedom	7
		Inertial Velocity Components	7
		Lateral and Longitudinal	7
		Optimal Control Theory	7
		Analysis and Control	6
		Attack and Sideslip	6
		Flight Control Law	6
		Performance and Stability	6
		Control is Presented	5
		Dynamics and Control	5
		Loss of Control	5
		Microburst Wind Shear	5
		Pitch and Yaw	5
		Singularly Perturbed Systems	5
		Design of Robust	4
		Guidance and Control	4
		Linear Stability Theory	4
		Partial Differential Equation	4
		Phase Nonlinear Systems	4

Ref. No.	Major Categories	Phrases	Frequency
		Roll and Yaw	4
		Two-Degree-of-Freedom Fuzzy Model	4
34	Handling Qualities (Flight Test) (Flight Test Data adjusted to reflect handling qualities related abstracts~20%)	Flight Test Data	9
		Stability and Performance	11
		Helicopter Handling Qualities	7
		Handling Qualities Ratings	6
		Handling Qualities Requirements	5
		Performance and Handling	
		Aircraft Handling Qualities	5
		Handling Qualities Levels	4
		Handling Quality Requirements	4
			4
35	Dynamic Interface (Helicopters and V/STOL with Ships)		
36	Flight/Propulsion Control	Flight Propulsion Control	4
		Propulsion Control System	---
37	Helicopter Rotors	Helicopter Rotor Blades	25
		Hover and Forward	22
		Helicopter Rotor Blade	19
		Rotor in Forward	15
		Flap and Lag	8
		Rotor in Hover	8
		Individual Blade Control	7
		Number of Blades	7
		Blade-Vortex Interaction BVI	6
		Rotors in Hover	6
		Helicopter Rotor Model	5
		Lag Mode Damping	5
		Rotor and Wing	5
		Rotor State Feedback	5
		Rotor Tip Vortex	5
		Rotors in Forward	5
		Track and Balance	5
		Blade in Forward	4
		Blade Passage Frequency	4
		Blade Passing Frequency	4
		Blade Tip Vortices	4
		Blade Vortex Interaction	4
		Blade Vortex Interactions	4
		Damaged Pitch-Control System	4
		Higher Harmonic Blade	4
		Soft-Inplane Hingeless Rotor	4
38	Signature (Configuration/Shaping)	Radar Cross Section	7
		Cross Section RCS	5
39	**Structures**	Aircraft Fuselage Structures	7
		Primary Aircraft Structures	4
		Principal Structural Elements	4
		Minimum Weight Structure	4
40	Design/Analysis - Finite Element	Finite Element Method	43
		Finite Element Analysis	28
		Finite Element Model	20
		Finite Element Alternating	16
		Element Alternating Method	---
		Elastic-Plastic Finite Element	8
		Stiffness and Damping	8

Ref. No.	Major Categories	Phrases	Frequency
		Finite Element Models	7
		Nonlinear Finite Element	6
		Continuum Beam-Rod	5
		Model	
		Finite Element Code	5
		Finite Element Formulation	5
		Finite Element Modeling	5
		Laminated Plate Theory	4
		Finite Element Analysis	4
		Finite Element Based	4
		Finite Element FE	4
		Finite Element Methods	4
		Finite Element Program	4
		Finite Element Results	4
		Finite Element Frequency	4
		Plate and Shell	4
		Plates and Shells	4
		Random Vibration Analysis	4
		Shell Finite Element	4
		Three-Dimensional Finite Element	4
		Using Finite Element	
			4
41	Loads and Dynamics	Forces and Moments	18
		Vibratory Hub Loads	8
		Load Carrying Capacity	6
		Bending and Torsional	5
		Frequencies and Mode	5
		Vibratory Hub Shear	5
		Active Vibration Control	4
		Bending and Torsion	4
		Control of Structural	4
		Fiber Optic Strain	4
		Shear and Warping	4
		Static and Cyclic	4
42	Aeroelastic Effects	Structural and Aerodynamic	11
		Aerodynamic and Structural	10
		Damping and Stiffness	5
		Gust Load Alleviation	5
		Motion-Induced Unsteady Airloads	5
		Static Aeroelastic Response	
		Loads and Aeroelastic	5
		Variable Structure Control	4
			4
43	Strength	Stress Intensity Factors	22
		Stress Intensity Factor	8
		Strain Fracture Toughness	6
		Stress and Strain	6
		Stiffness and Mass	5
		Strength and Stiffness	5
		Strength of Aircraft	5
		Maximum Tensile Stress	4
		Strength and toughness	4
		Strength to Weight	4
		Ultimate Tensile Strength	4
44	Impact Damage	Multiple Site Damage	11
		Visible Impact Damage	6

Ref. No.	Major Categories	Phrases	Frequency
		Low Velocity Impact	6
		Barely Visible Impact	5
		Site Damage MSD	---
		Low Energy Impacts	4
		Energy of Damage	4
45	Structural Life		
46	Fatigue	Widespread Fatigue Damage	9
		Fatigue and Fracture	8
		Fatigue Life Prediction	5
		Fatigue Test Data	4
		Full-Scale Fatigue Test	4
		Improving the Fatigue	4
		Increase of Cyclic	4
		Linear Cumulative Damage	4
		Low Cycle Fatigue	4
		Strength and Fatigue	4
47	Crack Initiation and Growth	Stable Crack Growth	11
		Crack Growth Rates	6
		Elastic Fracture Mechanics	6
		Plane Strain Fracture	6
		Crack Growth Predictions	5
		Crack Growth Rate	5
		Stress Corrosion Cracking	5
		Crack Growth Analysis	4
		Crack Growth Data	4
		Flaws in Aircraft	4
		Fretting Fatigue Crack	4
		Stable Crack Extension	4
48	Aging Aircraft	End of Life	4
49	Signature (Composite Construction – RAS) Materials	Radar Cross Section	7
		Cross Section RCS	5
50	Smart Structures		
51	**Materials**		
52	Metals/Alloys	Aircraft Grade Aluminum	4
		Aluminum Alloy D16AT	---
		Grade Aluminum Alloy	---
		Quenched and Tempered	4
53	Composites	Advanced Composite Materials	10
		Use of Composite	
		Carbon Fiber Reinforced	8
		Composite Rotor Blades	6
		Use of Composites	6
		Composite Helicopter Rotor	5
		Metal Matrix Composites	4
		Woven Fabric Composites	4
			4
54	Ceramics	Ceramic Metal Interface	5
		Ceramic Matrix Composites	4
55	Sealants		
56	Adhesives	Adhesively Bonded Joints	6
57	Chemicals		
58	Corrosion		
59	Chemical Analysis		
60	NDI/NDT	Frequency Eddy Current	6
		Nondestructive Evaluation NDE	4

Ref. No.	Major Categories	Phrases	Frequency
		Spectrometric Oil Analysis	4
61	Powder Metallurgy		
62	Signature (Electromagnetic)	Radar Cross Section	7
		Cross Section RCS	5
63	Smart Structures		
64	**Subsystems**		
65	Control Systems	Flight Control System	76
		Flight Control Systems	38
		Control System Design	---
		Quantitative Feedback	18
		Theory	
		Optimal Control Problem	14
		Higher Harmonic Control	11
		Aircraft Control System	9
		Mixed H-2 H-Infinity	9
		Optimal Control Problems	9
		Stability Augmentation System	9
		Feedback Theory QFT	
		Linear Quadratic Regulator	---
		Aircraft Flight Control	8
		Controller is Designed	---
		Control of Aircraft	8
		Design of Control	7
		Digital Flight Control	7
		Feedback Control Law	7
		Longitudinal Flight Control	7
		Control System FCS	6
		Fuzzy Logic Controller	---
		Minimum Control Authority	6
		Nonlinear Dynamic	6
		Inversion	6
		Constrained Optimization	
		Problem	5
		Controller is Compared	
		Controls and States	5
		Helicopter Flight Control	5
		Primary Flight Control	5
		Robust Flight Control	5
		Adaptive Flight Control	5
		Aircraft Control Surface	4
		Closed Loop System	4
		Command Attitude Hold	4
		Flight Control Design	4
		Full State Feedback	4
		Highly Augmented Aircraft	4
		Infinity Control Design	4
		Infinity Optimal Control	4
		Integrated Flight Propulsion	4
		Local Nonlinear Control	4
		Model-Following Control	4
		System	4
		Multiple Control Surfaces	
		Nonminimum Phase	4
		Nonlinear	4
		Nonlinear Control Law	
		Nonlinear Control Laws	4

Ref. No.	Major Categories	Phrases	Frequency
		Optimal Control Design	4
		Robust Control Design	4
		Robust Controller Design	4
		Rotocraft Flight Control	4
		State and Control	4
		State Feedback Control	4

66	Neural Nets	Artificial Neural Network	14
		Artificial Neural Networks	7
		Using Neural Networks	5
		Feedforward Neural Network	4
		Neural Network Controllers	4
		Neural Network Technology	4
		Use of Neural	4
		Used for Optimization	4
67	Actuators	Control Surface Deflections	9
		Actuator and Sensor	7
		Actuators and Sensors	4
		Aircraft Control Surface	4
		Sensors and Actuators	4
68	Fuzzy Logic		
69	Hydraulics		
70	Environmental Control Systems	Heat Transfer Coefficient	13
		Heat Transfer Coefficients	13
		Average Heat Transfer	4
		Embedded Cooling Channels	4
		Single-Pass Tubular Heat	4
		Tubular Heat Exchanger	---
71	Landing Gear	Aircraft Landing Gear	13
72	Fuel Systems	Aircraft Fuel Lines	4
73	Lightning Protection		
74	Fasteners		
75	Ice Removal		
76	**PROPULSION/POWER**		
77	Controls/Diagnostics	Flight Propulsion Control	4
		Propulsion Control System	---
78	Fuel Control System		
79	Engines		
80	Gas Turbine	Aircraft Gas Turbine	---
		Gas Turbine Engines	36
		Gas Turbine Engine	21
		Aircraft Gas Turbines	11
		Energy Release Rate	9
		Aircraft Engine Components	8
		Aircraft Turbine Engine	5
		Aircraft Turbine Engines	5
		Gas Turbine Combustor	5
		Industrial Turbines	5
		Specific Fuel Consumption	5
		Fully Expanded Mach	4
		Industry Gas Turbine	4
81	Propeller/Propfan	Propfan Test Assessment	5
		Propeller Blade Rate	4
82	Blades/Discs	Blades and Vanes	5
83	Coatings	Thermal Barrier Coatings	16

Ref. No.	Major Categories	Phrases	Frequency
		Barrier-Virtex Interaction (BVI) Thermal Spray Coatings	6 5
84	Diesel		
85	Spark Ignition		
86	Rotary		
87	Electrical Power	Cell or Battery	6
88	Generation	Switched Reluctance Machine	5
89	Distribution and Control		
90	Fuels/Lubricants		
91	Additives		
92	Pollution		
93	Contrails	Free Wake Analysis	6
94	Mechanical Drive		
95	Gear Boxes	Material Helical Gears	4
96	Helicopter Drive Systems		
97	**AVIONICS**	ALQ-131 Block II Avionics and Systems	4 4
98	Modular	Integrated Modular Avionics	9
99	Flight Info	Flight Management System	5
100	Data Fusion		
101	Fiber Optics		
102	Air Data	Particle Image Velocimetry Real-Time Wind Identification Laser Doppler Anemometer Laser Doppler Measurements	5 5 4 4
103	Artificial Intelligence Systems		
104	Information Management	Perspective Flight Path	5
105	Decision Aids (Processing)	Collision Avoidance System Avoidance System TCAS Fuzzy Associative Memory	7 --- 4
106	Neural Nets	Artificial Neural Network Artificial Neural Networks Neural Network Models Using Neural Networks Feedforward Neural Network Neural Network Technology Use of Neural	14 7 6 5 4 4 4
107	Case Based Reasoning		
108	Fuzzy Logic		
109	Navigation/Guidance	Tightly-Coupled GPS INS Future Air Navigation Navigation and Landing Navigation and Surveillance	5 4 4 4
110	GPS	Global Positioning System Positioning System GPS	19 ---
111	INS	Inertial Navigation System Navigation System INS	9 ---
112	Communication Systems	Digital Communication System	4
113	Electronic Warfare (Self Protection)		
114	Software/Hardware	Hardware and Software	18
115	Development	Nonlinear Programming Technique Software Development Process	5

Ref. No.	Major Categories	Phrases	Frequency
			4
116	Validation		
117	Reliability		
118	**CREW SYSTEMS**		
119	Emergency Egress		
120	Ejection		
121	Seating		
122	Protection Systems		
123	Loss of Consciousness	Loss of Consciousness	4
124	CBR		
125	Human/Machine Interface		
126	Displays		
127	Data/Information Fusion		
128	Decision Aids	Decision Support System	5
129	Cockpit		
130	Crew Workload		
131	**SUPPORT LOGISTICS**		
132	Launch and Recovery	Approach and Landing Takeoff and Landing Instrument Landing System Landing and Takeoff	12 8 4 4
133	Runways/Airfields	Rigid Airport Pavements	4
134	Platform Interface	Ship and Aircraft Ships and Aircraft	5 5
135	Reliability		
136	Maintenance	Reliability and Maintainability Frequency Eddy Current Maintenance and Repair Probability of Detection Probability of Failure	9 6 4 4 4
137	Costs		
138	Safety		
139	Inventory Management		
140	Environmental	Paint Stripping Processes	4
141	Hazmats		
142	Deicing		
143	**TRAINING**		
144	Simulation		
145	Local	Results of Simulation Capable of Simulating Simulation is Used Simulation Results Show Simulated Flight Data Use of Simulation	11 5 5 5 4 4
146	Distributed		
147	Manned Flight Simulation	Vertical Motion Simulator	4
148	Software		
149	Development		
150	Validation		
151	Instruction		
152	Techniques		
153	Types		
154	**MANUFACTURING**		
155	Processes	Materials and Processes	9

Ref. No.	Major Categories	Phrases	Frequency
		Design for Manufacture	5
156	Joints	Single Lap Joint Adhesively Bonded Joints Double Lap Joint Fuselage Lap Joints Aircraft Fuselage Lap	7 6 6 5 ---
157	Structural	Microstructure and Mechanical Aircraft Structural Components	7 4
158	Composite	Composite Aircraft Structures Composite Box Beam Laminated Composite Plates	5 5 4
159	New Alloys		
160	Powder Metallurgy		
161	Electronic Devices		
162	Concurrent Engineering	Design and Manufacturing Substantial Weight Savings	12 5

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APPENDIX D
DATA MINING FOR ENGINEERING COMPENDEX
STRATEGIC MAP (AIRCRAFT)

** Two-Word Phrases; f ≥ 20 **

Ref. No.	Major Categories	Phrases	Frequency
1	**SYSTEMS ENGINEERING**		
2	Conceptual Design	System Design	240
		Design Process	155
		Next Generation	120
		Advanced Aircraft	99
		Advanced Technology	90
		New Technology	82
		Future Aircraft	69
		Conceptual Design	61
		Design Concepts	60
		New Technologies	58
		System Designs	30
		System Concept	29
		Advanced Design	22
3	Aircraft Carrier	Flight Deck	98
		Aircraft Carrier	37
4	Fighter/Attack	High Performance	229
		Military Aircraft	228
		Fighter Aircraft	214
		Combat Aircraft	71
		Air Combat	57
		Supersonic Aircraft	57
		Tactical Aircraft	54
		F-16 Aircraft	43
		Air Defense	33
		High-Performance Aircraft	30
		Air-to-Air Combat	24
		Modern Fighter	22
5	Hypersonic Aircraft	Hypersonic Aircraft	32
		Hypersonic Vehicle	27
		Hypersonic Vehicles	20
6	Patrol/Transport	Transport Aircraft	218
		Low Speed	81
		Civil Transport	79
		Commercial Transport	50
		ER-2 Aircraft	36
		Large Aircraft	35
		Supersonic Transport	32
		KC-135 Aircraft	29
		DC-8 Aircraft	27
		High Speed Civil	23
		NASA DC-8	23
		Large Transport	21
		Subsonic Transport	20
7	Rotorcraft	Helicopter Flight	62
		Ground Effect	40
		Attack Helicopter	39
		Rotary Wing	35
		Black Hawk	32
		RAH-66 Comanche	29

Ref. No.	Major Categories	Phrases	Frequency
		Longbow Apache	28
		Ground Resonance	25
		Helicopter System	24
		Rotorcraft Flight	24
		Helicopter Model	23
		Helicopter Systems	23
		Apache Helicopter	22
8	V/STOL	Tilt Rotor	44
		Ground Effect	40
		Tilt Wing	40
		Vertical Landing	39
		Tiltrotor Aircraft	29
		Short Takeoff	28
		V-22 OSPREY	28
		STOL Aircraft	27
		Short Takeoff	21
		Vertical Takeoff	20
9	UAV/UCAV	Unmanned Aerial	54
		Aerial Vehicle	39
		Unmanned Air	36
		Vehicle UAV	32
		Remotely Piloted	28
10	General Aviation	General Aviation	107
		Civil Aviation	83
		Civil Aircraft	71
		Small Aircraft	29
11	Ground Traffic Control		
12	Air Traffic Control	Air Traffic	401
		Traffic Control	---
		Wind Shear	73
		Flight Safety	70
		Traffic Management	---
		Control ATC	---
		ATC System	22
		Traffic Controllers	22
13	Noise	Aircraft Noise	75
		BVI Noise	63
		Sonic Boom	38
		Noise Prediction	35
		Helicopter Noise	32
		Impulsive Noise	31
		Noise Sources	31
		Noise Source	30
		Interaction Noise	28
		Rotor Noise	25
14	Cockpit	Noise Control	96
		Noise Reduction	93
		Active Noise	53
		Interior Noise	47
		Noise Level	36
		Cabin Noise	21
15	Airport	Noise Levels	71
		Sound Pressure	57
		Noise Exposure	30
16	**COSTING**		
17	Affordability of New Systems	Low Cost	153

Ref. No.	Major Categories	Phrases	Frequency
		Acquisition System	60
		Lower Cost	30
18	Life Cycle Costs	Cost Effective	97
		Cost Savings	45
		Operating Costs	43
		Cycle Costs	38
		Maintenance Costs	35
		Cost Reduction	31
		Cost Effectiveness	28
		Operating Cost	27
		Cycle Costs	23
19	**PLATFORM/VEHICLE**		
20	**Aeromechanics**		
21	Design/Analysis	Numerical Results	146
		Aircraft Design	125
		Preliminary Design	100
		Design Variables	87
		Computer Simulation	79
		Design Parameters	77
		Numerical Simulation	71
		Design Requirements	68
		Design Approach	64
		Numerical Simulations	62
		Analysis Techniques	61
		Design Method	54
		Design Procedure	54
		Analysis Methods	50
		Analysis Results	50
		Analytical Model	50
		Design Optimization	45
		Design Methodology	43
		Design Considerations	41
		Design Specifications	35
		Design Analysis	33
		Design Philosophy	33
		Analytical Methods	32
		Model Predictions	32
		Design Objectives	30
		Design Techniques	30
		Numerical Analysis	30
		Integrated Design	29
		Computer Simulations	25
		Prediction Methods	25
		Modeling Techniques	24
		Theoretical Predictions	23
		Analysis Technique	22
		Simulated Aircraft	22
		Simulated Models	22
		Analytical Predictions	21
		Mathematical Modeling	21
		Numerical Optimization	20
22	Performance	System Performance	155
		Flight Envelope	96
		Performance Characteristics	87
		Performance Requirements	78
		Aircraft Performance	70

Ref. No.	Major Categories	Phrases	Frequency
		Aerodynamic Performance	52
		Performance Data	50
		Performance Aircraft	44
		Performance Parameters	39
		Tracking Performance	32
		Flight Performance	30
		Performance Results	30
		Overall Performance	28
		Dynamic Performance	27
		Performance Analysis	27
		Performance Specifications	24
		Performance Criteria	23
		Performance Degradation	22
		Performance Improvement	22
		Better Performance	21
		Operational Performance	21
		Performance Evaluation	21
		Performance Goals	21
23	Aerodynamics	Boundary Layer	238
		Mach Number	221
		Fluid Dynamics	129
		Computational Fluid	----
		Flow Field	122
		Reynolds Number	120
		Navier-Stokes Equations	98
		Mach Numbers	94
		Surface Pressure	76
		Aerodynamic Characteristics	75
		Pressure Distributions	67
		Euler Equations	66
		Flow Separation	66
		Dynamics CFD	---
		Flow Conditions	60
		Dynamic Pressure	58
		Pressure Measurements	55
		Total Pressure	49
		Aerodynamic Model	48
		Reynolds Numbers	45
		Pressure Distribution	44
		Turbulence Model	44
		Transonic Flow	43
		Panel Method	42
		Shock Wave	41
		Aerodynamic Coefficients	38
		Aerodynamic Design	37
		Lift Drag	37
		Supersonic Flow	37
		Flat Plate	36
		Aerodynamic Effects	35
		Surface Pressures	35
		Velocity Field	34
		Potential Flow	33
		Shear Layer	33
		K- Epsilon	32
		Axial Flow	30
		Flow Characteristics	30

Ref. No.	Major Categories	Phrases	Frequency
		Flow Fields	30
		Flow Structure	30
		Navier-Stokes Code	30
		Detailed Analysis	29
		Shock Waves	29
		CFD Code	---
		Computational Methods	27
		Nonlinear Model	27
		Numerical Solutions	27
		Turbulent Boundary	27
		Turbulent Flow	27
		Wave Propagation	26
		Thin-Layer Navier-Stokes	24
		Fluid Dynamic	23
		Viscous Effects	23
		Turbulence Models	23
		Boundary Layers	22
		CFD Methods	22
		Pressure Data	22
		Pressure Gradient	22
		Pressure Loss	22
		Viscous Flow	22
		Water Tunnel	22
		Aerodynamic Data	21
		Grid Generation	21
		Inlet Flow	20
		Navier-Stokes Solver	20
24	Wing Design	Delta Wing	180
		Leading Edge	170
		Trailing Edge	91
		Aircraft Wing	81
		Aspect Ratio	64
		Delta Wings	64
		Wing Aircraft	---
		Aircraft Wings	53
		Fixed Wing	47
		Leading Edges	38
		Separated Flow	31
		Lifting Surface	28
		Turbulent Boundary	27
		Sweep Angle	22
		Wing Box	21
		Lifting Surfaces	20
		Wing Surface	20
25	High Lift	Dynamic Stall	76
		Flow Separation	66
		Lifting Surface	28
		Lift Coefficient	22
		Maximum Lift	22
		High Lift	20
26	Vortex Flow	Vortex Breakdown	96
		Tip Vortex	84
		Vortex Core	45
		Wake Geometry	45
		Vortex Interaction	40
		Interaction BVI	---

Ref. No.	Major Categories	Phrases	Frequency
		Vortex Wake	38
		Wake Model	---
		Vortex Flow	34
		Free Wake	32
		Leading-Edge Vortex	29
		Blade Vortex	---
		Tip Vortices	27
		Vortical Flow	26
		Wake Vortex	23
		Leading Edge Vortices	22
		Vortex Structures	21
		Wake Vortices	21
		Wake Effects	20
27	Unsteady Flow	Unsteady Aerodynamic	81
		Unsteady Aerodynamics	40
		Unsteady Pressure	25
		Unsteady Flow	24
28	Wing Rock	Wing Rock	49
29	Drag Reduction	Laminar Flow	68
		Drag Reduction	36
		Drag Coefficient	24
		Induced Drag	21
30	Wind Tunnel	Wind Tunnel	394
		Flow Visualization	103
		Tunnel Test	52
		Tunnel Tests	34
		Wind Tunnels	32
		Wind Tunnel Tests	31
		Wind Tunnel Test	25
		Tunnel Testing	24
		Tunnel Data	22
31	Icing Conditions	Icing Conditions	22
32	**Flight Dynamics**		
33	Stability and Control	Control Laws	123
		Precision Approach	82
		Flight Dynamics	57
		Atmospheric Turbulence	56
		Parameter Estimation	47
		Aircraft Dynamics	43
		Aircraft Motion	41
		Vertical Tail	40
		Aerodynamic Coefficients	38
		Roll Angle	34
		Angular Velocity	32
		Flight Mechanics	30
		Horizontal Tail	30
		Stability Characteristics	30
		Aeromechanical Stability	29
		Rolling Moment	29
		Stability Analysis	29
		Parameter Identification	28
		Robust Stability	26
		Stability Derivatives	26
		State Vector	26
		Vehicle Dynamics	26
		Stability Robustness	25

Ref. No.	Major Categories	Phrases	Frequency
		Landing Aircraft	24
		Longitudinal Dynamics	23
		Sideslip Angle	23
		Control Power	20
		Stability Margins	20
		System Dynamics	20
34	Handling Qualities (Flight Test) (Flight Test, Flight Tests and Flight Testing adjusted to reflect handling qualities related abstracts ~20%)	Flight Test	122
		Handling Qualities	233
		High Angles	93
		Flight Tests	44
		Flight Testing	27
		Flight Data	26
		Flying Qualities	72
		Response Characteristics	41
		Pitching Moment	39
		High Angle	38
		Pitch Rate	33
		Motion Compensation	31
		Response Time	29
		High Angle-of-Attack	27
		Roll Rate	27
		Transient Response	26
		Flight Maneuvers	20
35	Dynamic Interface (Helicopters and V/STOL with Ships)		
36	Flight/Propulsion Control	Thrust Vectoring	72
37	Helicopter Rotors	Rotor Blade	191
		Helicopter Rotor	----
		Rotor Blades	148
		Main Rotor	147
		Tail Rotor	89
		Rotor System	86
		Tip Vortex	84
		BVI Noise	63
		Rotor Wake	63
		Blade-Vortex Interaction	60
		Blade Tip	44
		Hingless Rotor	40
		Rotor Speed	40
		Model Rotor	37
		Rotor Model	36
		Vibratory Hub	34
		Blade Element	33
		Helicopter Rotors	33
		Rotor Performance	31
		Composite Rotor	29
		Individual Blade	29
		Blade Vortex	27
		Helicopter Blades	27
		Lag Mode	27
		Rotor Design	27
		Rotor Dynamics	25
		Blade Control	24
		Helicopter Blade	24
		Bearingless Rotor	22
		Blades Loads	22

Ref. No.	Major Categories	Phrases	Frequency
		Blade-Vortex Interactions	22
		Rotor Helicopter	22
		Bearingless Main	21
		Rotor Thrust	21
		Rotor Tip	21
		Rotor Hub	20
38	Signature (Configuration/Shaping)	Cross Section	147
		Radar Cross	----
		Section RCS	----
39	**Structures**	Aircraft Structures	196
		Mechanical Properties	183
		Composite Structures	128
		Aircraft Structural	60
		Rigid Body	57
		Light Weight	43
		Weight Savings	41
		Weight Reduction	38
		Composite Structure	36
		Aerospace Structures	35
		Composite Aircraft	35
		Structural Applications	29
		Minimum Weight	24
		Reduced Weight	23
		Structural Elements	23
		Primary Structures	22
		Structural Weight	21
		Fuselage Structure	20
		Low Weight	20
40	Design/Analysis -Finite Element	Finite Element	563
		Element Method	---
		Element Analysis	---
		Structural Analysis	70
		Structural Design	60
		Thermal Expansion	46
		Engenstructure Assignment	45
		Finite Elements	45
		Numerical Method	43
		Structural Model	38
		Theoretical Analysis	38
		Modal Analysis	35
		Strain Energy	34
		Stress Analysis	33
		Structural Optimization	31
		Detailed Analysis	29
		Nonlinear Finite	28
		Wing Structure	28
		Computational Methods	27
		Nonlinear Model	27
		Numerical Solutions	27
		Transient Response	26
		Beam Model	24
		Three-Dimensional Finite	21
41	Loads and Dynamics	Dynamic Response	87
		Vibration Control	70
		Frequency Range	66
		Structural Dynamics	58

Ref. No.	Major Categories	Phrases	Frequency
		Dynamic Characteristics	56
		Dynamic Model	55
		Stress Intensity	55
		Transverse Shear	55
		Aerodynamic Forces	50
		Hub Loads	49
		Dynamic Analysis	45
		Vibration Reduction	44
		Active Vibration	42
		Aerodynamic Loads	40
		Bending Moments	38
		Dynamic Loads	33
		Dynamic Behavior	32
		Vibratory Loads	32
		Stress Distribution	31
		Shear Deformation	26
		Shear Stress	26
		Flight Loads	25
		Residual Stresses	25
		Residual Stress	24
		Bending Moment	23
		Power Spectral	21
		Vibration Test	21
		Dynamic System	20
		Structural Dynamic	20
		Structural Modes	20
		System Dynamics	20
42	Aeroelastic Effects	Aeroelastic Stability	75
		Aeroelastic Analysis	44
		Structural Response	39
		Aeroelastic Response	30
43	Strength	Fracture Toughness	75
		Aircraft Structure	72
		Failure Modes	68
		Residual Strength	67
		High Strength	66
		Material Properties	65
		Tensile Strength	32
		Physical Properties	30
		Strain Rate	25
		Plate Theory	23
		Wing Box	21
		Shear Strength	20
44	Impact Damage	Damage Tolerance	108
		Impact Damage	49
		Damage Tolerant	23
		Impact Resistance	21
45	Structural Life	Structural Integrity	119
		Service Life	95
		Failure Detection	43
		Life Prediction	42
		Integrity Monitoring	41
		Damage Detection	27
		Failure Mechanism	23
		Integrity Program	22
46	Fatigue	Fatigue Life	170

Ref. No.	Major Categories	Phrases	Frequency
		Residual Strength	67
		Fatigue Damage	63
		Fatigue Test	51
		Fatigue Strength	41
		Fatigue Tests	41
		Limit Cycle	32
		Fatigue Failure	24
		Fatigue Loading	22
		Fatigue Resistance	22
		Fatigue Testing	21
		Fatigue Properties	20
47	Crack Initiation and Growth	Crack Growth	219
		Fatigue Crack	109
		Fatigue Cracks	56
		Crack Propagation	55
		Fracture Mechanics	47
		Crack Initiation	40
		Crack Tip	32
		Catastrophic Failure	22
		Crack Closure	22
48	Aging Aircraft	Aging Aircraft	116
49	Signature (Composite Construction – RAS) Materials	Cross Section	147
		Radar Cross	---
		Section RCS	---
50	Smart Structures	Fiber Optic	173
		Smart Structures	57
		Fiber Optics	52
		Sensor Data	49
		Optical Fiber	47
		Optical Fibers	22
51	**Materials**	New Materials	49
		Advanced Materials	46
		Thermal Conductivity	43
		Structural Materials	38
		Silicon Nitride	20
52	Metals/Alloys	Aluminum Alloys	98
		Aluminum Alloy	69
		Titanium Alloys	57
		Heat Treatment	47
		Stainless Steel	37
		Aluminium Alloys	35
		Titanium Alloy	30
		Superplastic Forming	23
		Al-Li Alloys	20
53	Composites	Composite Materials	257
		Composite Structures	128
		Matrix Composites	85
		Graphite Epoxy	71
		Fiber Reinforced	69
		Composite Material	63
		Carbon Fiber	54
		Resin Transfer	51
		Advanced Composite	47
		Composite Laminates	47
		Metal Matrix	41
		Carbon Fiber	40

Ref. No.	Major Categories	Phrases	Frequency
		Laminated Composite	39
		Matrix Composite	38
		Composite Structure	36
		Composite Aircraft	35
		Advanced Composites	33
		Composite Panels	31
		Composite Rotor	29
		Polymer Matrix	28
		Lap Joints	27
		Composite Plates	25
		Composite Structural	24
		Boron Epoxy	23
		Ceramic Matrix	23
		Composite Parts	23
		Epoxy Composite	23
		Fiber Composites	23
		Fiber Reinforced	23
		Reinforced Plastics	22
		Resin Systems	22
		Ply Orientation	21
		Fiber Orientation	20
		Laminated Composites	20
54	Ceramics		
55	Sealants		
56	Adhesives	Adhesively Bonded	46
57	Chemicals		
58	Corrosion	Corrosion Resistance	60
		Stress Corrosion	29
		Corrosion Protection	22
59	Chemical Analysis	Thermal Stability	105
60	NDI/NDT	Eddy Current	92
		Nondestructive Evaluation	48
		Acoustic Emission	34
		Nondestructive Inspection	29
		Nondestructive Testing	28
		Detection System	25
		Evaluation NDE	21
61	Powder Metallurgy	Powder Metallurgy	26
62	Signature (Electromagnetic)	Cross Section	147
		Radar Cross	---
		Section RCS	---
		Electromagnetic Compatibilty	20
63	Smart Materials	Smart Material	23
64	**Subsystems**		
65	Control Systems	Control System	841
		Flight Control	----
		Control Systems	371
		Control Law	223
		Kalman Filter	139
		Optimal Control	137
		Landing System	134
		Control Laws	123
		Active Control	----
		Control Design	106
		Control Surfaces	96

Ref. No.	Major Categories	Phrases	Frequency
		Control Surface	90
		Feedback Control	85
		Control Problem	75
		Closed Loop	66
		State Feedback	64
		System Identification	63
		Augmentation System	62
		Frequency Response	62
		Control Theory	61
		Control Inputs	59
		Transfer Function	59
		Optimization Problem	58
		Controller Design	57
		Fourier Transform	57
		Adaptive Control	53
		Nonlinear Control	53
		Open Systems	50
		Closed-Loop System	48
		Control Techniques	---
		Fault Tolerant	47
		Parameter Estimation	47
		Robust Control	46
		Genetic Algorithm	45
		Optimization Procedure	45
		Output Feedback	42
		Higher Harmonic	40
		Stability Augmentation	39
		Control Algorithm	38
		Control Problems	38
		Extended Kalman	38
		Transfer Functions	38
		Nonlinear Systems	37
		Digital Flight	36
		Feedback Theory	34
		Control Technology	---
		Automatic Control	29
		Control Strategies	29
		Control Strategy	29
		Flight Controls	29
		Digital Control	28
		Harmonic Control	28
		Quantitative Feedback	28
		Control Scheme	27
		Infinity Control	27
		Quadratic Gaussian	26
		Control Input	24
		Control Modes	24
		Control Performance	24
		Optimal Design	24
		Optimal Loop	24
		Flight Critical	23
		Fly-by-Light Advanced	23
		Control Technique	----
		Nonlinear System	22
		Fuzzy Controller	21
		Inner Loop	20

Ref. No.	Major Categories	Phrases	Frequency
		Kalman Filters	20
		Pitch Control	20
66	Neural Nets	Neural Network	326
		Neural Networks	142
		Artificial Neural	---
		Intelligent Control	28
		Using Neural	20
67	Actuators	Actuation System	34
		Piezoelectric Actuators	28
68	Fuzzy Logic	Fuzzy Logic	80
69	Hydraulics	Hydraulic System	20
		Hydraulic Systems	20
70	Environmental Control Systems	Heat Transfer	219
		High Temperature	180
		Heat Flux	68
		Surface Temperature	60
		Thermal Management	56
		Heat Sink	49
		Environmental Control	45
		Heat Exchanger	45
		Radiative Transfer	40
		Fuel Thermal	36
		High Temperatures	35
		Thermal Performance	30
		Thermal Control	28
		Heat Exchangers	25
		Heat Pipe	23
		Film Cooling	22
71	Landing Gear	Landing Gear	138
		Aircraft Landing	91
		Landing Systems	57
72	Fuel Systems	Fuel Tank	30
73	Lightning Protection		
74	Fasteners		
75	Ice Removal		
76	**PROPULSION/POWER**	Propulsion Systems	77
77	Controls/Diagnostics	Engine Control	42
		Propulsion Control	34
78	Fuel Control System	Fuel Consumption	60
		Fuel Flow	28
79	Engines	Aircraft Engine	232
		Aircraft Engines	174
		Propulsion System	123
		Propulsion Systems	77
		Engine Performance	52
		Engine Design	30
80	Gas Turbine	Gas Turbine	409
		Turbine Engine	----
		Turbine Engines	----
		Jet Engine	103
		Gas Turbines	92
		High Pressure	69
		Jet Engines	39
		Turbofan Engine	35
		Usage Monitoring	35

Ref. No.	Major Categories	Phrases	Frequency
		Combustion Chamber Pressure Ratio Rotating Stall Engine Failure Engine Thrust Combustion Efficiency Turbine Engines Aircraft Turbine Turbojet Engine Gas-Turbine Engines Pressure Recovery	31 30 30 29 29 27 25 23 22 20 20
81	Propeller/Propfan		
82	Blades/Discs	Turbine Blades Turbine Blade Tip Clearance	58 34 21
83	Coatings	Thermal Barrier Barrier Coatings	30 23
84	Diesel		
85	Spark Ignition		
86	Rotary		
87	Electrical Power	Electrical Power High Power Electric Power Power Systems Switched Reluctance Electric Aircraft Power Requirements	76 59 49 46 41 37 28
88	Generation	Power System Power Generation Auxiliary Power Power Unit Power Supply	82 58 39 32 27
89	Distribution and Control	Power Consumption Secondary Power	30 30
90	Fuels/Lubricants	Jet Fuel Jet Fuels Aviation Fuel Aircraft Fuel	120 83 32 30
91	Additives		
92	Pollution	Aircraft Emissions Air Pollution Environmental Effects	39 23 23
93	Contrails	Water Vapor	85
94	Mechanical Drive		
95	Gear Boxes		
96	Helicopter Drive Systems	Drive System	32
97	**AVIONICS**	Avionics Systems Avionics System Avionic Systems Fault Tolerance Digital Data Integrated Avionics Electronic Systems Military Avionics Avionics Architecture	112 97 60 60 49 47 42 39 36

Ref. No.	Major Categories	Phrases	Frequency
		Advanced Avionics	34
		Avionics Applications	34
		Thermal Performance	30
		Aircraft Avionics	28
		Parallel Processing	23
		Digital Avionics	22
98	Modular	Modular Avionics	53
		Integrated Modular	22
		Open Architecture	20
99	Flight Info	Data Bus	78
100	Data Fusion	Sensor Fusion	21
101	Fiber Optics	Fiber Optics	52
		Optical Fiber	47
102	Air Data	Air Data	57
		Laser Doppler	40
103	Artificial Intelligence Systems	Collision Avoidance	69
		Artificial Intelligence	55
		Knowledge Base	30
		Knowledge Based	28
104	Information Management	Information System	33
		Information Management	32
		Information Processing	29
		Vehicle Management	23
105	Decision Aids (Processing)	Decision Making	78
106	Neural Nets		
107	Case Based Reasoning		
108	Fuzzy Logic	Fuzzy Logic	80
109	Navigation/Guidance	Navigation System	196
		Navigation Systems	96
		Aircraft Position	48
		Instrument Landing	43
		Avoidance System	39
		Aircraft Navigation	38
		GPS INS	38
		Guidance System	34
		Integrated Navigation	34
		Global Navigation	28
		INS GPS	23
		Precision Navigation	23
		Air Navigation	22
		Digital Map	21
		GPS Inertial	21
		Position Information	20
110	GPS	Global Positioning	199
		Differential GPS	111
		System GPS	----
		GPS Receiver	96
		GPS Receivers	46
		Satellite Navigation	43
		GPS Data	34
		Satellite Systems	30
		GPS Navigation	29
		Using GPS	29
		Differential Global	27
		GPS Global	25

Ref. No.	Major Categories	Phrases	Frequency
		GPS DGPS	24
		Geostationary Satellites	23
		Landing Guidance	23
		Integrated GPS	22
		GPS System	21
111	INS	Inertial Navigation	120
		Inertial Reference	27
112	Communication Systems	Communication Systems	34
		Communication System	32
		Satellite Communications	31
		Laser Communications	26
		Communications Systems	24
		Satellite Communication	21
		Data Communications	20
		Radio Communications	20
113	Electronic Warfare (Self Protection)	Electronic Warfare	32
114	Software/Hardware	Software Package	46
		Avionics Software	30
		Hardware Software	28
		System Software	22
115	Development	Software Development	50
116	Validation		
117	Reliability		
118	**CREW SYSTEMS**		
119	Emergency Egress	Escape System	20
120	Ejection	Ejection Seat	80
		Ejection Seats	21
121	Seating		
122	Protection Systems	Life Support	27
123	Loss of Consciousness		
124	CBR		
125	Human/Machine Interface	Human Factors	163
		Night Vision	59
		Speech Recognition	40
126	Displays	Display System	48
		Flat Panel	48
		Helmet Mounted	46
		Display HUD	44
		Vision System	44
		Head-up Display	---
		Cockpit Display	40
		Imaging System	39
		Image Data	38
		Synthetic Vision	37
		Active Matrix	35
		Glass Cockpit	31
		Display Systems	30
		Cockpit Displays	29
		Crystal Display	---
		Helmet-mounted Display	28
		Display Formats	24
		Display Unit	24
		Crystal Displays	23
		Display Format	21
		Display Technology	21

Ref. No.	Major Categories	Phrases	Frequency
127	Data/Information Fusion	Situational Awareness	80
		Situation Awareness	63
		Data Fusion	41
128	Decision Aids	Decision Making	78
		Expert System	74
		Decision Support	52
		Pattern Recognition	52
		Expert Systems	41
		Computer Aided	39
129	Cockpit	Crew Station	38
		Aircraft Cockpit	30
		Aircraft Cockpits	21
		Cockpit Design	20
130	Crew Workload	Pilot Workload	46
		Human Performance	31
		Pilot Performance	23
		Crew Members	21
		Subjective Workload	20
131	**SUPPORT LOGISTICS**	Support Systems	33
		Support Equipment	31
		Air Logistics	22
132	Launch and Recovery	Microwave Landing	30
		Final Approach	29
		Landing Aircraft	24
		Landing Guidance	23
		Precision Approaches	22
		Automatic Landing	21
		Landing Approach	20
133	Runways/Airfields	Airport Surface	46
134	Platform Interface		
135	Reliability	High Reliability	44
		Thermal Cycling	30
		System Reliability	29
		Reliability Analysis	28
		Highly Reliable	23
		Quality Control	20
		Reliability Maintainability	20
136	Maintenance	Aircraft Maintenance	82
		Test Equipment	73
		Fault Detection	64
		Health Monitoring	64
		Monitoring System	---
		Visual Inspection	51
		Aircraft Inspection	35
		Condition Monitoring	33
		Monitoring Systems	---
		Maintenance Personnel	31
		Flight Inspection	30
		Fault Diagnosis	29
		Inspection System	26
		Maintenance Requirements	20
137	Costs		
138	Safety	Aviation Safety	34
139	Inventory Management		
140	Environmental		

Ref. No.	Major Categories	Phrases	Frequency
141	Hazmats		
142	Deicing		
143	**TRAINING**		
144	Simulation	Simulation Results Simulation Model Simulation System Inverse Simulation	148 69 39 23
145	Local		
146	Distributed		
147	Manned Flight Simulation	Flight Simulator Flight Simulation Piloted Simulation Flight Training Motion Simulator Simulation Experiments Simulation Studies Real-Time Simulation Interactive Simulation Simulated Flight	88 75 35 34 26 26 26 25 24 21
148	Software		
149	Development		
150	Validation		
151	Instruction	Training System Pilot Training	30 22
152	Techniques		
153	Types		
154	**MANUFACTURING**		
155	Processes	Manufacturing Process Process Control Manufacturing Processes Processing Techniques Rapid Prototyping Process Development Manufacturing Technology Manufacturing Techniques Quality Control	59 58 51 45 29 28 26 25 20
156	Joints	Adhesively Bonded	46
157	Structural		
158	Composite	Composite Laminates Transfer Molding Laminated Composite Lap Joint Lap Joints Composite Parts Laminate Composites	47 43 39 31 27 23 20
159	New Alloys		
160	Powder Metallurgy		
161	Electronic Devices		
162	Concurrent Engineering	Concurrent Engineering Rapid Prototyping	64 29

APPENDIX E
DATA MINING THE ENGINEERING COMPENDEX STRATEGIC MAP (AIRCRAFT)

** Three-Word Phrases; f ≥ 10 **

Ref. No.	Major Categories	Phrases	Frequency
1	**SYSTEMS ENGINEERING**		
2	Conceptual Design	Computer Aided Design Design of Advanced Design of Future	15 14 14
3	Aircraft Carrier		
4	Fighter/Attack	High Performance Aircraft Modern Fighter Aircraft Advanced Strike Technology Joint Advanced Strike Tactical Aircraft Systems	42 15 12 --- 10
5	Hypersonic Aircraft	National Aerospace Plane Aerospace Plane NASP	22 ---
6	Patrol/Transport	High Speed Civil Speed Civil Transport Civil Transport HSCT Commercial Transport Aircraft High-Speed Civil Transport NASA DC-8 Aircraft Civil Transport Aircraft Subsonic Transport Aircraft Large Transport Aircraft	37 --- --- 21 19 18 16 14 13
7	Rotorcraft	Hover and Forward Search and Rescue Rotary Wing Aircraft UH-60A Black Hawk Black Hawk Helicopter UH-60 Black Hawk	38 25 16 14 --- 10
8	V/STOL	Hover and Forward Tilt Wing Aircraft Tilt Rotor Aircraft Takeoff and Vertical Takeoff and Vertical Vertical Landing STOVL Ducted Fan VTOL High Speed V/STOL	38 13 12 11 11 --- 10 10
9	UAV/UCAV	Unmanned Aerial Vehicles Aerial Vehicle UAV Unmanned Air Vehicle Unmanned Air Vehicles High Altitude Aircraft Remotely Piloted Vehicle Air Vehicle UAV	21 19 19 17 16 15 11
10	General Aviation	General Aviation Aircraft International Civil Aviation	32 23
11	Ground Traffic Control	Airport Surface Traffic	11
12	Air Traffic Control	Air Traffic Control Air Traffic Management Traffic Control ATC Air Traffic Controllers Air Traffic Controller	169 58 --- 20 19

Ref. No.	Major Categories	Phrases	Frequency
		Traffic Management ATM	---
		Air Traffic Flow	12
		Traffic Control System	---
		Traffic Management Systems	---
13	Noise	Noise and Vibration	29
		Blade-Vortex Interaction Noise	19
		Interaction BVI Noise	19
		Overall Sound Pressure	13
		High-Speed Impulsive Noise	12
14	Cockpit	Active Noise Control	33
		Vibration and Noise	17
15	Airport	Sound Pressure Level	27
		Sound Pressure Levels	17
16	**COSTING**		
17	Affordability of New Systems	Reduce the Cost	18
		Performance and Cost	12
18	Life Cycle Costs	Life Cycle Cost	37
		Life Cycle Costs	23
		Cost of Ownership	20
		Direct Operating Cost	19
19	**PLATFORM/VEHICLE**		
20	**Aeromechanics**		
21	Design/Analysis	Analysis and Design	47
		Design and Analysis	44
		Meet the Requirements	37
		Design of Aircraft	---
		Analysis of Aircraft	---
		Results of Simulation	24
		Computer Aided Design	15
		Analysis and Simulation	13
22	Performance	Design and Performance	29
		Evaluate the Performance	27
		Position and Velocity	25
		Level of Performance	18
		Performance and Robustness	16
		Predict the Performance	15
		Performance of Aircraft	11
		Requirements for Aircraft	11
		Significant Performance Improvements	11
		Rate of Climb	10
23	Aerodynamics	Angle of Attack	255
		Angles of Attack	216
		Computational Fluid Dynamics	113
		Fluid Dynamics CFD	---
		Turbulent Boundary Layer	21
		Freestream Mach Number	19
		K- Epsilon Turbulence	16
		Surface Pressure Measurements	16
		Computational Fluid Dynamic	14
		Euler and Navier-Stokes	14
		Surface Pressure Distributions	14
		Thin-Layer Navier-Stokes Equations	14
		Using an Implicit	12
		Epsilon Turbulence Model	---

Ref. No.	Major Categories	Phrases	Frequency
		Lift Drag Ratio Incompressible Navier-Stokes Equations Total Pressure Loss	11 10 10
24	Wing Design	Twist and Camber Wing Leading Edge	16 14
25	High Lift	Lift and Drag Trailing Edge Flap	33 17
26	Vortex Flow	High Alpha Research Free Wake Model Vortex Breakdown Location	14 12 12
27	Unsteady Flow	Steady and Unsteady Unsteady Aerodynamic Forces Unsteady Aerodynamic Effects Unsteady Aerodynamic Model	20 16 12 11
28	Wing Rock		
29	Drag Reduction	Lift and Drag Laminar Flow Control Natural Laminar Flow	33 18 10
30	Wind Tunnel	Wind Tunnel Test Wind Tunnel Tests Wind Tunnel Testing Wind Tunnel Data Low-Speed Wind Tunnel Speed Wind Tunnel Wind Tunnel Model Tunnel Test Data	51 32 24 21 18 13 --- 12
31	Icing Conditions		
32	**Flight Dynamics**		
33	Stability and Control	Forces and Moments Degrees of Freedom Stability and Control Pitch and Roll Force and Moment Center of Gravity Stability Augmentation System Aircraft Landing Dynamics Attack and Sideslip High Alpha Research Pitch and Yaw Stability and Performance Longitudinal Flight Control Performance and Stability Roll and Yaw Lateral and Longitudinal Stability and Response	46 34 34 32 30 25 15 14 14 14 12 12 11 11 11 10 10
34	Handling Qualities (Flight test) (Flight Test Data, Flight Test Results, Actual Flight Test, and Aircraft Flight Test adjusted to reflect handling qualities related abstracts~ 20%)	Flight Test Data Flight Test Results Handling Qualities Requirements Aircraft Landing Dynamics Performance and Handling Handling Qualities Ratings Loss of Control Actual Flight Test Aircraft Flight Test Helicopter Handling Qualities	26 16 16 14 12 11 11 2 2 10

Ref. No.	Major Categories	Phrases	Frequency
		Maneuverability and Agility	10
35	Dynamic Interface (Helicopters and V/STOL with Ships)		
36	Flight/Propulsion Control	Flight Propulsion Control	16
		Integrated Flight Propulsion	---
37	Helicopter Rotors	Helicopter Rotor Blades	38
		Helicopter Rotor Blade	29
		Blade-Vortex Interaction BVI	28
		Rotor in Forward	26
		Individual Blade Control	22
		Rotor in Hover	22
		Bearingless Main Rotor	21
		Blade Vortex Interaction	21
		Blade-Vortex Interaction Noise	19
		Interaction BVI Noise	---
		Composite Rotor Blades	17
		Flap and Lag	15
		Helicopter Main Rotor	36
		Rotors in Hover	12
		Main Rotor Wake	11
		Number of Blades	11
		Track and Balance	11
		Vortex Interaction BVI	---
38	Signature (Configuration/ Shaping)	Radar Cross Section	68
		Cross Section RCS	---
		Probability of Detection	26
		Detection and Tracking	22
39	**Structures**	Structures and Materials	23
		Materials and Structures	18
		Wing and Fuselage	13
		Fuselage and Wing	11
40	Design/Analysis - Finite Element	Finite Element Method	92
		Finite Element Analysis	83
		Finite Element Model	68
		Analysis and Design	47
		Design and Analysis	44
		Degrees of Freedom	34
		Finite Element Models	30
		Nonlinear Finite Element	---
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