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Review

Highly cited literature of high-speed compressible flow research ☆

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ABSTRACT

High-speed flow research has been sponsored and performed at differing levels of effort since the late 1800s. For example, hypersonic research has experienced numerous cycles since the 1950s, with various periods of high research activity, followed by equally long periods of very low activity. This lack of continuity in high-speed flow research has led to a situation where researchers of one "generation" often do not know what the researchers of previous "generations" have done, mainly due to large losses of institutional knowledge in government, industry, and academic organizations. Therefore, a chronically weak area in research papers, reports, and reviews is the complete identification of critical background documents that form the building blocks and intellectual heritage for modern compressible flow research. A method for systematically determining these critical references is presented in the context of its application to high-speed flow using Citation-Assisted Background, which is based on the assumption that many critical documents tend to be highly cited within the literature, although not necessarily recently. While Citation-Assisted Background is a highly systematic approach for identifying critical references, it is not a substitute for the judgement of the researchers, but rather complements their expertise. In this critical review of high-speed compressible flow, important documents have been identified using Citation-Assisted Background, but other documents have been added by the authors to enhance the picture provided by the highly-cited documents.

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1. Introduction

High-speed flow research (transonic, supersonic, and hypersonic flow) has been conducted for decades, if not centuries. A great deal of that research has taken place, however, in periods of intense interest, often followed by equally long periods of little or no interest. Because of this, the background literature available to researchers is very specialized and often not easily obtained.

When this situation is coupled with the relatively recent advent of computer-based citation indexes, additional difficulties arise for the current researchers in the field. How many of the seminal works in high-speed flow research are listed in various computer data base search engines and how easy are they to identify? Will current research students, who have a tendency to rely heavily on computer and web-based searches, be able to find the critical research documents in their field of interest? Will the fact that a great majority of that research happened prior to the advent of computer data bases adversely impact the research that is currently being conducted? These are all questions that have plagued researchers in a variety of fields, but perhaps one of the most difficult fields to obtain good background information for is high-speed flow research.

The primary purpose of this work is to outline the critical and highly-cited literature for high-speed flow research, going back over a century in time. The areas of high-speed flow research that will be included in the description are aerothermodynamics, propulsion/combustion, and vehicle design. Numerous sub-topics will be considered for each of these areas, as appropriate, with the critical literature of these fields listed and discussed. The literature for each of these areas was located using a modern computer data base search approach known as Citation-Assisted Background (CAB). The details of how CAB is used for the search are outlined, and the results are discussed. Using such an approach for citation searching should greatly help in insuring that the future of high-speed research will be solidly built upon the past, rather than missing critical and important previous work that would have been crucial to current and future research developments.

2. Background

Research is a method of systematically exploring the *unknown*, or determining more about the *known*, in order to acquire knowledge and understanding. Efficient research requires awareness of all prior research and technology that could impact the research

☆ The views in this paper are solely those of the authors, and do not represent the views of the United States Air Force Academy or the Georgia Institute of Technology.

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topic of interest, and builds upon these past advances to create discovery and new advances (like Isaac Newton, who said he was standing on the shoulders of giants). The importance of this awareness of prior science and art is recognized throughout the research community in all fields of science and engineering. The need for exploring the past prior to exploring the future can be expressed in diverse ways, including requirements for Background sections in journal research articles, invited literature surveys in targeted research areas, and required descriptions of prior work in patent applications.

For the most part, development of background material for any of the above applications has been relatively slow, labor intensive, and limited in scope. Background material development, although an important scholarly activity, usually involves some combination of manually sifting through outputs of massive computer searches, manually tracking references through multiple generations, and searching one's own records for personal references. The few studies that have been done on the adequacy of background material in documents show that only a modest fraction of relevant material is included [44,199,205].

In a study that is highly relevant to the topic of this paper, two background surveys of the abrupt wing stall (AWS) literature (as a precursor to establishment of a government research program) by an AWS expert were compared to a text-mining-based identification of relevant AWS documents from the Science Citation Index (SCI) [162]. In the first expert-based AWS background survey [49], three of the expert's total of 37 references were in common with the 40 245 references retrieved in the text-mining-based study. In the second expert-based AWS background survey [50], seven of the expert's total of 61 references were in common with the text mining study results.

For a relatively focused topic such as AWS, one would have expected a far more substantial overlap. Many of the expert's references appeared to be quite applied, with focus on tests of specific aircraft. In contrast, the text mining-based SCI papers tended to be more fundamental, concentrating on the analysis of basic flowfield phenomena and physics. In addition, authors tend to cite a handful of "favorite" fundamental references, and so the combination of fundamental papers from the SCI retrieval coupled with the author's personal favorite references complemented the more applied set in the expert's study. For the purpose of identifying gaps in the research literature to be addressed in a prospective AWS research program, a survey of the fundamental AWS research literature is essential.

This specific example shows perhaps the main value of the retrieval approach that underlies the CAB process; it allows the expert to go beyond his/her own experience to objectively access and retrieve literatures with which they may not be familiar. Had the objective of the AWS literature review been to identify seminal AWS papers, then the full CAB capabilities could have been exploited as well.

In another example of the inadequacy of background material, an analysis of Medline papers on the haemodynamic response to orotracheal intubation showed that recognized deficiencies in research method were not acknowledged. The authors of this study recommended that, when submitting work for publication, investigators should provide evidence of how they searched for previous relevant research work [286].

Another specific example was provided by MacRoberts and MacRoberts [206]. Replicating their earlier work in a journal on genetics that indicated only 30% of influences evident in the text were reflected in a paper's references, the text of an issue of *Sida* (now called the *Journal of the Botanical Research Institute of Texas*) was studied to extract influences of previous work evident therein. Influences they judged to be present in the text appeared in the references only 29% of the time.

Typically missing from standard Background section or review article development, as well as in the specific examples cited above, is a systematic approach for identifying the key documents and events that provided the groundwork for the research topic of interest. In the field of hypersonic research, for example, the Air Force Scientific Advisory Board noted that, "hypersonics has always suffered from a pattern of cyclical fits and starts at roughly 15-year intervals" [10]. This has led to a situation where entire generations of researchers and designers may be unaware of the programs or research which had previously been done, or the advances and concepts that those programs included. Programs like DYNASOAR, the X-15, the Space Shuttle, NASP, HOTOL, X-33, and Hyper-X were separated by fairly large periods of time, and often were performed by people who did not have the luxury of knowing the researchers or results of all the previous programs (in some cases because those results were not readily catalogued in modern data base systems; in other cases, such as AWS, because the vendors and sponsors did not want to over-advertise problems with their products). What impact has this cyclic nature of high-speed research had on the current generation of people working on various concepts and designs? How many times have current researchers "missed" previous work because it was too old to find in modern databases, or because they did not have the appropriate search algorithms to identify the relevant research of interest? How much has this impacted the growth of science and engineering within high-speed research? Finding a way to systematically (and to a lesser extent, permanently) solve this problem was a major motivation behind this work. The present paper presents such a systematic approach for identifying the key documents, called Citation-Assisted Background. The next section describes the CAB concept and provides an outline of how it is applied to the area of high-speed flow research.

The CAB concept of Kostoff and Shlesinger [161] identifies the seminal and other critical background documents for a research area using citation analysis. CAB rests on the assumption that a significant building block document for a specific research area will typically have been referenced positively by a substantial number of people who are (or were) *active researchers in that specific area*. The specific approach for applying CAB to high-speed compressible flow is outlined in Appendix A. With use of a comprehensive query, 10 556 high-speed compressible flow articles and their references were retrieved. As an illustration of results, Table 1 contains the twenty most cited references extracted from the 10 556 high-speed compressible flow articles.

Two citation frequencies are computed for each reference, but only the first is shown in Table 1. The frequency shown in the left-most column is the number of times each reference was cited *by the* 10 556 *records in the retrieved database only*. This number reflects the importance of a given reference to the *specific discipline of high-speed compressible flow*. The second frequency number (not shown) is the total number of citations the reference received from all sources, and reflects the importance of a given reference to *all the fields of science that cited the reference*. This number is obtained from the citation field or citation window in the SCI. In CAB, only the first frequency is used, since it is topic-specific. Using the first discipline-specific frequency number obviates the need to normalize citation frequencies for different disciplines (due to different levels of activity in different disciplines), as would be the case if total citation frequencies were used to determine the ordering of the references. References that have high values of the second frequency and low values of the first frequency are typically (but not always) of peripheral relevance to the discipline of interest.

A few observations about the twenty articles listed in Table 1 are in order before proceeding with more details about the search. The topics of the articles are dominated by presentations of numerical algorithms appropriate for compressible flow (a total of