The NASA Technical Report Server

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Abstract

The National Aeronautics and Space Act of 1958 established the National Aeronautics and Space Administration (NASA) and charged it to "provide for the widest practicable and appropriate dissemination of information concerning … its activities and the results thereof". The search for innovative methods to distribute NASA's information led a grass-roots team to create the NASA Technical Report Server (NTRS), which uses the World Wide Web and other popular Internet-based information systems.

Internet Research: Electronic Networking Applications and Policy
Volume 5 · Number 2 · 1995 · pp. 25–36
MCB University Press · ISSN 1066-2243

Introduction

The National Aeronautics and Space Act of 1958 established the National Aeronautics and Space Administration (NASA) and charged it to "provide for the widest practicable and appropriate dissemination of information concerning…its activities and the results thereof". To meet this goal, researchers at various NASA installations have developed several new methods of distributing information to the nation's research and industrial sectors. One key method is the NASA Technical Report Server (NTRS). The NTRS is an inter-center effort to provide uniform access to various distributed publication servers residing on the Internet. It currently provides access to documents from nine different NASA organizations spanning the USA: the Langley Research Center (LaRC), the Dryden Flight Research Center (DFRC), the Numerical Aerodynamic Simulation Division (NAS) of the NASA Ames Research Center (ARC), the Goddard Institute for Space Studies (GISS), the Institute for Computer Applications in Science and Engineering (ICASE) at LaRC, and the Selected Current Aerospace Notices (SCAN).

The NTRS is accessible via the World Wide Web (WWW) (Berners-Lee *et al.*, 1992), a multi-protocol Internet information system, using software such as the freely available and highly popular NCSA Mosaic (Andreessen and Bina, 1994), developed at the National Center for Supercomputing Applications (NCSA) at the University of Illinois Urbana-Champaign. There are many different WWW browsers available, most of them free of charge for all popular platforms (Unix, Mac, PC, VMS). Plate 1 shows the NTRS page as seen through a WWW client. Implementing NTRS with the WWW reduced the development time necessary for such an effort. WWW is used for many services, thus NTRS is built on the tools and lessons learned from many other WWW projects. From the users' perspective, NTRS is one of many available WWW services, allowing

The authors would like to thank James Gass and Michael Grabenstein (NASA Goddard) and Rick Dunbar, Gregory Decker, Steve Mullen and Richard Tuey (NASA STI) for their work with servers and coordination at their respective centers.

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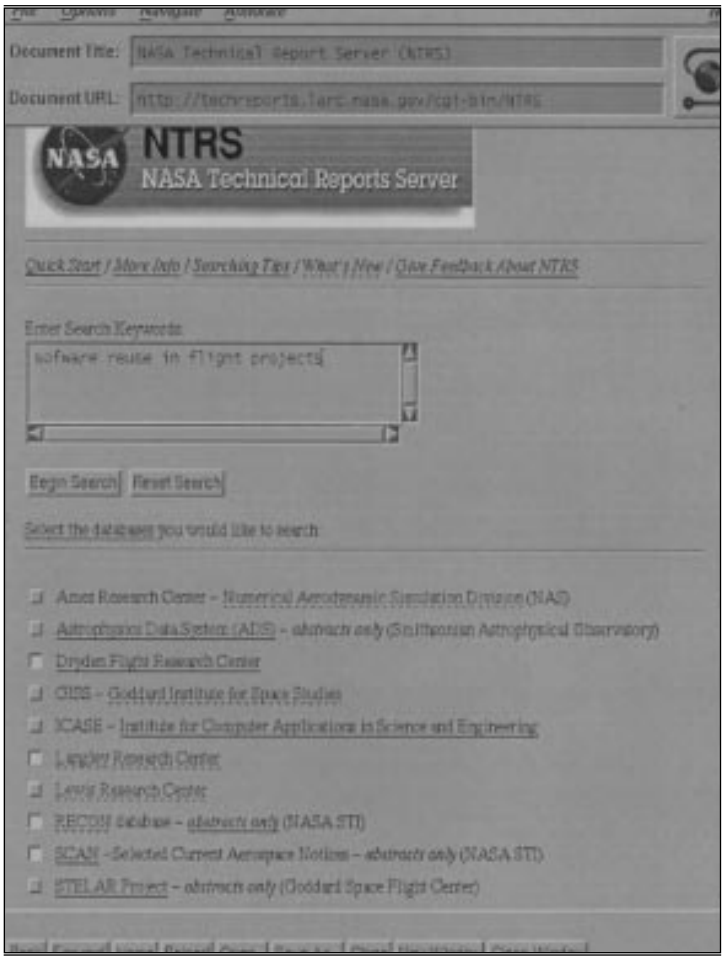
Plate 1 NTRS through NCSA Mosaic for the X Window System



access with a consistent and well-known interface. NTRS is available at the following uniform resource locator: http://techreports.larc.nasa.gov/cgi-bin/NTRS

Project goal

The goal of NTRS is to provide "one-stop-shopping" for NASA technical publications. The intended audiences are researchers and scientists, not information specialists or librarians. NTRS is not the final word in searching and indexing; its intent is to provide maximum connectivity and exposure to the already existing body of NASA electronic literature.

One can think of NTRS as a grass-roots, electronic document reuse effort. Many researchers prepare their conference papers, technical reports, and journal articles using sophisticated word processing and desktop publishing tools. High-quality document preparation systems for personal computers and workstations have enabled researchers to produce fully (or mostly) electronic publications. After the paper is printed and sent to the publisher, it is then assembled and preserved in hard copy format and often included in a proceedings document. While there are advantages to preserving the document in this format, most researchers maintain an electronic copy of the publication. NTRS attempts to gather the diffuse collection of electronic publications, index them, and offer them to the scientific community.

NTRS is not a document life-cycle management system; there are many commercial products that are. The internal procedures involved in creating and reviewing documents are the focus of such systems. Some of these systems offer interesting and useful functionality, such as remote collaborative editing and annotation. These systems do not necessarily compete with the components of NTRS because NTRS is focussed only on the customer side of searching and retrieval. While NTRS could be expanded to provide access to different document types, only "finished products" are currently indexed in NTRS. NTRS provides access only to publications that have passed through the existing approval and review mechanisms; it does not directly address internal approval processes prior to publication.

Initially, attempts were not made to convert existing paper documents to electronic form, although it is desirable that all significant publications, such as National Advisory Committee for Aeronautics (NACA) (predecessor of NASA, 1917-1958) reports, eventually be accessible via the WWW. The more difficult problem of providing electronic access to legacy collections is the focus of other projects (Smith, 1992). The results of these other projects will be included in NTRS when they are available.

Services provided

The NTRS provides the following services to the user:

- *A single standard interface to multiple disparate NASA technical paper databases* – the NTRS is a virtual "wrapper" script for several different Internet database servers NASA-wide. It reduces the user interfaces for all servers to a single, common-user format. The NTRS

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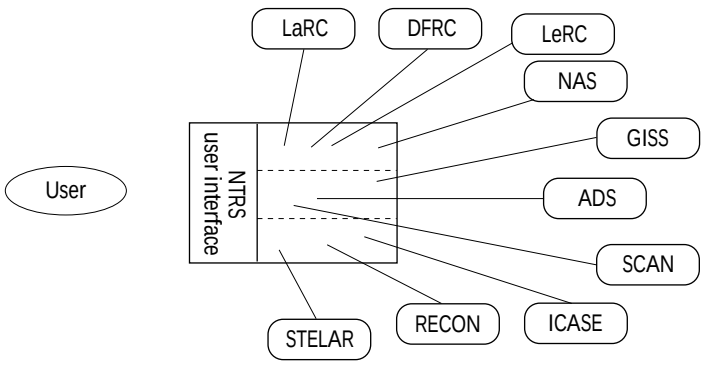
script hides the operational differences of each of the servers from the user and submits the properly formatted query to each participating report server. This system is essentially a widely distributed database, allowing each site participating in NTRS to update and maintain data locally, and eliminating the need for central administration of the system. Figure 1 shows the interface of NTRS to the various servers.

- *Simple and rapid searches for information on NASA technical reports* – since the NTRS is available via the WWW, the user interface provided is a common, familiar, easy-to-use "point-and-click" style. WWW interfaces are available for most Unix workstations, Macintosh computers, Windows-based PCs, and DEC VAXes. The information is available to users' desktops 24 hours a day. Currently, searching is limited to only the abstract and bibliographic information, not the full text of the document. At this time, only the Astrophysics Data System (ADS) database implements field searches. All other databases do not allow restricting search terms to specified fields (e.g. author, title or abstract).
- *Rapid delivery of complete copies of technical reports* – If a report is available on the NTRS system, the user may choose to download a copy by a single click. The reports are currently stored in either PostScript or Hypertext Markup Language (HTML) format, saving users significant time and effort. Retrieval time is measured in seconds, not days. If a report is not available online, the user is allowed to order a paper copy via more traditional means.

Figure 1 NTRS access hierarchy



NTRS architecture and history

Much of the design and toolset for implementing NTRS was developed for the Langley Technical Report Server (LTRS) (Nelson and Gottlich, 1994; Nelson *et al.*, 1994). LTRS began in 1993 as an anonymous file transfer protocol (FTP) server, with just over 100 LaRC formal technical reports. While use of anonymous FTP was adequate for those audiences familiar with computers, it intimidated some of the more casual users of computers. The transition of LTRS to a WWW interface integrated keyword searching and document retrieval, and allowed casual computer users to access the publications.

When the LTRS proved useful for researchers at LaRC and beyond, it became obvious that technical publications other than LaRCs should be made available as well. Specifically, the implementors of NTRS desired easy electronic access to publications at other NASA facilities. The shell scripts, methods and other products developed for LTRS were shared so that LTRS-like nodes could be implemented at other sites. Thus each participating facility was able to initiate and maintain its own technical report server, and all that was needed was a way to provide integrated access to them. The NTRS home page was developed as a common gateway interface (CGI) perl script that would present users with a single page from which to perform a search. While the individual centers maintain their own publications servers for administrative efficiency, the NTRS page provides users with a single, integrated search facility.

Technical publication servers have developed in a number of scientific communities, most in notably physics (Ginsparg, 1994), computer science (David and Lagoze, 1994; Maly *et al.*, 1994), and astronomy (Accomazzi *et al.*, 1995; Van Steenberg *et al.*, 1992). These specific scientific communities led the way in electronic document exchange, partly because they are heavily computer-oriented and have access to the Internet. The aerospace community is becoming more Internet capable. In addition to servicing the primary aerospace customers, NTRS provides a well-known location for secondary customers to gain access to NASA research activities for potential technology

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transfer (Nelson and Bianco, 1994; Nelson *et al.*, 1994).

NTRS provides a service substantially different from those provided by common CD-ROM products. While there are many useful CD-ROM products available (commercial and government), they suffer the distribution problems of print products. Unless the CD-ROM is available on the Internet, the fact that one site has a particular CD-ROM does little or nothing to assist a site without the CD-ROM. In economic terms, CD-ROM distribution is still a zero-sum game. NTRS is a non-zero-sum game in that, although only one copy exists, it is accessible to all servers simultaneously.

NTRS is different from previous NASA "electronic library systems" such as NASA electronic library system (NELS) (Smith, 1993) and NASA access mechanism (NAM) (Hunter *et al.*, 1993) in several ways. The most obvious is that NTRS is provided in the context of the World Wide Web: NTRS does not introduce a custom client program with specialized features. The other difference is that NTRS is limited to the domain of technical publications and does not directly address non-publication information and data. While the models developed for NTRS are generally applicable, the current scope is limited to technical publications.

Software implementation decisions

Most technical work is built on previous work, so it is desirable to have both historical and current work easily available from within the same information system, which often support hypertext or hypermedia. Hypertext systems, of course, allow information objects to be linked to one another in what is often a more intuitive manner than the linear nature of most text. The most successful hypertext implementation to date is the World Wide Web. The Hypertext Transfer Protocol used in the WWW is efficient in enabling a distributed knowledge network, and the uniquely extensible Mosaic offers an elegant interface.

The Wide Area Information Server (WAIS) (Kahle *et al.*, 1992) software was chosen to implement searching for the components of NTRS for several reasons. First, WAIS is freely available. Second, WAIS is a simple, generic search engine that is supported by many different platforms and integrates into a WWW environment easily. The source code for WAIS is available, allowing site customization where necessary. While WAIS is an attractive implementation for the NTRS searching requirement, NTRS does not directly depend on WAIS. Should a successor to WAIS appear, it would not be difficult to replace WAIS transparently with another search engine, and the user should notice little, if any, difference. The citations for the publications in the various servers are archived in a format different from their presentation. For example, most of the citations are stored in "refer" format (see Figure 2) (Lesk, 1978), even though the user sees only a properly formatted HTML citation. Separating the archival format from the presentation format will allow for easier transition to successor systems and the sharing of data with other non-HTML or even non-WWW systems. Refer format was chosen because it is simple, and it is easy to write various translators for refer to HTML and other formats. There is no reason that a richer archival format cannot be used, such as bibtex (Lamport, 1986), RFC-1357 (Cohen, 1992), or even machine-readable catalogue.

NTRS tools, customizations, and hardware

A number of interesting tools, programs, and methodologies was employed to create NTRS. When existing tools lacked adequate functionality, enhancements were developed. Significant pieces of NTRS include:

- the NTRS home page, a perl CGI script;
- an online user feedback form, a perl script;
- CERN WAIS-HTTP gateway 3.0;
- NCSA httpd 1.3;
- modified "waisindex" program;
- FreeWAIS 0.202 server;
- modified refer → HTML converter, a perl script.

Many of these products have been shared with system developers outside of NASA interested in similar technologies, and other, related, products are constantly being developed. While some participants in NTRS may eventually elect to use commercial versions of some software components, there is no requirement to do so; it

Figure 2 A formatted abstract

Langley Technical Report Server

1. Gary E. Erickson, **Wind Tunnel Investigation of the Interaction and Breakdown Characteristics of Slender – Wing Vortices at Subsonic, Transonic, and Supersonic Speeds**, NASA TP-3114, November 1991, pp. 223

   Keywords: Vortex flows, Subsonic flow, Transonic flow, Supersonic flow, Leading-edge extension, Vortex interactions, Vortex breakdown, Flow visualization, Shock waves

   Abstract: The vortex-dominated aerodynamic characteristics of a generic model of a 65^circ cropped delta wing were studied in a wind tunnel at subsonic through supersonic speeds. The lee-side flow fields over the wing-alone configuration and the wing with a leading-edge extension (LEX) added were observed at free-stream Mach numbers from 0.40 to 1.60 using a laser vapor screen technique. These results were correlated with surface streamline patterns, upper surface static pressure distributions, and six-component forces and moments. The wing-alone model exhibited vortex breakdown and asymmetry of the breakdown location at subsonic and transonic speeds because of the interaction of the leading-edge vortex with a normal shock wave. The development of a shock wave between the vortex and wing surface caused an early separation of the secondary boundary layer. With the LEX installed, wing vortex breakdown and vortex breakdown asymmetry did not occur up to the maximum angle of attack 24^circ in the present test. The favorable interaction of the LEX vortex with the wing flow field reduced the effects of shock waves on the wing primary and secondary vortical flows. The direct interaction of the wing and LEX vortex cores diminished with increasing Mach number. The maximum attainable vortex-induced pressure signatures were constrained by the vacuum pressure limit at the transonic and supersonic speeds.

is possible to be a fully functioning node constructed entirely with freely available software.

While NTRS can be used by any machine supporting WWW, most machines serving NTRS information are Unix workstations, many of which are non-dedicated. Additionally, while the index of publications for a given site must be centralized, some sites take advantage of the distributed nature of WWW and maintain full-text copies of the reports in different locations. Table I lists the machines that make up NTRS.

NTRS components

The following sections discuss the contents and direction of the various database components of NTRS. Each database is managed locally at its respective site. Sensitive, proprietary, or classified information is not made available through NTRS.

ADS Astrophysics Science Information and Abstract Service

The Astrophysics Science Information and Abstract Service (ASIAS) of the NASA Astrophysics Data System, formerly known as "Abstract Service", has been very successful in providing researchers and librarians with the capability to search the astronomical literature. It currently provides access to more than 160,000 astronomical abstracts with a sophisticated search engine.

Usage of the service dramatically increased after it was made available on the WWW, and now averages 30,000 queries and 500,000 retrieved abstracts per month. Its ease of use, flexibility and data coverage have made it a well-known resource in the astronomical community. A WAIS interface to the database was made available in September 1994, and, as a result, the service has been integrated into the NTRS.

ASIAS queries

The abstract server allows users to specify queries on separate fields in the documents. For instance, by requesting the search engine to search in the abstract text and paper title fields, a query can specify a term to be searched for only in the title of the paper but not in the abstract. Complex queries are composed by searching for different terms in some of the fields and then combining the results according

Table I NTRS machines

Service	Internet protocol name	Hardware	Operating system	Dedicated for WWW?	Local WAIS server
NAS	www.nas.nasa.gov	SGIPower Challenge S	IRIX 5.2	Yes	No
ADS	adswww.harvard.edu	Sun 690MP	SunOS 4.1.3	No	Yes
DTRS	www.dfrf.nasa.gov	Sun 690MP	SunOS 4.1.3	No	Yes
GPOL	www.giss.nasa.gov	IBM 590	AIX 3.2.5	No	No
ITRS	www.icase.edu	Sun SS10	SunOS 4.1.3	No	Yes
LTRS	www.larc.nasa.gov	Sun IPX	SunOS 4.1.2	No	Yes
LeTRS	letrs.lerc.nasa.gov	SGI Indigo 2	IRIX 5.3	No	Yes
RECON	www.sti.nasa.gov	Sun 10/41	Solaris 2.3	No	Yes
SCAN	www.sti.nasa.gov	Sun 10/41	Solaris 2.3	No	Yes
STELAR	hypatia.gsfc.nasa.gov	SGI 4GX340	IRIX 3	No	Yes

Key:
NAS = Numerical Aerodynamic Simulation Division, AR, Moffet Field, California
ADS = Astrophysics Data System, Smithsonian Astrophysical Observatory, Cambridge, Massachussetts
DTRS = Dryden Technical Report Server
GPOL = GISS Publications Online
ITRS = ICASE Technical Report Server
LTRS = Langley Technical Report Server
RECON = NASA Remote Control, an internal database for registered users
SCAN = Selected Current Aerospace Notices
STELAR = Study of Electronic Literature in Astronomical Research

to their relevance with respect to the original query. All query terms are case-insensitive and are compared with a list of synonyms before the term is searched in the database. Query results are ranked by a score determining how they match the input query.

The searchable fields in the database are: author (au); title (ti); NASA/STI keywords (kw); bibliographic code (bc); and abstract text (at). A field search consists of the two-letter keyword associated with a particular field, followed by the term(s) to be searched for. If the search text consists of more than one word, it must be enclosed in parentheses. For example:

au = smith

searches for "Smith" in the author index, while

ti = (galaxy cluster)

searches for "galaxy" or "cluster" in the title index.

Search terms may contain (nested) Boolean expressions, specified using the Boolean operators AND, OR and NOT; partial words, specified by appending an asterisk (*) to the root of the search term; and literal expressions, specified by a single (') or double (") quotation mark.

What follows are some examples of searches:

- 'black hole' – a literal query: the expression "black hole" is considered as a single search term;
- m31 AND 'black hole' – a Boolean query: both "m31" and "black hole" must be found in the database;
- au = stain* – a partial word query: look for authors whose names start with the word "stain".

Combinations of field queries are allowed:

- ti = m31 'black hole' – find documents having either "m31" in their titles or "black hole" anywhere in them;
- ti = m31 AND 'black hole' – find documents having "m31" in their titles and "black hole" anywhere in them;
- ti = (m31 AND 'black hole') – find documents having both "m31" and "black hole" in their titles;
- ti = m31 AND at = 'black hole' – find documents having "m31" in their titles and "black hole" in their abstracts.

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Dryden Technical Report Server

The Dryden Technical Report Server (DTRS) database makes two sets of information available. First, all unrestricted, unclassified, unlimited distribution NASA technical papers written since June 1994 are available in PostScript form for downloading from the Web. FTP and Gopher access to the online papers are currently under development. Second, the database for Dryden technical papers is being expanded to retrieve papers written before June 1994. This expansion will provide another way to find older papers usually obtained via the more traditional hard-copy order methods. Currently, information back to 1979 is online, and there are plans to populate the database with the complete set of bibliographic citations on all technical papers generated at Dryden. This task will be pursued as time permits.

The data files for the technical papers are maintained in directories by year of publication. Every file uses the unique paper number issued to that publication (H-####). Dryden's "H" number was instituted during the years it was known as the High-speed Research Station.

New bibliographic citation files and technical papers are periodically added to the DTRS. A WWW CGI program was written to allow the editing and creation of citation files for the database. These "refer" format files generate the HTML files that build the WAIS database for searching.

Goddard Institute for Space Studies Publications Online

The publications server at the Goddard Institute for Space Studies contains abstracts for approximately 440 abstracts of publications (co)written by GISS staff members during the past 20 years. The majority of the documents included in the GISS Publications Online (GPOL) database are papers which have appeared in peer-reviewed journals, although documents such as doctoral theses and NASA conference publications are also included. A valuable feature of GPOL is that it has been integrated with GISS WWW personnel locator information to provide a current bibliography for each employee.

Papers in GPOL are automatically entitled using an NN.XXX method, where NN is the year of publication and XXX is the last name(s) of the (first two) author(s). Using author names in file names provides pre-performed alphabetic sorting when a perl script is run to convert the "refer" files in the database to the HTML indices which users actually see when they access GPOL via a Web browser. In addition, papers can easily be found if corrections or changes are necessary.

Presently, only 6 percent of GPOL abstracts are linked to a copy of the full paper. Owing to copyright constraints, there is still some debate about whether papers written by many GISS researchers may be included, because these persons are actually research faculty or post-doctoral employees of nearby Columbia University. An effort is currently being made to solicit additional online papers aggressively in conjunction with the assembly of an annual hard copy volume of GISS research publications abstracts.

A lesser issue to be addressed is the support of in-house users who wish to search the GPOL database. At present, this searching has been enabled by using an off-site WAIS engine at Langley Research Center, which requires that the LTRS periodically copies the entire GPOL database. It is expected, however, that an in-house WAIS engine will be installed in 1995.

The Institute for Computer Applications in Science and Engineering Technical Reports Server

The Institute for Computer Applications in Science and Engineering is a center for research in applied mathematics, numerical analysis, fluid dynamics and computer science, providing a natural mechanism for interactions among NASA scientists and engineers, the ICASE staff, and the wider community in universities and related industries. Its main products are research papers produced from this research. For this reason, ICASE chose to participate in the NTRS project by supplying the ICASE Technical Report Server (ITRS).

ITRS follows the NTRS model and uses the same basic tools. Abstract lists are available for approximately half of the technical reports generated in 1993 and all of the reports generated in 1994. Ninety percent of the 1994 documents are available as compressed PostScript documents and can, therefore, be retrieved directly by the user. If an online version of the

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document is not available, there is an electronic form provided for the user to request a hard copy. Only about half of the 1993 technical reports and abstracts are available online owing to the difficulties of acquiring an electronic version of the papers that can be converted to PostScript. Ideally, all future ICASE technical reports will be available online via the ITRS.

Langley Technical Report Server
The LTRS contains all "unclassified, unlimited", formal (four-digit) technical papers and technical NASA memoranda written since 1992. Some 1991 formal reports are also available. Authors have contributed conference papers, high-number (six-digit) technical memoranda, LaRC-sponsored contractor reports, journal articles, and LaRC-sponsored theses to LTRS, dating as far back as 1986. The author-contributed reports currently account for roughly 30 per cent of the LTRS database. Since there is currently no requirement for LaRC authors to participate, papers representing only a subset of LaRC's research products are present. Participation is increasing as LaRC authors become more familiar with WWW and electronic publishing.

Some of the reports do not contain all the original graphics, although most include at least some of this material. There are no statistics on the level of completeness for the reports. Generally, older reports are less likely to be totally electronic. Most reports are in PostScript and compressed with the Unix compress utility. Some reports are in HTML, if the authors have made the conversion.

Lewis Technical Report Server
The Lewis Technical Report Server (LeTRS) contains publicly available titles published at Lewis Research Center for the years 1990-1994. At the moment, LeTRS contains mostly abstracts. Full reports will be added as they are available.

LeTRS contains two distinguishing features. First, it does not present the abstract and citation information in the same format as the other servers, but rather constructs the report documentation page (RDP) found at the end of NASA technical reports (the RDP is prescribed by Z-39-18). Second, it is possible for the LeTRS database managers to edit citations using an interface for WWW forms protected by a password.

Numerical Aerodynamic Simulation Facility Database
In the first quarter of 1994, several people at the NAS facility at NASA Ames Research Center began publishing branch technical reports via the WWW. After the publication of the first few reports went well, NAS management decided to use the World Wide Web as the primary means of publication for NAS technical reports. The initial attempt far exceeded expectations. This success led NAS to stop printing paper reports, which resulted in an increase of several orders of magnitude in the total number of reports disseminated. There was also an enormous improvement in the ease of using the technical reports as references, largely due to the ease of searching the reports with NTRS.

Based on initial success with the technical reports server, NAS is currently undertaking projects to develop new procedures to index and eventually publish other forms of data, including scientists' research notes, datasets, software, and training videos. The consensus at NAS is that WWW publication of technical reports has been highly successful.

NASA Remote Control, SCAN and Study of Electronic Literature in Astronomical Research

NTRS employs "database reuse" as well. The experimental WAIS subset of NASA Remote Control (RECON) and internal database for registered users, and the SCAN current awareness notes, both offered by the Scientific and Technical Information program and the publicly accessible version of The Study of Electronic Literature in Astronomical Research (STELAR), are also accessible via NTRS. RECON is a large, all-encompassing collection of aerospace-related references, and the years 1990-1994 are offered experimentally in WAIS. SCAN is a current awareness service the contents of which are constantly updated. STELAR is an early experiment in providing access to astronomical abstracts with WAIS. These databases were online before the development of WWW and Mosaic. They offer WAIS access, but documents are not in HTML and cannot be

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downloaded. Despite these limitations, they make a useful addition to NTRS. This is especially true of RECON, which has the breadth to provide search results for most topics.

NTRS access statistics

The NTRS has been well received by the WWW user community. Figure 3 shows accesses to NTRS by month from July 1994 to March 1995, a total of over 93,000 connections during the initial nine-month period. The NTRS components that contain full text reports have served over 38,000 copies of reports. Table II shows the number of reports distributed per site. Table III, although incomplete, shows where many NTRS accesses originate by domain. It shows the broad base of world-wide interest in the information that NASA has made available.

Figure 3 Monthly NTRS accesses

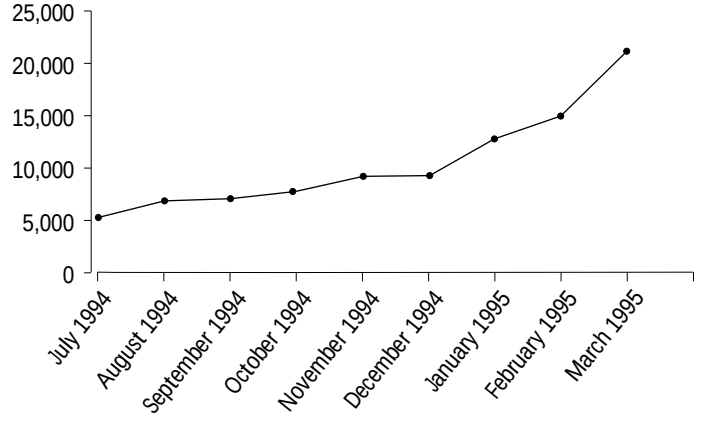

Table II NTRS contents and usage

Service	Reports online	Citations online	Reports served
NAS	113	113	13,000+
ADS	0	165,000+	–
DTRS	26	648	167
GPOL	28	441	143
ITRS	92	113	1,429
LTRS	502	502	24,000+
LeTRS	2	920+	30
RECON	0	270,000+	–
SCAN	0	1,000+	–
STELAR	0	75,000+	–

Note: Contents and distribution for each site not normalized with respect to time available. For explanation of terms see Table I

Table III NTRS accesses by domain

Domain	Total accesses	Percentage of total accesses
Australia	295	<1%
Austria	1,687	2%
Canada	2,843	3%
Finland	767	<1%
France	2,803	3%
Germany	4,206	5%
Israel	2,826	3%
Italy	1,375	1%
Japan	2,080	2%
Korea (South)	824	1%
The Netherlands	1,635	2%
Network	2,267	2%
Non-profit	827	<1%
Norway	998	<1%
Sweden	1,543	2%
US commercial	13,697	15%
US educational	17,603	19%
US government	1,436	2%
US military	2,628	3%
US – NASA	9,016	10%
United Kingdom	5,706	6%
All other countries	2,870	3%
Unresolved Internet address	14,139	15%
Total	93,236	100%

Note: Not including NASA

User reactions

A simple online form is provided for users to share their reactions to the NTRS. A sampling of user feedback can be found at:<http://techreports.larc.nasa.gov/ntrs/feedback/>.

To date, feedback generally falls in the categories of:

- compliments and suggestions;
- syntax questions (i.e. how to invoke Boolean searching correctly); and
- questions about how to obtain an electronic or hard copy of a paper when only the abstract is provided in NTRS.

Cost savings

Use of NTRS results in direct savings over the traditional method of report distribution. Printing and binding a report is estimated to cost

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$1.75 per copy. The estimated cost is based on an average report length of 25 pages, 100 copy print runs, $0.04 per page duplication, labor at $15.00/hour, and paper at $2.00/ream. There is an additional cost for postage and handling estimated at $1.00 per report.

Using the raw numbers of reports distributed through the NTRS, the cost of distribution of 29,500 report copies at $2.75 per report is over $81,000. All NASA facilities are already networked, so the only direct cost to NASA for NTRS is the increased bandwidth usage of the campus network. It is important to note that NAS has tentatively ceased paper production of the NAS report series and that the online versions are now the only method of distribution.

A more useful metric of the NTRS is in time savings to the customer. When using NTRS, downloading a report takes no longer than a few minutes, and, depending on the printer speed, it should take no longer than one to two hours to print. In contrast, it can currently take two to four weeks to request and receive a paper copy of a report, based on researchers' experience at NASA Dryden Flight Research Center. When this time delay is multiplied over 29,500 reports, the time savings to the customers exceeds 1,400 years.

These numbers optimistically assume 100 per cent usage of all reports distributed. Even if only a significant fraction of the service is used to aid research, however, the payback in time and cost savings is tremendous, with the largest dividends paid to NASA customers.

Lessons learned

Implementing NTRS taught or reinforced many lessons about Internet-based information systems. They include the following:

- The most frequent problems involved incorrectly configured machines and the somewhat unstable nature of early WWW software. These problems were especially pronounced for PC and Macintosh platforms, and they will be resolved in the near future with availability of more robust, commercial-grade WWW browsers.
- The search syntax was not immediately intuitive to some users. The free text searching of WAIS would sometimes puzzle users expecting a more complicated interface and search protocol.
- If the documents that users wanted were not online, it did not make them feel better knowing that hundreds of other documents were available. More and more, users expect all information to be online. It is anticipated that services which can meet these expectations will be the ones on which users come to depend. It is possible that those collections which do not have a path from paper or microfiche to electronic distribution stand a good chance of being forgotten by online researchers.
- Use of NTRS, as well as of other WWW services, indicates that the online public has a real interest in obtaining NASA information. Some NTRS users were looking for specific reports, and some were searching for NASA work in general subject areas.
- The previous lesson highlights another: the public considers NASA information difficult to obtain. Users report that many libraries do not receive the information in a timely fashion, if at all. Other users expect NASA to deliver information online and do not consider traditional distribution methods acceptable.
- Interestingly, users' reactions ranged from surprise that NASA provides this information electronically to impatience about the fact that all of NASA's information is not available via the Web.
- ADS has implemented the optimal WAIS solution. To serve the astronomical community better, it provided a WAIS interface to its existing abstracts database. After testing several packages currently available in the public domain, it selected a variation of the Clearinghouse for Networked Information, Discovery, and Retrieval (CNIDR) freeWAIS called freeWAIS-sf16 (Pfeifer *et al.*, 1994). In particular, freeWAIS-sf16 is superior to the CNIDR freeWAIS version in that it introduces the concepts of structured fields in the document that can be searched separately.

Some time was spent in enhancing the freeWAIS code to run faster by storing some frequently accessed data in shared memory, to allow better control of what words would be ignored when indexing, and to support

extended headlines (the document identifier strings returned by the server on completion of a query). These changes have since been incorporated in the freeWAIS code. Thanks to the efforts of the author of freeWAIS-sf, typical bottlenecks in the indexing of source documents (hard-coded limits about the size of headlines, inverted indexes, etc.) have been either eliminated or isolated. These enhancements over freeWAIS make freeWAIS-sf the best public-domain, general purpose, full-text indexing and search engine available today.

Further implementation

The most pressing issue for NTRS is the inclusion of other NASA centers and institutions, especially the remaining NASA research centers. Ames Research Center, Goddard Space Flight Center, and Kennedy Space Center have preliminary prototypes of ATRS, GTRS, and KTRS (respectively). There may be a need for more sophisticated searching capabilities, possibly even a new search engine. Perhaps two different interfaces to NTRS, "beginner" and "expert", are needed to serve both groups of users.

Other issues to be addressed include:

- increasing the number of reports available;
- ensuring that all present and future reports are stored electronically;
- converting existing archives and completing partially electronic reports (e.g. making all figures electronic); and
- presenting a choice of formats for the user (e.g. PostScript, HTML, Adobe Acrobat (PDF), and native word-processing format if applicable).

The ADS plans to expand its abstract service to include scanned images of full-text articles from selected journals. As a test case, it is scanning all issues of the *Astrophysical Journal (Letters)* from 1975 to date. If an article is available for a selected abstract, links to the bitmaps (stored in PostScript format) will be present in the returned report.

Conclusion

The NASA Technical Report Server is an experimental, grass-roots project with the goal of providing maximum connectivity to existing electronic publications and publications servers. Using World Wide Web and other Internet information systems, NTRS has achieved great initial success in providing access to NASA research publications to the worldwide scientific and research community. The WWW also allows the implementation of NTRS to be both logically centralized and physically distributed. All participating institutions maintain their own servers, and the NTRS WWW page provides a single-access point for the entire collection. NTRS demonstrates that significant results in technology awareness and distribution can be achieved, with minimal resource investment, using the latest in information technology.

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