E-Technologies for Wind Effects on Structures

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ABSTRACT: The fusion of engineering and information technologies provides today's engineer with the potential for analysis and research programs that defy geographic boundaries and create new venues for remote sensing and data analysis and archiving. The following study discusses the use of information technologies in two wind engineering projects to enhance the accessibility, organization, interpretation and dissemination of data. The first is an ongoing full-scale monitoring program involving several tall buildings in the city of Chicago. As the management of years of full-scale data from this project poses a daunting task, Internet technologies provide an attractive solution, through local communications hubs and secured web interfaces to catalog, convert, download and display the measured time histories. Similar interfaces are also developed in the second study to provide interactive frameworks for manipulation of wind tunnel data to produce preliminary estimates of wind-induced response for alongwind, acrosswind and torsion: a prototype for the next generation of e-codes and standards.

KEYWORDS: wind engineering, JAVA, WWW, database, information technologies.

1 INTRODUCTION

Internet technologies have emerged as promising solutions to the traditional challenges in full-scale monitoring projects and in transmission and sharing of experimental data with the broader wind engineering community. Recent advancements not only facilitate the transmission of data from the remote computing stations to a host computer, but the emergence of JAVA-based applets now permit data retrieval and analysis by authorized users worldwide. In particular, within the context of larger health monitoring initiatives, such use of Internet technologies and simplified user interfaces can facilitate the active involvement of building owners and management, helping to improve the overall attitude toward monitoring of structures within the United States. Since most users are already equipped with a working understanding of the Internet, as well as the appropriate hardware and software, Internet-based monitoring and sharing of data become inexpensive tools to facilitate long-term monitoring initiatives. This study will discuss how JAVA-based applets and other information technologies are being utilized in two wind engineering research programs to enhance the ability to interpret and share experimental data worldwide.

2 DATA PORTALS IN FULL-SCALE MONITORING

Possibly the greatest challenge in long-term monitoring projects is the management, transfer, processing and dissemination of collected data. Traditionally, the archiving of data and its analysis was conducted on a single platform at an isolated location, often in close proximity to the monitored structure. However, with the advancement of computer and Internet technologies,

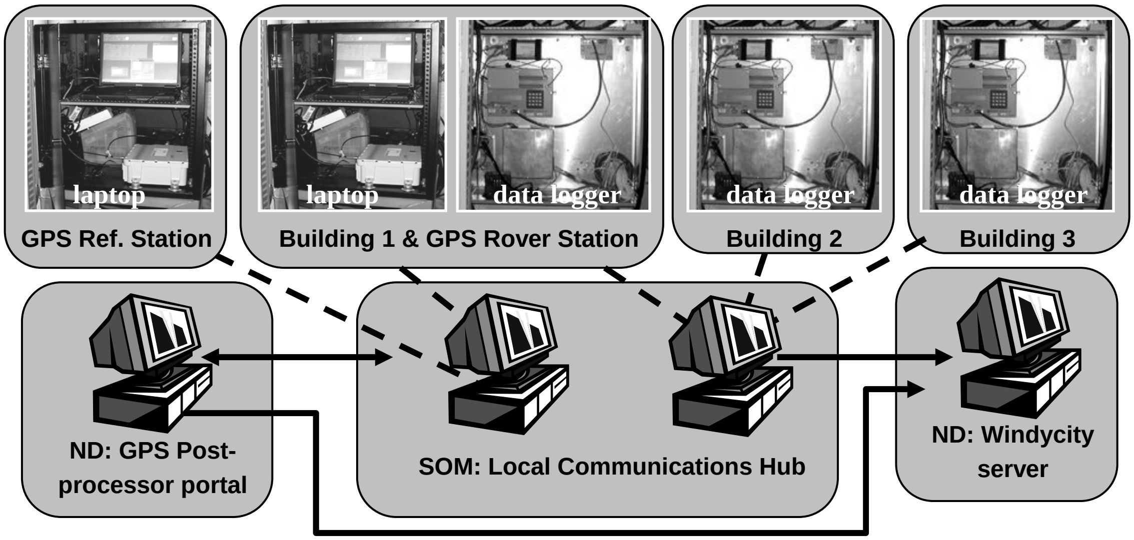

Figure 1. Communications framework for Chicago full-scale monitoring program (--- local dial-up connection; — Ethernet connection).

the possibility of remote monitoring has become increasingly more viable. Still, the challenges in operation of monitoring systems, downloading of measured data, and its archiving and distribution can be considerable, particularly for a project whose investigators, participants and advisory board are distributed geographically throughout the world, as is the case in the Chicago full-scale monitoring project discussed by Kilpatrick *et al.* [1]. This project provides an opportunity to exercise such strategies to enhance the efficiency of the project team in archiving, post-processing and interpretation of measured wind velocity, acceleration and Global Positioning System (GPS)-calculated displacements.

2.1 *Data Transmission*

Each of the three monitored structures in the program is instrumented with accelerometers that are interrogated by Campbell CR23X data loggers on-site. The data transmission strategy adopted in this study then initiates with the periodic download of data from each building via modem to a PC at a local communications hub in Chicago, housed in the offices of project partner, Skidmore Owings and Merrill, as shown in Figure 1. This download is automatically initiated from this communications hub by Campbell's PC 208W software. The data is then uploaded via Ethernet to an FTP server that is accessed by the project's "windycity" server at the University of Notre Dame. The use of this local communications hub in Chicago insures that long distance costs are not incurred in transmitting the data from each building, as would be the case if direct modem connections were maintained for long durations over state and even international lines.

This is particularly of concern since the outputs of two high-precision GPS sensors are also being post-processed in this study [1]. Since this GPS receiver pair (termed the "reference" and "rover" sensors) can generate large volumes of data associated with monitoring up to 8 satellites every 0.1 seconds, all of which must be downloaded to an off-site post-processing portal at the University of Notre Dame, the local communications hub becomes a cost-effective and relatively efficient means to operate the GPS sensor pair. Through the use of this local communications

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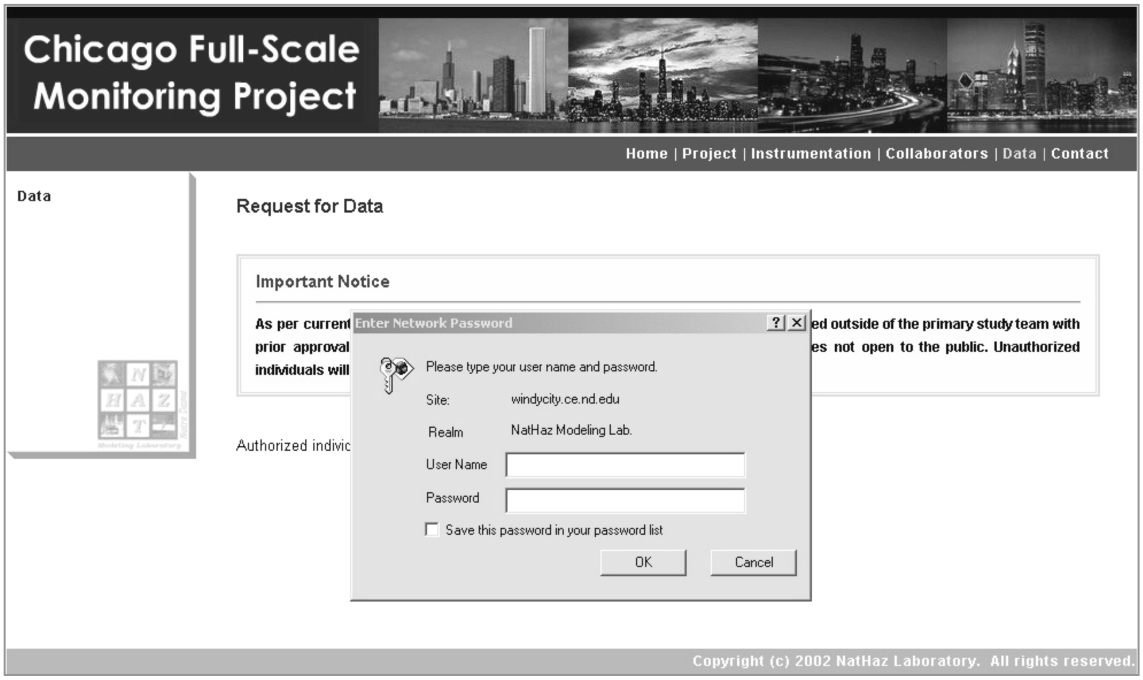

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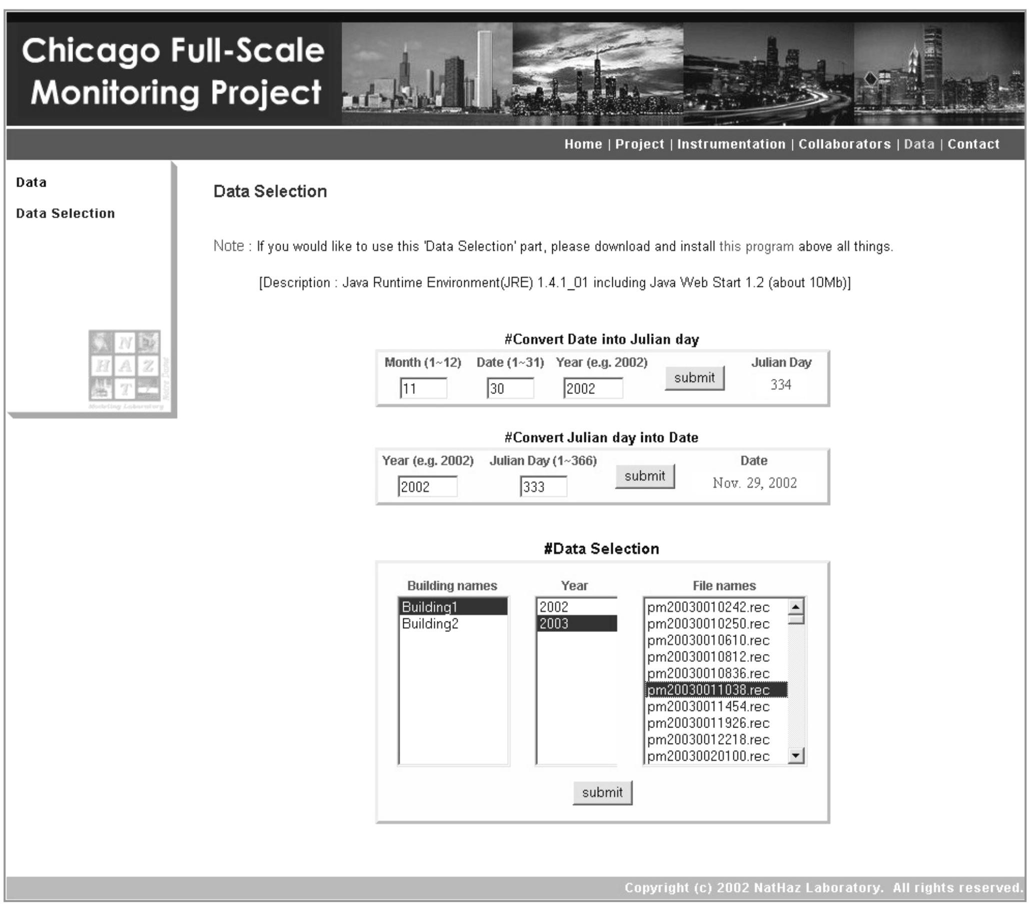

Figure 2. (a) Website main page with secured access login responding to click on "Data" link; (b) data selection CGI interface.

hub, researchers at the university can utilize commercial software (PC Anywhere) to remotely control a second PC at the local communication hub via Ethernet and then launch on that computer a nested remote operations interface using PC Anywhere to allow the dial-up access of the GPS reference and rover laptops individually by modem (Fig. 1). In this "nested host" protocol, the laptops at each of the GPS sites can be used to monitor and manually trigger the GPS receivers from any location worldwide and download the collected data again without the expense of long distance communications.

2.2 *Data Processing and Web Display*

The windycity desktop server (Fig. 1), operated by an Apache 2.0.44 web server [2], provides a mechanism by which the geographically dispersed project team can easily access the data collected in this full-scale program from any location worldwide. This is facilitated through a centralized project website coded in HyperText Markup Language (HTML) and available to the public at http://windycity.ce.nd.edu. While the site has a large public domain component, its primary function is data organization and processing through an interactive web portal that will display, on-the-fly, data archived at the site and perform some basic post-processing of data and calculating of statistics. JAVA programming [3], which is an object-oriented language like C or C++ and is platform-independent, provides a viable tool to accomplish this end. In spite of these merits, it is known that the processing time of JAVA is about ten to twenty times slower than languages like C++. However, by merging programming languages, an efficient yet computationally robust web interface can be generated by JAVA, as long as more efficient languages such as C++ are used for all the numerical calculations. A related language, MATLAB, provides an attractive programming framework for more complicated computations and can be easily extended to more sophisticated numerical transforms, such as wavelets, thanks to the many pre-defined function capabilities. For these reasons, MATLAB 6.1 (R 12) will be used as the computational framework for this study, and JAVA SDK 1.41-01 and JAVA Webstart 1.2 will provide the interfacing technology.

Because of confidentiality agreements with the building owners, the segment of the site housing this JAVA-based data presentation applet must only be made available to members of the project team. By invoking Apache's directory restraint on the server, a security protocol is provided that restricts access only to those possessing a valid username and password through the interface shown in Figure 2a. Upon receiving authorization, first-time users are asked to download a software bundle that enables them to run the JAVA applet from their personal computer. Hypertext preprocessor (PHP) 4.3.1 [4], a kind of Common Gateway Interface (CGI), is then utilized to create interactive displays allowing users to select the desired building, resulting in an updated listing of the available files for that building (Fig. 2b). This programming construct also provides an on-line calculator to translate calendar dates to Julian dates and vice versa, since this latter convention was used to name the files archived by the data loggers in the monitoring program. Upon selection of a file, additional security checks are performed by JAVA and the applet is launched. Once the user selects the start command button at the bottom of the window (Fig. 3a), on-the-fly, web-based processing of wind conditions and building response initiates. Through the MATLAB portion of the architecture, the selected wind velocity and acceleration records are converted from measured voltages to engineering units, and the accelerations are then decomposed using the sum and differencing of the various channels of data to isolate the sway response along the two building axes and the torsional response. Any spurious spikes due to electronic noise are automatically corrected, and any DC offsets in the accelerations are noted and removed. The resulting mean, minimum, maximum and standard deviation of the response are then calculated within MATLAB on the windycity server, and plots

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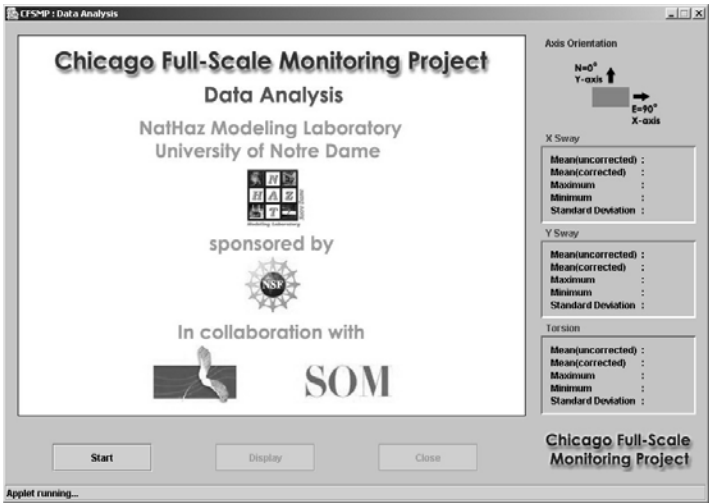

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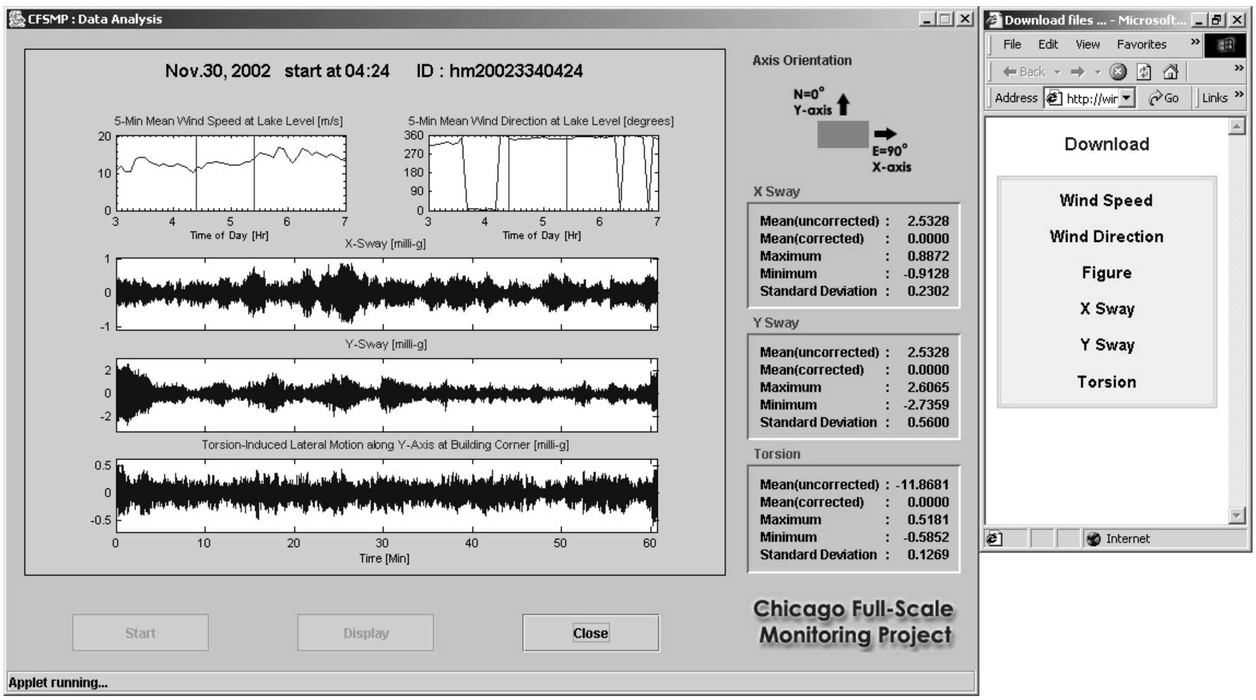

Figure 3. (a) Entrance point to JAVA interface; (b) JAVA-enabled graphical display of wind speed, direction and accelerometer data with statistics and pop-up window for download of processed data files.

of the converted time histories are generated. Through JAVA, these statistics are displayed on the right side of the screen, and the plots of acceleration and wind speed and direction are centered in the main window, as shown in Figure 3b. If the user finds the data useful or worthy of further analysis, they can elect to download the fully converted and corrected ASCII data via the download browser to the right of JAVA interface (Fig. 3b). The attractive feature of this on-the-fly processing approach is that no human effort is expended in converting the data and only truly useful data is ever downloaded to the user's desktop.

Finally, it should be noted that the software versions used to originally establish the interface are listed herein but are periodically updated as evolving security and vulnerability issues are identified. Due to this constant updating, the interfaces are likely to have evolved since the time of publication.

3 AERODYNAMIC LOADS DATABASE

The response of structures under the action of wind is customarily divided into three components: alongwind, acrosswind and torsion. Although the alongwind response can be determined through analytical procedures readily available in codes and standards worldwide, most standards and codes provide little guidance for the critical acrosswind and torsional responses. This is partially attributed to the fact that the acrosswind and torsional responses result mainly from the aerodynamic pressure fluctuations in the separated shear layers and wake flow fields, which have prevented, to date, any acceptable direct analytical relation to the oncoming velocity fluctuations. For many high-rise buildings, the acrosswind and torsional responses may exceed the alongwind response in terms of both serviceability and survivability design requirements, necessitating careful consideration of these response components.

One means to address this limitation was proposed through compact empirical formulas, which in general provide acceptable agreement with the experimental data. However, as such expressions were developed as a best fit to a number of side/aspect ratios for rectangular sections, there can be considerable deviation from the actual experimental data for specific side ratios, frequency ranges or other geometric shapes. Such deviations can have notable impacts on the predicted response. Direct use of the spectral data can bypass the opportunity for the errors introduced by curve-fit expressions, which are currently constrained to only rectangular shapes, limiting the structures that can be considered. Fortunately, the Internet provides an internationally accessible platform for archiving experimental results, permitting the efficient presentation of actual data for a host of geometries, dimensions, and turbulence conditions.

The first step towards such a database has been initiated at http://www.nd.edu/~nathaz through the Aerodynamic Loads Database, available to Microsoft Explorer users [5]. Upon entrance to the database, the user will step through a series of HTML links to identify, with certainty, the data of interest. Once the desired building model has been selected, the database will recap the selections and prompt the user to select the alongwind, acrosswind or torsional load results, as shown in Figure 4a. JAVA programming is again used to create an interface that allows the retrieval of a building-specific value from the non-dimensional power spectrum. The interface, shown in Figure 4b, displays the entire non-dimensional power spectrum and then allows the user to input an arbitrary value of the non-dimensional frequency in order to obtain the corresponding spectral value using the command buttons, as would be done to determine the value of the power spectrum at the fundamental frequency of the structure. The use of digitized spectra removes the opportunity for human errors that result from picking off values from hardcopy spectra and eliminates the uncertainty associated with curve-fit expressions. In addition, the calculated RMS coefficient is also provided.

After obtaining the value of the non-dimensional power spectrum and associated RMS coefficient, the user can access on-line a procedure to calculate the corresponding global response, along with a detailed example, permitting this digital aerodynamic load data to be directly used in the computation of wind-induced response of tall buildings with similar turbulence and geometrical features in the preliminary design stages.

4 CONCLUSIONS

The face of wind engineering is being transformed through emerging information technologies that allow for the rapid transfer, archiving, display and interpretation of large amounts of data generated though extensive laboratory and full-scale monitoring programs. A number of commercial software packages and readily available freeware and shareware, along with a basic understanding of programming languages, enables today's researcher to rapidly and inexpensively transfer remote stores of data and create secured, interactive interfaces through the World Wide Web. This study provides an example of two current projects exploiting these technologies. In the context of an on-going full-scale monitoring program (http://windycity.ce.nd.edu), PHP and JAVA programming is fused with MATLAB to create efficient yet computationally robust interfaces that convert, post-process and display measured full-scale data on-the-fly. This interface will be coupled in the future with database query capabilities to allow users to search available by the desired level of wind speed, wind direction or response to determine the data sets meeting specified characteristics or manifesting the largest levels of response. Such technologies reduce the labor-intensive organization, elementary processing and archiving of massive amounts of measured data.

The second study uses similar JAVA frameworks to create a virtual database of digital wind tunnel data, for a variety of geometries, aspect ratios and wind conditions. This framework is readily expandable to wind tunnel data collected at other facilities to enhance the reliability of the data set. This Aerodynamic Loads Database (http://www.nd.edu/~nathaz) provides a prototype to launch the next generation of codes and standards for high-rise buildings as the spectrum for a given geometry, dimension and turbulence condition can be presented digitally on-line with the promise of expansion to more sophisticated digital databases. These applications are but two examples of the new potential research venues facilitated by information technologies and hopefully will motivate continued efforts and innovations in their synthesis with wind engineering to create new possibilities for research, design and practice.

5 ACKNOWLEDGEMENTS

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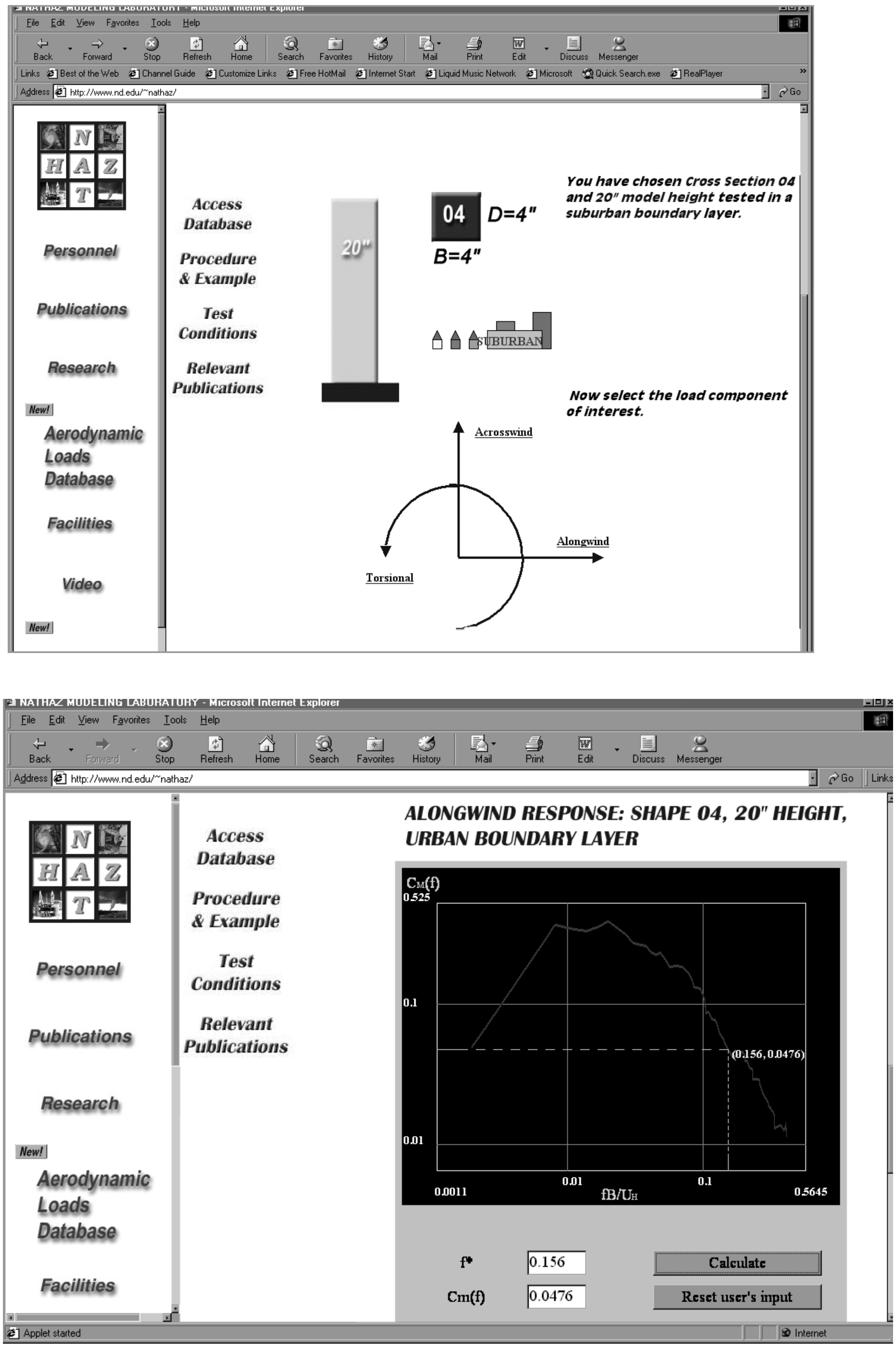

Figure 4. (a) Aerodynamic Loads Database gateway for selection of desired aerodynamic load spectra; (b) Aerodynamic Loads Database interface: user inputs non-dimensional frequency and non-dimensional power spectral value is provided by JAVA script.