be further improved by aligning the body with the freestream direction. For example, based on Fig. 4 and using a designed cruise lift coefficient of about $C_L = 1.0$, wing incidence can be increased to 6 deg relative to the fuselage to obtain L/D ratios higher than 27.9, and much higher than the reported L/D = 23 of some advanced configurations.[4,5]

The pitching moment data for the smooth and tripped fuselage-boundary layer flows are presented in Fig. 4, and the differences between these two cases are quite small. With the tripped boundary layer a slight increase in the nose-down moment was measured, particularly within the visually attached airfoil-flow region (5 deg $< \alpha <$ 14 deg). This incremental effect is caused by the slightly increased drag on the rougher surface, which also causes a small reduction in the lift. The most dominant feature of the pitching moment curve in Fig. 4 is the sharp increase in the nose-down moment beyond wing stall ($\alpha >$ 15 deg). At the lower angles of attack, however, the pitching moment in the present test was quite independent of α (near a value of $C_M = -0.1$), contrary to the continuous negative slope of the data in Ref. 1. The present and perhaps more desirable location for the pitch axis is a result of the modified wing geometry and some other minor model mounting changes in the wind-tunnel setup. The very large nose-down moment beyond wing stall, shown in this figure, is a result of the lift created by the aft-fuselage side-edge vortices. As noted in Ref. 1, this large increase in the negative slope of C_M can be considered as a stall resistant feature with important safety-related implications. Therefore, when airplane c.g. calculations and elevator sizing are complete, the use of these data can make airplane stall unreachable (note that effects such as fuselage side-edge vortex burst are delayed beyond $\alpha >$ 30 deg). For example, the pitching moment data presented in Ref. 1 show that the trailing-edge flap (elevator) is capable of creating a change of $\Delta C_M \sim 0.3$, which is much smaller than the poststall moments shown in Fig. 4. Finally, the incremental trim drag measured at an extreme flap deflection of $\delta_{\text{flap}} = 10$ deg reduced the L/D ratio (at $\alpha = 6$ deg) to 24.65, from 27.9 at zero flap deflection, demonstrating only moderate penalty in configuration efficiency caused by excessive trim.

Conclusions

Aerodynamic tailoring was used to demonstrate the performance of a lifting-body/wing configuration using a low-Reynolds-number test. A relatively high-camber airfoil shape was designed for the small-scale test so that wing stall would occur in the range expected of a full-scale aircraft. Wind-tunnel tests confirmed that the fuselage can be used as a simple and inexpensive high-lift device, demonstrating a maximum L/D value of 27.9. In addition, at high angles of attack the fuselage side-edge vortex lift creates a large nose-down pitching moment that can be used to obtain a stall-safe lifting-body configuration. Finally, from a theoretical point of view the aircraft model with the highly cambered airfoil can be seen as the low-speed configuration of a single element, adaptive (flexible) wing section, which transforms to a high-speed shape at cruise. Transition between the two airfoil shapes (in this particular case) would take place at about $\alpha = 4$ deg.

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Database Tomography Applied to an Aircraft Science and Technology Investment Strategy

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I. Introduction

THIS Note summarizes the results of applying text data mining (TDM) techniques to aircraft science and technology (S&T) records retrieved from two source technology databases for the purpose of obtaining technical intelligence on aircraft S&T. A much more detailed presentation of the results and TDM techniques is contained in the study's final report.[1] Two complementary TDM techniques were used in this study: 1) bibliometrics to identify the infrastructure of aircraft S&T (e.g., who are the performers, where are the results archived, what are the seminal papers) and 2) computational linguistics to identify the main aircraft S&T thematic areas and the relationships of these thematic areas to each other and to the infrastructure. The source databases examined were the science citation index (SCI)[2] (basic research, 1991–1998) and the engineering compendex (EC)[3] (applied research/technology, 1990–1998). Records were retrieved from these databases using an iterative query technique and then examined using a patented software system for analyzing large amounts of textural material.[4,5]

Aircraft S&T, as defined here, consists of development of different aircraft/helicopter components or technologies to improve system performance or safety or to 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.

The final query used to retrieve records from the SCI contained 207 terms and is shown in Ref. 1. The final query used to retrieve records from the EC contained essentially the 13 terms preceding the NOT Boolean in the SCI query (aircraft or air vehicle* or helicopter* or rotorcraft or unmanned air vehicle or uninhabited combat air vehicle (UCAV) or vertical takeoff and landing or very short takeoff and landing or advanced short takeoff and vertical landing or short takeoff and vertical landing or avionic* or cockpit or aircrew*). Very few abstracts that were extraneous to the focus of the study were retrieved from the EC, and the EC database did not require the same number of iterations used for the SCI database. This derives from the fact that the platform technology focus of the study is better aligned with the platform technology orientation of the EC database than

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the science orientation of the SCI database. In the prefiltered SCI aircraft-related records, many records related to the use of aircraft as a platform for performing research, and the resultant SCI query had to be expanded with negation terms to excise these records from the final retrieval.

II. Results

A. Bibliometrics

The SCI/EC metrics are summarized in Table 1.

The most prolific aircraft related authors are, for SCI, I. Chopra, S. N. Atluri, A. Chattopadhgay, T. Ford, R. Hess, and L. E. Ericsson. The most prolific, for EC, are I. Chopra, R. Celi, A. Ray, B. Parkinson, and B. Sridhar. The presence of a moderate number of collaborators per aircraft paper (Table 1) means that the expected large experimental research projects from laboratory and flight experiments do not dominate what is reported to the literature, and that individual small-scale projects play an important role in aircraft research.

The journals containing the most aircraft-related papers, for SCI, are: *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*; *AIAA Journal*; *Aeronautical Journal*; *Izvestiya Vysshikh Uchebnykh Zavedenii Aviatsionaya Tekhnika*; *Aerospace Engineering*; *Aerospace America*; and *Nouvelle Revue Aeronautique Astronautique*.

Of the 11 journals highest in the SCI list, all but 3 appear in the top 25 of the EC listing. They were *Aircraft Engineering and Aerospace Technology* (number 38), *Aerospace America* (number 40), and *Nouvelle Revue Aeronautique*, which 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 near-Earth space TDM study,[6] 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.

A listing of the organizations producing the most aircraft papers, for SCI, follows: NASA; U.S. Air force; U.S. Navy; Georgia Institute of Technology; General Electric; U.S. Army; Virginia Polytechnic Institute and State University; Technion—Israel Institute of Technology; The Boeing Company; Purdue University; McDonnell Douglas; Pennsylvania State University; DLR, German Aerospace Research Center; and the Indian Institute of Technology (India).

For EC, the organizations are NASA, McDonnell Douglas, The Boeing Company, Lockheed Martin, Georgia Institute of Technology, General Electric, University of Maryland, U.S. Air Force, Northwestern Polytechnical University (People's Republic of China), and University of California.

In both databases, the NASA laboratories were the most prolific producers by far, as was the case in a similar study of the hypersonic and supersonic literature.[7] Because funding levels were not examined, bibliometric productivity per dollar was not generated.

The countries producing the most aircraft-related papers, for SCI, are the United States (2771), the United Kingdom (507), Germany (250), France (218), and Japan (218). For EC, the countries are the United States (8527), the United Kingdom (875), the People's Republic of China (562), Germany (468), and Canada (363). The dominance of a handful of countries is clearly evident. The United States is 5 times (SCI) and 10 times (EC) more prolific than its nearest competitor (the United Kingdom). In both the aircraft SCI and EC databases, the United States is as prolific as all its competitors combined.

For SCI, the most cited aircraft-related authors are L. E. Ericsson (117), W. Johnson (97), A. Miele (96), J. C. Doyle (82), and M. B. Tischler (80). The most cited authors, although prolific, are not the most prolific authors and vice versa. For example, the authors listed (Ericsson, Johnson, Miele, Doyle, and Tischler) ranked 14, 918, 87, not listed, and 35, respectively, in the prolific authors list. The five most prolific technical paper authors (I. Chopra, S. N. Atluri, A. Chattopadhyay, T. Ford, and R. Hess) ranked 91, 41, 11, not listed, and 9, respectively, in citability.

Compared to a similar recent TDM analysis of fullerenes (a particular construct of carbon atoms), these aircraft author citation numbers are very low.[8] The most cited aircraft authors [Ericsson (117) and Johnson (97)] were cited more than an order of magnitude less than the most cited fullerene authors [Kroto (4328) and Kratschmer (3472)]. This reflects both the more applied nature of aircraft research relative to fullerenes and the high level of fullerenes research activity relative to aircraft research activity.

The most cited aircraft-related papers, for SCI, were by Johnson, 1980 (28); Snell, 1992 (25); Doyle, 1989 (23); Lane, 1988 (22); and Isidori, 1989 (20). Essentially all of the highly cited papers, for example, 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 earlier cited study of fullerenes[8] 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 database indicates that the highly cited papers were published in the 1970s and 1980s with only a few in the early 1990s.

The most cited aircraft-related journals, for SCI, are *Journal of Aircraft*; *AIAA Journal*; *Journal of Guidance, Control, and Dynamics*; *Journal of the American Helicopter 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*; and *Automatica*.

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.

Bradford's law[9] for journal publications allows journals to be grouped by primary core, secondary core, etc., where each group of journals contains the same number of papers. For the aircraft SCI database, the first group selected contains three journals with 857 papers (*Journal of Aircraft*, *Aviation Week and Space Technology*, and *Journal of Guidance, Control, and Dynamics*), the second group has 10 journals with 864 papers, etc. The 10 most highly cited papers in the aircraft study were examined. It was found that only 1 of

Table 1 Bibliometric indicators for SCI and EC

Metric	SCI	EC
Papers retrieved	4,346	15,673
Authors	6,619	25,586
Author listings	9,085	34,973
Listings per author	1.37	1.37
Authors per paper	2.09	2.23
Journals per conference proceeding	713	1,876
Papers per journal	6.1	8.4
Organizations	1,486	4,759
Papers per organization	2.93	3.29
Countries	56	71
U.S. papers	2,771	8,527
% U.S. papers	64	54
Total references	45,744	na
References per paper	10.5	na
Authors cited	21,868	na
Citations per author	2.09	na
Papers cited	38,792	na
Citations per cited paper	1.18	na

these 10 was contained in the first core group of three highest cited journals (based on the Bradford law). In addition, none of the 10 were found in the second core group of 8 journals. One can, therefore, conclude that to research a particular aircraft technology, confining one's reading to the first one or two core journal groups will exclude many high-quality documents. TDM 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 that could impact the target field.

B. Database Tomography Results

1. *Phrase Frequency Analysis: Pervasive Themes*

High-frequency double and triple word phrases (from the Abstract texts within the databases) whose technical content were deemed to be significant were identified and mapped to a strategic taxonomy of 163 categories that addressed all of the major aircraft-related technologies. 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. Their associated frequencies of occurrence were then totaled to give a picture of the database 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 database in that specific area. Analysis of the SCI and the EC listing aircraft-related interest areas by major grouping based on phrase frequency analysis of text Abstracts showing highest subcategories produced the results shown in Table 2.

Examining Table 2 provides some insight into the high as well as low interest areas in the technical community and where, over the past 6–7 years, the majority of effort has been focused. For example, the highest categories for both the SCI and EC databases tend to be related to aircraft performance issues, for example, structures and aeromechanics and subsystems. Systems engineering and avionics tended to be of somewhat greater interest in the EC than the SCI, whereas flight dynamics and propulsion and power issues tended to be of greater interest in the SCI. 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 program. In both cases, one might suspect that the work would more likely be published in the fundamental journals, represented by the SCI.

The lowest categories in both databases tended to be in the costing, training, crew systems, manufacturing, and support/logistics areas. Note that despite all of 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 and manufacturing, maintenance-related work (support/logistics), and training. This might suggest that these areas are being neglected by the technical community despite all of the rhetoric to the contrary. If there is increased focus in these areas, it does not appear to be reflected in improved technologies that would warrant research and a published paper, or it is being worked in the engineering community that does not generally publish their work in open literature and journals. From an aircraft technology perspective, this is unfortunate because 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 Department of Defense 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 and/or report literature not accessed by the SCI or EC.

2. *Phrase Proximity Analysis: Relationships Among Themes and Subthemes*

This technique allows for the quantitative determination of closely associated technology themes and subthemes. Once a theme is chosen and the phrase proximity analysis applied to the database, it is possible to determine the technologies, authors, institutions,

Table 2 Highest aircraft related interest areas

SCI	EC
Structures: strength, design/analysis, crack initiation and growth, loads and dynamics, fatigue	Aeromechanics: aerodynamics, design/analysis, performance (aircraft), wing design, wing 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, unmanned air vehicle/uninhabited combat air vehicle, vertical/standard takeoff and landing
Systems engineering: fighter/attack, cockpit noise, patrol/transport, conceptual design, air traffic control, airport noise	Avionics: global positioning system (GPS), navigation and guidance, avionics (general), communication systems, artificial intelligence, inertial navigational system, software/hardware, 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	Propulsion and power: gas turbine engine, engines (general), electrical power (general), fuels/lubricants, electrical generation, blades/disks
Materials: composites, metals/alloys, nondestructive inspection/testing, corrosion, adhesives, ceramics	Materials: composites, metals/alloys, non-destructive inspection/testing, materials (general), corrosion, smart materials
Support/logistics: maintenance, take-off and landing, safety (maintenance), platform interface, deicing	Support/logistics: maintenance, reliability, Takeoff and landing, support/logistics (general), runways/airfields
Manufacturing: joints, processes, structural (manufacturing), concurrent engineering, composites (manufacturing)	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 (manufacturing), 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

and journals most closely associated with the theme phrase within the database. In the example provided, where structures was the theme and the aircraft SCI database 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. Heslehurst, 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 Federal Aviation Administration), journals (*Journal of Solids* and *Journal of Intelligent Material*) and countries (United States, 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 database.

Similarly, for the aircraft EC database, the most closely associated technology subcategories were the same as for the SCI database (just indicated), 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 Aeronautical Systems Center of Wright Laboratories and the American Helicopter Society, although many technical societies, such as the American Institute of Aeronautics and Astronautics, the American Society of Mechanical Engineers, the American Society of Civil Engineers, and the Society for Advancement of Material and Process Engineering 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 United States 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 database.

III. Potential Areas of Additional Technology Effort

Based on the distribution of effort, represented by the published papers, over the past 7–8 years, it would appear that there are several areas that, in conjunction with recently expressed naval aviation priorities,[10] could benefit from increased attention and deserve a hard look for additional investment. These would include such areas as helo 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 protection systems; and training with increased use of simulation. All of the cited 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.

IV. Conclusions

In summary, database tomography (DT) and bibliometrics would appear to be extremely effective tools for technology program managers in the development of an investment strategy. The process allows for the development of a very focused database that 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 database 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. This will greatly assist the program manager as a new program plan is being developed 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 will rapidly 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. Last, through the use of DT, closely related themes to a given technology can be identified and pursued.

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Fast and Robust Viscous/Inviscid Interaction Code for Wing Flowfield Calculations

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Introduction

IN this study[1] a three-dimensional potential solution has been combined with two-dimensional viscous/inviscid interaction flow analysis at several cross sections across the wing span. With the assumption of no crossflow at these stations, the method provides a flow solution with the viscous effects taken into account. The two-dimensional flow solver used in the new combined method is XFOIL,[2] which has a built-in two-dimensional panel code, and a viscous/inviscid interaction solver, which is based on empirical formulas. One remarkable property of this flow solver is that it treats the boundary-layer edge velocity as the sum of the inviscid part and the viscous part, which embodies the effect of viscous/inviscid interaction. Therefore, the inviscid solution can come from anywhere and is totally independent of the viscous solution. In the combined method the two-dimensional panel code in XFOIL is bypassed, and instead, a cross section of the three-dimensional panel solution is read in and treated as a two-dimensional solution.

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